International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 14, Issue 6 (Nov. – Dec. 2025), PP. 104-109

The Response of Testate Amoebae and Ciliate Species of The Nakhchivan Autonomous Republic to Key Environmental Factors

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Abstract
Free-living protozoa—testate amoebae (Testacea) and ciliates (Ciliophora)—are widely distributed in the biotopes of freshwater ecosystems, and their distribution, abundance, and species diversity are influenced by a variety of ecological factors. Among these factors, temperature, water depth, gas regime, and trophic interactions play a particularly important role.
Key Words: *Testate amoebae, Ciliates, Freshwater ecosystems, Temperature influence, Aquatic biotopes*

Date of Submission: 14-11-2025 Date of acceptance: 30-11-2025

I. Introduction

Testate amoebae (Testacea) and ciliates (Ciliophora) are microscopic organisms in the hydrosphere that show high sensitivity to the physical and chemical characteristics of water, with their biological rhythms closely linked to temperature. Temperature is one of the key ecological factors influencing metabolism rate, reproduction frequency, and species diversity (4,5).

Observations show that the optimal temperature range for both groups is between 15–28°C. Testate amoebae (Arcella, Centropyxis, Difflugia) generally exhibit high activity at temperatures of 20–25°C. Ciliates, especially species such as Paramecium and Colpoda, have maximal reproductive capacity at temperatures between 18–26°C (1,2,3). When the temperature exceeds 30°C, population density decreases, and at 35°C, mortality rates rise. Lower temperatures (5°C and below) weaken metabolic processes and stimulate cyst formation.

The seasonal variations in temperature affect the abundance and species diversity of protozoa:

Spring-Summer: With increasing temperature and sunlight intensity, photosynthesis is enhanced, bacterial biomass increases, and consequently, the numbers of ciliates and testate amoebae sharply rise.

Autumn: As temperatures decrease, there is a decline in ciliate populations, and some species enter the cyst stage.

Winter: When temperatures fall below 5–10°C, the activity of protozoa diminishes, with many testate amoebae entering diapause or cyst forms.

Temperature and Metabolic Indicators

As temperature increases, the rate of respiration, intracellular enzyme activity, and osmotic regulation processes in protozoa accelerate. Short-term heat stress (e.g., 30–32°C) can lead to intracellular vacuolization and lysis in some species (Fenchel & Finlay, 2004). The Q_{10} effect (where the metabolic rate doubles for every 10°C rise in temperature) is also observed in ciliates.

Impact of Excessive Temperature

Temperature is one of the most important abiotic factors in aquatic ecosystems. Even small fluctuations in temperature can significantly affect the development and distribution of many organisms. Temperature directly influences the rate of metabolic processes in testate amoebae. While some species are capable of tolerating significant temperature changes, most species have adapted to the warmer seasons. Each species has an optimal temperature range. When the temperature exceeds this optimal range, newly formed individuals during division tend to have smaller shells and fewer projections.

In water bodies, when water temperature exceeds 30°C, the reproductive rate of testate amoebae declines. Approaching 35°C, protein denaturation occurs, leading to a rapid decrease in population. At lower temperatures (0–4°C), life processes stop, but some species (e.g., Arcella) can survive for long periods in cyst form.

II. Discussion of Results

The testate amoebae fauna in the natural region of the Autonomous Republic can be classified into three ecological complexes based on temperature dependence (Table 1).

Speçies	Optimum Temperature
Evriterm	
Arcella vulgaris	8-31°C
A.conica	8,2-29°C
A.discoides	7,5-30,5°C
A.artocrea	5,1-27°C
Centropyxisaculeata	5,2-32°C
C.aerophila	5,2-27,4°C
C.discoides	8-30°C
C.ecornis	7,3-32,1°C
C.marsupiformis	8,6-30,3°C
C.plagiostoma	6,9-30,4°C
Difflugiaacuminata	6-30,8°C
D.curvicaulis	12,5-30,6°C
D.corona	5,7-32,5°C
D.elegans	6,9-30,4°C
D.oblonga	8,9-30,1°C
D.linearis	6,5-21,5°C
D.gramen	6,5-32°C
D.penardi	5,4-30,8°C
Termofil	
Centropyxis gibba	18,4-23,2°C
Difflugia difficilis	11,9-20,6°C
D.claviformis	18,4-25°C
D.capreolata	19,1-27°C
D.urceolata	10,5-25,4°C
Pontigulasia bigibbosa	21,4-26°C
P.compressa	21,8-29,1°C
Lesquereusia spiralis	21,2-30,1°C
Cyphoderia ampulla	14,8-28,2°C
Stenoterm kriofil	
Difflugia lobostama	5-8,6°C
Difflugia globularis	5,1-9°C

1. Group of Eurythermal Species Found Mainly Throughout the Year
The group of eurythermal species includes Arcella vulgaris, Centropyxis aculeata, Centropyxis marsupiformis, Centropyxis plagiostoma, Difflugia oblonga, Difflugia corona, Difflugia elegans, Difflugia gramen, and others. These species are found across a wide temperature range throughout the year.
2. Group of Thermophilic Species Found Only in High-Temperature Intervals
Thermophilic species are found only during the warmer months, from the beginning of summer to the middle of autumn. This group includes Difflugia difficilis, Difflugia claviformis, Pontigulasia bigibbosa, Pontigulasia compressa, Cyphoderia ampulla, and others. These species thrive in higher temperature ranges.
3. Group of Stenothermal Cryophilic Species Found in Relatively Low Temperatures (4–9°C)
Stenothermal cryophilic species, such as Difflugia lobostama and Difflugia globularis, are found to have maximum development in relatively low temperatures ranging from 4–9°C.

The overall number of testate amoebae species and their maximum species richness were observed from May to October. This indicates that the majority of the testate amoebae species prevalent in the area's water bodies are thermophilic.

As shown in Table 1, the temperature range for eurythermal species is broad, varying from 5.1°C to 32.5°C. The temperature range for stenothermic thermophilic species is between 10.5°C and 30.1°C, while for stenothermic cryophilic species, the temperature range is between 5°C and 9°C. Among the recorded species of testate amoebae, 18 species were categorized as eurythermal, 9 species as thermophilic, and 2 species as cryophilic.

Significance in the Context of Climate Change

Climate change and the warming of water bodies affect the phenology and biogeography of protozoa. Contemporary research shows that a 2–3°C increase in water temperature in Arctic and temperate zones accelerates the phenotypic adaptation of infusorians (Foissner et al., 2008).

Studies have demonstrated that for Paramecium caudatum, the reproduction cycle lasts 12 hours at 25°C, but at 15°C, it extends to 48 hours (10,11,12).

Testate amoebae dominate in microzones within sediment where the temperature remains more stable (Graph 1).

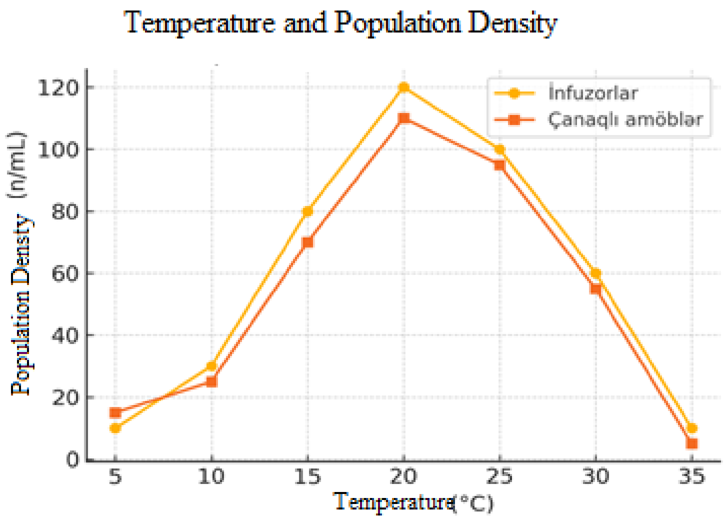

Figure 1. The Effect of Temperature on the Population Density of Infusorians and Testate Amoebae (Graph: Y-axis – Population density (n/mL), X-axis – Temperature (°C). The optimal zone shows maximum growth between 18–25°C.)

Relation to Water Depth

The depth gradient of water boies creates sharp variations in light, temperature, and gas regimes, which directly impact the distribution of protozoans. In the epilimnion zone (0–2 m), the abundance of light and oxygen facilitates the proliferation of infusorians. Species such as Paramecium caudatum, Stentor coeruleus, and Spirostomum dominate this zone (Alekperov, 2005).

Testate amoebae, on the other hand, primarily exhibit benthic lifestyles. They are more commonly found in substrates rich in silt and detritus, at depths ranging from 0.5–2 meters (e.g., Difflugia oblonga, Centropyxis aculeata). In the hypolimnion, oxygen depletion results in reduced species diversity, with only anaerobic infusorian species (such as Metopus contortus) being found (Fenchel, 1987).

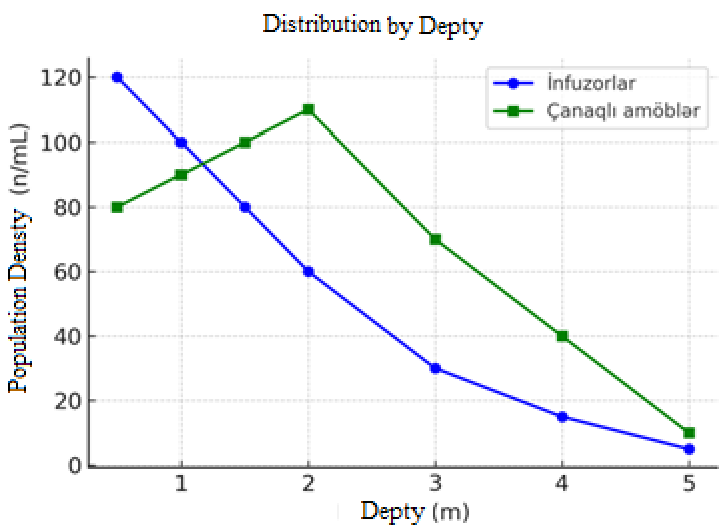

Figure 2. Diagram of Protozoan Distribution by Depth
(Epilimnion – high species diversity, Hypolimnion – fewer species, only anaerobic forms.)

Relation to Gas Regime in Water
Dissolved oxygen (O_2) and carbon dioxide (CO_2) play crucial roles in the life activities of protozoans. Most infusorians are aerobic, and they develop optimally at O_2 concentrations of 5–8 mg/L (Curds, 1973). A reduction in oxygen levels promotes the dominance of anaerobic species (e.g., Metopus, Spathidium).
The CO_2 concentration influences the pH level of the water. Neutral (pH 7) and slightly alkaline (pH 7.5–8.5) environments are ideal for infusorians. However, the presence of H_2S and ammonia can be toxic to protozoans, with only some anaerobic species capable of surviving under such conditions (Table 2).

Table 2.
Water Gas Regime and Adaptation of Protozoa

Parametr	Optimal səviyyə	Adapted species
O_2	5–8 mg/L	*Paramecium*, *Euplotes*
CO_2	0,2–0,5 mg/L	Suitable for many species
H_2S	0 mg/L	Only anaerobs

Food Relationships with Other Aquatic Organisms. Protozoa Form the Key Link in the Microbial Food Chain of Hydroecosystems (Figure 2).

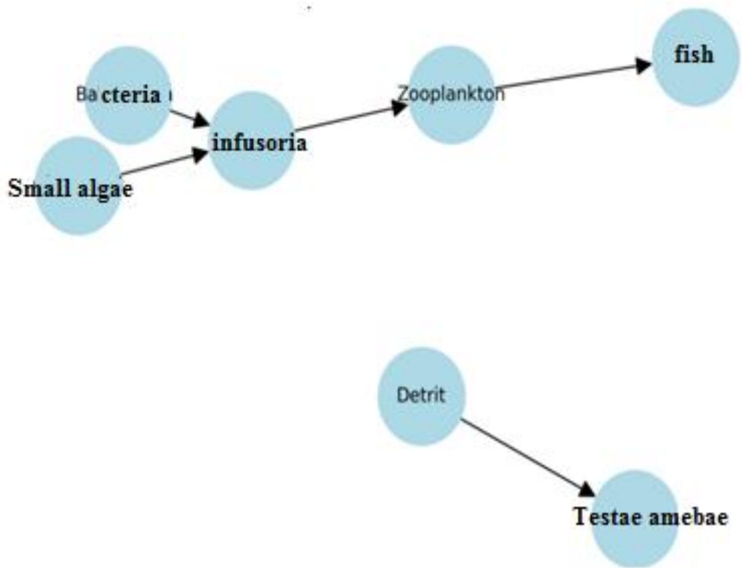

Figure 2. Trophic Relationships in the Hydroecosystem

Their food spectrum is wide:
Bacteriovores: Paramecium, Colpidium feed on bacteria.
Algivores: Euplotes, Frontonia consume small green algae.
Predators: Didinium, Lacrymaria feed on other infusorians. These trophic relationships are crucial for the cycling of organic matter and energy flow in the ecosystem (Azam et al., 1983).

Food Relationships with Other Aquatic Organisms. Testate amoebae (Testacea) and ciliates (Ciliophora) are considered the main components of the microbial trophic network in hydroecosystems. They play an essential role in the cycling of organic matter by acting as both consumers and, in some cases, predators. In terms of food relationships, protozoa can be classified into several functional groups: bacteriovores, algivores, detritivores, and predator forms (7, 8,9,10).
Bacterivory. A large proportion of testate amoebae and ciliates feed on bacteria. This characteristic makes them an important link in the microbial food chain. Paramecium, Colpidium, Tetrahymena are examples of bacteriovorous infusorians.
Testate amoebae (*Difflugia oblonga, Arcella vulgaris*) feed on bacterial biofilms in sediment. Bacterivory accelerates the mineralization of organic matter and the nitrogen-phosphorus cycle in aquatic ecosystems.
Algivory. Some infusorians and occasionally amoebae consume microscopic algae and phytoplankton. Euplotes, Frontonia, and Stentor species feed on chlorophyllous algae. This interaction is important for regulating phytoplankton populations and maintaining the balance of the trophic structure in the water.

Predation (Protozoa – Protozoa). Some large infusorians feed on other protozoans, leading to intra-guild predation. Didinium nasutum is a classic predator and often feeds on Paramecium. Lacrymaria olor uses a phagocytosis method to ingest other protozoans. These relationships directly influence the dynamics and species diversity of protozoan populations (Figure 3).

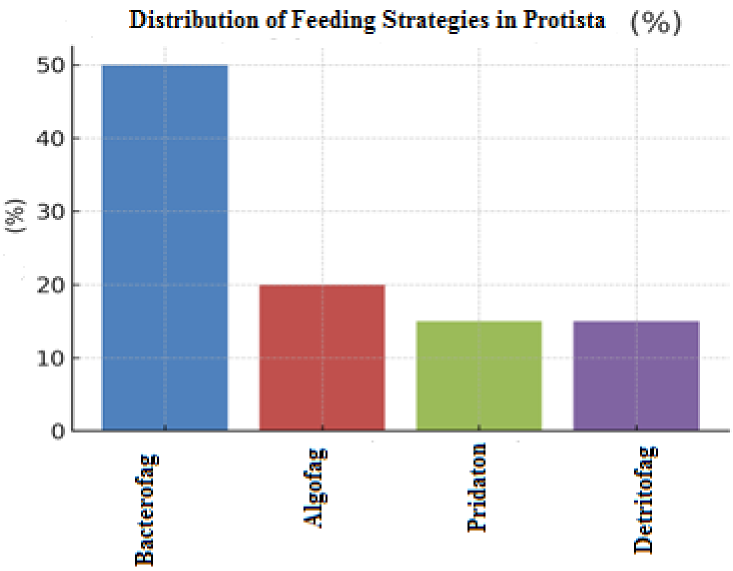

Figure 3. Distribution of Food Strategies in Protozoans

Detritivory and Use of Organic Particles. Testate amoebae feed on organic remains and detritus accumulated in sediments and mud. Centropyxis aculeata and Difflugia corona consume saprophytic material from sediment layers to obtain energy and nutrients. This process plays a key role in the cycling of organic matter in benthic biotopes.

Role in the Food Web of the Ecosystem. Testate amoebae and ciliates act as consumers in the microbial food loop and are the main link in transferring bacterial biomass to higher trophic levels. They serve as a food source for zooplankton (rotifers, copepods), which ensures the flow of energy and cycling of matter (15, 16,17, 18, 19). These interactions help maintain the stability and functionality of aquatic ecosystems and the cycling of biogenic elements.

Trophic Relationships Diagram:

Bacteria → Ciliates → Zooplankton → Fish
Detritus → Testate Amoebae → Higher Organisms

Importance as Bioindicators. The food spectrum and species composition of protozoans are used as bioindicator indicators to assess the trophic state and degree of pollution in water bodies (Alekperov, 2005; Foissner, 1998).

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