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PHYTOPLANKTON, PHYTOBENTHOS, AND PHYTOPERIPHYTON

Structural and Quantitative Features of Phytoperiphyton Communities in Watercourses of the Zeya River Basin, Amur Oblast

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Abstract—The results of a study of periphyton algae in the Zeya River and nine watercourses of its drainage basin (Amur Oblast) are presented. The composition of dominant species is determined, the structural features of algal communities are considered, and quantitative characteristics of some of their components are obtained. The total abundance of phytoperiphyton in the Zeya River is 583 billion cells/m^2; biomass is 102–1106 g/m^2. In medium-sized watercourses, the total abundance of algae ranges from 16.2 to 100 billion cells/m^2; biomass is from 2.0 to 18.3 g/m^2. Most of the biomass is formed by diatoms (*Encyonema silesiacum*, *Hannaea arcus*, *Ulnaria ulna*, *Gomphoneis olivaceum*, and large-celled species of the genus *Gomphonema*); most of the abundance is formed by cyanobacteria and diatoms from the genera *Achnanthes*, *Fragilaria*, *Gomphonema*, and the species *Encyonema minutum*.

Keywords: algae, periphyton, abundance, biomass, community structure, watercourses of the Zeya River basin

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INTRODUCTION

Lotic ecosystems of the Far East are dominated by attached algae (phytoperiphyton and epilithon) capable of withstanding the impact of water flow. Fouling algocenoses are typical for small rivers, where the presence of a solid substrate and high flow velocities limit the development of other ecological groups of algae [15]. The structure of phytoperiphyton determines the formation and functions of all elements of an aquatic biocenosis. Algal fouling is formed by species that differ in size (from a few micrometers to several dozens of centimeters) and morphology. Communities most frequently consist of attached unicellular, predominantly heteropolar colonial and filamentous, forms adapted to conditions of a dynamic water flow [15, 24, 31].

Studies of fouling algocenoses in freshwater bodies have been reported in a large number of works [4, 7, 9, 13–21, 23, 26, 29, 32, 35, 42–45], which basically describe a succession of species or a structure of phytoperiphyton at the level of divisions. Data on biomass and abundance of algae, as well as their seasonal dynamics, are provided less frequently [3, 34].

The first information about algae of the Zeya River was published by B.V. Skvortsov [28]. *Desmidium* algae and diatoms, among which *Cosmarium amurense* Skvortzow prevailed, were found in peat bogs located in the upper reaches of the river. A survey of a number of watercourses carried out by the authors has significantly expanded the knowledge of freshwater algae of Amur oblast [19].

The goal of the work is to study the structure of communities of attached algae in watercourses of the Zeya River drainage basin at the level of divisions, genera, and species, as well as to perform a quantitative assessment of fouling algocenoses.

MATERIALS AND METHODS

Periphyton samples were collected in the summer of 2014 from the Zeya River and nine watercourses of its basin: the Allenga, the Tynda, the Malyi Garmakan, the Bol'shoi Garmakan, the Shirokovskaya, the Malaya Makcha, the Bol'shaya Makcha, the Bol'shaya Erakingra, and the Gulik (Fig. 1). The material was processed according to the commonly accepted methods [6]. Algal fouling from stones (epilithon) was washed out with water (100 mL) and fixed in 4% formalin solution. The samples were counted in a counting chamber of our design [2] under an Amplival microscope (magnification ×400 and ×1000); to identify species, the works [5, 8, 10–12, 22, 33, 36–39] were used. Diatoms were identified in permanent mounts prepared by the peroxide method. The species with abundance or biomass reaching ≥10% of the total

Fig. 1. Location of sampling stations in the watercourses of the Zeya River basin: (1) Allenga, (2) Tynda, (3) Malyi Garmakan, (4) Bol'shoi Garmakan, (5) Shirokovskaya, (6) Zeya downstream the HES dam, (7) Zeya off Ovsyanka Village, (8) Malaya Makcha, (9) Bol'shaya Makcha, (10) Bol'shaya Erakingra, and (11) Gulik.

were considered dominant. The weight of the filamentous alga *Stigeoclonium tenue* (C. Agardh) Kützing, 1843 was measured by weighing the material, slightly dried at room temperature, on a torsion scale.

The Zeya River is one of the largest left-bank tributaries of the Amur River. The river source is located on the Tokinsky Stanovik Range (55°44′10″ N, 130°34′20″ E), and the mouth is near the city of Blagoveshchensk (50°14′31″ N, 127°35′52″ E). The length of the river is 1242 km; the total catchment area is 233000 km^2. The drainage basin, which is entirely located within Amur oblast, is characterized by a mountainous terrain and a complex orographic structure. Almost all the tributaries originate on the spurs of the mountain ranges; in the upper reaches they become torrents flowing down narrow canyons. The southern part of the basin covers the territory of the Zeya–Bureya Lowland, where the flow of watercourses becomes calmer [25, 27]. Permafrost is distributed all over the territory of the basin: in some places the riverine and ground ice keeps until the summer season. The monsoon characteristics of the climate determine the main features of the water regime in the river. The share of rain feeding constitutes on average 50–70% of the total annual discharge. From April to October, 4–5 floods occur, during which the water level rises by 4–6 m, and the flow velocity increases to 3–4 m/s. The waters of the Zeya River and its tributaries are considered slightly mineralized (mineralization <100 mg/dm^3) ultrafresh ones [30]; according to the classification of O.A. Alekin [1], they are categorized as type 2 hydrocarbonate-calcium-magnesium waters.

RESULTS

In fouling of stones in the watercourses of the Zeya River basin, a total of 128 species of algae and cyano-

Table 1. Data on biomass and abundance of the major divisions of epilithon in the surveyed watercourses of the Zeya River basin

No. of watercourse	River	Number of species	Cyanobacteria	Golden algae	Euglenophytes	Diatoms	Red algae	Green algae	Total
1	Allenga	17	0.7 / 0.0	–	–	15.4 / 4.1	–	0.5 / 0.2	16.6 / 4.3
2	Tynda	18	–	–	–	31.5 / 11.8	–	0.3 / 0.1	31.8 / 11.9
3	Malyi Garmakan	21	14.4 / 0.4	–	–	2.0 / 0.8	–	9.0 / 3.1	25.4 / 4.3
4	Bol'shoi Garmakan	23	0.9 / 0.0	–	–	6.5 / 3.6	1.3 / 1.6	7.5 / 4.5	16.2 / 9.7
5	Shirokovskaya	14	95.9 / 2.0	–	–	4.2 / 1.1	–	–	100 / 3.1
6	Zeya, downstream the HES dam*	25	36.9 / 10.3	–	–	27.8 / 31.3	–	27.6 / 1064	92.3 / 1106
7	Zeya off Ovsyanka Village	28	386 / 6.6	0.4 / 0.4	0.4 / 0.6	196 / 94.0	–	–	583 / 102
8	Malaya Makcha	38	–	–	–	4.5 / 2.8	12.2 / 15.3	0.5 / 0.2	17.2 / 18.3
9	Bol'shaya Makcha	29	–	–	–	16.2 / 8.2	–	–	16.2 / 8.2
10	Bol'shaya Erakingra	14	20.0 / 0.1	–	–	47.7 / 15.3	–	1.2 / 0.7	68.9 / 16.1
11	Gulik	23	44.8 / 0.9	–	–	2.9 / 1.0	0.1 / 0.1	–	47.8 / 2.0

Here and in Table 2, value in the numerator is abundance, billion cells/m^2; that in the denominator is biomass, g/m^2 epilithon. A dash means that group is absent.
* Abundance is estimated without taking into account filamentous algae.

bacteria (131, taking into account the intraspecific taxa) from 58 genera were found: *Cyanobacteria*, 7 species; *Euglenophyta*, 2; *Chrysophyta*, 1; *Bacillariophyta*, 104 (107); *Rhodophyta*, 3; and *Chlorophyta*, 11.

The largest number of species and intraspecific taxa (28–38) were recorded from the Zeya off the village of Ovsyanka and from the Bol'shaya and Malaya Makcha rivers; the smallest number (14) were recorded from the Shirokovskaya and Bol'shaya Erakingra rivers (Table 1). In the rest of the watercourses, 17–25 species were identified.

In the structure of the community in the Allenga River, diatoms dominated in abundance: *Achnanthidium minutissimum* (Kützing) Czarnecki, *Gomphoneis olivaceum* (Hornemann) Dawson ex Ross et Sims, *Gomphonema angustatum* (Kützing) Rabenhorst, and *G. angustum* C. Agardh.

The species composition of epilithon in the Tynda River was similar to that in the Allenga River. It was also dominated by *Achnanthidium minutissimum*, *Gomphoneis olivaceum*, *Gomphonema angustatum*, and *G. angustum*; as subdominants, there were also *Planothidium lanceolatum* (Brébisson ex Kützing) Round et Bukhtiyarova and *Reimeria sinuata* (Gregory) Kociolek et Stoermer.

In the Malyi Garmakan River, cyanobacteria, diatoms, and one species of green algae developed. The abundant vegetation of *Achnanthidium minutissimum*, *Cocconeis placentula* Ehrenberg, and *Reimeria sinuata* was observed. The subdominant was *Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot, not found in other surveyed watercourses. This species is referred to xenooligosaprobionts, i.e., indicators of good quality waters, which prefers water with a low salt content.

In the composition of epilithon in the Bol'shoi Garmakan River, besides cyanobacteria, diatoms, and green algae, we also identified *Audouinella* Bory, a member of the division of red algae (Rhodophyta). Species of the genus *Gomphonema* (*G. angustum* and *G. parvulum* (Kützing) Kützing), as well as *Achnanthidium minutissimum*, *Cocconeis placentula*, and *Reimeria sinuata*, dominated in abundance.

In the epilithon of the Shirokovskaya River, *Gomphonema parvulum* and *Gomphoneis olivaceum* were attributed to species dominant in abundance; *Achnan-*

thidium minutissimum and species of the genus *Encyonema* were attributed to subdominants.

In the Zeya River channel, downstream of the Zeya Hydroelectric Station (HES) dam, stones were covered with thick aggregations of the green filamentous alga *Stigeoclonium tenue*. The composition of dominants also included the diatoms *Achnanthidium minutissimum*, *Diatoma mesodon* (Ehrenberg) Kützing, *Fragilaria capucina* Desmazières, *Gomphoneis olivaceum*, *Gomphonema parvulum*, *Tabellaria fenestrata* (Lyngbye) Kützing, and *T. flocculosa* (Roth) Kützing. The latter two species are typical of stagnant ponds and river backwaters. Downstream of the village of Ovsyanka, abundant aggregations of *Stigeoclonium tenue* were not observed. The complex of diatom species dominating in abundance and biomass remained almost unchanged: *Gomphonema parvulum*, *Achnanthidium minutissimum*, and *Gomphoneis olivaceum*; in addition to them, *Homoeothrix janthina* (Bornet et Flahault) Starmach also proliferated abundantly.

One characteristic feature of epilithon in the Malaya Makcha River was the predominance of red algae of the genus *Audouinella*. The diatoms *Gomphonema angustatum*, *G. angustum*, and *G. parvulum* vegetated abundantly. Unlike other rivers, this one was inhabited by several species of the genus *Eunotia* Ehrenberg (*E. bilunaris* (Ehrenberg) Mills, *E. diadema* Ehrenberg, *E. diodon* Ehrenberg, *E. fallax* A. Cleve-Euler, *E. minor* (Kützing) Grunow, and *E. praerupta* Ehrenberg). Its members are most frequently found in swampy waters with low pH values.

Epilithon of the Bol'shaya Makcha River was represented exclusively by diatoms. Common species included *Achnanthidium minutissimum*, *Encyonema minutum*, *Fragilaria capucina*, *Cocconeis placentula*, and *Gomphoneis olivaceum*. The latter two species dominated in biomass also.

The group of algae in the Bol'shaya Erakingra River also consisted mainly of diatoms with a predominance of *Achnanthidium minutissimum*, *Gomphoneis olivaceum*, *Gomphonema angustatum*, and *G. angustum*. Species of the genera *Gomphoneis* and *Gomphonema* accounted for the major portion of the community biomass.

The fouling of stones in the Gulik River was dominated in abundance by the small-celled cyanobacteria *Homoeothrix janthina*; among diatoms, the highest frequency of occurrence was recorded for *Reimeria sinuata*.

Values of the parameters of epilithon development in the small watercourses ranged within narrow limits (Table 1): total abundance 16.2–100 billion cells/m^2; biomass 2.0–18.3 g/m^2. The lowest abundance was recorded from the rivers Bol'shaya Makcha, Bol'shoi Garmakan, and Allenga; the lowest biomass was from the rivers Gulik, Shirokovskaya, and Allenga. The epilithon of the Zeya River from the HES dam to the village of Ovsyanka was characterized by very high quantitative characteristics, reaching 583 billion cells/m^2 and 102–1106 g/m^2. At the same time, downstream of the Zeya HES dam, the biomass of the filamentous alga *Stigeoclonium tenue*, from which we could not separate diatoms, was 996 mg/m^2.

DISCUSSION

The analysis of the structure of fouling algocenoses in the watercourses of the Zeya River basin made it possible to identify the main types of communities at the level of divisions. In the rivers Malyi Garmakan, Shirokovskaya, and Gulik and in the segment of the Zeya River off the village of Ovsyanka, the communities are dominated in abundance by cyanobacteria; in the rivers Allenga, Tynda, and Bol'shaya Makcha, they are dominated by diatoms. In the studied segments of the rivers Bol'shoi Garmakan and Zeya downstream of the HES dam, cyanobacteria, diatoms, and green algae are represented in approximately equal proportions of abundance. In the Malaya Makcha, we found groups where diatoms or red algae prevail (Fig. 2a).

In total biomass, a major contribution is often made by diatoms that dominate in the rivers Tynda, Zeya off Ovsyanka Village, Bol'shaya Makcha, and Bol'shaya Erakingra. Communities with green algae prevailing in biomass occur more rarely (the Zeya River downstream of the Zeya HES dam and the Malyi and Bol'shoi Garmakan rivers); only in single cases are communities dominated by red algae (Malaya Makcha River) and cyanobacteria (Shirokovskaya River) (Fig. 2b).

Most rivers of the Far East have a similar structure of phytoperiphyton with a predominance of diatoms and cyanobacteria [18–20, 41]. In general, our data are comparable with those obtained in the study of periphyton algae from various rivers in this region [4, 15, 21, 32, 35, 42–45]; the mass proliferation of cyanobacteria and green algae was observed only in rare cases [40, 46].

Diatoms are characterized by high species diversity in all the surveyed watercourses; they often prevail quantitatively, especially in the total community biomass (Table 2). The most common species are *Achnanthidium minutissimum*, *Cocconeis placentula*, *Gomphoneis olivaceum*, *Gomphonema angustatum*, *G. parvulum*, *G. angustum*, *Reimeria sinuata*, and *Ulnaria ulna* (Nitzsch) Compère. The composition of dominants frequently includes members of the few-species or monotypic genera *Hannaea* Patrick, *Tabellaria* Ehrenberg ex Kützing, *Cocconeis* Ehrenberg, and *Meridion* C. Agardh.

The major contribution to the formation of epilithon is made by heteropolar cells of the genera *Gomphonema* Ehrenberg and *Gomphoneis* Cleve. When processing quantitative samples, an accurate determination of species in them is impossible and, therefore, we conditionally distinguished three groups with dif-

ferent cell sizes. An examination of permanent mounts made it possible to attribute large *Gomphonema* cells to *Gomphonema affine* Kützing and *G. angustum*, medium-sized cells to *G. angustatum* and *Gomphoneis olivaceum*; small ones to *Gomphonema parvulum*. The usual satellites of *Gomphonema* are species of the genus *Achnanthidium* Kützing, *Cocconeis placentula*, and *Hannaea arcus* (Ehrenberg) Patrick, exhibiting the ability to attach to a substrate. Species of the genera *Encyonema* Kützing (*E. minutum* and *E. silesiacum*) and *Fragilaria* Lyngbye are also typical of the communities. The large-celled *Ulnaria ulna* was usually found in small quantities, but due to its size it frequently prevailed in biomass.

Species that dominate in abundance and biomass, or those characterized by maximum values of these parameters, are frequently different. Thus, in periphyton of rivers of eastern Fennoscandia, diatoms prevail in abundance, and the biomass is formed mainly by filamentous green and red algae [15]. The causes are associated with the structure of communities and the morphological features of fouling algae, represented by species with different sizes.

In the surveyed watercourses, the species dominant in abundance include the small-celled diatoms *Achnanthidium* sp., *Fragilaria* sp. 1, *Gomphonema* sp. 3 (Zeya River, off the village of Ovsyanka), and *Encyonema minutum* (Bol'shaya Makcha River). A major part of biomass is most frequently made up of large-celled forms of *Gomphonema* sp. 2 (cf. *Gomphoneis olivaceum*), *Encyonema silesiacum*, *Hannaea arcus*, *Ulnaria ulna*, and *Tabellaria fenestrata* (Zeya River, off the village of Ovsyanka). *Gomphonema* sp. 2 (cf. *Gomphoneis olivaceum*) dominates also in the Bol'shaya Erakingra, and *Tabellaria fenestrata* dominates in the Zeya River downstream of the HES dam (Table 2). In total biomass, small-celled species with high abundance sometimes play a substantial role: *Achnanthidium* sp. and *Gomphonema* sp. 3 (Zeya River, off the village of Ovsyanka).

In algal fouling of the Zeya River, in contrast to its tributaries, along with periphyton algae, we also found planktonic forms in significant quantities: *Asterionella formosa* Hassall, *Diatoma tenue* C. Agardh, *D. vulgare* Bory, *Fragilaria capucina*, *Nitzschia* sp., *Tabellaria fenestrate*, and *T. flocculosa*. Only downstream of the Zeya HES dam, the composition of dominants includes the halophilic species *Brebissonia boeckii* (Ehrenberg) Grunow, growing in mildly brackish waters. High values of abundance and biomass of epilithon are always recorded from this segment of the river. Thus, in 2010, stones in the river channel were covered with a 2-cm-thick carpet of algae composed of several filamentous forms. The major part of fouling in a stream pool was formed by the cyanobacteria *Phormidium corium* (C. Agardh) Gomont, *Phormidium* sp., *Symploca* sp., *Lyngbya* sp., *Aphanizomenon* sp., and single-celled *Synechococcus* sp.; in a whitewater, it was

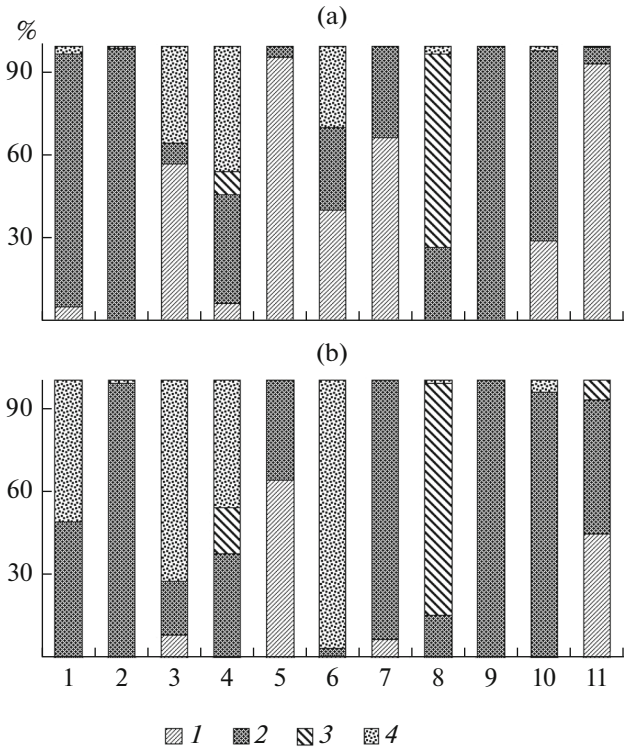

Fig. 2. Relative abundance (a) and biomass (b) of the divisions of fouling algae in watercourses of the Zeya River basin: (*1*) cyanobacteria, (*2*) diatoms, (*3*) red algae, and (*4*) green algae. The numerals 1–11 on the X-axis are explained in Fig. 1.

formed by the filamentous green alga *Ulothrix zonata* (Weber et Mohr) Kützing and *U. tenuissima* Kützing. The biomass of algae in the whitewater reached 1130 g/m^2 [19], although the water temperature in this segment does not rise above 5°C even in summer. The high abundance of epilithon may be explained by the reduction in the flow velocity or by the inflow of waters rich in dissolved nutrients from the deep layers of the reservoir into the river bed.

CONCLUSIONS

A total of 128 species of algae from six divisions, with the predominance of cyanobacteria, diatoms, and green algae, have been found in the watercourses of the Zeya River basin. The species dominant in abundance are the diatom *Encyonema minutum* and members of the genera *Achnanthidium*, *Fragilaria*, and *Gomphonema*. The major part of biomass is formed by *Encyonema silesiacum*, *Hannaea arcus*, *Ulnaria ulna*, *Gomphoneis olivaceum*, large-celled species of the genus *Gomphonema*, and (rarely) *Tabellaria fenestrata*. The maximum abundance and biomass were recorded from epilithon of the Zeya River.

Table 2. Species diversity of diatoms in epilithon of the surveyed watercourses

Species	Watercourse*										
	1	2	3	4	5	6	7	8	9	10	11
Achnanthidium sp.	7.4 0.9	5.8 0.9	0.3 0.1	0.4 0.1	–	2.1 0.3	83.8 13.4	–	4.1 0.7	21.3 3.4	0.9 0.1
Asterionella formosa	–	–	–	–	–	–		–	–	–	–
Brebissonia boeckii	–	–	–	–	–	0.3 1.1	–	–	–	–	–
Cocconeis placentula	–	–	0.2 0.2	2.4 2.4	–	–	–	–	0.5 0.5	0.2 0.2	0.4 0.5
Diatoma mesodon	–	–	–	–	–	9.3 10.9	5.6 4.3	–	–	–	–
D. tenue	–	–	–	–	–	0.3 0.1	4.0 0.7	–	–	–	–
D. vulgare	–	–	–	–	–	–	5.6 5.0	–	–	–	–
Encyonema minutum	0.2 0.0	1.6 0.2	–	1.7 0.2	0.8 0.1	–	4.0 0.4	–	6.7 0.7	0.5 0.1	–
E. silesiacum	–	–	–	0.4 0.3	0.5 0.4	0.8 0.6	5.2 4.2	0.2 0.2	2.0 1.6	0.2 0.1	–
Fragilaria capucina	–	–	–	–	–	1.1 0.4	1.2 0.7	0.2 0.1	0.5 0.4	–	–
F. sp. 1	–	0.3 0.1	0.1 0.0	–	–	0.3 0.1	5.2 1.6	0.5 0.1	2.0 0.6	0.2 0.1	0.2 0.1
F. vaucheriae	–	2.0 0.4	–	–	–	0.3 0.1	–	–	–	–	–
Gomphonema sp. 1 (large-sized) *Gomphonema. affine*	–	–	–	0.2 0.3	–	0.5 0.4	1.6 2.6	–	1.0 1.6	1.5 2.4	–
Gomphonema sp. 2 (medium-sized) *Gomphonema angustatum;* *Gomphoneis olivaceum*	5.0 2.2	7.9 4.0	0.8 0.4		0.3 0.1	1.1 0.5	11.2 5.0	–	–	17.5 7.9	–
Gomphonema sp. 3 (small-sized) *Gomphonema parvulum*	2.4 0.4	9.9 1.8	0.3 0.1	0.2 0.0	2.4 0.4	0.3 0.1	38.9 7.0	0.2 0.0	4.1 0.7	6.0 1.1	0.9 0.2
Hannaea arcus	–	0.3 0.3	0.1 0.1	–	–	2.1 1.5	9.8 6.9	–	1.0 1.1	0.1 0.1	–
Meridion circulare	–	–	–	–	–	–	0.8 0.2	–	0.5 0.1	–	0.2 0.1
Navicula sp.	–	–	–	–	–	–	4.0 1.8	0.2 0.1	–	–	0.2 0.1
Nitzschia sp.	–	0.1 0.1	–	–	–	1.3 0.5	3.2 0.5	–	–	–	–
Reimeria sinuata	0.2 0.0	0.8 0.2	–	0.6 0.1	0.3 0.1	–	–	–	–	–	–
Rhoicosphenia abbreviata	–	–	0.1 0.1	–	–	–	–	–	–	–	–

Table 2. (Contd.)

Species	Watercourse*										
	1	2	3	4	5	6	7	8	9	10	11
Ulnaria ulna	0.1 / 0.4	0.4 / 2.5	–	–	–	0.9 / 6.5	4.2 / 29.5	–	–	–	–
Tabellaria fenestrata	–	–	–	–	–	4.0 / 6.2	6.2 / 9.6	–	–	–	–
T. flocculosa	–	–	–	–	–	1.3 / 1.1	–	–	–	–	–

* Watercourse nos. correspond to the names listed in Table 1.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

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