

Composition and structure of macroinvertebrate communities of lakes in different altitudinal zones of Russian Altai

Olga N. Vdovina¹, Liubov V. Yanygina^{1,2}, Dmitry M. Bezmaternykh¹

1 Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences (IWEP SB RAS), 1 Molodezhnaya st. Barnaul, 656038, Russia

2 Altai State University, 61 Lenina pr., Barnaul, 656049, Russia

Corresponding author: Olga N. Vdovina (olgazhukova1984@yandex.ru)

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Abstract

In 2002–2020, the composition and structure of benthic invertebrate communities from 36 lakes of the Russian Altai located at various (low, mid and high) altitudes were studied. Low-mountain and lowland lakes have a similar zoobenthos structure. With height, the taxonomic structure becomes more complicated, and the dominant taxa of macroinvertebrates change. The peculiar feature of bottom zoocenoses in mid- and high-altitude lakes is high frequency of occurrence and large contribution to the total biomass of crustaceans of the family Gammaridae. We described the trophic structure of zoobenthos and identified five main trophic groups. In terms of species number, the collector-detritus feeder and predator groups dominated in the trophic structure of all lakes. By biomass, the growing proportion of filter feeders and shredders was observed with increasing height.

Keywords

Altitudinal environmental gradient, benthic invertebrates, mountain lakes

Introduction

Worldwide, about 20% of lakes are located at an altitude above 1000 m (Verpoorter et al. 2014). In terms of physical and biological properties, there is a big difference between high- and low-mountain lakes (Moser et al. 2019). Most mountain lakes are located in severe climate with low water temperatures, a prolonged period of snow and ice cover, and are characterized by poor food conditions. Compared to low-mountain lakes, high-mountain lake ecosystems are usually distinguished by low species richness (Fureder et al. 2006; Fjellheim et al. 2009) and simplified food webs, often consisting of less than three trophic levels (McNaught et al. 1999). To what extent an altitude affects the characteristics of a lake basin and related biogeochemical processes or how these environmental conditions influence biological properties and structures of communities are still poorly studied (Loria et al. 2019). The altitude gradient includes changes in various environmental factors, such as temperature, organic matter content, substrate type, macrophyte diversity (Hoffman et al. 1996; Nyman et al. 2005; Collado and De Mendoza 2009). When studying the altitude influence, the greatest attention is paid to temperature effects on distribution of macroinvertebrate groups, including Chironomidae (Larocque et al. 2001; Nyman et al. 2005; Bitusik et al. 2006), Oligochaeta (Dumnicka, Galas 2002; Collado and De Mendoza 2009; De Mendoza and Catalan 2010), and Trichoptera (Solem and Birks 2000) in different-altitude lakes. In mountain lakes, environmental factors are closely associated with altitude that generates complicated relationships and an inability to distinguish the impact of individual variables.

The studies of the macroinvertebrate faunas of mountain lakes throughout Europe (Fjellheim et al. 2009) demonstrate the presence of the same species, but different taxonomic composition. They also emphasize the importance of detailed knowledge of the regional faunas. Currently, the problem of identifying the formation patterns of benthic invertebrates in specific regions remains relevant.

Altai is the highest mountain region in southern Siberia; the ridges of its central and eastern parts rise above 3–4 km and are covered with eternal snow and glaciers. In the Russian Altai, there are more than 3,500 lakes, but the area of only 75 of them exceeds 1 km² (Gvozdetsky and Mikhailov 1978). Most of the glaciers high-mountain lakes located in the subalpine zone at the very edge of the snow are almost completely devoid of life. With descending from Altai peaks, the fauna of lakes becomes similar to that of lowland ones (Zhadin and Gerd 1961). It became known about the entry of air pollutants into European mountain regions from industrially developed lowlands at the end of the last century (Brittain and Milner 2001). Air pollution poses a threat to alpine ecosystems because many organisms in these areas exist at the limit of their tolerance to chemical and physical environmental factors (Fjellheim et al. 2000). Unlike mountain lakes of Europe, the anthropogenic load on the mid- and high Altai mountains is quite low or completely absent because of their remoteness and inaccessibility. It allows the latter as reference areas for indicating environmental changes.

Macroinvertebrates of the Altai region have been investigated since the beginning of the XX century (Gundrizer et al. 1982; Johansen 1981). In expeditions to the upper reaches of the Ob River, attention was traditionally paid to studying lakes, and primarily, Lake Teletskoye (Koveshnikov 2014). Since these lakes are situated in regions that are difficult to reach, the zoobenthos data are often fragmentary (with only evaluated fish forage reserves) or even missing altogether (Vesnina et al. 2012; Zalozny and Vorobev 2006; Krylova 2016; Popov et al. 2003).

In this study, we examine taxonomic richness, composition and trophic groups of macroinvertebrate communities in lakes located at different heights (321–2899 m asl). We assumed that with altitude climatic conditions would become more severe, species richness of benthic invertebrates decrease, feeding selectivity of organisms remains the same, shredders and filter feeders replace predators and collectors-detritus feeders.

Material and methods

In 2002, 2003, 2007, 2008, 2018 and 2020, bottom macroinvertebrate communities from the Russian Altai lakes located at various (low, medium, high) altitudes were studied within the framework of implemented complex limnological expeditions. We investigated 36 lakes, where collected and analyzed 108 quantitative and 28 qualitative samples of zoobenthos. The analyzed material was selected and processed using the standard methods (Guidelines 1992; Wetzel, Likens 2000). Qualitative samples were taken with a water net or scraper, while quantitative ones were taken with a GR-91 bottom grab (70 cm² mouth area). Bottom samples (boulders and pebbles) were collected using a hydrobiological net (with subsequent calculation of the area of stones by their projection in a plane), then washed through a nylon gauze with a mesh size of 350x350 µm. The animals were isolated and fixed in 70% ethanol. When taken two to three times, quantitative samples were combined into an integrated sample. For a more complete accounting of the zoobenthos composition, the samples were collected manually in various biotopes. The soil taken by a bar dredge was washed through a kapron bag with a 320-µm mesh. The samples were examined portion-wise, and the organisms found were placed in test tubes with 70% ethyl alcohol. After drying on a filter paper, we weighed the organisms on a torsion balance. Each species was determined by the "Key to Freshwater Invertebrates of Russia and Adjacent Lands" (1992–2004).

The lakes studied are located at various heights, ie low mountain – 1–4, middle-mountains 5–26, high-mountains 27–36 (Fig. 1). For the Russian temperate zone of the northern hemisphere, the following altitudes have been accepted: low mountains – up to 1000 m, middle mountains – 1000–2000 m, highlands – more than 2000 m (Gvozdetsky 1977). The area of the lakes studied is within 0.01–4.52 km², most of them do not exceed 1 km² (Table 1). These lakes are characterized by low water salinity and low concentrations of macro and microcomponents. The hydro-

gen index corresponds to neutral or slightly acidic waters (pH = 5.8–8.6). Lake waters are pure and oxygen-saturated (Frolova et al. 2011; Zarubina and Fetter 2019, 2020). As compared to the data of the 30s – 40s of the XX century, the dissolved oxygen concentration, pH and salinity of water have changed insignificantly (Alekin 1935; Gundrizer 1950; Johansen 1950).

A detailed description of the lakes studied is given in our previous work (Yanygina and Krylova 2006, 2008; Vdovina and Bezmaternykh 2020). The affiliation of macroinvertebrates with a certain trophic group was defined according to the Moog O. and Hartmann A. classification (2017), which is a revised version of the Cummins classification (1973) for insects (Cummins et al. 2008). Dominant species were identified on frequency of their occurrence (Bakanov, 1987). Discriminant analysis was performed to reveal the composition of differences in the macroinvertebrate species observed for low, mid and high mountain lakes. Analysis of variance (one-way ANOVA) was employed in assessing the impact of various factors (lake size, substrate type, altitude, altitudinal zone) on relative abundance of macrozoobenthos trophic groups.

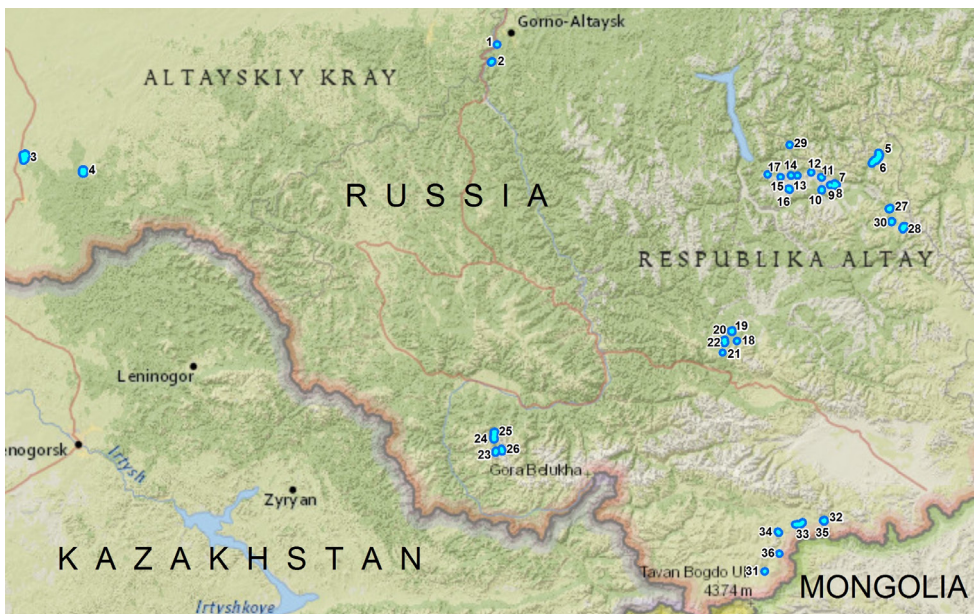


Figure 1. Map of the lakes studied. Low mountain lakes (<1000 meters above sea level): 1. Aya; 2. Manzherokskoe; 3. Kolyvanskoye; 4. Beloye middle mountain lakes (1000–2000 m): 5. Verkhny Itykul'; 6. Nizhny Itykul'; 7. Saygonysh; 8. Maly Saygonysh; 9. Kubyshka; 10. Arsoyok; 11. El'dengem; 12. Tugunrluachekkol'; 13. Maldu; 14. Tashtu; 15. Unnamed lake in the Kayry River basin; 16. Sundruk; 17. Ayukol'; 18. Bezymyanoye; 19. Igistu-Kul'; 20. Maly Uzenkol'; 21. Pridorozhnoye; 22. Podkova; 23. Verkhnee Mul'tinskoye; 24. Srednee Mul'tinskoye; 25. Nizhnee Mul'tinskoye; 26. Poperechnoye High-mountain lakes (> 2000 m): 27. Yakhansoru; 28. Unnamed lake near Uzunkel'; 29. Kandash; 30. Sostukel'; 31. Argamdzhi; 32. Bol'shoye Tarkhatinskoye; 33. Zerlyukol'-Nur; 34. Krasnoye; 35. Maloye Tarkhatinskoye; 36. T'eply klyuch.

Table 1. Main features of the studied lakes

Nº	Lakes	Coordinates	Altitude, m asl	Altitudinal belt	Area, km ²	Substrate
1.	Aya	51°54'14"N 85°51'12"E	321	Premontane subtaiga	0.06	Detritus, gray silt
2.	Manzherok	51°49'16"N 85°48'45"E	373	Premontane subtaiga	0.33	Muddy with detritus
3.	Kolyvanskoye	51°21'56"N 82°11'38"E	332	Premontane steppe	4.52	Silt and sand
4.	Beloye	51°17'40"N 82°38'47"E	537	Premontane forest-steppe	2.83	Silt and pebbles, stones
5.	Verkhny Itykul'	51°22'32"N 88°46'57"E	1664	Mountain-taiga	0.99	Stones, sand
6.	Nizhny Itykul'	51°20'57"N 88°48'37"E	1661	Mountain-taiga	2.77	Stones, sand
7.	Saygonysh	51°13'37"N 88°27'39"E	1612	Mountain-taiga	0.81	Silted sand
8.	Maly Saygonysh	51°13'34"N 88°27'17"E	1627	Mountain-taiga	0.02	Silted stones, detritus
9.	Kubyshka	51°13'44"N 88°25'54"E	1728	Mountain-taiga	0.02	Macrophytes, detritus
10.	Arsoyok	51°12'32"N 88°22'2"E	1473	Mountain-taiga	0.17	Stones, detritus, sand
11.	El'dengem	51°15'58"N 88°21'46"E	1736	Mountain-taiga	0.06	Silt, detritus
12.	Tugunrluachekkol'	51°17'25"N 88°17'08"E	1688	Mountain-taiga	0.05	Stones
13.	Maldu	51°16'30"N 88°10'42"E	1649	Mountain-taiga	0.02	Stones
14.	Tashtu	51°16'02"N 88°07'06"E	1765	Mountain-taiga	0.11	Stones
15.	Unnamed lake in river basin Kayry river	51°16'03"N 88°02'50"E	2082	Podgolets-subalpine	0.01	Silted sand, pebbles
16.	Sundruk	51°12'33"N 87°06'51"E	1990	Podgolets-subalpine	0.37	Sand, pebbles, stones
17.	Ayukol'	51°16'347"N 87°56'51"E	2015	Podgolets-subalpine	0.06	Stones
18.	Bezmyannoye	50°28'00"N 87°42'35"E	2192	Podgolets-subalpine	0.01	Stil
19.	Igistu-Kul'	50°30'53"N 87°40'22"	1823	Mountain-taiga	0.66	Boulders
20.	Maly Uzenkol'	50°28'15"N 87°36'37"E	1991	Mountain-taiga	0.24	Boulders

№	Lakes	Coordinates	Altitude, m asl	Altitudinal belt	Area, km ²	Substrate
21.	Pridorozhnoye	50°24'32"N 87°35'60"E	1838	Mountain-taiga	0.01	White silt over boulders and pebbles
22.	Podkova	50°27'38"N 87°37'00"E	1971	Mountain-taiga	0.26	Silt
23.	Verhnee Mul'tinskoye	49°55'03"N 85°50'42"E	1797	Podgolets-subalpine	0.39	Stones
24.	Srednee Mul'tinskoye	49°59'00"N 85°49'47"E	1646	Mountain-taiga	0.92	Stones
25.	Nizhnee Mul'tinskoye	50°00'11"N 85°49'50"E	1627	Mountain-taiga	1.73	Stones
26.	Poperechnoye	49°55'27"N 85°53'25"E	1883	Podgolets-subalpine	0.43	Stones
27.	Yakhansoru	51°06'49"N 88°53'33"E	1949	Podgolets-subalpine	0.52	Stones
28.	Unnamed lake near Uzunkel'	51°03'20"N 88°37'21"E	1957	Podgolets-subalpine	1.09	Stones
29.	Kandash	51°22'35"N 88°08'40"E	1945	Podgolets-subalpine	0.07	Stones
30.	Sostukel'	51°03'01"N 88°54'29"E	2023	Podgolets-subalpine	0.22	Stones
31.	Argamdzhi	49°19'03"N 87°55'31"E	2376	Montane tundra-steppe	0.09	Black silt with detritus
32.	Bol'shoeye Tarkhatinskoye	49°34'14"N 88°23'02"E	2320	Montane tundra-steppe	0.48	Silt with detritus
33.	Zerlyukol'-Nur	49°34'32"N 88°23'19"E	2321	Montane tundra-steppe	1.61	Silt
34.	Krasnoye	49°24'24"N 88°02'18"E	2329	Montane tundra-steppe	0.24	Boulders
35.	Maloye Tarkhatinskoye	49°17'49"N 88°01'38"E	2333	Montane tundra-steppe	0.05	Silt, sand, pebbles
36.	Teply klyuch	49°24'24"N 88°02'18"E	2899	Golets-alpine	0.03	Silted fine gravel

Results

Taxonomic composition. In low mountain lakes, 103 species of macrozoobenthos of seven classes were recorded: Oligochaeta (15 species), Hirudinea (4), Phylactolaemata (1), Gastropoda (5), Acari (11), Crustacea (1) and Insecta (66) (Table 2). Among insects, the maximum species richness fell on Diptera (37 species, of which 30 are chironomids). The rest of the species represented dragonflies, mayflies, true bugs, caddisflies, and beetles. Tubificidae (*Limnodrilus hoffmeisteri* – 66%) and

Chironomidae (60%) showed the highest frequency of occurrence. The genera *Cricotopus* (33%), *Procladius* (33%), *Chironomus* (26%) and *Ablabesmyia* (26%) were the most often detected chironomids. In low-mountain lakes, the species richness of the zoobenthos was relatively high (8.5 ± 2.3 species per sample), the Shannon species diversity index reached on average 1.7 ± 0.3 bits/ind.

Macrozoobenthos of middle mountain lakes included 94 species of 10 classes: Demospongiae (1 species), Turbellaria (1), Nematoda (1), Oligochaeta (9), Hirudinea (4), Bivalvia (2), Gastropoda (5), Acari (2), Crustacea (4), and Insecta (65). Amphibiotic insects accounted for 69% of the identified taxa, most of them (39 species) belong to the Diptera. Mayflies, beetles, caddisflies, stoneflies, and net-winged insects were also present. In Diptera, chironomid larvae (36 species) prevailed, mainly from the subfamily Orthoclaadiinae. Larvae of the genera *Cricotopus* (28%), *Synorthocladus* (25%) and *Eukiefferiella* (23%) were the most common. In other taxa, the Gammaridae family made up 40% and Naididae – 30%. The species richness of benthic invertebrates was low, i.e., 0–11 species in a sample (on average 5.1 ± 0.3), the Shannon diversity index varied within 0–2.85 (on average 1.4 ± 0.1 bits/ind.).

In high mountain lakes, a total of 36 species of macrozoobenthos were recorded of 7 classes (Table 2): Demospongiae (1 species), Nematoda (1), Oligochaeta (2), Hirudinea (2) Bivalvia (2), Crustacea (2), and Insecta (26). Among insects, dipterans demonstrated the highest species richness (17 species, chironomids). Beetles, mayflies, caddisflies, and true bugs were also found. Chironomids were observed in 86% of the samples, among them *Chironomus* (44%) and *Stictochironomus* (27%), as well as the *Cladotanytarsus* A (27%) predominated. For other taxa, crustaceans of genus *Gammarus* prevailed (50%). Taxonomically, the benthic communities in the studied lakes were not rich (on average 4.4 ± 0.6 species per sample); the Shannon diversity index varied from 0 to 3.04 (on average 1.11 ± 0.2 bits/ind.).

Table 2. Taxonomic composition of macrozoobenthos

Taxon	Low-mountains	Middle-mountains	High-mountains
Phylum Porifera			
Classis Demospongiae			
Familia Spongillidae			
Spongillidae indet.	–	19, 21, 22, 25	25
Phylum Plathelminthes			
Classis Turbellaria			
Turbellaria indet.	–	24, 26	–
Phylum Nematelminthes			
Classis Nematoda			
Mermithidae indet.	–	18, 22	31, 33

Taxon	Low-mountains	Middle-mountains	High-mountains
Phylum Annelida			
Classis Oligochaeta			
Familia Lumbriculidae			
<i>Lumbriculus variegatus</i> (O.F. Müller)	–	10, 12, 23, 24	–
Familia Naididae			
<i>Chaetogaster</i> sp.	–	20	–
<i>Chaetogaster diaphanus</i> (Gruithuisen)	3	5	–
<i>Dero</i> sp.	3	–	–
<i>Nais barbata</i> O.F. Müller	3, 4	–	–
<i>Nais bretscheri</i> Michaelsen	4	–	–
<i>Nais communis</i> Pigué	3, 4	–	–
<i>Nais pardalis</i> Pigué	3, 4	–	–
<i>Nais pseudobtusa</i> Pigué	4	–	–
<i>Nais</i> sp.	–	23, 25	–
<i>Nais variabilis</i> Pigué	–	5	–
<i>Ophidonais serpentina</i> (O.F. Müller)	3, 4	–	–
<i>Ripistes parasita</i> (Schmidt)	3	–	–
<i>Stylaria lacustris</i> (Linnaeus)	3, 4	20	–
<i>Uncinaiis uncinata</i> (Oersted)	3, 4	–	–
Familia Tubificidae			
<i>Limnodrilus claparedeanus</i> Ratzel	3, 4	–	–
<i>Limnodrilus hoffmeisteri</i> Claparède	2, 3, 4	25	34
<i>Tubifex tubifex</i> (O.F. Müller)	3, 4	7	34, 36
<i>Spirosperma ferox</i> (Eisen)	3	10, 15	–
Classis Hirudinea			
<i>Erpobdella octoculata</i> (L.)	1, 3	5, 10, 20, 21, 22	28
<i>Erpobdella</i> sp.	–	8, 16	–
<i>Glossiphonia complanata</i> (L.)	3, 4	5, 6, 22	30, 32
<i>Helobdella stagnalis</i> (L.)	1, 3	12	–
<i>Hemiclepsis marginata</i> (O.F. Müller)	3	–	–
Phylum Bryozoa			
Classis Phylactolaemata			
<i>Plumatella repens</i> (L.)	1	–	–
Phylum Mollusca			
Classis Bivalvia			
<i>Euglesa</i> sp.	–	7, 8, 9, 10, 11, 15	–
<i>Sphaerium corneum</i> (L.)	–	18	35

Taxon	Low-mountains	Middle-mountains	High-mountains
<i>Sphaerium</i> sp.	–	–	32, 33, 34, 35
Classis Gastropoda			
Familia Planorbidae			
<i>Anisus acronicus</i> (Férussac)	–	24	–
<i>Anisus</i> sp.	3, 4	–	–
<i>Armiger</i> sp.	4	–	–
<i>Hippeutis euphaea</i> (Bourguignat)	3	–	–
Familia Lymnaeidae			
<i>Lymnaea fontinalis</i> (Studer)	3	24	–
<i>Lymnaea ovata</i> (Draparnaud)	3	–	–
<i>Lymnaea stagnalis</i> (L.)	–	19, 22	–
<i>Lymnaea</i> sp.	–	23	–
Familia Physidae			
<i>Physa</i> sp.	–	25	–
Phylum Arthropoda			
Classis Euchelicerata			
Familia Arrenuridae			
<i>Arrenurus sinuator</i> (Müller)	4	–	–
<i>Arrenurus</i> sp.	3	–	–
Familia Hydrachnidae			
<i>Hydrachna</i> sp.	3, 4	–	–
Familia Lebertiidae			
<i>Lebertia</i> sp.	–	14	–
Familia Mediopsidae			
<i>Mediopsis orbicularis</i> (Müller)	4	–	–
Familia Pionidae			
<i>Forelia</i> sp.	3	–	–
<i>Piona coccinea</i> Koch	3	–	–
<i>Piona pusila</i> (Neuman)	3	–	–
<i>Piona</i> sp.	4	10, 23, 24	–
<i>Tiphys</i> sp.	4	–	–
Familia Sperchontidae			
<i>Sperchon</i> sp.	3	–	–
Familia Unionicolidae			
<i>Neumania</i> sp.	4	–	–
Classis Crustacea			
Familia Gammaridae			

Taxon	Low-mountains	Middle-mountains	High-mountains
<i>Gammarus c.f. barnaulensis</i> Schellenberg	–	6, 8, 9, 11, 12, 14	–
<i>Gammarus lacustris</i> G.O. Sars	3	10, 13, 19, 21, 22, 24, 26	27, 32, 34, 35
<i>Gammarus korbuensis</i> Martynov	–	5, 7	29
<i>Gammarus</i> sp.	–	5, 7	29
Classis Insecta			
Ordo Neuroptera			
Familia Sisyridae			
<i>Sisyra fuscata</i> (F.)	–	9	–
Ordo Odonata			
Familia Aeshnidae			
<i>Aeschna culumberculus</i> Harris	3	–	–
Familia Coenagrionidae			
<i>Erythromma najas</i> (Hansemann)	1	–	–
<i>Erythroma</i> sp.	3	–	–
Coenagrionidae indet.	4	–	–
Familia Corduliidae			
<i>Somatochlora</i> sp.	2	–	–
Familia Gomphidae			
Gomphidae indet.	3	–	–
Familia Lestidae			
<i>Sympecma fusca</i> (Vanderlinden)	4	–	–
<i>Sympecma paedisca</i> (Brauer)	3	–	–
Ordo Plecoptera			
Familia Nemouridae			
<i>Nemoura</i> sp.	–	6	–
Familia Chloroperlidae			
Chloroperlidae indet.	–	26	–
Ordo Ephemeroptera			
Familia Ameletidae			
<i>Ameletus</i> sp.	–	–	29
Familia Baetidae			
<i>Baetis</i> sp.	–	5	–
<i>Baitis</i> gr. <i>vernus</i>	–	13	–
<i>Baitis</i> gr. <i>rhodani</i>	–	26	–
<i>Cloeon dipterum</i> L.	4	20	–
Familia Caenidae			

Taxon	Low-mountains	Middle-mountains	High-mountains
<i>Caenis lactea</i> (Burmeister)	–	22	–
<i>Caenis miliaria</i> (Tshernova)	–	22	–
<i>Caenis horaria</i> L.	3, 4	–	–
<i>Caenis</i> sp.	1	–	–
Familia Ephemerellidae			
<i>Ephemerella</i> (T.) <i>lenoki</i> Tshernova	–	24	–
Familia Haptageniidae			
<i>Ecdyonurus</i> (A.) <i>vicinus</i> (Demoulin)	–	5	–
<i>Ecdyonurus</i> sp.	3	25	–
<i>Heptagenia</i> sp.	–	24, 25	–
Familia Leptophlebiidae			
<i>Leptophlebia</i> (P.) <i>strandii</i> Eaton	–	11, 12, 24	–
<i>Leptophlebia</i> (N.) <i>chocolate</i> (Imanishi)	–	26	–
Ordo Heteroptera			
Familia Corixidae			
<i>Corixa</i> sp.	3	–	–
Familia Gerridae			
<i>Gerris lacustris</i> (L.)	–	–	27
Familia Nepidae			
<i>Nepa cinerea</i> L.	1	–	–
Familia Naucoridae			
<i>Ilyocoris cimicoides</i> (L.)	3	–	–
Familia Pleidae			
<i>Plea minutissima</i> Leach	3, 4	–	–
Ordo Trichoptera			
Familia Apataniidae			
<i>Apatania zonella</i> Zett	–	5	–
<i>Apatania</i> sp.	–	26	–
Apataniidae indet.	–	26	–
Familia Hydroptilidae			
<i>Agraylea multipunctata</i> Curtis	4	–	–
<i>Agrypnia pagetana</i> Curt.	3	–	–
<i>Agraylea sexmaculata</i> Curtis	4	–	–
<i>Oxythira costalis</i> Curt.	4	–	–
Familia Leptoceridae			
<i>Oecetis</i> sp.	–	10, 20	–
Familia Limnephilidae			

Taxon	Low-mountains	Middle-mountains	High-mountains
<i>Limnephilus borealis</i> Zett	–	–	27, 28
<i>Limnephilus nigriceps</i> Zett	–	–	27
<i>Limnephilus rhombicus</i> (L.)	–	24, 25	–
<i>Limnephilus stigma</i> Curtis	–	–	27
Familia Molannidae			
<i>Molanna albicans</i> (Zetterstedt)	–	16	–
Familia Phryganeidae			
<i>Agrypnia obsoleta</i> (Hagen)	–	14	28
<i>Phryganea bipunctata</i> Retzius	3	–	–
Familia Rhyacophilidae			
<i>Rhyacophila</i> sp.	–	17	–
Ordo Coleoptera			
Familia Chrysomelidae			
<i>Donacia</i> sp.	–	9	–
<i>Calerucella</i> sp.	3	–	–
Chrysomelidae indet.	3	–	–
<i>Plateumaris</i> sp.	3	–	–
<i>Prasocuris</i> sp.	4	–	–
Familia Dytiscidae			
<i>Acilius canaliculatus</i> (Nicolai)	–	–	27
<i>Agabus</i> sp.	–	–	27, 29
<i>Dytiscus circumflexus</i> Fabricius	–	–	29
<i>Graphoderus</i> sp.	2	–	–
<i>Hydrotus</i> sp.	4	–	–
<i>Hygrotus</i> sp.	–	8	–
<i>Oreodytes</i> sp.	–	24	–
Familia Hydraenidae			
<i>Hydraena</i> sp.	3	–	–
Familia Hydrophilidae			
Hydrophilidae indet.	1	–	–
Ordo Diptera			
Diptera indet.	–	9	–
Familia Dixidae			
<i>Dixella aestivalis</i> (Meigen)	–	9	–
Familia Chaoboridae			
<i>Chaoborus</i> (C.) <i>crystallinus</i> (De Geer)	3	–	–
<i>Chaoborus</i> (C.) <i>flavicans</i> (Meigen)	2	–	–

Taxon	Low-mountains	Middle-mountains	High-mountains
Familia Simuliidae			
<i>Simulium</i> sp.	–	23	–
Familia Ceratopogonidae			
<i>Bezzia</i> (H.) <i>bicolor</i> (Meigen)	3, 4	–	–
<i>Bezzia</i> sp.	1	–	–
<i>Mallochoholea setigera</i> (Loew)	4	–	–
<i>Palpomyia lineata</i> (Meigen)	2, 3	–	–
<i>Sphaeromyias pictus</i> (Meigen)	2	–	–
Familia Chironomidae			
<i>Ablabesmyia</i> gr. <i>monilis</i>	3, 4	6, 7, 13, 17, 24, 25	27, 28
<i>Ablabesmyia</i> sp.	–	24	34
<i>Chironomus plumosus</i> (L.)	2, 3, 4	–	–
<i>Chironomus</i> sp.	3	15, 18, 20, 21, 22, 23, 25	32, 35
<i>Cladotanytarsus mancus</i> (Walker)	3, 4	20	32, 36
<i>Cladotanytarsus</i> gr. A	–	22	33, 34
<i>Cladotanytarsus</i> sp.	–	25	–
<i>Corynoneura</i> gr. <i>edwarsi</i>	3	–	–
<i>Corynoneura scutellata</i>	–	5, 14, 25	–
<i>Corynoneura</i> sp.	–	20	–
<i>Cricotopus</i> gr. <i>laricomaris</i>	–	–	30
<i>Cricotopus sylvestris</i> (Fabricius)	3, 4	24	–
<i>Cricotopus tibialis</i> (Meigen)	2	–	–
<i>Cricotopus</i> gr. <i>tremulus</i>	–	12, 24, 25	–
<i>Cricotopus</i> sp.	4	5, 6, 13, 14, 17, 20, 25	34
<i>Cryptochironomus defectus</i> (Kieffer)	3, 4	25	35
<i>Diamesa bertrami</i> Edwards	–	23	–
<i>Diplocladius cultriger</i> Kieffer	–	23	–
<i>Dicrotendipes nervosus</i> (Staegeer)	4	25	34
<i>Dicrotendipes setemmaculatus</i> (Becker)	4	–	–
<i>Endochironomus albipennis</i> (Meigen)	1, 3	–	–
<i>Endochironomus donatoris</i> Shilova	3	–	–
<i>Endochironomus stackelbergi</i> Goetghebuer	4	5	34
<i>Endochironomus tendens</i> (Fabricius)	3	–	–
<i>Eukiefferiella</i> gr. <i>devonica</i>	–	23, 24, 25	–
<i>Eukiefferiella</i> sp.	–	23	–

Taxon	Low-mountains	Middle-mountains	High-mountains
<i>Glyptotendipes glaucus</i> (Meigen)	1, 2, 3, 4	9, 20	–
<i>Glyptotendipes paripes</i> (Edwards)	–	16	–
<i>Hydrobaenus lugubris</i> (Fries)	–	–	35
<i>Microchironomus tener</i> (Kieffer)	3	–	–
<i>Micropsectra</i> sp.	–	25	–
<i>Orthocladius</i> sp.	–	22, 24	–
<i>Parachironomus varus</i> Goethgebuer	3, 4	–	–
<i>Paratanytarsus confusus</i> Palmen	3, 4	23	–
<i>Paratanytarsus</i> sp.	–	12, 13, 14, 17	–
<i>Polypedilum bicrenatum</i> Kieffer	3	–	–
<i>Polypedilum convictum</i> (Walker)	3	–	–
<i>Polypedilum</i> cf. <i>litofiles</i> Akhrorov	1	–	–
<i>Polypedilum nubeculosum</i> (Meigen)	–	22	–
<i>Polypedilum scalaenum</i> (Schrank)	–	–	31
<i>Polypedilum tetracrenatum</i> Hirvenoja	3, 4	–	–
<i>Procladius</i> (H.) <i>ferrugineus</i> (Kieffer)	1, 2, 3, 4	–	–
<i>Procladius</i> (H.) <i>choreus</i> Meigen	3, 4	8, 11, 15	–
<i>Procladius</i> sp.	–	18, 19, 22	34, 36
<i>Prodiamesa olivacea</i> (Meigen)	–	23	–
<i>Psectrocladius delatoris</i> Zelentzov	–	9	28
<i>Psectrocladius obvius</i> (Walker)	4	–	–
<i>Psectrocladius</i> sp.	–	23, 25	–
<i>Psectrocladius</i> (P.) <i>zetterstedti</i> Brundin	–	22	–
<i>Sergentia</i> gr. <i>coracina</i>	–	16	–
<i>Synorthocladius semivirens</i> (Kieffer)	–	6, 10, 23, 24, 25, 26	–
<i>Stictochironomus crassiforceps</i> (Kieffer)	4	–	28, 36
<i>Stictochironomus</i> gr. <i>histrion</i>	–	–	35
<i>Tanytus punctipennis</i> Meigen	3, 4	–	–
<i>Tanytus</i> sp.	4	23, 24	36
<i>Tanytarsus medius</i> Reiss et Fittkau	–	23	–
<i>Tanytarsus</i> sp.	–	23, 24	–
Chironomidae pupae	4	–	–
Total species	103	94	36

Note: 1–36, habitat numbers corresponding to Fig. 1; –, no record.

Discriminant analysis (Fig. 2) suggested significant differences in the macroinvertebrate structure of lakes located in different altitudinal zones (Wilks' $\lambda = 0.01$, $F=10.01$, $p<0.0001$). In the study groups, the families Tubificidae (Wilks' $\lambda = 0.03$; $F=15.80$; $p=0.0001$), Euglesidae (Wilks' $\lambda = 0.03$; $F=16.25$; $p=0.0001$), Caeniidae (Wilks' $\lambda = 0.024$; $F=11.17$; $p=0.0006$) and the subfamily Chironominae (Wilks' $\lambda = 0.03$; $F=16.25$; $p=0.0001$) made the greatest contribution to lakes' difference (Wilks' $\lambda = 0.025$; $F=11.66$; $p=0.0005$).

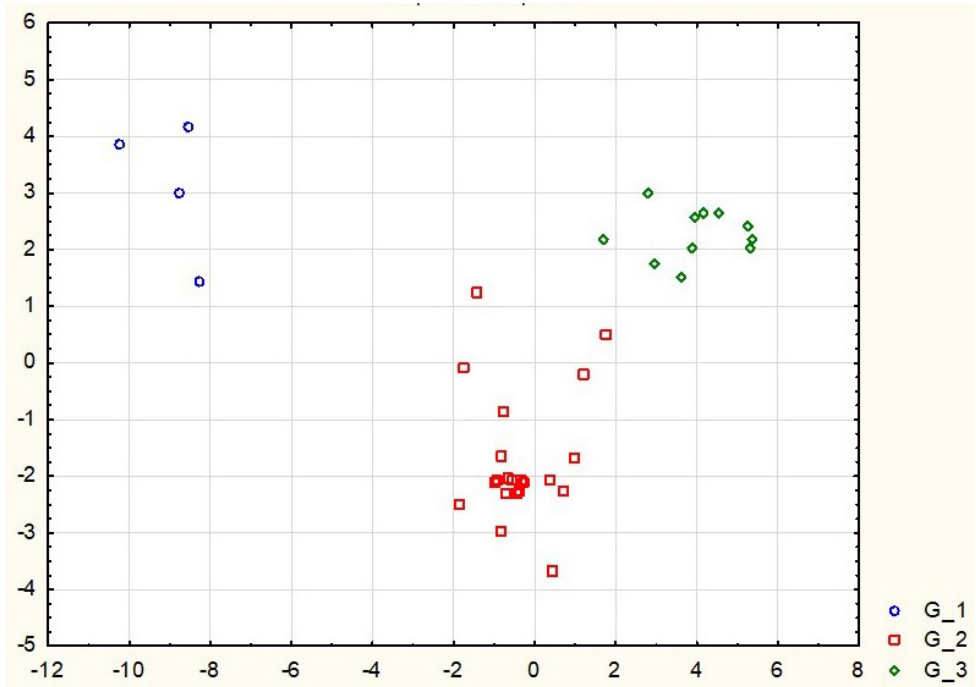


Figure 2. The discriminant analysis of the macroinvertebrate composition of the Russian Altai lakes located in different altitudinal zones. 1 – low-mountains (<1000 meters above sea level), 2 – medium mountain ranges (1000–2000 m), 3 – high mountain ranges (> 2000 m).

Trophic groups. Based on the type of feeding, five major trophic groups of macroinvertebrates from the study lakes were identified as follows: (1) Collectors-detritus feeders, facultative filter feeders (hereinafter – Collectors-detritus feeders); (2) Collectors-obligate filter feeders; (3) Scrapers; (4) Shredders; (5) Predators.

Here, the greatest species richness falls on detritus collectors eating detritus from the ground surface (Table 3). This group is represented by larvae of diptera of the family Chironomidae, mayflies, and oligochaetes. A large number of species belong to predators with predominance of leeches, flatworms, dragonfly larvae, bedbugs of the families Pleidae, Gerridae, Nepidae and Notonectidae, beetles of the family Dytiscidae, diptera larvae from the families Chaoboridae and Ceratopogonidae. In

these communities, predatory larvae from caddisflies of the families Leptoceridae and Rhyacophilidae, chironomids of the subfamily Tanypodinae, and megalopterans of the family Sialidae were also identified. The collector-obligate filter feeder group was formed mainly by bivalve mollusks. Among shredders, the Gammaridae and beetles of the Chrysomelidae prevailed. It is hard to attribute the feeding spectrum of many species to a specific trophic group unambiguously; therefore, scrapers and some shredders include organisms with a mixed type of feeding in appropriate proportions (Moog and Hartmann 2017).

Table 3. Trophic groups of macrozoobenthos in lakes from different altitudinal zones

Trophic groups	Lakes, N/M±m		
	Low-mountains	Middle-mountains	High-mountains
Collectors-detritus feeders	38.9/1.71±0.55	46/0.31±0.07	15.2/0.79±0.29
Shredders	8.4/0.19±0.18	10.9/1.23±0.37	2.7/0.37±0.17
Scrapers	7.4/0.13±0.07	11.4/0.22±0.1	1.9/0.04±0.02
Predators	39.3/0.54±0.31	17.6/0.29±0.09	12.3/0.16±0.06
Collectors-obligate filter feeders	3/0.09±0.05	6.1/0.16±0.07	3.9/0.55±0.25
Others	6/0.06±0.03	2/0.06±0.05	–

Note: N – number of species; M±m – mean and error of mean biomass of trophic groups, g/m² – no records.

By the biomass of zoobenthos, collectors-detritus feeders and predators dominated in low mountain lakes. In midmountain lakes, shredders (represented by the Gammaridae) dominated in biomass, collectors-detritus feeders and predators subdominated, the remaining groups were represented equally. In high mountain lakes, the role of shredders decreased, collector-detritus feeders were again dominated by biomass, and the role of collector-obligate filter feeders increased as well.

ANOVA revealed that the distribution of the lakes trophic groups in the studied depends on height, altitudinal zone, and substrate type (Table 4). The size of the lake is less important; this indicator significantly affects only the proportion of scrapers in benthic biomass. The proportion of collectors-detritus feeders and shredders depends on height, altitudinal zone, and soil type, whereas scrapers – on lake size ($p=0.011$), height ($p < 0.001$) and substrate ($p=0.001$). The proportion of collector-obligate filter feeders is influenced solely by substrate type ($p=0.024$), while predators are influenced by the altitudinal zone ($p < 0.001$).

Table 4. One-way analysis of the variance of functional feeding group of lakes in different altitudinal zones of the Russian Altai (figures in italic indicate significance at $p < 0.05$)

Variable	Effect	R	F	p
Collectors- detritus feeders	altitudinal zones	<i>0.51</i>	6.67	≤ 0.001
	lake area	0.02	0.04	0.848
	altitude	<i>0.47</i>	<i>10.98</i>	≤ 0.001
	substrate	<i>0.47</i>	<i>11.06</i>	≤ 0.001
Collectors- obligate filter feeders	altitudinal zones	0.22	0.94	0.444
	lake area	0.12	1.14	0.288
	altitude	0.25	2.61	0.080
Scrapers	altitudinal zones	0.26	1.52	0.206
	lake area	<i>0.36</i>	<i>11.19</i>	<i>0.001</i>
	altitude	<i>0.42</i>	<i>8.36</i>	≤ 0.001
	substrate	<i>0.33</i>	<i>4.71</i>	<i>0.011</i>
Shredders	altitudinal zones	<i>0.52</i>	6.77	≤ 0.001
	lake area	0.04	0.11	0.746
	altitude	<i>0.44</i>	<i>9.24</i>	≤ 0.001
	substrate	<i>0.35</i>	<i>5.26</i>	<i>0.007</i>
Predators	altitudinal zones	<i>0.42</i>	3.93	≤ 0.001
	lake area	0.01	0.02	0.900
	altitude	0.17	1.19	0.309
	substrate	0.08	0.23	0.795

Discussion

The taxonomic structure of the studied lakes is characterized by the dominance of chironomids and oligochaetes that is typical for the mountain lakes (Manca et al. 1998; Krno et al. 2006; Boggero and Lencioni 2006; Loskutova 2011). The predominance of various subfamilies of chironomids and families of oligochaetes was observed at different altitudes. In low mountain lakes, among oligochaetes – Tubificidae (66%), while among chironomids - Chironominae (60%) and Tanypodinae (50%) were detected most frequently, which is typical for lowland lakes of western Siberia (Bezmaternykh and Vdovina 2020). In mid-mountain lakes, the number of macroinvertebrate taxa increased with height. Here, Orthoclaadiinae were more common among chironomids (58%) and Naididae – among oligochaetes (30%). The predominance of species of the subfamily Orthoclaadiinae in the chironomid fauna is typical for the mountain lakes (Fureder et al. 2006). Above 2000 m, the number of species and taxa diversity of benthic communities declined. In zoobenthos, chi-

ronomids of the subfamily Chironominae (73%) predominated. Oligochaetes of the Naididae family fell out of the dominant complex. The same phenomenon was marked in alpine lakes of the Pyrenees (Collado and de Mendoza 2009; de Mendoza and Catalan 2010). A peculiar feature of bottom zoocenoses from the mid- and high-mountain lakes is the high frequency of gammarid occurrence (40 and 50%, respectively) as well as their large contribution to the total biomass that is also characteristic of the mountain and alpine lakes of the Altai-Sayan mountain country (Vershinin 1979; Lepneva 1933). Among other peculiarities of the taxonomic composition of the bottom communities is the low diversity of mollusks that reside in these and other lakes adjacent to Lake Teletskoye. This indicator is associated with an unfavorable slightly acid hydrochemical composition of waters (Johansen 1950).

As for the species composition of macroinvertebrate communities, the group of collectors-detritus feeders is most abundant, which is confirmed by other researchers (Baturina et al. 2014; Kurashov 1994; Yakovlev 2000, 2005; Timm and Mols 2005); predators are in the second position by species number in all lakes. The ratio of trophic groups by biomass varies significantly. If in low-mountain lakes the dominant collectors-detritus feeders account for more than 50% of macroinvertebrate biomass, above 1000 to 2000 m asl they (together with predators) take the second place, thus giving the pas to shredders. At high altitudes, collector-detritus feeders dominate, collectors-obligate filter feeders join them as a subdominant group, and shredders move to the third position. The cluster analysis suggests the best similarity of the trophic structure of macrozoobenthos in mid- and high-mountain lakes, and the least one for low-mountain lakes (Figure 3). With the transition from low- to mid-mountain lakes, an increase in average biomass of shredders and scrapers is observed. It is also true for the southwestern Scandinavian watercourses located at different heights (Brönmark et al. 1984). This is most likely due to the fact that allochthonous organic matter predominates in mountain reservoirs and trophic groups focus on the consumption of certain food resources. Shredders are actively involved in disposal of large plant residues being the detritus suppliers to filter feeders, scrapers and collectors-detritus feeders (Cummins 1973; Wallace et al. 1996). With height, the average biomass of the filter feeders also increases, although this fact has not been confirmed by any reliable dependencies. This distribution of filter feeders is explained by the type of substrate in lakes. In lowland reservoirs, the soils are mainly represented by silts and water contains a lot of suspended inorganic substances. With height, a rocky substrate prevails, and the amount of suspended matter decreases that facilitates the feeding of filter feeders.

Our main hypothesis that with an altitude increase climatic conditions become more severe and species richness of macroinvertebrates declines has been confirmed. Similar trends for some lakes and rivers that cover wide altitudinal gradients also reveal an almost linear decrease in local macroinvertebrate taxa with increasing altitude. This pattern is true for alpine lakes (Fjellheim et al. 2000), lakes of the Perineas (de Mendoza and Catalan 2010), alpine rivers (Jacobsen et al. 2020), rivers of Nepal (Suren 1994), Ecuador (Jacobsen 2004) and Colorado (Harrington et al.

2015). The decrease in species diversity with increasing altitude depends on many factors and is primarily associated with changing environmental conditions. The species distribution response to environmental changes is mainly determined by their ability to settle and survive under suitable conditions (Lavergne et al. 2010). In mountain lakes, only extreme temperature fluctuations are responsible for the reduction in species richness (Fureder et al. 2006; Havens et al. 2015). As a result, species with short life cycles appear (Belle and Goedkoop 2020). It is apparent that organic matter content and aquatic vegetation are essential drivers of changes in species diversity along the altitude gradient (Hoffman et al. 1996; Nyman et al. 2005; Bigler et al. 2006; Kernan et al. 2009; Collado and de Mendoza 2009). As is well known, the ability to use available food resources is of great importance to organisms. Therefore, eurybiont species with their small body size and broader food preferences are more likely to find suitable habitats in extreme conditions (Angert et al. 2011). It should be noted that, a decrease in species diversity may be induced by various environmental factors like snow melting rates (Obertegger et al. 2007), short summers, intense ultraviolet radiation (Hansson et al. 2007; Miller and Mc-Knight 2015), water level fluctuations, substrate type (Bretschko 1995; de Mendoza and Catalan 2010), etc. The altitude gradient is a set of interrelated environmental factors with different impacts on the composition and structure of hydrobionts communities; distinguishing the influence of individual variables is hardly possible.

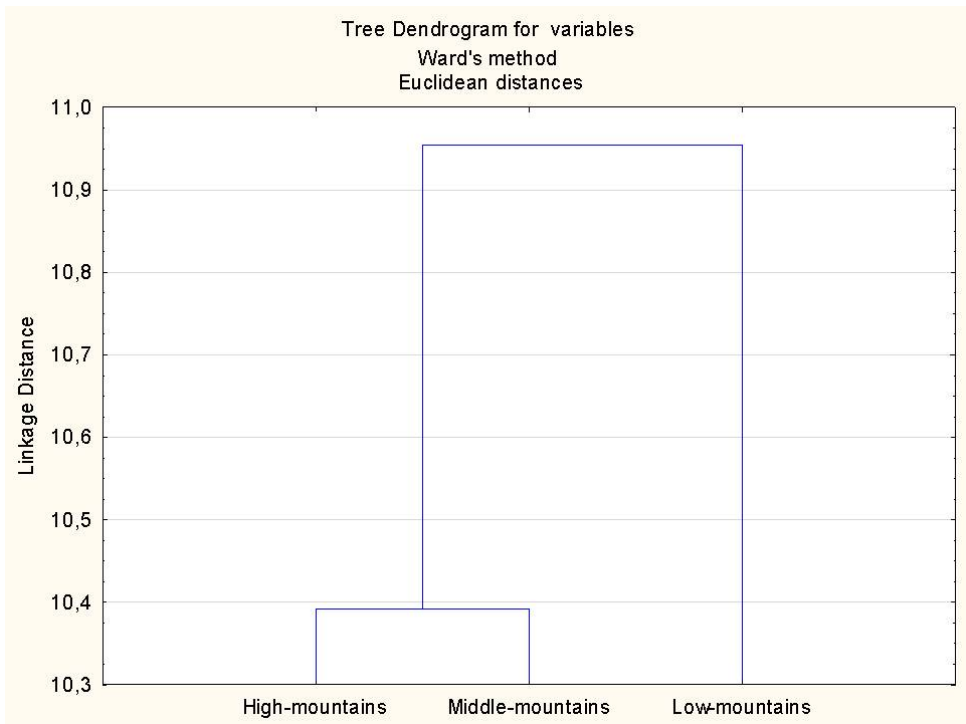


Figure 3. The cluster analysis of the trophic spectrum and species composition in study lakes.

Therefore, the taxonomic and trophic structures of the lakes zoobenthos in the studied lakes are differed, while the structure of zoobenthos in low-mountain and lowland lakes is similar. With height, the taxonomic structure becomes more complicated, and the dominant taxa change. The fauna of mid- and high-mountain lakes is specific due to the presence of homotopic species of the family Gammaridae and low diversity of molluscs. In the lakes under study, we have identified five major trophic groups of benthic invertebrates. By species number, collectors-detritus feeders and filter feeders dominated in trophic structure. By biomass, the trophic groups of various altitude lakes were represented differently; the proportion of filter feeders and shredders increased. Recent studies have paid great attention to the effect of the altitude gradient on benthic invertebrate communities. The study of this factor in remote areas of the Russian Altai characterized by low anthropogenic loads makes it possible to determine major trends in natural dynamics of communities, to use these lakes as the reference areas indicating the environmental changes and to develop the programs for monitoring of the transformed lake ecosystems.

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