The biodiversity and community structure of soil ciliates of Talish forests in south-eastern Azerbaijan

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New information on the fauna of the soil ciliates of south-eastern Azerbaijan is presented in this article. As a result of surveys conducted in 2017–2019, 65 species of soil ciliates assigned to 33 families were recorded. The highest diversity of pedobiont ciliates was observed in Masalli and Lankaran forest soils. On the other hand, the lowest species diversity was recorded in the Astara region. The highest species diversity was found for the family Colpodidae, of which 7 species were found. Four of them belong to the pedobiont genus Colpoda. Almost all representatives of this genus are typically soil species and euribionts with wide ecological plasticity. In addition, two species that are the representatives of the genus Aspidisca, almost all representatives of this genus are typically soil species and euribionts with wide ecological plasticity. In addition, two species that are the representatives of the genus Aspidisca, Aspidisca, and Nassula, Aspidisca, Blepharisma, Frontonia, Urotichia and U. The accumulation of ciliates in forest soils in spring was observed in the upper horizon of the 5 cm soil litter layer in summer. Due to the decrease in humidity in upper layers, pedobiont ciliate migrates to deeper layers (10–15 cm), and in autumn with the increase in precipitation and humidity in the upper soil horizons, the mass of soil ciliates is again localized in the forest litter and in the upper soil layer. It is also worth noting another specific complex of ciliates in the forest soils of south-eastern Azerbaijan. It can be occasionally found in freshwater bodies. It is also worth noting another specific complex of ciliates in the forest soils of south-eastern Azerbaijan. In early spring and autumn, with the maximum moisture content in the forest soil, we often observed ciliates, which usually dwell in fresh waters. Among them are representatives of such genera as Zosterodasys, Nassula, Aspidisca, Blepharisma, Frontonia, Urotichia etc. The species diversity and community similarity index of soil ciliates in Talish forests of Lankaran natural area were also calculated. The study attempts to compare the difference in ciliates
community among five different regions of south-eastern Azerbaijan. The analysis showed that there are 3 clusters of the similarity of species diversity of ciliate communities. The similarity between the ciliate fauna of the high mountainous regions and fauna of the plain regions was 52.15–69.00 %.

**Key words:** ciliates; south-eastern Azerbaijan; Talish Mountains; soil; Bray-Curtis cluster analysis; pedobionts; euribionts.

**Introduction**

Being an important group in nutrient cycling, energy flow and food webs (Christoffersen, González, 2003; Janssen, Heijmans, 1998), soil ciliates participate in the decomposition of benthic residual deposit and the formation and development of soil and accelerate the mineralization processes of carbon, nitrogen and other mineral nutrient elements (Ekelund, Renn, 1994). As the main bacterial consumers, soil ciliates also have special characteristics such as high respiration, short generation times and rapid multiplication. In the rhizosphere of living plants, protozoa play an important role in the mineralization of mineral nutrient elements (Jing Li et al., 2010). Organic matter released by plants could stimulate bacterial and ciliate activity in the root zone leading to mineralization of organic soil nitrogen and assimilation by plants. On other hand, the growth of plants may also significantly affect the soil quality and ciliate community. The plant roots and soil ciliate community are interdependent. Moreover, they are good bioindicators of soil environments (Foissner, 1987, 1997, 1999). It is important to study the community structure of soil ciliates and their significance in soil environments, to have a better understanding of the function of the ecosystem. The present study aims to investigate the species abundance, biodiversity and community similarity index of soil ciliates in Talish forests of Lankaran natural area. The study also attempts to compare the difference in ciliates community among five different regions of south-eastern part of Azerbaijan.
Methodology
The material was collected seasonally in 2017–2019 years from different parts of the forest zone of the south-eastern Azerbaijan, which is known as a region of humid subtropics (Fig. 1).

In total, over 230 soil samples were collected and processed during the research. The collection of soil samples from the surface was carried out by small plastic containers. For studying the distribution of ciliates in deeper layers, 3 cm in diameter and 30 cm long metal tube was driven into the soil. Some of the collected samples were processed in the field, and the main part was delivered to the laboratory and processed according to standard methods (Alekperov, 2005). To identify the species composition, methods of impregnation of infrastructure by silver nitrate (Chatton, Lwoff, 1930) and protargol (Alekperov, 1992) were used. Quantitative accounting was carried out using the Bogorov chamber. Taxonomic identification of ciliates was carried out according to the monographs of Foissner (Foissner, 1992) and Alekperov (Alekperov, 2005).

Results and discussion
In total, 65 species of free-living ciliates belonging to 33 families were found. The species composition and distribution of soil ciliates by collection points are presented in table 1.

As can be seen from the table, the greatest species diversity (47 species) was observed in forest soils in Masalli region. Lankaran where 43 species were recorded was next in species diversity. And the lowest species diversity was observed in Astara (26 species).

The table indicates that the greatest species diversity was found in the family Colpodidae of which 7 species were recorded. Four of them belong to the pedobiont genus *Colpoda*. Almost all representatives of this genus are typically soil species and euribionts with wide ecological plasticity. In addition, two species that are the representatives of the genus *Tillina* were found to be inhabitants of soil in spite the fact that they can be occasionally found in freshwater bodies. Characteristically, those representatives of *Tillina* and *Colpoda* were found at all sampling points of our research and almost a
whole year, sometimes falling out of soil communities only in the winter period. Thus, on the basis of the obtained data, we attribute representatives of the *Tillina* and *Colpoda* genera to background species, unlike *Bresslaua dissimilis*, which, although it is also a pedobiont, belongs to rare species that are present in soil communities in very low numbers.

It should be noted that the special climatic conditions of south-eastern Azerbaijan impact on the distribution regularity of ciliates in the mountain-forest soils. The accumulation of ciliates in forest soils in spring is observed in the upper horizon of the 5 cm soil litter layer. In summer due to a decrease in humidity in the upper layers, pedobiont ciliates migrate to deeper layers (10–15 cm) and in autumn with an increase in precipitation and humidity in the upper soil horizons, the mass of soil ciliates is again localized in the forest litter and in the upper soil layer. It is also worth noting another specific complex of ciliates in the forest soils of south-eastern Azerbaijan. In early spring and autumn, with the maximum moisture content in the forest soil, we often observed ciliates that usually dwell in fresh waters. Among them there are representatives of such genera as *Zosterodasys*, *Nassula*, *Aspidisca*, *Blepharisma*, *Frontonia*, *Urotricha* etc. This is explained by the fact that at high humidity of forest soils, in its upper horizons, cavities between soil particles are completely filled with precipitation water. Thus, in the upper layers of forest soil, especially in the forest litter during the period of maximum moisture, the habitat conditions become similar to fresh water.

**Table 1.**

Species composition and distribution of ciliates in forest soils of south-eastern Azerbaijan

| Species | Sampling points |
|---------|-----------------|
| **Order Heterotrichida Stein, 1859** | |
| Fam. Blepharismidae Jankowski in Small et Lynn, 1985 | |
| 1. *Blepharisma hyalinum* Perty, 1849 | + + + + + |
| 2. *B. dileptus* Kahl, 1928 | + + + + |
| 3. *B. salinarum* Florentin, 1899 | + + + + |
| 4. *B. tardum* Kahl, 1928 | + + + |
| 5. *B. steini* Kahl, 1932 | + + + + + |
| Fam. Spirostomatidae Stein, 1867 | |
| 6. *Spirostomum minus* Roux, 1901 | + + + + |
| 7. *S. teres* Claparede et Lachmann, 1858 | + + + + |
| Fam. Condylostomatidae Kahl in Dofflein and Reichenov, 1927 | |
| 8. *Condyloma kasymovi* Alekperov, 1984 | + + + + |
| 9. *C. arenarium* Spiegel, 1926 | + + |
| Fam. Climacostomidae Repak, 1972 | |
| 10. *Climacostomum emarginatum* Stokes, 1885 | + |
| **Order Hypotrichida Stein, 1859** | |
| Fam. Kahliellidae Tuffrau, 1979 | |
| 11. *Kahliella acrobates* Horvath, 1932 | + + + + |
| 12. *K. microstoma* Alekperov, 1985 | + + |
| Fam. Holostichidae Faure-Fremiet, 1961 | |
| 13. *Holosticha azerbaijanica* Alekperov and Asadullayeva, 1999 | + |
| 14. *H. grisea* Kahl, 1932 | + |
| Fam. Bakuellidae Jankowski, 1979 | |
| 15. *Pseudobakuella alveolata* Maupas, 1883 | + + |
| Fam. Urostylidae Butschli, 1889 | |
| 16. *Urostyla marina* Kahl, 1932 | + + |
| Fam. Oxytrichidae Ehrenberg, 1838 | |
| 17. *Oxytricha fallax* Stein, 1859 | + + |
| 18. *O. ovalis* Kahl, 1932 | + + |
| 19. *O. chlorelligera* Kahl, 1932 | + + |
| **Order Euplotida Jankowski, 1980** | |
| Fam. Euplotidae Ehrenberg, 1838 | |
| 20. *Euplotes charon* Müller, 1785 | + + + + |
| Fam. Aspidiscidae Ehrenberg, 1838 | 21. Aspidisca fusca Kahl, 1928 | + | + |
|----------------------------------|-------------------------------|---|---|
| Order Metopida Jankowski, 1980   | Fam. Lacyymariidae Foissner, 1983 | 22. Lacyymaria coronata Clap. et L., 1858 | + | + |
| Fams. Ancistromonidae Stein, 1859| 23. L. acuta Kahl, 1933 | + | + |
| Fam. Chlamybdontidae Deroux, 1976| 24. Trighigmostoma cucullulus Müller, 1786 | + | + |
| Fam. Chlamybdontidae Stein, 1859| 25. Chlamybdodon mnemosine Ehrenberg, 1857 | + | + |
| Fam. Placalidae Song and Wilbert, 1989| 26. Nassula citrea Kahl, 1930 | + | + |
| Order Nassulida Jankowski, 1968 | Fam. Colepidae Ehrenberg, 1838 | 27. Coleps hirtus Müller, 1786 | + | + |
| Fam. Holophryidae Perry, 1852    | 28. Holophrya vorax Dragesco, 1960 | + | + |
| Fams. Acropliidae Foissner, 1988| 29. C. ellipticus Kahl, 1932 | + | + |
| Order Scuticociliatida Small, 1967| Fam. Loxocephalidae Jankowski, 1964 | 30. Sathrophilus agitatus Corliss, 1960 | + | + |
| Fam. Macropliidae Song and Wilbert, 1989| 31. S. mobilis Kahl, 1931 | + | + |
| Fam. Spathidiidae Kahl, 1881     | 32. Cinetochoilum margaritaceum Ehrenberg, 1831 | + | + |
| Fam. Parastomatida Jankowski, 2007| Fam. Tracheliidae Ehrenberg, 1838 | 33. Dileptus falciformis Kahl, 1932 | + | + |
| Fam. Cycldiidae Ehrenberg, 1838 | 34. D. sulcata Claparede et Lachmann, 1885 | + | + |
| Fam. Pseudoparastomatidae Kent, 1881| Fam. Pleuronematidae Kent, 1881 | 35. Pseudoparastoma Kahl in Dofflein and Reichenow, 1929 | + | + |
| Fam. Microthoracidae Jankowski, 1870 | 36. Microthorax pusillus Engelmann, 1862 | + | + |
| Fam. Zosterodasys agamalievi Deroux, 1978 | 37. Zosterodasys agamalievi Deroux, 1978 | + | + |
Table 1, continuation

| No. | Species                        | Order/Family                                      |
|-----|--------------------------------|---------------------------------------------------|
| 52. | *Z. cantabrica* Fernandez-Leborans and Alekperov, 1996 | + + + |
| 53. | *Bresslaua dissimilis* Alekperov, 1985 | + + + + |
| 54. | *T. magna* Gruber, 1879 | + + + + + |
| 55. | *T. minor* Alekperov, 1985 | + + + + + |
| 56. | *Colpoda cucullus* Müller, 1786 | + + + + + |
| 57. | *C. inflata* Stokes, 1885 | + + + + + |
| 58. | *C. bifurcata* Alekperov, 1993 | + + + + + |
| 59. | *C. steini* Maupas, 1883 | + + + + + |

Order *Peniculida* Faure-Fremiet in Corliss, 1956

| No. | Species                        | Order/Family                                      |
|-----|--------------------------------|---------------------------------------------------|
| 60. | *Frontonia arenaria* Kahl, 1926 | + + + |
| 61. | *F. macrostoma* Dragesco, 1960 | + + + |
| 62. | *Paramecium caudatum* Ehrenberg, 1838 | + + + + + |
| 63. | *P. woodruffii* Wenrich, 1928 | + + + + + |

Order *Turaniellidae* Didier, 1971

| No. | Species                        | Order/Family                                      |
|-----|--------------------------------|---------------------------------------------------|
| 64. | *Colpidium colpoda* Losana, 1829 | + + + + + |
| 65. | *C. striatum* Stokes, 1886 | + + + + + |
| Total |                              |                                                   |

| No. | Total |
|-----|-------|
| 52. | 43    |
| 53. | 47    |
| 54. | 30    |
| 55. | 26    |
| 56. | 37    |

Notes: 1 – Lankaran, 2 – Masalli, 3 – Lerik, 4 – Yardimli, 5 – Astara.

Figure 2 presents the results of the cluster analysis of the similarity of species diversity of soil ciliate communities of Talish forests. As can be seen from Fig. 2, the highest similarity of species diversity (69%) was observed among three collection points – Astara, Masalli and Lankaran regions. The similarity of these three points with the Lerik districts was 60.27%. Comparison of the Lerik forest ciliate fauna with the Yardimli fauna also demonstrated their large similarity, 52.15%.

![Fig. 2. The similarity of species diversity of ciliate communities in different parts of South-eastern Azerbaijan](image)

This analysis showed that there are three clusters of the similarity by species diversity of ciliate communities. One of them unites the three regions (95.5%) of south-eastern Azerbaijan (Lankaran, Masalli and Lerik), the second one unites all these three points with the Lerik district. And the third cluster covers Yardimli forests and other 4 points. The low similarity between the ciliate faunas of Lankaran, Masalli and Astara regions and the fauna of the other two districts can be explained by geographical

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location of the regions. However Lerik and Yardimli regions are located in the highlands, but other three districts are located on the plain.

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