Frontiers in Bioscience Landmark

Front. Biosci. (Landmark Ed) **2022**; 27(7): 221
https://doi.org/10.31083/j.fbl2707221

Original Research

Remote sensing and *in-situ* approach for investigation of pelagic communities in the reservoirs of the electrical power complex

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Academic Editor: Graham Pawelec
Submitted: 30 December 2021 Revised: 27 January 2022 Accepted: 28 January 2022 Published: 13 July 2022

Abstract

Background: Two closely located reservoirs on the Southern Bug River and its tributary in the southern region of Ukraine were compared to study the impact of temperature on hydrobionts and pelagic communities, a major ecologic issue in the climate warming context, using in-situ and satellite remote sensing data. These reservoirs are parts of the South-Ukraine electric power-producing complex. The Tashlyk reservoir is a cooling reservoir for the nuclear power plant, and Oleksandrivske reservoir is used for production of hydroelectricity and irrigation. The cooling reservoir is replenished by pumping water from the upper part of the Oleksandrivske reservoir. **Methods**: The relationships of temperature, transparency, and distribution of phytoplankton and zooplankton communities were established based on satellite remote sensing data and in-situ during 2013–2021. The main variables of phytoplankton and zooplankton were compared, and for improved understanding features, spatial distribution maps were created. **Results**: It was found that the distribution of coenotic groups of phytoplankton and zoonplankton in the cooling reservoir (Tashlyk) corresponds to thermal conditions. Three communities of phytoplankton and two communities of zooplankton were identified in the Tashlyk reservoir. However, in the Oleksandrivske reservoir, separate communities of phytoplankton and zooplankton were reported along its length. **Conclusions**: It was shown that both on land and in the Oleksandrivske reservoir, there is an increase in temperature in summer, an increasing trend in the global warming context, but that was not observed in the cooling reservoir of the nuclear power plant (NPP). It let us assume that the factors such as temperature or nutrients impact can be assessed as external significant factors related to the catchment area for the reservoirs with different types of using.

Keywords: earth remote sensing; cooling reservoir; Ukraine; nuclear power plant; plankton; climate warming model

1. Introduction

The water quality in many natural water bodies and artificial reservoirs has been declining over the last few decades. The conventional method of water quality monitoring is point data collection, which is often employed [1]. Point-based sampling is more expensive, time-consuming, labor-intensive and with a lower areal extent. To overcome the limitations of *in-situ* water quality monitoring, there is a need for real-time water quality measurements, for many purposes [2].

In the 1970s there was an idea [3] that studies in the field of the effect of high temperatures, which usually do not occur in nature, are of a purely academic in nature, associated with the physiology of extreme conditions, or refer to particular problems of local impact of thermal power plants and nuclear power plants on water bodies. However, climate change has posed this problem on a completely different, global scale [4].

There are four nuclear power plants in Ukraine with a total capacity of 13.8 MW. Forecast data [5] show that by 2050, electricity generation in Ukraine may increase by 27%, while the share of nuclear energy will be 50%, and the share of thermal power plants will be 25% (those stations that consume water for cooling). If at present in Ukraine an amount of water is used for cooling that is comparable with the flow of such a river as the Southern Bug, then by 2050 this amount may increase by almost a third. Forecasts in the 1970s showed [6] that in the year 2000 up to 1/3 of all US river flow would pass through the cooling systems of power plants. Data on the development of the world energy sector [7] do not allow us to assume that the structure of the energy sector in the world has changed dramatically and will change in the near future.

With the advent of high resolution satellite remote sensing products, it is easy to monitor surface water quality using different satellite sensors and to assess the status

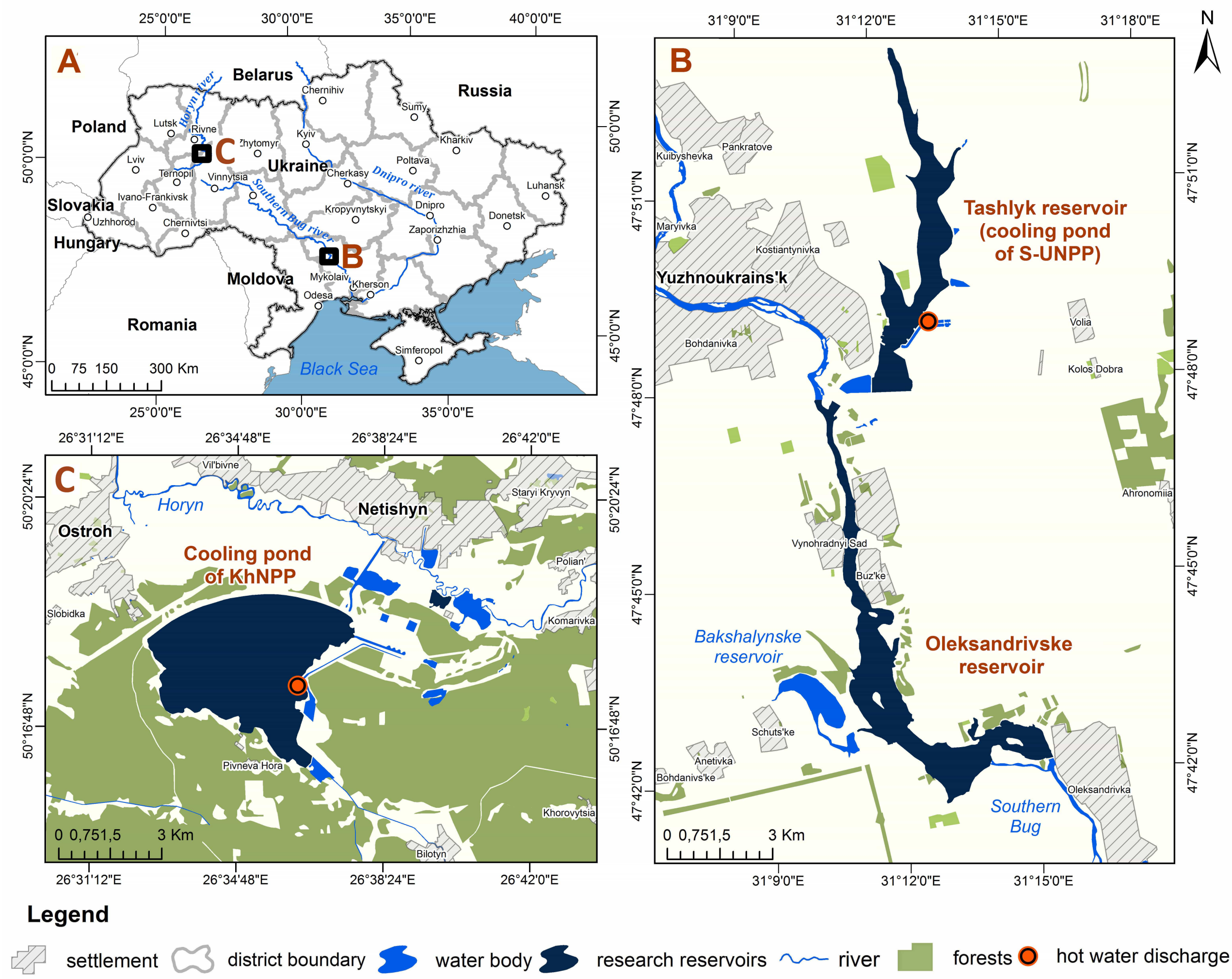

Fig. 1. Location map of study area on the territory of Ukraine. (A) Location of sites B and C on the territory of Ukraine. (B) A cooling reservoir of the Khmelnitsky nuclear power plant (NPP). (C) The Tashlyk and Oleksandrivske reservoirs.

of water bodies at synoptic scale in almost near real time [8–16]. Landsat series satellites have the largest archive of earth resource data sets. Landsat sensors have been widely used in the estimation of water quality parameters such as total suspended matter, chlorophyll-a, turbidity, water depth, total phosphorus, dissolved oxygen (DO), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) [17–21]. Nevertheless, many issues related to hydrobiological assessments of the ecological state of water bodies remain poorly studied. In particular, there are practically limitted studies that allow to assess the biological factors of the life of aquatic organisms in reservoirs under the influence of heated wastewaters from power plants. Protasov *et al*. [22] suggested change in the thermal regime and hydrodynamics in such water bodies significantly affect biotic parameters.

There are a number of studies aimed to study the distribution of a thermal plume from nuclear power plants using satellite data [23,24]. The purpose of the work was (1) to identify change in thermal regime and the turbidity mode, i.e., the main conditions for the existence of plankton organisms in two reservoirs with different habitat conditions and peculiarities in composition and quantitative parameters of phytoplankton and zooplankton (the Oleksandrivske and the Tashlyk reservoir), and (2) make assumptions and predictions regarding abiotic factors and life in water bodies under conditions of global climatic changes and potential trends in lotic systems.

2. Materials and methods

2.1 Description of study site

We have used water temperature measurements in the cooling pond of the Khmelnytsky nuclear power plant (NPP) in 2013–2021 (Fig. 1). Field studies of the Tashlyk and Oleksandrivske reservoirs were carried out in July 2018 at a number of stations (seven stations for each reservoir). The distributions of variables were analyzed according to conventionally identified longitudinal profiles (transects), Fig. 2A,B. The Oleksandrivske reservoir was created as a reservoir for a hydroelectric power plant (OHPP) with two

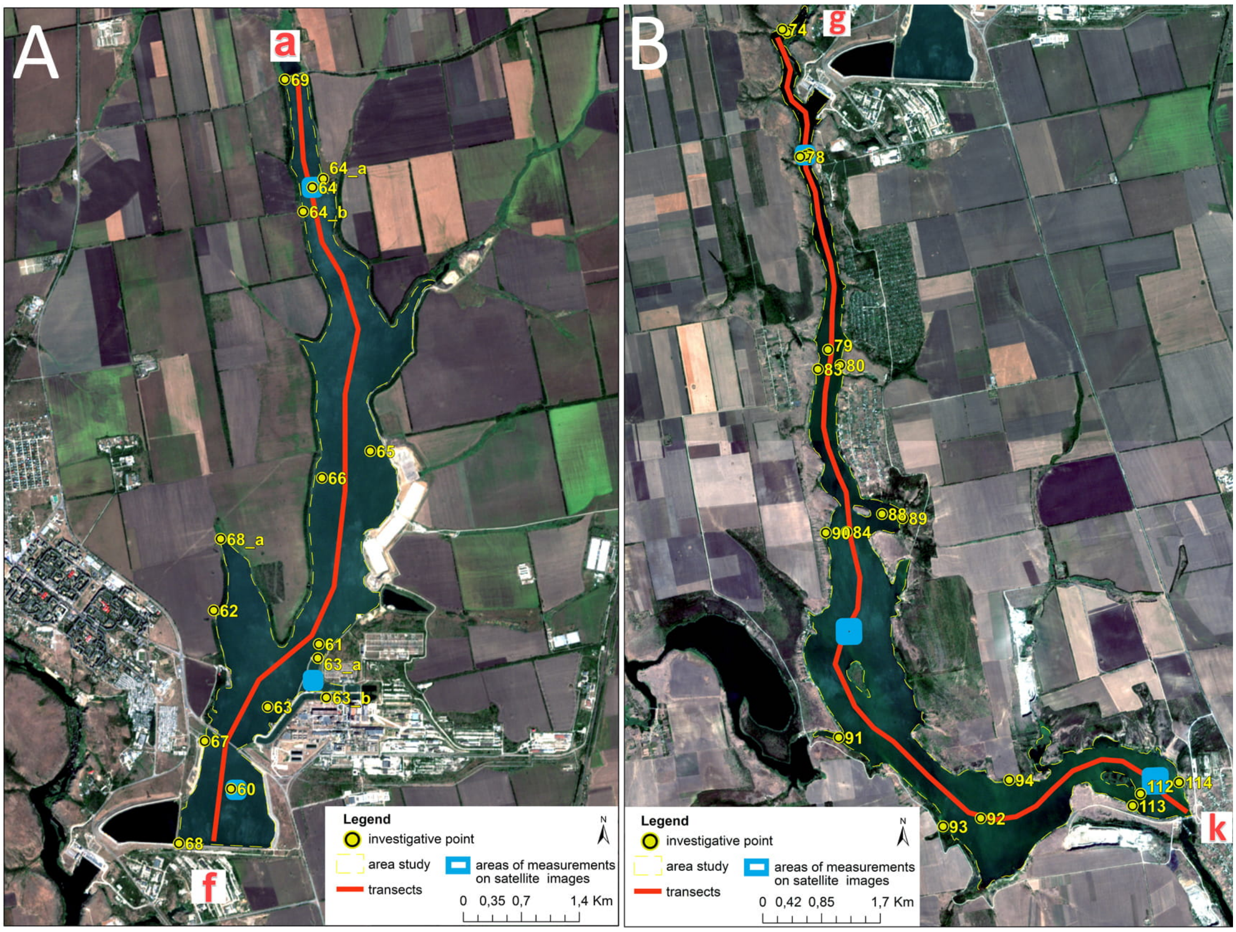

Fig. 2. Location of study stations (A) the Tashlyk reservoir, and (B) Oleksandrivske reservoir. The location of transects of (a–f) the Tashlyk reservoir, and (g–k) the Oleksandrivske reservoir on satellite image Sentinel-2 (for 30.08.2020).

hydraulic units with a total capacity of 9.8 MW, located in the canyon of the Southern Bug River. Tashlyk is a cooling reserve for South Ukraine NPP. It has three nuclear power units with a total installed capacity of 3000 MW.

The NPP is located on the left bank of the Tashlyk reservoir (TR) formed on the inflow of the River. SUNPP is included as the basic part in the infrastructure of the South-Ukrainian Power Complex (SUPC), the only company in Ukraine with integrated use of basic nuclear and followmode hydroaccumulave capacies, as well as water resources of the Southern Bug River. Today, the SUPC includes SUNPP, Oleksandriske Hydroelectric Power Plant (OHPP) and Tashlyk Pumped-Storage Power Plant (TPSPP) [5]. Pumping water for compensation of evaporation from the cooling reservoir is used from the South .Bug River by a pumping station located on the border with the Oleksandrivske reservoir. The amount of this water is more than 36 million m^3 per year. TESPP has its own upper reservoir, which, according to the primary project, was connected with the Tashlyk reservoir, but is currently separated from it. For reduce the mineralization of water in the Tashlyk reservoir, a constant water shnge is formed, the discharge of water from the Tashlyk reservoir into a upper part of the Oleksandrivske reservoir, its volume is less than 1 m^3/s.

If we differ the fundamental differences between the two studied water bodies, then the following should be pointed out: differences in the nature of the thermal regime and differences in the general hydrodynamics of waters [4]. Oleksandrivske reservoir is a typical reservoir on a middle river in which flow rates gradually decrease towards the dam, depth increases, sediments accumulate, based on the needs of water use, water flow from the reservoir can increase, however, basically there is a certain balance of inflow and outflow, water temperature at surface is practically unchanged throughout the water area. The Tashlyk reservoir has no flow through the dam; its natural replenishment due to a very small river is insignificant, the replenishment of water, a significant part of which evaporates, occurs due to pumping from the Southern Bug River. The so-called “internal water exchange”, that is, the ratio of the circulating waters of the nuclear power plant and the volume of the reservoir is very high: a volume of water equal to the volume of the entire reservoir could pass through the cooling systems, with the constant operation of three power units more than 90 times a year. Deep-water intake contributes

Table 1. Data on temperature, transparency, depth of the reservoir on the stations, oxygen content, and pH at stations of hydrobiological sample collection.

Station	Temperature, °C	Transparency, m	Oxygen, mg O_2/dm^3	Depth, m	pH
Tashlyk reservoir					
60	32.7	1.50	7.28	30.00	8.63
61	34.3	0.70	-	-	8.60
61a	41.2	-	-	8.00	8.64
63	34.5	0.90	-	5.90	-
64	34.1	1.10	-	7.00	8.77
65	35.4	0.70	-	8.00	8.67
68a	34.5	0.85	-	1.15	-
IC1	31.4				8.75
Oleksandrivske reservoir					
74	26.9	2.30	8.02	7.50	8.35
76	26.3	2.00	8.16	8.00	8.40
79	26.1	2.05	8.32	8.00	8.20
84	26.1	1.65	8.24	8.00	8.25
88	26.1	1.60	7.92	4.50	8.33
91	27.9	1.10	7.68	6.00	8.37
92	26.7	0.70	7.92	6.00	8.35
112	26.7	0.85	8.00	5.40	8.38

to the mixing of the water mass, so heated, but oxygen-rich waters can move into the depths. In the reservoir, the water temperature is much higher than in the Oleksandrivske reservoir, in addition, there are significant differences in the water temperature in the reservoir itself.

Water bodies created specifically for technical purposes are complex techno-ecosystems [25–28]. The long-term dynamics of plankton in the Tashlyk reservoir has been described [29]. It was found that the changes in plankton primarily occurred due to changes in the regime of temperature and exploitation of the reservoir.

2.2 Description of satellite data sets

Remote sensing data aid to solve problem related to surface temperature through identification of patterns of changes in the state temperature of a resevior [23,30–34]. The Landsat Thermal Infrared Sensor (TIRS) data were collected for the period of 2013 to 2020 to create distribution maps of surface temperature of reservoir. The longwave infrared radiation (wavelength 8–14 μm) allows to obtain data on the intensity of thermal radiation from heterogeneous types of ground cover and surfaces.

2.3 Thermal data processing

The inverse Planck equation was used for thermal radiation of gray body. It converts the spectral density of energy brightness of thermal radiation provided by the TIRS sensor taking into account the thermal radiation coefficient [35]. Land surface temperature (LST) from satellite can be calculated by Eqn. 1:

$$T_\lambda = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda + 1}\right)} - 273.15 \tag{1}$$

Where T_λ is the at-satellite brightness temperature (°C); L_λ is the at-satellite radiance in W/(m^2 *ster* μm); K1 and K2 are prelaunched calibration constants. The temperature calculated by Eqn. 1 is not the actual LST. To obtain a fairly reliable LST from at-satellite brightness temperature calculated by Eqn. 1, has four steps of correction [36]:

(a) top of atmosphere radiance conversion to an at-satellite brightness temperature

(b) correction for atmospheric absorption and re-emission

(c) correction for surface emissivity

(d) correction for surface roughness

The first step is calculation process, as shown in Eqn. 1. The second to fourth steps of correction process are usually very complicated [37]. These steps can be simplified, and LST can be calculated using Eqn. 2:

$$LST = \frac{T_\lambda}{1 + \left(\frac{\lambda * L_\lambda}{p}\right) \ln e} \tag{2}$$

Where LST is the land surface temperature; T_λ is satellite brightness temperature (°C); λ is the wavelength of emitted radiance in μm; p = h*c/j (1.438 $\times$ 10^{-2} mK), where j= Boltzmann constant (1.38 $\times$ 10^{-23} J/K), h = Planck's constant (6.626 $\times$ 10^{-34} Js), and c = velocity of light (2.998 $\times$ 10^{8} m/s); e is the land surface emissivity [38].

Table 2. **Hydrochemical variables at stations of hydrobiological sample collection.**

Station	General hardness, mmol/dm^3	Dry residue, mg/dm^3	Nitrogen of nitrates, mgN/dm^3	Phosphorus of phosphates, mgP/dm^3	Permanganate oxidizability, mg/dm^3
Tashlyk reservoir					
60	9.5	1090	0.66	0.016	6.56
61	9.6	1098	0.62	0.016	7.04
61a	9.5	1089	0.62	0.023	7.52
IC1	9.4	1115	0.77	0.016	5.76
64	9.7	1084	0.54	0.016	7.52
65	9.8	1099	0.52	0.016	7.04
Oleksandrivske reservoir					
74	5.7	616	0.66	0.15	7.84
76	5.7	628	0.58	0.17	8.00
79	5.8	611	0.77	0.19	7.36
84	5.6	635	0.83	0.21	6.88
88	6.2	618	0.76	0.19	7.44
91	6.2	610	0.52	0.16	7.52
92	6.2	609	0.49	0.19	7.12
112	6.2	596	0.45	0.15	7.36

In this case, the ground surface emissivity was obtained from the normalized difference vegetation index (NDVI). The dependence is based on the density of vegetation in relation to the open soil, Eqn. 3:

$$e = 0.004\text{Pv} + 0.986 \tag{3}$$

Where Pν is the vegetation proportion, which is calculated by Eqn. 4. For large homogeneous areas, such as water surfaces, the common table-value can be used (water emissivity is ≈0.9856).

$$P_{\text{v}} = \left(\frac{NDVI - NDVI_0}{NDVI_\infty - NDVI_0}\right)^2 \tag{4}$$

Where NDVI is the value of normalized difference vegetation index in the current pixel; NDVI0 is the maximum NDVI value for the open soil; NDVI∞ is the maximum NDVI value for a completely covered vegetation surface.

2.4 Hydrobiological research methods

The temperature was measured by a mercury thermometer with an accuracy of 0.1 °C, and an electronthermometre (Hanna Co). The water transparency was measured using Secchi disk with a diameter of 30 cm. In the pelagic part of reservoir, samples of phyto- and zooplankton were determined. Phytoplankton were obtained from the surface horizon with a bathometer, and zooplankton were collected using total fishing method of the Apstein net (mesh size 80 μm) from a depth of 3 m to the water surface at Station 68a.

Standard methods were applied to determine the taxonomic composition, biomass, and abundance [39]. The lowest identified taxon (LIT) method was applied to describe taxonomic composition. The names and systematic affiliation of phytoplankton taxa are cited according to the Algae database [40]. Most phytoplankton (94%) and zooplankton (75%) LITs were identified to the species rank or higher. Phytoplankton communities were allocated by the similarity of dominant complex in biomass, and zooplankton communities by destruction. The share of the dominant species of phytoplankton accounted for 50% of the total biomass, and that for zooplankton was 50% of the total destruction. To plot the curves of phytoplankton dominance, we took species that biomass reached to 1% or more of the total. The coefficient of variation (CV) was used to assess the heterogeneity of distribution of plankton indicators over water area [41]. The diversity in abundance and biomass was evaluated using the Shannon index [42]. The similarity of the taxonomic composition was assessed by the Serensen coefficient [42]. Hydrochemical data were provided by the South-Ukraine NPP Ecological and Hydrochemical Laboratory.

Canonical Correspondence Analysis (CCA) was used [43] to determine the influence of some environmental factors (see Tables 1,2), as well as to identify the originality of individual communities, both by the nature of their habitat and by the parameters of their structure (Tables 3,4). CCA type of analysis was chosen from the models of gradient analysis because in our case it covered maximal number of row data in species and environmental variables for the direct unimodal calculation.

Table 3. The cenotic structure of the phytoplankton in the Tashlyk and Oleksandrivske reservoirs in July 2018.

Zone of reservoir	Community	Richness of LIT	Shannon index on abundance, HN, bit/ind	Shannon index on biomass, HB, bit/mg	Abundance, N, mln cells/dm^3	Biomass, B, mg/dm^3
Tashlyk reservoir, discharge area, Station 61a	*Scenedesmus magnus* + *Cosmarium* sp.+ *Nitzschia kuetzingiana* (1phT)	23	3.56	3.47	15.76	2.69
Tashlyk reservoir, Zones a–e, gulf (Stations 61, 63, 64, 65, and 68a)	*Cosmarium* sp.+ *Scenedesmus magnus* + *Nitzschia kuetzingiana* (2phT)	39	2.65 ± 0.22	3.23 ± 0.13	32.88 ± 3.71	3.09 ± 0.41
Tashlyk reservoir, Zones e–f (Station 60)	*Binuclearia lauterbornii* + *Cosmarium* sp.+ *Rhodomonas pusilla* (3phT)	25	3.48	3.45	20.02	2.53
Oleksandrivske reservoir, Zones g–h (Stations 74 and 76)	*Scenedesmus armatus* + *Ankistrodesmus arcuatus* + *Cyclotella meneghiniana* (1phA)	19	3.22 ± 0.12	2.97 ± 0.17	3.64 ± 0.46	0.28 ± 0.10
Oleksandrivske reservoir, Zone I Station 79	*Rhodomonas pusilla* + *Cocconeis placentula* (2phA)	14	3.30	2.97	3.29	0.20
Oleksandrivske reservoir, Zone j Station 84	*Cryptomonas* sp. (3phA)	11	2.04	1.87	4.83	0.64
Oleksandrivske reservoir, Zone j Station 88	*Microcystis aeruginosa* + *Tetrachlorella alternans* (4phA)	20	2.70	2.80	8.51	0.75
Oleksandrivske reservoir, Zones j–k Stations 91, 92, and 112	*Microcystis aeruginosa* (5phA)	26	0.68 ± 0.22	1.04 ± 0.43	441.76 ± 230.38	28.43 ± 14.29

Table 4. The cenotic structure of the zooplankton of the Tashlyk and Oleksandrivske reservoirs in July 2018.

Zone of Reservoir	Community	Richness of LIT	Index Shannon on Abundance, HN, bit/ind	Index Shannon on Biomass, HB, bit/mg	Abundance, N, thousand ind/m^3	Biomass, B, g/m^3	Destruction, R, kJ/m^3h
Tashlyk reservoir, Zones c–e (Stations 63, 65, and 61a)	*Moina micrura* + Nauplii (1zT)	14	3.39 ± 0.04	2.40 ± 0.20	233.46 ± 89.97	1.97 ± 0.74	221.45 ± 79.07
Tashlyk reservoir, Zones a–c, e–f (Stations 60 and 64)	*Thermocyclops oithonoides* + Cyclopoida juv. + *Diaphanosoma dubium* (2zT)	14	2.40 ± 0.08	2.38 ± 0.23	589.87 ± 112.04	5.56 ± 1.1.69	576.46 ± 191.07
Tashlyk reservoir, bay (Station 68a)	Cyclopoida juv. (3zT)	10	0.64	0.30	159.52	1.02	197.73
Oleksandrivske reservoir, Zone g (Station 74)	*Camptocercus rectirostris* + *Acroperus harpae* (1zA)	14	3.68	2.23	0.33	0.00975	0.34
Oleksandrivske reservoir, Zones g–j (Stations 76, 79, and 88)	*Bosmina coregoni* + Nauplii + Cyclopoida juv. + *Diaphanosoma orghidani* (2zA)	23	2.22 ± 0.3	2.91 ± 0.12	74.01 ± 34.99	0.83 ± 0.41	42.72 ± 19.87
Oleksandrivske reservoir, Zone j (Station 84)	Calanoida juv. + *Daphnia cucullata* + *Bosmina coregoni* (3zA)	16	3.01	2.77	372.03	8.57	369.95
Oleksandrivske reservoir, Zone j (Station 91)	*Diaphanosoma orghidani* (4zA)	19	1.67	1.60	647.94	6.94	292.82
Oleksandrivske reservoir, Zones g–k (Stations 92 and 112)	*Diaphanosoma mongolianum* + Cyclopoida juv. + *Daphnia cucullata* (5zA)	17–21	2.72 ± 0.01	2.80 ± 0.1	519.75 ± 134.70	11.04 ± 1.60	498.13 ± 92.79

2.5 Verification of temperature measurements

The estimate of satellite based water temperature was compared with in-situ measurements [44]. We did not have a series of temperature measurements in the Tashlyk and Oleksandrivske reservoirs. Therefore, considering that within the temperate zone, the amendment could be the same in different localities. For verification, we have used data of cooling reservoir (Khmelnitsky NPP), in which a thermal regime was determined. Similarly, the Tashlyk reservoir, by discharge of heated water from the NPP. *In-situ* temperature measurements in the Khmelnitsky NPP cooling reservoir and technical reservoir were carried out on a monthly scale. Therefore, the closest date of Ladnsat-8 was selected and relationship between in-situ measurements and remote sensing data was determined. Errors and discrepancies between the calculated data and in-situ are associated with differences in timing of measurements and processing of remote sensing data.

3. Results and discussion

3.1 Physico-chemical property of water

Table 1 show information of water quality. The minimum transparency in lower zone where heated water is discharged at the Tashlyk reservoir (Fig. 3A,B). The maximum value in the Tashlyk reservoir reached at 1.6 m and in the Oleksandrivske reservoir (2.5 m) respectively. The mineral content and organic suspensions, including plankton organisms affect water transparency. Transparency indicators in lentic water bodies are related to biotic factors (chlorophyll and biomass of planktonic algae) by complex indirect dependence [45–47]. The in-situ temperature distribution show that in the Tashlyk reservoir there are 20 classes at intveral of 0.5 degrees (Fig. 4A,B). However, in the Oleksandrivske reservoir there are only four classes. The temperature range in two water bodies differed from 31.1 °C to 41.2 °C in the Tashlyk reservoir and from 26.1 to 27.8 °C in the Oleksandrivske reservoir. The satellite based retrieved temperature map is illustrated in Fig. 5. The heterogeneity of temperature is higher in Tashlyk reservoir. In the Tashlyk reservoir, a decrease in temperature near dam and in upper reach of reservoir's. In the Oleksandrivske reservoir, a slight decrease in temperature in middle part. It was due to an increase in depth and hydrodynamic processes. A lower temperature was also noted in the Tashlyk reservoir in the deep-water near-dam.

3.2 Phyto- and zooplankton dynamics

In the Tashlyk reservoir during summer phytoplankton richness varied from 51 to 70 LITs in the period 1980–2018. Green algae and diatoms are dominant in the region. The composition of phytoplankton at the phylum level was relatively stable throughout the reservoir. At the same time, there are changes in biomass of algae. In the initial stages of research, amid increasing power plant capacity, an increase in biomass was reported from 3.98–4.75 mg/dm^3 in 1980–1982 to 9.6 mg/dm^3 (average value) in the summer

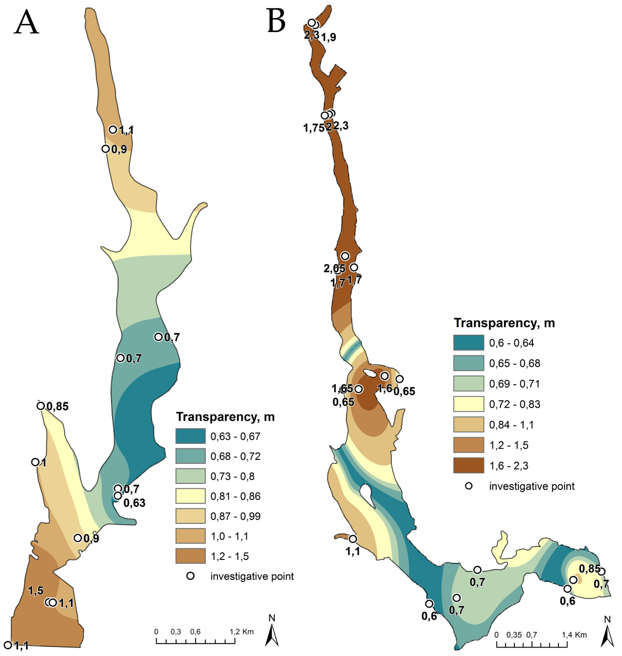

Fig. 3. Field (in-situ measurements) based transparency distribution map. (A) the Tashlyk reservoir, and (B) the Oleksandrivske reservoir. The quantile form of displaying transparency with homogeneous value was selected (seven uneven classes).

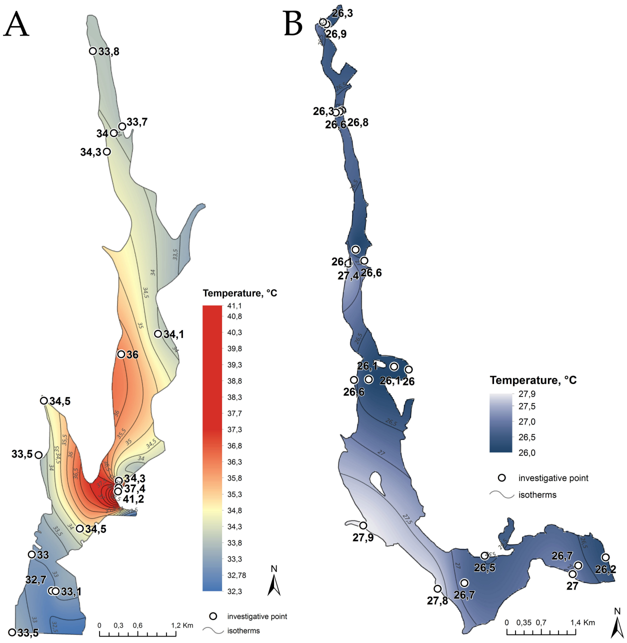

Fig. 4. Field (in-situ measurements) based temperature distribution map. (A) the Tashlyk reservoir, and (B) Oleksandrivske reservoir. The quantile form of displaying temperature with homogeneous value was selected (19 uneven classes for Tashlyk reservoir and five uneven classes for Oleksandrivske reservoir).

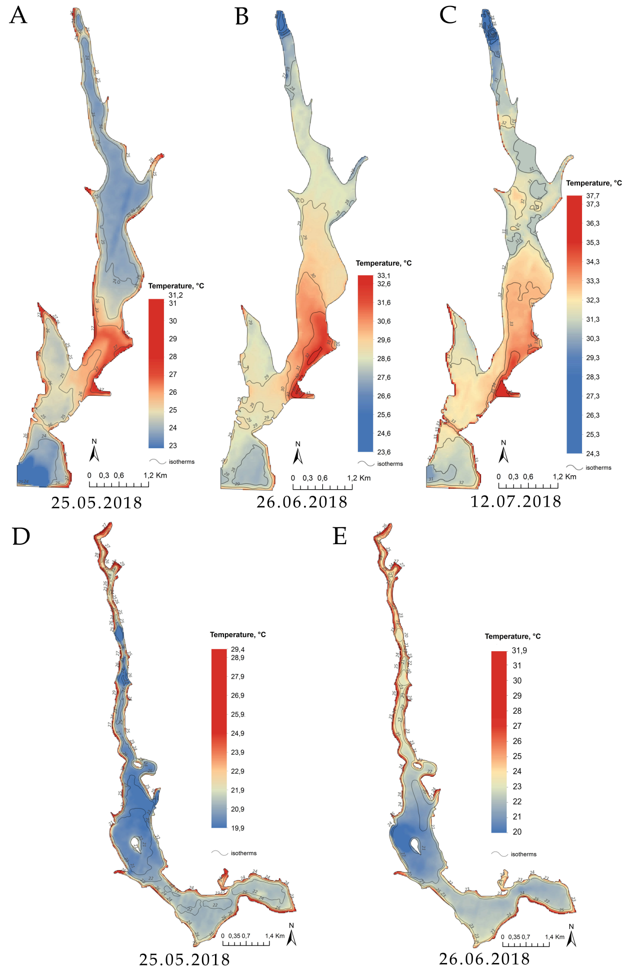

Fig. 5. Satellite based temperature distribution map. (A, B, C) the Tashlyk reservoir, and (D, E) the Oleksandrivske reservoir.

of 1985. It was mainly due to Aulacoseira granulate. In 1986, an increase in temperature was reported not only in area of discharge channel outlet, but also throughout reservoir. During this period, minimum biomass of phytoplankton was registered, with an average of 0.3 mg/dm^3. In next 10 year, there was an increase in biomass of phytoplankton. However, the range of fluctuations of summer phytoplankton biomass did not surpassed. In 2018, level of abundance and biomass of phtoplankton was low. Thus, for phytoplankton, a decrease was observed from 1986.

In summer green alage and diatom was pre-dominated in the Oleksandrivske reservoir. In early 1980s the biomass of phytoplankton was similar to the Tashlyk reservoir: 0.363–4.994 mg/dm^3 in 1980–1982. The Oleksandrivske reservoir it was characterized by an increase in abundance of algae from upstream to downstream in summer of 1990. Whereas the difference between phytoplankton biomass of upper and lower parts of reservoir was 2–3 orders of magnitude (0.51 $\pm$ 0.01 and 135.76 $\pm$ 71.87 mg/dm^3, respectively). In subsequent years, this trend has continued, and in 2018 difference in phytoplankton biomass was also high (0.28 $\pm$ 0.11 in the upper reaches and 38.42 $\pm$ 17.70 mg/dm^3 in the lower reaches). In lower part of reservoir, water bloom was reported in 1990, it was due to biomass of *Gynmnodinium sp*. and *Chlamidomonas sp*., and in 2018—*Microcystis aeruginosa*.

Many studies have been carried out for zooplankton of Ukrainian reservoirs [48–54]. In 1980–1984, the species composition of zooplankton in water bodies consisted of 42 taxa, including *Dreissena* larvae, varying from 11 to 34 species in different seasons. Before the start-up of the nuclear power plant (NPP) (1981–1982), in the Tashlyk reservoir, the biomass of summer zooplankton averaged on the reservoir was 2.2 and 1.8 g/m^3, and it was based on *Eudiapto musgracilis* (Sars), *Daphnia longispina* (O.F. Müll.), and *D. cucullata*. After the start-up of the first NPP unit (1984), the level of zooplankton biomass increased on an average to 5.7 g/m^3, and *D. cucullata* dominated. At the same time, the maximum biomass (up to 11.5 g/m^3) was noted in the upper part of the reservoir, where the water temperature was lower than the area of the heated water discharge.

Changes in conditions, in particular, an increase in water temperature with an increase in NPP power while two power units were already operating (1985), led to a decrease in zooplankton biomass to 1.6 g/m^3 and a change in the dominant complex, in which a more thermophylic species *Diaphanosoma brachyurum* (Liévin) prevailed. An increase in the temperature of the discharge water to 40.5 °C in 1986 led to a decrease in the quantitative development of zooplankton in the middle and near-dam areas of the reservoir due to the mass death of *D. brachyurum*. In general, the discharge of heated waters did not lead to significant changes in the distribution of zooplankton in most cases. The maximum abundance values were in the upper reaches, and the minimum values were in the warmed area. In 1990–92, in the Tashlyk reservoir, the biomass of summer zooplankton was 0.96–2.45 g/m^3. In the summer of 1997, significant changes in the species composition of the zooplankton was marked. Fourteen species,43% of the species found in 1990–92, were found. However, *D. brachyurum*, as before, had a dominant position. Zooplankton biomass was within the values of previous years—on average 1.8 g/m^3. In the Oleksandrivske reservoir, in the summer of 1990, high values of quantitative variables of zooplankton were noted in the area of the dam; for example, the biomass of the dominant *D. brachyurum* reached 5.3 g/m^3.

3.3 Diversity of thermal conditions

In the Tashlyk reservoir, according to field data, the sub-range of 33–35 °C prevailed in the area; in the Oleksandrivske reservoir, the sub-range was 23–24 °C. The Shannon diversity function to define the diversity of fields, similar to the diversity of landscape patterns [55], allowed to define the diversity of thermal conditions in each of reservoirs at different periods. According to in-situ measurements, the diversity of temperature conditions was higher in the Oleksandrivske reservoir due to a more uniform distribution of thermal fields. This seems to be quite logical since there is no discharge of additionally heated water masses. In the Oleksandrivske reservoir, the diversity approached to maximum and evenness was close to 1. According to the WEB resource [56], on days when fields with a high relative temperature prevailed in the Tashlyk reservoir, the wind speed was less than 1 m/s. On days with a predominance of fields of lower relative temperature, the wind speed was higher. The direction of wind was north and northeast, that is, the wind shifted the flow of hot water to the place of discharge and did not allow it to spread over large areas.

3.4 The diversity of distribution of biotic indicators

Similarly, with abiotic characteristics, the distribution of biotic indicators can be obtained, which makes it possible to compare the diversity of conditions, the diversity of biotic indicators, and the diversity of phytoplankton abundance and biomass. Although the diversity of thermal conditions was lower in the Tashlyk reservoir, the diversity of biotic parameters was somewhat higher. The diversity of field distribution for zooplankton is higher than for phytoplankton, and it was noted for both reservoirs. Obviously, the distribution of phyto- and zooplankton was influenced by other factors—not just the distribution of surface temperature.

3.5 Variables distribution (temperature and transparency)

The distribution of temperature and transparency illustrated in Fig. 6. The distribution of temperature on transects shows two main differences in thermal regime. The difference in temperature is significant, whereas temperature in the Oleksandrivske reservoir is rather monotonous. However, in the middle part of Tashlyk, where area of heated water discharge, a certain increase in temperature is noticeable. Transparency shows a mirror image with temperature along the transect. For the Oleksandrivske reservoir, both variables are divided into two groups, dividing the transect almost in half (about 7 km south of the beginning of the transect). Transparency differed in these zones (g–i and j–k) by almost four times.

There is a significant difference in distribution of values of biomass of phytoplankton and zooplankton in two reservoirs. When comparing distributions of different indicators, several characteristic zones on transects that can be distinguished as original zones of water bodies. In the Tashlyk reservoir, two are zones allocated: a,b and e,f. A decrease in temperature is reported in this zone. These zones are outside of direct influence of discharge. In these zones, there is an increase in transparency, number, and biomass of zooplankton. The abundance of phytoplankton in b–d zone has changed slightly, in contrast to zooplankton, the abundance and biomass decreased. In the c–d zone, slight increase in plankton diversity both in terms of abundance and biomass. In the d–f zone, an increase in abundance and

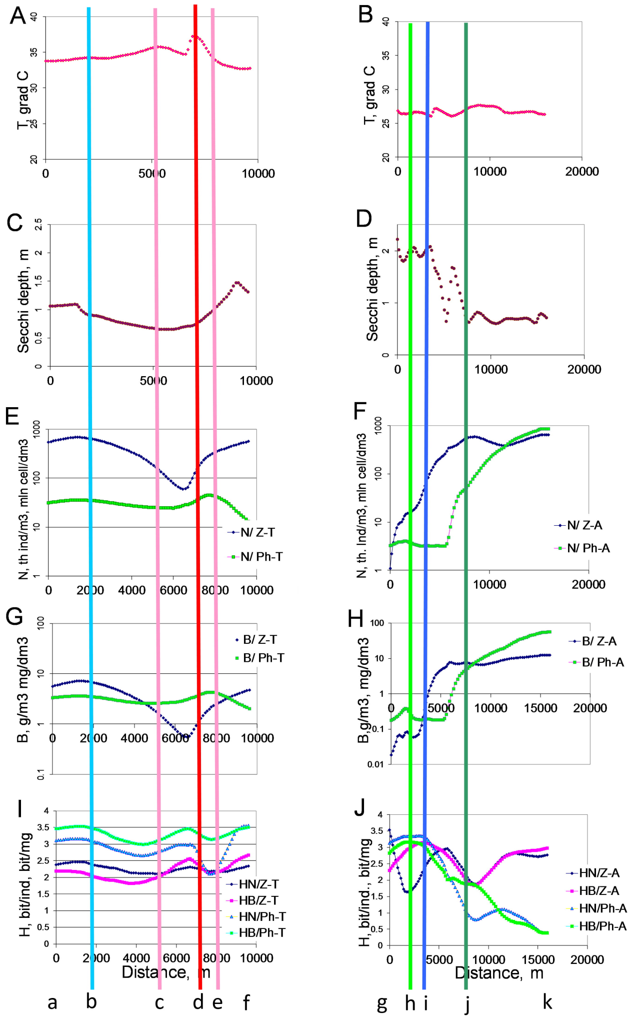

Fig. 6. Changes of hydrobiological variables along transects (a-f, see Fig. 2A) in the Tashlyk reservoir and Oleksandrivske reservoir (g-k, see Fig. 2B). Changes of temperature along transects in the Tashlyk reservoir (A) and Oleksandrivske reservoir (B); the Secchi depth value in the Tashlyk reservoir (C) and Oleksandrivske reservoir (D); the abundance of phyto- and zooplankton in the Tashlyk (E) and Oleksandrivske (F) reservoirs, the biomass of phyto- and zooplankton along transects in the Tashlyk (G) and Oleksandrivske (H) reservoirs; the diversity indices by abundance and biomass of phyto- and zooplankton along transects in the Tashlyk (I) and Oleksandrivske (J) reservoirs. Colored lines for the Tashlyk reservoir (a, b, c, d, e, f) and for Oleksandrivske reservoir (g, h, i, j, k) show the characteristic sections of each transect, explained in the text.

biomass of zooplankton and an increase in diversity.

Another zonation takes place along a longitudinal transect in the Oleksandrivske reservoir. If the temperature indicator is distributed fairly evenly, those three zones are distinguished according to the transparency value: the high (g–i), intermediate (i–g), and low transparency zones (j–k). Algae biomass indices correspond well to the zonation: there was an inverse relationship between transparency and phytoplankton biomass values. Zooplankton biomass indicator also differ quite substantially in the three zones. High value in the g–i zone characterized the indicators of the phytoplankton LDL diversity and then decreased in the i–k zone. Certain rearrangements probably took place in phytoplankton communities, and there was a change from polydominant communities to monodominant ones. Zooplankton was characterized by changes in diversity along the transect similar to oscillation.

3.6 Phytoplankton communities

In 2018, 73 LITs of algae from 7 phyla were found in the phytoplankton of two reservoirs. In the Tashlyk reservoir, there were 52 LITs, of which 30 belonged to the phylum Chlorophyta, 15 to Bacillariophyta, 3 to Cyanobacteria, and 2 each to Cryptophyta and Charophyta. In the Oleksandrivske reservoir, there are 47 LITs (31—Chlorophyta, 8—Bacillariophyta, 4—Cyanobacteria, 2—Cryptophyta, and 1 each of Miozoa and Ochrophyta). Only 4 from 7 phyla were common for the phytoplankton of both reservoirs. However, similarity of LIT composition reached 0.52 according to the Serensen index. The distribution of LIT richness over water area was quite uniform. In the Tashlyk reservoir, the coefficient of variation (CV) was 3.83%; and in the Oleksandrivske reservoir, it was 28.99%. The similarity of the phytoplankton composition at different research stations was higher in the Tashlyk reservoir and was 0.68 ± 0.02; in the Oleksandrivske reservoir, it was 0.36 ± 0.03, according to the Serensen index.

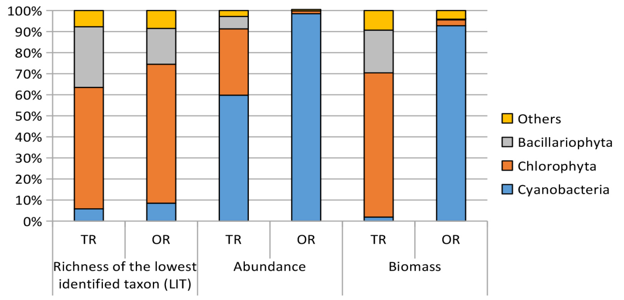

Fig. 7. Ratio of main phytoplankton phyla in two reservoirs represented as richness of LIT, abundance, and biomass. Note: TR, the Tashlyk reservoir; OR, the Oleksandrivske reservoir respectively in July 2018.

In the Tashlyk reservoir, the average value of phytoplankton is (25.82 ± 4.30 million cells/dm^3 and 12.72 ± 0.35 mg/dm^3) compared to the Oleksandrivske reservoir (168.65 ± 109.91 million cells/dm^3 and 10.93 ± 6.94 mg/dm^3). Throughout water area of the Tashlyk reservoir, representatives of Cyanobacteria dominated in abundance and at some stations representatives of Chlorophyta (Fig. 7). In biomass, at all stations, the dominant complex included *Cosmarium sp.* (Charophyta), to which algae from the phyla Chlorophyta, Bacillariophyta, and Cryptophyta joined at some stations. In the Oleksandrivske reservoir, the composition of dominants varied from upstream to downstream. In the upper part, Chlorophyta dominated in abundance, and Cyanobacteria dominated in the middle and lower parts. In the biomass in the upper part, Chlorophyta and Bacillariophyta dominated in the middle, it was Cryptophyta and Bacillariophyta; in the lower part, it was Cyanobacteria. The distribution over water area was more uniform in the Tashlyk reservoir (CV_N = 35.13%, and CV_B = 26.61%; in the Oleksandrivske reservoir (CV_N = 184.33%, and CV_B = 179.53%). The phytoplankton biomass in the Tashlyk reservoir was formed mainly due to Chlorophyta. An analysis of the similarity of the share of LITs in the total biomass at individual stations of the Tashlyk reservoir showed a continual nature of the distribution of phytoplankton over the water area of the reservoir. All three communities have a polydominant structure and similar dominants, which, nevertheless, occupy different rank positions (Table 3). However, the main difference is the steepness of the graph of dominance: in the communities *Scenedesmus magnus* + *Cosmarium sp.* + *Nitzschia kuetzingiana* and *Binuclearia lauterbornii* + *Cosmarium sp.* + *Rhodomonas pusilla*, the graph of dominance have a gradual form, which indicates a fairly uniform distribution of biomass between the dominant species. Whereas, in the community of *Cosmarium sp.* + *Scenedesmus magnus* + *Nitzschia kuetzingiana*, the steep curve of dominance indicates a higher dominance of *Cosmarium sp* (Fig. 8). The distribution of phytoplankton along water area of the Oleksandrivske reservoir was uneven, and some of the communities were distinguished by relative role of LITs in biomass. In the upper reaches of the reservoir (Zones g–h; Stations 74 and 76), the community *Scenedesmus armatus* + *Ankistrodesmus arcuatus* + *Cyclotella meneghiniana* was distinguished with a low level of quantitative parameters and a polydominant structure. Geographically closest to it (Zone i; Station 79), the community *Rhodomonas pusilla* + *Cocconeis placentula* was characterized by a similar quantitative development and diversity level. Further, downstream, in the middle of the reservoir area, there was a gradual increase in quantitative parameters and a decrease in diversity. In Zone j, phytoplankton is divided into two communities, one of which was *Cryptomonas sp.*, localized in the channel part of the reservoir (Station 84), and the second of which was *Microcystis aeruginosa* + *Tetrachlorella alternans*, in the bay (Station 88). The maximum value of quantitative development characterized the community of the lower part of the reservoir (Zones j–k; Station 91, 92, and 112), and the biomass of cyanobacteria reached to the bloom level. The high level of dominance *Microcystis aeruginosa* led to low value of diversity (Table 3). The nature of the relative biomass distribution and the structure of the dominance in phytoplankton communities have changed from upstream to downstream of the

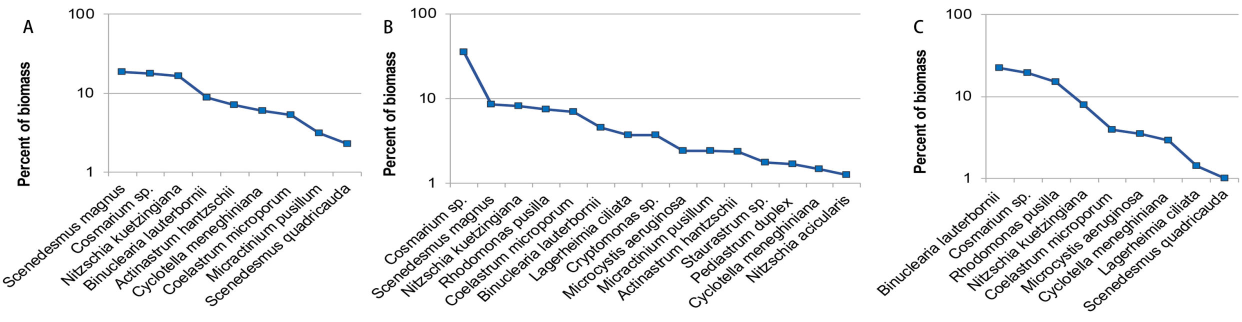

Fig. 8. The graph of dominance–diversity of phytoplankton communities in the Tashlyk reservoir. Illustration (A) community *Scenedesmus magnus* + *Cosmarium* sp. + *Nitzschia kuetzingiana*, (B) *Cosmarium* sp. + *Scenedesmus magnus* + *Nitzschia kuetzingiana*, and (C) *Binuclearia lauterbornii* + *Cosmarium* sp. + *Rhodomonas pusilla.*

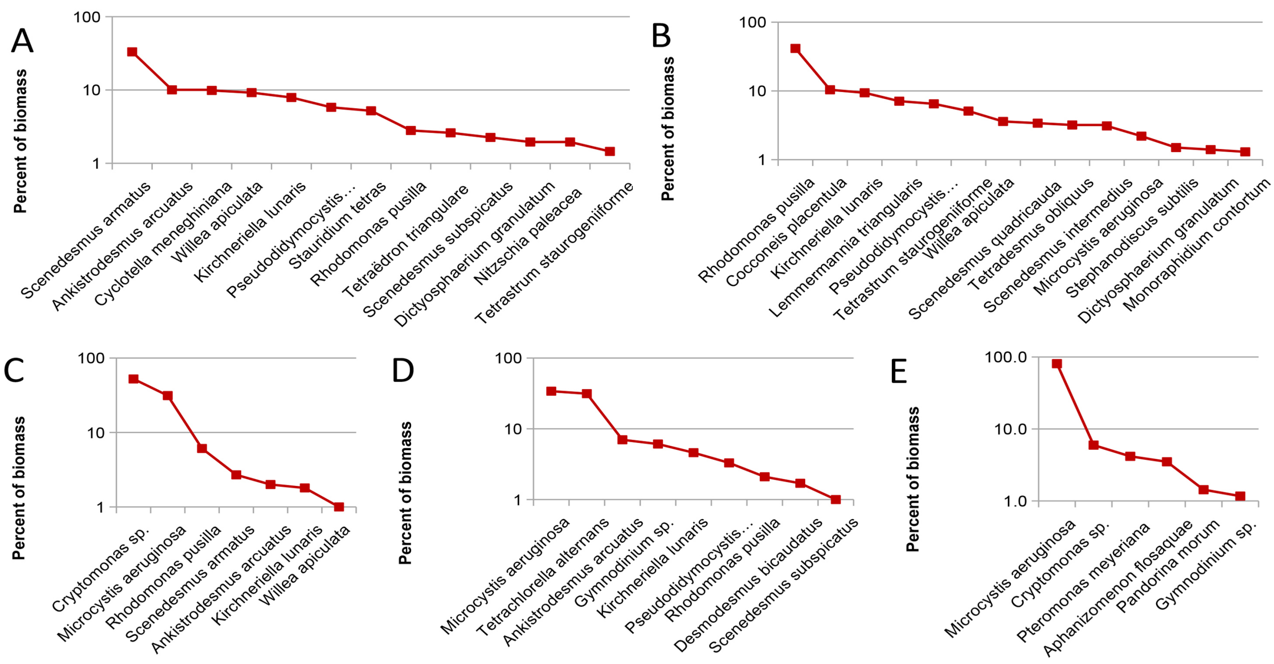

Fig. 9. Graph of dominance–diversity of phytoplankton communities in the Oleksandrivske reservoir. Illustration (A) community *Scenedesmus armatus* + *Ankistrodesmus arcuatus* + *Cyclotella meneghiniana*, (B) *Rhodomonas pusilla* + *Cocconeis placentula*, (C) *Cryptomonas* sp., (D) *Microcystis aeruginosa* + *Tetrachlorella alternans*, and (E) *Microcystis aeruginosa.*

Oleksandrivske reservoir. Downstream, the curve of dominance became steeper, that is, most of the biomass accounted for a smaller abundance of species. In the channel part of reservoir from upstream to downstream. There was a trend towards a decrease in LITs in the community, which account for more than 1% of the biomass (Fig. 9).

3.7 Zooplankton communities

In both water bodies a total of 42 LITs of zooplankton were found, including Rotifera (13), Cladocera (17), Copepoda (11), and *Dreissena* veligers (Fig. 10). Tashlyk reservoir reported less number of zooplankton as a total of 17 LITs, including Rotifera Cladocera (6), and Copepoda (3). The amount of LITs of zooplankton in the Oleksandrivske reservoir was almost twice as large, i.e., 35, including Rotifera (8), Cladocera (15), Copepoda (11), and Dreissena veligers. In the composition of zooplankton of the Tashlyk resevior, only one species was found common with the studies in 1997 (*Brachionus calyciflorus* Pall.). At the same time, most of the species recorded in the Oleksandrivske reservoir were previously reported. Such eurythermic and thermophylic species as *Conochiloides deltaicus* Rud., *Keratella tropica* (Apstein), *Tripleuchlanis plicata* (Lev.), *Diaphanosoma dubium* Manuilova, and *D. orghidani* Negrea were presented as part of the LIT composition of the Tashlyk reservoir. The similarity of the taxonomic composition of the two reservoirs in 2018 was low—0.35 according to the Serensen index.

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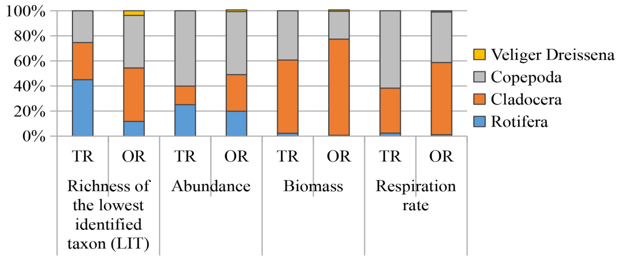

Fig. 10. Ratio of the main zooplankton taxonomic groups in two reservoirs regarding the richness of LIT, abundance, biomass, and destruction (Respiration rate). TR, Tashlyk reservoir; OR, Oleksandrivske reservoir (July 2018).

The distribution of the zooplankton quantitative parameters over the Tashlyk reservoir, in contrast to the composition, was less uniform (CV_N = 67.74%, and CV_B = 80.30%). The abundance varied from 54,130 to 701,913 ind/m^3, and biomass ranged from 0.52 to 7.25 g/m^3, with the lowest value in area of discharge channel and large bay and a highest value in upper reaches. The distribution of the zooplankton quantitative parameters over the water area of the Oleksandrivske reservoir was more heterogeneous (CV_N = 94.42%, and CV_B = 99.12%). Abundance indicator increased from the upper reaches (333 ind./m^3 and 9.75 mg/m^3) to the dam (654449 ind./m^3 and 12647.8 mg/m^3). Both water bodies, have high copepods, in the Tashlyk reservoir, averaged 65.1% and, in the Oleksandrivske reservoir, averaged 55.3%. Cladocerans constituted the largest part of the zooplankton biomass 55.7% and 74.4%, respectively. The *Dreissena* veligers, which were reported only in the Oleksandrivske reservoir, and did not exceed 5.1% and 8.3% of the abundance and biomass, respectively. In the Tashlyk reservoir, the cluster of similarity of zooplankton has relative share of taxa in destruction showed, in general, a rather high homogeneity of communities in the reservoir. The greatest similarity was between the stations located in the zone of a highest water temperature and a lowest transparency (Stations 63, 65, and 61a), where *Moina micrura* and individuals of copepod nauplial stages prevailed. In remote areas of the reservoir (Stations 60 and 64), more abundant communities were formed with the dominance of *Thermocyclops oithonoides*, Cyclopoida juv. and *Diaphanosoma dubium*. The zooplankton of the bay (Station 68a) was characterized by the least quantitative development and diversity, with Cyclopoida juv. dominating (Table 4). Thus, the identified zones of zooplankton groupings turned out to be similar; in the large bay (Station 68a), the zooplankton had a great peculiarity. Zooplankton communities *Moina micrura* + Nauplii and *Thermocyclops oithonoides* + Cyclopoida juv. + *Diaphanosoma dubium* were characterized by a relative decrease in quantitative variables, and LIT diversity indices were similar. The Cyclopoida juv. community was characterized by high dominance of a first rank; of Cyclopoida juv., the diversity was very low—only 0.3 bit/mg. Differences in the structure of communities were also observed in value of quantitative parameters. In the *Moina micrura* + Nauplii community, the indices of abundance, biomass, and destruction were two times lower than in the *Thermocyclops oithonoides* + Cyclopoida juv. + *Diaphanosoma dubium* community.

In the Oleksandrivske reservoir, changes in structure of zooplankton communities were observed from the upper reaches to the lower reaches. The cluster of similarity of communities at stations according to the distribution of destruction showed significant isolation in the upper part (Station 74), where phytophilic species of cladocerans prevailed, and the level of abundance and destruction was lowest (Table 4). Downstream (Stations 76 and 79) and in the bay (Station 88), that is, in the g–j zones, the community in which, in addition to juvenile copepods, the main role belonged to *Diaphanosoma orghidani* Negrea and/or *Bosmina coregoni* Baird was formed (Table 4). In the middle part of the reservoir (Station 84), the community with dominant taxa Calanoida juv., *Daphnia cucullata* Sars, and *B. coregoni* was formed, and the level of quantitative development increased significantly. A special community was noted in the area of Station 91, which is influenced by the tributary of the river Bakshala and the reservoir on it. In the lower dam area (Stations 92 and 112), the zooplankton community reached its maximum development with the dominance of the large pelagic cladocera *D. mongolianum* Ueno (Fig. 11).

Thus, in the Oleksandrivske reservoir, zooplankton communities were formed in accordance with the general zonation of the reservoir. However, the existence of some local communities have also been observed. The zooplankton of the Oleksandrivske reservoir consisted of five communities. Most of the zooplankton communities in the Oleksandrivske reservoir were characterized by a similar, relatively gradual decrease in the rates of relative destruction, and the proportion of the first rank did not exceed 23%. A more expressed role of the first rank (37%), expressed dominance, was characteristic of the community of the upper part of the reservoir, *Camptocercus rectirostris* + *Acroperus harpae*, and especially of the community *Diaphanosoma orghidani* (64%), formed under the possible influence of the tributary of the Bakshala river and the reservoir on it. As for the abundance value, in the lower part of the reservoir, the zooplankton biomass was the highest (*Diaphanosoma mongolianum* + Cyclopoida juv. + *Daphnia cucullata*) and was twice as high as the maximum biomass in the Tashlyk reservoir (in the community *Thermocyclop soithonoides* + Cyclopoida juv. + *Diaphanosoma dubium*). Not a single community of the same name in the two reservoirs has been reported (Fig. 12).

3.8 Influence of environmental factors and originality of communities

Species and environmental data relationships can help to reveal most influenced biological variables and to define

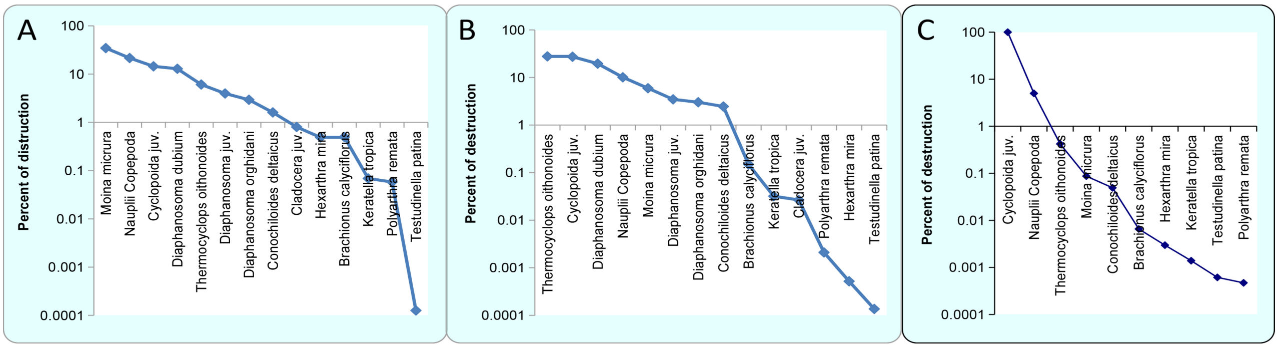

Fig. 11. Graph of dominance–diversity of zooplankton communities in the Tashlyk reservoir. Illustration (A) community *Moina micrura* + Nauplii, (B) *Thermocyclops oithonoides* + Cyclopoida juv. + *Diaphanosoma dubium*, and (C) Cyclopoida juv.

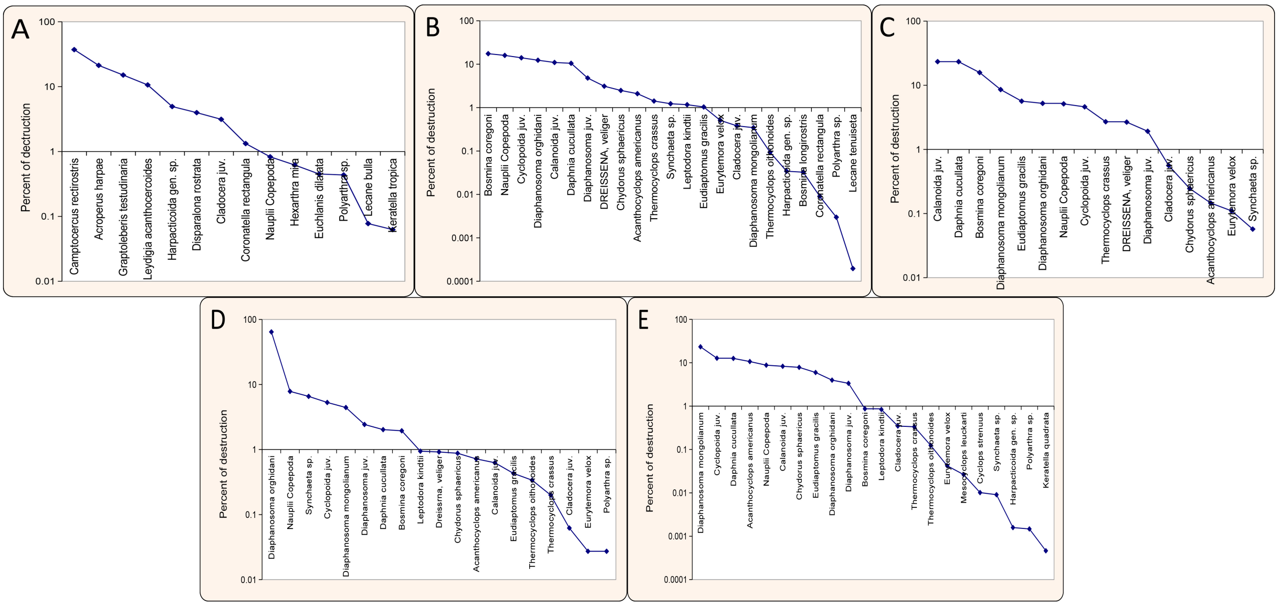

Fig. 12. Graph of dominance–diversity of zooplankton communities in the Oleksandrivske reservoir. Illustration (A) community *Camptocercus rectirostris* + *Acroperus harpae*, (B) *Bosmina coregoni* + Nauplii + Cyclopoida juv. + *Diaphanosoma orghidani*, (C) Calanoida juv.+ *Daphnia cucullata* + *Bosmina coregoni*, (D) *Diaphanosoma orghidani*, and (E) *Diaphanosoma mongolianum* + Cyclopoida juv. + *Daphnia cucullata.*

major influencing environmental factors. There are various approaches to identifying these relationships based on statistical correspondences [57]. In our case, the analysis was based on data on the distribution of the communities characterized by us (the structure and abundance of their constituent species) along the gradient of water parameters in which these communities existed. We deliberately separated the biological parameters of both phytoplankton and zooplankton communities in each of the studied reservoirs. Thus, four sets of biological data were identified and an analysis of their correspondence to the chemical parameters of water was carried out. Communities were identified according to their coenotic structure, which was done for the first time for this type of analysis. (Tables 3,4). In total, three types of zooplankton communities and five types of phytoplankton communities participated in the analysis for each of the reservoirs. Several analyzes were carried out previously and as a result, CCA type of analysis was chosen from the models of gradient analysis because in our case it covered maximal number of row data in biological and environmental variables for the direct unimodal calculation. As noted by Thrush *et al*. [57], the use of models to identify relationships between species and the environment can help explain various aspects of the variability in the structure of biological parameters under different conditions. Most importantly in such an analysis is assessment of model validity should focus on the variability of abundance, species ecology, and environmental influences, rather than how well the model predicts observed small-scale variability in fluctuations in environmental parameters.

In the Tashlyk reservoir both phyto- and zooplankton communities (Figs. 13,14) were very original and peculiar, this is especially significant for phytocommunities. For the phytoplankton community (Fig. 13) *Scenedesmus magnus*

+ *Cosmarium sp.* + *Nitzschia kuetzingiana* (1phT), the most significant factors were temperature and the content of organic matter and phosphorus of phosphates. The second (2phT) (*Cosmarium sp.* + *Scenedesmus magnus* + *Nitzschia kuetzingiana*) had salinity, and (3phT) the third, (*Binuclearia lauterbornii* + *Cosmarium sp.* + *Rhodomonas pusilla*) had nitrate nitrogenn and transparency.

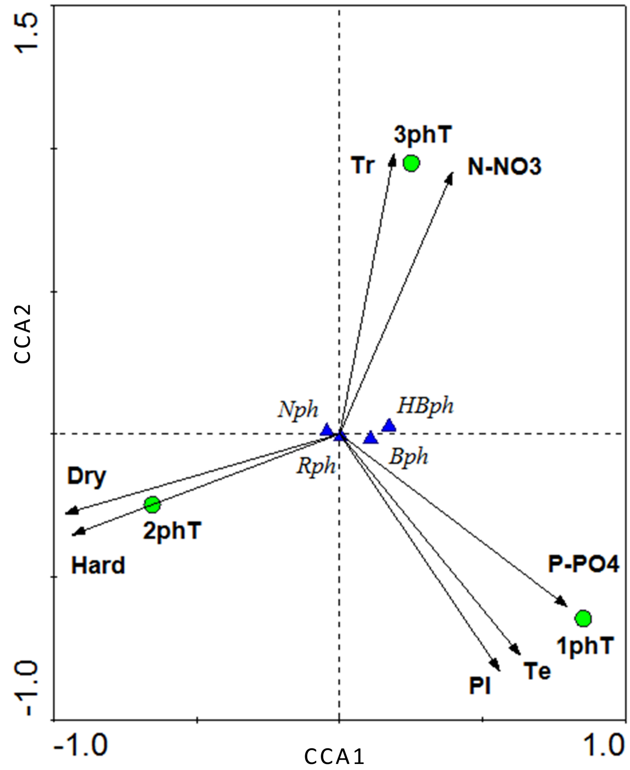

Fig. 13. Results of Canonical Correspondence Analysis for phytoplankton communities of Tashlyk reservoir. *p*-value $<$ 0.05. Here and after: Te, temperature; Tr, transparency; Hard, water hardness; Dry, dry residue, equivalent to water salinity; N-NO$_3$, nitrate nitrogen; P-PO4, phosphorus of phosphates PI, permanganate oxidizability; Rph, phytoplankton richness; HBph, phytoplankton biomass diversity; Nph, abundance of phytoplankton. Communities are designated according to Table 3.

For the 1zT zooplankton community (Fig. 14) (*Moina micrura* + Nauplii), the temperature factor was the significant factor. For the second (2zT) (*Thermocyclops oithonoides* + Cyclopoida juv. + *Diaphanosoma dubium*), water transparency was the significant factor. Salinity and organic matter content were significant for the third community (3zT), which was dominated by Cyclopoida juv. At the same time, the indicators of the structure of communities were not significantly associated with indicators of environmental conditions, these indicators were similar in the middle of the plot.

In the Oleksandrivske reservoir, in contrast to Tashlyk, it is rather difficult for phyto- and zooplankton com-

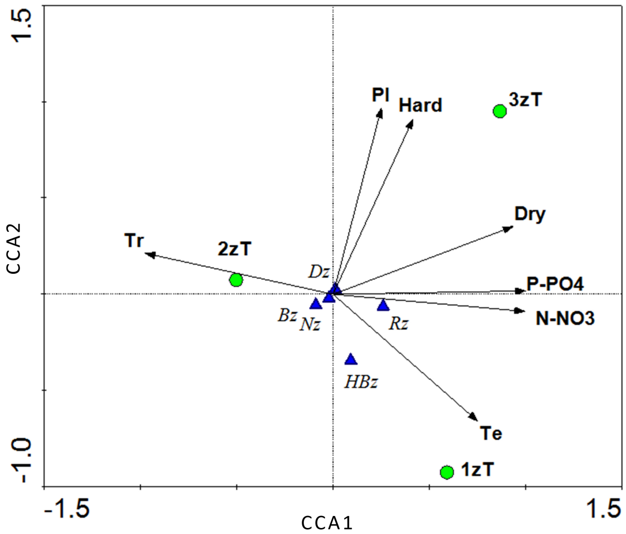

Fig. 14. Results of Canonical Correspondence Analysis for zooplankton communities of the Tashlyk reservoir. *p*-value $<$ 0.05. Here and after: Rz, zooplankton richness; HBz, diversity of zooplankton in biomass; Nz, abundance of zooplankton; Bz, biomass of zooplankton; Dz, destruction of zooplankton. Communities are designated according to Table 4.

munities to make a conclusion about their originality and uniqueness (Figs. 15,16). Community 5phA of phytoplankton (*Microcystis aeruginosa*) was somewhat more original, which could be assumed, based on the fact that it was mononodominant, had minimal values of the Shannon index, very large indices of quantitative parameters. Community 2phA (*Rhodomonas pusilla* + *Cocconeis placentula*) can also be considered quite original, with the lowest indices of both abundance and biomass. However, it is difficult to say which environmental factors were significant here. Most likely these were biogenic elements.

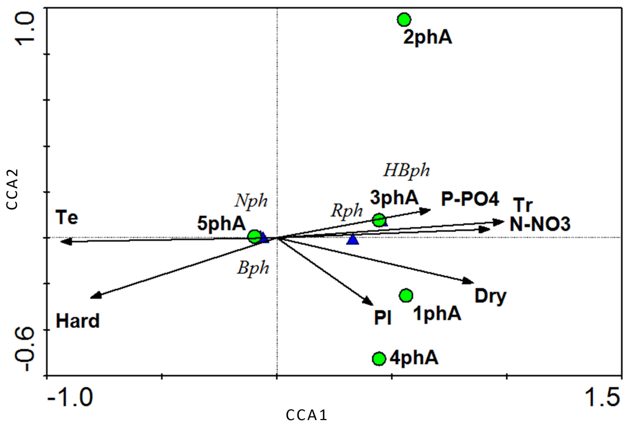

Fig. 15. Results of Canonical Correspondence Analysis for phytoplankton communities of the Oleksandrivskoye reservoir. *p*-value $<$ 0.05.

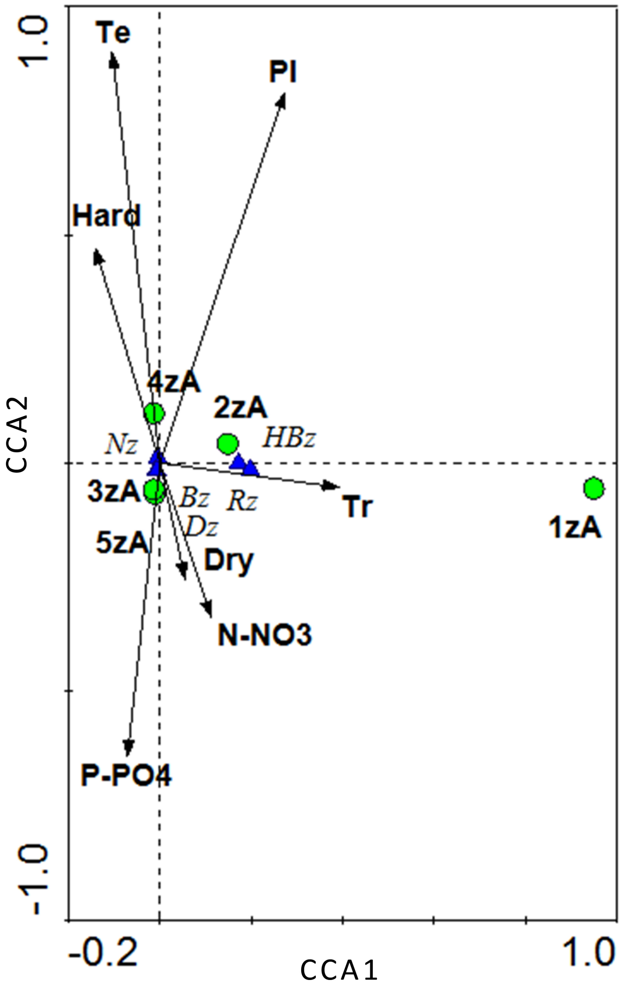

Fig. 16. Results of the Canonical Correspondence Analysis for the zooplankton community of the Oleksandrivske reservoir. p-value < 0.05.

Among the zooplankton communities (Fig. 16) in the Oleksandrivske reservoir, the 1zA community (*Camptocercus rectirostris* + *Acroperus harpae*) can be considered the most original. Of all the factors, the most significant for him was the transparency of the water. This community was localized at the top river-like part of the reservoir. It was distinguished by very small indices of abundance and biomass, with a rather large wealth of LITs. The rest of the communities were quite similar in terms of their structural indicators. At the same time, the indicators of the structure of communities were not significantly associated with indicators of environmental conditions, they were close to the middle part of the plot.

In addition to abiotic factors, the potential composition and abundance of phytoplankton and zooplankton can be significantly influenced by factors such as biotic interactions with fish. We have not specifically studied this issue, but some remarks can be made. More than 40 fish species [58] inhabit the basin of the Southern Bug River, most of which can be considered planktophages, at least in the early stages of ontogenesis. Special studies of the ichthyofauna in the Oleksandrivske reservoir showed the presence of 32 fish species, of which 18 can be considered planktophages [59]. In the Tashlyk reservoir was introduction of invasive fish Tilapia sp. [60], which can affect the degree of plankton development. This issue requires further research.

3.9 Climate variability and forecasts

A land polygon was selected near the water body locations (Object 3, Fig. 17), and the average temperature of water surface in two reservoirs was determined (Objects 1 and 2, Fig. 17). The minimum temperature decreased in investigated period. At the same time, the maximum temperature had a steady upward trend. It is obvious that the temperature on land had a well-pronounced upward trend, from 33 to 35 °C from 2013 to 2020. In the Tashlyk reservoir, as a technical object, the thermal regime was more associated with the NPP cooling systems' functioning.

During the period of climate change, the situation may look like a paradox, when the average temperature in Tashlyk did not change, while in a reservoir with a natural thermal regime, an increase in average temperatures occurred. The fact is that during the summer period, as a rule, all nuclear power units do not work, so the technogenic thermal effect decreases during periods of high summer temperatures. In addition, with an increase in the temperature of the circulating water at the NPP water intake above 30 °C, there is a sharp decrease in the energy efficiency of the power plant, therefore, all technical means are used to reduce the water temperature in the cooling reservoir (deep water intake, water direction devices for maximum cooling, etc.).

For the Oleksandrivske reservoir and land, the increase in the average temperature was observed. If this trend continues for the Oleksandrivske reservoir, in the next 10 years, it will be possible to observe an increase in average summer temperature up to a level typical of the cooling reservoir at present. As the comparative analysis of hydrobiological data shows, in the Oleksandrivske reservoir, in the case of an increase in temperature, changes in the composition and quantitative parameters indices and the coenotic structure of hydrobionts will occur. In contrast to the Tashlyk reservoir, Oleksandrivske is a flowing, non-closed reservoir, so changes can be expected in other water bodies and watercourses of the basin. At the same time, attention should be paid to the fact that, in the technoecosystem of the Tashlyk reservoir, there are certain factors that can reduce the negative impact of temperature increases. In any case we can pay attention to the reservoirs and their catchment basin interaction because both, earth and water are influenced the biodiversity in the basins of the rivers inputted to the Black Sea [61]. Thus, it was found that, in the southern part of the reservoir, near the dam and to a depth of about 30 m, a fairly favourable oxygen regime (more than 7 mg O_2/dm^3) remains due to deepwater intake of cooled bottom waters in the circulating water supply sys-

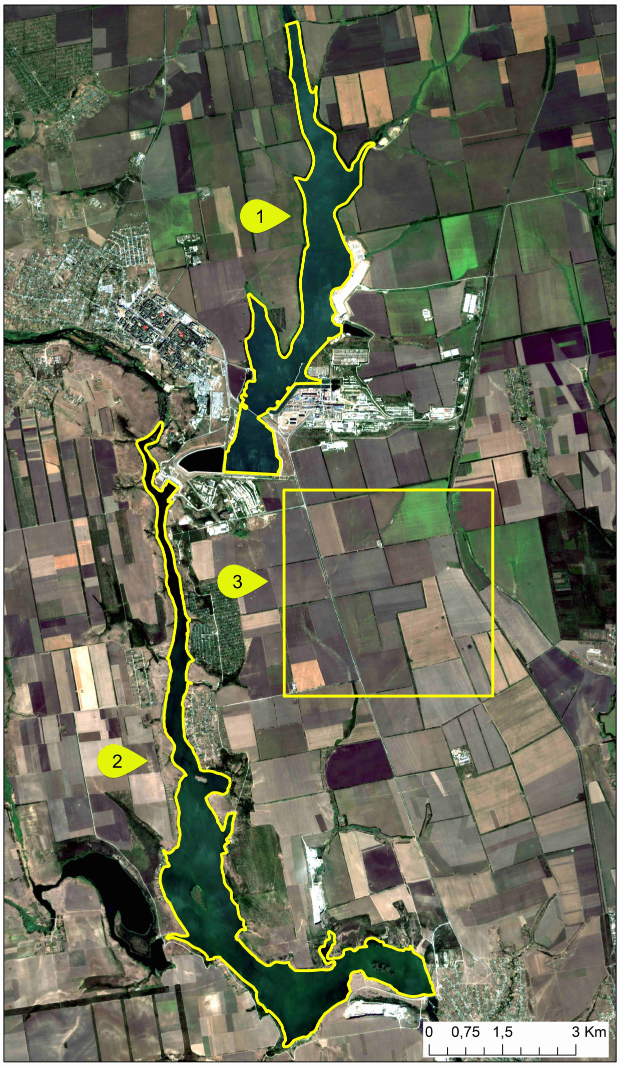

Fig. 17. Objects on the Earth's surface, within the boundaries of which the average temperatures were measured. 1, Tashlyk reservoir; 2, Oleksandrivske reservoir; 3, land polygon.

tem. Therefore, there is a mechanical movement of water masses from the surface, where the oxygen regime is relatively favorable, even at high temperatures when its solubility in water decreases. There are no such factors in the Oleksandrivske reservoir; therefore, when temperature will rise, there is a high probability of formation of conditions of deep catastrophic oxygen deficiency. There is an analysis of data showing that changes can occur even in oceanic ecosystems [62].

4. Conclusions

The remote sensing and GIS technologies has enormous applicability in hydrobiological researches. This comparative study shows that technical cooling reservoirs can be considered as model of climate change and temperature rise in water bodies. Also the study revealed the fact that the technical cooling reservoirs have additional to climate warming negative changing effects on aquatic ecosystems. Abundant plankton communities inhabit the Tashlyk reservoir with a high temperature is a consequence of a fairly wide variety of conditions that are created by technogenic factors. With a general increase in temperature, there will be no such factor in the Oleksandrivske reservoir, and the consequences can be much more adverse. Furthermore, certain technogenic factors in the Tashlyk reservoir and the structural and operational conditions in which the oxygen regime in the reservoir are improved should also be taken into account. Due to water temperature increase in the Oleksandrivske reservoir and factors related to the absence of oxygen regime improvement, the effects of warming can be catastrophic due to oxygen deficiency.

Noteworthy is the different level of development of cyanobacteria in reservoirs. In Tashlyk reservoir, the biomass of cyanobacteria was 1.9% of the total phytoplankton biomass, in the Oleksandrivske reservoir–92.8% and in general, the phytoplankton biomass in the Oleksandrivske reservoir was several times higher than in Tashlyk. We suppose the limiting factor for phytoplankton in Tashlyk was the low content of phosphorus of phosphates in the water (0.017 mgP/dm^3) compared to the Oleksandrivske reservoir (0.18 mgP/dm^3). The N/P ratio was also unfavorable for cyanobacteria. In addition, the hydrodynamic regime in the Tashlyk reservoir was also unfavorable for cyanobacteria: constant mixing and passage of phytoplankton together with water through the NPP cooling systems.

The analysis of the cenotic structure of plankton communities, including CCA, showed that aquatic organisms in the cooling pond live in more heterogeneous conditions, the structure of communities is less homogeneous than in the Oleksandrivskoye reservoir, where conditions are more continual. It let us to assume that the factors such as temperature or nutrients impact can be assessed as external factors related to the catchment area for the reservoirs with different type of using and that the cooling ponds are anthropogenic habitats which increase the basin heterogeneity and influence it from this point of view.

Abbreviations

NPP, nuclear power plant; MW, Mega Watt; DO, dissolved oxygen; COD, chemical oxygen demand; BOD, biochemical oxygen demand; OHPP, The Oleksandrivske Hydroelectric Power Plant; TR, the Tashlyk reservoir; SUNPP, South-Ukrainian Nuclear Power Plant; SUPC, South-Ukrainian Power Complex; TPSPP, Tashlyk Pumped-Storage Power Plant; TIRS, Thermal Infrared Sensor; LST, Land surface temperature; NDVI, normalized difference vegetation index; LIT, lowest identified taxon; CV, coefficient of variation; CCA, Canonical Correspondence Analysis; LDL, Lower Determination Level of diversity; OR, the Oleksandrivske reservoir; GIS, Geographic Information System.

Author contributions

AP and TN designed the research study; AP, TN, OT, SKS, YG performed the research; SB and ACB provided help and advice on the conclusions; AP, TN, OT and SB analyzed the data; AP, TN, OT, SKS, YG wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Acknowledgment

Our thanks to the administration of the South Ukraine NPP, employees of the Environmental Protection Department, and the Tashlyk PSP. We are also thanks to the Israel Ministry of Aliyah and Integration that partly supported this work. The authors also express their gratitude to Ecotur Sibiu Environmental Association (Sibiu, Romania, CUI 5841004), which paid the publication fee for this research paper.

Funding

This work was partially supported by the by the Ministry of Education and Science of Ukraine (Project No. M/22-2018) and partly by the program "Support for the development of priority areas of research" (project No 1230/0120U000172). The publication fee was paid by Ecotur Sibiu. CUI 5841004.

Conflict of interest

The authors declare no conflict of interest.

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