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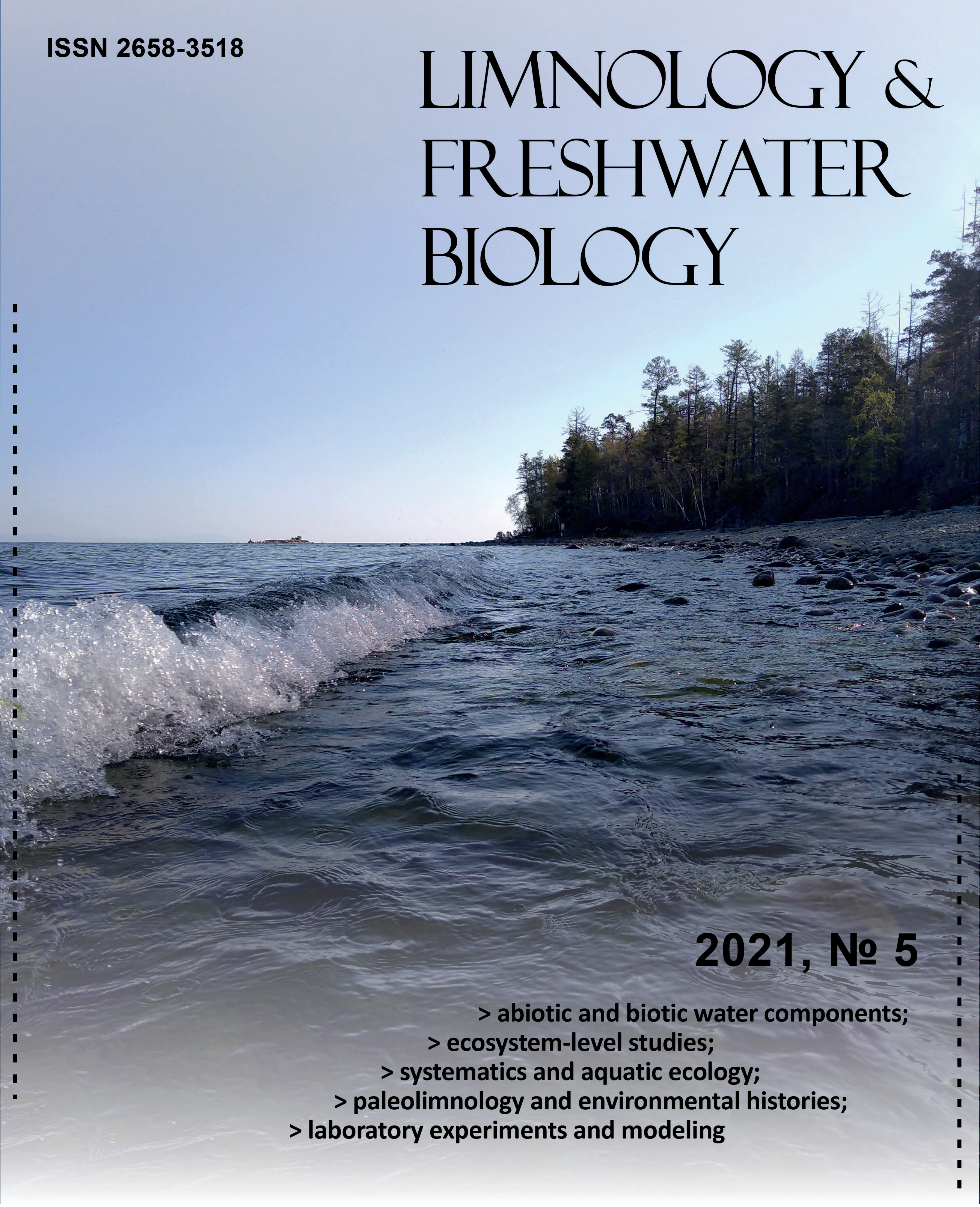

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Influence of environmental factors onto reproductive characteristics of *Daphnia galeata* from Lake Baikal

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ABSTRACT. The influence of various factors onto the reproductive characteristics of the cladoceran *Daphnia galeata* Sars, 1863 Lake Baikal was studied. With an increase in the concentration of available feed, the size of the body, average fertility, the size of the brood and the proportion of egg-bearing females increase. At high temperatures, significantly greater fecundity and the proportion of egg-bearing females were noted; other features did not change significantly with temperature increase. Under the conditions of strong turbulence, the fertility and the proportion of egg-bearing females are lower than under the conditions of low turbulence. The presence of a predator with an increase in the concentration of feed and temperature results in the decrease in the size of crustaceans and in the increase of the proportion of egg-bearing females.

Keywords: fertility, brood size, average fertility, proportion of egg-bearing females, feed, temperature, turbulence

1. Introduction

Daphnia are widely distributed in water bodies of various types; they serve as food for the higher links of the trophic chain. The biology, morphology and reproductive characteristics of these organisms are greatly influenced by various factors, such as the amount of available food, temperature, turbulence and among biotic factors - the influence of predators (nocturnal and invertebrates) (Zhukova, 1953; Jacobs, 1961; 1987; Gilyarov, 1987; Achenbach and Lampert, 1997; Laforsh and Tollrian, 2004; Dodson, 1988; Polishchuk and Vijverberg, 2006).

Among the above listed factors determining the animals' life activity, food is the most important one, in influences greatly onto the rate of reproduction, postnatal development, body size, eggs size and number, development of protective structures, life expectancy and development (Zhukova, 1953; Vijverberg, 1976; Gilyarov, 1987; Jacobs, 1987; Semenchenko, 1990; Burns, 1995; Boersma and Vijverberg, 1996; Czeczuga et al., 2003; Jeyasingh and Weider, 2005; Dodson, 1988; Polishchuk and Vijverberg, 2006; Manca et al., 2008). Under the laboratory conditions, major part of *D. pulex* clones cultivated at high food concentration manifest the increase of fertility and of crustaceans amount (Pitul'ko et al., 2009; Feniova et al., 2013).

The main food of planktonic crustaceans includes phytoplankton, detritus, bacteria, as well as protozoa. The size rank of objects is 3-30 microns (Monakov, 1998). Basically, for daphnia, these are small protococcal algae with a diameter of 3.5 microns, then *Scenedesmus* (15 microns) and *Chlorococcum* (20-30 μm), as well as species of the genus *Chroomonas*: *Ch. acuta* and *Ch.* sp. (7-11 μm long and 3-7 wide) and *Stephanodiscus binderanus* (7.5-12.3 μm in diameter), represented among the phytoplankton of Baikal. Algae of the genus *Chroomonas* dominate among lake phytoplankton (Bondarenko et al., 1991).

Temperature has a great influence onto the duration of embryogenesis, but influences less onto the growth after birth (Venkataraman and Job, 1980; Gilyarov, 1987). With an increase of temperature, metabolism and individual development of animals accelerate, respectively, egg maturation and reproduction accelerate (Deng, Xiea, 2003). More energy is required for the functioning of the organism and reproduction, hence the relative decrease in definitive sizes during accelerated puberty and reproduction, when the temperature in a water body increases (Achenbach and Lampert, 1997).

Turbulence is formed by the movement (flow) of water due to various reasons (wind, runoff, interaction of water layers with different temperatures or densities, moving organisms) (Jacobs, 1987; Laforsh and Tollrian, 2004; Tollrian and Laforsh, 2006). In summer, at optimal temperatures, increased turbulence results in the development of swimming-related problems (swimming antennas) and motion control: tail spine, helmet, carinea (Jacobs, 1961; 1962; 1987; Havel and

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Dodson, 1985; Laforsh and Tollrian, 2004). Strong turbulence can hinder the food flow to food consumers, it weakens the distant detection of prey by a predator, increases the consumption of metabolic energy for movement and results in the decrease of fertility (Visser and Stips, 2002; Visser et al., 2008; Baranyai et al., 2011).

Size-selective predation, as well as substances secreted by the predator – kairomones, have a special effect onto cladoceran crustaceans. The presence of a predator results in morphological variability (cyclomorphosis) and various changes in fertility (Gilyarov, 1987; Jacobs, 1987; Burns, 1995; Jeyasingh and Weider, 2005; Dodson, 1988; Polishchuk and Vijverberg, 2006; Zuykova and Bochkarev, 2010).

The aim of the work is to analyze the effect of feed concentration, water temperature, turbulence on the reproductive characteristics of *Daphnia galeata* Sars, 1863 in Lake Baikal.

2. Materials and methods

D. galeata crustaceans were collected by a Djedi net (the area of the inlet is 0.1 m2, the mesh of the filter cone is 90 microns) in pelagic area and lake bays of Lake Baikal in August-September, 1993, 1995 and 1997 at 36 stations. The samples were fixed with 40% formalin. The main data were obtained for two large bays (Barguzin and Chivyrkuy – st. 18-33) and for the pelagic area of Central Baikal (st. 10-17). Data on the open coastal area and the Ushkany Islands area (st, 27), Selenginsk area (st. 8-9), the coastal zone of South Baikal (1-9), and coastal areas of North Baikal (st. 34-36) were used.

The obtained samples of daphnia were divided into mature, pre-mature and juvenile females. A total of 25 individuals of *D. galeata* were studied. The total number of mature females, the number of egg-bearing females and the number of eggs in the brood chamber were calculated, the average fertility (the ratio of the sum of all eggs and embryos in brood bags to the number of mature females) and the average brood size obtained by dividing the total number of eggs and embryos to the number of egg-bearing females (Schultz and Sterner, 1999) were calculated.

To characterize the level of feed supply of daphnia, we will use the daily production of phytoplankton expressed in mg of carbon per m^3 (mg C/m^3). This is an integrated indicator reflecting the amount of food in the habitats of daphnia. The materials available in the papers allow us to present the distribution of the number of bacterioplankton and phytoplankton included in the diet of lower crustaceans in Lake Baikal water area. Based on the data given in the work (Bondarenko et al., 1991), we identified six gradations for this indicator. Its lowest value (19 mg C/m^3) was registered in South Baikal. Stations 1-7 are assigned to this gradation. Further we studied the outlet parts of Barguzin and Chivyrkuy Bays, where feed concentrations for this indicator are very close to 35.0 and 30.0 mg C/m^3, therefore we combined samples

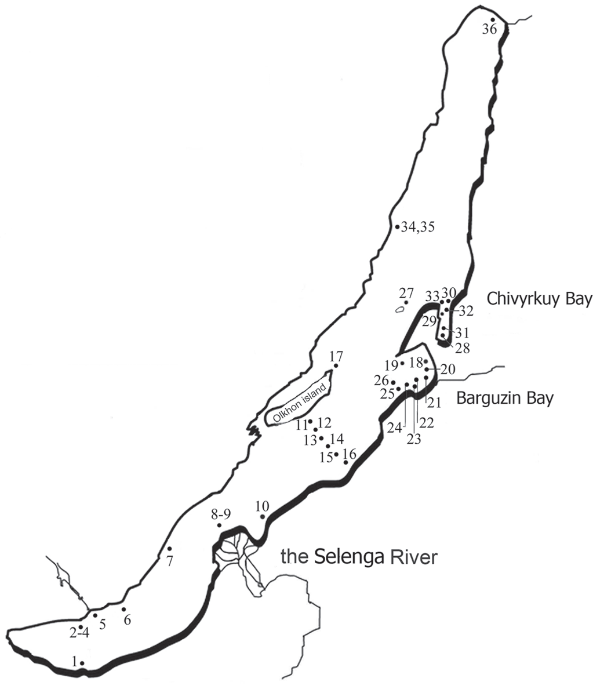

Fig.1. Stations of zooplankton sampling in Lake Baikal in 1993-1997. 1-7 - the coastal zone of South Baikal; 8-9 – the Selenginsk area; 10-17 - the pelagic area of Central Baikal; 18-26 - Barguzin bay; 27-33 - Chivyrkuy bay; 34-36 – the coastal areas of North Baikal.

from these areas into one gradation of 33 mg C/m^3 (st. 19, 25, 26, 30, 33). In Central and North Baikal, the daily production of phytoplankton according to this indicator is equal to 38 mg C/m^3 (st. 11-17, 27, 34-36). In the fourth gradation (the Selenginsk shallow water area), this indicator is 160 mg C/m^3 (st. 8-10). In the inner part of the Barguzin Bay it is 190 mg C/m^3 (st. 18, 20, 22-24). The inner part of the Chivyrkuy Bay is 250 mg C/m^3 (st. 28-29, 21-32). As follows from the above data, the selected gradations are divided into two qualitatively different groups. The values of the daily phytoplankton production index in the first three gradations are less than in the last three ones almost by one order of magnitude.

On the base of on the materials of long–term studies of seasonal changes in the temperature of the surface water layer, the following temperature levels were determined: North Baikal - 2.9 ° C, Central Baikal – 3.2 °C, South Baikal – 3.3 °C, South Baikal, Barguzin strait, Chivyrkuy strait – 3.3 ° C, Selenginsk shallow water area – 3.5 °C, Barguzin inner area – 5.7 °C, Chivyrkuy inner area – 7.1 °C (Bondarenko et al., 1991; Troitskaya et al., 2003).

The flow velocities of the surface water layer in the studied areas of the lake were taken from various sources, distributed as follows: Chivyrkuy and Barguzin inner areas - 1 m/s, South Baikal, North Baikal, Barguzin strait, Chivyrkuy strait – 2 m/s, South Baikal – 2.5 m/s, Central Baikal and Selenginsk shallow water area – 3 m/s (Verbolov, 1977; Fialkov, 1983; Einbund, 1988; Shimaraev and Troitskaya, 2005). The studied samples are grouped according to the prevailing flow rates of the surface water layer. Each grouping, except the third, included samples (2.5) with a predator/

without a predator. In order to exclude the influence of other factors, the studied samples were divided into groups with maximum uniformity according to other factors studied. The first group included all samples, the second one only without a predator, the third one with a predator.

According to the data obtained, the average value of the attribute, the error of the average, was calculated. The differences were assessed using the Student's criterion, the significance levels are indicated: * - P<0.05; ** - P<0.01; *** – P<0.001. (Rokitsky, 1973).

3. Results

The effect of the amount of available feed on the reproductive characteristics of populations of *D. galeata*. One of the most important population characteristics is the average fertility, or the number of offspring per mature female. In *D. galeata*, according to all available data, the average fertility is significantly higher at high feed concentrations (P < 0.001) (Table). The regression coefficient was 0.004 ± 0.0007 (t = 5.42; P < 0.001). Under these conditions, the average value of mature females is significantly higher at high feed concentrations (P < 0.05). In predator-free conditions, the length of mature females is significantly longer at high feed concentrations (P < 0.01). In the samples without a predator, the average fertility is significantly higher at high feed concentrations (P < 0.05). The regression coefficient is 0.0003 ± 0.0012 (t = 2.68; P < 0.05). Under the conditions with a predator, the size of mature females is significantly smaller at high feed concentrations (< 0.001), but there are no differences in fertility at low and high feed concentrations.

According to all available data, *D. galeata* (Table) at high concentrations, the brood size is significantly higher (P < 0.001). Under the conditions without a predator at high feed concentrations, the size of the brood does not differ. In the presence of a predator, with an increase in feed concentrations, the brood size decreases (P < 0.05). The regression coefficient is -0.004 ± 0.0010 (t = 3.49; P < 0.001).

The proportion of egg-bearing females in all variants of our study is greater at high feed concentrations (Table). Under the conditions without a predator, at low feed concentrations, the smallest number of egg-bearing females was obtained, and the largest one was at high concentrations. In the presence

Table. The effect of feed quantity, temperature and turbulence onto the reproductive characteristics of *Daphnia galeata*

Characteristics	Analysis options					
	All data		Without predators		With predator	
	Low food concentration (19-38 mg C/m³)	**High food concentration** (160-250 mg C/m³)	**Low food concentration** (19-38 mg C/m³)	**High food concentration** (160-250 mg C/m³)	**Low food concentration** (19-38 mg C/m³)	**High food concentration** (160-250 mg C/m³)
Number of studied individuals	818	405	595	78	223	327
Body length (μm)	948.2 ± 4.14	965.1 ± 6.01*	927.2 ± 4.82	976.4 ± 15.91**	1004.3 ± 6.81	962.4 ± 6.40***
Average fertility	1.91 ± 0.079	2.64 ± 0.111***	1.55 ± 0.08	2.10 ± 0.209*	2.86 ± 0.177	2.75 ± 0.127
Average brood size	3.25 ± 0.096	3.42 ± 0.110	2.80 ± 0.106	2.73 ± 0.212	4.14 ± 0.178	3.59 ± 0.124*
Proportion of egg-bearing females	58.8	76.8	55.5	76.9	69.1	76.8
Temperature	Low temperature (2.9-3.5 °C)	High temperature (5.7-7.1 °C)	Low temperature (2.9-3.5 °C)	High temperature (5.7-7.1 °C)	Low temperature (2.9-3.5 °C)	High temperature (5.7-7.1 °C)
Number of studied individuals	944	279	624	49	320	228
Body length (μm)	953.5 ± 3.84	954.9 ± 7.50	930.5 ± 4.75	965.1 ± 21.03	998.3 ± 5.74	953.2 ± 7.86***
Average fertility	1.97 ± 0.075	2.76 ± 0.132***	1.55 ± 0.80	2.41 ± 0.257***	2.79 ± 0.146	2.84 ± 0.151
Average brood size	3.33 ± 0.088	3.33 ± 0.132	2.82 ± 0.103	2.74 ± 0.254	4.12 ± 0.144	3.44 ± 0.150**
Proportion of egg-bearing females	59.3	83.8	55.1	87.8	67.5	82.9
Turbulence intensity	Low turbulence (1-2 m/s)	High turbulence (2.5-3 m/s)	Low turbulence (1-2 m/s)	High turbulence (2.5-3 m/s)	Low turbulence (1-2 m/s)	High turbulence (2.5-3 m/s)
Number of studied individuals	939	282	326	282	548	0
Body length (μm)	958.4 ± 3.86	938.5 ± 7.28*	928.8 ± 6.11	938.5 ± 7.28	972.7 ± 6.46	-
Average fertility	2.31 ± 0.076	1.59 ± 0.120***	1.87 ± 0.116	1.59 ±0.120	2.80 ± 0.104	-
Average brood size	3.41 ± 0.082	2.87 ± 0.153**	2.48 ± 0.122	2.89 ± 0.153	3.80 ± 0.103	-
Proportion of egg-bearing females	67.6	53.3	61.7	55.0	73.7	-

Note: * – P<0.05; ** – P<0.01; *** – P<0.001

of a predator at all feed concentrations, the proportion of egg-bearing females is higher than in samples without a predator. Under the conditions with a predator, there are more egg-bearing females at low feed concentrations than under the conditions without a predator, slightly more than at high feed concentrations. Consequently, the number of egg-bearing females is influenced by two factors, food and predator.

Thus, over the entire data set and under the conditions without a predator, the fertility increases with an increase of the concentration of available food. At presence of a predator, there are no differences between fertility at different feed concentrations. The average brood size at all feed concentrations does not differ across the entire data set and under the conditions without a predator. Under the conditions with a predator, the average size of the brood is larger at low feed concentrations, and at high body length and the size of the hatch become smaller, and the proportion of egg-bearing females increases. Changes in the first two features result from size-selective predation, an increase in the proportion of egg-bearing females is a selective response that allows maintaining the population size.

The influence of temperature onto the reproductive characteristics of daphnia populations. Over the entire data set, the average fertility was significantly ($P < 0.001$) higher at high temperatures (Table). The value of the regression coefficient was 2.94 ± 0.644 ($t = 4.56$; $P < 0.001$). In the samples without a predator, a significant stimulating effect of temperature on fertility was also noted ($P < 0.001$). The regression coefficient is 0.24 ± 0.073 ($t = 3.24$; $P < 0.001$). According to all available data, and under the conditions without a predator, there are no differences in body length under the conditions of low and high temperatures. In the presence of a predator, the size of adult females is significantly smaller at high temperatures ($P < 0.001$), and there are no differences in fertility in daphnia from low and high temperatures. Nevertheless, in the presence of a predator at the studied temperatures, fertility is higher than under the conditions without a predator.

In the whole data set and under the conditions without a predator at low and high feed concentrations, the average brood size does not differ in values (Table). At presence of a predator, on the contrary, there is a significant decrease in the brood size ($P < 0.001$). The regression coefficient was -0.19 ± 0.06 ($t = 3.56$; $P < 0.001$).

One of the important characteristics of the population is the proportion of mature females simultaneously participating in reproduction. The proportion of mature females in the whole data set and under the conditions without a predator is greater at high temperatures. At the presence of a predator, the proportion of egg-bearing females is slightly higher at high temperatures, and at low temperatures, the proportion of females at greater in the presence of a predator than under the conditions without a predator. Consequently, the reproductive potential of the population is influenced by both studied factors.

The average fertility under the conditions without a predator is greater at high temperatures than at low ones. At the presence of a predator, there are no differences in fertility between high and low temperatures, but the average fertility under these conditions is greater than under the conditions without a predator. Average fertility is associated with the proportion of egg-bearing females, and the size of the brood depends on the size of the body. Under the conditions without a predator and at high temperatures, there are more crustaceans than at low temperatures. At absence of a predator, the size of the brood, on the contrary, does not depend on the temperature under the conditions without a predator. At presence of a predator at high temperatures, crustaceans are smaller than at low temperatures. Under these conditions, under the conditions without a predator, the size of the brood, on the contrary, does not depend on the temperature under conditions without a predator. At low temperatures, the proportion of egg-bearing females is higher than under the conditions without a predator, but lower at high temperatures.

Consequently, a temperature increase under the conditions without a predator positively affects the size of mature crustaceans, there is an increase in average fertility and in the proportion of egg-bearing females. The temperature does not have a pronounced effect on the size of the brood. At the presence of a predator, the size of the brood and the proportion of egg-bearing females are greater at low temperatures.

The effect of turbulence onto reproductive characteristics. Over the entire data set, *D. galeata*'s average fertility is significantly lower with high turbulence ($P < 0.001$). Under these conditions, the size of mature females is much smaller with high turbulence ($P < 0.05$). In the samples without a predator, there is a slight decrease in fertility, and there are no significant differences in the number of mature females. In samples with a predator with a high level of turbulence, fertility is significantly lower ($P < 0.05$). The regression coefficient was -0.46 ± 0.207 ($t = 2.22$; $P < 0.05$). At presence of a predator, the size of mature females is slightly larger with high turbulence.

The average brood size in the whole data set is significantly higher at a low water flow rate of -0.18 ± 0.166 ($t = 1.08$; $P < 0.001$) (Table). The regression coefficient is -0.67 ± 0.099 ($t = 6.80$; $P < 0.001$). In the samples without a predator, there are no differences in the average size of the brood. At the presence of a predator, the average brood size does not differ at different levels of turbulence.

The proportion of egg-bearing females in all variants of the analysis (in the whole data set and under the conditions without a predator and with a predator) is greater at low water flow rates (Table). At presence of a predator, regardless the flow rates, the proportion of egg-bearing females is higher than under the conditions without a predator.

As it can be seen from the results presented above, the effect of water turbulence onto the productive characteristics of *D. galeata* is negative. Average fertility is always lower at high water flow rates. At presence of a predator, the average fertility is significantly higher with low turbulence, compared to conditions without a predator. The average brood size at presence of a predator at all levels of turbulence is larger than under the conditions without a predator. The proportion of egg-bearing females is smaller at high water flow rates, but is always higher under the conditions with a predator than under the conditions without a predator. Thus, of all the analyzed factors, predators availability is the strongest one.

4. Discussion

The results obtained showed that fertility increases in the whole data set and under the conditions without a predator with an increase in the concentration of available food. The average brood size at all food concentrations does not differ in the whole the entire data set and under the conditions without a predator. At presence of a predator at high levels of turbulence, the average fertility is significantly less, the proportion of egg-bearing females increases. We have the right to assume that this is results directly from selective influence of the predator, which caused a significant decrease in the body size of mature females at high food concentrations, and this results in a decrease of fertility and size of the brood. Invertebrate predators consume small crustaceans, their pressure affects the number of pre-mature and small adult crustaceans. Large-sized adult crustaceans have a multiple advantage, since on the one hand they can accumulate large food reserves and produce large broods, on the other hand they are inaccessible to a predator. Thus, the birth rate increases, and some of the new crustaceans reach their adulthood and have time to leave an offspring. As it was shown in our work (Korzun and Pitul'ko, 2010), under the conditions of low concentration of food, the density of the predator is small and the temperature and concentration of food play the greatest role. At high food concentrations and a large number of predators, intensive size-selective predation is observed; it results in the fact that daphnia begin to multiply at smaller sizes, and this results in to a decrease of the amount of yield and average fertility. Such responses have been shown previously for natural and laboratory populations (Vijverberg, 1976; Czeczuga, et al., 2003; Boersma and Vijverberg, 1996; Polishchuk and Vijverberg, 2006; Heungens et al., 2006). With large quantities, food ceases to be a limiting factor, and all resources are used to increase the number of eggs and somatic growth, large crustaceans have a greater number of descendants (Polishchuk and Vijverberg, 2006).

In Lake Baikal, temperature increase up to the maximum observed values has a positive effect onto reproductive characteristics. The greatest increase of average fertility and the proportion of egg-bearing females was observed under the conditions without a predator. At high temperatures, the average fertility and the proportion of egg-bearing females significantly increase. The size of the body increases slightly, and the size of the brood remains unchanged. A similar response is observed in terms of body size, with large crustaceans present at high temperatures, especially under the conditions without a predator. At presence of a predator, the average fertility and the size of the brood greatly increase. It should be noted that under these conditions, a large brood size is observed at low temperatures. The proportion of egg-bearing females abruptly increased at low concentrations but not as much as under the conditions without a predator at high concentrations. Thus, the influence of the predator in many cases is more significant than the influence of temperature. The usual reaction of cladocerans to an increase of temperature is an acceleration of growth and development in the pre-mature stages and is maximally recorded at high food concentrations (Deng and Xiea, 2003; Heungens et al., 2006). Thus, it is possible to note the specifics observed in Lake Baikal, given that the water temperature reaches optimal for *D. galeata* only near the shores and in closed bays and coves. At high temperatures, under the conditions without a predator, an increase in body size was noted. It should be noted that in Lake Baikal, the water temperature rarely reaches optimal values for *D. galeata*. At presence of a predator, the sizes of bodies and broods decrease, while the proportion of egg-bearing females increases.

The results presented above clearly show the negative effect of water turbulence onto the reproductive characteristics of *D. galeata*. The average fertility, the size of the brood and the proportion of egg-bearing females are lower with high turbulence than with low one. In the presence of a predator, the average fertility is high at low turbulence and decreases at high speeds, while remaining higher than under the conditions without a predator. It should be noted that the conditions of severe turbulence are presented in areas with low values of other factors (food and temperature), so the observed results may result from their combined action. The average brood size at presence of a predator does not depend on turbulence and is greater than under the conditions without a predator. The proportion of egg-bearing females is always lower at high water flow rates, but under the conditions with a predator, it is higher than under the conditions without a predator. Under these conditions, there is no sufficiently pronounced effect onto body size. The decrease in the size of the body is presented only with high turbulence over the entire data array.

Thus, it can be noted that the influence of the predator is more important than the influence of turbulence. In addition, other factors studied (the amount of available food and water temperature), as well as the predator, have a greater influence onto population characteristics than turbulence.

5. Conclusions

An increase of amount of available food and of temperature have a significant positive effect onto all the studied reproductive characteristics (fertility, brood size, the proportion of egg-bearing females) in

D. galeata. The fertility and the size of the brood are determined by food and temperature. At the same time, the smallest response is in the size of the brood. At high feed concentrations, an increase in body size, fertility and the proportion of egg-bearing females was noted.

The influence of the predator stimulates the reproduction of the population by increasing the number of egg-bearing females. In addition, an invertebrate predator results in a decrease in the size of mature females and the size of the brood.

Turbulence in all cases has a negative effect, sometimes reduced by the presence of a predator. In the presence of a predator at low levels of turbulence, the average fertility and the proportion of egg-bearing females are higher, with a high level of turbulence, the fertility and the proportion of egg-bearing females decrease.

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Conflict of interests

The author declares no conflict of interests.

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Quantitative development and structure of zoobenthos in channels on the left margin of the Selenga River delta

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ABSTRACT. There are only a few studies on zoobenthos in the delta of the Selenga River located at the junction of Lake Baikal and its largest tributary. The present work provides the results of research on zoobenthos in the southern (left) Selenga delta channels in 2002. Baikal amphipods and bivalves are widespread up to the upper delta. The direction and velocity of the water flow in the delta induced change of a river zoobenthos complex for a limnophilous one. Baikal amphipods are responsible for high quantitative indicators of zoobenthos in the southern channels of the delta. Low parameters of quantitative development of zoobenthos were registered during summertime. Organic matter from the catchment area of the Selenga River provides trophic resources for zoobenthos. Amphipods, bivalves and oligochaetes are involved in the transformations of suspended, sedimented and buried fractions of allochthonous matter. The authors obtained evidence on maintenance of the principal properties of the delta ecosystem as an ecotone at the time of research.

Keywords: Selenga delta, zoobenthos, Baikal endemics, quantitative development, ecotone, allochthonous matter

1. Introduction

Selenga River with its drainage basin as a major tributary of Lake Baikal is an object of special concern of researchers (Ecosystems…, 2005). The Selenga River delta is located at the junction of the river and Lake Baikal. Over 50% of its water and suspended matter runoff is carried by the river flow into Lake Baikal, therefore estimation of matter and energy balance as well as drivers of their physical, chemical and hydrobiological changes within the delta ecosystem with the focus on the trophic chains is considered one of the most important trends in research of the delta ecosystem (Tulokhonov, 2008). Moreover, further monitoring of the river delta ecosystem based on relevant previous studies is required for a projected regulation of the Selenga River discharge.

The delta ecosystem has obvious distinctions from the main Selenga River channel in several parameters (Sorokovikova et al., 2000; 2005; Khazheeva et al., 2005). A significant portion of biogenic elements present in the Selenga waters is involved in a biotic turnover with a contribution of the plankton communities (Sorokovikova et al., 2005). Compared to well studied on the Selenga avandelta and adjacent shallows, as well as the main Selenga riverbed (Vershinin, 1964; Bekman, 1971; Syroezhkina, 1973; Bazova, 2004; Bazova and Bazov, 2006), the data published on zoobenthos of the Selenga River delta are rare. Information on the state of zoobenthos prior to intense industrial activities in the catchment area (Vershinin, 1964; Syroezhkina, 1973; Sorokina, 1975) gives us a very general idea. Problems of the delta ecosystem and its zoobenthos became a matter of special concern during 2002–2003 research surveys (The Selenga river delta…, 2008). At that time, studies were carried out with the participation of INREC SB RAS. In 2011, Institute of General and Experimental Biology (IGEB) SB RAS undertook investigations of gammarid populations (Matafonov and Bazova, 2014). Researchers from the Limnological Institute (LIN) SB RAS studied zoobenthos in some channels of the delta under unstable hydrological conditions in 2012 (Rozhkova et al., 2016).

We suggest that the initial stage of investigating matter exchanges between Selenga and Baikal, and the role of aquatic biota in their transformations should include collection of data on zoobenthos from the main delta channels. The bulk of the water runoff and matter flow passes through the channels of the left (southern) delta margin. The authors' publications (Matafonov and

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**Matafonov D.V. was the researcher of the INREC during the research of the Selenga River delta

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Matafonov, 2008; Matafonov, 2014; Matafonov et al., 2018) provide only a partial view of the zoobenthos in the southern channels in 2002–2003 and are insufficient to describe it during this period.

The present work is aimed at elucidating the quantitative development and structure of zoobenthos from the channels in the left part of the Selenga river delta.

2. Materials and methods

Methodologically this study is based on a structural and functional approach to investigation of aquatic ecosystems (Alimov, 2000). For this study zoobenthos samples were collected during complex studies of the ecosystem of the entire delta from March until October 2002 at the part of the Selenga River from Kabansk settlement up to the mouth of the channels on the left side of the delta: Kharauz, Galatuy, Levoberezhnaya and Shamanka (Fig.1). Totally, collected 26 samples, taking up to 3 zoobenthos samples from each site by means of a Petersen grab (sample area 0.025 m^2). Samples were washed through a mill sieve (mesh size 0.3 mm) and fixed in 4% formalin. Standard error is given for mean values.

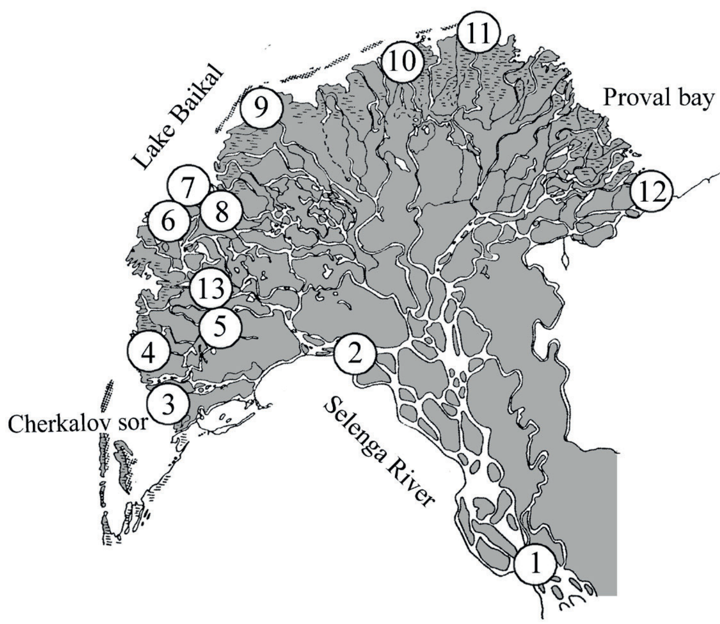

Fig.1. Schematic presentation of zoobenthos sampling sites in the Selenga delta in 2002.

1 – Selenga River near Kabansk village; 2 – Selenga River near Murzino village; 3 – Levoberezhnaya channel (mouth); 4 – Shamanka channel (mouth); 5 – Kharauz channel near Semenovsky Island; 6 – Kharauz channel (mouth); 7 – Galatuy channel (mouth); 8 – Galatuy channel; 9 – Srednyaya channel (mouth); 10 – Kolpinaya channel (mouth); 11 – Severnay channel (mouth); 12 – Lobanovskaya channel (mouth); 13 – Lake Zavernyaikha.

3. Results

A characteristic component of communities in the main stream of the Selenga River are mayflies (Vershinin, 1964; Syroezhkina, 1973; Bazova, 2004), their highest species richness was observed at the river part near Kabansk settlement. We registered *Ephemera orientalis* (McLachlan, 1875), *Baetis* sp., *Isonychia ussurica* (Baykova, 1970), *Heptagenia flava* (Rostock, 1878) and *Rhithrogena* sp. Species of a rheophilic Heptageniidae family were most abundant. The Selenga River looks like a typical piedmont river in this place and the biotopes are represented by gravel-pebble grounds with algal fouling. The mayflies are a particularly rare and sparse constituent in this location represented by *Caenis* sp., *H.a flava* and *Potamanthus luteus* (L., 1767). The first species is found everywhere in the delta: in streams Galatuy and Kharauz, for instance, in the lake system of the delta and in the Selenga River near Murzino settlement. The abundance of *Caenis* sp. reached 120 ind./m^2 in the channels. Generally, *Caenis* sp. was common at the sites with lower flow velocity, warmer water and deposited plant residues. In the delta, Heptageniidae family is represented by only one *H. flava* species due to the absence of rocky substrates, high water turbidity and predominance of silty soils. The presence of submerged substrates, such as driftwood, on which it is able to settle, favors the settlement of this species. *P. luteus* was registered once at the river part near Murzino village, whereas it was very rare in the delta.

Baikal amphipods, *Gmelinoides fasciatus* (Stebbing, 1899) and *Micruropus possolskii* Sowinsky, 1915 (Table) were found in abundant at most studied delta sites. *Micruropus wohlii platycercus* (Dybowsky, 1874) was encountered at the outer side of the Selenga avandelta facing Baikal, as well as in Galatuy and Kharauz channels (mouth area). The largest numbers of this species (up to 240 ind./m^2) were observed in the region of Bolshaya Prorva in October 2002. No Baikal amphipod species were registered either at the part of the Selenga River near Kabansk settlement where the river did not yet branch into delta channels and was a typical submountain river, or in the vicinity of Murzino settlement (upper delta part).

The abundance of zoobenthos in the upper delta part near Murzino settlement was as high as 7280 ind./m^2, biomass – 16.24 g/m^2, their average values from May until October being 1975 ± 1358 ind./m^2 and 2.90 ± 2.23 g/m^2. Directly in the channels of the left delta margin these values were significantly higher (Table). Their abundance peak was registered in March with subsequent decrease up to minimal numbers in May (Table), in October, zoobenthos showed relatively high abundances again. In October 2002, average abundance values of zoobenthos varied from 6720 to 17960 ind./m^2, biomass – from 19.24 to 50.52 g/m^2 (Table), maximal values reached 34320 ind./m^2 and 73.32 g/m^2 in Kharauz channel. The dominant zoobenthos species, ranked by biomass in channels on the left delta side, were amphipods (65.9%), bivalves (14.5%), represented by *Pisidium baicalense* Dybowski, 1902, and oligochaetes (13.8%) (Table). Amphipods were dominated by *Gm. fasciatus* and *M. possolskii*, oligochaetes by the representatives of the family Tubificidae.

Table. Quantitative development of zoobenthos in the channels on the left margin of the Selenga delta in 2002.

Taxon	March	May	June	July	October	March-October
Oligochaeta	5893 ± 2713 8.51 ± 4.10	1427 1.12	2185 ± 932 3.41 ± 1.69	5960 ± 2996 1.89 ± 0.88	8485 ± 3876 6.25 ± 3.26	4790 ± 1310 4.23 ± 1.38
Bivalvia	320 ± 162 5.31 ± 3.75	27 0.37	435 ± 228 1.58 ± 0.62	190 ± 53 2.79 ± 1.19	285 ± 121 12.18 ± 6.03	251 ± 68 4.45 ± 2.10
Amphipoda	6453 ± 1205 67.37 ± 16.63	1027 4.69	4790 ± 1840 4.21 ± 1.33	4530 ± 3761 12.19 ± 10.59	1260 ± 250 12.38 ± 2.74	3612 ± 1061 20.17 ± 11.93
Others	226 ± 207 1.00 ± 0.90	173 0.40	1321 ± 840 2.53 ± 1.59	420 ± 195 0.35 ± 0.11	1565 ± 531 4.37 ± 2.42	745 ± 294 1.74 ± 0.77
Benthos	12893 ± 3794 82.19 ± 22.50	2653 6.59	8731 ± 1643 11.73 ± 2.69	11100 ± 2922 17.22 ± 10.82	11595 ± 3912 35.18 ± 7.18	9395 ± 1814 30.58 ± 13.77

Note: In the numerator – abundance (ind./m^2), in the denominator – biomass (g/m^2).

4. Discussion

Abundance of Baikalian amphipods and molluscs as well as their penetration into the delta led to the mixed zoobenthos composition represented both widespread and endemic Baikal taxons. *Gm. fasciatus* and *M. possolskii* abundant in the delta were not able to move against fast river current and overcome upper delta boundary. None of them were registered in zoobenthos of the main river channel on the territory of the Russian Federation (Vershinin, 1964; Bazova and Bazov, 2006). Typical lake forms of amphipods belonging to Baikal fauna – *M. wohlii platycercus* and Holarctic fauna – *Gammarus lacustris* Sars, 1863 have a limited distribution in delta (Matafonov and Matafonov, 2008). Their biotopes are clearly delineated in the delta: *M. wohlii platycercus* is confined to clean well-drained sands of the avandelta, *G. lacustris* to slow-flowing streams overloaded with organic matter and the community dominated by *Erpobdella octoculata* (L., 1758) leech. Substitution of rheophilic mayfly species by amphipods adapted to lotic-lentic environments indicates a buffer function of the delta and ecotonisation of its communities.

Zoobenthos inhabiting channels on the left Selenga delta margin is characterized by high quantitative parameters compared to that from the main river channel (Bazova, 2004). Decrease in the zoobenthos abundance during summer may be a result of specific seasonal dynamics of the dominating zoobenthos populations. For example, analysis of the demographic structure of amphipod populations showed decrease of average weight of crustaceans in spring-summer period caused by juvenile hatching and loss of the parental population (Fig. 1). Another reason of that was, probably, spring floodings which are one of the main factors decline of zoobenthos abundance in the main river channel in spring and summer (Vershinin, 1964).

We assume that factors determining changes in the zoobenthos from the delta are as follows: silting of bootom sediments (Vershinin, 1964) and transformation of sediments chemical composition (Khazheeva et al., 2005), decrease in the concentration of water pollutants (Sorokovikova et al., 2000), increase of the abundance and biomass of phytoplankton as well as heterotrophic microorganisms, and involvement of the bulk of biogenic elements of Selenga water into the biological turnover in the delta (Sorokovikova et al., 2005). Apparently, these factors in total determine changing the rheophilic zoobenthos complex from the upper and middle river streams into the lacustrine-riverine complex of the delta channels even before Selenga enters Lake Baikal. It allows us to consider the delta as an ecological barrier, on the one hand, preventing introduction of Baikal fauna into middle and upper streams of the Selenga River, and on the other hand, penetration of widespread rheophilic fauna into Lake Baikal. In the authors' opinion, decrease of the stream velocity in the delta (Sinyukovich et al., 2004) and opposite direction of the flow, requiring significant efforts to overcome it, are main factors in the formation of a mixed composition of zoobenthos in the delta.

Apparently, the trophic basis of the delta zoobenthos, as has been shown previously for Selenga shoal of Lake Baikal (Bekman, 1971), is allochthonous organic matter, abundantly represented by the remains of terrestrial vegetation in the delta sediments and in the gut of benthic animals. Thus, allochtonic matter determines the trophic relationships of Baikal fauna with that of the Selenga drainage basin and contributes to specialization and functional role of zoobenthos of the delta channels in utilizing its different fractions: suspended (bivalves), sedimented (amphipods) and buried (oligochaetes). Abundant of amphipods may attest to supply of low-mineralized organic matter (Cherepanov, 1978) and significant role of zoobenthos and Baikal endemics in particular in its transformations in bottom biotopes.

The results obtained during studies on the channels of the left side of the delta in 2002 are comply with the previous data (Vershinin, 1964) on increase numbers of zoobenthos as it reaches the lower part of the Selenga River, and change of litho-rheophilic zoobenthic communites by psammo-pelophilous lake-river communites, as well as with the reports on mixing of river and lake faunas in the delta channels, and oligochaete and Baikal amphipod abundance in the delta channels (Syroezhkina, 1973). Taking into account scarcity of multi-year observations on the state of zoobenthos in the delta, the results provide evidence on preservation of principal characteristics of the delta ecosystem as an ecotonic zone at the time of investigations in 2002.

5. Conclusions

Despite the limited amount of material and the approximate results of the study we believe that the results of this work will be useful in understanding the long-term dynamics of zoobenthos and delta ecosystem, as well as in designing optimal a network of monitoring stations and research approaches. In our view, further studies of zoobenthos in the Selenga delta from structural and functional approach will enable us to understand physical, energetic and informative relationships of a unique biota of Lake Baikal and the catchment area of the Selenga River.

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Conflict of interests

The authors declare no conflict of interests.

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Water quality and zooplankton community of the Eme River, Umuahia, Southeast Nigeria

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ABSTRACT. Aquatic ecosystems and biota are often adversely affected by anthropogenic activities. Consequently, zooplanktons have been used to monitor anthropogenic impacts because of their sensitivity to their environment. Water quality and zooplankton community of the Eme River, Umuahia, was assessed between December 2017 and November 2018. The study was carried out in six stations in relation to human activities. Human activities in the watershed were dominated by sand mining. A quantitative filtration method was used for the zooplankton sample collection while standard sample collection and analytical methods were used for the water samples. The zooplankton species recorded were 27 while the most abundant zooplankton group was Rotifera. A known pollution indicator, *Daphnia pulex*, had the highest number of individuals. The effects of human activities in the watershed were reflected in the results of some of the physicochemical parameters of the river. The zooplankton assemblage and community structure also reflected the effects of human activities in the river. Combined effects of human activities and season contributed to the relatively low zooplankton abundance recorded particularly in some downstream stations. The impacts of sand mining on water quality and zooplankton were more remarkable in the downstream stations (4 – 6) where the activity was intense while a large number of children swimming and related activities during the dry season had some impacts in station 1. The dominance of indicator and tolerant species indicated that the river was undergoing eutrophication. Sand mining among other observed anthropogenic activities was a major contributor to the nutrient enrichment in the river. The major water quality parameters influencing the zooplankton community structure was revealed by canonical correspondence analysis.

Keywords: zooplankton, diversity, anthropogenic impact, bioindication, water quality, sand mining

1. Introduction

The water quality of the rivers is of considerable importance because they are generally used for multiple purposes (Venkatramanan et al., 2014). Freshwater bodies across the world have been subjected to intense human activities that have degraded the quality and utility of the water (Amah-Jerry et al., 2017). Water pollution is a serious problem in developing countries; adequate monitoring of water quality is necessary to appraise the suitability, assist management and control (Kozaki et al., 2020). The quality of the aquatic ecosystem and the ecological effects of human activities can be predicted by the assessment of its biological communities (Santos and Ferreira, 2020). One of the essential biological communities found in lotic freshwater ecosystems is zooplankton. Zooplankton is microscopic animals that serve as an important link in the conversion of energy from producers to consumers; playing an essential role in the aquatic food webs (Sharma et al., 2010; Schmidt et al., 2020). Zooplanktons are weak swimmers and usually drift along with the currents (Prygiel and Coste, 1993). They strongly respond to environmental changes and are used in the assessment of the conditions in aquatic ecosystems (Primo et al., 2015). Temporal and spatial variations of physicochemical environmental conditions often lead to dramatic and rapid changes in zooplanktons because they have a short life span and fast regeneration (Pace and Orcutt, 1981). Environmental parameters (dissolved oxygen (DO) and nutrients) are important for the presence and distribution of zooplankton. Low values of DO would limit their development. Nutrients (NH_4^+ and PO_4^{3-}) are important for their growth while pH and total suspended solids (TSS) are essential for their distribution (Duc et al., 2016). The efficiencies

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of trophic transfer from phytoplankton to zooplankton and from zooplankton to fish depend largely on the taxa of zooplankton available in an aquatic ecosystem (Hairston and Hairston, 1993). A decline in zooplankton diversity in aquatic ecosystems will ultimately affect higher trophic levels. This will result in loss of species, habitat or even ecosystems and ecosystem services if there is no control (Gaygusuz and Dorak, 2013). Some anthropogenic activities take place at the Eme River, of which illegal and indiscriminate sand mining is the major. The objective of this study was to assess the water quality and zooplankton diversity vis-à-vis anthropogenic activities.

2. Materials and methods

2.1. Study area

The Eme River is located in Umuahia, Abia State, Nigeria. It originated in Uzuakoli, flowed through some communities and fell into the Imo River at Onuimo. The section studied is from Ofeme to Umudiawa across the Port Harcourt - Enugu expressway in Umuahia; about 3.25km in length and situated between latitude 5°38' and 5°37'N and longitude 7°25' and 7°26'E (Fig. 1). The study area is characterized by mean annual rainfall (4000mm), high relative humidity (>70%) and high temperature (29-31°C). There are two main seasons in the area: wet (June to November) and dry (December to May), with double maximum rainfalls recorded in July and September. "August break" is a short period of dryness usually occurring in between the peaks.

2.2. Sampling stations

Six sampling stations were selected in the river based on accessibility and human activities. Five of the stations were within the dredged section, except for station 1. Station 1 is upstream, and the reference site is located in Mbato, Ofeme community. The substrate is muddy. A large number of children was observed swimming during the dry season up to early rains due to the proximity to the village, easy accessibility and low water depths. Other activities observed include washing of clothes and extraction of water for domestic purposes during the dry season. Station 2 is about 1.84 km downstream of station 1 and located at the outsketch of Ofeme community at Eme – Ihite. The substrate is a mixture of sand and stones. It was a less active or abandoned sand mining site, and minimal washing of clothes, swimming and extraction of water for domestic purposes were observed during the dry season. Station 3 is located at Eme – Ihite, towards the expressway, about 419.67 m downstream of station 2. Large clayey boulders dominated the substrate. The only activity observed was periodic boat movements of sand miners across the station. Station 4 is about 490.26 m downstream of station 3 and is located in the Umudiawa community across the expressway. The substrate was sandy. An intensive sand mining and two sand landing sites were located upstream of the station. Station 5 is about 200.22 m downstream of station 4, within the Umudiawa community. Sand mining was observed because the substrate is sandy. Station 6 is about 300.14 m downstream of station 5, within Umudiawa community. The substrate was sandy. Sand mining was observed in the river channel and banks.

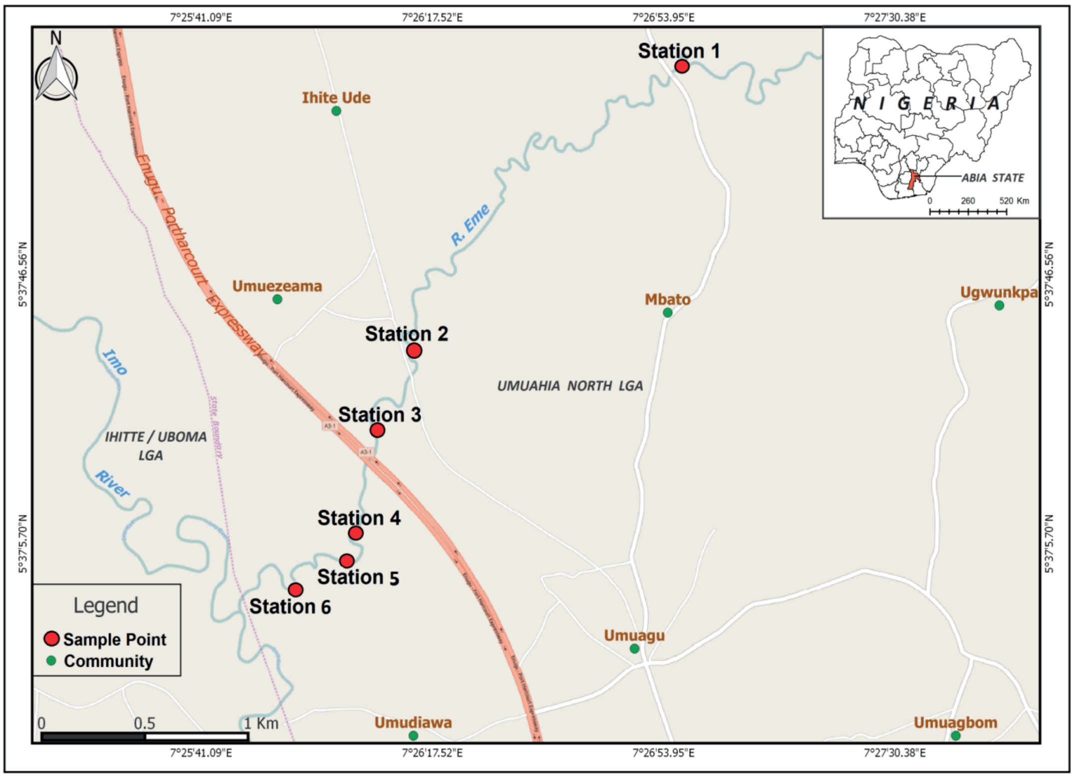

Fig.1. Map of Umuahia, Abia State, Nigeria, showing the sampling stations on the Eme River.

2.3. Samples collection and analysis

This study was carried out between December 2017 and November 2018. Samples for water quality and zooplankton analyses were collected once a month. One litre water sampler was used for the sample collection, transferred into sterilized 1 litre plastic bottles and taken to the laboratory for analyses in ice chests. Water temperature (mercury-in-glass thermometer), flow velocity (floatation method), transparency (Secchi disk), pH, electrical conductivity, and total suspended solids (pH/EC/TDS Meter- HANNA 3100 model) were determined in situ while others were determined in the laboratory using standard methods described by APHA (2012) - dissolved oxygen and biochemical oxygen demand (Winkler's method with azide modification method), nitrate (UV spectrophotometric method), and phosphate (Stannous Chloride Method).

The quantitative filtration method was used for zooplankton sample collection. One hundred litres of water from undisturbed sections of each station were collected and filtered through a 55 μm Hydro-Bios plankton net as a composite sample. The net content was poured into plankton bottles (250 mL) and preserved in a 4% formalin solution. A subsample (1 mL) of the preserved sample was taken using a pipette. The collected sample was put on the Sedgwick-rafter counting chamber and viewed under a light binocular microscope (Nikon 400 binocular microscope) using a low magnification of x10. The zooplankton was sorted into different groups, and the cells per ml were counted. The identification was done to the lowest practicable taxonomy using key literature by Jeje and Fernando (1986) and Dang et al. (2015).

2.4. Data analysis

The results were summarized using a descriptive statistic package of Microsoft Excel. One-way ANOVA was used to test for statistical differences among the stations while Tukey's pairwise test was used for post hoc analysis. The zooplankton community structure was analysed using Margalef (D), Shannon-Weiner (H) and Evenness (E) indices while canonical correspondence analysis (CCA) was used to determine the relationship between the zooplankton groups and some environmental variables.

3. Results and discussion

3.1. Spatial and temporal variations of physico-chemical parameters

The summary of the physicochemical parameters is presented in Table 1. The water temperatures were moderate and ranged between 22.0 and 28.5°C. The lowest value was recorded in station 1 (May 2018) while the highest value was recorded in station 6 (April 2018). The ambient surface water temperatures were influenced by seasons and sampling periods. An early rain event was responsible for the lowest temperature recorded in May 2018 while the highest temperature in April 2018 was due to the dry season. Air temperatures are the major determinant of surface water temperatures (Park et al., 2016), and water temperature is a critical factor in some biotic and abiotic processes in the aquatic environment (Dugdale et al., 2018).

The flow velocity was moderate (0.21 - 0.85 m/s). Station 1 had the lowest value in April 2018, and the highest one was recorded in station 3 in December 2017. Stations 2 and 3 were significantly higher ($F = 31.59$; $P < 0.05$). Flow velocity can significantly influence the self-purification capacity of a waterbody (Chapman and Kimstach, 1996). Flow velocity can considerably affect the composition, abundance and distribution of aquatic biota (Brooks et al., 2005; Oldmeadow et al., 2010). CCA also showed that flow velocity was a strong negative factor especially in station 3. Increased flow velocity and river discharge can result in low species composition and abundance due to low residence time, especially in the wet season (Anyanwu et al., 2013).

The turbidity values ranged between 0.5 and 9.4 NTU; some exceeded the acceptable limit (5 NTU) of the Federal Ministry of Environment (FMEnv., 2011) in all the stations. The turbidity values exceeding limits in all the stations, especially between December 2017 and March 2018, could be attributed to the cumulative effect of receding flood and anthropogenic activities. The lowest and highest values were both recorded at station 4 in March and February 2018, respectively. High turbidity values were recorded at station 1 during the dry season due to a large number of children swimming, bathing, washing, and extraction of water for drinking. The station was shallow during the dry season and located close to the community. However, relatively higher values were recorded at stations 4 – 6 between May and November 2018 because of the effect of sand mining activities that increased with the intensity of rains (Anyanwu and Umeham, 2020). This was more remarkable in station 4 that was immediately downstream of sand mining and landing sites with a steady decline further downstream (Seiyaboh et al., 2013). CCA also showed that turbidity had a negative effect on zooplankton at station 4.

The pH values were acidic (4.3 - 6.3) and did not comply with the acceptable limit. FMEnv. (2011) recommended 6.5 to 8.5 for aquatic life. The lowest pH was recorded at station 2 (June 2018) while the highest was recorded at station 1 (September 2018). These low pH values could be due to both geogenic (Anyanwu and Emeka, 2019) and anthropogenic influences (Akankali et al., 2017). Seiyaboh et al. (2013) reported that sand mining contributes to low pH in water bodies. Extremes of pH cannot be tolerated by most aquatic organisms. Aquatic biota is very sensitive to pH levels lower than 5, which may result in death (Kale, 2016).

The electrical conductivity (EC) values ranged between 45.2 and 168.4 μS/cm. The lowest value was recorded at station 2 (March 2018) while the highest value was recorded at station 5 (January 2018). The electrical conductivity (EC) values were moderate, but the upstream stations (1 – 3) were significantly ($F = 29.59$; $p < 0.05$) lower than the downstream stations

Table 1. Summary of physicochemical parameters of the Eme River, Umuahia, Nigeria.

Parameter	Stn 1 X ± SEM	Stn 2 X ± SEM	Stn 3 X ± SEM	Stn 4 X ± SEM	Stn 5 X ± SEM	Stn 6 X ± SEM	P-value	FMEnv.
Water temperature (°C)	24.8 ± 0.59	24.9 ± 0.54	24.8 ± 0.53	24.9 ± 0.51	24.4 ± 0.53	24.8 ± 0.53	P > 0.05	< 40
	(22.0-28.0)	(22.5-28.2)	(23.0-28.2)	(23.2-28.4)	(23.0-28.3)	(22.9-28.5)		
Turbidity (NTU)	4.2 ± 0.61	3.5 ± 0.52	3.0 ± 0.48	5.0 ± 0.72	3.9 ± 0.61	4.1 ± 0.56	P > 0.05	5
	(1.5-9.3)	(1.3-8.1)	(0.6-5.4)	(0.5-9.4)	(0.7-7.8)	(0.9-6.9)		
Flow velocity (ms^{-1})	0.35 ± 0.02[a]	0.56 ± 0.04[b]	0.71 ± 0.02[c]	0.36 ± 0.02[a]	0.37 ± 0.02[a]	0.45 ± 0.03[a]	P < 0.05	-
	(0.21-0.49)	(0.37-0.80)	(0.63-0.85)	(0.24-0.46)	(0.28-0.50)	(0.26-0.58)		
pH	5.69 ± 0.11	5.43 ± 0.13	5.42 ± 0.10	5.53 ± 0.10	5.49 ± 0.10	5.55 ± 0.10	P > 0.05	6.5 – 8.5
	(5.0 – 6.3)	(4.3 – 5.9)	(4.9 - 6.1)	(5.0 – 6.1)	(5.1 – 6.2)	(5.1 - 6.1)		
Electrical conductivity (μScm^{-1})	86.0 ± 4.40[a]	71.3 ± 4.43[a]	65.7 ± 3.50[a]	130.4 ± 5.86[b]	115.4 ± 6.04[b]	119.6 ± 5.38[b]	P < 0.05	-
	(55.6-115.8)	(45.2-95.4)	(49.6-88.7)	(90.3-160.2)	(88.5-168.4)	(87.1-148.4)		
Dissolved oxygen (MgL^{-1})	3.7 ± 0.38	3.6 ± 0.34	3.7 ± 0.40	3.9 ± 0.46	3.6 ± 0.37	3.8 ± 0.42	P > 0.05	6
	(2.3-5.7)	(2.2-5.9)	(1.8-6.1)	(1.6-6.1)	(2.0-5.5)	(1.8-5.8)		
Biochemical oxygen	1.7 ± 0.14[ab]	1.5 ± 0.08[b]	1.7 ± 0.12[b]	2.6 ± 0.37[ac]	1.9 ± 0.20[ab]	2.1 ± 0.25[ab]	P < 0.05	3
Demand (MgL^{-1})	(1.0-2.5)	(1.1-1.9)	(1.1-2.4)	(0.8-4.3)	(1.0-3.2)	(0.9-3.9)		
Nitrate (MgL^{-1})	2.9 ± 0.30[b]	2.2 ± 0.17[b]	1.6 ± 0.12[a]	4.5 ± 0.20[c]	2.6 ± 0.37[ab]	2.9 ± 0.27[b]	P < 0.05	9.1
	(1.8-4.9)	(1.3-3.2)	(1.1-2.4)	(3.4-5.6)	(1.2-5.3)	(1.9-5.2)		
Phosphate (MgL^{-1})	1.3 ± 0.08[a]	0.8 ± 0.10[a]	0.7 ± 0.07[a]	3.4 ± 0.18[b]	2.8 ± 0.22[bc]	2.9 ± 0.21[bc]	P < 0.05	3.5
	(1.0-1.9)	(0.5-1.7)	(0.4-1.2)	(2.8-4.6)	(1.9-4.3)	(2.0-4.5)		

Note. a, b, c, d, e – Means with different superscripts across the rows are significantly different at $p < 0.05$; SEM – Standard error of the mean; FMEnv. (2011) – National environmental (surface and groundwater quality control) regulations (2011).

(4 – 6) due to the effects of sand mining activities in the downstream stations. Sand mining activities increase the levels of EC in surface water (Rehman et al., 2016) and usually contribute to an increase in water pollution. The relatively higher EC values recorded in station 1 compared to stations 2 and 3 could be attributed to perturbation from a large number of children swimming during the dry season as well as allochthonous inputs in the wet season from increased runoffs.

Dissolved oxygen is an essential parameter used in the assessment of water quality (Kale, 2016), and its level is very important to support biodiversity in aquatic ecosystems. Only two of the dissolved oxygen values exceeded the acceptable limit (6 mg/L) set by FMEnv (2011). The values ranged from 1.6 to 6.1 mg/L; the lowest one was recorded in station 4 (November 2018), and the highest – in stations 3 (January 2018) and 4 (February 2018). Most of DO values were below the acceptable limit, especially in station 4 due to anthropogenic impact (sand mining). Rao et al. (2013) reported that some environmental impacts associated with sand mining activities such as re-suspension of nutrients and chemicals, altered water flow and increased water temperature can contribute to the depletion of oxygen in the water. CCA showed that dissolved oxygen was one of the major positive factors influencing the zooplankton community.

Biochemical Oxygen Demand (BOD) is another important parameter used in evaluating the health and self-purification capacity of freshwater bodies. BOD ranged between 0.8 and 4.3 mg/L; the lowest and highest values were recorded in station 4 in November 2018 and February 2018, respectively. Some of the values, especially in the downstream stations (4 – 6), exceeded the acceptable limit (3 mg/L). Station 4 was significantly different ($F = 3.43$; $p < 0.05$) from stations 2 and 3. This is also due to sand mining activities. Akankali et al. (2017) observed that sand mining activities greatly increase the release and circulation of organic matter from the sediments into the water column, which can contribute to an increase in BOD levels.

Nitrate occurs naturally in many environments at moderate levels, except for those under the impact (Chapman and Kimstach, 1996). The nitrate values (1.1 - 5.6 mg/L) were within the acceptable limit. The lowest value was recorded in station 3 (June 2018) while the highest value was recorded in station 4 (February 2018). Higher values were recorded in the downstream stations (4 – 6), which could be caused by sand mining activities. In particular, station 4 was significantly higher ($F = 14.62$; $p < 0.05$) than the others. Akankali et al. (2017) recorded higher values (10.7 - 12.4 mg/L) in the Okoro Nsit stream, South South Nigeria that is also subjected to intense sand mining activities. The effect of a large number of children swimming during the dry season and allochthonous inputs during the wet season could be responsible for the elevated values in station 1 compared to stations 2 and 3.

Phosphate exhibited the same trend as nitrate. The values ranged between 0.4 and 4.6 mg/L, with the lowest values recorded in June and July 2018 (station 3) and the highest values in September 2018 (station 4). The values of the downstream stations (4 – 6) exceeded the acceptable limit set by FMEnv. (2011) and were significantly ($F = 56.71$; $p < 0.05$) higher than the upstream stations (1 – 3) values. This could be also caused by sand mining activities. Akankali et al. (2017) recorded lower values (2.5 to 3.6 mg/L) in the Okoro Nsit stream, South South Nigeria. Relatively higher phosphate values were also recorded in station 1 compared to stations 2 and 3 as observed for nitrate and attributed to the same factors.

3.2. Zooplankton composition, abundance and distribution

The zooplankton species composition, abundance and distribution are presented in Table 2. A total of 3382 zooplankton individuals were recorded. The most abundant group was Rotifera (1064 individuals/L or 31.5%) followed by Cladocera (961 individuals/L or 28.4%), Protozoa (741 individuals/L or 21.9%), and Copepod (616 individuals/L or 18.2%). Rotifera was also reported as the dominant group in other Nigerian rivers subjected to intense sand mining (Ekwu and Udo, 2014; Ekpo et al., 2015). Small size, parthenogenesis and rapid reproduction of rotifers under favourable conditions (nutrient-enriched water) could be responsible for their high abundance (Levine et al., 1999). Other factors include their morphological variations and adaptations (Wetzel, 2001) as well as their diverse feeding habits (Mustapha, 2009). Rotifers minimize competition through niche exploitation and food utilization owing to their ability to migrate vertically, which could also be responsible for their dominance (Ekpo et al., 2015).

The number of species recorded was higher than 4 and 8 species recorded in the Odot stream and Ikpa River, respectively, in the Niger Delta, Nigeria, which were also subjected to sand mining activities (Ekwu and Udo, 2014; Ekpo et al., 2015). The relatively low zooplankton abundance could be attributed to anthropogenic impact exacerbated by seasonal influences. Arimoro and Oganah (2010) recorded a higher abundance (4322 individuals/1) in the Orogodo River of the Niger Delta, Nigeria, perturbed by abattoir effluent and sand mining activities.

Table 2. Species composition, abundance and distribution of zooplankton in the Eme River, Umuahia, Nigeria.

Group	Taxa	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Total	RA (%)
Copepoda	*Campthocamptus staphylinus*	26	21	14	33	22	22	138	4.08
	Eucyclops speratus	10	22	39	29	12	32	144	4.26
	Microcyclops varicans	21	27	22	11	16	21	118	3.49
	Sinodiaptomus sarsi	23	20	20	0	3	22	88	2.6
	Mesochra suifunensis	24	18	26	16	10	34	128	3.78
Cladocera	*Alona affins*	12	19	25	27	34	13	130	3.84
	Daphnia longis	20	26	23	10	20	35	134	3.96
	D. pulex	25	25	35	27	37	26	175	5.17
	D. magna	26	26	25	12	22	28	139	4.11
	Moina dubia	44	22	19	20	26	35	166	4.91
	M. micrura	11	18	22	20	22	15	108	3.19
	Diaphanosoma Brachyurum	21	15	19	27	20	7	109	3.22
Rotifera	*Keratella cochlearis*	20	20	21	14	15	14	104	3.08
	Brachionus capsuliflorus	20	26	12	25	23	35	141	4.17
	B. plicatilis	16	24	18	25	17	30	130	3.84
	Asplanchna priodonta	27	19	25	27	31	22	151	4.47
	Notholca labis	15	36	14	11	33	22	131	3.87
	Synchaeta pectinata	26	23	30	23	21	29	152	4.49
	Conochilus umcormis	25	23	25	21	6	28	128	3.79
	Ascomorpha ecaudis	29	30	20	13	17	18	127	3.76
Protozoa	*Paramecium candatum*	15	21	13	12	24	20	105	3.11
	Difflugia candatum	14	18	22	15	17	7	93	2.75
	Didinium bolbanic	26	25	22	8	8	14	103	3.05
	Tintinnopsis lacustris	17	27	12	20	23	25	124	3.67
	Amoeba radiosa	11	17	12	13	11	23	87	2.57
	Vorticella radians	20	30	17	24	18	32	141	4.17
	Arcella nitrata	19	21	25	15	3	5	88	2.60
	Total	**563**	**619**	**577**	**498**	**511**	**614**	**3382**	

The most abundant zooplankton recorded was *Daphnia pulex* (Cladocera) with 175 individuals/L (5.17% of the total zooplankton abundance). *Daphnia pulex* is the most common cladoceran found almost in all permanent and eutrophic freshwater environments (Miller, 2000). The large body sizes of *Daphnia* makes it possible for them to graze on large quantities and diverse forms of phytoplankton; contributing to their predominance among the cladocerans (Mustapha, 2009), and their composition and abundance is also dependent on food supply (Miller, 2000).

Spatially, the most abundant individuals (619 individuals/L or 18.3%) were recorded in station 2 followed by station 6 (614 individuals/L or 18.2%), station 3 (577 individuals/L or 17.1%), station 1 (563 individuals/L or 16.6%), station 5 (511 individuals/L or 15.1%), and station 4 (498 individuals/L^{-1} or 14.7%). Little or no human activities were responsible for the high zooplankton abundance in station 2 while sand mining activities were responsible for the low abundance in station 4. Arimoro and Oganah (2010) recorded lower abundance in station 3, where sand mining occurred in contrast to station 1 (control) with no activity recorded. Station 6 showed signs of recovery after the impacts. Arimoro and Oganah (2010) observed that sensitive species usually disappears when water becomes polluted and recovers quickly downstream of the impact source while tolerant species survive stress associated with pollution and flourish. Ko et al. (2020) also reported a significant recovery in the number of species and individuals after dredging operations. High flow velocity could be also responsible for the relatively lower abundance in station 3. Planktonic organisms are continuously washed downstream by flowing water; therefore, their development is usually affected (Redden et al., 2009).

3.2.1. Zooplankton community structure

In the assessment of pollution and waterbody productivity using plankton, diversity indices have an important application (Hastuti et al., 2018). It is general knowledge that species diversity and richness are usually reduced as the perturbation increases; though some tolerant species tend to flourish (Xu et al., 2005). The zooplankton groups showed varied responses to the effects of anthropogenic activities as reflected in their community structures (Table 3).

Generally, Rotifera was the most abundant group while Copepoda was the least one. The abundance ranged between 63 individuals/L (copepoda, station 5) and 201 individuals/L (Rotifera, station 2). Lower abundance was recorded in stations 4 (Cladocera and Rotifera) and 5 (Copepoda and Protozoa). Highest abundance was recorded in stations 2 (Rotifera and Protozoa), 5 (Cladocera) and 6 (Copepoda). The abundance though varied among the groups was relatively higher at the less perturbed stations (1 – 3) while lower abundances were recorded in the more perturbed stations (4 and 5) and station 6 showing signs of recovery (Ko et al., 2020).

Rotifera and Copepoda had the highest and lowest Shannon-Weiner diversity index (H), respectively. Among the Rotifera, station 2 had the highest value (2.059), and station 5 – the lowest value, (1.992) followed by station 4 (2.033). The highest Shannon-Weiner diversity index (H) was recorded in station 2 (1.600), and the lowest one – in station 4 (1.300) among the Copepoda. The Shannon-Weiner diversity indices were all low (1 – 2), indicating some level of pollution. Station 2 had relatively higher values in all the zooplankton groups while station 6 showed signs of recovery in some groups. Water bodies are classified

Table 3. Community structure of zooplankton in the Eme River, Umuahia.

Group	Biodiversity indices	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Copepoda	Individuals	104	108	121	89	63	131
	Shannon-Weiner (H)	1.567	1.6	1.552	1.3	1.468	1.587
	Evenness (E)	0.9583	0.9906	0.9445	0.9175	0.8685	0.9779
	Margalef (D)	0.8613	0.8543	0.8341	0.6684	0.9655	0.8205
Cladocera	Individuals	159	151	168	143	181	159
	Shannon-Weiner (H)	1.85	1.928	1.925	1.888	1.916	1.833
	Evenness (E)	0.909	0.9822	0.9795	0.9442	0.971	0.8934
	Margalef (D)	1.184	1.196	1.171	1.209	1.154	1.184
Rotifera	Individuals	178	201	165	159	163	198
	Shannon-Weiner (H)	2.055	2.059	2.042	2.033	1.992	2.044
	Evenness (E)	0.9755	0.9797	0.9628	0.955	0.9162	0.965
	Margalef (D)	1.351	1.32	1.371	1.381	1.374	1.324
Protozoa	Individuals	122	159	123	107	104	126
	Shannon-Weiner (H)	1.913	1.927	1.905	1.895	1.809	1.804
	Evenness (E)	0.9678	0.9813	0.9596	0.9504	0.872	0.868
	Margalef (D)	1.249	1.184	1.247	1.284	1.292	1.241

with Shannon-Weiner diversity Index as clean (>4.5), slightly polluted (4.5-3), moderately polluted (3-2), heavily polluted (2-1), and highly polluted (<1) according to Zheng et al. (2007).

Margalef Species Richness index had a similar trend with Shannon-Weiner Diversity Index (H) among the groups; though, there were differences in the spatial variations. Among the Rotifera, station 4 had the highest value (1.381) followed by station 5 (1.374) while the relatively unperturbed station 2 (1.300) and station 6 (1.324) had lower values. The highest Margalef Species Richness index among the Copepoda was recorded in station 5 (0.9655), and the lowest – in station 4 (0.6684). The values were generally low in all the stations and among the groups indicating some level of perturbation (Shah and Pandit, 2013). The more perturbed stations had higher values than the less perturbed stations, especially among Rotifera and Protozoa. Meng et al. (2020) explained this observation that the Margalef index concentrates on the richness and taxonomic composition instead of community abundance.

The evenness index did not show any trend, though the highest values were recorded in station 2 in all the groups while the lowest values were recorded in stations 5 (Copepoda, 0.8685 and Rotifera, 0.9162) and 6 (Cladocera, 0.8934 and Protozoa, 0.8680). The evenness index indicates how the organisms are evenly distributed in a sample (Kaparapu and Geddada, 2013). Evenness values were relatively higher in station 2 in all the groups, indicating the effect of the anthropogenic activities in the other stations. However, flow velocity could be responsible for the values recorded in station 3 (Redden et al., 2009) and anthropogenic activities other than sand mining in station 1. Generally, the upstream stations (1 – 3) were relatively higher, indicating the negative impact of sand mining in the downstream stations (4 – 6).

3.2.2. Relationship between zooplankton groups and environmental variables

CCA showed that water temperature, flow velocity and dissolved oxygen exerted a greater positive influence on the relative abundance of the zooplankton groups compared to the higher negative influence exerted by electrical conductivity, phosphate and turbidity (Fig. 2). Flow velocity exerted a positive influence on Copepoda while biochemical oxygen demand exerted a negative influence on Rotifera and Cladocera. Spatially, dissolved oxygen exerted a positive influence on stations 3 and 6 while electrical conductivity, phosphate and turbidity exerted a negative influence on stations 1 and 4.

Conclusions

Some of the physicochemical parameters showed that the river was perturbed by the anthropogenic activities in the watershed especially in the downstream stations where sand mining was intense. The zooplankton assemblage and community structure also indicated some levels of perturbation. The relatively low zooplankton abundance, especially in some downstream stations, could be due to anthropogenic impact exacerbated by seasonal influences. The presence of some eutrophic indicators and tolerant species especially cladocerans showed that the river was undergoing eutrophication. Sand mining among other observed anthropogenic activities was a major contributor to the nutrient enrichment in the river. Therefore, it needs to be regulated.

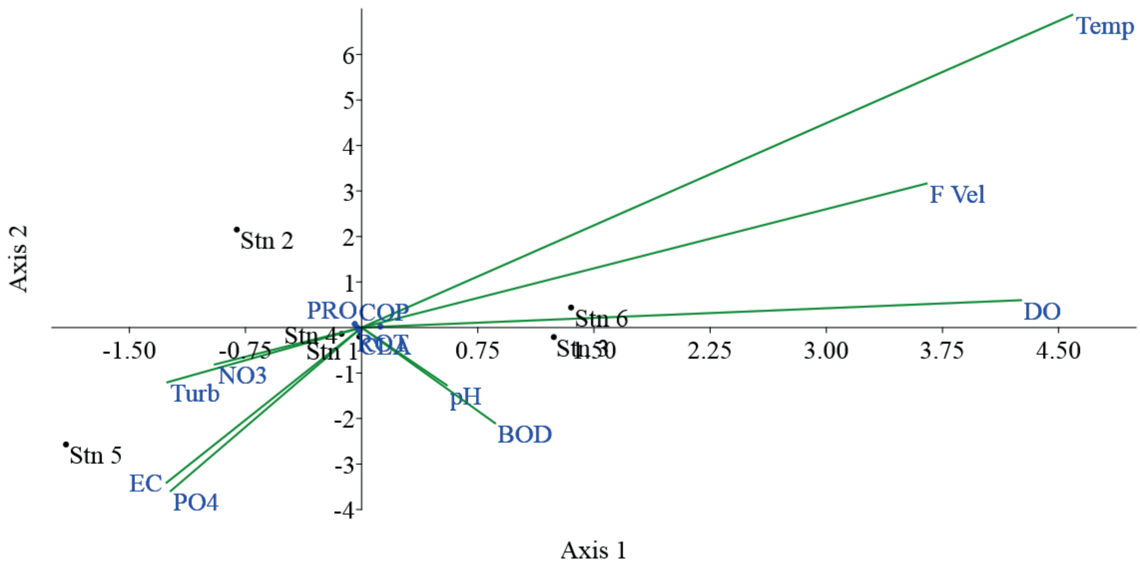

Fig.2. Canonical correspondence analysis (CCA) ordination showing relationships between zooplankton groups, stations and environmental variables. BOD – biochemical oxygen demand, DO - dissolved oxygen, Turb - turbidity, Temp - water temperature, NO_3 – nitrates, PO_4 - phosphates, EC – electrical conductivity, FVel – flow velocity, ROT – Rotifer, COP – Copepod, CLA – Cladocera, and PRO – Protozoa.

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Conflict of interests

The authors declare that they have no competing interests.

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