ISSN 1067-4136, Russian Journal of Ecology, 2010, Vol. 41, No. 2, pp. 167–172. © Pleiades Publishing, Ltd., 2010.
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# Relationship between the Biodiversity of Phyto- and Zoobenthos in the Continuum of the Model Mountain River Komarovka (Primorye, Russia)

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Received May 22, 2008

**Abstract**—The structure of benthic communities was studied in the continuum of the model mountain river Komarovka, which flows in the conifer–broadleaf forest subzone in the southwest of the Silkhote-Alin Mountain Range (Primorye, Russia). The lowest species diversity of phyto- and zoobenthos was recorded in the upper reaches of the river, in a heterotrophic area; the highest species diversity, in the central part of autotrophic area. At the same time, the Shannon index for algal communities had the highest values in the heterotrophic area, while that for bottom invertebrate communities, within the autotrophic area. Thus, the increase in invertebrate species diversity in the river continuum was accompanied by complication of the structure of zoobenthos, while the increase in the taxonomic diversity of phytobenthos took place against the background of increasing dominance of a few algal species.

*Key words*: river continuum, algae, invertebrates, species diversity, Shannon index.

**DOI:** 10.1134/S1067413610020098

In river systems, specialists distinguish the crenal (source springs), rithral, and potamal zones. The rithral and potamal zones may be divided into parts corresponding to habitats of particular fish groups: epirithral (upper trout area), metarithral (lower trout area), hyporithral (grayling area), epipotamal (barbel area), metapotamal (bream area), and hypopotamal (ruffe–flatfish area) (Illies and Botosaneanu, 1963). This division follows the regular pattern of changes in the environment of hydrobionts that took place as the water moves from the sources to the mouth of a river system; these changes are reflected in structural and functional properties of communities replacing each other along the river course. For instance, according to the concept of river continuum (Vannote et al., 1980), communities inhabiting the upper river reaches (the crenal zone), with catchment basins covered by forests, are shaded by the forest canopy and receive little light. The ratio of organic matter production ($P$) to destruction ($R$) in this area is lower than unity, indicating the heterotrophic type of ecosystem metabolism. In the rithral zone, the river becomes wider, and its temperature regime changes; the river community is not shaded by trees and is less dependent on allochthonous organic matter. The biotic diversity in such areas reaches a peak. The system of these areas is believed to be autotrophic, with the $P/R$ ratio close to unity (Dodds, 2002). In plain areas of rivers (the potamal zone), the current slows down, and planktonic organisms appear; the water is usually less transparent, accounting for a lower rate of photosynthesis. Species diversity at the majority of trophic levels decreases in these areas, and the community becomes heterotrophic again.

It has been shown earlier that the basic features of the river continuum are typical for rivers of the Russian Far East. In particular, the autotrophic areas of these are characterized by the most complex structure of zoobenthic communities, with high values of the Shannon index (Alimov and Teslenko, 1988; Vshivkova, 1989; Levanidova et al., 1989; Bogatov, 1994; etc.). Unfortunately, we have no clear understanding of trends in the distribution of algae along the river course; therefore, considerations of the river continuum concept as applied to producers are so far based on estimates of only one parameter, the $P/R$ ratio. Obviously, structural parameters of the periphyton cannot be similar to those of bottom invertebrates. In algal communities, for instance, increased dominance of individual species can be expected at high $P/R$ values, which has to be reflected in low values of the Shannon index (Alimov, 2003).

The purpose of this study was to analyze in detail the biodiversity of phyto- and zoobenthic communities in the continuum of a model mountain river flowing in the temperate forest zone and to test the hypothesis of increasing dominance of individual algal spe-

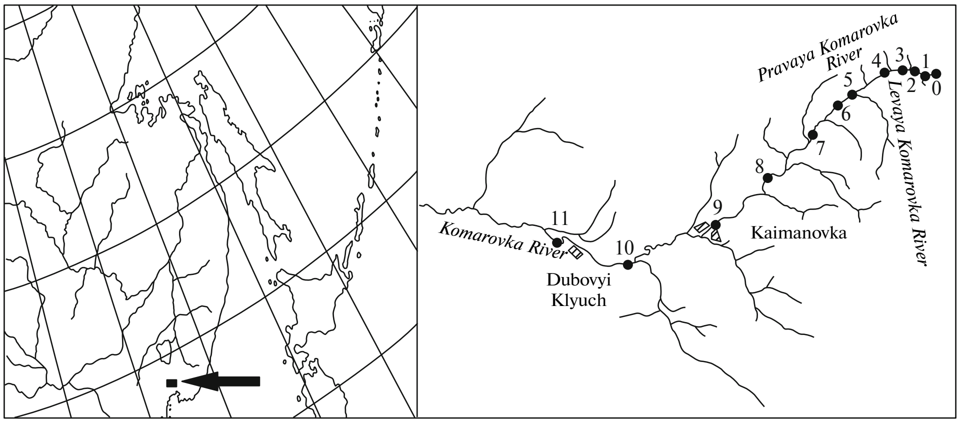

**Fig. 1.** Schematic map of the study area and locations of sampling stations (figures).

cies in the autotrophic area of the watercourse, where the zoobenthic community usually has an especially complex structure.

## STUDY AREA

The study was performed on the Komarovka River flowing in the conifer–broadleaf forest subzone in the southwest of the Silkhote-Alin Mountain Range (the Razdol'naya River basin, southern Primorye) (Fig. 1). The river has a mountain segment (down to the village Kaimanovka), a semi-mountain segment (down to the village Dubovyi Klyuch), and plain segment. The mountain part of its basin is free from any anthropogenic pressure, since it lies within the Ussuriiskii Nature Reserve. Thus, the upper river segment is a convenient natural model for studying trends in the distribution of hydrobionts in the river continuum.

The Komarovka River is formed by the confluence of the Pravaya (Right) Komarovka and Levaya (Left) Komarovka rivers, 7 km from the source of the former (both originating on the southern slopes of the Przewalski Range). The length of the Komarovka River, from the Pravaya Komarovka source to the mouth, is 67 km, total elevation drop 386 m and an average slope of 5.8‰, drainage area 1490 km$^2$. About 90% of the river basin in the study area is covered by forest. The water in the river is weakly mineralized, of hydrocarbonate class, with pH 7.0–7.2 in the warm season period.

The channels of the Pravaya and Levaya Komarovka vary in width from 0.2–0.5 to 3.5–4.5 m and are shaded by the forest canopy; the maximum water temperatures are 7–10°C. Downstream from their confluence, the width of the Komarovka channel increases from 6–8 m in the upper reaches to 25–28 m near the village Dubovyi Klyuch, with its maximum depth ranging from 0.2–0.5 m on rapids to 0.5–1.2 m in pools. The bottom is rubbly pebble. Flow velocity is 0.8–2.0 m/s on rapids and 0.3–0.7 m/s in pools. The maximum water temperature increases from 10–12°C at the confluence of the Right and Left Komarovka to 23–24°C near Dubovyi Klyuch.

The river is fed mainly by rainfall, with its proportion in the annual flow discharge reaching 85–90%. The summer low-water period is usually reduced to a short-term drop in the water level between floods but may reach 50–80 days when annual precipitation is low. The highest daily average air temperatures, about 20°C, are recorded in August.

The river freezes up in late November. January is considered to be the coldest month, with daily average air temperatures decreasing to –25°C. The spring flood begins in late March to early April and continues until the end of April.

## MATERIALS AND METHODS

The study was performed in the mountain and semi-mountain areas of the Komarovka River (the total drainage area 670 km$^2$). The bulk of material consisted of algae and bottom invertebrates collected at four stations on the Pravaya Komarovka River (0.5, 1, 2, and 4 km from its source) and seven stations on the Komarovka River: 7, 9, 11.5, 16, 23.5 (Kaimanovka), 31, and 37 km (Dubovyi Klyuch) from the source of the Pravaya Komarovka River (Fig. 1). All the stations were located on rapids. According to the species composition of zoobenthos, stations 1 and 2 were attributed to the crenal zone, station 3 to epirithral zone, stations 4–7 to metarithral zone, and stations 8–11 to hyporithral zone (Vshivkova, 1988).

Samples of phyto- and zoobenthos were collected in different seasons of 1983–1985 and 1989–1993; phytobenthos was additionally collected in different seasons of 1994, 1999, and 2000. The total material consisted of 70 quantitative and 170 qualitative samples of algae and 210 quantitative and 140 qualitative samples of zoobenthos. The abundance and biomass of phyto- and zoobenthic organisms were compared using samples taken during the summer low-water period of 1984, on July 8–12. The species diversity of bottom communities was estimated using the entire collected material.

For quantitative sampling of algae, two to three stones taken from the bottom at each station were placed in a tray filled with water. Algae were washed from their surface with a hard brush and fixed in 4% formaldehyde. The projective area of the stones was estimated from their weight. The abundance of algae was calculated using a counting chamber 0.01 $cm^3$ in volume, and the biomass of each taxon was estimated from data on cell count and volume (*Vodorosli..., 1989*).

For quantitative sampling of bottom invertebrates, benthometers with capture areas of 0.3 ± 0.4 and 0.25 ± 0.25 $m^2$ (Bogatov, 1994) and standard water nets of nylon gauze no. 21 were used. Three to four quantitative samples were taken from each station and fixed in 4% formaldehyde.

The diversity of algal and bottom invertebrate communities was estimated taking into account the degree of dominance for each taxon, using the Shannon index ($H$) (Shannon and Weaver, 1963) calculated on the basis of data on the abundance of these organisms.

## RESULTS

**Phytobenthos.** A total of 245 species of algae (including forms and varieties, 300 taxa) were recorded in samples from the mountain and semimountain segments of the Komarovka River, with 90.3% of these taxa belonging to the phylum Bacillariophyta (Nikulina, 2005). As shown in Fig. 2a, the smallest numbers of taxa were found in the periodically drying source of the Pravaya Komarovka (9 taxa) and at station 1 (94 taxa), and the greatest number, at station 7 (189 taxa). The average number of taxa in the entire autotrophic zone (stations 3–11) proved to be relatively large, 159 ± 13 ($n = 9$). On average, about nine species and varieties of algae per kilometer are added to their list in the stretch between the stations with the lowest (1) and highest (7) number of taxa.

However, the most drastic increase in the taxonomic diversity was recorded along the 1.5-km river stretch between stations 1 and 3: from 94 to 170 taxa, i.e., about 50 taxa per kilometer. A probable explanation is that the river channel in this area widens from 0.2–0.5 to 4.5 m, with consequent improvement of illumination level. Farther downstream, in the stretch of about 7 km between stations 4 and 6, the number of taxa decreased to 154–157 due probably to shading by broadleaf trees abounding in this mountain belt. Thus, the epirithral zone (station 3) and the upper metarithral zone (stations 4–6) probably mark transition between the heterotrophic and autotrophic areas. As the river channel widened to 10–12 m, the species diversity of benthic algae increased again and reached a peak of 189 taxa at station 7.

In the hyporithral zone (stations 8–11), the number of taxa decreased from 189 to 102, or approximately by two taxa per kilometer of the river channel (Fig. 2a), probably reflecting changes in the hydrologic and temperature regimes of water flow upon transition from the semimountain to the plain segment of the river. As a result, rheophilic taxa disappeared from the phytobenthic community, while the plankton community typical of the potamal zone was not yet formed in this stretch of the river.

The total abundance and biomass of algae (Figs. 2b, 2c) during the summer low water of 1994 were minimal in the crenal zone, i.e. in the most shaded part of the river channel: 3–4 × $10^9$ cells/$m^2$ and around 1 g/$m^2$, respectively. This is explained not only by shading but also by prevalence of small diatom forms in this area. As the river channel widened and the illumination level improved, the abundance and biomass of algae increased to 6–8 × $10^9$ cells/$m^2$ and 5–7 g/$m^2$.

Changes in the taxonomic diversity and amount of phytobenthos in the river continuum markedly influenced the value of the Shannon index (Fig. 2d). It has to be noted that the highest values of the index, close to 3, were recorded in the crenal zone (stations 1–2), where the parameters of algal taxonomic diversity and biomass were the lowest. Farther downstream (stations 3–6), the Shannon index dropped to about unity (although the total number of species sharply increased in this area) and then decreased gradually. Thus, the recorded values of this biotic index indicated that the degree of dominance of individual taxa in the autotrophic part of the river was higher than in its heterotrophic part.

**Zoobenthos.** The zoobenthos of the Komarovka River in its mountain and semimountain segments includes 361 species (Vshivkova, 1988), most of them being larvae of amphibiotic insects. For instance, members of the orders Ephemeroptera, Plecoptera, Trichoptera, and Diptera (Chironomidae) constituted 60% of the total number of recorded species.

Changes in the species composition of zoobenthos in the continuum of the Komarovka River were similar to those in the phytobenthos (Fig. 2e). The smallest number of invertebrate taxa, as well as algal taxa, was recorded at the source of the Pravaya Komarovka (8 species) and at station 1 (48 species), the greatest number was recorded at station 7 (173 species), and the most drastic increase in the species diversity of benthic animals was recorded between stations 1 and 3: by approximately 32 species per kilometer of the river channel. Moreover, in the hyporithral zone (downstream from station 7), the number of bottom invertebrate species proved to decrease from 173 to 82, i.e., by 3.6 species per kilometer, which was due appar-

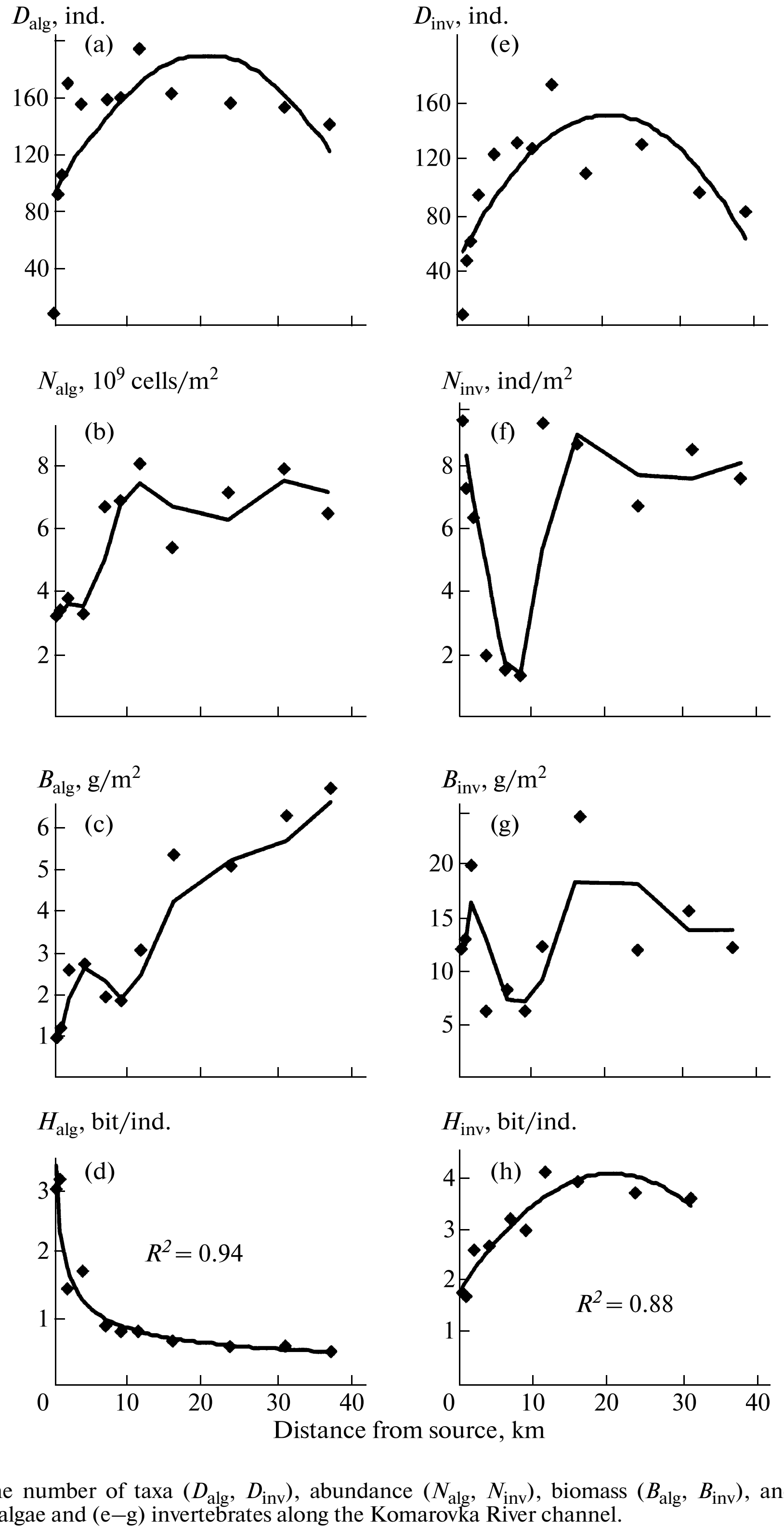

**Fig. 2.** Changes in the number of taxa ($D_{\mathrm{alg}}$, $D_{\mathrm{inv}}$), abundance ($N_{\mathrm{alg}}$, $N_{\mathrm{inv}}$), biomass ($B_{\mathrm{alg}}$, $B_{\mathrm{inv}}$), and the Shannon index ($H_{\mathrm{alg}}$, $H_{\mathrm{inv}}$) for (a–d) algae and (e–g) invertebrates along the Komarovka River channel.

ently to slowdown of river flow and increasing water temperature. These two factors obviously limited the distribution of cold-loving rheophilic species in the downstream part of the hyporithral zone; on the other hand, conditions for potamophilic invertebrates in this zone are probably not quite suitable, since it marks the upstream boundary of their distribution in the river.

The quantitative distribution of benthic animals in the Komarovka River had some characteristic features (Figs. 2f, 2g). For instance, invertebrate abundance

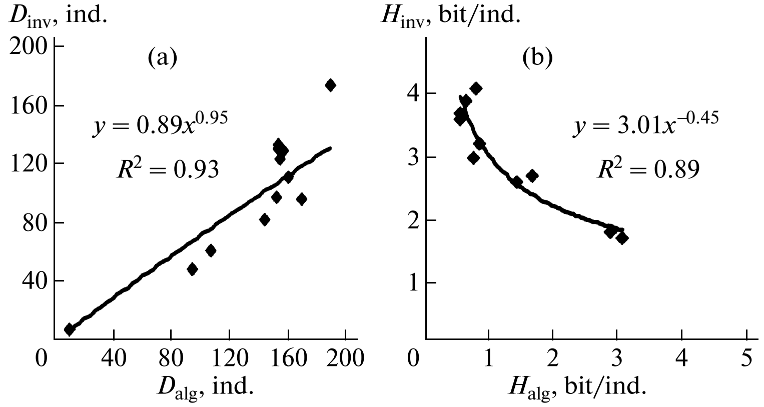

**Fig. 3.** Relationships between (a) the numbers of invertebrate taxa $D_{inv}$ and algal taxa $D_{alg}$ and (b) the values of Shannon index for invertebrate communities $H_{inv}$ and algal communities $H_{alg}$.

and biomass proved to be the lowest in the zone of transition between the heterotrophic and autotrophic areas (stations 4–6), reaching the peak values in the heterotrophic (stations 1–2), upper transitional (station 3), and autotrophic (stations 7–11) areas of the river. It should be noted that consumers of leaf litter and coarse detritus prevailed among bottom organisms in the upper three stations (heterotrophic and upper transitional areas), while filter-feeders, collectors, and scrapers were prevalent in the autotrophic area (Vshivkova, 1988).

Shannon index for zoobenthos changed in the downstream direction from 1.7 to 4.1 (Fig. 2h). In contrast to the algoflora, the lowest and highest values of this index for invertebrates were recorded in the upper part of the heterotrophic area ($H = 1.7–1.8$ at stations 1–2) and in the central part of the autotrophic area ($H \sim 4$ at stations 7–9).

## DISCUSSION

The number of invertebrate taxa within the mountain and semimountain segments of the Komarovka River was 1.2 times as great as the number of algal taxa. The species diversity of phyto- and zoobenthos was the lowest in the crenal zone (stations 1 and 2) and the highest in the lower part of the metarithral zone (station 7), where the numbers of taxa in both ecological groups was similar: 189 taxa of algae and 173 species of invertebrates. In the heterotrophic and upper autotrophic parts of the river (stations 1–3), the taxonomic diversity of algae increased to a greater extent than that of invertebrates. At the same time, the decrease in the number of taxa in the hyporithral zone was less pronounced in phytobenthos than in zoobenthos. On the whole, the correlation between the number of phyto- and zoobenthic species within the mountain and semimountain segments of the river was highly statistically significant (Fig. 3a).

Although changes in the taxonomic composition of phyto- and zoobenthos in the river continuum had similar patterns, the Shannon indices for these two hydrobiont groups showed negative correlation (Fig. 3b). For instance, the diversity index for the phytobenthos had the highest values in the crenal zone and the lowest values in the meta- and hyporithral zones, while that for the zoobenthos had the highest values in the lower metarithral and upper hyporithral zones and the lowest value in the crenal zone. The observed changes in the Shannon index along the Komarovka River channel conform with the concept of the river continuum. Similar changes in this index were recorded previously in zoobenthic communities of other rivers of the region. For instance, in the Frolovka River (the southeastern Sikhote-Alin), the structure of the macrobenthos also proved to be more complex in the meta- and hyporithral zones ($H = 3.9–4.6$) and the least complex in the crenal zone ($H = 2.0–3.0$) (Levanidova et al., 1989). In the Rudnaya River (the eastern Sikhote-Alin), the highest values of the Shannon index for invertebrates (2.6–3.9) were also recorded in the metarithral zone (Alimov and Teslenko, 1988). It should be noted that these structural characteristics of the zoobenthos manifest themselves at low or medium values of algal biomass. Under hypereutrofic conditions, however, the structure of the benthic invertebrate community is usually simplified (Bogatov, 1994).

Thus, the increase in the taxonomic diversity of the zoobenthic community in the continuum of the model river Komarovka is accompanied by structural complication of this community, while the increase in the taxonomic diversity of the phytobenthos is accompanied by the growth of its biomass and increasing dominance of a limited number of algal species. In other words, the high biotic diversity of the zoobenthic community in the autotrophic zone of the river is maintained in account of relatively high production of phytobenthos, while the high level of primary production in this part of the watercourse is achieved owing to the development of a few algal species.

The data that the number of algal species sharply increases as the river channel widens provide evidence for the key role of illumination in the formation of the river continuum. This indirectly confirms Hutchinson's (1964) idea that algae in small rivers do not suffer from shortage in nutrients. At the same time, all other conditions being equal, the chemical composition of water (Biggs, 1990, 1995) and flow velocity (Stevenson, 1996) may play a decisive role in of the formation of river phytocenosis. The positive correlation between the number of phyto- and zoobenthic taxa indicates the existence of common mechanisms maintaining the taxonomic diversity of hydrobionts. In mountain and semimountain segments of rivers, these mechanisms are probably connected with the diversity of environmental parameters, including the diversity of refugia that allow living organisms to survive unfavorable natural phenomena such as floods, droughts, or riverbed freezing (Bogatov, 1995, 2001).

## ACKNOWLEDGMENTS

This study was supported by the Presidium of the Russian Academy of Sciences, project no. 06-1-P11-023, and by the Far East Division of the Russian Academy of Sciences, project nos. 07-III-D-06-044 and 09–III-A-06-165.

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