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SPECIES DIVERSITY OF CILIATES IN FOREST SOILS OF THE SAMUR-YALAMA NATIONAL PARK

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Species Diversity of Ciliates in Forest Soils of the Samur-Yalama National Park (Azerbaijan). Mamedova, V. F., Alekperov, I. Kh. — The results of studies on soil ciliate diversity in different parts of the Samur-Yalama National Park undergoing human impact of different force are presented. It is shown that the highest species diversity observed in forest soils with minimal human impact. Cultivated soils in gardens and farmlands are characterized by low species diversity, often with mass development of a few dominant eurybiont species. A strong influence of land treatment on soil fauna of ciliates shown.
K e y w o r d s: ciliates, soils, forest, agrocenosis, anthropogenic impact.

Introduction

The up-to-date studies of soil ciliates in Azerbaijan have started much later than studies of aquatic groups (since 90's of the twentieth century). Despite a number of studies (Alekperov, Sadikhova, 2005; Alekperov, Mamedova, 2015 a, b), the soil ciliates of Azerbaijan are still insufficiently studied. The systematic study of soil ciliates of Samur-Yalama National Park (NP) (North-East Azerbaijan) has been carried out by us since 2009. Taking into consideration the important role of soil ciliates in the processes of production and destruction of the organic matter, as well as their quick response to changes of environmental conditions under the influence of various factors including technological ones, it was of interest to study their species diversity and ecological features on the sites of the NP undergoing the human activity of different degree. Apart from the purely practical aspect, the results of such studies are of important scientific value because they help to evaluate the possibility of soil ciliate communities to rehabilitate themselves after the adverse human impact. In our opinion, based on the data of comparative studies in the future it will be possible to create a more precise system of biomonitoring of the quality of soils and identification of anthropogenic influence on soil communities of different groups of animals.

Material and method

A total of 640 soil samples were collected and investigated in the period 2012–2015 at 9 stable sample sites (fig. 1) on the territory of the Samur-Yalama NP.

In the Samur-Yalama National Park, forest and meadow-forest soils dominate. The summer soil temperature is 23–25 ^{0}C, in winter the temperature is 0.8–2.4 ^{0}C. Humus content is 2.2–2.8, pH = 7.5–8.2. Annual rainfall is 300–380 mm, ground water is located close to the soil surface. The soil moisture is 15–21 % in summer and 45–68 % in winter.

Soil samples were analyzed by standard methods (Alekperov, 2005). Taxonomic determination of soil ciliates followed the widely accepted methods of impregnation of kinetom by nitrate (Chatton et Lwoff, 1930) and silver proteinate (Alekperov, 1992). The taxonomy follows that of D. Lynn (2008). Environmental analysis of pedobiont ciliate communities was carried out on the basis of Simpson's index of dominance, Margalef's index of species diversity, as well as the cluster analysis of Bray-Curtis.

Results

A total of 153 species of ciliates were found in the soils of the Samur-Yalama NP during the studies, of which 40 species are new to the fauna of Caucasus. All species found are listed in table 1.

As the table shows, most species were found in the sampling sites 2, 5, 7, 8, and 9, i. e. in forest soils of the central part of the NP, located far enough away from the influence

Fig. 1. The soil sampling points in the Samur-Yalama National Park.

of the human factor. In these sampling sites, 95, 85, 97, 100, and 91 species of pedobiont ciliates were observed, respectively. It should also be noted that in addition to rich diversity of species in these sample sites, more rare stenobiontic species that are not characteristic for human influence areas were found there. *Colpoda lusida, C. orientalis, Placiocampa difficilis, P. incisa, Urotricha atypica, Birojimia terricola, Nassula terricola, Colpidium singular* are as examples of such ciliate species.

Interestingly, on these sample sites we found many pedobiont ciliates that are recorded in the Caucasian fauna for the first time. We compared the diversity of pedobiont ciliates for each of the 9 sampling sites in the forests of the Samur-Yalama NP. As it can be seen from fig. 3, the results of the cluster analysis indicate the greatest similarity in species diversity between sites 2, 5, 7, 8 and 9 of the Samur-Yalama NP, all located in the central part where the impact of human activity is minimal.

Similarity between the species diversity of these areas ranges from 67.6 % to 78.6 %. The lowest similarity of species diversity (66.4 %) was noted between these sections and sample site 6, the closest to the settlements. As shown by the data presented, the diversity in pedobiont ciliate fauna quite clearly reflects the influence of anthropogenic factors.

Table 1. Species composition of the soil ciliates in the different sites of the Samur-Yalama National Park

Family, species	Sample points								
	1	2	3	4	5	6	7	8	9
Family Blepharismidae Jankowski in Small et Lynn, 1985									
Blepharisma minima Gelei, 1926		+			+		+	+	
B. steini Kahl, 1932		+			+		+	+	
B. lateritim Stein, 1859		+			+		+	+	
Family Phacodiniidae Corliss, 1979									
Phacodinium metchnikoffii Prowazek,1900					+			+	
Family Amphisiellidae Jankowski, 1979									
Amphisiella acuta Foissner, Agata, Berger, 1982		+			+		+	+	
**A. magnigranulosa* Foissner, 1988		+			+		+	+	
A. raptans Buitkamp et Wilbert, 1974		+			+			+	+
A. terricola Gellert, 1956	+		+		+			+	+
Hemiamphisiella granulifera Foissner,1987		+			+		+	+	+
**H. terricola* Foissner,1988						+	+		+
H. wilberti Foissner, 1982		+			+		+	+	
Periholosticha lanceolata Hemberger, 1985		+			+		+	+	
Family Oxytrichidae Ehrenberg, 1838									
**Oxytricha elegans* Foissner, 1999		+		+			+	+	+
O. lanceolata Shibuya, 1930	+	+	+				+	+	+
O. longa Gelei et Szabados, 1950					+		+	+	+
**O. longigranulosa* Berger et Foissner, 1989		+		+	+		+	+	
O. setigera Stokes, 1891		+		+	+		+		+
O. immemorata Alekperov, 1984	+		+		+				
O.minor Kahl, 1932		+		+			+	+	+
O. formosa Alekperov, 1984	+	+	+	+	+		+	+	
Gonostomum minima Hemberger, 1982		+			+		+	+	+
**G. singhii* Kamran, Kumar, Sapra, 2008					+		+	+	
Histriculus muscorum Kahl, 1939					+	+	+	+	+
H. admirabilis Alekperov, 1980	+								+
Tachysoma humicola Gellert, 1957		+		+		+			+
Australocirrus oscitans Blatterer et Foissner, 1982					+		+		+
**A. zechmeisterae* Foissner at al., 2005							+	+	+
Family Keronidae Dujardin, 1840									
Keronopsis wetzeli Wenzel, 1953					+		+	+	
Family Bakuellidae Jankowski, 1979									
Bakuella polycirrata Alekperov, 1988		+						+	
B. granulifera Foissner, Agatha et Berger, 2002	+		+			+	+		
B. pampinaria Eigner et Foissner, 1992		+			+			+	+
B. munsterlandii Alekperov, 2006					+		+	+	
Pseudobakuella gracilis Alekperov, 1992					+		+	+	
Family Urostylidae Bütschli, 1889									
Urostyla grandis Ehrenberg, 1830	+	+	+	+	+	+	+	+	+
Holostycha adami Foissner, 1982	+	+	+	+	+		+	+	+
**H. australis* Blatterer et Foissner, 1988	+					+	+		+
H. stueberi Foissner, 1987					+		+	+	
H. tetracirrata Buitkamp et Wilbert, 1974	+	+	+		+	+			
**H. pullaster* Müller, 1773					+		+	+	
Uroleptus lepisma (Wenzel), 1953				+		+	+		
U. notabilis (Foissner), 1982		+							+
Paraurostyla weissei (Stein), 1859		+				+		+	
**P. caudata* (Stokes), 1886	+	+			+			+	+
P. herbicola Kahl, 1932		+			+	+		+	
**Birojimia terricola* Berger and Foissner, 1989		+		+	+		+		+
Family Kahliellidae Tuffrau, 1979									
Cladotricha koltzowi Gajewskaya, 1926	+	+						+	
Family Aspidiscidae Ehrenberg, 1859									
Aspidisca poljanski Alekperov, 1985	+				+			+	

Table 1. Continued

A. leptaspis Fresenius, 1865		+			+		+	+	
A. aculeata Ehrenberg, 1838	+	+							+
Family Spathidiidae Kahl, 1929									
Spathidium amphoriforme Greeff, 1888		+			+		+	+	
S. seppelti Petz et Foissner, 1931			+			+			+
Epispathidium ascendes (Wenzel), 1965	+			+			+		+
E. papilliferum (Kahl), 1930		+			+		+		+
**E. polynucleatum* Foissner, Agatha et Berger, 2002		+				+			+
E. regium Foissner, 1984	+		+			+			
E. terricola Foissner, 1986	+			+		+	+		+
**Latispathidium truncatum* Foissner, Berger, Xu, Zechmeister-Boltenstern, 2005	+				+			+	+
Family Tracheliidae Ehrenberg, 1838									
Dileptus terrenus Foissner, 1981	+	+	+	+	+	+	+	+	+
D. gracilis Kahl, 1931			+		+			+	
D. alpinus Kahl, 1931		+				+		+	+
D. anguillula Kahl, 1931	+	+					+		
D. armatus Foissner et Shade, 2000	+		+			+		+	+
**D. costaricanus* Foissner,1995				+			+	+	+
D. falciformis Kahl, 1932	+								
D. visscheri Dragesco, 1963	+			+			+	+	+
Family Litonotidae Kent, 1882									
Litonotus alpestris Foissner, 1978		+				+		+	
L. triqueter Penard, 1922	+				+			+	
**L. muscorum* (Kahl, 1931)			+		+			+	
L. anguilla (Kahl, 1931)	+						+		+
Family Chilodonellidae Deroux, 1970									
Chilodonella uncinata (Ehrenberg), 1838	+							+	+
Trithigmostoma bavariensis (Kahl), 1931		+		+			+		
Alinostoma multivacuolata Alekperov, 1993	+		+						
**A. polyvacuolatum* (Foissner et Didier), 1981	+					+	+		+
Family Orthodonellidae Jankowski, 1968									
Chilodontopsis depressa (Perty), 1852	+	+							+
C. muscorum Kahl, 1931	+		+			+		+	+
Zosterodasys debilis Alekperov, 1984	+	+	+	+	+	+	+	+	+
Z. cantabrica Fernandez-Leborans et Alekperov, 1996			+			+			
Z. vorax (Stokes), 1887	+	+		+		+	+		+
Family Nassulidae Fromentel, 1874									
**Nassula terricola* Foissner, 1989			+	+				+	+
**N. exigua* Kahl, 1931		+			+				
Family Pseudomicrothoracidae Jankowski, 1967									
**Pseudomicrothorax agilis* Mermod, 1914		+				+	+	+	+
P. dubius Maupas, 1914	+	+	+	+	+	+	+	+	+
Family Microthoracidae Wrzesniowski, 1870									
Microthorax pusillus Engelmann, 1862	+	+	+	+	+	+	+	+	+
**M. glaber* Kahl, 1926						+	+		+
**M. elegans* Kahl, 1931	+			+					
M. costatus Kahl, 1926	+	+	+	+	+		+	+	+
Drepanomonas muscicola Foissner, 1986	+	+	+	+	+	+	+	+	+
D. revoluta Penard, 1922	+	+	+	+	+	+	+	+	+
Leptopharynx margaritata Alekperov, 2005	+	+	+	+	+	+	+	+	+
Family Colpodidae Bory de St. Vincent, 1838									
Colpoda minor (Alekperov, 1985)		+		+			+		
C. cucullus Muller, 1786	+	+	+	+	+	+	+	+	+
C. inflata (Stokes, 1885)	+	+	+	+	+	+	+	+	+
C. colpidiopsis Kahl, 1930	+	+	+	+	+	+	+	+	+
C. bifurcata Alekperov,1993	+		+		+			+	
C. atra Alekperov, 1993	+		+	+					

Table 1. Continued

C. maupasii Enriques, 1908	+	+	+	+	+	+	+	+	+
C. steini Maupas, 1883	+	+	+	+	+	+	+	+	+
C. elliotti Bredbery et Outka, 1967	+	+	+	+	+	+	+	+	+
C. aspera Kahl, 1926	+	+	+	+	+	+	+	+	+
C. distincta (Smith, 1899)		+							
**C. ecaudata* (Liebmann, 1936)	+	+		+		+	+		+
C. henneguyi Fabre-Domergue, 1889		+			+		+	+	+
**C. lucida* Greeff, 1888		+			+		+	+	+
C. orientalis Foissner, 1993		+			+		+	+	+
**C. variabilis* Foissner, 1980	+			+			+	+	
Bresslaua vorax Kahl, 1932	+		+			+			+
B. dissimilis Alekperov, 1985		+			+			+	
B. sidiatrix Graff, Dewey et Kidder, 1941		+		+			+		
Family Hausmanniellidae Foissner, 1987									
**Hausmanniella patella* (Kahl, 1931)					+		+		
**H. discoidea* (Gellert, 1956)				+			+		
Family Cyrtolophosididae Stokes, 1888									
Cyrtolophosis muscicola Stokes, 1888	+	+	+	+	+	+	+	+	+
C. minor Vuxanovichi, 1963			+			+		+	
**C. acuta* Kahl, 1926		+				+		+	+
C. major Kahl, 1926					+		+	+	
C. elongata (Schewiakoff, 1896)	+	+	+			+		+	+
Family Grossglockneriidae Foissner, 1980									
**Grossglockneria acuta* Foissner, 1980				+	+		+		
G. ovata Foissner, 1999				+			+		
**G. hyalina* Foissner, 1985		+						+	+
Pseudoplatyophrya nana Kahl, 1926			+				+		
P. leningradica Alekperov, 2005		+		+			+		
Family Plagiocampidae Kahl, 1926									
Plagiocampa difficilis Foissner, 1981		+			+		+	+	
P. caudata Alekperov, 1993		+					+		+
P. macrostoma Tucolesco, 1962	+								+
**P. incisa* Kahl, 1933		+			+			+	+
**P. multiseta* Kahl, 1930	+	+	+	+	+	+	+	+	+
Family Urotrichidae Small et Lynn, 1985									
Urotricha atypica Alekperov, 1993		+			+		+	+	
**U. striata* Penard, 1922				+			+		+
U. parvula Penard, 1922	+	+				+	+	+	
Family Frontoniidae Kahl, 1926									
Frontonia terricola Foissner, 1986	+	+						+	+
**F. solea* Foissner, 1986		+		+	+				+
F. parvula Penard, 1922	+	+			+	+		+	+
F. nigricans Penard, 1922		+		+		+	+	+	+
Family Urocentridae Claparede et Lachmann, 1858									
*Urocentrum turbo*Muller, 1786	+	+	+	+	+	+	+	+	+
Family Turaniellidae Didier, 1971									
Colpidium kleini Foissner, 1969		+					+		
C. colpoda (Losana), 1829	+		+						+
**C. singular* Vuxanovici, 1962		+			+		+		+
Family Loxocephalidae Jankowski, 1964									
**Sathrophilus agitates* Stokes, 1887	+	+	+	+	+	+	+	+	+
S. ovatum Kahl, 1926	+		+		+	+		+	+
S. mobilis Kahl, 1926		+	+	+			+	+	+
Cinetochilum margaritaceum Ehrenberg, 1830	+	+	+	+	+	+	+	+	+
**Stammeridium kahli* Wenzel, 1969		+			+		+	+	
Family Spirozonidae Kahl, 1926									
Stegochilum fusiforme Schewiakoff, 1892		+			+		+	+	
**S. smalli* Alekperov, 1993	+			+			+		+

Table 1. Continued

**Tetrahymena edaphoni* Foissner, 1986	+		+	+				+	
Family Cyclidiidae Ehrenberg, 1838									
Cyclidium muscicola (Kahl, 1931)		+			+		+	+	+
C .graucoma Muller, 1856	+	+	+	+	+	+	+	+	+
**C. heptatrichum* Schewiakoff, 1893	+	+				+		+	
Family Uronematidae Thompson, 1964									
Uronema nigricans (Muller, 1786)	+	+	+	+	+	+	+	+	+
U. acutum Buddenbrock, 1920	+	+	+	+	+		+	+	+
U. parva Czapik, 1968	+		+			+		+	+
Uronemella filicium (Kahl, 1931)		+			+				+
Homalogastra setosa Kahl, 1926	+	+	+	+	+	+	+	+	+
**Cristigera pleuronemoides* Roux, 1899		+			+				+
Total	71	95	52	57	85	56	97	99	91

* Species new to Caucasian fauna.

We compared the species diversity of pedobiont ciliates in each of the 9 sampling sites in the forests of Samur-Yalama NP. As shown on fig. 2, the results of cluster analysis indicate the greatest similarity of species diversity between sites 2, 5, 7, 8, and 9, i. e. the sections of the Samur-Yalama NP located in the central part, where the impact of human activity is minimal.

The greatest diversity in forest soil ciliates fauna was observed throughout the study period in spring, and the lowest was in winter (fig. 3, *A*). For example, from 85 to 130 species were recorded in spring. It should be noted that the basis of the composition of the soil ciliate communities is formed by numerous stenobiontic species rarely reaching high numbers and occuring in soil communities only for a short period of time. Many ciliate species of this group were often observed in soils within 3–12 days, then they were replaced by other species, which in turn were replaced by the next group of stenobiont ciliates after a few days. Of course, the overall increase in species diversity in spring is related to the increase in ambient temperature, but according to our observations the determining factors for soil ciliates were humidity and abundant development of food organisms. This is indirectly confirmed by a decrease in species diversity of pedobiont ciliates in the dry summer.

Interestingly, in the moist soil in sun-protected areas of forest the species diversity of soil ciliates remains to be quite high, sometimes reaching values of more than 100 species, but this is only on a small piece of ground areas with relatively high humidity.

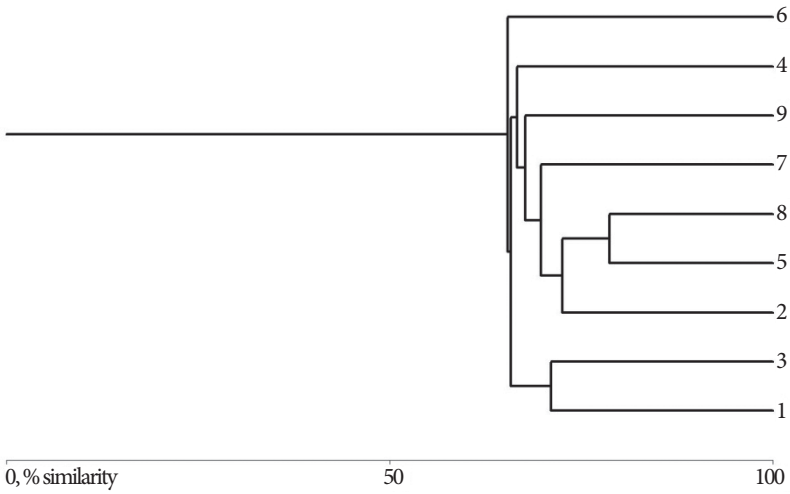

Fig. 2. Similarity of species composition between different sample points according to Bray-Curtis cluster analysis.

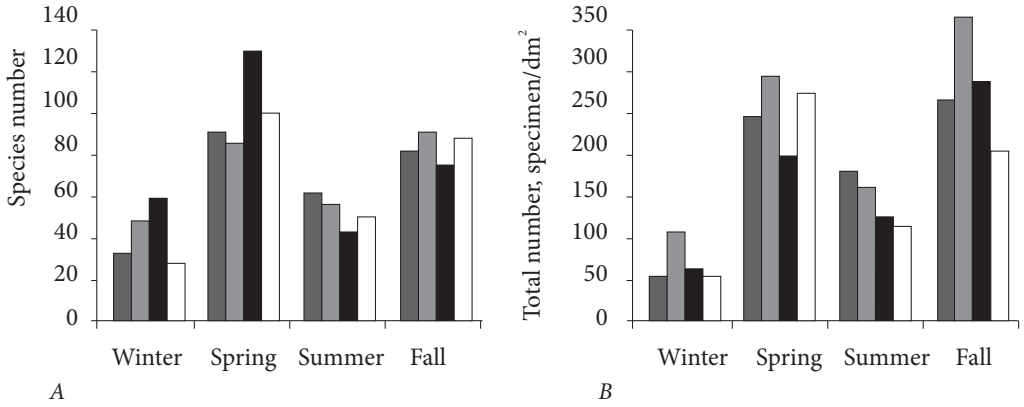

Fig. 3. Seasonal dynamics of species number (*A*) and the total number (*B*) of the forest soil ciliates (average of 2012–2015).

On average, in dry summer season the species diversity of soil ciliates is greatly reduced (fig. 3, *A*).

In autumn, due to atmospheric precipitation the diversity of forest soilciliates is increased again (fig. 3, *A*), although not to the maximum value of the spring maximum.

It should be noted that in the forest soil ciliate communities in the Samur-Yalama NP there is an alternation of species in spring and autumn, with a gradual decrease in their number in winter. In addition, comparison of the data for several years leads to the conclusion that the main core of spring stenobiontic species of communities is very different from that in autumn communities. We can confirm as a result of long-term researches that there are eurybiontic species of pedobiont ciliates occurring in almost all seasons. These are the representatives of the genus *Colpoda*: *C. cucullus, C. inflata, C. aspera, C. maupasii*; the genus *Uronema*: *U . acutum, U. nigricans,* the genus *Cyclidium claucoma, C. muscicola*, etc.

Throughout the year the wet soils contain the low numbers of the representatives of the genus *Blepharisma* (*B. steini, B. lateritium*) — 5–17 ind./dm^2, and single specimens of the *Hypotrichida — Aspidisca poljanski, A. leptaspis* and *A. aculeata*, as well as the representatives of the genus *Oxytricha*: *O. minor, O. elegans* and *O. formosa*. These species of ciliates can be found in almost any season in the Samur-Yalama NP soils.

The basis of the spring maximum of the species diversity is formed by rare stenobiont species of pedobiont ciliates, among which are: *Phacodinium metchnikoffi, Gonostomum kuehnetti, Histriculus admirabilis, Keronopsis wetzeli, Bakuella polycirrata, Holostycha stueberi, Uroleptus lepisma, Nassula exigua* and *Colpidium kleini*. Most rare species in spring communities of pedobiont ciliates occur only at low numbers, often as single specimens. These species are usually observed in the number of 10–35 ind./dm^2.

Summer faunistic complex of soil ciliates of the Samur-Yalama NP is represented by a set of core eurybionts occurring year-round, with the addition of typical for soil fauna smaller species of such genera as *Pseudomicrathorax, Drepanomonas, Leptopharynx, Colpoda, Urotricha, Sathrophilus, Cinetochilum*, *Cyclidium, Uronema* и *Homalogastra*.

In autumn, with an increase in soil moisture by frequent precipitation, species diversity in communities of soil ciliates is significantly increased again. For example, during the research period in autumn the species diversity ranged from 74 to 90 species (fig. 3, *A*).

At this time, there are stenobiontic communities, some of which we have observed in spring, but a number of species (*Amphisiella terricola, Hemiamphisiella granulifera, H. wilberti, Periholosticha lanceolata, Oxytricha longa, O. immemorata, Bakuella pampinaria, Chilodontopsis depressa, Trithigmostoma bavariensis*, etc.) were recorded in autumn only.

Analysis of quantitative indices (fig. 3, *B*) showed that the minimum quantitative development of forest soil ciliates in the Samur-Yalama NP observed in the range of 45–100 spec./dm^2. The greatest quantitative indices have been observed in spring and autumn seasons. The maximum total number of pedobiont ciliates in these periods was 280 spec./dm^2 in spring, and 350 spec./dm^2 in autumn. The minimum value of the total number of ciliates was 180 spec./dm^2 in spring, and 190 spec./dm^2 in autumn. The lowest rates of quantitative indices are in winter and summer, 45–100 spec./dm^2 and 20–170 spec./dm^2, respectively.

Conclusions

Thus, summing up the data on the ciliate fauna in the virgin forest soils of the Samur-Yalama NP, we can say that it is quite rich, and 40 species of soil ciliates recorded for the first time for the fauna of the Caucasus indicate this. Species diversity in soil ciliate communities is changed both qualitatively and quantitatively depending on the seasons. The minimum of number and species diversity is observed in winter with a consequent increase in warmer seasons. In species diversity of the forest soil ciliates of the Samur-Yalama NP, clearly distinguished is the group of core eurybiontic species that are present in a given amount in the soil communities throughout the year. The second largest group comprises the majority of rare species of stenobiontic ciliates successively replacing each other in communities during seasonal succession. Representatives of this group, in spite of the low numbers of most of its species, are the basis of high qualitative and quantitative indices in the communities of free-living ciliates of forest soils of the Samur-Yalama NP.

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