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MAHMOOD MEHRAFROOZ MAYVAN

HUSSEIN SADEGHI NAMAGHI

MASOUMEH SHAYANMEHR

PENELOPE GREENSLADE

GRANT PALMER

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Density, diversity, and seasonal fluctuations in soil Collembola in three differently managed ecosystems in North Khorasan, Iran

Mahmood MEHRAFROOZ MAYVAN[1], **Hussein SADEGHI-NAMAGHI**[1,*], **Masoumeh SHAYANMEHR**[2], **Penelope GREENSLADE**[3,4], **Grant PALMER**[5]

[1]Department of Plant Protection, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Razavi Khorasan, Iran
[2]Department of Plant Protection, Faculty of Crop Sciences, Sari University of Agricultural Sciences and Natural Resources, Sari, Iran
[3]Centre for Environmental Management, School of Science, Psychology and Sport, Federation University, Ballarat, Victoria, Australia
[4]Department of Biology, Australian National University, Australian Capital Territory.
[5]School of Science, Psychology and Sport, Federation University, Ballarat, Victoria, Australia

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Abstract: We examined the density, diversity, and seasonal fluctuation of soil inhabiting Collembola in different ecosystems: agricultural, rangeland, and forest ecosystems in the North Khorasan province of Iran from June 2018 to May 2019. The sampling program was conducted monthly on the three sites. Density was measured on the number of individuals per square meter. Species diversity was calculated using Shannon–Wiener index, Simpson's diversity, and species richness by Rarefaction method. Fifty-three species belonging to 42 genera and 17 families were collected and identified. The density of Collembola in the forest was higher than in either rangeland or agroecosystem. Highest densities were recorded during October and April in the forest. A similar seasonal trend was observed in the rangeland and in the agroecosystem. The lowest densities in agroecosystem and rangeland were recorded during June and from forest in January. PERMANOVA analysis showed that the soil Collembola community differed between the three ecosystems. The SIMPER analysis revealed that the agriculture sites show the highest similarity (68.3), followed by pasture (51.8), and then forest (49.7). Indices of diversity and species richness values are discussed in light of land use. We found that forest harboured a higher density and diversity of Collembola compared to rangeland and agroecosystems.

Key words: Species composition, North Khorasan, population dynamics, springtails

1. Introduction

Collembola (springtails) are among the most abundant microartropods and are found in a variety of habitats with densities up to 200,000 individuals per square meter (Hopkin, 1997). They play an important role in plant litter decomposition, nutrient cycling, soil microbial ecology and also in modifying plant growth (Culic et al., 2002; Petersen, 2002; Chahartaghi et al., 2006; Greenslade, 2007; Mehrafrooz Mayvan et al., 2015; Meloni et al., 2020). They are vital in the functioning of ecosystems and maintenance of soil health and above ground productivity, both in natural and disturbed ecosystems.

Soil biodiversity can be negatively influenced by disturbances such as agricultural practices, plants, monocultures, tillage, and weed management (Tsiafouli et al., 2015). Losses of species and functional diversity in soil communities can lead to reductions in nutrient turnover, soil carbon storage, and pest suppression (Bardgett and van der Putten 2014; Wagg et al., 2014; Bender and van der Heijden, 2015; Lundgren and Fausti, 2015). Tillage is an agricultural practice that affects the soil arthropod food web community, as it changes both the biophysical and biochemical attributes of the soil (Roger-Estrade et al., 2010). By redistributing litter and other organic materials throughout the soil profile, tillage changes the availability of habitats and resources which affects the activity density species richness, and community composition of soil arthropods (Reeleder et al., 2006; Diehl et al., 2012; Chang et al., 2013; Fiera et al., 2020). The use of pesticides, which interferes with the composition of soil communities and reduces the density of soil invertebrates (Loranger et al., 1998), may also reduce decomposition in the soil (Stork and Eggleton, 1992).

Our aim was to collect, identify, and measure the density and diversity of the soil inhabiting Collembola in three different terrestrial ecosystems. We hypothesized that intensive disturbance in agroecosystems negatively alter the environmental conditions for soil Collembola

* Correspondence: Sadeghin@um.ac.ir

and that density, richness, and diversity would be lower in agricultural systems compared to forest and pasture systems. Secondly, we hypothesized that environmental factors such as soil moisture and temperature influence seasonal variation of Collembola density. Also, it is predicted that in summer and winter, population densities of Collembola will be lower because of unfavourable microclimatic conditions.

2. Materials and methods

2.1. Study area and sampling sites

The study was carried out in a high relief area of the North Khorasan Province in North-East, Iran. This Province lies between 36°37′ to 38°17′ N latitude and 55°53′ to 58°20′ E longitude and has an area of about 28,400 km^2. Altitude is from 1000 to 2500 m above sea level (Meghdadi and Kamkar, 2011) and there is a common border in the North East with Turkmenistan. The province has a moderate climate, with an average annual rainfall about 250 mm (Moshaverinia et al., 2012). The minimum and maximum temperatures recorded in the North Khorasan province are–15 °C and +40 °C, respectively.

The three sampling sites were the forest of Darkesh-Jozak, Golil-Sarany rangeland conservation area, and alfalfa fields in the vicinity of Shirvan city in North Khorasan province (Table 1), the latter being as a representative of agricultural ecosystems. The Darkesh-Jozak forest is a part of Hyrcanian forests and is located in the north of Khorasan Province of Iran (Figure 1). It has an area of about 22,500 hectares with a climate in the range of cold-humid category according to Amberger coefficient (Mashayekhan et al., 2015a). The elevation ranges from 1000 m to more than 2455 m above sea level (Mashayekhan et al., 2015b). The sampling site of the forest was located between 37°23′–37°26′ N latitude and 56°43′–56°58′ E longitude. The average annual rainfall in this region is 377 mm and the average annual temperature is 10.6 °C. The highest rainfall is in April (61.53 mm) and the lowest is in September (7.12 mm). The minimum and maximum annual temperature is –10.69 °C in January and + 33.4°C in July (Karimi et al., 2016). The rangeland area under this study was the Golil-Sarany protected rangelands (Figure 2). It is a protected area of 17,800 hectares and is located North of Shirvan city between 37°42′–37°54′ N latitude and 57°13′–57°52′ E longitude (Mehrafrooz Mayvan and Greenslade, 2020). The lowest altitude in this area is about 1422 m and the highest is about 2922 m above sea level (Farkhani 2016). The average annual rainfall in the region is 338 mm and the minimum and maximum annual temperature is –8.67° C in January and +26° C in July (Figure 3) (Esmaeelpoor, 2014).

2.2. Collembola sampling

For sampling of soil Collembola, a plot of about one hectare was selected at each of the three sampling sites (e.g., Darkesh-Jozak forest, Golil-Sarany rangeland, and alfalfa fields). At each sampling site, six samples spaced at least 20 m apart were taken on each sampling date. Sampling locations were randomly selected within each plot. The soil samples were collected with a soil corer of 5 in diameter and at a depth of 0–10 cm. Soil sampling started in June 2018 and continued monthly until May 2019. Sampling was carried out between 8.00 AM and 10.00 AM on each date. Each sample was immediately placed individually in a sealed plastic bag and transferred to the laboratory. Springtails in each soil sample were extracted using a modified Berlese-Tullgren funnel and collected in a bottle containing 75% ethanol. Extracted specimens were sorted, counted, and kept at room temperature for later identification. The springtails were mounted on microscopic slides and examined at high magnification using a compound light microscope (Olympus BH-2) under phase contrast illumination. The specimens were cleared with either Nesbitt's fluid or lactic acid. Permanent microscopic slides were prepared using Hoyer's medium. Specimens were identified using Richards (1968), Bretfeld (1999), Fjellberg (1998, 2007), Potapov (2001), and Jordana (2012).

Species diversity was calculated using the Shannon–Wiener and Simpson's diversity indices (Pielou, 1971). In the Shannon–Wiener index, n is the total number of organisms of a particular species; N is the total number of organisms of all species and in Simpson's diversity index p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and s is the number of species. Species richness was calculated using Rarefaction's index where S is the total number of species found in the census and Ni is the number of individuals in species i (Ardakani, 2007). Collembola density is reported as the number of individuals per square meter.

2.3. Statistical analysis

Analysis of variance was used for analysing variations in the number of Collembola compared with sampling data and ecosystems. 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 SPSS software version 2.10 and with Minitab software version 16.0. Further, differences in species composition between sites were assessed using nonmetric multidimensional scaling (nMDS) ordinations of soil Collembola based on a Bray-Curtis distance/similarity matrix. A PERMANOVA was used to quantify differences in collembolan community composition between the three sampling sites. We used squared-root transformed data for analyses, taking the option for a

Table 1. Latitude, longitude, and altitude (above sea level) of ecosystems from June 2018 to May 2019.

	Darkesh-Jozak forest	Golil-Sarany rangelands	Agricultural fields
June 2018	37° 25′ 14″ N 56° 40′ 30″ E 1325 m altitude	37° 48′ 17″ N 57° 56′ 22″ E 1591 m altitude	37°18′07″ N 57°55′33″ E 1188 m altitude
July 2018	37° 25′ 32″ N 56° 45′ 25″ E 1284 m altitude	37° 48′ 12″ N 57° 56′ 24″ E 1645 m altitude	37°12′41″ N 58°02′14″ E 1357 m altitude
August 2018	37° 26′ 43″ N 56° 47′ 21″ E 1540 m altitude	37° 50′ 38″ N 57° 51′ 51″ E 1972 m altitude	37°22′16″ N 57°45′16″ E 1146 m altitude
September 2018	37° 27′ 46″ N 56° 50′ 43″ E 1424 m altitude	37° 46′ 46″ N 57° 59′ 09″ E 1818 m altitude	37° 30′ 40″ N 57° 28′ 10″ E 919 m altitude
October 2018	37° 27′ 09″ N 56° 49′ 49″ E 1543 m altitude	37° 46′ 36″ N 58° 00′ 11″ E 1841 m altitude	37°19′11″ N 57°44′16″ E 1283 m altitude
November 2018	37° 27′ 06″ N 56° 49′ 27″ E 1593 m altitude	37° 49′ 50″ N 57° 54′ 02″ E 1759 m altitude	37° 35′ 56″ N 57° 57′ 49″ E 1391 m altitude
December 2018	37° 19′ 11″ N 57° 44′ 16″ E 1283 m altitude	37° 52′ 34″ N 57° 53′ 15” E 1952 m altitude	37° 36′ 26” N 57° 51′ 13” E 1488 m altitude
Junuary 2019	37° 26′ 15″ N 56° 47′ 51″ E 1282 m altitude	37° 46′ 54″ N 58° 00′ 28″ E 1988 m altitude	37° 29′ 36″ N 58° 12′ 31″ E 1756 m altitude
February 2019	37° 25′ 03″ N 56° 41′ 05″ E 1328 m altitude	37° 48′ 42″ N 57° 55′ 18″ E 1850 m altitude	37° 16′ 28″ N 58° 16′ 13″ E 1188 m altitude
March 2019	37° 25′ 17″ N 56° 10′ 31″ E 1265 m altitude	37° 48′ 01″ N 57° 57′ 30″ E 1635 m altitude	37° 18′ 02″ N 58° 02′ 02″ E 1147 m altitude
April 2019	37° 25′ 17″ N 56° 40′ 29″ E 1255 m altitude	37° 49′ 11″ N 57° 55′ 33″ E 1629 m altitude	37°19′42″ N 57°44′31″ E 1258 m altitude
May 2019	37° 27′ 01″ N 56° 48′ 46″ E 1573 m altitude	37° 50′ 38″ N 57° 51′ 51″ E 1972 m altitude	37°32′19″ N 58°10′43″ E 1604 m altitude

dummy variable in the Bray-Curtis calculation because there are a few site/month combinations with sparse data. Following Clark (1993), the goodness of the fit of the ordination plot is indicated by a stress value of <0.14.

3. Results

3.1. Collembolan species composition

53 species belonging to 42 genera in 17 families of Collembola were identified at the three sites (Table 2). Among them, the order Poduromorpha with 20,565 ind/m^2 was more abundant than the Entomobryomorpha (14,914 ind/m^2) and Symphypleona (3,414 ind/m^2). The Poduromorpha fauna was dominated by the family Hypogasturidae with 53% of total density. The family Neelidae was with fewest individuals (1%) (Figure 4). In the Hypogasturidae, *Ceratophysella gibbosa* (Bagnall, 1940) was the most abundant species (23%), while *Hypogastrura vernalis* (Carl, 1901) was recorded as

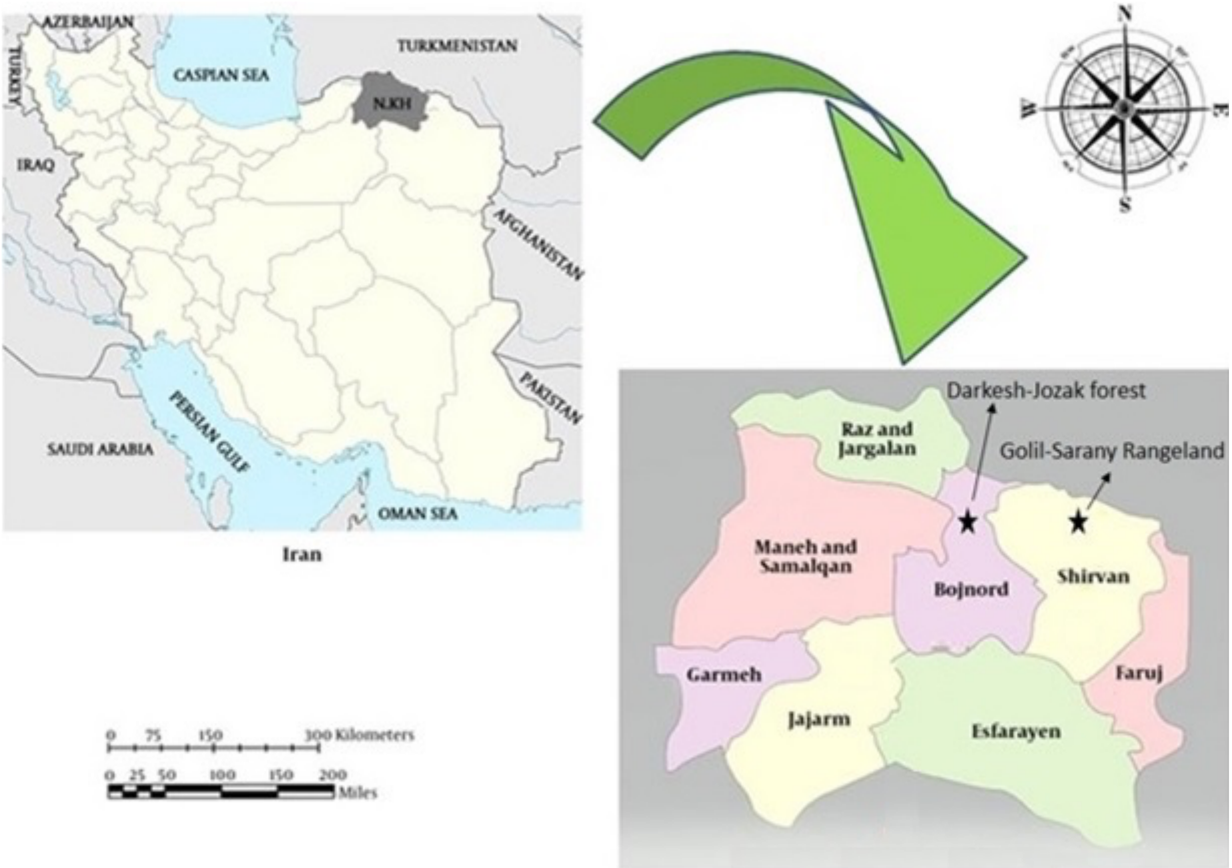

Figure 1. Map of Iran. a) Map of Iranian provinces, b) Study area indicated by arrow (North Khorasan province).

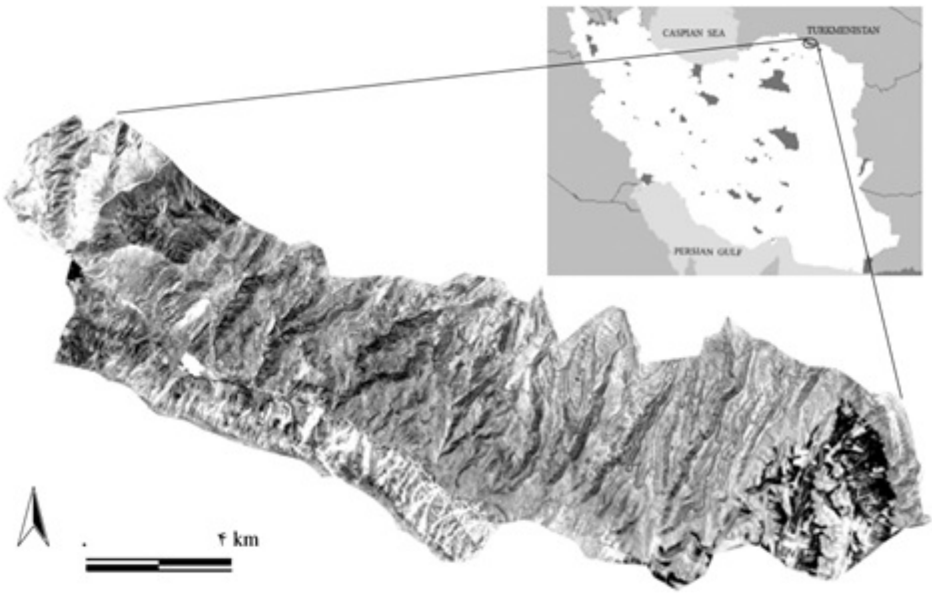

Figure 2. Map of Iran and location of the study area (Golil-Sarany, the protected rangeland) along with the IRS-P6 LISS III satellite image of the area.

species with low density (1%). The Entomobryidae with 61% of total individuals was the dominant family in Entomobryomorpha. In the Symphypleona, the species *Sminthurinus aureus* (Lubbock, 1862) was the most

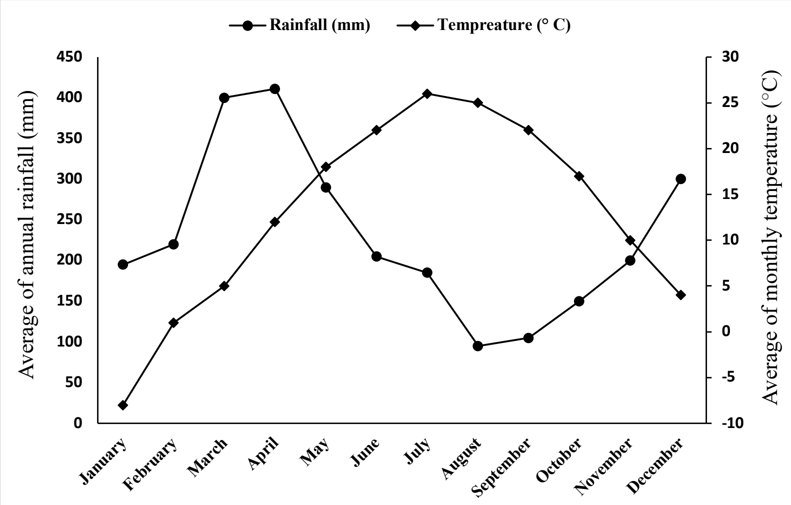

Figure 3. Climatogram (monthly measurements of temperature and precipitation) of the study area, Shirvan, based on the data obtained from the Meteorological Station of Shirvan over the period 2004–2014.

abundant (9%), while *Megalothorax minimus* was found at a low density (1%).

As it is shown in Figure 5, the three differently managed ecosystems (forest, rangeland, and agriculture), all separate out on the nMDS plot with 50% resemblance levels, as indicated by the green lines. All treatments differ in species composition as shown by an ANOSIM analysis (analysis of similarity) (Global R = 0.773, $p < 0.05$). Using a SIMPER analysis (Similarity Percentage) it is clear that sampled sites in the agroecosystem show the highest similarity (68.3), followed by rangeland (51.8) and forest (49.7). In terms of dissimilarity between sites, forest vs agriculture shows greatest dissimilarity (81.4), followed by forest vs pasture (74.3), and pasture vs agriculture (59.5). In all cases, dissimilarity is strongly driven by species which are absent from one ecosystem but present in another. For example, in forest vs agricultural soil, *Protaphorura* sp. and *Hypogastura* sp. were present in the agricultural soil, but absent in the forest, while *Paratullbergia callipygos* (Börner, 1902) was present in forest, but absent in agricultural system.

3.2. Density and diversity of Collembola

Population density varied from 164 ± 82 to 564 ± 229 ind./m^2 in the forest, 72 ± 25 to 433 ± 184 ind./m^2 in the pasture land, and 38 ± 20 to 391 ± 299 ind./m^2 in the agricultural soil (Table 3). ANOVA showed significant differences in population densities between samples ecosystems (df = 2, F = 21.87, $p < 0.001$). Overall, the Collembola population was higher in the forest ecosystem (564 ± 229 ind./m^2), but this varied with season (Figure 6). Moreover, total density of Collembola varied significantly with time (d f= 11, F = 10.78, $p < 0.001$). The highest density was observed in October. Thereafter, total density decreased towards winter (318 ± 160 ind./m^2 in January). With the onset of spring, the population increased (974 ± 460 ind./m^2 in April), stayed at a similar level during spring (868 ± 492 and 730 ± 389 ind./m^2 in May and July, respectively) and then started to decrease again towards the end of the summer (757 ± 361 ind./m^2 in August). Generally, variation in Collembola density in the forest soil was most pronounced between early spring and early autumn.

The Shannon–Wiener index shows that the diversity of Collembola in the forest soil (1.81 ± 0.62) markedly exceeded that of pasture land (1.39 ± 0.50) and agricultural land (1.07 ± 0.43) (Figure 7). The highest values of species diversity in all three studied ecosystems were observed in October, but the lowest values recorded for the forest, pasture and agroecosystem were in June, January and July, respectively. Based on the Simpson diversity index, the diversity of soil springtails in forest was the higher than either pasture or agroecosystem. The highest values were recorded in April (forest), April (pasture), October (agroecosystem) and the lowest values were recorded in January for forest, July (pasture), and July (agroecosystem) (Table 3). Using the rarefaction method, the mean value for species richness measured for forest (2.94 ± 0.51) was significantly higher than those of the rangeland (2.28 ± 0.55) and agroecosystem (2.10 ± 0.40). In the forest soil, the highest and lowest values for species richness were measured in October (3.89 ± 0.18) and in July (1.95 ± 0.35), respectively. A similar trend was observed in the agricultural and rangeland systems. The highest and lowest values of species richness in agroecosystem were 2.76 ± 0.43, 1.55 ± 0.01 and in rangeland were 2.88 ± 0.30, 1.66 ± 0.01 (Table 3).

Table 2. Order, family, habitat, and distribution of Collembolan species recorded in the North Khorasan Province, Iran.

Order	Collembola species		Family	Presence or absence in the ecosystem			Distribution
				Forest	Pastureland	Agriculture	
Poduromorpha	1	*Ceratophysella gibbosa* (Bagnall, 1940)	Hypogastruridae	+	+	+	Cosmopolitan
	2	*Hypogastrura* sp.	Hypogastruridae	-	+	+	---
	3	*Hypogastrura vernalis* (Carl, 1901)	Hypogastruridae	+	+	-	Cosmopolitan
	4	*Mesachorutes* sp.	Hypogastruridae	+	-	+	---
	5	*Neanura muscorum* (Templeton, 1835)	Neanuridae	+	-	-	Palaearctic
	6	*Paratullbergia callipygos* (Börner, 1902)	Tullbergiidae	+	-	-	Holarctic
	7	*Paratullbergia macdougalli* Bagnall, 1936	Tullbergiidae	+	+	-	Palaearctic
	8	*Protaphorura* sp.	Onychiuridae	-	+	+	---
	9	*Pseudachorutes subcrassus* Tullberg, 1871	Neanuridae	+	-	+	Palaearctic
	10	*Triacanthella intermedia* Dunger & Zivadinovic, 1984	Hypogastruridae	+	-	-	Palaearctic
	12	*Willemia similis* Mills, 1934	Hypogastruridae	+	+	+	Holarctic
	13	*Xenylla mucronata* Axelson, 1903	Hypogastruridae	+	+	-	Palaearctic
Symphypleona and Neelipleona	14	*Arrhopalites caecus* (Tullberg, 1871)	Arrhopalitidae	+	-	+	Palaearctic
	15	*Bourletiella* sp.	Bourletiellidae	-	-	+	---
	16	*Caprainea marginata* (Schött, 1893)	Sminthuridae	+	-	-	Palaearctic
	17	*Megalothorax minimus* Willem, 1900	Neelidae	+	+	+	Cosmopolitan
	18	*Sminthurinus aureus* (Lubbock, 1862)	Katiannidae	+	+	-	Palaearctic
	19	*Sminthurus viridis* (Linnaeus, 1758)	Sminthuridae	+	+	+	Cosmopolitan
	20	*Sphaeridia* sp.	Sminthurididae	+	-	-	---
	21	*Stenacidia violacea* (Reuter, 1881)	Sminthurididae	+	+	+	Cosmopolitan

Table 2. (Continued).

Entomobryomorha	22	*Agrenia* sp.	Isotomidae	-	-	+	---
	23	*Corynothrix* sp.	Entomobryidae	-	+	+	---
	24	*Cryptopygus* sp.	Isotomidae	+	-	+	---
	25	*Cyphoderus* sp.	Paronellidae	-	+	-	---
	26	*Desoria* sp.	Isotomidae	+	+	+	---
	27	*Desoria trispinata* (MacGillivray, 1896)	Isotomidae	-	+	-	Cosmopolitan
	28	*Drepanura* sp.	Entomobryidae	+	+	-	---
	29	*Drepanosira hussi* Neuherz 1976	Entomobryidae	+	+	-	Palaearctic
	30	*Entomobrya* sp.	Entomobryidae	+	+	+	---
	31	*Folsomia* sp.	Isotomidae	+	+	+	---
	32	*Folsomides* sp.	Isotomidae	-	+	-	---
	33	*Folsomides parvulus* (Stach, 1922)	Isotomidae	-	+	-	Cosmopolitan
	34	*Heteromurtrella* sp.	Orchesellidae	+	-	-	---
	35	*Heteromurus* sp.	Orchesellidae	+	+	+	---
	36	*Heteromurus variabilis* (Martynova, 1974)	Orchesellidae	+	-	-	Palaearctic
	37	*Isotoma* sp.	Isotomidae	+	+	+	---
	38	*Isotomiella gracilimucronata* Rusek, 1981	Isotomidae	-	+	-	Iraq & Iran
	39	*Isotomurus* sp.	Isotomidae	+	+	+	---
	40	*Isotomurus graminis* Fjellbeg, 2007	Isotomidae	-	+	-	Palaearctic
	41	*Isotoma viridis* (Bourlet, 1839)	Isotomidae	-	+	-	Holarctic
	42	*Lepidocyrtus* sp.	Entomobryidae	+	+	+	---
	43	*Orchesella* sp.	Orchesellidae	+	+	+	---
	44	*Orchesella cincta* (Linnaeus, 1758)	Orchesellidae	+	+	-	Holarctic
	45	*Orchesella flavescens* (Bourlet, 1839)	Orchesellidae	-	+	-	Holarctic
	46	*Parisotoma* sp.	Isotomidae	+	+	+	---
	47	*Parisotoma notabilis* (Schäffer, 1896)	Isotomidae	+	-	-	Cosmopolitan
	48	*Pseudodicranocentrus* sp.	Entomobryidae	+	-	-	---
	49	*Pseudosinella* sp.	Entomobryidae	+	+	+	---
	50	*Seira* sp.	Entomobryidae	+	+	+	---
	51	*Sinella* sp.	Entomobryidae	+	+	+	---
	52	*Tomocerus vulgaris* (Tullberg, 1871)	Tomoceridae	+	-	-	Cosmopolitan
	53	*Willowsia* sp.	Entomobryidae	+	+	+	---

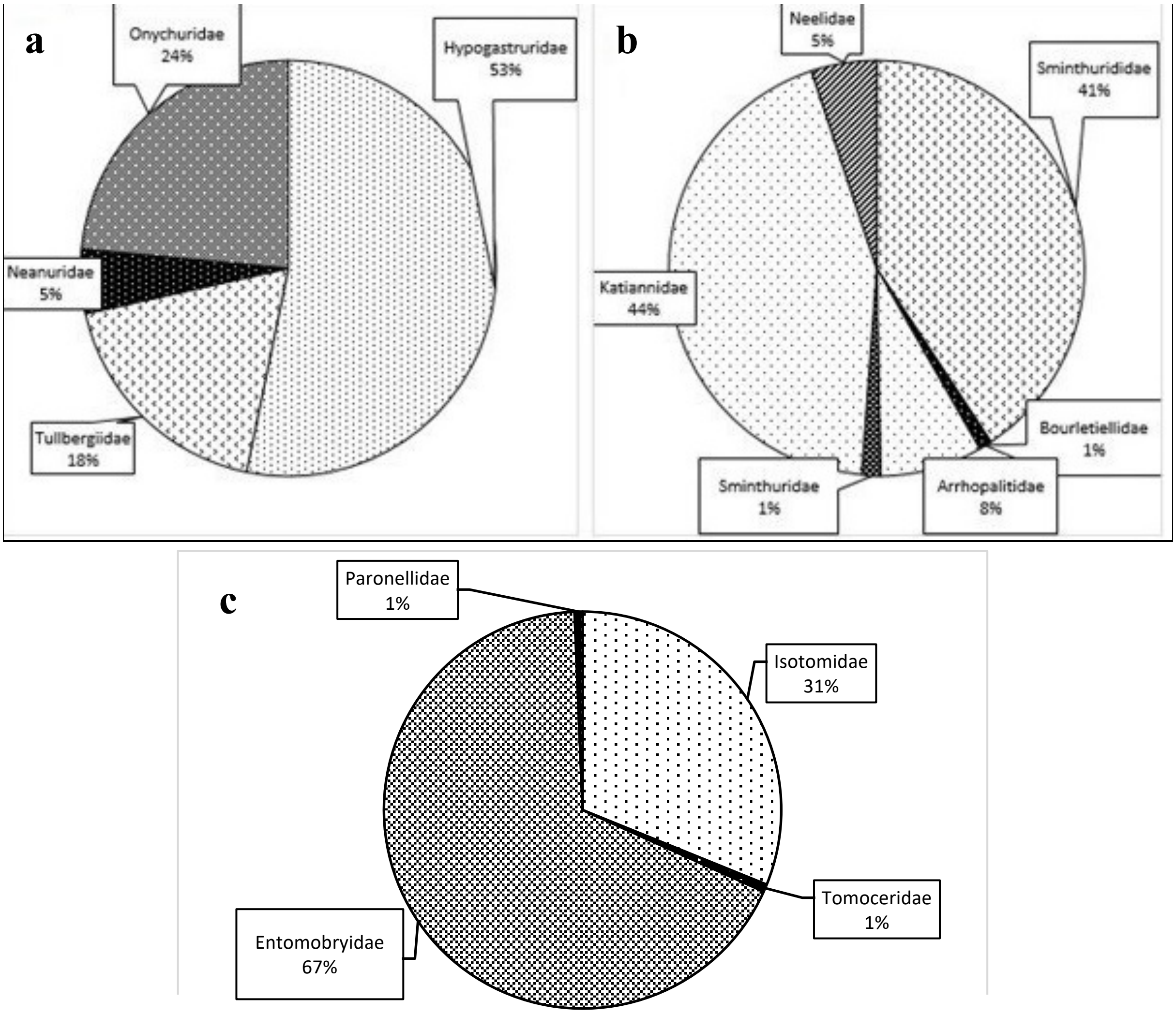

Figure 4. Relative density of Collembola in North Khorasan province. a) Poduromorpha, b) Symphypleona. c) Entomobryomorpha in three different ecosystems of North Khorasan province.

Ceratophysella gibbosa was found in all three ecosystems and numerically was the dominant species at almost all sampling dates (Figure 8). The density of this species in all three ecosystems was higher during wet season. Other abundant species in forest soil throughout the year were *Lepydocyrtus* sp., *P. callipygos*, *Pseudosinella* sp., and *Triacanthella intermedia* Dunger & Zivadinovic, 1984. The following species *Heteromurus* sp., *Lepydocyrtus* sp., *Protaphorura* sp., and *W. similis* had the highest densities in the agroecosystem.

4. Discussion

Our results support the hypothesis that in soil ecosystems with no or low human intervention, the density and diversity of springtails are higher than in disturbed soil. Our hypothesis was based on the assumption that human activities in agricultural ecosystems (e.g., ploughing, pesticide and fertilizer application, weed management, etc.) negatively affect the density and diversity of soil dwelling organisms relative to less- and undisturbed systems. Our findings that there was higher density of soil Collembola and higher values for Shannon–Weiner and rarefaction indices associated with forest and rangeland soils compared to agricultural soil support our hypothesis. This agrees with that the undisturbed lands like forests support springtails more than cultivated lands (Venter et al., 2014; Ceballos et al., 2015; Lingbeek et al., 2017; Rahleeva et al., 2020). It is expected that the soil of natural Hyrcanian forest in the study area, due to less human intervention, with dense, permanent, old vegetation with a higher

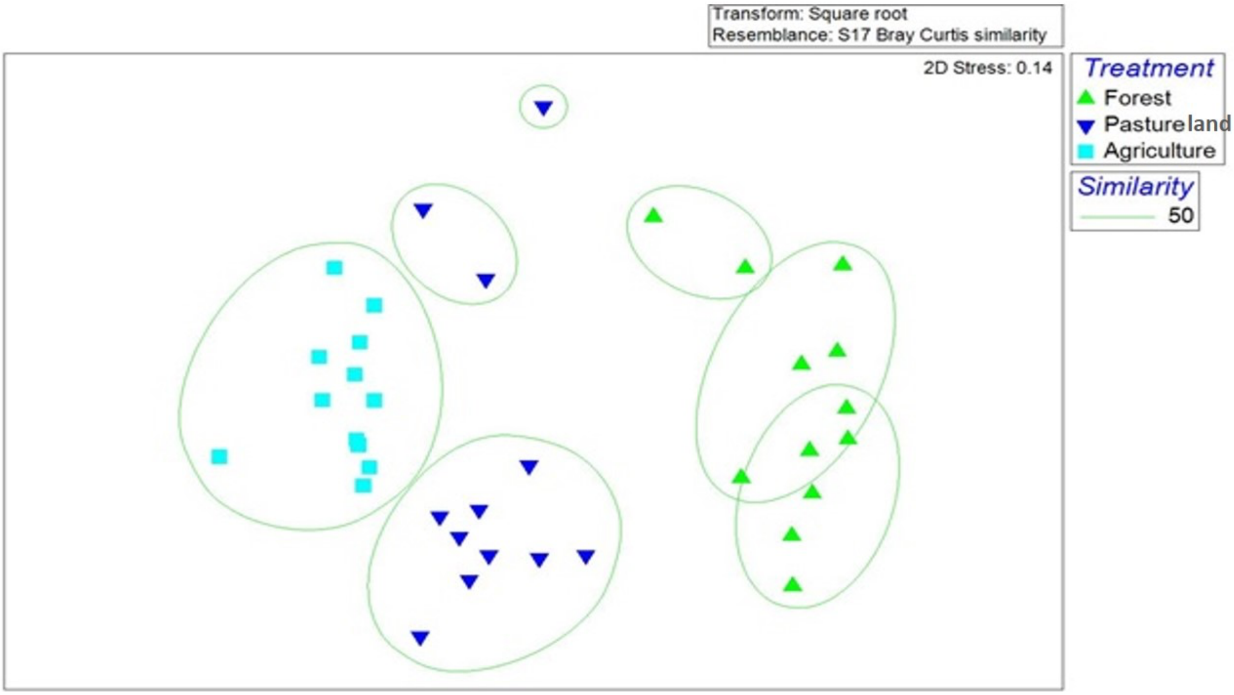

Figure 5. Nonmetric multidimensional scaling (nMDS) plot. Resemblance pattern of soil Collembolan fauna in three ecosystems, using total density of each taxon. Groups are delineated according to the results of the cluster analysis.

content of organic matter and water content enhance the population of springtails. In contrast, the low density and diversity of Collembola in the agricultural soils (e.g., alfalfa fields) might be explained by more human intervention in these systems. Activities such as tillage, weed management, applying agrochemical including pesticides, fungicides, and fertilizers have negatively influenced soil Collembola. Although the use of pesticides and herbicides in alfalfa fields has been superseded, they are still used in Iran. At the first cut of alfalfa crops, Phosalone pesticides are used to repel leaf-eating insects in many alfalfa fields. Also, application of the Paraquat herbicide on early April is common in some parts of the study area. It has been shown that the application of agrochemicals in agricultural ecosystems causes a decrease in the density and diversity of Collembola (Hallmann et al., 2014; Lister and Garcia, 2018; Fiera et al., 2020) and because some species are more sensitive to these application than others, changes in community structure would be expected (Chelinho et al., 2014). Also, conventional tillage, such as deep plowing and heavy machinery use, has an adverse effect on soil structure of Collembola (Heisler, 1991; Kracht and Schrader, 1997).

In all three ecosystems, the lowest densities of springtails were observed during winter and summer seasons and this may be occurring due to unfavourable soil microclimatic conditions, which is common in the study area that has dry and semiarid summers and cold winters. Similar results have been reported in other studies (Lindberg and Bengtsson, 2006; Sabais et al., 2011; Mehrafrooz Mayvan et al., 2015; Raschmanová et al. 2016). The highest population of soil fauna during autumn and spring with a declining trend in summer and winter imply that temperature and water content are two of the most important environmental factors affecting populations of soil-dwelling Collembola. In comparison with the forest ecosystem, the Golil-Sarany protected rangelands begin to dry out in early summer, and this continues until next year's spring rains. High temperatures in the dry season result in litter catching fire and this fire causes profound changes in this ecosystem (Farkhani, 2016). This phenomenon along with overgrazing might explain to some extent the reduction in density and diversity of soil Collembola in this ecosystem. Similarly, other researchers (Filazzola et al., 2020; Wang et al., 2020; Winck et al., 2017; Dombos, 2001) have stated that the intense grazing reduces the diversity and density of springtails populations in the pastures.

5. Conclusion

We found overall diversity and density of Collembola was higher in the forest as compared to either the agroecosystem or the rangeland, especially in autumn and early spring. The values for both the Shannon–Wiener index of diversity and rarefaction index of species richness in the forest soil markedly exceeded those in pasture and agricultural soils. These findings support our prediction

Table 3. Mean (±SE) values of the density, diversity, and species richness indices of Collembola at three ecosystems in North Khorasan Province of Iran during 2018–2019.

	June	July	August	September	October	November	December	January	February	March	April	May	Average
Density (ind. m^{-2})													
Forest	205 ± 113	274 ± 182	299 ± 153	326 ± 165	564 ± 229	379 ± 70	254 ± 97	164 ± 82	255 ± 154	386 ± 197	466 ± 236	387 ± 274	329 ± 162
Pastureland	72 ± 25	271 ± 118	270 ± 118	306 ± 130	433 ± 184	237 ± 86	262 ± 189	86 ± 42	122 ± 70	245 ± 83	253 ± 108	260 ± 136	234 ± 107
Agriculture	38 ± 20	185 ± 89	188 ± 90	270 ± 122	391 ± 299	184 ± 87	143 ± 70	68 ± 36	49 ± 12	131 ± 55	255 ± 116	221 ± 82	177 ± 89
Diversity (*H´*)													
Forest	0.96 ± 0.34	1.26 ± 0.61	2.07 ± 0.79	2.09 ± 0.82	2.70 ± 0.67	2.14 ± 0.18	1.59 ± 0.41	1.81 ± 0.62	1.13 ± 0.29	1.51 ± 0.72	2.04 ± 0.73	2.34 ± 0.88	1.93 ± 1.05
Pastureland	0.87 ± 0.22	0.72 ± 0.16	1.35 ± 0.48	1.49 ± 0.45	2.41 ± 0.78	1.71 ± 0.60	1.41 ± 0.81	1.39 ± 0.50	0.71 ± 0.24	0.89 ± 0.63	1.51 ± 0.47	1.89 ± 0.68	1.72 ± 0.51
Agriculture	0.97 ± 0.42	0.66 ± 0.14	0.86 ± 0.33	0.90 ± 0.35	1.88 ± 0.98	1.29 ± 0.55	1.21 ± 0.42	1.07 ± 0.43	0.76 ± 0.14	0.71 ± 0.20	0.99 ± 0.41	1.51 ± 0.69	1.10 ± 0.53
Diversity (*S´*)													
Forest	0.77 ± 0.06	0.81 ± 0.04	0.87 ± 0.04	0.87 ± 0.02	0.88 ± 0.02	0.83 ± 0.02	0.79 ± 0.05	0.71 ± 0.07	0.84 ± 0.07	0.84 ± 0.07	0.89 ± 0.06	0.84 ± 0.03	0.82 ± 0.04
Pastureland	0.74 ± 0.09	0.72 ± 0.04	0.80 ± 0.05	0.81 ± 0.05	0.84 ± 0.04	0.78 ± 0.14	0.75 ± 0.10	0.77 ± 0.10	0.78 ± 0.10	0.81 ± 0.04	0.89 ± 0.03	0.82 ± 0.03	0.79 ± 0.06
Agriculture	0.59 ± 0.21	0.56 ± 0.11	0.76 ± 0.04	0.77 ± 0.06	0.85 ± 0.04	0.80 ± 0.04	0.77 ± 0.06	0.68 ± 0.08	0.61 ± 0.19	0.81 ± 0.05	0.83 ± 0.09	0.71 ± 0.11	0.72 ± 0.09
Species Richness (*S´*)													
Forest	2.88 ± 0.71	1.95 ± 0.35	3.17 ± 0.29	3.33 ± 0.48	3.89 ± 0.18	3.27 ± 0.63	2.70 ± 0.46	2.94 ± 0.51	2.55 ± 0.61	2.62 ± 0.7	2.66 ± 0.59	3.18 ± 0.36	3.12 ± 0.83
Pastureland	1.83 ± 0.32	1.66 ± 0.01	1.71 ± 0.10	2.50 ± 0.93	2.88 ± 0.30	2.51 ± 0.84	2.30 ± 0.60	2.28 ± 0.55	2.20 ± 0.69	2.29 ± 0.62	2.48 ± 0.58	2.81 ± 0.86	2.26 ± 0.81
Agriculture	1.82 ± 0.33	1.55 ± 0.01	1.80 ± 0.15	1.95 ± 0.28	2.76 ± 0.43	2.58 ± 0.58	2.28 ± 0.75	2.10 ± 0.40	1.89 ± 0.27	1.86 ± 0.45	2.18 ± 0.71	2.58 ± 0.44	1.98 ± 0.47

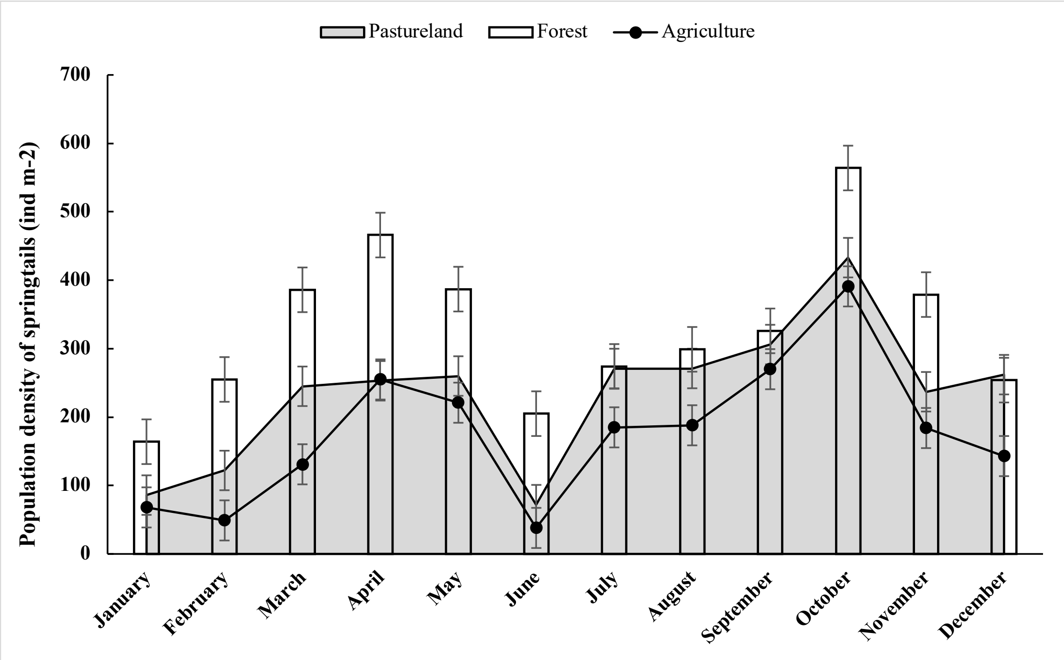

Figure 6. Seasonal changes in density (individuals per m²) of Collembola in different ecosystems.

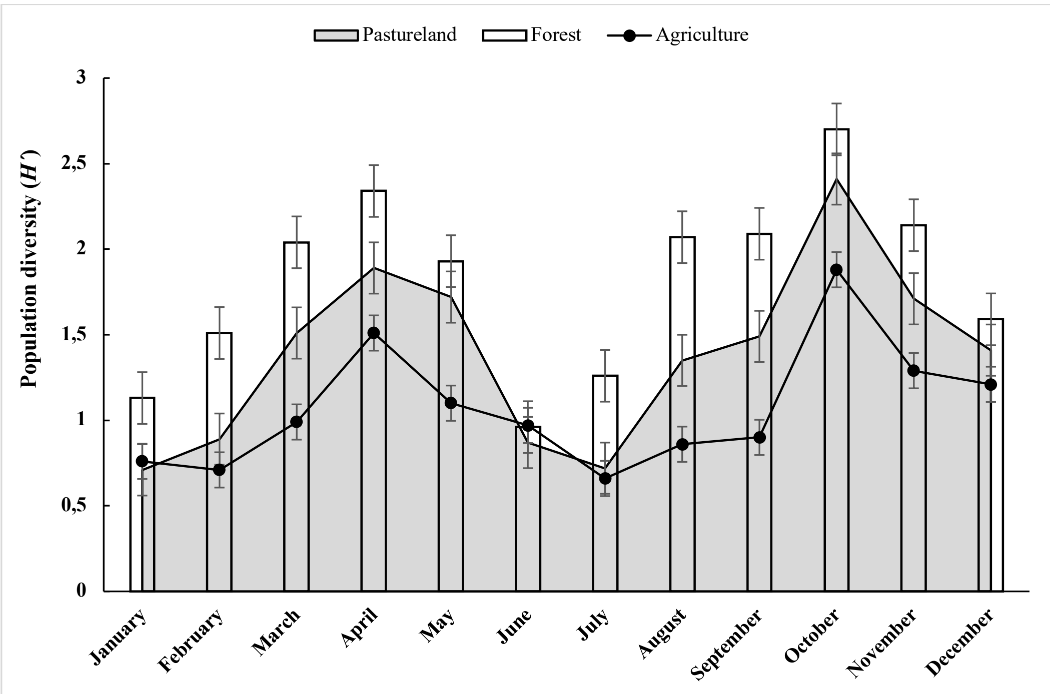

Figure 7. Seasonal changes in Diversity (H′) of Collembola in different ecosystems.

that undisturbed natural ecosystems like forests with more diverse vegetation and in turn heterogeneity of the litter results in a greater diversity of soil dwelling springtails. Reduction in the density and diversity of fauna in the agroecosystem and rangeland probably reflects the intensity of human disturbance in these systems. Fewer disturbances to ecosystems, and more attention to conservation programs for rangelands and especially agricultural lands on which human life depends are suggested to protect soil biodiversity.

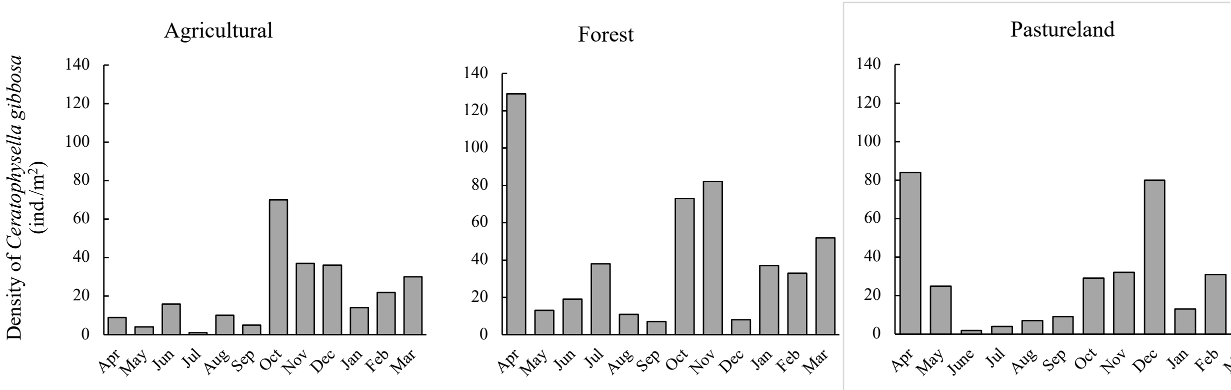

Figure 8. Density of dominant *Ceratophysella gibbosa* in different ecosystems over the study period (2018–2019).

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