Zooplankton community structure in mouth areas of different rivers (tributaries of the lowland Cheboksary Reservoir, European Russia)

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Abstract. Main features of the structural organization of zooplankton communities are assessed for different morphological types of mouth areas found in tributaries of a lowland reservoir. It is shown that a river mouth with a distinguished delta is characterized by the highest species richness and diversity of all studied mouth types in both the free-flowing part of the stream and in the reservoir zone. In the transitional zone between the river and the reservoir, no statistically significant differences between zooplankton community structures of different types of river mouths were found, which can be explained by high heterogeneity of zooplankton communities in these zones, substantial shift in the dominant species composition, and higher quantitative development of zooplankton. The shift between dominance of various species in different river mouths was not uniform, but had a common direction – from the dominance of riverine rotifers to lacustrine crustacean species.

1. Introduction

Natural predominance of lowland watersheds in Russian landscapes has substantially defined priorities in national practices of water ecology research. In literary sources, patterns and variation of structural organization, species diversity and spatial distribution of zooplankton are provided for longitudinal profiles of rivers and lakes in European Russia and Siberia [1-6]. However, studies of zooplankton communities of transitional zones, including mouth areas of rivers feeding into even well-studied lakes and reservoirs, are relatively scarce, and available data is uneven and incomplete, so the issue remains.

It is known that zooplankton communities undergo substantial changes in the zones of transition between a river and a receiving reservoir. This effect is caused by a shift between habitats with drastically different environmental properties. In reservoir cascades, an upstream reservoir usually serves as a main provider of zooplankton for a downstream reservoir. However, small streams (that dominate in a total number of inflows) and large rivers (that dominate in terms of total water discharge) cannot be dismissed as sources of zooplankton species diversity, often accounting for the enrichment of aquatic communities with uncommon and atypical plankton species [7]. River mouth zones can represent species pools for watersheds of lowland reservoirs due to elevated diversity and abundance of zooplankton in river-reservoir ecotones compared to adjacent waters [8].

The aim of this study is to analyse specifics of the structural organization of zooplankton communities in different types of river mouths in a lowland Cheboksary Reservoir (European Russia).
2. Materials and methods

2.1. Study area
Mouth areas of four rivers feeding into the Cheboksary Reservoir (table 1) were studied in July of 2019. The mouth of the large Vetluga River is an estuarine type, wide and shallow, and located in the lacustrine part of the reservoir. Another large river – Sura – has a wide estuarine-deltaic mouth with islands and vast areas of macrophyte growth and flows into the transitional zone between the riverine and the lacustrine parts of the reservoir. The middle-sized Kerzenets River has a distinguished delta with many small islands, several main channels and sand bars. The mouth of the smallest of the rivers – the Sundovik River – is artificially transformed into a straight canal for navigation purposes. Rivers Kerzenets and Sundovik both flow into the riverine part of the reservoir.

Table 1. Characteristics of rivers and types of their mouth areas.

| River            | L, km | S, km² | Q, m³/s | Z   | River type      | Mouth area type |
|------------------|-------|--------|---------|-----|----------------|-----------------|
| Kerzenets River  | 290   | 6 140  | 19.6    | I   | middle river   | delta           |
| Sundovik River   | 97    | 1 120  | –       | I   | small river    | ordinary AT     |
| Sura River       | 841   | 67 500 | 260.0   | II  | large river    | estuarine-deltaic|
| Vetluga River    | 889   | 39 400 | 255.0   | III | large river    | estuarine       |

Note: L – length of the river; S – river’s watershed area; Q – water discharge (at the mouth); Z – part of the reservoir into which the river flows (I – river zone; II – transition zone; III – lake zone); AT – anthropogenic-transformed; classification of mouth areas according to V.N. Korotaev [9].

2.2. Sampling and laboratory analysis
Zooplankton samples were collected with a 70 μm plankton net by dragging the net from the bottom to the surface (at stations with total depth >3 m) or by pouring 100 L of water through the net (at shallower stations). Samples were preserved in 4% formaldehyde and subsequently examined with a Zeiss Stemi 2000C stereoscopic microscope (Carl Zeiss Microscopy, Germany) under low magnification. To perform a more detailed analysis, a Zeiss Primo Star microscope was used (Carl Zeiss Microscopy, Germany). Identification of zooplankton species was conducted with aid of specialized guides, keys and other literary sources [10-16].

2.3. Data analysis
For each river, zooplankton diversity at each of several stations along its mouth and total zooplankton diversity were assessed using Shannon-Wiener Diversity Index and Berger-Parker index. Multivariable vector analysis was used to allocate plankton communities and specify their spatial distribution [17-18]. Optimal number of clusters (representing different communities) for cluster analysis was determined based on silhouette widths and Mantel correlation test [19-21]. The Shapiro–Wilk test was used for assessing the normality of distributions, and Levene’s test – for assessing the equality of dispersion values between data sets. For non-normal distributions of morphometrical features, nonparametric tests were used, such as the Kruskal–Wallis test and the Wilcoxon signed-rank test [19-20].

3. Results and discussion

3.1. Species richness
In total, 137 zooplankton species were identified in all studied river mouths around the lowland Cheboksary Reservoir, including 74 species of Rotifera, 46 species of Cladocera, and 17 species of Copepoda (table 2). The highest zooplankton diversity was recorded in the Vetluga River, and the lowest – in the Sura River. Among all four mouth areas, rotifers were dominant in species
composition, with their share in the total number of identified species ranging from 51% (in the Sundovik) to 56% (in the Kerzhenets). The predominance of rotifers in zooplankton species can be explained by their preference for flowing water, which gives them an advantage in mostly riverine conditions found within studied areas.

Table 2. Species richness of zooplankton in studied river mouths.

|                | Kerzhenets River | Sundovik River | Sura River | Vetluga River |
|----------------|-------------------|----------------|------------|---------------|
| Rotifera       | 37                | 38             | 28         | 52            |
| Cladocera      | 19                | 27             | 16         | 34            |
| Copepoda       | 9                 | 10             | 9          | 12            |
| All taxa       | 65                | 75             | 53         | 98            |

3.2. Zooplankton communities
Multivariable vector analysis was used to determine typical zooplankton communities for each mouth area from data on the species structure, based on average linkage clustering followed by determination of the optimal number of clusters. For all four rivers, similar clusters/zones were outlined, corresponding to distinct zooplankton communities: the free-flow part of the river (Zone I), the transitional river-reservoir zone (Zone II), and the actual reservoir zone (Zone III) (figure 1).

![Figure 1](image)

**Figure 1.** Dendrograms of hierarchical clustering of zooplankton samples from the mouth areas of tributaries of the Cheboksary Reservoir by the mean coupling method with subdivision into 3 clusters (zooplankton communities): a – the Kerzhenets River, b – the Sundovik River, c – the Sura River, d – the Vetluga River; Zone I – the free-flowing part of the river, Zone II – transitional zone, Zone III – reservoir.
3.3. *Species structure of zooplankton communities*

The estuary of the large Vetluga River can be used as an illustration of typical zooplankton community structure in studied areas. The highest zooplankton abundance, biomass and quantity of species are all observed in the transitional zone (ecotone) between the river and the reservoir (figure 2), with statistically significant ($p<0.05$) differences from other zones. In the free-flow zone, the *Synchaeta pectinata* Ehrenberg, 1832 and *Asplanchna priodonta* Gosse, 1850 rotifers were predominant, together contributing to 54.5% of total zooplankton abundance, while in the transitional zone a completely different set of dominant species was found. The rotifer *Brachionus angularis* Gosse, 1851 was dominant at 21.1% of the total abundance, and nauplii and copepodite stages of Copepoda contributed to 17.5% and 11.5%, respectively. In the reservoir zone, a typical limnic species *Daphnia galeata* G.O. Sars, 1864 was added to the list of dominants (12.7% of total abundance).

![Figure 2. Boxplots of the variability abundance ($N$), biomass ($B$), species richness in the one sample ($S_{one}$), Shannon-Wiener Diversity Index ($H'$), Berger-Parker Index ($d$) and Margalef Species Richness Index ($D_{mg}$) in mouth areas (zone I – free flow zone of the river; zone II – transition zone (ecotone); zone III – reservoir receiver area).](image)

Furthermore, the highest zooplankton diversity ($H'$) and species richness ($D_{mg}$) were also observed in the transitional zone, as well as the lowest values of the Berger-Parker Index ($d$). This indicates that in the estuary of the large river Vetluga, the highest quantity and diversity of zooplankton were observed at the transitional zone, as opposed to riverine and lacustrine areas. The composition of dominant species in the transitional zone is mixed, with both rotifers and crustaceans present in comparative amounts. Differences between the transitional zone and zones I and II were statistically significant at $p<0.05$ only for the Berger-Parker Index and were not confirmed for the total abundance.
and species richness ($p=0.27$) due to a high dispersion between samples, although their median values were also noticeably higher in the transitional zone.

Similar patterns were observed in other studied mouth areas, as well as a gradual transition between riverine and lacustrine communities, despite the variation in morphological types of mouth areas and their location along the reservoir’s length. Similar patterns were earlier outlined by A.V. Krylov and S.E. Bolotov [5; 22-24] for small streams flowing into a lowland reservoir. Our data suggest that an increase in species richness and abundance of zooplankton in the transitional zone, or ecotone, is likewise observed in morphologically different mouth areas of medium and large tributaries.

Between the various types of river mouths covered by this study, maximum median values of the Shannon-Wiener ($p<0.05$) and Margalef ($p=0.34$, non-significant differences) indexes for the free-flow zone (Zone I) were registered for the mouth area with a developed delta (Fig. 3). In the transitional zone (Zone II), both indexes were the highest in a river mouth with both estuarine and deltaic features, although the differences were not confirmed by statistical tests, and in the reservoir (Zone III) – again in the delta-type river mouth (differences significant at $p<0.05$ for both indexes).

**Figure 3.** Boxplots of the variability of Shannon-Wiener Diversity Index ($H'$) and Margalef Species Richness Index ($D_{Ma}$) in the mouth area zones (zone I – free flow zone of the river; zone II – transition zone (ecotone); zone III – reservoir receiver area) and different types mouth areas (ordinary AT – Sundovik River; estuarine – Vetluga River; delta – Kerzhenets River; estuarine-delta – Sura River).

An analysis of the zooplankton species composition within the defined zones/communities showed that in the free-flowing parts of rivers, rotifers, nauplii (in the deltaic river mouth) and a cladoceran crustacean *Moina micrura* Kurz, 1875 (in an estuarine-deltaic mouth) were dominant (table 3). In the Zone II of different river mouths, the set of dominant species was either completely different from Zone I (as observed in an estuarine and deltaic mouths), or was expanded to include other limnophilic species, such as *Alona costata* G.O. Sars, 1862 and *Daphnia cucullata* Sars, 1862.
Table 3. Dominant species (>10% of total abundance) of zooplankton communities (zones) In mouth areas of different morphological types (ordinary AT – Sundovik River; estuarine – Vetluga River; delta – Kerzhenets River; estuarine-deltaic – Sura River).

| Zone I          | Zone II         | Zone III              |
|-----------------|-----------------|-----------------------|
| **Ordinary AT** |                 |                       |
| *Brachionus angularis* (23,9%) | *Conochilus unicornis* (38,3%) | *Daphnia cucullata* (18,6%) |
| *Conochilus unicornis* (23,3%) | *Copepodit Juv.* (15,0%) | *Nauplii* (17,0%) |
| *Bipalpus hudsoni* (10,5%) | *Alona costata* (13,3%) | *Keratella quadrata* (14,7%) |
|                 | *Synchaeta pectinata* (12,2%) | *Copepodit Juv.* (11,0%) |
| **Estuarine**   |                 |                       |
| *Synchaeta pectinata* (34,5%) | *Brachionus angularis* (21,1%) | *Nauplii* (20,8%) |
| *Asplanchna priodonta* (20,0%) | *Nauplii* (17,5%) | *Daphnia galeata* (12,7%) |
|                 | *Copepodit Juv.* (11,5%) | *Brachionus angularis* (11,5%) |
| **Delta**       |                 |                       |
| *Kellicotta bostoniensis* (14,9%) | *Keratella quadrata* (33,0%) | *Nauplii* (13,1%) |
| *Nauplii* (11,7%) | *Chydorus sphaericus* (32,5%) |                       |
| **Estuarine-delta** |                 |                       |
| *Moina micrura* (17,3%) | *Daphnia cucullata* (21,2%) | *Nauplii* (23,3%) |
| *Brachionus angularis* (12,2%) | *Nauplii* (11,4%) | *Copepodit Juv.* (16,3%) |
|                 | *Brachionus angularis* (10,3%) | *Moina micrura* (10,1%) |
|                 |                 | *Daphnia cucullata* (10,8%) |
|                 |                 | *Leptodora kindti* (10,3%) |

**Note:** zone I – free flow zone of the river; zone II – transition zone (ecotone); zone III – reservoir

Similar patterns of shifting dominant composition were observed in moving to Zone III: for example, in the artificially transformed channel it was characterized by the most diverse set of dominant species, which included a typical lacustrine species *D. cucullata* as well as nauplii, copepods and rotifer species that have not been identified as dominant in other zones. In estuarine and estuarine-deltaic mouths, lacustrine species typical for the Cheboksary Reservoir – *D. galeata* and *Leptodora kindti* Focke, 1844 – were added to dominant species in Zone III. In the delta-type river mouth, zooplankton community of Zone III was monodominated by nauplii.

4. Conclusion

Extensive studies conducted in morphologically diverse mouth areas of the lowland Cheboksary Reservoir’s tributaries allowed to create a comprehensive record of their zooplankton fauna. Patterns of structural organization of zooplankton community previously observed in mouth areas of small streams were confirmed for other types of streams.

Zooplankton communities of selected areas of tributaries of the Cheboksary Reservoir were generally rather rich and its overall composition was presented by 137 species during the study period, which included a number of rare and foreign zooplankton species.

A more detailed analysis of the zooplankton’s species structure in the studied mouth areas allowed to identify zones with specific zooplankton communities: a free-flowing part of the river, a transitional zone, and a reservoir zone. For the first time, an increase in the number, biomass, and species richness of zooplankton in the transition (ecotone) zone has been confirmed for various types of river mouths of large and medium-sized tributaries of a lowland reservoir.

Our study shows that in the free-flow zone of the river (Zone I), as well as in the reservoir zone (Zone III), the highest species diversity and richness is observed in the delta-type mouth. In the transitional (ecotone) zone (Zone II) no statistically significant differences between different types of mouth areas were found. This may be due to the high variability of the species structure of this zone,
complete or partial change of the dominant species composition, and an increase in the quantitative
development of zooplankton.

The shift between dominance of riverine rotifera species to lacustrine crustacean zooplankton did
not occur in a uniform manner. In the free-flowing zone of the river, rotifers dominated. In the
transition zone of different-type river mouths, the complex of dominant species either changed
completely (in estuarine and deltaic river mouths) or was only joined by different species (in
estuarine-deltaic and anthropogenically transformed mouths). In the reservoir zone, the dominance
of lacustrine crustacean species was strengthened.

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