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The structure and distribution of phytoperiphyton community in the Teno River and its tributaries (Finnish Lapland)

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Communiuties of attached algae (phytoperiphyton) from the Teno River and its tributaries were studied and their floristic composition and spatial distribution were analysed. A total of 215 taxa from 49 locations were identified. Attached algae communities, characteristic of oligotrophic waters, prevailed in the studied streams. Diatoms, dominated by typical attached forms such as *Tabellaria flocculosa*, *Synedra ulna*, *Achnanthes minutissima*, *Eunotia pectinalis* and *Cymbella affinis*, were most common and abundant. However, the bulk of biomass (0.8–42.9 g m^{-2}) was formed mainly by the filamentous green algae Zygnema, Bulbochaete and Oedogonium.

Introduction

Northern water ecosystems are of great interest because they clearly reflect the increasing anthropogenic impact on nature. Therefore, algological research in northern water bodies becomes increasingly important since algal flora is the most sensitive constituent of aquatic ecosystems. Furthermore, in a deteriorating environment, algae start to play a more important role in ecosystems than macrophytes. Algological research have been carried out to assess the present condition of water bodies and to elucidate the formation patterns of biological regime in rivers affected by human activities. Phytoperiphyton can help assess long-term changes in rivers (Wetzel 1979, 1983, Eloranta and Kwadrants 1995, Dell'Uomo 1999, Hurlimann *et al*. 1999, Komulaynen 2002b, Ács *et al*. 2003, Szabó *et al*. 2004, 2005), such as those associated with eutrophication and river management, and changes in land use on the watershed scale.

In fast-flowing, oligotrophic lotic habitats, attached algal communities (phytoperiphyton) are often the only primary producers that contribute greatly to the transformation of the ecosystem energy status. Phytoperiphyton is a demonstrative example of an ecotonic boundary community, whose formation is affected by benthic and planktonic algal cenoses. Therefore, the species composition of phytoperiphyton is analysed to structurally assess phytoplankton and microphytobenthos in adjacent zones and to provide a better understanding of algal flora in a water body. However, until 1994, integrated studies of algal flora, such as those attempted in the Teno River watershed, were conducted in lakes, an emphasis being placed on phytoplankton (Eloranta 1986, Weckström *et al*. 1997). Knowledge of the phytoperiphyton of the Teno River was limited to the data obtained in the Norwegian part of the watershed (Traaen *et al*. 1990).

The present study of the Teno River (northern Finland) was carried out under the Russian–Finnish Programme "Assessment of the status of lake and river ecosystems in the Northwest". An algological sampling project was launched in 1994 to collect phytoperiphyton samples from the Teno River and its tributaries and to study phytoperiphyton structure. The goal of the project was to analyse phytoperiphyton composition, to assess the relative abundance of species, and to estimate the community biomass.

Material and methods

The Teno River is a typical uncontaminated subarctic river system in the northernmost Finnish Lapland. It forms a border between Finland and Norway. With an average annual flow of about 1500 m^3 s^{-1}, the Teno River is one of the largest rivers in the region, draining 14 891 km^2 and flowing to the Barents Sea. The streams studied were poor in mineral components and showed a conductivity of 20 to 35 μS (Hinneri 1975, Ministry of Environment 1993). In the study period, total phosphorus concentration was about 3 μg l^{-1}, nitrate concentration was ca. 150 μg l^{-1}, and pH varied from 7.2 to 7.5. Water temperature in the streams during the sampling period was 10–12 °C. Several light measurements were carried out with a photocell in sunny weather in open-canopy and heavily shaded areas.

Phytoperiphyton samples were collected during late summer low-water discharge period (4–8 August 1994) in riffle zones in the Teno River and its first- and second-order tributaries. A total of 49 riffle locations were sampled (Fig. 1), of which 10 were located in the Teno River, 13 in the Utsjoki and 26 in other tributaries. As a rule, there was one location per tributary in the first rapid upstream of the mouth. In some tributaries, samples were collected from upstream reaches to the mouth.

The methods used are generally comparable to the CEN standard (CEN 2005). Sampling procedures developed from the methodology previously described (Wetzel 1979, Jarlman *et al*. 1996) were used. To minimized the loss of attached material substrates were placed in polyethylene bags under the water before being taken out. Samples (5–15 cm^2; three replicates) of attached mats were collected in each location to describe phytoperiphyton assemblages. When possible, this was done by scraping or brushing the surface of rocks, stones and pebbles with a knife, scalpel or nylon-bristled nailbrush, by squeezing mosses or by scraping the surface of stems and leaves of vascular plants. The scraped material was washed off the brush and rock with 200–500 ml of filtered river water and then homogenized in a blender. Tree subsamples, which were kept unpreserved, were then taken for chlorophyll *a* analysis. Another tree subsamples were preserved with formalin (2%–4% depending on amount of material), and examined microscopically for types and numbers of algae.

To assess anthropogenic impact, to minimize the effects of shading by riparian vegetation and to eliminate the influence of the substrate and variations in hydrological regime, samples were collected in an open-canopy area from a rock sized 20–30 cm at a depth of 20–30 cm, where current velocity was 20–30 cm s^{-1}. Our general observations indicate that such conditions are optimal for phytoperiphyton formation, at least in this region (Komulaynen 2004).

In the laboratory, the samples were studied in two steps. First, filamentous algae were analysed using the counting chamber technique at a magnification of 150×. The relative abundance of each periphyton element was estimated as a degree of coverage i.e. percentage of the bottom surface that is covered by the element. Simultaneously, the filamentous algae/diatoms ratio was estimated as the percentage of cells. Diatoms were then treated for identification by boiling in acid mixture (concentrated nitric acid and sulphuric acid in a 2:1 ratio, boiling time 2–4 h). Diatom slides were mounted in Hyrax. Identifications were made at 1000× upon oil immersion. At least 200 valves per slide were identified and counted. Species, showing a relative abundance of ≥ 10% in the algal flora of a particular location, were considered dominant. Cell counts were used to calculate the Shannon-Weaver diversity index (H') (Shannon and Weaver 1963).

Algal cells were measured under a microscope, and biovolume was calculated using the table from Kuzmin (1984), and 10^{12} μm^3 was considered equal to 1 g of biomass (Guseva

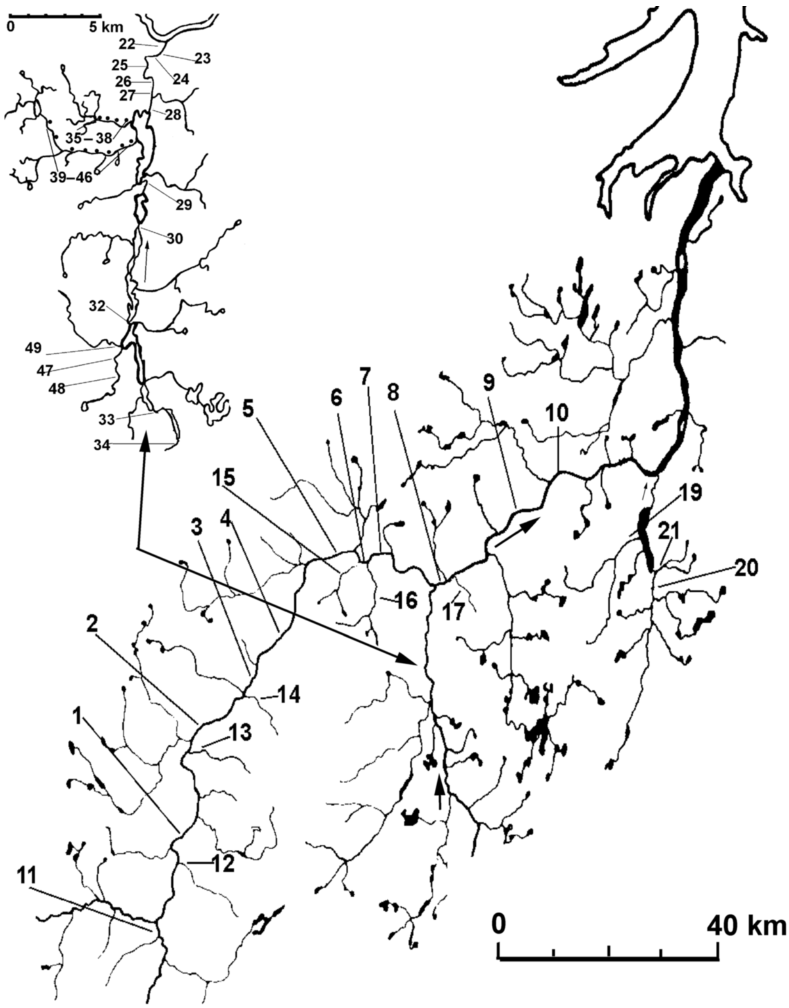

Fig. 1. Location of sampling sites in the Teno River and its tributaries. Stations 1–10: Teno River from Karigasniemi to Nuorgam. Stations 11–21: tributaries of the Teno River: 11 = Inarjoki, 12 = Piesjoki, 13 = Jagelvijoki, 14 = Niljoki, 15 = Paddajoki, 16 = Kuoppilasjoki, 17 = Vadgvajoki, 18 = Vetsijoki, 19 = Kelddasjoki, 20 = Pulmankijoki, 21 = Leaibajoki. Stations 22–34: the Utsjoki from Kenesjärvi to the mouth in the Teno River. Stations 35–49: tributaries of the Utsjoki: 35–38 = Ulosetiko, 39–46 = Allosetiko, 48–49 = Kevo, 47 = Tsarsjoki.

1956). The contribution of individual taxa to the formation of phytoperiphyton biomass was thus assessed. The rest of the sample was used to estimate phytoperiphyton biomass on each rock from chlorophyll *a* (Chl *a*) (mg m^{-2}). Chlorophyll *a* was determined spectrophotometrically (Strickland and Parsons 1972), and the percentage of chlorophyll *a* was calculated as the ratio of chlorophyll *a* concentration to ash-free dry weight of organic matter. Results on algal abundance and biomass were also presented as the number of cells and as fresh biomass (mg) per square centimetre of the substrate. Surface areas were estimated according to Graham *et al*. (1988).

The taxonomy proposed by Gleser *et al*. (1988, 1992) was adopted for diatoms, and that proposed by Gollerbakh (1951–1983) was used for other groups. Data on the geographic distribution of algae were from Raspopov (1971), Getsen (1985), Levadnaya (1986) and Jakovlev (2000). The environmental characteristics of algae were evaluated according to Lecointe *et al*. (1993). Cluster analysis was based upon relative abundance of algal species in the periphyton and carried out using the Statistica software (Ward's method, Euclidean distance).

Results and discussion

In the studied rivers, algal communities were rich in taxa. A total of 215 species from 70 genera, 39 families, 17 orders and 6 divisions were identified (Table 1 and Appendix) in 328 phytoperiphyton samples collected.

Most of the dominant algal species identified are typical of cold, oligotrophic North-European water bodies (Johansson *et al*. 1977, Komulaynen 1990, 2002, 2004a, 2004b).

The most diverse group was formed by diatoms (76% of the total number of taxa). The second largest group was green algae (15%), followed by cyanobacteria (10%).

Pennate (Araphales and Raphales) diatoms were the most numerous, with the greatest abundance of taxa shown by Naviculaceae (19%). *Achnanthes*, *Cymbella*, *Eunotia*, *Gomphonema* and *Navicula* were the most diverse genera. The most common diatoms that exhibited substantial cell densities were: *Achnanthes minutissima*, *Aulacoseira italica* subsp., *Cymbella affinis*, *C. silesiaca*, *Didymosphenia geminata*, *Eunotia pectinalis*, *E. veneris*, *Gomphonema clavatum*, *Synedra ulna*, *Tabellaria fenestrata*, *T. flocculosa*, and *Tetracyclus lacustris*.

Poorly diverse centric diatoms (orders Thalassiosirales, Pseudopodosirales, Melosirales and Aulacosirales) were usually less common, but were occasionally encountered in phytoperiphyton at sites located downstream from lakes (sites 28, 29, 30).

Cyanobacteria often play an important role in attached communities in running waters (Whitton 1984, Ács *et al*. 2003). In the phytoperiphyton of the Teno River, they fall into three groups. Group 1 is made up of *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* that are more typical of lentic systems, dominate in late-summer plankton and cause water "blooming". In the rivers studied, they were found at few locations (sites 11, 28, 23), where they were rather scarce. Group 2 comprises species that occur in both aquatic and terrestrial habitats. In the rivers studied, this was primarily *Stigonema mamillosum*, which dominated in the lower Utsjoki (sites: 22, 23) and covered rocks just above the average water level. Group 3 consists of typical rheophilic forms of the genera *Tolypothrix* and *Calothrix*. The most abundant species were *Tolypothrix tenuis*, *T. saviczii*, *Calothrix gypsophylla* and *C. ramenskii*. These algae are capable of forming aggregates both on and over the substrate, so that the substrate surface is expanded and epiflora formation is enhanced. Algae of the two latter groups are also known to dominate in other North-European rivers. (Prescott 1959, Kawecka and Eloranta 1987, Lindstrøm 1999).

Table 1. Position of divisions with respect to the number of taxa in the algal flora of periphyton S = number of species, Do = number of dominant species in a division.

	S	S%	Do	D%
Cyanophyta	22	10	3	14
Chrysophyta	4	2	0	0
Dinophyta	1	1	0	0
Bacillariophyta	153	71	13	62
Chlorophyta	33	15	4	19
Rhodophyta	2	1	1	5
Total algal flora	215	100	21	100

Boreal rivers are typically rich in red algae (Eloranta and Kwandrans 1996). In the rivers studied, only two species were identified in attached communities of the Utsjoki: *Batrachospermum gelatinosum* (sites 23, 33, 34) and *Audouinella chalybea* (site 33).

The biomass of the attached communities was strongly dominated by green algae, e.g. the filamentous algae *Mougeoti*a sp., *Oedogonium* sp., *Zygnema* sp., *Spirogyra* sp. and *Ulothrix zonata* that occur in large numbers in the rivers. Their distribution in the watershed was patchy, with total coverage varying from less than 1% to 60% of the streambed. *Zygnema*, which occurred in about 50% of the locations studied, was most common.

Most of the species were rare or very rare, i.e. had a frequency less than 2%, and some species, mainly planktonic and benthic, non-attached forms, were found only in a single sample. The most common species, found at about 50% of the locations, were *Achnanthes minutissima*, *Ceratoneis arcus*, *Cymbella affinis*, *C. silesiaca*, *Eunotia pectinalis*, *Frustulia rhomboides* and *Tabellaria fenestrata*, but only *Tabellaria flocculosa* was a persistent species found in all samples. In addition to the above species, *Gomphonema*, *Stigonema*, *Synedra*, *Tolypothrix* and *Zygnem*a were most persistent. These taxa form the basis of the dominant complex of algal cenoses and represent a "northern" type of algal flora. Most species identified were epilithic and epiphytic algae, typical attached, colony-forming euperiphytic forms morphologically adapted to settled life.

Because of the relatively cold climate and prevalent Precambrian bedrock, the rate of weathering is slow. Therefore, the low concentrations of inorganic substances in Finnish surface waters (Eloranta 2004) are eventually responsible for an indifferent pattern of the algal flora. Most of the algae (73%) are oligohalobiotic, followed by halophobes (18%) and halophyts (9%). Based on this ratio, the algal flora is classified as oligohalobic, which agrees with the low conductivity of the waters.

Algae were also shown to be good indicators of water pH (62% of tthe taxa), alkaliphile and acidophile species making up 18% and 20%, respectively.

The most significant parameters of the phytoperiphyton suggest that it is a boreal type because truly high-latitude elements were scarce. The phytoperiphyton was dominated by widespread and cosmopolitan algae (44% of taxa), boreal species (39%), and arct-alpine algae (17%). However, persistence and dominance were shown mainly for cold-resistant arctalpine forms such as *Stigonema mamillosum*, *Tolypothrix tenuis*, *Ceratoneis arcus*, *Cymbella affinis*, *Didymosphenia geminata*, *Eunotia fallax* var. *gracillima*, *E. pectinalis*, *E. praerupta*, *E. sudetica*, *Frustulia rhomboides*, *Tabellaria flocculosa*, *Oedogonium* spp. and *Zygnema* spp.

Northern traits, typical of the phytoperiphyton, were also apparent at other levels of taxonomic analysis. In the Teno River periphyton, cyanobacteria were generally more diverse than green algae. It should be noted that the diversity of green algae depends on representatives of Desmidiaceae that do not contribute markedly to the formation of the cenoses.

Another characteristic of the rivers studied was the ratio of taxon numbers in the orders Nostocales and Oscillatoriales. The prevalence of Nostocales is typical of the algal flora in North-European rivers (Getsen 1985, Komulaynen 1999). Nine species of the order Nostocales were identified in phytoperiphyton from the Teno River and its tributaries. Some of them (*Calothrix gypsophila*, *Tolypothrix tenuis*) were widespread and often dominated in attached communities. Oscillatoriales were less diverse, and only three species of *Oscillatoria* were occasionally encountered in the phytoperiphyton.

The northern location of the river watersheds is also evidenced by the families present and their order. The list of phytoperiphyton is topped by the families whose species diversity reflects the Holarctic floristic pattern of the northern hemisphere (Prescott 1959, Getsen 1985). The families Eunotiaceae, Naviculaceae and Desmidiaceae are most remarkable in this respect.

Northern floras are typically dominated by families and genera with a single taxon (Getsen 1985). The reduced number of species is also due to low surface water mineralization. In the phytoperiphyton of the Teno River, five major genera (*Cymbella*, *Cosmarium*, *Eunotia*, *Gomphonema* and *Navicula*) and four families (Cymbellaceae, Desmidiaceae, Eunotiaceae and Naviculaceae) contribute 41% and 47%, respectively, to the total number of species identified.

The longitudinal variability pattern of phytoperiphyton in rivers is dependent on the local heterogeneity of algal habitats, substrate dimensions, the microdistribution of flow rate, landscape differences responsible for stream morphometry, and the development of riparian vegetation (Komulaynen 1999, 2004b). It is only in some small tributaries that the spatial dynamics of the phytoperiphyton generally agrees with the river continuum concept. Downstream stretches of the Allosetiko and Ulosetiko Rivers showed a higher biomass and a lower diversity. In the Teno and Utsjoki, the phytoperiphyton structure was fairly distinctive in each segment. Alternation of rapids and still reaches, the branching pattern of the river systems and the occurrence of lakes with circulating water are responsible for the pulse-like pattern of variations in the taxonomic composition and structure of the phytoperiphyton. However, longitudinal profile analyses of the phytoperiphyton structure in the Utsjoki showed the structure of phytoperiphyton communities to change as the stream size increases (Fig. 2); e.g., benthic forms in the phytoperiphyton grew more diverse and constant, and chlorophyll *a* concentration in the total organic matter attached to the substrate showed a general upward tendency downstream in the Utsjoki, whereas the species

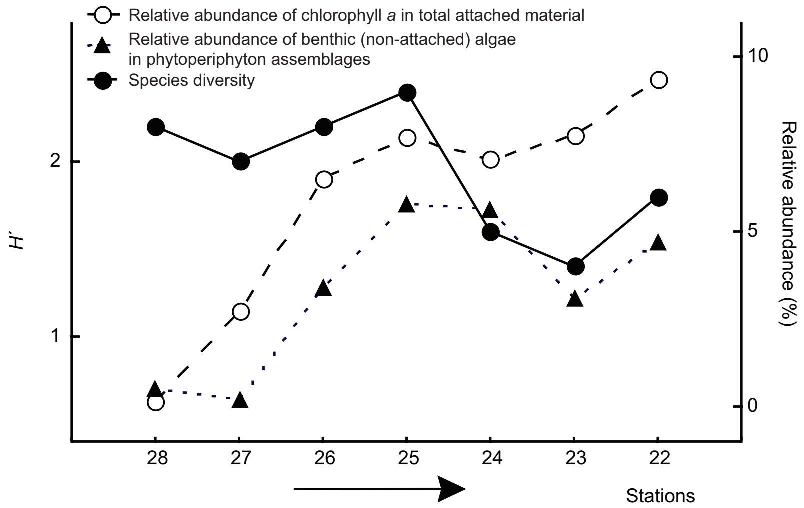

Fig. 2. Longitudinal patterns of phytoperiphyton from sampling sites in the Utsjoki.

diversity decreased slowly.

Analysis of the taxonomic composition of the main genera also showed them to be unevenly distributed in river segments. Diatoms of the genera *Ceratoneis*, *Eunotia*, *Frustulia* and *Synedra* were commonly more diverse in the upper stretches of the rivers. Typical attached forms of the genera *Cymbella* and *Gomphonema* were distributed evenly throughout the rivers studied, whereas freely moving diatoms, such as *Navicula* and *Pinnularia*, were most diverse and abundant in the lower parts of the rivers, with slower current velocity and softer streambed.

No considerable changes were found in the species composition of phytoperiphyton to testify to large-scale restructuring caused by a growing anthropogenic impact. Based on the species composition of the phytoperiphyton and the relative values estimated for individual taxa, the water of the rivers belongs to purity class II in accordance with Sládeček's classification (Sládeček 1973). For phytoperiphyton in general, the group of β-mesosaprobic algae was the most diverse. However, χ-, oligo- and χ-oligosaprobes were relatively most abundant at most sites. The index of diversity also showed a moderate stability of algal communities at particular localities (Stevenson 1984).

Phytoperiphyton abundance was highly variable in the studied rivers and varied significantly with samples, locations and rivers. Phytoperiphyton biomass ranged from 0.4 to 42.9 g m^{-2} and chlorophyll *a* ranged from 0.4 to 1180 mg m^{-2}. Maximum biomass was reported from sites 8, 28, 38 and 46. Variations in discharge affect chlorophyll-*a* accumulation through algal shearing at high flow, changes in the biomass of Chlorophyta and increase in the amount of organic matter. The percentage of organic matter in the attached material was low at all locations. On the average, only 10% of the dry weight of attached material was organic matter. The average percentage of chlorophyll *a* in organic matter dry weight was 0.7% in the Utsjoki (sites 24–29) and 0.2% in the Teno River (sites: 3–8). This suggests that much of the organic matter in the phytoperiphyton consisted of detritus and heterotrophic organisms.

The characteristics of the phytoperiphyton at 49 locations in the 22 rivers studied differed. Algal cenoses become more diverse as new taxa were added or as the same species occured in different combinations. In the former case, the diversity of the phytoperiphyton depends on allochthonous planktonic or benthic species, lake surface/drainage area ratio being important. Cluster analysis revealed three main groups of sites with different types of algal communities (Fig. 3). In group I, which includes 16 localities, two subgroups, IA and IB, were distinguished. Both showed the dominance of *Tabellaria flocculosa*, but the relative abundance of the species in subgroup IA was > 70%.

Subgroup IIB was represented by 11 localities. There, algal communities were dominated by *Achnanthes minutissima* with a relative abundance from 30% to 50%.

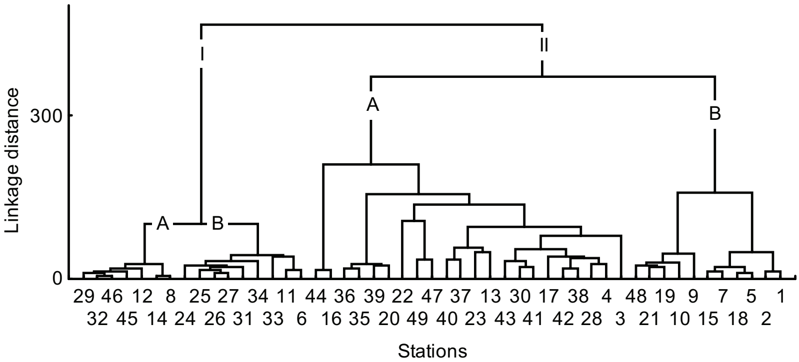

Fig. 3. Dendrogram showing sampling sites grouping according to the species composition (relative abundance) of periphyton (Ward's method, Euclidian distances).

In other parts of the diagram (IIA), clusters are not so clearly discernible. As a rule, the relative abundance of *Tabellaria flocculosa* there did not exceed 30%, and the species was accompanied by other diatoms (*Didymosphenia geminata*, *Eunotia pectinalis*) or green algae (*Oedogonium* sp., *Zygnema* sp.) and cyanobacteria (*Calothrix gypsophylla*, *Stigonema mamillosum*, *Tolypothrix saviczii*).

The above evidence has led me to conclude that the phytoperiphyton in the Teno River and its tributaries comprises small numbers of genera and families overall but, at the same time, numbers of genera and families with few species are high, thus adding to the complexity of florogenetic processes. Eurythermic species, characteristic of the taiga zone, stenothermic rheophilous species of alpine genesis, and boreal species, typical of wetlands, are all present simultaneously in the dominant species complex. This trend suggests that an allochthonous way of evolution contributes greatly to the formation of phytoperiphyton in the rivers studied.

All factors, as well as the changes they induce in the attached communities' structure, are natural. I have found no taxonomic or structural features indicating a noticible rise in anthropogenic impact on the river. It is safe to assume that the Teno River system has relatively unpolluted waters and a high self-purifying potential. However, a continuous, detailed analysis of its hydrobiological regime is needed.

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