SOIL ORGANISMS **87** (3) · December 2015 pp. 239–247

Depth distribution and inter-annual fluctuations in density and diversity of Collembola in an Iranian Hyrcanian forest

Mahmood Mehrafrooz Mayvan[1], Masoumeh Shayanmehr[1]* and Stefan Scheu[2]

[1] Department of Plant Protection, Faculty of Crop Sciences, Sari University of Agricultural Sciences and Natural Resources, Iran
[2] J.F. Blumenbach Institute of Zoology and Anthropology, Georg August University Goettingen, Germany
* Corresponding author, e-mail: Shayanm30@yahoo.com

Received 9 February 2015 | Accepted 12 November 2015
Published online at www.soil-organisms.de 1 December 2015 | Printed version 15 December 2015

Abstract

The Hyrcanian forests as an ancient and one of the most unique temperate deciduous broadleaved forests in the world are located partly in the north of Iran near the Caspian Sea. Collembola as a major group of soil animals have never been studied in the Hyrcanian forests. We investigated the Collembola fauna of the Semeskandeh forest as a part of the Hyrcanian forests in northern Iran (Mazandaran province) in different soil horizons as well as in different seasons to gain insight into the diversity and dynamics of the Collembola community. Samples from leaf litter ($O_{L,F,H}$ horizons), 0–3 and 3–6 cm of the mineral soil (A_h horizon) were assessed in two-month intervals during one year (2012–2013). A total of 20 species belonging to 16 genera and 9 families were identified. *Heteromurus major* (Moniez, 1889) was most abundant and the species *Lipothrix lubbocki* (Tullberg, 1872), *Heteraphorura japonica* (Yosii, 1967), *Sminthurus* cf. *ghilarovi* Stebaeva, 1966, *Paralipothrix* cf. *natalicius* (Ellis, 1974), *Dicyrtoma* cf. *ghilarovi* Bretfeld, 1996 and two *Sphaeridia* spp. were recorded for the first time for the Iranian Collembola fauna. Abundance of Collembola was highest in leaf litter in winter (January) and lowest in 3–6 cm soil depth in summer (July). Species diversity was highest in winter in leaf litter and low in summer particularly deeper in soil. Overall, the depth distribution of Collembola resembled that of temperate forests, whereby seasonal dynamics differed with highest densities in winter, indicating that reduced moisture in summer functions as a major determinant factor. The results provide for the first time information on the diversity and dynamics of an important decomposer animal taxon in an endangered forest system of southwest Asia.

Keywords Springtails | population dynamics | Caspian Sea forest

1. Introduction

The Hyrcanian forests are located in the north of Iran near the Caspian Sea (Hosseini 2006). Hyrcanian forest ecosystems are considered to be among the most important and unique temperate deciduous broadleaved forests in the world (Haghdoost et al. 2011). These mesic deciduous forests are characterized by a closed canopy, in contrast to the arid and semi-arid steppe landscapes characterizing most of Iran. It extends from the Talish region southeast of the Republic of Azerbaijan to the Golestan Province in northeast Iran and covers approximately 50,000 km^2. The forest forms an important refuge for a number of Tertiary relict species such as Persian ironwood (*Parrotia persica*) (Naqinezhad et al. 2012). Old-growth northern forests of Iran are major sources of genetic variation, biodiversity, commercial woody products and various environmental services (e.g., ground water reservation, auxiliary forest products provision, wildlife habitation and erosion control). *Fagus orientalis* (Oriental Beech), *Carpinus betulus* (European Hornbeam), *Acer velutinum* (Velvet Maple), *Quercus castaneifolia* (Caucasian Oak), *Acer cappadocicum* (Cappadocian Maple), *Alnus subcordata* (Alder) and *Tilia platyphyllos* (Large-leaved Linden) are the most important tree species in these forests (Haghdoost et al. 2011).

ISSN 1864-6417

Collembola (Springtails) are among the most abundant and species-rich soil animals of forests worldwide and play an important role in plant litter decomposition, nutrient cycling, soil microstructure formation and in modifying plant growth (Parkinson 1988, Petersen 2002, Filser et al. 2002, Chahartaghi et al. 2006, Steffen et al. 2012). Given the important role of Collembola, many studies have been conducted characterizing Collembola communities in different ecosystems including different types of forests all over the world (Chahartaghi et al. 2006, Mitrovski-Bogdanovic & Blesic 2006, Rodgers & Kitching 2011, Paul et al. 2011). However, the Collembola fauna of Iran have received little attention and this applies in particular to the Hyrcanian forests in northern Iran. Recent studies on Iranian Collembola documented the paucity of knowledge on these animals (Yoosefi Lafooraki & Shayanmehr 2013, Shayanmehr et al. 2013, Daghighi et al. 2013). Most studies on Collembola in Iran are qualitative faunistic surveys; virtually no information is available on diversity and density of these important soil animals. The present study aims at contributing to close this gap of knowledge, concentrating on the unique Hyrcanian forests and providing information on the density and diversity of Collembola in different soil layers and their seasonal variation.

2. Materials and methods

2.1. Study Site

The investigations were performed in the Semeskandeh forest as part of the Hyrcanian forest in the Mazandaran province of Iran (Fig. 1). In Iran, the Hyrcanian forest ranges over five provinces from east to west including North Khorasan Province, Golestan Province, Mazandaran Province, Gilan Province and Ardabil Province. In the Mazandaran Province, the Hyrcanian forest covers a total area of about 965,000 ha. Semeskandeh is located 5 km southeast of Sari (capital of Mazandaran Province), south of the Sari – Neka road. The forest covers an area of about 1000 ha, ranging in altitude between 50 and 190 m above sea level. The Semeskandeh forest has been protected as a wildlife refuge for more than 40 years and is managed by the Iranian Department of Environment. Most of the Semeskandeh area belongs to a Pleistocene alluvial plain.

The Hyrcanian forest in Iran has a humid climate and is affected by the Caspian Sea. The climate of the area is Mediterranean pluviseasonal-oceanic (Djamali et al. 2011). Annual rainfall in Sari is on average 650 mm and average annual temperature is 15°C (http://www.yr.no/place/Iran/Mazandaran/Semeskandeh/statistics.html). Mean maximum temperature in the hottest month (July) and mean lowest temperature in the coldest month (January) is 22.2 and 13.0°C, respectively (Naqinezhad et al. 2012). Winters are rainy and cool whilst summers are hot and dry. Unfortunately, little information on soils is available for the studied area, but the results of a soil profile analysis in areas adjoining the Semeskandeh forest show that the pH is close to neutral, ranging between 6.2 and 7.9 and electrical conductivity from 0.14 to 1.18 ds m^{-1}. Soil texture includes clay, silty clay, silty clay loam, silty loam and clay loam (Zarrinabad Forestry, Natural Resource Department, Mazandaran, unpubl. data). The tree layer is dominated by oak (*Q. castaneifolia*) and Oriental Beech (*F. orientalis*) with interspersed Persian Ironwood (*P. persica*). The understory is dominated by Hornbeam (*C. betulus*). The forest sites studied were bare of understory vegetation.

2.2. Collembola sampling and analysis

For investigating the Collembola fauna, samples were taken from soil and leaf litter. Samples of the leaf litter ($O_{L,F,H}$ horizons), 0–3 and 3–6 cm soil depth (A_h horizon) were taken using a steel corer of 5 cm diameter. Eight replicate samples were taken at each of six sampling campaigns. Replicate samples were spaced at least 10 m apart and taken at bimonthly intervals in July, September and November 2012, and in January, March and May 2013. Samples were transported to the laboratory and Collembola were extracted by heat using a modified Berlese funnel system. Specimens were collected in glycerol – water solution (1 : 1), preserved in 75 % ethanol and separated under a dissecting microscope. Further, to also cover rare species, additional non-quantitative leaf-litter and soil samples were taken at every sampling date and extracted by heat. Permanent microscopic slides were prepared using Hoyer medium. Specimens were identified using Gisin (1960), Fjellberg (1980, 1998, 2007), Bretfeld (1999) and Potapov (2001). Collembola diversity was calculated according to Shannon–Wiener as $H' = -\Sigma\, p_i \ln p_i$, with p_i the ratio between the number of the *i*th species and the total number of Collembola for each layer per sampling date (Pielou 1971, Ardakani 2007). Analysis of variance was used for analyzing variations in the number of Collembola with sampling data and soil layer. Means were compared using the least significant difference (LSD) multiple range test at $p < 0.01$. Prior to statistical analysis data were inspected for homogeneity of variance using the Levene test and log (x+1) transformed if necessary. Statistical analyses were performed using MSTAT-C software version 2.10 for DOS (MSTATC version 2.10, 1989).

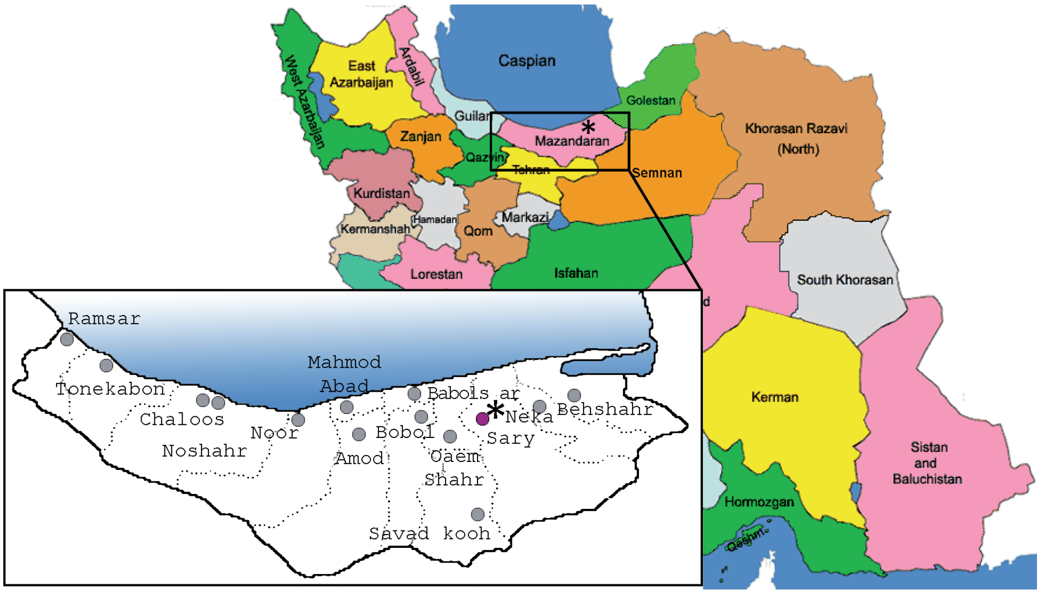

Figure 1. Map of the Mazandaran province of Iran with the location of the Semeskandeh forest indicated by *.

3. Results

3.1. Species composition

We identified a total of 15 species from 13 genera and 8 families of Collembola by the corer samplings (Tab. 1). Among the 15 collected species *Lipothrix lubbocki* (Tullberg, 1872) and *Heteraphorura japonica* (Yossi, 1967) were recorded for the first time in Iran. The other 13 species had been recorded previously from other regions in Iran (Shayanmehr et al. 2013), except *Persanura hyrcanica*, which is new to science. By the additional leaf-litter and soil samples, five more species new to the fauna of Iran were identified: *Sminthurus* cf. *ghilarovi* Stebaeva, 1966 (Sminthuridae), *Paralipothrix* cf. *natalicius* (Sminthuridae) (Ellis, 1974), *Sphaeridia* sp.1 and *Sphaeridia* sp.2 (Sminthurididae) and *Dicyrtoma* cf. *ghilarovi* Bretfeld, 1996 (Dicyrtomidae). Since these five species were not present in our quantitative samples, they were excluded from density and diversity estimations.

The quantitative samples indicate that the Collembola fauna was dominated by Entomobryidae (31 % of total), with Neanuridae being least abundant (0.5 %). Among the collected species, *Heteromurus major* (Moniez, 1889) was most abundant (17 % of total). *Persanura hyrcanica* nov. sp. (Mehrafrooz et al. 2014), a new genus and species of Neanurinae, was only found in low density (0.5 %). Notably, with nine species the Collembola fauna was dominated by Symphypleona.

3.2. Density and diversity

Population density varied from 1847±814 to 5477±1408 ind. m^{-2} in the leaf litter, 1273±471 to 2484±504 ind. m^{-2} in 0–3 cm and 764±385 to 3057±1218 ind. m^{-2} in 3–6 cm soil depth (Tab. 2), with the differences between soil layers being significant (df = 2, F = 145.1, $p < 0.001$). Overall, Collembola predominantly colonized the litter layer (3556±1045 ind. m^{-2}), but this varied with season (Fig. 2). Further, density of Collembola varied significantly with time (df = 5, F = 43.4, $p < 0.001$). Total density was highest in winter (January, 11,019±3131 ind. m^{-2}). Thereafter, total density decreased towards

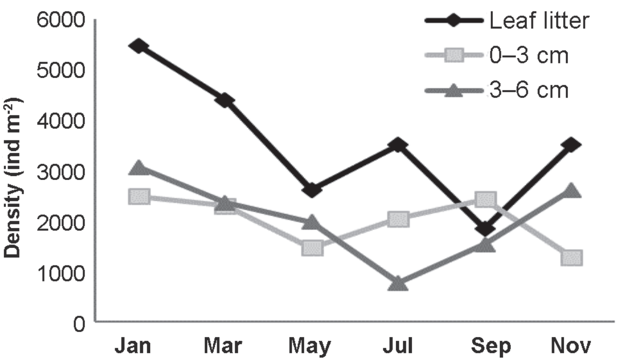

Figure 2. Seasonal changes in density (ind. m^{-2}) of Collembola in different soil layers. Samples were taken at bimonthly intervals from July 2012 to May 2013 in the leaf litter ($O_{L, F, H}$), 0–3 and 3–6 cm soil depth.

summer (9042±3042 and 6049±1897 ind. m^{-2} for March and May, respectively), stayed at a similar level during summer (6305±2367 and 5796±2371 ind. m^{-2} for July and September, respectively) and then started to increase again towards winter (November, 7388±1943 ind. m^{-2}). Generally, variation in collembolan density in the leaf litter layer was most pronounced in winter and spring.

As indicated by the Shannon-Wiener index, the diversity of Collembola in the litter layer (1.16±0.21) markedly exceeded that in 0–3 (0.86±0.20) and 3–6 cm soil depth (0.86±0.24) (Fig. 3). In soil, diversity varied little throughout the year, except in November in 3–6 cm soil depth (1.02±0.41), where it increased markedly. Species diversity in the litter layer increased in autumn, reached a maximum in winter and then decreased in summer.

According to their vertical distribution in different soil horizons, species such as *Dicyrtoma* sp., *S. elegans*, *C. marginata* and *L. lubbocki*, which predominantly occurred in leaf litter, were classified as epedaphic or hemiedaphic, and species such as *I. minor*, *H. japonica* and *I. italicus*, which predominantly occurred in mineral soil layers (0–6 cm), were classified as euedaphic. Species including *H. major*, *S. elegans*, *I. minor* and *C. stercoraria* were the most dominant species, with *H. major* being the most dominant species with a peak in density in the leaf litter in July (Fig. 4). In contrast, the density of *S. elegans* and *C. stercoraria* peaked in winter and declined continuously until summer. Contrary to these epedaphic or hemiedaphic species, the density of the euedaphic *I. minor* varied little with time throughout the year.

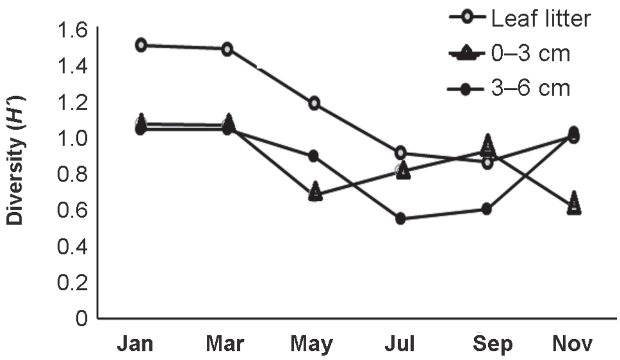

Figure 3. Changes in diversity (*H′*) of Collembola during one year. Samples were taken at bimonthly intervals from July 2012 to May 2013 in the leaf litter ($O_{L, F, H}$), the 0–3 and 3–6 cm soil depth.

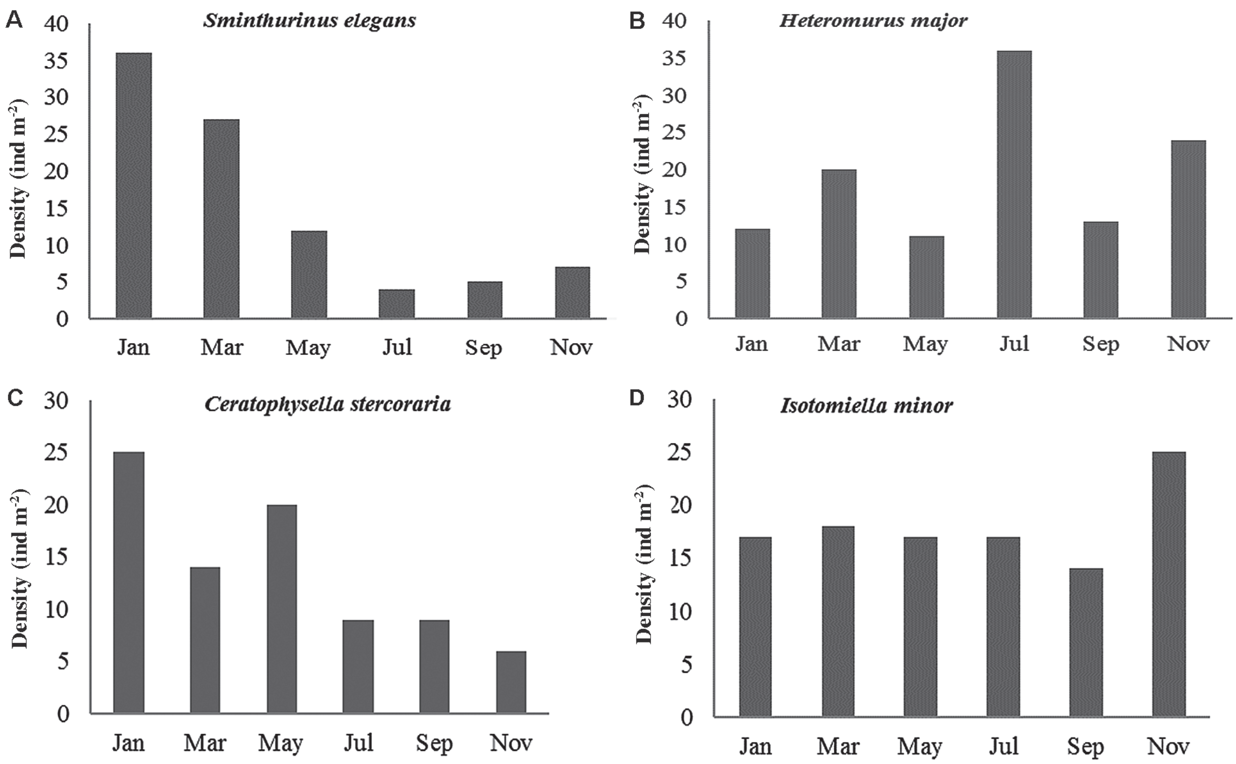

Figure 4. Changes in density (ind. m^{-2}) of dominant Collembola species during one year. Samples were taken at bimonthly intervals from July 2012 to May 2013 in the leaf litter ($O_{L, F, H}$), the 0–3 and 3–6 cm soil depth.

Table 1. Family, ecomorphological life form and dominance of collembolan species recorded in the Semeskandeh forest (Mazandaran Province, Iran). Species marked with (*) were collected from additional samples of leaf litter.

	Collembola species	Family	Ecomophological life form	Dominance (% of total)
1	*Heteromurus major* (Moniez, 1889)	Entomobryidae	Epedaphic	17
2	*Sminthurinus elegans* (Fitch, 1863)	Katiannidae	Epedaphic or hemiedaphic	14
3	*Isotomiella minor* (Schäffer, 1896)	Isotomidae	Euedaphic	14
4	*Ceratophysella stercoraria* Stach, 1963	Hypogastruridae	Hemiedaphic	13
5	*Folsomia penicula* Bagnall, 1939	Isotomidae	Hemiedaphic	9
6	*Heteromurus nitidus* (Templeton, 1836)	Entomobryidae	Epedaphic	7
7	*Isotomurus italicus* (Carapelli et al., 1995)	Isotomidae	Euedaphic	6
8	*Caprainea marginata* (Schött, 1893)	Sminthuridae	Epedaphic or hemiedaphic	6
9	*Pseudosinella octopunctata* Börner, 1901	Entomobryidae	Epedaphic	6
10	*Tomocerus vulgaris* (Tullberg, 1871)	Tomoceridae	Epedaphic	3
11	*Heteraphorura japonica* (Yosii, 1967)	Onychiuridae	Euedaphic	3
12	*Dicyrtoma* sp.	Dicyrtomidae	Epedaphic or hemiedaphic	1
13	*Lepidocyrtus* sp.	Entomobryidae	Epedaphic	1
14	*Lipothrix lubbocki* (Tullberg, 1872)	Sminthuridae	Epedaphic or hemiedaphic	1
15	*Persanura hyrcanica* nov. sp.	Neanuridae	Hemiedaphic	1
16	**Sminthurus* cf. *ghilarovi* Stebaeva, 1966	Sminthuridae	Hemiedaphic	-
17	**Paralipothrix* cf. *natalicius* (Ellis, 1974)	Sminthuridae	Hemiedaphic	-
18	**Dicyrtoma* cf. *ghilarovi* Bretfeld, 1996	Dicyrtomidae	Hemiedaphic	-
19	**Sphaeridia* sp.1	Sminthurididae	Hemiedaphic	-
20	**Sphaeridia* sp.2	Sminthurididae	Hemiedaphic	-

Table 2. Changes in density and diversity of Collembola at three soil depths recorded in the Semeskandeh forest (means ± SD).

	January	March	May	July	September	November	Average
Density (ind. m^{-2})							
Leaf litter	5477±1408	4394±1413	2611±425	3503±1373	1847±814	3503±836	3556±1045
0–3 cm	2484±504	2292±861	1465±836	2038±609	2420±805	1273±471	1995±681
3–6 cm	3057±1218	2354±767	1971±635	764±385	1528±751	2611±635	2047±731
Total	11019±3131	9042±3042	6049±1897	6305±2367	5796±2371	7388±1943	7600±2458
Diversity (*H′*)							
Leaf litter	1.50±0.1414	1.48±0.18	1.18±0.15	0.91±0.27	0.86±0.24	1.00±0.2727	1.16±0.21
0–3 cm	1.07±0.27	1.06±0.26	0.68±0.15	0.81±0.21	0.92±0.27	0.61±0.06	0.86±0.20
3–6 cm	1.04±0.40	1.04±0.32	0.89±0.19	0.55±0.03	0.60±0.06	1.02±0.41	0.86±0.24
Total	3.63±0.82	3.59±0.77	2.75±0.50	2.28±0.51	2.39±0.59	2.65±0.74	2.88±0.66

Samples were taken in bimonthly intervals from July 2012 until May 2013 in the litter layer ($O_{L,F,H}$), in 0–3 and 3–6 cm soil depth (A_h).

4. Discussion

Collembola are among the most abundant and diverse soil microarthropods in virtually any habitat, but in particular in forest soils, especially old-growth forests (Hopkin 1997, Addison et al. 2003). The Semeskandeh forest as a part of the Hyrcanian forest represents an old-growth forest little disturbed by human activity. In the present study, the diversity and density of Collembola in this forest were investigated for the first time. In total 20 Collembola species were identified. Thirteen species have been previously recorded in Iran, most of which are distributed widely in the Palaearctic, while a few species are distributed throughout the Holarcic and some have a worldwide distribution (Tab. 3). On the other hand, *L. lubbocki*, *H. japonica, S.* cf. *ghilarovi*, *P.* cf. *natalicius*, *D.* cf. *ghilarovi* and two *Sphaeridia* spp. were recorded for the first time for the Iranian Collembola fauna. *L. lubbocki* is widespread in the Holarctic, typically occurs in forests, but only in low numbers (Bretfeld 1999), while *H. japonica* is an Asian species (Arbea 2014). *S.* cf. *ghilarovi* was collected from leaf-litter of the study site. Previously, this species had been collected from a mixed forest in Russia (Bretfeld 1999). Of the genus *Sminthurus*, only one species, the cosmopolitan distributed *S. viridis*, has been previously recorded from Iran (Khuzestan; Farrahbakhsh, 1961). *P.* cf. *natalicius* was also recorded for the first time in Iran, but is widespread in Europe (France, Greece) and northern Africa (Morocco) (Bretfeld 1999). From *Sphaeridia*, only one species, *S. pumilis* (Krausbauer, 1898), had been previously recorded in Iran from Central, Gilan and Kermanshah (Cox 1982, Kahrarian et. al. 2012); the two unknown species from this study need to be described. *D.* cf. *ghilarovi,* also recorded for the first time in Iran, has been found previously in forests in Russia (Bretfeld 1999).

Collembolan densities varied significantly between the cool wet season (winter) and the hot dry season (summer), with Collembola reaching maximum densities in winter and minimum densities in late summer. It is known that survival of Collembola is heavily affected by temperature and moisture, with most Collembola species being sensitive to hot dry conditions and benefiting from moist conditions and cooler temperature (Hopkin 1997, Muturi et al. 2009, Jalaluddin Abbas 2012). The importance of moist conditions is documented by generally high density of Collembola during the wet as compared to the dry season in the tropics (Muturi et al. 2009, Janion 2011). Low Collembola density in summer also is typical for temperate forests (Jonsson et al. 2006, Cuchta et al. 2012, Huebner et al. 2012, Fujii et al. 2012, Jiang et al. 2013). The seasonal dynamics of Collembola

Table 3. Species identified from the corer samples that have been previously recorded in Iran, grouped according to their general distribution.

Species	Recorded in Iran (Provinces)	Authors
Palaearctic distributed species		
Caprainea marginata (Schött, 1893)	Kermanshah	Kahrarian et al. 2012
Ceratophysella stercoraria Stach, 1963	Kermanshah	Kahrarian et al. 2012
	Kohgilueh and Boyerahmad provinces	Falahati et al. 2012
Isotomiella minor (Schäffer, 1896)	Tehran	Moravvej et al. 2007
	Rasht/Gilan	Daghighi et al. 2013
	Azerbaijan	Cox 1982, Shayanmehr et al. 2013
Isotomurus italicus (Carapelli et al., 1995)	Mazandaran/Sari	Yahyapour 2012
Heteromurus major (Moniez, 1889)	Sari/Mazandaran	Yahyapour 2012, Yahyapour & Shayanmehr 2013
	Golestan/Grogan and Kermanshah	Shayanmehr et al. 2013
Holarctic distributed species		
Folsomia penicula Bagnall, 1939	Golestan, Mazandaran, Azarbaijan and Gilan provinces	Cox 1982
Sminthurinus elegans (Fitch, 1863)	Sari/Mazandaran	Yahyapour 2012
	Golestan/Grogan and Kermanshah	Ghahramaninezhad et al. 2013
Worldwide distributed species		
Heteromurus nitidus (Templeton, 1836)	Mazandaran	Cox 1982
Pseudosinella octopunctata Börner, 1901	Sari/Mazandaran, Zanjan, Central and Azerbaijan provinces	Cox 1982
Tomocerus vulgaris (Tullberg, 1871)	Golestan, Mazandaran, Azarbaijan and Gilan provinces	Cox 1982

in the Semesknadeh forest differs from those in temperate forests of the Holarctic, however, in that the highest densities were observed in January, whereby in temperate forests of Europe or North America densities are usually lowest in winter. Winter temperatures in temperate forests are generally below freezing, while the winters in the study area can be considered to be mild as well as being moister than in summer.

The number of species in the Semeskandeh forest is rather low compared to other forests in Europe and America. A number of factors might be responsible for the low species number, including, e.g., the lack of understory, as it has been demonstrated that Collembola diversity increases with increasing plant diversity (Cortet & Poinsot-Balaguer 1998, Rusek 2001, Materna 2004, Chahartaghi et al. 2006, Rodríguez-Loinaz et al. 2008). Soil characteristics, such as pH and organic matter content, also have been shown to affect Collembola diversity and community composition (Vilkamaa & Huhta 1986). Soil pH in Semeskandeh forest is high (6.2–7.9), contrasting with more acidic forests with higher densities and species diversities of Collembola, such as the beech – oak forest in south Germany investigated by Chahartaghi et al. (2006) and the sugar maple forest in Canada studied by Chagnon et al. (2000). Low numbers of Collembola species were also recorded from alkaline turfgrass ecosystem in North America (Rochefort et al. 2006). In recent years, Mazandaran province experienced declining rainfall and prolonged drought periods in summer, which may have contributed to low Collembola density.

Despite the presumed importance of drought as driving factor of the Collembola community, most of the species of the study site colonized the leaf litter layer, particularly in winter. This is consistent with earlier studies documenting that, if environmental conditions are beneficial, most Collembola and other soil invertebrates colonize the litter layer (Detsis 2000). Therefore, the decline in density and diversity of Collembola with soil depth suggests that environmental conditions in the litter layer were most favorable for Collembola at the study site and this also applies to other forest ecosystems (Yoshida & Hijii 2005, Mohammadnezhad Kiasari et al. 2011, Shilenkova & Tiunov 2013). Species such as *H. major*, *S. elegans* and *C. stercoraria* are abundant and widespread in many regions of Iran (Shayanmehr et al. 2013), whereas others including *H. japonica*, *C. marginata* and *P. hyrcanica* nov. sp. presumably are more locally distributed and only reach low densities. These species may be typical for the studied forest and Hyrcanian forests may be important for their conservation. However, to understand the factors which limit their abundance and distribution, further analyses are needed in a wider geographic range of Hyrcanian and related forest systems.

5. Conclusion

The present study is the first on the Collembola fauna of Hyrcanian forests. Among Collembola families Entomobryidae were most abundant with *H. major* being the most dominant species. Density of Collembola in total and that of most Collembola species was highest in winter with most Collembola colonizing the litter layer. Generally, Collembola density and diversity was unexpectedly low with the dominant species being widespread. However, for some species of low abundance and more restricted geographic distribution, the Hyrcanian forest presumably serves as an important habitat underlining the importance for conserving this unique ecosystem.

6. Acknowledgment

We thank Rafael Jordana (Latvia, Spain), Igor Kaprus (Ukrine), Zeppelini (Brazil) and Dariusz Skarzynski (Wroclaw, Poland) for help in Collembola species identification. We are grateful to Ulrich Burkhardt (Goerlitz, Germany) for hints on how to improve the paper.

7. References

Addison, J. A., J. A. Trofymow & V. G. Marshall (2003): Abundance, species diversity, and community structure of Collembola in successional coastal temperate forests on Vancouver Island, Canada. – Applied Soil Ecology **24**: 234–246.

Arbea, I. J. (2014): A new species of *Heteraphorura* Bagnall, 1948 (Collembola, Poduromorpha, Onychiuridae) from Apennine Mountains (Tuscany, Italy). – Arquivos Entomoloxicos **12**: 3–10.

Ardakani, M. R. (2007): Ecology. – University of Tehran Press, Tehran: 340 pp.

Bretfeld, G. (1999): Synopses on Palaearctic Collembola Vol. 2: Symphypleona. – Abhandlungen und Berichte des Naturkundemuseums Görlitz: 318 pp.

Chagnon, M., C. Hébert & D. Parél (2000): Community structures of Collembola in sugar maple forests: relations to humus type and seasonal trends. – Pedobiologia **44**: 148–174.

Chahartaghi, M., S. Scheu & L. Ruess (2006): Sex ratio and mode of reproduction in Collembola of an oak-beech forest. – Pedobiologia **50**: 331–340.

Cortet, J., & N. Poinsot-Balaguer (1998): Collembola populations under sclerophyllous coppices in Provence (France): comparison between two types of vegetation, *Quercus* *ilex* L. and *Quercus coccifera* L. – Acta Oecologica **19**: 413–424.

Cox, P. (1982): The Collembola fauna of north and north western Iran. – Entomologist's Monthly Magazine **118**: 39–43.

Cuchta, P., D. Miklisová, L. Ková (2012): A three-year study of soil Collembola communities in spruce forest stands of the High Tatra Mts (Slovakia) after a catastrophic windthrow event. – European Journal of Soil Biology **50**: 151–158.

Daghighi, E., J. Hajizadeh, R. Hosseini & A. Moravvej (2013): Introduction of eighteen of springtails (Arthropoda: Collembola) from Guilan Province with three new records for Iran. – Entomofauna **34**: 177–184.

Detsis, V. (2000): Vertical distribution of Collembola in deciduous forests under mediterranean climatic conditions. – Belgian Journal of Zoology **130**: 55–59.

Djamali, M., H. Akhani, R. Khoshravesh, V. Andrieu-Ponel, P. Ponel & S. Brewer (2011): Application of the global bioclimatic classification to Iran: implications for understanding the modern vegetation and biogeography. – Ecologia Mediterranea **37**: 91–114.

Filser, J., K. H. Mebes, K. Winter, A. Lang & C. Kampichler (2002): Long-term dynamics and interrelationships of soil Collembola and microorganisms in an arable landscape following land use change. – Geoderma **105**: 201–221.

Fjellberg, A. (1980): Identification Keys to Norwegian Collembola. – Norsk Entomologisk Forening, Ås: 180 pp.

Fjellberg, A. (1998): The Collembola of Fennoscandia and Denmark. Part I: Poduromorpha. – Brill, Leiden: 183 pp.

Fjellberg, A. (2007): The Collembola of Fennoscandia and Denmark. Part II: Entomobryomorpha and Symphypleona. – Brill, Leiden: 266 pp.

Fujii, S, A. Yamada, F. Keitaro, S. Saitoh, K. Kitayama & H. Takeda (2012): Relationships among distribution of fine roots, soil DOC concentration and Collembola. – Plant Root **7**: 21–27.

Ghahramaninezhad, S., M. Shayanmehr & E. Yoosefi Lafooraki (2013): New records for Iranian Collembola fauna from Kermanshah city. – Journal of Plant Protection **27**: 136–138 (In Persian).

Gisin, H. (1960): Collembolenfauna Europas. – Museum d'Histoire Naturelle, Genève, Switzerland: 312 pp.

Haghdoost, N., M. Akbarinia, S. M. Hosseini & Y. Kooch (2011): Conversion of Hyrcanian degraded forests to plantations: Effects on soil C and N stocks. – Annals of Biological Research **2**: 385–399.

Hopkin, S. P. (1997): Biology of Springtails (Insecta: Collembola). – Oxford University Press, Cambridge, UK: 340 pp.

Hosseini, S. M. (2006): Death of Elm trees in the Hyrcanian forests of Iran. – Proceedings of the Workshop, Gmunden, Austria: 183–186.

Huebner, K., Z. Lindo & M. J. Lechowicz (2012): Post-fire succession of collembolan communities in a northern hardwood forest. – European Journal of Soil Biology **48**: 59–65.

Jalaluddin Abbas, M. (2012): Seasonal diversity of Collembola assemblages in two different habitats of Aligarh. – Indian Journal of Fundamental and Applied Life Sciences **2**: 18–25.

Janion, C., A. Bedos, J. Bengtsson, L. Deharveng, B. J. Vuuren, H. P. Leinaas, A. Liu, A. Malmström, D. Porco & S. L. Chown (2011): Springtail diversity in South Africa. – AOSIS Open Journals **107**: 1–7.

Jiang, Y., X. Yin & F. Wang (2013): The influence of litter mixing on decomposition and soil fauna assemblages in a *Pinus koraiensis* mixed broad-leaved forest of the Changbai Mountains, China. – European Journal of Soil Biology **55**: 28–39.

Jonsson, L. M., J. Dightona, J. Lussenhop & R. T. Koide (2006): The effect of mixing ground leaf litters to soil on the development of pitch pine ectomycorrhizal and soil arthropod communities in natural soil microcosm systems. – Soil Biology and Biochemistry **38**: 134–144.

Kahrarian, M., A. Nikpay & L. Mohammadi Noor (2012): Preliminary Checklist of The Collembolan fauna in Kermanshah, Sahneh and Harsin counties (Kermanshah: Iran) with three new records from Iranian fauna. – Pakistan Entomologist **34**(1): 27–30.

Materna, J. (2004): Does forest type and vegetation patchiness influence horizontal distribution of soil Collembola in two neighbouring forest sites? – Pedobiologia **48**: 339–343.

Mehrafrooz Mayvan, M., M. Shayanmehr, A. Smolis & D. Skarżyński (2014): *Persanura hyrcanica* nov sp., a new genus and species of Neanurinae (Collembola: Neanuridae) from Iran, with a key to genera of the tribe Neanurini. – Zootaxa **3918**: 552–558.

Mitrovski-Bogdanovic, A. & B. Blesic (2006): Investigation of soil Apterygota (Insecta) in memorial park Sumarice (Kragujevac). – Kragujevac Journal of Science **28**: 77–81.

Mohammadnezhad Kiasari, S. H., K. H. Saghebe Talebi, R. Rahmani & M. Amoozad (2011): Comparison of soil invertebrates diversity in the areas of natural forest and forest plantation Sari. – Journal of Science and Natural Resources **6**: 55–69 (In Persian).

Moravvej, S. A. (2003): Bioviversity of Collembola of Tehran region and preliminary observation on several species. MSc thesis, Sari, Vol. 1. – Tarbiat Modarres University, Iran: 137 pp. [in Persian with English abstract].

MSTATC version 2.10. (1989): Michigan State University: East Lansing, MI; MSDOS.

Muturi, J. J., J. P. Mbugi, J. M. Mueke, J. Lagerlóf, J. K. Mungatu, G. Nyamasyo & M. Gikungu (2009): Collembola density and diversity along a gradient of land-use types in Embu district, Eastern Kenya. – Tropical and Subtropical Agroecosystems **11**: 361–369.

Naqinezhad, A., S. H. Bahari, H. Gholizadeh, R. Esmaeili, B. Hamzeh'ee, M. Djamali & H. Moradi (2012): A phytosociological survey of two lowland Caspian

(Hyrcanian) remnant forests, Northern Iran, for validation of some forest syntaxa. – Phytologia Balcanica **18**: 173–186.

Parkinson, D. (1988): Linkages between resource availability, microorganisms and soil invertebrates. – Agriculture, Ecosystems and Environment **24**: 21–32.

Paul, D., A. Nongmaithem & L. K. Jha (2011): Collembolan density and diversity in a forest and in an agroecosystem. – Open Journal of Soil Sciences **1**: 54–60.

Petersen, H. (2002): General aspects of collembolan ecology at the turn of the millennium. – Pedobiologia **46**: 246–260.

Pielou, E. C. (1971): An Introduction to Mathematical Ecology. – Wiley and Sons, New: 300 pp.

Potapov, M. (2001): Synopses on Palaearctic Collembola vol. 3: Isotomidae. – Abhandlungen und Berichte des Naturkundemuseums Görlitz: 603 pp.

Rochefort, S., F. Therrienb, D. J. Shetlarc & J. Brodeura (2006): Species diversity and seasonal abundance of Collembola in turfgrass ecosystems of North America. – Pedobiologia **50**: 61–68.

Rodgers, D. J. & R. L. Kitching (2011): Rainforest Collembola (Hexapoda: Collembola) and the insularity of epiphyte microhabitats. – Insect Conversation and Diversity **4**: 99–106.

Rodríguez-Loinaz, G., M. Onaindiaa, I. Amezagaa, I. Mijangosb & C. Garbisub (2008): Relationship between vegetation diversity and soil functional diversity in native mixed-oak forests. – Soil Biology & Biochemistry **40**: 49–60.

Rusek, J. (2001): Microhabitats of Collembola (Insecta: Entognatha) in beech and spruce forests and their influence on biodiversity. – European Journal of Soil Biology **37**: 237–244.

Santamaria, J. M., M. L. Moraza, D. Elustondo, E. Baquero, R. Jordana, R. Bermejo & A. H. Arino (2012): Diversity of Acari and Collembola along a pollution gradient in soils of a pre-pyrenean forests ecosystem. – Environmental Engineering and Management Journal **11**: 1159–1169.

Shayanmehr, M., E. Yahyapour, M. Kahrarian & E. Yoosefi Lafooraki (2013): An introduction to Iranian Collembola (Hexapoda): an update to the species list. – Zookey **335**: 69–83.

Shilenkova, O. L. & A. V. Tiunov (2013): Soil–litter nitrogen transfer and changes in $\delta^{13}C$ and $\delta\,^{15}N$ values in decomposing leaf litter during laboratory incubation. – Pedobiologia **56**: 147–152.

Sousa, J. P., M. Manuela da Gama, C. Pinto, A. Keating, F. Calhoa, M. Lemos, C. Castro, T. Luz, P. Leitao & S. Dias (2004): Effects of land-use on Collembola diversity patterns in a Mediterranean landscape. – Pedobiologia **48**: 609–622.

Steffen, J. F., J. Palincsar, F. M. Funk & D. J. Larkin (2012): Activity and Diversity of Collembola (Insecta) and Mites (Acari) in Litter of a Degraded Midwestern Oak Woodland. – The Great Lakes Entomologist **45**: 1–18.

Vilkamaa, P. & V. Huhta (1986): Effect of fertilization and pH on communities of Collembola in pine forest soil. – Annales Zoologici Fennici **23**: 167–174.

Yahyapour, E. (2012): Faunistic Study on Collembola (Insecta: Apterygota) in Sari Regions. MSc thesis, Sari, Vol. 1. – Sari Agricaltural Science and Natural Resources University, Iran, 96 pp. (in Persian with English abstract).

Yahyapour, E. & M. Shayanmehr (2013): Introduction of some Entomobryidae species (Collembola) from different Caspian regions. – Taxonomy and Biosystematic **15**: 15–24.

Yoosefi Lafforaki, E. & M. Shayanmehr (2013): New records of Collembola (Hexapoda: Entognatha) for Iranian fauna from Mazandaran, Semnan and Isfahan provinces. – Natura Somogyiensis **23**: 135–142.

Yoshida, T. & N. Hijii (2005): Vertical distribution and seasonal dynamics of arboreal collembolan communities in a Japanese cedar (*Cryptomeria japonica* D. Don) plantation. – Pedobiologia **49**: 425–434.