water

MDPI

Article

Dependence of Long-Term Dynamics of Zooplankton in the Ob River on Interannual Changes in Hydrological and Hydrochemical Parameters

Nadezhda Yermolaeva *, Serafima Dvurechenskaya, Vladimir Kirillov and Aleksandr Puzanov

Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences, Molodezhnaya Str. 1, 656038 Barnaul, Russia; serafima_dv@mail.ru (S.D.); heller53@mail.ru (V.K.); puzanov@iwep.ru (A.P.)

* Correspondence: hope413@mail.ru; Tel.: +7-952-903-11-59

Abstract: Here we summarize a long-term study on qualitative and quantitative composition of zooplankton (Cladocera, Copepoda, Rotifera) in the Ob River. We carried out these investigations at 13 sampling stations of the Middle and Low Ob in the years 1994, 1996, 1999, 2001, 2002 and 2009. It was found that the species richness of all zooplankton and abundance of cladocerans and rotifers is significantly determined by the temperature conditions of the month preceding sampling. In contrast, among other factors, we revealed that pH decreases as well as phosphate and nitrate concentrations increase zooplankton abundance. Dissolved oxygen and oxidizable organic substances (BOD_5) were positively correlated to copepod population levels (according to abundance and biomass); on the other hand, an increase in difficult-to-oxidize substances (COD) inhibited their development. During this study, we found that high water levels had a positive influence on zooplankton richness in river itself probably due to being downstream from Ob River floodplain lakes.

Keywords: zooplankton; long-term dynamics; water level; Ob River; environmental factors

Citation: Yermolaeva, N.; Dvurechenskaya, S.; Kirillov, V.; Puzanov, A. Dependence of Long-Term Dynamics of Zooplankton in the Ob River on Interannual Changes in Hydrological and Hydrochemical Parameters. *Water* **2021**, *13*, 1910. https://doi.org/10.3390/w13141910

Academic Editors: Xin'an Yin, Xufeng Mao, Jianguo Zhou and Zhengjian Yang

Received: 7 June 2021
Accepted: 6 July 2021
Published: 9 July 2021

1. Introduction

Solving the problem of influence of hydrological and hydrochemical characteristics of streams as well as climate change on qualitative and quantitative features of hydrobionts is of particular importance for working out a strategy for water use and protection of water resources on the worldwide scale, including little studied large waterway such as the Ob River. In contrast to lentic freshwater systems, understanding the influence of hydrological and chemical characteristics of streams on zooplankton is difficult as the environmental conditions of the flow change rapidly.

The Ob is the largest watercourse in Western Siberia and one of the largest rivers in the world. The source of the river is the confluence of the rivers Biya and Katun; the river mouth is the Ob Bay in the Kara Sea of the Arctic Ocean. The river is 3650 km long; its catchment area makes up 2,990,000 km^2. The Ob basin (about 85%) is mainly located on the West Siberian Plain, crossing all natural zones of temperate latitudes (steppe, forest-steppe and taiga). In its low reaches, the Ob River flows in the permafrost zone. Dams do not tangibly regulate the flow of the river. In the upper reaches, only the Novosibirsk reservoir (near the city of Novosibirsk) with its small regulating capacity (4.4 km^3) is functioning [1]. The Ob River is characterized by considerable interannual fluctuations in water levels [2], which depend on its annual hydrological regime. Changes in flow volumes and water levels make an effect on physical properties of the flow and the chemical composition of waters [3] thus affecting zooplankton as well [4–8].

Unlike fish and other large river organisms, zooplankton, including Cladocera, Copepoda and Rotifera, comprise a diverse group of heterotrophic organisms transported passively by flowing waters [9–14]. Filter-feeding organisms are the main part of the zooplankton community of rivers [7,8,15–18]. They feed on phytoplankton, bacterioplankton, detritus and each other; thus, they are critical elements in both the classical and microbial loop food web. Their nutrients and energy are transfer to higher trophic levels, including fish and insects. They also contribute to purification of water bodies by removing suspended dead organic matter. Zooplankton is a chain in matter and energy transformation and an important factor of water quality formation [16,17,19–22]. Numerous researchers report that physical-chemical factors, such as concentrations of biogenic elements (i.e., phosphorus, nitrogen), organic substances (according to BOD_5), dissolved oxygen, pH, water temperature and a number of other parameters (flow rate, discharges, water levels, etc.), are closely related with the development of different zooplankton species [23,24]. The composition of the zooplankton community has been used to assess water quality and is often used as a pollution indicator [25–29].

Therefore, studies of the long-term dynamics of zooplankton in large river systems are promising because they allow scientists to assess changes occurring in the aquatic ecosystem.

In fact, there are only few studies of zooplankton in large rivers and their dependence on environmental parameters. It happens due to the complexity of studying large river systems, including their huge extent. For studying seasonal dynamics, not lengthy sites of river are usually used [7,18,30–32]. Large-scale studies are conducted in spring-summer, i.e., a period that characterized by high biological activity, relatively stable flows and mild weather favorable for sampling to investigate spatial heterogeneity [6,8,11,12,24,33–38].

Though a large number of researchers have shown a scientific interest in the Ob River for many decades, just few separate hydrological and hydrochemical [39–48] as well as hydrobiological [15,49,50] issues have been studied. In particular to date, the species composition of zooplankton has been studied in sufficient detail only in some parts of the Ob [15]. However, complex studies that would allow assessing the impact of various factors on the qualitative and quantitative characteristics of zooplankton in the Ob River were not conducted.

This project is focused on studying the long-term dynamics of zooplankton of the Ob River related to interannual changes in hydrological and hydrochemical parameters.

2. Materials and Methods

Investigations were carried out in the years 1994, 1996, 1999, 2001, 2002 and 2009 during route surveys of the Middle and Low Ob River section, namely, from the dam of the Novosibirsk HPP to the village of Karymkary (Figure 1). The studied section of the river is almost entirely located in the taiga landscape zone [2]. Here, the river receives large tributaries (the Tom, Chulym, Ket', Tym, Vakh, Vasyugan, Irtysh, etc.), which have an essential impact on its hydrochemical and hydrobiological parameters both in the sites of confluence and downstream.

Taking into account the time, required for carrying out the work in all sites, the speed of the research vessel along the route was commensurable with the rate of water mass. It was assumed that we studied the same water mass undergoing transformation when it moves downstream and is influenced by the lateral inflow, changes in the catchment features, etc.

Sampling was made in the last decade of August during the period of water stage stabilization and maximum development of crustacean zooplankton. Hydrobiological and hydrochemical sampling was made concurrently at the same sites (Table 1, Figure 1).

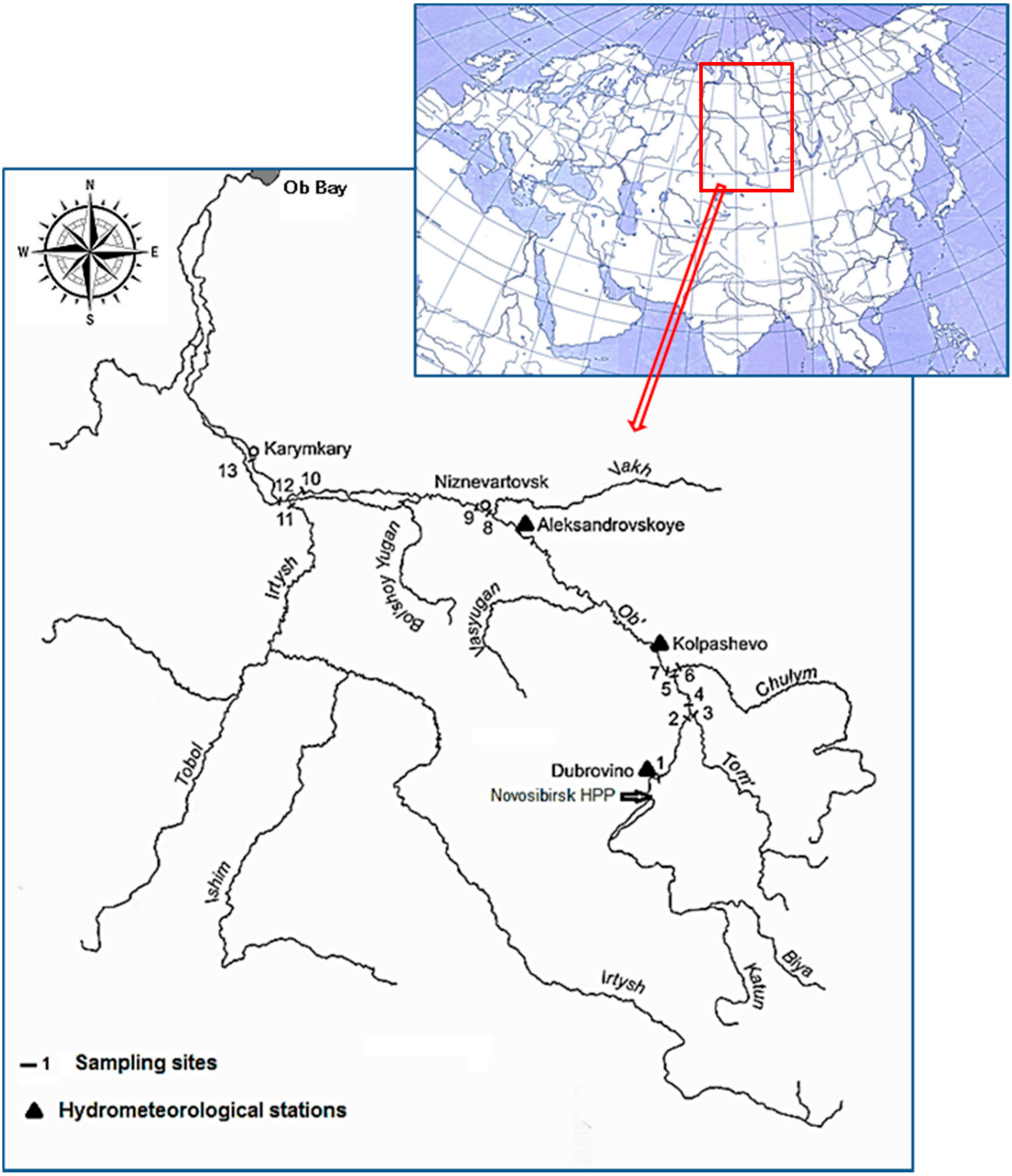

Figure 1. Schematic map of sampling sites (sites numbers correspond to those specified in Table 1).

Table 1. Location of sampling sites and hydrometeorological stations.

No	Sampling Site Names	Sampling Site Coordinates	Km From the OB Source
	Hydrochemical and hydrobiological samples		
0	Novosibirsk HPP	54°50′51″ N 82°59′30″ E	678
1	Dubrovino	55°28′42″ N 83°16′36″ E	785
2	7 km above Tom River mouth	56°44′56″ N 84°24′47″ E	963
3	Tom River mouth	56°53′21″ N 84°27′42″ E	987
4	10 km below Tom River mouth	56°58′14″ N 84°24′08″ E	997
5	1 km above R.Chulym mouth	57°42′58″ N 83°51′15″ E	1132
6	R.Chulym mouth	57°43′30″ N 83°49′35″ E	1133
7	3 km below R.Chulym mouth	57°42′40″ N 83°46′28″ E	1136
8	1 km above Nizhnevartovsk	60°50′37″ N 76°38′28″ E	1940
9	1 km below Nizhnevartovsk	60°51′33″ N 76°23′55″ E	1956
10	30 km above R.Irtysh mouth	60°10′46″ N 69°11′17″ E	2430
11	R.Irtysh mouth	61 04′48″ N 68 49′50″ E	2500
	Hydrometeorological stations		
	Dubrovino	55°28′42″ N 83°16′36″ E	785
	Kolpashevo	58°18′04″ N 82°54′19″ E	1250
	Aleksandovskoye	60°26′36″ N 77°52′57″ E	1840

Field measurements included Secca disc visibility (SDV), temperature, electrical conductivity and pH using an ANION 7051. Dissolved oxygen concentration was detected by the Winkler method. We also collected water samples from the upper 50 cm layer using a 5-L bathometer for laboratory analysis of total phosphorus (TP), ammonium, nitrates and chemical oxygen demand (COD). The samples were filtered under argon pressure through White Tape paper filters with a pore size of 5–8 µm to remove coarse suspension and then frozen at −18°C before the delivery to the laboratory (for 14 to 30 days). Subsequently, after thawing, the water parameters were identified in the laboratory according to standard methods: ammonium, nitrates and phosphate—by photometric method; COD—by the method that based on oxidation of organic substances with an excess of potassium dichromate in a sulfuric acid solution when heated at the presence of a catalyst (silver sulfate). The excess of the potassium dichromate was titrated by Mohr's salt.

Zooplankton samples were collected by straining 100 L of water from the 0–30 cm surface layer through the Apstein net with a mesh size of 30 µm. Annually, zooplankton was taken from 13 sampling sites (right bank, midstream and left bank) (Figure 1) and fixed with a 4% buffer solution of formalin. For a cameral treatment, we used the Bogorov chamber, a binocular microscope MBS-10 and a microscope BIOLAR PI (PZO-Polskie Zakłady Optyczne, Warsaw, Poland) with x400-fold magnification. We identified organisms up to species by classical keys [51–61]. Individual dry weight and maximum length (95th percentile) were calculated directly from the sampled zooplankton. A minimum of 20 specimens of each species were measured. Raw weight is calculated using weight versus length equations [62]. The biomass of zooplankton community was calculated through multiplying the individual mass of each species by its abundance. To assess the dominance (in terms of numbers), the Lyubarsky scale was used [63]. The dominant species were considered to be at least 35% of the total density, subdominants, at least 15%.

The ecological conditions of the river were evaluated by using Pantle and Buck saprobity index (S) [64]. Regional indices of indicator significance for zooplankton organisms from water bodies of Western Siberian were used in calculations [29].

The data of the Federal Service for Hydrometeorology and Environmental Monitoring on flow rates and water levels of the Ob River (including the average monthly water temperature) for all studied years were received from Hydrological Yearbooks [65]. Observations of level fluctuations are carried out at stationary water measuring posts and consist of measuring the height of the water surface above a certain constant plane, taken as the initial mark or zero. A plane passing through this mark that is slightly below the lowest water level is usually used as a zero plane. The absolute or relative level of this plane is called the zero datum level. The elevation above this level is a measured level (datum level).

Hydrological parameters were not measured during the expedition. The official data of Roshydromet, obtained at stationary hydrological stations, were used for the analysis. This allows to avoid discrepancies when comparing interannual parameters. There are 3 stationary observation hydrometeorological posts in the investigated area: Dubrovino, Kolpashevo and Aleksandovskoye. Regular measurements of discharges and water level, as well as water and air temperature, are carried out at these stations. For comparison, we used data from the station closest to the analyzed section for taking hydrochemical and hydrobiological samples. Data on precipitation amounts were also available at http://www.meteomanz.com. (accessed on 25 February 2021) Since the average development time of the zooplankton community is about one month (the development of parthenogenetic Rotifera in July-August achieve 3–4 days, Cladocera—12–18 days, the duration of metamorphosis of Copepoda is from 10 to 30 days in different species [54–59]), we decided to check how its formation was influenced by hydrological and hydrothermal conditions in the river not only during the month of sampling (August) but also during the month preceding sampling (July).

We used the principal component analysis (PCA) to analyze the dependences of hydrological, physical-chemical variables and numerical indicators of zooplankton. The statistical analysis was performed by the Statistica 6.0 software package. Spearman's correlation coefficient was used in statistical calculations. Binary relationships built on descriptions of the species composition of the zooplankton of the Ob River have been calculated based on presence or absence of species.

3. Results and Discussion

The hydrological and hydrochemical data obtained during all the years of research, averaged over the entire investigated section of a river, are shown in Table 2.

Hydrological parameters. Hydrological conditions in the years under review were different. For example, the year of 1994 was distinguished by its extremely low-water content in contrast to the most high-water year of 2002 (Figure 2). Figure 2 demonstrates that in 1994 and 1996 the water level was equally low.

Table 2. Mean values and SE of hydrological and hydrochemical variables in Ob river.

Variables	1994	1996	1999	2001	2002	2009
Precipitation, mm (July),	99.8 ± 31.1	48.2 ± 5.8	22.6 ± 2.6	101.1 ± 8.9	105.7 ± 24.7	79.9 ± 14.8
Precipitation, mm (August)	79.0 ± 22.9	75.6 ± 5.9	33.6 ± 5.1	84.5 ± 9.7	71.3 ± 20.9	50.4 ± 1.7
Temperature, °C (July)	23.2 ± 0.2	21.1 ± 0.4	21.8 ± 0.5	19.3 ± 0.9	20.6 ± 0.5	19.9 ± 0.3
Temperature, °C (August)	20.1 ± 0.5	18.8 ± 0.4	18.5 ± 0.9	19.7 ± 0.5	18.7 ± 1.1	19.7 ± 0.2
Discharge, m^3/s (July)	4083.3 ± 1310.7	3530.0 ± 1137.7	4883.3 ± 2069.9	6040.0 ± 2164.3	7740.0 ± 3108.8	6140.0 ± 1947.9
Discharge, m^3/s (August)	2446.7 ± 522.2	2283.3 ± 646.7	3023.3 ± 521.2	3756.7 ± 984.4	4440.0 ± 1510.7	3713.3 ± 1065.9
Water level, sm * (July)	401.0 ± 58.6	370.0 ± 59.5	458.0 ± 113.9	567.7 ± 138.0	653.0 ± 146.4	541.3 ± 82.9
Water level, sm * (August)	244.0 ± 8.4	240.7 ± 14.8	308.3 ± 14.2	392.3 ± 50.0	418.7 ± 62.6	355.0 ± 38.1
PO_4^{3-}, mg/L	0.153 ± 0.048		0.036 ± 0.022	0.015 ± 0.005	0.018 ± 0.004	0.062 ± 0.011
NH_4^+, mgN/L				0.133 ± 0.038	0.159 ± 0.024	0.153 ± 0.040
NO_2^-, mgN/L			0.038 ± 0.014	0.021 ± 0.001	0.014 ± 0.012	0.020 ± 0.010
NO_3^-, mgN/L				0.133 ± 0.031	0.257 ± 0.125	0.132 ± 0.023
O_2, mg/L				9.50 ± 0.19	8.99 ± 0.21	8.97 ± 0.14
pH				8.13 ± 0.12	8.20 ± 0.12	7.13 ± 0.15
BOD_5, mgO_2/L				2.21 ± 0.25	2.18 ± 0.31	2.30 ± 0.19
COD, mgO/L				14.13 ± 1.85	14.61 ± 0.92	18.41 ± 3.66

* Above zero datum level.

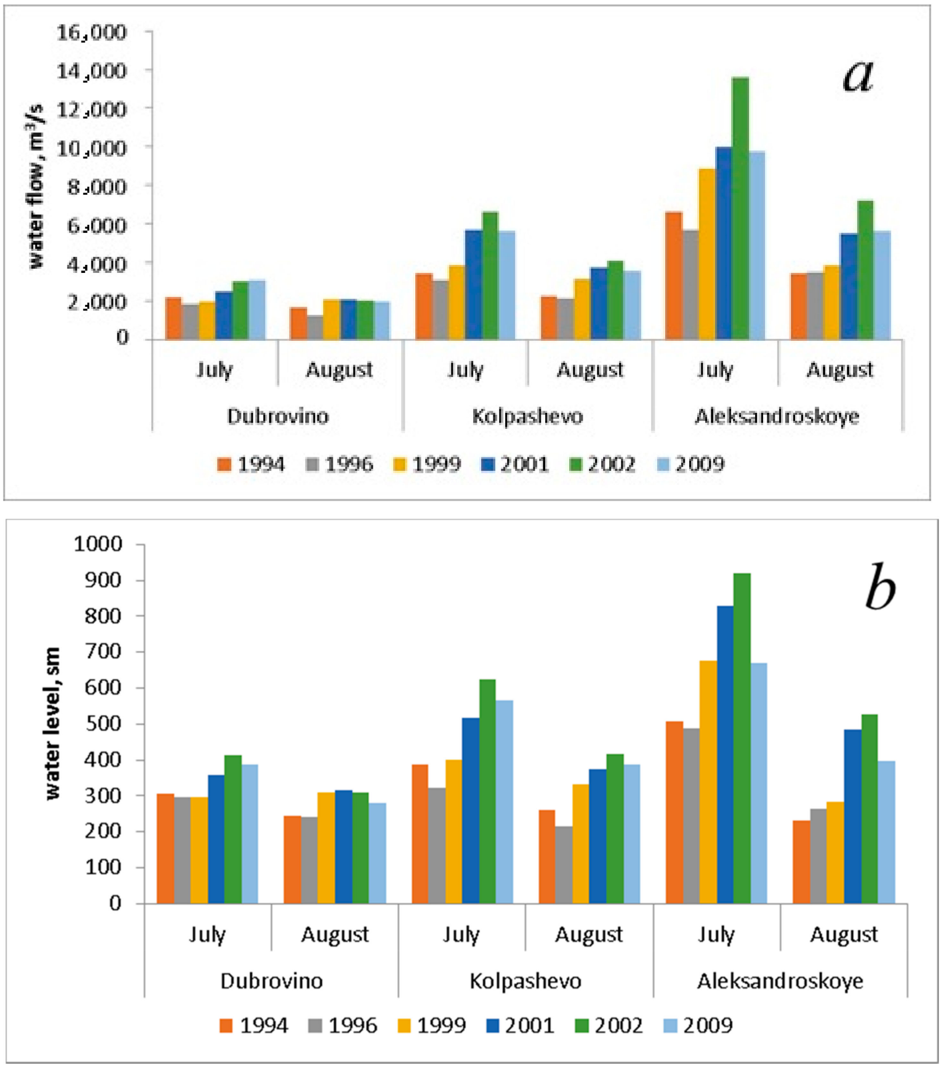

Figure 2. Average monthly discharges (**a**) and water levels above the graph zero (**b**), at sampling stations.

Water levels in all river sections correlated with water discharge (Figure 2a,b). At Dubrovino, the influence of the river discharge regulated by the Novosibirsk HPP dam was noted. In July (during the second flood wave), some fluctuations in level and runoff occurred (according to the long-term series). There were no interannual differences in these characteristics in August, since the regulating influence of the dam smooths out interannual differences in levels downstream. Maximum differences in levels during low- and high-water years made up 71 cm (according to the observation series). Downstream, such differences became stronger because of significant contribution of lateral inflow. At the sampling station Kolpashevo, the main flow of the Ob River was summed up with the contributions of rivers Tom and Chulym. At the upper sampling station Alexandrovskoye, the Ob River receives a number of large tributaries, i.e., the Ket′ River, the Tym River and the Vasyugan River. Here, the maximum difference in levels in July 1994 and 2002 reached 411 cm, and during the period of level stabilization in August, it reached 297 cm. For reference, the maximum depths of the Ob River relative to the zero level of the stationary water measuring posts vary from 4.5 m in the Dubrovino area (site 1) to 24.4 m in the Nizhnevartovsk area (site 9). Thus downstream, the water mass transforms every year due to the contribution of large and small tributaries with different watersheds and their own hydrochemical water composition. However, the range of hydrological fluctuations that depends on water content of a year is more noticeable in the middle and especially in the low reaches of the Ob River.

Physical and chemical parameters. Water temperature largely depended on weather conditions during sampling as well as on air temperature and precipitation amount over the previous few days [66,67]. In different years, it ranged from 17.6 to 20.6 °C. Temperature peaks were recorded annually at Dubrovino and Kolpashevo, whereas the lowest temperature were detected in low reaches (sampling station Alexandrovskoye) (Figure 3).

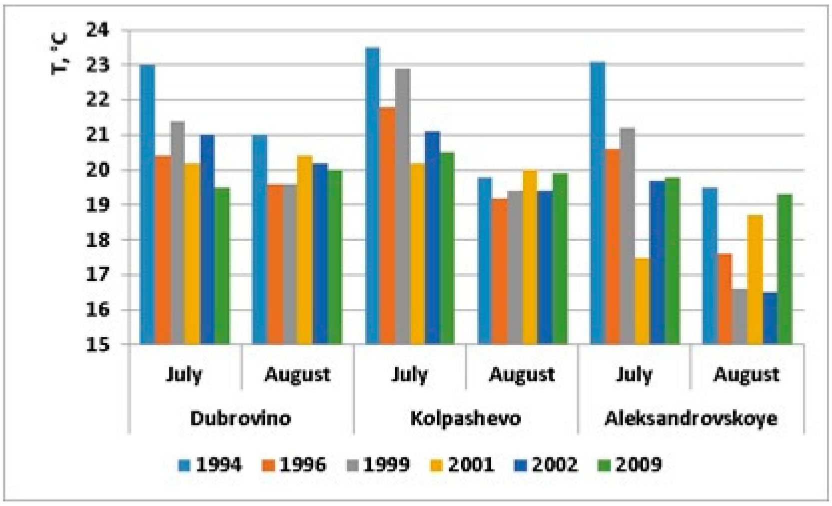

Figure 3. Average monthly water temperature.

Precipitation was unevenly distributed along the Ob River flow axis. According to the long-term series, the greatest amount of total precipitation in July was recorded in the Middle Ob (Kolpashevo station). In August of some years, it was recorded, on low reaches of the studied section (Aleksandrovskoye station) (Figure 4) [65]. In summer, flow rates and water levels of the Ob River (in sites not subject to the Novosibirsk HPP regulation) fluctuated depending on the amount of precipitation.

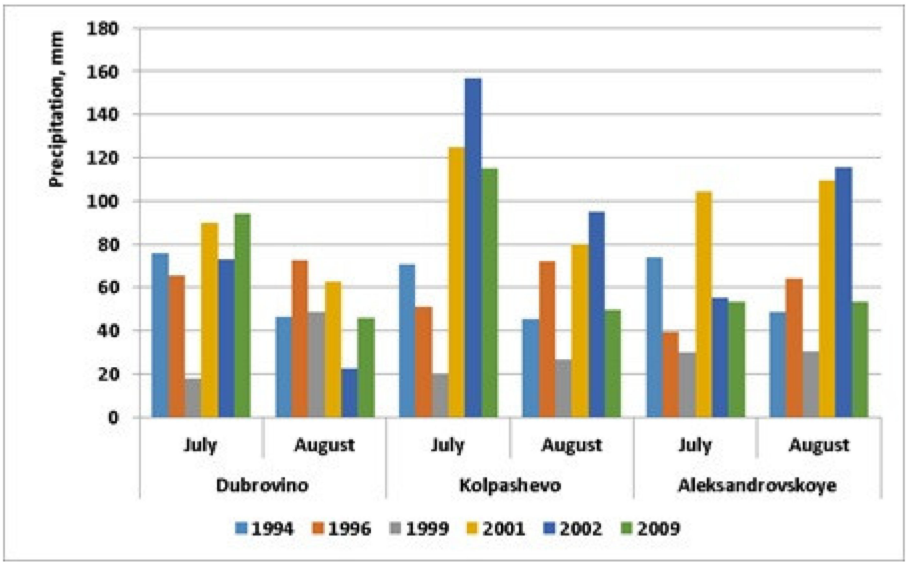

Figure 4. Monthly precipitation amount [64].

Complete data on all considered hydrochemical parameters from all river stations became available since 2001 (Table 2). Though the data for 1994–1999 are not complete, they are included in the discussion of the trend of changes in the chemical composition of the Ob River. But they are not used in statistical analysis.

The Ob River water is characterized by low mineralization and, according to the classification by [39], it belongs to hydrocarbonate class of calcium group, type 2.

The studies suggest that water is slightly alkaline (by pH) almost all over the studied area (Figure 5a). According to a number of observations, the average pH values in the Ob River were 7.3–7.5 [2]. Alkalization was observed during the high-water years (2001, 2002) (from the Tom mouth to the Vasyugan one (almost to site 9)). Downstream, pH values slightly decreased, apparently due to water inflow from the swampy floodplain.

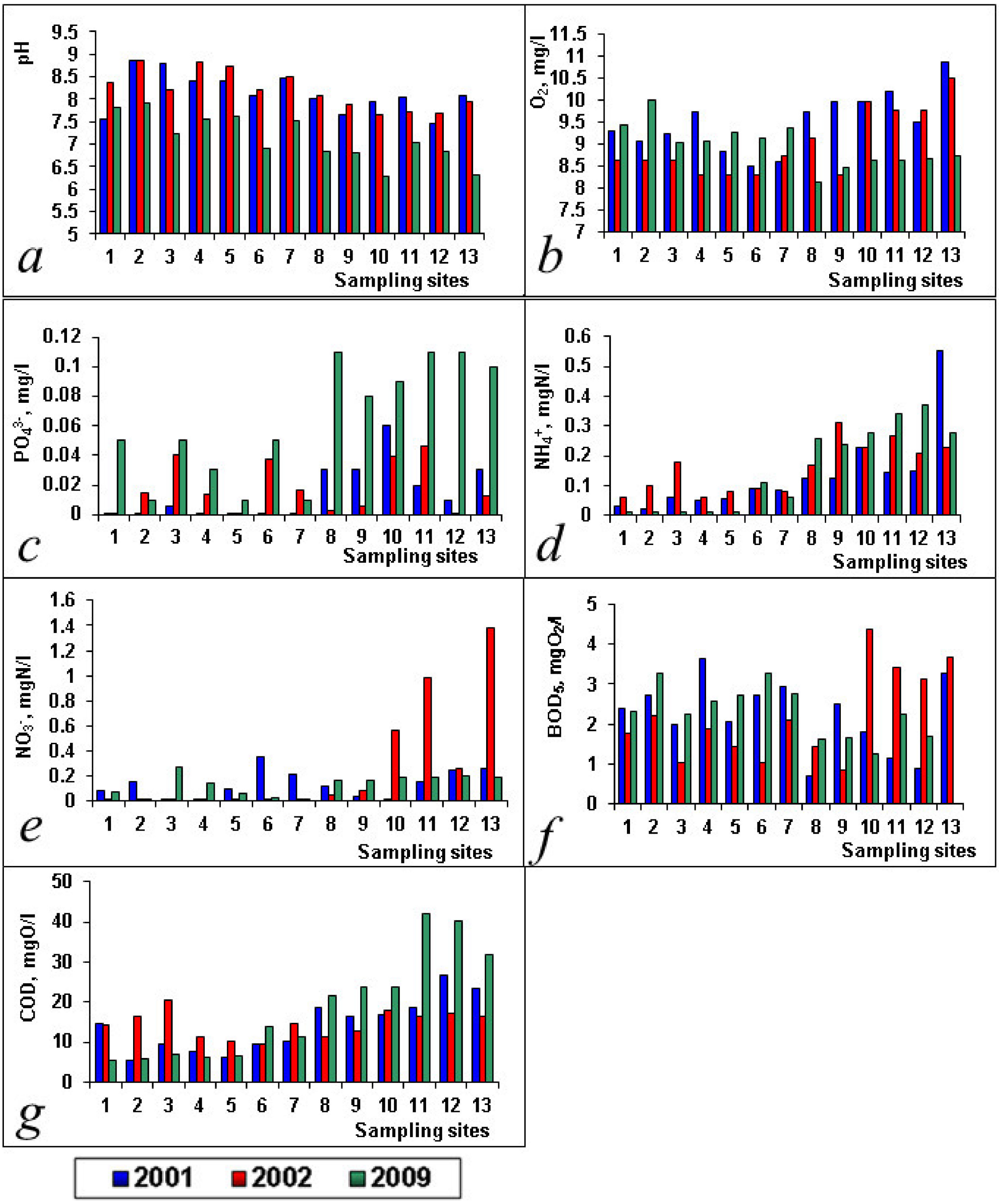

Figure 5. Long-term variations in hydrochemical parameters (in August) of the Middle and Low Ob River in investigated sites (sites numbers correspond to those specified in Table 1). (**a**)—pH; (**b**)—O_2; (**c**)–PO_4^{3-}; (**d**)–NH_4^+, (**e**)–NO_3^-; (**f**)–BOD_5; (**g**)–COD.

The oxygen regime of the Ob River (at all sampling stations and during all years under consideration) was favorable for hydrobionts development. Concentrations of O_2 ranged from 8.13 to 10.87 mg/L (Figure 5b).

The content of biogenic elements varied greatly. According to our data, phosphate concentrations in high- and medium-water years at various sites fluctuated from concentrations below the detection limit up to 0.11 mg/L. An increase in phosphate concentrations occurred throughout downstream (Figure 5c).

Concentrations of ammonium nitrogen compounds also varied widely. There was an annual increase in concentrations downstream, which in some years amounted to 0.55 mgN/L (Figure 5d).

In 2001, 2002 and 2009, nitrate contents ranged from analytical zero to 1.38 mgN/L. Increased concentrations were detected in low reaches of the Ob at sites 10–13 (Figure 5e). It is worth noting that in the extremely low-water year (1994), nitrate concentrations varied between 0.49 and 0.63 mgN/L and were rather constant almost throughout the studied section of the Ob river [39,42]. These concentrations significantly exceeded those for the high-water years of 2001 and 2002 at the same sites of the Middle Ob River.

During the present study, we observed rather high content of easily oxidizable organic substances (according to BOD_5) in the Ob River waters, i.e., from 0.68 to 4.36 mgO_2/L. In the years under consideration, BOD_5 values decreased downstream. However, in the high-water year of 2002, this parameter increased in low reaches (in the Irtysh mouth and downstream) probably because of specific catchment features of this large river (Figure 5f) [2]. As for the COD values, the content of oxidizable substances was several times higher downstream with exception of 2002, when the uppermost stations' values were the highest (Figure 5g). Obviously, water enrichment occurred due to intake of hard-to-oxidize substances from wetlands of the Central Siberian Lowland. This effect may be due to the waters coming from vast wetlands that are enriched with hardly soluble humic acid compounds. The influx of bog waters has a noticeable effect on the chemical composition of the Ob River water in this area. Increased COD (up to 21 mgO/L) at sites of the Middle Ob was registered during extremely low-water year of 1994 [39].

4. Zooplankton

According to our studies conducted during 1994–2009, a total of 119 species and forms of zooplankton were found (Table. S1): 23 Copepoda (19%), 40 Cladocera (34%), 56 Rotifera (47%) in the Ob River section from the Novosibirsk reservoir to Karymkary village. According to the literature [15,49], 131 zooplankton species in the Middle and Low Ob sites (except for the Ob Bay) were identified during the past century of hydrobiological research that preceded our study. Therefore, we cover almost all species diversity ox zooplankton in the Ob River.

In 1994, a total of 23 species were recorded. As moving downstream (Table S1), numerical parameters of zooplankton increased from 734 ind./m^3 and 22.57 mg/m^3 (in the area below Novosibirsk) to 15,592 ind./m^3 and 554.2 mg/m^3 in Karymkary (Table 3). A sharp decline in abundance and biomass of zooplankton was marked below the mouth of the Tom River; water inflow from the rivers Chulym and Irtysh was responsible for an increase in these parameters (Table 1, Figure 6).

In 1996, a total of 25 species and forms, mostly everybionts, were identified (Table S1). As in 1994, there was a growth in number and diversity of zooplankton downstream, especially at sites below the confluence with large tributaries. The number and biomass of zooplankton at almost all study sites were similar to those noted in 1994 (Table 3).

Table 3. Abundance (N, ind./m^3), biomass (B, mg/m^3) and number of zooplankton species (n) in various sites of the Ob River (sites numbers correspond to those specified in Table 1).

Sites	1994			1996			1999			2001			2002			2009		
	N	B	n	N	B	n	N	B	n	N	B	n	N	B	n	N	B	n
1	734	22.57	8	570	9.6	5	10.550	573.31	9	1780	64.40	6	60	1.78	2	2810	41.10	18
2	510	9.11	10	660	15.37	8	5080	139.11	10	640	12.30	7	100	1.88	3	8080	90.90	24
3	2887	29.71	8	340	8.61	7	2800	47.31	11	1860	52.30	9	400	6.24	5	3460	13.80	17
4	533	8.95	8	610	14.57	11	11.200	314.62	10	2880	83.30	10	180	5.33	5	24.220	329.90	31
5	1355	26.05	9	800	24.10	10	11.200	238.63	12	2880	83.30	10	740	13.87	9	28.320	302.60	35
6	667	5.71	6	685	6.30	9	2700	61.71	11	720	21.10	9	600	27.24	7	32.000	81.50	23
7	5688	87.20	9	1860	38.50	12	9580	184.87	11	2400	40.10	10	260	1.01	6	62.810	621.00	40
8	5778	76.68	10	4430	81.26	12	33.000	714.69	12	23.140	172.20	10	3100	46.33	9	185.510	1021.90	40
9	19.553	314.25	10	9700	196.22	14	14.200	296.12	14	23.500	130.60	11	8940	84.04	12	192.200	835.90	45
10	14.955	348.98	9	8100	78.90	10	5150	94.97	11	17.620	88.70	8	3200	48.59	11	169.860	384.80	35
11	1689	62.88	9	1580	31.50	11	3200	46.51	7	21.660	90.70	10	2320	45.50	6	61.210	72.30	45

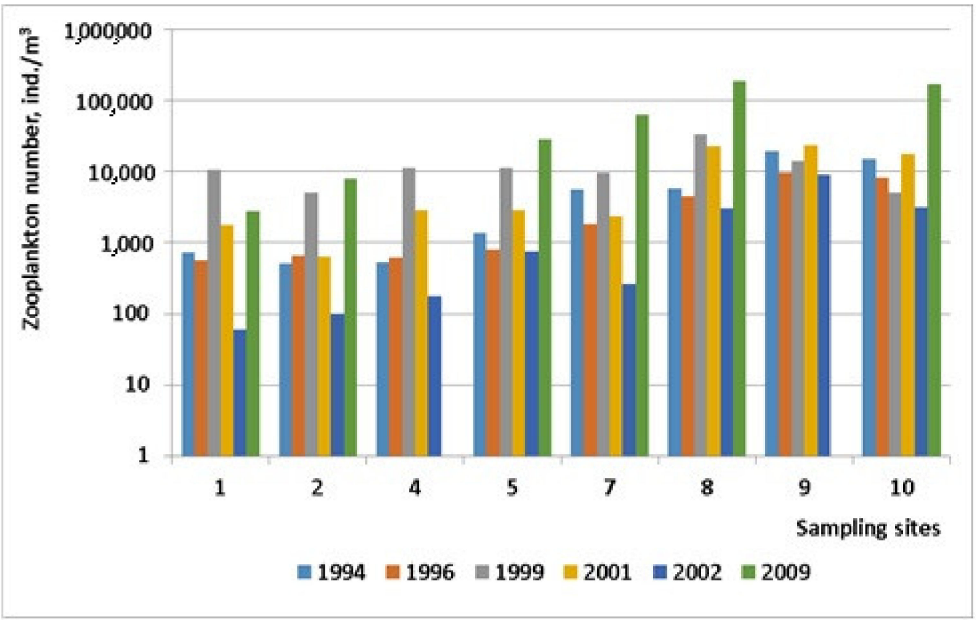

Figure 6. Dynamics of zooplankton densities in different sites of Ob River (sites numbers correspond to those specified in Table 1).

In 1999, 36 species and forms of zooplankton were found (Table S1). Among them, major species-subdominants, i.e., *Eudiaptomus graciloides* Lilljeborg, *Paracyclops fimbriatus* (Fischer), *Daphnia cucullata* G.O. Sars and *Eubosmina coregoni* Baird, were collected below site 7. Crustacea from the family Chydoridae: *Alona quadrangularis* (O. F. Müller), *Biapertura affinis* (Leydig) and *Peracantha truncata* (O. F. Müller) developed intensively at all study river sections. In some parts of the Low Ob, they could be classified as subdominants. In 1994, the species mentioned above were met sporadically. Due to massive development of rotifers, their species range significantly expanded. *Polyarthra dolichoptera* Idelson, *Asplanchna priodonta* Gosse and *Euchlanis dilatata* Ehrenberg dominated below Novosibirsk. Downstream (site 2–5), they were replaced by the species from genus *Lepadella*, *Keratella* and *Brachionus* that resulted in the improvement of their species richness. There were no negative effects of the Tom River waters in 1999. Below the mouth of the Chulym River (site 6–7) and below Nizhnevartovsk (site 9–11), zooplankton abundance and biomass decreased (Table 3). As compared to 1994, abundance and biomass of the Ob zooplankton became 8–10 times higher (with a notable exception at station 10), especially in the river reach crossing the taiga zone.

In 2001, 41 species and subspecies of zooplankton were found in Ob river (Table S1). Its abundance and biomass are quite comparable (taking into account interannual fluctuations) with the data of 1994 and 1999 (Table 3). As in previous years, rotifers prevailed in abundance in the river as a whole. The dominant complex within the Copepoda again consisted of juvenile stages of *Megacyclops viridis*, *Mesocyclops leuckartii* and *Cyclops strenuus*, from Rotifera *Asplanchna priodonta*, *Brachyonus calyciflorus*, *Brachyonus angularis* Gosse and *Keratella quadrata* (Müller), from Cladocera *Bosmina longirostris*, *Chydorus sphaericus*, *Daphnia cucullata*. There were spatial differences of species that dominated the zooplankton community. *Asplanchna priodonta*, *Bosmina longirostris*, *Chydorus sphaericus* and *Mesocyclops leuckartii* dominated in the area from the Novosibirsk HPP to the mouth of the Tom River. Below the mouth of the Tom River, *Brachyonus calyciflorus* and *Brachyonus angularis* were dominant among rotifers and below the Vasyugan mouth, *Keratella quadrata*. *Biapertura affinis*, *Alona quadrangularis* and *Peracantha truncata* appeared in the dominant complex of Cladocera (up to 20%) downstream (below the Chulym mouth), whereas *Simocephalus vetulus* (O. F. Müller) and *Syda crystallina* (O. F. Müller), below the Vasyugan mouth. As for Copepoda, *Eucyclops serrulatus* (Fischer) and *Paracyclops fimbriatus* (Fischer) gradually became the community members. In 2001, neither negative nor stimulating effects of large inflows on zooplankton abundance, biomass and species richness were observed.

In 2002, 34 species and forms of zooplankton were identified in the Ob River (Table S1). In contrast to previous years of the research, abundance, biomass and number of species were almost the least in each site. Zooplankton abundance naturally increased below the city of Novosibirsk from 60 ind./m^3 to 2320 ind./m^3 below the Irtysh mouth; the biomass accordingly increased from 1.78 to 45.5 mg/m^3, not exceeding the long-term (1994–2001) average data (Table 3). Being dominants, everybionts were annually met in the community. *Thermocyclops oithonoides* (Sars) were among subdominants throughout the study area. Below the mouth of the Chulym River, *Picripleuroxus striatus* (Schödler), *Disparalona rostrata* (Koch) as well as rotifers from genus *Polyarthra* demonstrated considerable development.

In 2009, abundance and biomass of zooplankton in almost all study sites of the river increased by one or two orders of magnitude (Table 3). Cladocera from family Chydoridae: *Alona quadrangularis*, *Biapertura affinis* and *Peracantha truncata*, which could be classified as subdominants in abundance, developed significantly throughout, whereas in previous years, they were found sporadically. Rotifers developed massively; their species range was largely expanded. *Polyarthra dolichoptera* Idelson, *A. priodonta*, *Euchlanis dilatata* Ehrenberg dominated in the area from the dam to the mouth of the Tom River. Downstream, they were replaced by the species from genus *Lepadella*, *Keratella* and *Brachionus*. Species diversity of the latter increased. In general, species diversity of zooplankton also augmented greatly in 2009, i.e., 102 species and subspecies, i.e., 23 species (23%) of Copepoda, 34 species (33%) of Cladocera, and 45 species (44%) of Rotifera (Table S1). There was an intensive development of phytophilic forms of Rotifera and Cladocera, which are characteristic for the littoral zone of lakes and reservoirs.

Downstream, abundance, biomass and species richness of zooplankton increased annually (Table 3, Figure 6). In some years, there was a decline in abundance and biomass of zooplankton from the mouth of the Tom River to the station located 10 km downstream. Inflow of the Chulym and Irtysh waters usually increases these three variables.

In 1994, Pantle–Buck saprobity index ranged within 1.8–2.4, in 1999, and in 2001, it did not exceed 1.70; in 2002, the index ranged within 1.64–1.72; in 2009, in all studied sections of the Ob river below the Novosibirsk HPP, this index varied between 1.56 and 1.73.

The PCA of the dependence of zooplankton densities on environmental factors (Figure 7, Table 4) shows that the factors distributed along axis 1 explain 65.39% of variability in zooplankton abundance.

As can be seen from Figure 7, the total abundance and biomass of zooplankton depend on abundance and biomass of Cladocera and Rotifera. Thus, filterers respond equally to environmental factors. Cladocera and Rotifera are negatively affected by water temperature during the month preceding sampling. It is possible that this is due to low water temperature that hindered the development of most species and forms of filtering zooplankton, both by slowing the processes of parthenogenesis and lowering food availability because of phytoplankton inability to actively develop at low temperatures [68–71]. Typically, temperature conditions were analyzed at the time of sampling. As a result, it was noted in many manuscripts that temperature is not a determining factor affecting the development of zooplankton in large rivers [6,12,68,72,73]. Our studies have shown that thermal conditions during the month preceding the study are of great importance for the formation of the zooplankton community in the conditions of rivers with a continental climate.

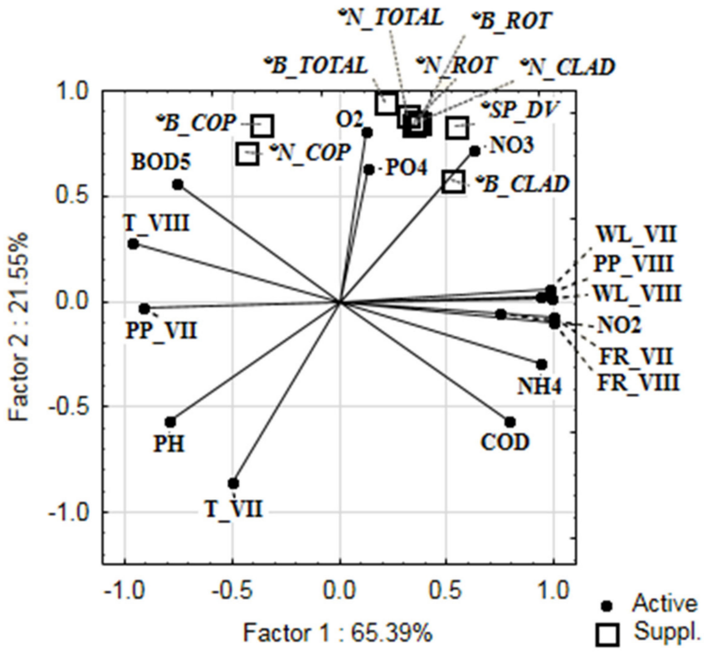

Figure 7. Biplot of Principal component analysis of zooplankton groups (number of Rotifera N_ROT, number of Cladocera N_CLAD, number of Copepoda N_COP, total number of zooplankton N_TOTAL, biomass of Rotifera B_ROT, biomass of Cladocera B_CLAD, biomass of Copepoda B_COP, total biomass of zooplankton B_TOTAL, quantity of species SP_DV) and environmental variables including precipitation in July (PP–VII), precipitation in August (PP–VIII), temperature in July (T–VII), temperature in August (T–VIII), flow rate in July (RF–VII), flow rate in August (FR–VIII), water level in July (WL–VII), water level in August (WL–VIII), phosphate (PO_4^{3-}), ammonia nitrogen (NH_4^+-N), nitrite (NO_2^{--} -N), nitrate (NO_3^--N), dissolved oxygen (O_2), pH, chemical oxygen demand-(COD) and biochemical oxygen demand (BOD_5) in the Ob River.

Table 4. Mean, standard deviation and correlation coefficients (*p*-value < 0.05) between physical-chemical parameters and zooplankton abundance of Ob River in the long-term observations (1994–2009).

	Means ± St.Dev.	Copepoda	Cladocera	Rotifera	Total Zooplankton
Precipitation (July)	110.28 ± 42.55	0.146	−0.164	−0.187	−0.167
Precipitation (August)	99.93 ± 15.86	**−0.584**	0.485	0.479	0.433
Temperature (July)	19.63 ± 1.536	−0.333	**−0.940**	**−0.952**	**−0.954**
Temperature (August)	18.65 ± 1.53	**0.586**	−0.069	−0.075	−0.032
Flow rate (July)	8960.0 ± 3599.82	−0.478	0.273	0.280	0.240
Flow rate (August)	5130.0 ± 1574.27	−0.482	0.232	0.240	0.201
Water level (July)	722.5 ± 183.74	−0.499	0.466	0.467	0.424
Water level (August)	451.75 ± 68.15	−0.523	0.420	0.421	0.378
PO_4^{3-}	0.012 ± 0.014	−0.041	**0.893**	**0.874**	**0.861**
NH_4^+	0.15 ± 0.14	−0.497	−0.016	−0.005	−0.042
NO_2^-	0.02 ± 0.02	−0.003	−0.066	−0.036	−0.044
NO_3^-	0.04 ± 0.06	0.072	**0.944**	**0.948**	**0.935**
O_2	9.23 ± 0.68	**0.835**	0.479	0.514	0.551
pH	8.30 ± 0.33	−0.183	**−0.648**	**−0.672**	**−0.665**
BOD_5	2.20 ± 1.17	**0.913**	0.078	0.093	0.148
COD	11.04 ± 2.88	**−0.874**	−0.119	−0.129	−0.183

The concentrations of biogenic elements, primarily phosphates and nitrates, were the main stimulating factors for the development of Cladocera and Rotifera (Table 2, Figure 7). It is possible that such indirect impact is determined by the food supply, including phytoplankton. However, data on the degree of phytoplankton development over the period under the study are insufficient to confirm this hypothesis. However, the positive effect of phosphorus and nitrogen compounds on the abundance and biomass of filtering cladocerans and rotifers is consistent also with the data of other authors [12,24,32,36].

Change in pH from weakly alkaline range to neutral downstream the river also had a stimulating effect. Many works have shown that the highest abundance and biomass of zooplankton are observed at pH values close to neutral (7.0–7.5) [74–81]. With a change in pH to both acidic and alkaline ranges, there is a decrease in species diversity and numerical characteristics of zooplankton, as a rule [82–84]. In a number of works devoted to the study of river ecosystems, the influence of pH on zooplankton is noted as leading factor [12,24].

Abundance and biomass of Copepoda depended on precipitation amount and water temperature during the sampling month. The lower the precipitation, the higher the water temperature. Accordingly, abundance and biomass of copepods increased as well. Numerical parameters of Copepoda were also positively affected by dissolved oxygen and easily oxidizable organic substances (according to BOD_5). A similar relationship was noted for the zooplankton of a number of other large rivers [12,85]. On the contrary, an increase in the content of hard-to-oxidize compounds (according to COD) inhibited their development. In a number of earlier works, it was shown that the high values of COD (>9 mg O_2/l) constrained the numerical development of Copepoda. There were the less quantity of nauplii and oviparous females of Cyclopoida and Diaptomidae in samples. However, the average linear sizes of organisms were slightly increased, so that considerable deviations in biomass were not observed [24,86–88].

Species richness of the Ob River zooplankton community was primarily determined by species richness of Rotifera and Cladocera. The graph shows that species richness of zooplankton largely depends on temperatures during the month preceding sampling as well as on phosphate/nitrate concentrations and pH (Figure 7). The water level during our study is also among decisive factors for species richness because high water levels provide organisms' removal from floodplain lakes.

We did not identify the dependence of zooplankton abundance on flow rate, precipitation and water level, which are the main factors influencing zooplankton abundance in many large rivers [6–8,32,37,89]. One of the reasons may be a less significant difference in flow rates between years. Maximum water flow rate is 5–5.6 km/h, minimum, 2.7–3.0 km/h.

Our results show that the species composition of zooplankton was represented by typical, widespread in fresh water bodies of temperate latitudes, species typical for the faunistic complex of the temperate climate zone. The zooplankton community in the Ob River demonstrated not very high spatio-temporal variation between all study sites and all years of investigation. Every year, eurybiont species with a wide ecological plasticity were the important component of the community. Figure 8 shows that the annual affinity of zooplankton communities of the Ob River exceeds 60%. Therefore, year-to-year variations of the community are not very high. The river community of the Ob River zooplankton has a fixed taxonomic basis. The species variability of the community that depends on abiotic factors during each particular year is defined by a small number of species.

Figure 9 demonstrates that the affinity of the zooplankton species composition (taking into account all the species assemblage found at each site during all years under research) between the studied sites also exceeds 60%. This similarity of the sites can be explained by the fact that zooplankton communities in each reach have a continuous heritage rather than an isolated temporal composition within a sequence of discrete successional stages [90].

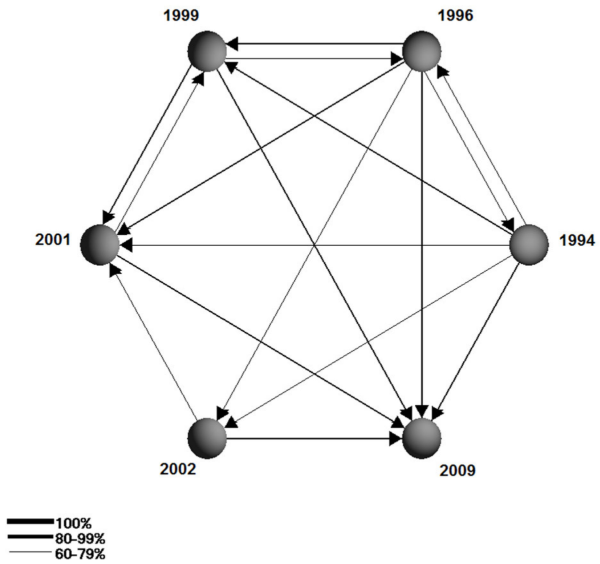

Figure 8. An oriented multigraph of binary relations, built on an array of descriptions of species composition of the zooplankton of the Ob River during the years of research.

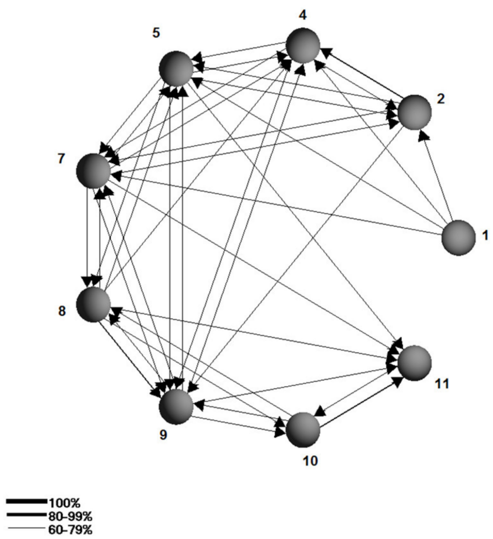

Figure 9. Oriented multigraph of binary relations, built on an array of descriptions of long-term species composition of the Ob River zooplankton in the studied sites (sites numbers correspond to those specified in Table 1).

According to many authors, zooplankton communities of large rivers have typically been found to be dominated by rotifers, with relatively few cladocerans and copepods [10,89,91]. During our study, rotifers contributed up to 90% of the total zooplankton abundances in the main channel of the lower river. Higher Cladocera and Copepoda abundances recorded at the upstream site 1 during the present study could reflect influences of the upstream dam, as observed in the Missouri River [18].

Generally, among the copepods juvenile individuals of *Megacyclops viridis* (Fischer), *Mesocyclops leuckartii* Claus, *Cyclops strenuus* (Fischer) dominated (up to 5% of the total zooplankton abundances or up to 88% of the Copepoda numbers). Among the Cladocera *Bosmina longirostris* O.F. Müller (up to 58% of the Cladocera abundances), *Chydorus sphaericus* (O.F. Müller) (up to 43%), Daphnia longispina O.F. Müller (up to 16%) and *Ceriodaphnia quadrangula* (O.F. Müller) (up to 11%) were considered to be dominant or subdominant members of the community every year as well as at all sites (Table S1). Rotifers *Asplanchna priodonta* Gosse (up to 11% of the Rotifera abundances) and *Keratella quadrata* (Müller) (up to 8%) usually prevailed in the area up to the mouth of the Tom River, whereas a significant number of rotifers from the genus *Brachionus* (Pallas)–mainly *B. calyciflorus* Pallas (together with the morphological form of *B. calyciflorus spinosus* (Wierzejski), *B. diversicornis* Daday and *B. quadridentatus* Hermann were found downstream, often up to 33% of the number of Rotifera.

As a rule, the less diverse zooplankton community at the site 1 (Dubrovino) gradually changed into a more diverse community towards the site 9 (above the Irtysh River mouth). Seemingly, this effect is due to changes in hydrological conditions (growth of depths, decrease in flow rates) and due to the arrival of limnic phytophilic species from floodplain reservoirs (Table 3, Table S1). This gradual change in the average long-term species diversity of the community along of the river can be described by the following degree equation: $y = 7.9926\ x^{0.3918}$, with approximation validity value $R^2 = 0.99$ (Figure 10a). This trend was most pronounced during high water years (2001–2009), while during the years with low levels and lower discharges (1994–1999), downstream species diversity did not change significantly. The obtained data are consistent with the data of a number of other researchers and confirm the concept of the river continuum [68,90,92,93].

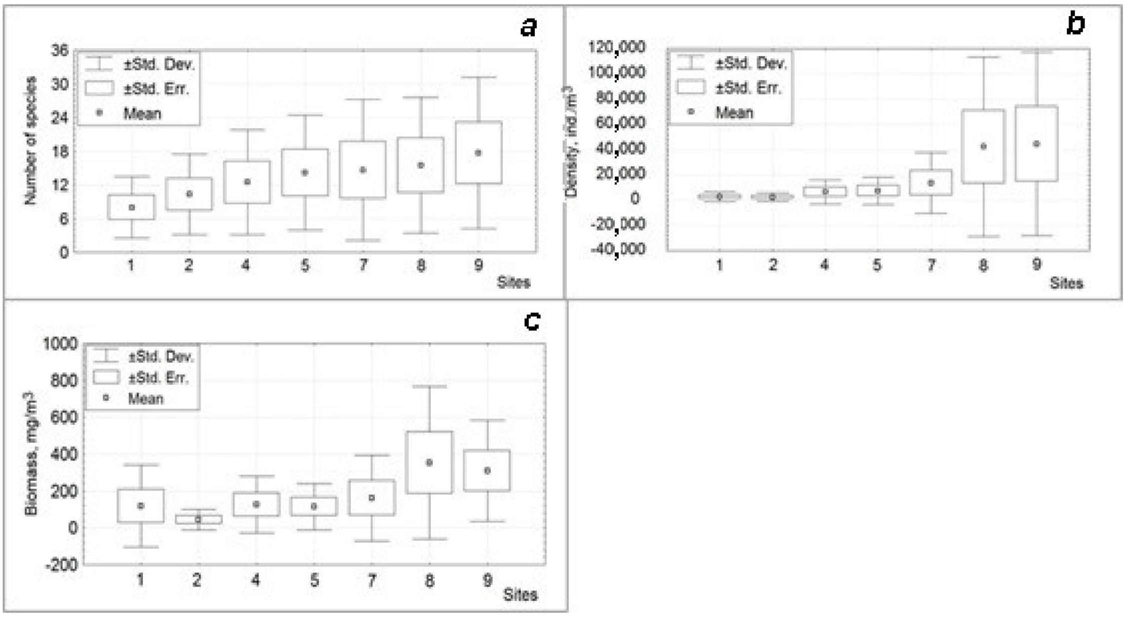

Figure 10. The change in the average long-term species richness (***a***), density (***b***) and biomass (***c***) of zooplankton downstream the main channel of the river (sites numbers correspond to those specified in Table 1).

However, annually, there is a change in species composition downstream. Figure 9 shows that site 1 and site 11 are similar in species composition of zooplankton by less than 60%. Some species are eliminated (such as *Cephalodella catellina* (Müller), *Lecane luna* (Müller), *Platyias quadricornis* (Ehrenberg), *Peracantha truncata* (O.F. Müller), *Biapertura (Alona) affinis* (Leydig), *Acroperus harpae* (Baird), *Diacyclops bicuspidatus* (Claus) and so on) and replaced by others. At sites 9–11 the appearance of characteristic species for less alkaline waters, cold-loving and brackish-water takes place (*Daphnia cristata* G.O. Sars, *Bosminopsis deitersi* Richard, *Notholca acuminata* (Ehrenberg), *Notholca squamula* (Müller), *Kellicottia longispina* (Kellicott), *Hexarthra mira* (Hudson), *Cyclops kolensis* Lilljeborg and so on). As a result, these sites are distinguished by a specific composition of zooplankton. The Ob River is characterized by an increase in the concentration of chlorides [42], since below the mouth of the Vasyugan River, it flows through the territory of actively developed oil and gas fields [2]. The influence of highly mineralized drilling muds on to the river with groundwater contributes to an increase in the mineralization of the river water long before its interaction with the waters of the Kara Sea. In this section, the species such as

Eurytemora affinis (Poppe) and *Holopedium gibberum* Zaddach characteristic to the estuarine zone of Arctic rivers were noted in 2009.

Zooplankton number and biomass also increase downstream. The change in the average long-term number of zooplankton in the main channel of the river can be described by the following exponential equation: $y = 1197e^{0.5269x}$, with approximation validity value $R^2 = 0.94$ (Figure 10b). The change in biomass occurs in a more difficult way, since, as we have already mentioned, large forms are replaced by smaller ones. This tendency can be most reliably described by the polynomial equation: $y = 9.7365x^2 - 34.214x + 117.59$, with approximation validity value $R^2 = 0.81$ (Figure 10c). The mouth areas of large tributaries and zones of influence of large industrial agglomerations (such as Nizhnevartovsk) were wittingly excluded from the analysis of changes in the numerical characteristics of zooplankton downstream, since they have a negative impact on the zooplankton community. The impacts of lateral inflow and anthropogenic influence are the subject of a separate study and are not the purpose of the work presented in this article.

When comparing the quantitative and qualitative characteristics of zooplankton during different years, it is clear that 2009 is distinguished by high abundance and biomass and species richness of zooplankton. According to our own data, only 50 taxa were recorded before 2009 in the Ob River, whereas in 2009 there were 101 species and forms (Table S1). When comparing the data on precipitation, it should be noted that during the years 1994 and 1999, the amount of summer precipitation in Western Siberia did not exceed the average level; in July 1999, even abnormally dry weather conditions were observed. During the years 2001 and 2002, precipitation was high, and summer temperature was rather low. However, precipitation was evenly distributed during the summer season and entered the river network mostly due to underground filtration. July and August (2009) were characterized by excessive moisture (180–300% of the average monthly precipitation). Heavy rains caused waterlogging of soils in most agricultural areas of Western Siberia (gismeteo.ru, http://meteoinfo.ru) (accessed on 15 May 2021) and increased flat drain. As a result, a large amount of soluble organic matter entered the water of the Ob River. Increased phosphate and hard-to-oxidize compounds (according to COD) concentrations were also detected in 2009, especially in low reaches of river. Currently, it is believed that with an increase in precipitation in watercourses, de-eutrophication occurs [94]. However, this statement is true only for mountain streams or for rivers with a poorly developed floodplain. In large lowland watercourses, such as the river Ob, with a developed floodplain and an extensive drainage area, active eutrophication, i.e., an increase in the concentration of available organic substances, is observed with an increase in precipitation. This is typical for other large rivers with an extensive drainage basin [95,96]. These processes are easy detected by the composition and quantitative characteristics of zooplankton.

It is hard to explain why the years with similar climatic and hydrological characteristics (2002 and 2009) demonstrate such a striking difference in qualitative and quantitative parameters of zooplankton. Perhaps this is due to specific water content and climatic conditions of the years preceding the study. The years 2001 and 2002 were high-water with low seasonal temperatures, heavy rainfalls and peaks in levels during floods. That resulted in flushing floodplain reservoirs and slowed down zooplankton development. The year 2008 was a low-water one with warm weather and little precipitation. Probably, zooplankton development in floodplain reservoirs and streams in 2008 induced its mass influx into the Ob in 2009. Though 1999 was the average in water content with a small amount of summer precipitation, it followed a number of high-water years. Floods united the main riverbed with water bodies of the first floodplain terrace providing river zooplankton enrichment [91,97,98].

Despite peculiar formation of the zooplankton community in each river section (by abundance and biomass of zooplankton and Pantle–Buck saprobity index), the Ob River water in all the surveyed sections belongs to moderately polluted beta-mesosaprobic class. The multi-year series suggest a tendency in reduction of river pollution. Even in 2009, the Pantle–Buck saprobity index at all study sites of the Ob River below the Novosibirsk HPP ranged within 1.56–1.73, indicating that the river ecosystem had coped with trophy growth. In other words, the buffer capacity of the river ecosystem provided self-purification by means of filtration (due to mass development of thin filter-feeding and phytophilous forms of zooplankton) to overcome the increasing eutrophication. The maximum values of filtration activity are observed in July–August [20].

The main feature of the middle section of Ob River (nearly 2000 km long) is some spatial heterogeneity of zooplankton due to the changes of hydrochemical parameters. Anthropogenic impacts, especially in the lower river, are influenced by actively oil and gas production. It can significantly alter the ecosystem of the river, even as large as the Ob River. Thus, further studies of zooplankton structure are required to develop an environmental monitoring system for the Ob River.

5. Conclusions

The zooplankton abundance and biomass appeared to be governed mainly by the nitrate and phosphate concentration in the water, pH values, organic matters and oxygen. The highest zooplankton diversity at the downstream locations of the river is most probably due to low flushing rates and increased organic matters concentration.

The long-term series demonstrates a decrease in the pollution level of the Ob River and an increase in species diversity and abundance of zooplankton. Perhaps, one of the facts explaining this trend is industrial production decline from late 1990s to early 2000s and, consequently, a decrease in anthropogenic loads on the river ecosystem.

The present study of the variation of zooplankton diversity and abundance and biomass along the Ob River endorses and sets a classic example for the River Continuum Concept (RCC) [68,90,92,93].

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/w13141910/s1, Table S1: Species composition of zooplankton in the Ob River according to surveys of 1994–2009.

Author Contributions: N.Y.: writing—original draft preparation, conceptualization, species identification, statistical analysis, data curation, data analysis, validation, visualization; S.D.: data curation, data analysis, review and editing; A.P.: project administration, resources, supervision, review and editing; V.K.: conceptualization, field sampling, review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out as part of State Task (registration no. 121031200178-8).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are part of this article and are available in the Supplementary Materials.

Acknowledgments: The authors are thankful to Mikhail Koveshnikov for his help in the collection of samples, to Olga Kondakova for help in collection of hydrological data and to Department of the quality control of natural water and sewage of the VerkhneOb'regionvodkhoz Federal State Institution of the Ministry for Protection of the Environment and Natural Resources of the Russian Federation for their help in the water chemistry analyses.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Savkin, V.M.; Dvurechenskaya, S.Y. Resources-related and water-environmental problems of the integrated use of the Novosibirsk reservoir. *Water Resour.* **2014**, *41*, 446–453. [CrossRef]
2. *Modern State of Water Resources and Functioning of Water Management Complex of the Basin of the Ob and Irtysh*; Vinokurov, Y.I.; Puzanov, A.V.; Bezmaternykh, D.M. (Eds.) Publishing House of the SB RAS: Novosibirsk, Russia, 2012; 236p. (In Russian)
3. Savichev, O.G. *Rivers of the Tomsk Region: Condition, Protection and Use*; Tomsk Polytechnic University: Tomsk, Russia, 2003; 170p. (In Russian)

4. Viroux, L. Zooplankton distribution in flowing waters and its implications for sampling: Case studies in the River Meuse (Belgium) and the River Moselle (France, Luxembourg). *J. Plankton Res.* **1999**, *21*, 1231–1248. [CrossRef]
5. Combs, S.A. Protecting freshwater ecosystem in the face of global climate change. In *Buying Time: A User's Manual for Building Resistance to Climate Change in Natural Systems*; Hoffman, L.J., Ed.; WWF: Morges, Switzerland, 2003; pp. 177–216.
6. Massicotte, P.; Frenette, J.J.; Proulx, R.; Pinel-Alloul, B.; Bertolo, A. Riverscape heterogeneity explains spatial variation in zooplankton functional evenness and biomass in a large river ecosystem. *Landsc. Ecol.* **2014**, *29*, 67–79. [CrossRef]
7. Baranyi, C.; Hein, T.; Holarek, C.; Keckeis, S.; Schiemer, F. Zooplankton Biomass and Community Structure in a Danube River Floodplain System: Effects of Hydrology. *Freshw. Biol.* **2002**, *47*, 1–10. [CrossRef]
8. Napiórkowski, P.; Napiórkowska, T. The diversity and longitudinal changes of zooplankton in the lower course of a large, regulated European river (the lower Vistula River, Poland). *Biologia* **2013**, *68*, 1163–1170. [CrossRef]
9. Bertani, I.; Segers, H.; Rossetti, G. Biodiversity down by the flow: New records of monogonont rotifers for Italy found in the Po River. *J. Limnol.* **2010**, *69*, 321–328. [CrossRef]
10. Lair, N. A review of regulation mechanisms of metazoan plankton in riverine ecosystems: Aquatic habitat versus biota. *River Res. Appl.* **2006**, *22*, 567–593. [CrossRef]
11. Steinberg, D.K.; Condon, R.H. Zooplankton of the York River. *J. Coast. Res.* **2009**, *57*, 66–79. [CrossRef]
12. Zhao, K.; Song, K.; Pan, Y.; Wang, L.; Da, L.; Wang, Q. Metacommunity structure of zooplankton in river networks: Roles of environmental and spatial factors. *Ecol. Indic.* **2017**, *73*, 96–104. [CrossRef]
13. Tóth, F.; Zsuga, K.; Kerepeczki, É.; Berzi-Nagy, L.; Körmöczi, L.; Lövei, G.L. Seasonal differences in taxonomic diversity of rotifer communities in a Hungarian lowland oxbow lake exposed to aquaculture effluent. *Water* **2020**, *12*, 1300. [CrossRef]
14. Sindt, A.R.; Wolf, M.C. Spatial and temporal trends of Minnesota River phytoplankton and zooplankton. *River Res. Appl.* **2021**, 1–20. [CrossRef]
15. Gundrizer, A.N.; Zalozny, N.A.; Golubykh, O.S.; Popkova, L.A.; Ruzanova, A.I. Studies of hydrobionts from Middle Ob. *Sib. Ecol. J.* **2000**, *3*, 315–322. (In Russian)
16. Turner, J. Zooplankton Feeding Ecology: Contents of Fecal Pellets of the Copepod Centropages velificatus from Waters near the Mouth of the Mississippi River. *Biol. Bull.* **1987**, *173*, 377–386. [CrossRef]
17. Turner, J. Zooplankton feeding ecology: Does a diet of Phaeocystis support good copepod grazing, survival, egg production and egg hatching success? *J. Plankton Res.* **2002**, *24*, 1185–1195. [CrossRef]
18. Dickerson, K.D.; Medley, K.A.; Havel, J.E. Spatial variation in zooplankton community structure is related to hydrologic flow units in the Missouri river, USA. *River Res. Appl.* **2010**, *26*, 605–618. [CrossRef]
19. Porter, K.G.; Robbins, E.I. Zooplankton Fecal Pellets Link Fossil Fuel and Phosphate Deposits. *Science* **1981**, *212*, 931–933. [CrossRef] [PubMed]
20. Gutelmakher, B.L. Plankton metabolism as a whole. In *Trophometabolic Interactions of Zoo- and Phytoplankton L.*; Zoological Institute of USSR Academy of Sciences: Saint Petersburg, Russia, 1986; 155p. (In Russian)
21. Yermolaeva, N.I. The role of zooplankton in the formation of sapropel in the lakes south of Western Siberia. *World Sci. Cult. Educ.* **2013**, *6*, 545–549. (In Russian)
22. Yermolaeva, N.I.; Zarubina, E.Y.; Puzanov, A.V.; Romanov, R.E.; Leonova, G.A. Hydrobiological conditions of sapropel formation in lakes in the South of Western Siberia. *Water Resour.* **2016**, *43*, 129–140. [CrossRef]
23. Abdulwahab, S.; Rabee, A.M. Ecological factors affecting the distribution of the zooplankton community in the Tigris River at Baghdad region, Iraq. *Egypt. J. Aquat. Res.* **2015**, *41*, 187–196. [CrossRef]
24. Lim, B.; Han, S.; Choi, I.; Yoon, J.; Lee, J.; Cheon, S.; Cho, K. Evaluation of physico-chemical parameters regulating zooplankton community structure in the Geum River, Korea. *Iran. J. Fish. Sci.* **2020**, *19*, 352–371. [CrossRef]
25. Ejsmont-Karabin, J. The usefulness of zooplankton as lake ecosystem indicators: Rotifer trophic state index. *Pol. J. Ecol.* **2012**, *60*, 339–350.
26. Sládeček, V. Rotifers as indicators of water quality. *Hydrobiologia* **1983**, *100*, 169–201. [CrossRef]
27. Krupa, E.; Romanova, S.; Berkinbaev, G.; Yakovleva, N.; Sadvakasov, E. Zooplankton as Indicator of the Ecological State of Protected Aquatic Ecosystems (Lake Borovoe, Burabay National Nature Park, Northern Kazakhstan). *Water* **2020**, *12*, 2580. [CrossRef]
28. Pashkova, O.V. Zooplankton as Indicator of Organic and Toxic Pollution and Ecological State of Aquatic Ecosystems (a Review). *Hydrobiol. J.* **2013**, *49*, 3–20. [CrossRef]
29. Ermolaeva, N.I.; Dvurechenskaya, S.Y. Regional indices of the indicator significance of zooplanktonic organisms in water bodies of Southern Western Siberia. *Russ. J. Ecol.* **2013**, *44*, 527–531. [CrossRef]
30. Saunders, J.F., III; Lewis, W.M.J. Zooplankton abundance in the lower Orinoco River, Venezuela. *Limnol. Oceanogr.* **1989**, *34*, 397–409. [CrossRef]
31. Burger, D.F.; Hogg, I.D.; Green, J.D. Distribution and abundance of zooplankton in the Waikato River, New Zealand. *Hydrobiologia* **2002**, *479*, 31–38. [CrossRef]
32. Rossetti, G.; Viaroli, P.; Ferrari, I. Role of abiotic and biotic factors in structuring the metazoan plankton community in a lowland river. *River Res. Appl.* **2009**, *25*, 814–835. [CrossRef]
33. Deksne, R.; Škute, A.; Gruberts, D.; Paidere, J. Effects of climate change on zooplankton community structure of the middle stretch of the Daugava river over the last 50 years. *Ecohydrol. Hydrobiol.* **2011**, *11*, 79–95. [CrossRef]

34. Shevtsova, L.V.; Guleykova, L.V. Long-term dynamics of zooplankton of the Desna river. *Hydrobiol. J.* **2005**, *41*, 3–14. [CrossRef]
35. Lansac-Tôha, F.A.; Bonecker, C.C.; Velho, L.F.M.; Simões, N.R.; Dias, J.D.; Alves, G.M.; Takahashi, E.M. Biodiversity of zooplankton communities in the Upper Paraná River floodplain: Interannual variation from Long-Term studies. *Braz. J. Biol.* **2009**, *69* (Suppl. 2), 539–549. [CrossRef] [PubMed]
36. Deksne, R.; Škute, A. The influence of ecohydrological factors on the cenosis of the Daugava River zooplankton. *Acta Zool. Litu.* **2011**, *21*, 133–144. [CrossRef]
37. Kulakov, D.V. Seasonal and interannual changes of the zooplankton of the Neman River. *Principy èkologii* **2018**, *7*, 87–102. [CrossRef]
38. Chará-Serna, A.M.; Casper, A. How do large river zooplankton communities respond to abiotic and biotic drivers over time? A complex and spatially dependent example. *Freshw. Biol.* **2021**, *66*, 391–405. [CrossRef]
39. Shvartsev, S.L.; Savichev, O.G.; Vertman, G.G.; Zarubina, R.F.; Nalyvayko, N.G.; Trifonova, N.G.; Turov Yu., G.; Friesen, L.F.; Yankovsky, V.V. Ecological and geochemical state of river waters in the Middle Ob. *Water Resour.* **1996**, *23*, 723–731.
40. Savichev, O.G. Spatial and temporal changes in the chemical composition of the river waters of the Central Ob basin. *Geogr. I Prir. Resur.* **2000**, *2*, 60–66. (In Russian)
41. Savichev, O.G. The hydrochemical drain of the middle Ob river basin. *Bull. Tomsk Polytech. Univ.* **2007**, *310*, 27–31. (In Russian)
42. Sorokovikova, L.M.; Netsvetaeva, O.G.; Khodzher, T.V.; Kobeleva, N.A.; Chebykin, E.P.; Golobokova, L.P.; Chubarov, M.P. Chemical composition and water quality of the Ob River. In *Ecological and Biogeochemical Studies in the Ob River Basin*; Zuev, V.V., Kurovsky, A.V., Shvartsev, S.L., Eds.; RASKO Publishing House, LLC: Tomsk, Russia, 2002; pp. 21–26. (In Russian)
43. Goncharov, A.V.; Isaev, V.A.; Lobchenko, E.E.; Nichiporova, I.P. Oxygen regime of rivers in Volga, Ob, and Lena basins. *Water Resour.* **2011**, *38*, 608–614. [CrossRef]
44. Goncharov, A.V.; Zaslavskaya, M.B.; Isaev, V.A.; Lobchenko, E.E.; Nichiporova, I.P. Types of oxygen's regime of Ob' basin rivers. *Geogr. Nat. Resour.* **2013**, *3*, 69–76. (In Russian)
45. Uvarova, V.I. Hydrochemical description of the low Ob waterways. Vestnik ekologii, lesovedeniya i landshaftovedeniya. *Int. J. Environ. Stud.* **2011**, *11*, 132–142. (In Russian)
46. Lapin, S.A. Features of freshwater runoff formation in the estuarine systems of the Ob and Yenisei. *Proc. Russ. Sci. Res. Inst. Fish. Oceanogr.* **2017**, *166*, 139–150.
47. Pipko, I.I.; Pugach, S.P.; Semiletov, I.P.; Savichev, O.G.; Shakhova, N.E.; Moiseeva, Y.A.; Repina, I.A.; Barskov, K.V.; Sergienko, V.I. Dynamics of dissolved inorganic carbon and CO_2 fluxes between the water and the atmosphere in the main channel of the Ob river. *Dokl. Chem.* **2019**, *484*, 52–57. [CrossRef]
48. Pokrovsky, O.S.; Manasypov, R.M.; Loiko, S.; Shirokova, L.S.; Krickov, I.A.; Pokrovsky, B.G.; Kolesnichenko, L.G.; Kopysov, S.G.; Zemtzov, V.A.; Kulizhsky, S.P.; et al. Permafrost coverage, watershed area and season control of dissolved carbon and major elements in Western Siberian rivers. *Biogeosciences* **2015**, *12*, 6301–6320. [CrossRef]
49. Novikova, O.D. Rotifera, Cladocera and Copepoda of the Middle Ob Basin. Ph.D. Thesis, Tomsk State University, Tomsk, Russia, 1973; 19p. (In Russian).
50. *Fish Ecology of the Ob-Irtysh Basin*; Pavlov, D.S. (Ed.) KMK Scientific Press: Moscow, Russia, 2006; 596p. (In Russian)
51. *Key to Freshwater Invertebrates of Russia and Adjacent Territories. Vol. 1. Lower Invertebrates*; Tsalolikhin, S.Y. (Ed.) Nauka: St Petersburg, Russia, 1994; 395p.
52. *Key to Freshwater Invertebrates of Russia and Adjacent Territories. Vol. 2. Crustaceans*; Tsalolikhin, S.Y. (Ed.) Nauka: St Petersburg, Russia, 1995; p. 629.
53. *Key to Freshwater Invertebrates of the European Part of the USSR. Plankton and Benthos*; Kutikova, L.A.; Starobogatova, Y.I. (Eds.) Hydrometeoizdat: Leningrad, Russia, 1977; 511p.
54. Kutikova, L.A. *Kolovratki Fauny SSSR. [Rotifer Fauna of USSR]*; Nauka: Leningrad, Russia, 1970; 742p. (In Russian)
55. Manuylova, E.F. *Cladocera of fauna the USSR*; Nauka: Leningrad, Russia, 1964; 326p. (In Russian)
56. Rylov, V.M. *Cyclopoida of Fresh Water. Fauna of the USS*; New Series, N 35; Publishing House of the USSR Academy of Sciences: Leningrad, Russia, 1948; 416p. (In Russian)
57. Rylov, V.M. *Freshwater Calanoida of the USSR. Freshwater Fauna. Issue 1*; Institute of Fisheries and Commercial Research: Moscow, Russia, 1930; 318p. (In Russian)
58. Smirnov, N.N. *Fauna of the USSR. Crustaceans. Volume 1, Issue. 2*; Chydoridae of the Fauna of the World; Nauka: Moscow, Russia, 1971; 268p. (In Russian)
59. Smirnov, N.N. *Fauna of the USSR. Crustaceans. Volume 1, Issue 3*; Macrothricidae and Moinidae of the Fauna of the World; Nauka, Leningrad Branch: Moscow, Russia, 1976; 237p. (In Russian)
60. Borutsky, E.V. *Determinant of Free-Living Freshwater Copepod Crayfish of the USSR and Neighboring Countries by Fragments in Fish Intestines*; Publishing House of the USSR Academy of Sciences: Moscow, Russia, 1960; 219p. (In Russian)
61. Borutsky, E.V.; Stepanova, L.A.; Kos, M.S. *Key to Freshwater Calanoida of the USSR*; Nauka: St. Petersburg, Russia, 1991; 503p. (In Russian)
62. Balushkina, E.V.; Vinberg, G.G. Relationship between Length and Weight of Planktonic Crustaceans. In *Eksperimental'nye I Polevye Issledovaniya Biologicheskikh Osnov Produktivnosti Ozer (Experimental and Field Studies of Biological Bases of Productivity of Lakes)*; Izd. Zool. Inst. AN SSSR: Leningrad, Russia, 1979; pp. 169–172. (In Russian)

63. Bakanov, A.I. Quantitative assessment of domination in ecological communities. In *Quantitative Methods of Ecology and Hydrobiology: Book of Papers Dedicated to A.I. Bakanov's Memory*; Publishing House of Samar Scientific Center of RAS: Togliatti, Russia, 2005; p. 44. (In Russian)
64. Slàdeček, V. System of water quality from the biological point of view. *Arch. Hydrobiolgia. Ergeb. Der Limnol.* **1973**, *7*, 1–218.
65. *Annual Data on the Regime and Resources of Land Surface Waters; Part 1; Rivers and canals. RSFSR. The Ob Basins (Without the Irtysh basin), Nadym, Pura, and Taza*; West Siberian Regional Research Hydrometeorological Institute: Novosibirsk, Russia, 2009. (In Russian)
66. Magritsky, D.V. *Heat Runoff to the Russian Arctic Seas and Its Changes*; Vestnik Moskovskogo Unviersiteta: Moscow, Russia, 2009; Volume 5, pp. 69–77. (In Russian)
67. Bulavina, A.S. Reconstruction of the Ob river runoff according to meteorological observations data. *Proc. Kola Sci. Cent. RAS* **2020**, *11*, 17–27. [CrossRef]
68. Basu, B.K.; Pick, F.R. Phytoplankton and Zooplankton Development in a Lowland Temperature River. *J. Plankton Res.* **1997**, *19*, 237–253. [CrossRef]
69. Canale, R.P.; Vogel, A.H. Effects of Temperature on Phytoplankton Growth. *J. Environ. Eng. Div.* **1974**, *100*, 229–241. [CrossRef]
70. Reynolds, C.S.; Walsby, A.E. Water blooms. *Biol. Rev. Camb. Philos. Soc.* **1975**, *50*, 437–481. [CrossRef]
71. Baird, M.E.; Emsley, S.M.; Mcglade, J.M. Modelling the interacting effects of nutrient uptake, light capture and temperature on phytoplankton growth. *J. Plankton Res.* **2001**, *23*, 829–840. [CrossRef]
72. Zhao, Q.; Liu, S.; Niu, X. Effect of water temperature on the dynamic behavior of phytoplankton–zooplankton model. *Appl. Math. Comput.* **2020**, *378*, 125211. [CrossRef]
73. Işkın, U.; Filiz, N.; Cao, Y.; Neif, É.M.; Öğlü, B.; Lauridsen, T.L.; Davidson, T.A.; Søndergaard, M.; Tavşanoğlu, Ü.N.; Beklioğlu, M.; et al. Impact of Nutrients, Temperatures, and a Heat Wave on Zooplankton Community Structure: An Experimental Approach. *Water* **2020**, *12*, 3416. [CrossRef]
74. Alimov, A.F. The fundamentals of the theory of the functioning of aquatic ecosystems. *Hydrobiol. J.* **1990**, *26*, 3–12. (In Russian)
75. Ivanova, M.B. Influence of active reaction and general water salinity on the formation of zooplankton community in lakes when the values of these factors approach extreme ones. *Proc. Zool. Inst. RAS* **1997**, *272*, 71–86. (In Russian)
76. Ivanova, M.B. Dependence of the number of species in zooplankton of lakes on the total mineralization of water and the pH value. *Inland Water Biol.* **2005**, *1*, 64–68. (In Russian)
77. Ivanova, M.B.; Kazantseva, T.I. Influence of active reaction and total salinity of water on the species diversity of pelagic zooplankton in lakes (statistical analysis). *Russ. J. Ecol.* **2006**, *4*, 294–300. (In Russian)
78. Brett, M.T. Zooplankton communities and acidification process (a review). *Water Air Soil Pollut.* **1989**, *44*, 387–414. [CrossRef]
79. Havens, K.E. Summer zooplankton dynamics in the limnetic and littoral zones of a humic acid lake. *Hydrobiologia* **1991**, *215*, 21–29. [CrossRef]
80. Havens, K.E.; Carlson, R.E. Functional complementarity in plankton communities along a gradient of acid stress. *Environ. Pollut.* **1998**, *101*, 427–436. [CrossRef]
81. Fischer, J.M.; Frost, T.M.; Ives, A.R. Compensatory Dynamics in Zooplankton Community Responses to Acidification: Measurement and Mechanisms. *Ecol. Appl.* **2001**, *11*, 1060–1072. [CrossRef]
82. Dyga, A.K.; Zolotareva, V.I. Influence of the active reaction of water on individual representatives of zooplankton and macrozoobenthos in connection with industrial pollution of water bodies. *Water Resour.* **1983**, *5*, 104–107. (In Russian)
83. Havens, K.E.; Hanazato, T. Zooplankton community responses to chemical stressors: A comparison of results from acidification and pesticide contamination research. *Environ. Pollut.* **1993**, *82*, 277–288. [CrossRef]
84. Hansen, B.W.; Andersen, C.M.B.; Hansen, P.J.; Nielsen, T.G.; Vismann, B.; Tiselius, P. In situ and experimental evidence for effects of elevated pH on protistan and metazoan grazers. *J. Plankton Res.* **2019**, *41*, 257–271. [CrossRef]
85. Imant, E.N.; Novoselov, A.P. Dynamics of Zooplankton Composition in the Lower Northern Dvina River and Some Factors Determining Zooplankton Abundance. *Russ. J. Ecol.* **2021**, *52*, 59–69. [CrossRef] [PubMed]
86. Dvurechenskaya, S.Y.; Yermolaeva, N.I. Interrelations between Chemical Composition of Water and Characteristics of Zooplankton in the Novosibirsk Water Storage Basin. *Contemp. Probl. Ecol.* **2014**, *7*, 464–472. [CrossRef]
87. Khamitova, M.F. Study of Changes in Hydrobiological Characteristics under Conditions of Local Pollution in the Region of the Middle Volga. Ph.D. Thesis, Kazan University, Kazan, Russia, 2017; 24p. (In Russian).
88. Aleksevnina, M.S.; Pozdeev, I.V. *Sanitary Hydrobiology with the Basics of Aquatic Toxicology*; Perm National Research University: Perm, Russia, 2016; 205p. (In Russian)
89. Frutos, S.M.; Poi de Neiff, A.S.G.; Neiff, J.J. Zooplankton of the Paraguay River: A comparison between sections and hydrological phases. *Ann. De Limnol. Int. J. Limnol.* **2006**, *42*, 277–288. [CrossRef]
90. Vannote, R.L.; Minshall, G.W.; Cummins, K.W.; Sedell, J.R.; Cushing, C.E. The river continuum concept. *Can. J. Fish. Aquat. Sci.* **1980**, *37*, 130–137. [CrossRef]
91. Górski, K.; Collier, K.J.; Duggan, I.C.; Taylor, C.M.; Hamilton, D.P. Connectivity and complexity of floodplain habitats govern zooplankton dynamics in a large temperate river system. *Freshw. Biol.* **2013**, *58*, 1458–1470. [CrossRef]
92. De Ruyter van Steveninck, E.D.; Admiraal, W.; Breebaart, L.; Tubbing, G.M.J.; van Zanten, B. Plankton in the River Rhine: Structural and functional changes observed during downstream transport. *J. Plankton Res.* **1992**, *14*, 1351–1368. [CrossRef]

93. Scherwass, A.; Bergfeld, T.; Schoel, A.; Weitere, M.; Arndt, H. Changes in the plankton community along the length of the River Rhine: Lagrangian sampling during spring. *J. Plankton Res.* **2010**, *32*, 32–491. [CrossRef]
94. Otyukova, N.G.; Tselmovich, O.L.; Krylov, A.V. The Effect of the Precipation Amount and Flow Regulation on Chemical Composition of Water and Zooplankton of a Small River. *Inland Water Biol.* **2007**, *3*, 48–55. (In Russian)
95. Berggren, M.; Bengtson, P.; Soares, A.R.A.; Karlsson, J. Terrestrial support of zooplankton biomass in northern rivers. *Limnol Oceanogr.* **2018**, *63*, 2479–2492. [CrossRef]
96. Groeneveld, M.; Catalán, N.; Attermeyer, K.; Hawkes, J.; Einarsdóttir, K.; Kothawala, D.; Bergquist, J.; Tranvik, L. Selective adsorption of terrestrial dissolved organic matter to inorganic surfaces along a boreal inland water continuum. *J. Geophys. Res. Biogeosciences* **2020**, *125*, e2019JG005236. [CrossRef]
97. Duggan, I.C. The ecology of periphytic rotifers. *Hydrobiologia* **2001**, *446–447*, 139–148. [CrossRef]
98. Lucena-Moya, P.; Duggan, I.C. Macrophyte architecture affects the abundance and diversity of littoral microfauna. *Aquat. Ecol.* **2011**, *45*, 279–287. [CrossRef]