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Assessment of the ecological state of the Kiev Reservoir by the bioindication method

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Key words: epiphytic algae, taxonomic structure, higher aquatic plants, Kiev Reservoir, ecological characteristics, species-indicators.

Abstract

The ecological state of the Kiev Reservoir affected by intensive contamination as a result of the accident at the Chernobyl Nuclear Power Station in 1986 was assessed in terms of the species-indicators of epiphytic algae occurring in the fouling of higher aquatic plants. It has been found that inhabitants of slowly flowing and moderately warm waters, alkaliphiles, indifferent organisms in relation to water salinity, nitrogen-autotrophic taxa tolerating elevated concentrations of organically bound nitrogen, β-mesosaprobionts and eurysaprobes (in relation to organic contamination) and eutraphentic organisms (indicators of the trophic state) prevailed in phytoepiphyton of the Kiev Reservoir. As a result of comparison of the original results with literature data obtained prior to the accident, it has been found that over a span of about 30 years (from the 1970s-1980s to 2010-2013), the taxonomic structure of phytoepiphyton remained almost unchanged. At the same time, the intensity of eutrophication, alkalization, and thermofication processes increased.

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INTRODUCTION

The Kiev Reservoir is a head-cascade reservoir of the Dnieper River located within the territory of Ukraine. In 1986, as a result of the accident at the Chernobyl Nuclear Power Station (NPS), the ecosystem of the Kiev Reservoir was exposed to intensive radioactive contamination, especially its upper part (the Dnieper and Pripyat spurs), which were included into the 30-km exclusive zone. During the process of investigation of radioactive contamination of the Dnieper reservoirs, it has been found that higher aquatic plants are capable of accumulating almost all radionuclides found in the water. In May – August 1986, the content of ^{90}Sr in higher aquatic plants of the Kiev Reservoir accounted for 2400-4000 Bq kg^{-1} of dry mass, whereas that of ^{137}Cs – 160-67 000 Bq kg^{-1} (Romanenko et al. 1992, Yevtushenko et al. 1992).

In 2000, ^{137}Cs specific activity in higher aquatic plants was three orders of magnitude lower than that observed in 1986. In this case, ^{90}Sr specific activity decreased from 1987 to 2003 by a factor of 10 and remained almost unchanged until 2009. Even at the present time, however, the content of ^{137}Cs and ^{90}Sr in hydrobionts of the Kiev Reservoir is higher than that registered prior to the accident (Romanenko et al. 2011).

It is likely that not only radioecological situation, but also hydrochemical and hydrobiological regime of the Kiev Reservoir has changed since 1986. Thus, an assessment of the modern state of the ecosystem of the Kiev Reservoir using the bioindication method, which makes it possible to follow the response of the ecosystem to changes in the environmental conditions, takes on great significance. At present, Ukrainian scientists try to adapt to international standards and to principles of the European Water Framework Directive (The

Directive… 2000) in performing hydrobiological research. For example, the method of bioindication was used in studies of the Yuzhny Bug River in Ukraine (Bilous et al. 2012).

Phytoepiphyton of the Kiev Reservoir was thoroughly studied in the 1970s-1980s (Sirenko et al. 1989). Because of the economic crisis, however, these investigations were discontinued. As a consequence, over the course of almost 30 years, the biota of the Kiev Reservoir, including epiphytic algae, has not been studied.

The objective of the present work was to study the ecological characteristics of epiphytic algae occurring in the fouling of higher aquatic plants of the Kiev Reservoir at the present time, and also to compare original results with the data obtained prior to the accident.

MATERIALS AND METHODS

Description of the study site

The head-cascade Kiev Reservoir (50°54' N, 30°29' E) was formed in 1966 on the Dnieper River within the territory of Ukraine in the Polesye zone. It is supplied mainly by the water of the Dnieper River and its tributaries – the Pripyat and Teterev rivers. The area of the reservoir is 922 km^2, the volume – 3.73 km^3, and the length – about 100 km. In this case, the length of the main stretch is 68 km, of the Dnieper spur – 20 km, whereas of the Pripyat spur – about 30 km. The maximum width of the reservoir is 14 km, whereas its average width is 8.4 km. The maximum depth of the Kiev Reservoir is 14.5 m, whereas the average depth – 4.0 m (Tseeb & Maystrenko 1972, Denisova 1989, Timchenko 2006). Samples were collected at 11 sites located both along the right and the left shore of the reservoir (Fig. 1).

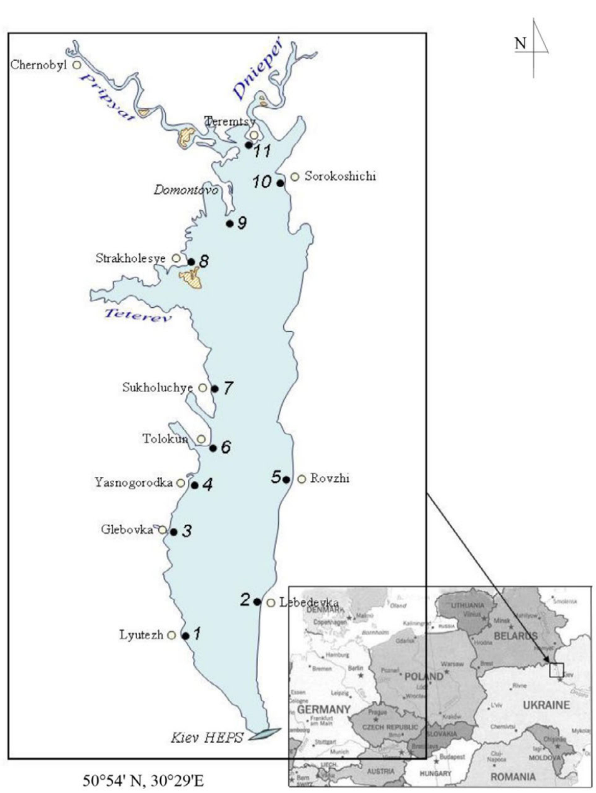

Fig. 1. Map-scheme of the Kiev Reservoir: 1–11 – sampling sites

Sampling and laboratory studies

Samples of phytoepiphyton were collected from 17 species of higher aquatic plants belonging to three ecological groups: half-submerged (*Acorus calamus* L., *Butomus umbellatus* L., *Glyceria maxima* (C. Hartm.) Holmb., *Phragmites australis* (Cav.) Trin. ex Steud., *Sagittaria sagittifolia* L., *Scirpus lacustris* L., *Sparganium erectum* L., *Stratiotes aloides* L., and *Typha angustifolia* L.), with floating leaves (*Trapa natans* L. and *Nuphar lutea* (L.) Smith), and submerged plants (*Ceratophyllum demersum* L., *Myriophyllum spicatum* L., *Potamogeton gramineus* L., *P. pectinatus* L., *P. perfoliatus* L., and *P. praelongus* Wulf.).

Samples of phytoepiphyton were collected and processed following the commonly accepted hydrobiological procedures (Topachevskiy & Masyuk 1984, Arsan et al. 2006). Samples were collected in summertime of 2010-2013. A total of 176 samples were collected and processed. The following manuals were used to identify algae taxa (Ettl 1978, 1983, 1988; Komarek & Fott 1983; Starmach 1985; Krammer & Lange-Bertalot 1986, 1988, 1991, 1991a; Popovský & Pfiester 1990; Komarek & Anagnostidis 1999, 2005; Vetrova 2002; Palamar-Mordvintseva 2003; Palamar-Mordvyntseva 2005; John et al. 2011). Taxonomic analysis was carried out using the methods accepted for the comparison of floras (Shmidt 1980). The Latin names and the volume of algae taxa are given in accordance with the classification systems (Blümel 2003, Tsarenko et al. 2006, Calisová & Gabka 2009). Ecological characteristics of algae-indicators are given according to Coesel (1975), Van Dam & Mertens (1994), Barinova et al. (2006), Štastný (2010). Recent publications (Oksiyuk 2009, Klochenko et al. 2013) on the ecological groups of algae were also taken into account.

The content of inorganic compounds of nitrogen and phosphorus in the water was determined by the colorimetric method (Semenov 1977). The concentration of oxygen dissolved in the water was determined by the Winkler method (Arsan 2006). Permanganate and dichromate oxidizability of the water, as well as water salinity, were determined following commonly accepted methods (Semenov 1977, Arsan 2006). The value of pH was determined using the EV-74 ion-meter.

Results

Altogether, 281 algae species represented by 287 infraspecific taxa (including those containing the nomenclatural type of species) of 8 divisions, 14 classes, 35 orders, 58 families, and 108 genera were found during the period of investigations (in 2010-2013) in the fouling of higher aquatic plants of the Kiev Reservoir. Bacillariophyta, Chlorophyta, and Charophyta were highly diverse in their species composition. Their contribution to the total number of species accounted for 85.0% (Table 1).

The most abundant and frequent species of epiphytic algae found in the Kiev Reservoir were represented mainly by Bacillariophyta (31 species), Charophyta (10), Chlorophyta (5), and Cyanoprokaryota (1) (Table 2).

Among the organisms found, 280 taxa (97.6% of their total number) are indicators of environmental conditions: habitats – 278 taxa, water flow – 181, temperature regime – 51, pH – 168, water salinity – 188, nitrogen uptake metabolism – 91, trophic state of water bodies – 119, organic contamination according to R. Pantle and H. Buck (1955) – 220 and according to T. Watanabe (1986) – 100 taxa.

Table 1

The number of species (infraspecific taxa) of epiphytic algae found in the Kiev Reservoir

Division	Original data 2010-2013	Literature data (Sirenko et al. 1989) 1970-1980s
Cyanoprokaryota	25 8.9	36 9.5
Euglenophyta	9 3.2	16 (17) 4.3
Chrysophyta	3 1.1	3 0.8
Xanthophyta	2 0.7	6 1.6
Bacillariophyta	129 (135) 45.9	165 (184) 43.9
Dinophyta	3 1.1	4 1.1
Chlorophyta	73 26.0	96 25.5
Charophyta	37 13.1	50 (53) 13.3
Total	281 (287) 100	376 (399) 100

Note. The number of species is given above the bars, whereas their contribution to the total number of species – below the bars. The number of infraspecific taxa, including those containing the nomenclatural type of species, is given in parentheses.

Table 2

The most abundant and frequent species of epiphytic algae found in the Kiev Reservoir

Taxa	Abundance	Frequency of occurrence
Cyanoprokaryota		
Lyngbya kuetzingii (Kütz.) Schmidle	d	
Chlorophyta		
Desmodesmus brasiliensis (Bohlin) E. Hegew.		f
Desmodesmus communis (E. Hegew.) E. Hegew.		f
Desmodesmus opoliensis (P.G. Richter) E. Hegew.		f
Stigeoclonium farctum Berthold	d	
Oedogonium sp.st.	d	f
Charophyta		
Mougeotia sp.	d	
Spirogyra bellis (Hassal) P.L. Crouan et N.M. Crouan	d	
Spirogyra crassa Kütz.	d	
Closterium leibleinii Kütz.	d	f
Cosmarium botrytis Menegh.	d	f
Cosmarium granatum Bréb.	d	f
Cosmarium obtusatum Schmidle	d	f
Cosmarium reniforme (Ralfs) W. Archer	d	
Cosmarium subprotumidum Nordst.		f
Penium margaritaceum Bréb.	d	
Bacillariophyta		
Melosira varians C. Agardh	d	f
Aulacoseira italica (Ehrenb) Simonsen	d	
Fragilaria vaucheriae (Kütz.) Boye-Pet.		f
Staurosira construens Ehrenb.	d	f
Synedra ulna (Nitzsch) Ehrenb.	d	f
Diatoma vulgare Bory	d	
Eunotia formica Ehrenb.	d	
Aneumastus tusculus (Ehrenb.) D.G. Mann et Stickle	d	f
Rhoicosphenia abbreviata (C. Agardh) Lange-Bert.		f
Cymbella cistula (A. Hempel in A. Hempel et Ehrenb.) Kirchner	d	f
Cymbella cuspidata Kütz.	d	
Cymbella lanceolata (C. Agardh) Ehrenb.	d	f
Encyonema elginense (Krammer) D.G. Mann	d	f
Encyonema caespitosa Kütz.	d	f
Gomphonema truncatum Ehrenb.		f
Planothidium lanceolata (Bréb. in Kütz.) Round et Bukht.		f
Cocconeis pediculus Ehrenb.	d	f
Cocconeis placentula Ehrenb.	d	f
Neidium dubium (Ehrenb.) Cleve	d	
Sellaphora bacillum (Ehrenb.) D.G. Mann		f
Navicula cryptocephala Kütz.	d	f
Navicula rhynchocephala Lange-Bert.	d	
Navicula tripunctata (O.F. Müll.) Bory	d	f
Navicula viridula (Kütz.) Ehrenb.	d	
Gyrosigma spenceri (J.T. Quekett) Griffith et Henfr.	d	
Amphora ovalis (Kütz.) Kütz.	d	
Amphora veneta Kütz.	d	
Rhopalodia gibba (Ehrenb.) O. Müll.	d	
Epithemia sorex Kütz.	d	
Epithemia turgida (Ehrenb.) Kütz.	d	
Epithemia adnata (Kütz.) Bréb.	d	

Note. "d" – species with the contribution to the total phytoepiphyton biomass > 25%; "'f" – species with the incidence >50% of the total number of samples.

The ecological analysis has shown that the identified algae belong to four ecological groups of habitat preferences. Benthic organisms (in a broad sense), including periphyton forms, were represented by the largest number of taxa – 156 (mainly Bacillariophyta and Chlorophyta). Planktonic-benthic organisms included 82 taxa (mainly Chlorophyta and Bacillariophyta), whereas planktonic organisms (mainly Chlorophyta) – 36 taxa. In this case, obligate epiphytic algae were represented only by four species (*Fragilaria vaucheriae* (Kütz.) Boye Pet., *Protoderma viride* Kütz., *Characium ornithocephalum* A. Braun, and *Stigeoclonium farctum* Berthold) (Fig. 2).

Representatives of moderately warm waters (*Cocconeis placentula* Ehrenb., *Cymbella tumida* (Bréb.) Van Heurck, *Epithemia adnata* (Kütz.) Bréb., etc.) predominated among the algae – indicators of the temperature regime (74.5%). The contribution of eurythermal organisms was much lower – 15.7%. Cold-loving (5.9%) and thermophilous organisms (3.9%) were not abundant (Fig. 3).

Species of slowly flowing waters (*Amphora ovalis* (Kütz.) Kütz., *Cocconeis pediculus* Ehrenb., *Cymbella cistula* (A. Hempel in A. Hempel et Ehrenb.) Kirchn., etc.) dominated among indicators of water flow and oxygen saturation (70.2%). The contribution of species of lentic waters accounted for 18.8%, whereas that of indicators of rapidly flowing waters − 11.0% (Fig. 4). The highest water velocity in the Kiev Reservoir is observed within the main riverbed. The remaining part of the water region, the so-called non-transit zone is covered by waters, dynamics of which depends to a large extent on the wind flow (Timchenko et al. 2013). During the study period, the concentration of oxygen dissolved in the water was 7.02–8.35 O_2 mg l^{-1}.

Indicators of pH, alkaliphiles were represented by the largest number of algae species (44.6%). The most frequent species were *Gomphonema acuminatum* Ehrenb., *Epithemia sorex* Kütz., *E. turgida* (Ehrenb.) Kütz., etc. The contribution of pH-indifferent organisms accounted for 41.7%, acidophiles – 10.1%, and alkalibionts – 3.6% (Fig. 5).

During the study period, values of pH in the studied environment ranged from 7.2 to 8.5. These values are optimal for the development of alkaliphiles and alkalibionts.

Indifferent organisms (*Nitzschia amphibia* Grunow, *Cosmarium botrytis* Menegh., *Closterium moniliferum* (Bory) Ehrenb., etc.) dominated among the species – indicators of the water salinity (79.3%).

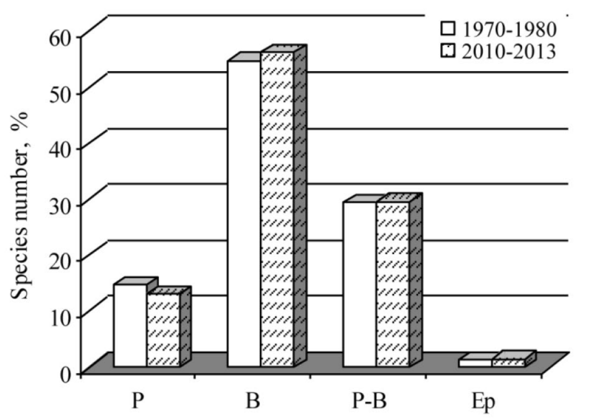

Fig. 2. Distribution of algae taxa over their ecological groups: P – planktonic; B – benthic; P-B – planktonic-benthic; Ep – epiphytic

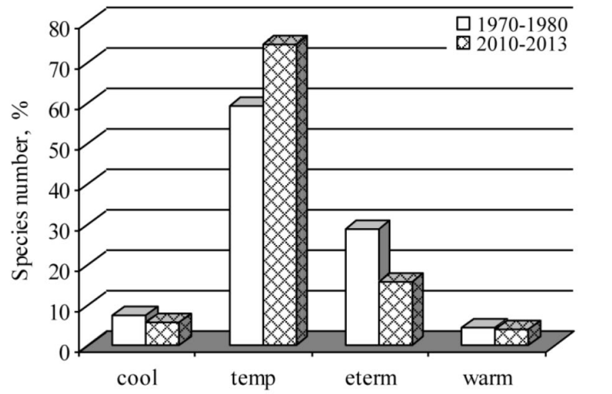

Fig. 3. Distribution of algae taxa – indicators of the temperature regime: cool – cold-loving; temp – taxa occurring in moderately warm waters; eterm – eurythermal; warm – thermophilous

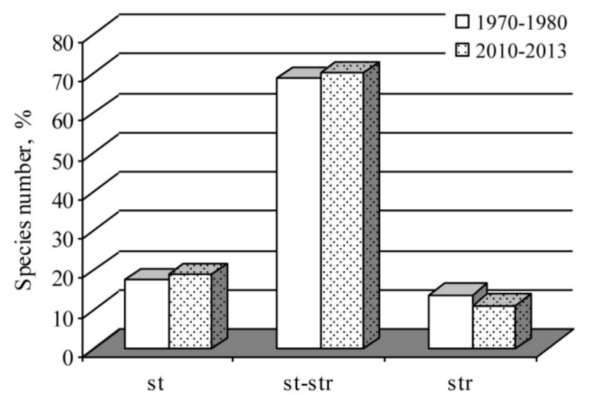

Fig. 4. Distribution of algae taxa – indicators of water flow and oxygenation: st – species of lentic waters with low oxygenation; st-str – species of slowly flowing and moderately oxygenated waters; str – species of rapidly flowing and oxygen-rich waters

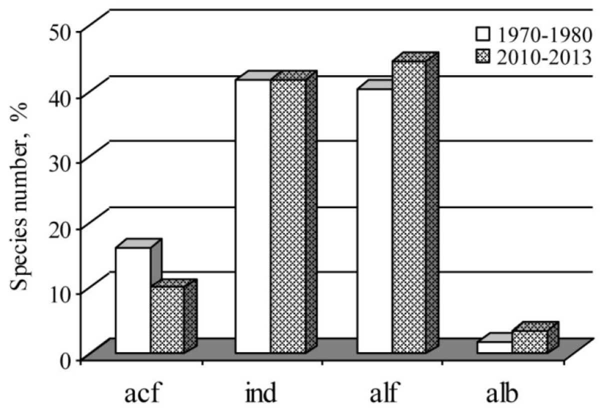

Fig. 5. Distribution of algae taxa – indicators of pH: acf – acidophiles; ind – indifferent organisms; alf – alkaliphiles; alb – alkalibionts

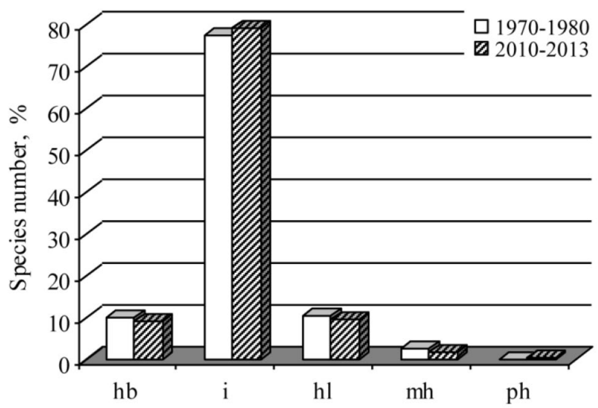

Fig. 6. Distribution of algae taxa – indicators of water salinity: hb – halophobes; i – indifferent organisms; hl – halophiles; mh – mesohalobes; ph – polyhalobes

The contribution of halophiles (9.6%), halophobes (9.0%), mesohalobes (1.6%), and polyhalobes (0.5%) was much lower (Fig. 6). The total content of dissolved solids in the Kiev Reservoir was on average 285 mg l^{-1}. The concentration of chloride was on average 25 mg l^{-1}.

Nitrogen-autotrophic taxa tolerating elevated concentrations of organically bound nitrogen (G. Van Dam & A. Mertens 1994) dominated in phytoepiphyton of the Kiev Reservoir (51.6%). The most frequent species were *Cymbella lanceolata* (C. Agardh) Ehrenb., *Encyonema minuta* (Hilse ex Rabenh.) D.G. Mann, *Gomphoneis olivaceum* (Horn) Daw., etc. They were followed by nitrogen-autotrophic taxa tolerating very small concentrations of organically bound nitrogen (38.5%), by facultative nitrogen-heterotrophic taxa requiring periodically elevated concentrations of organically bound nitrogen (5.5%) and by obligate nitrogen-heterotrophic taxa requiring continuously elevated concentrations of organically bound nitrogen (4.4%) (Fig. 7).

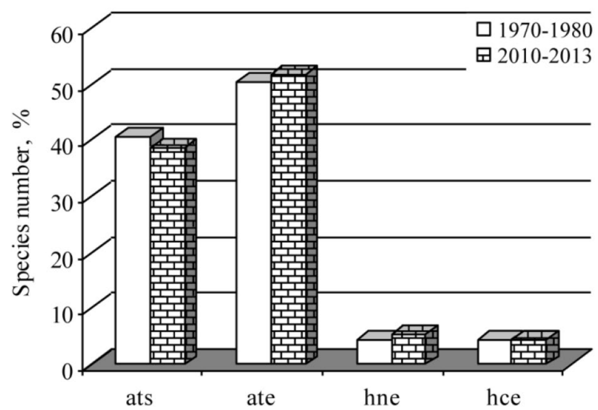

Fig. 7. Distribution of algae taxa – indicators of nitrogen uptake metabolism: ats – nitrogen-autotrophic taxa tolerating very small concentrations of organically bound nitrogen; ate – nitrogen-autotrophic taxa tolerating elevated concentrations of organically bound nitrogen; hne – facultative nitrogen-heterotrophic taxa requiring periodically elevated concentrations of organically bound nitrogen; hce – obligate nitrogen-heterotrophic taxa requiring continuously elevated concentrations of organically bound nitrogen

Indicators of the trophic state of aquatic ecosystems (Van Dam & Mertens 1994; Štastný 2010), oligotraphentic, oligo-mesotraphentic, mesotraphentic, meso-eutraphentic, eutraphentic, hypereutraphentic, and species with a wide amplitude of indicator values from oligo- to eutraphentic (hypereutraphentic) were identified among the algae. The contribution of eutraphentic organisms (*Rhoicosphenia abbreviata* (C. Agardh) Lange-Bert., *Closterium moniliferum* (Bory) Ehrenb., *C. venus* Kütz., *Cosmarium formosulum* Hoffm., *C. obtusatum* Schmidle, etc.) accounted for 37.8%, whereas the contribution of meso-eutraphentic taxa (*Stauroneis anceps* Ehrenb., *Cosmarium botrytis* Menegh., *C. granatum* Bréb., C. *meneghinii* Bréb., etc.) − 21.0%. The contribution of algae occurring in mesotrophic waters (*Closterium gracile* Bréb., *Pleurotaenium ehrenbergii* (Bréb.) De Bary, *Cosmarium margaritiferum* Menegh., *Euastrum bidentatum* Nägeli, etc.) accounted for 12.6%, whereas the contribution of oligo-mesotraphentic (*Penium* *margaritaceum* (Ehrenb.) Bréb., etc.), oligotraphentic (*Mesotaenium endlicherianum* Nägeli, etc.), hypereutraphentic taxa, and species with a wide amplitude of indicator values was 9.2, 5.1, 2.5 and 11.8%, respectively (Fig. 8). During the research, values of permanganate oxidizability were within the range of 13.8-18.9, while values of dichromate oxidizability (chemical oxygen demand) – 41.1-63.9 mg O_2 l^{-1}. The concentration of ammonium was 0.33-0.40 mg N l^{-1}, nitrite – 0.003-0.015, and nitrate – 0.05-0.14 mg N l^{-1}. In this case, the concentration of phosphate ranged from 0.012 to 0.025 mg P l^{-1}.

Indicators of organic contamination (according to the system of R. Pantle and H. Buck in the modification of V. Sladeček) (Barinova et al. 2006), taxa belonging to five main groups were identified among algae. They were χ-saprobionts, o-saprobionts, β-mesosaprobionts, α-mesosaprobionts, and polysaprobionts. As indicated in Fig. 9, β-mesosaprobionts were represented by the largest number of taxa (51.4%), including the most frequent: *Gomphonema augur* Ehrenb., *Epithemia adnata* (Kütz.) Bréb., *Closterium moniliferum* (Bory) Ehrenb., *C. parvulum* Nägeli, *Cosmarium botrytis* Menegh., etc.

According to the system of organic contamination indication presented by T. Watanabe (Barinova et al. 2006), eurysaprobes prevailed in the Kiev Reservoir (57.0%). The most frequent species were *Rhopalodia gibba* (Ehrenb.) O. Müll., *Gomphonema truncatum* Ehrenb., etc. The contribution of saproxenes was 32.0% and saprophiles – 11% (Fig. 10).

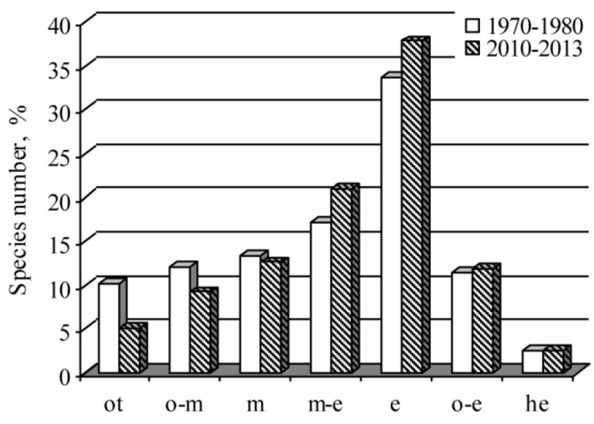

Fig. 8. Distribution of algae taxa – indicators of trophic state: ot – oligotraphentic; o–m – oligo-mesotraphentic; m – mesotraphentic; m–e – meso-eutraphentic; e – eutraphentic; o–e – oligo- to eutraphentic (hypereutraphentic); he – hypereutraphentic

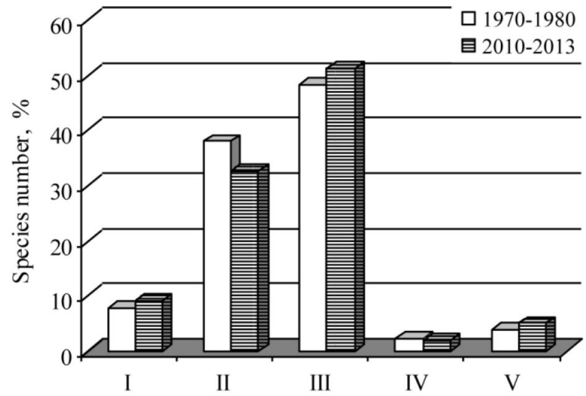

Fig. 9. Distribution of algae taxa – indicators of organic contamination [according to R. Pantle and H. Buck (1955) in the modification of V. Sladechek (1973)] over the main groups: I – χ-saprobionts (saprobity index *S* = 0–0.5), including χ- and χ–o-saprobionts; II – o-saprobionts (*S* = 0.5–1.5), including o–χ-, χ–β-, o-, and– β-saprobionts; III – β-mesosaprobionts (*S* = 1.5–2.5), including β–o-, o–α-, β-, and β–α-saprobionts; IV – α-mesosaprobionts (*S* = 2.5–3.5), including α-, β–ρ-, ρ–α-, and α–ρ-saprobionts; V – polysaprobionts (*S* = 3.5–4.0), including α–β- and ρ-saprobionts

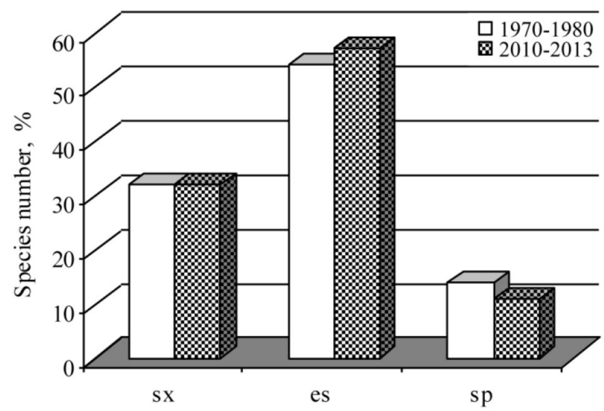

Fig. 10. Distribution of algae taxa – indicators of organic contamination [according to T. Watanabe (1986)]: sx – saproxenes; es – eurysaprobes; sp – saprophiles

Thus, taxa of slowly flowing and moderately warm waters, alkaliphiles, indifferent organisms in relation to water salinity, nitrogen-autotrophic taxa tolerating elevated concentrations of organically bound nitrogen, β-mesosaprobionts and eurysaprobes (in relation to organic contamination) and eutraphentic organisms (indicators of the trophic state) prevailed in phytoepiphyton of the Kiev Reservoir.

DISCUSSION

The comparison of original and literature data (Sirenko et al. 1989) has shown that the number of epiphytic algae species found in the Kiev Reservoir was higher in the 1970s-1980s compared to 2010-2013 (Table 1). However, in the 1970s-1980s investigations were carried out for a longer period of time (from 1976 to 1984) than those performed in 2010-2013. From our point of view, this is the main reason behind the difference in the number of species. At the same time, this phenomenon calls for further research. Despite the fact that the number of epiphytic algae species was higher in the 1970s-1980s compared to 2010-2013, the taxonomic structure of phytoepiphyton occurring in the fouling of higher aquatic plants in the Kiev Reservoir remained almost unchanged over the period elapsed after the accident at the Chernobyl NPS (Table 1). In this case, the percentage relationship between the main taxa was also almost the same.

Both in the 1970s-1980s and in 2010-2013, Bacillariophyta, Chlorophyta, and Charophyta were highly diverse in their species composition. The same classes − Bacillariophyceae, Chlorophyceae, and Zygnematophyceae (68.8% and 70.5% of the total number of species found in the 1970s-1980s and in 2010-2013, respectively), and the same orders: Sphaeropleales, Desmidiales, Naviculales, Cymbellales, Bacillariales, Fragilariales, Chlorellales, Oscillatoriales, Eunotiales, and Euglenales (73.1% and 74.7%) were represented by the largest number of species.

A high similarity of the taxonomic structure of phytoepiphyton in different periods of investigations is supported by high values of the Kendal coefficient of rank correlation calculated in terms of the dominant families (τ = 0.78) and dominant genera (τ = 0.71). This fact suggests that the method of bioindication is a useful tool in assessing the response of algae communities to changes in environmental conditions.

The distribution of epiphytic algae species over ecological groups was also similar (Fig. 2). In both periods, benthic organisms (in a broad sense), including periphyton forms, (54.7% and 56.1% of the total number of species found in the 1970s-1980s and in 2010-2013, respectively) were represented by the largest number of species. The contribution of planktonic-benthic organisms accounted for 29.4% and 29.5%, planktonic – 14.6% and 13.0%, and obligate epiphytic algae – 1.3% and 1.4%. Both literature (Makarevich 2003) and original data (Klochenko et al. 2013) suggest that algae from other biotopes (about 30% of the total number of species) constantly occur in the fouling of higher aquatic plants, which is determined by hydrodynamic factors. They included species occurring mainly in the water column (18%), the frequency of occurrence and abundance of which were much higher in plankton than in epiphyton. Also species occurring rarely and with low abundance were found both in the fouling of higher aquatic plants and in the water column (10%), as well as species frequent and/or abundant in both biotopes (2%) (Klochenko et al. 2013).

The pattern of the distribution of algae species – indicators of water flow and water salinity remained almost unchanged over the studied period (Fig. 4 and 6). This also applies to the percentage relationship between the species of diatoms – indicators of nitrogen uptake metabolism (Van Dam & Mertens 1994) (Fig. 7).

At the same time, the pattern of the distribution of algae – indicators of the temperature regime significantly changed in 2010-2013 as compared to the 1970s-1980s (Fig. 3). The contribution of taxa of moderately warm waters significantly increased (from 59.4% to 74.5%), whereas the contribution of eurythermal organisms decreased (from 29.0% to 15.7%). Analysis of the water temperature dynamics in the Kiev Reservoir, carried out on the basis of monitoring data collected by the Hydrometeorological Service of Ukraine, has shown that water temperature has rapidly increased since 1989 (Timchenko et al. 2013). On the whole, the average annual temperature of water in the Kiev Reservoir increased by 1.2-1.5°C from 1965 to 2011, whereas the average annual air temperature (in Kiev within the same period) increased by 1.8°C. The increase in the water temperatures in the Kiev Reservoir is supported by the results of analysis of their maximum temperatures. Between 1965 and the 1990s, water temperature in the Kiev Reservoir did not exceed 30°C, while since the late 1990s till now – it periodically exceeded 30°C (Timchenko et al. 2013). It is likely that a decrease in the contribution of eurythermal organisms and an increase in the contribution of taxa of moderately warm waters can be determined by climate changes.

The distribution of epiphytic algae – indicators of the trophic state of water bodies has also changed (Fig. 8). The contribution of eutraphentic organisms increased from 33.6% to 37.8% in 2010-2013 compared to the 1970s-1980s, whereas that of meso-eutraphentic taxa – from 17.1% to 21.0%. In this case, the contribution of oligotraphentic, oligo-mesotraphentic, and mesotraphentic taxa increased. The contribution of hypereutraphentic taxa and taxa with a wide range of indicator values remained unchanged. The obtained data are indicative of the increase in the intensity of the eutrophication process in the Kiev Reservoir. This statement is supported by the increase in the number of algae taxa – indicators of organic contamination belonging to the group of β-mesosaprobic organisms (S = 1.5-2.5) accompanied by the decrease in the number of algae taxa belonging to oligosaprobic organisms (S = 0.5-1.5) (Fig. 9), and also by the increase in the number of eurysaprobes (from 54.1% to 57.1%) (Fig. 10).

It should be noted that in 2010-2013 the distribution of the algae taxa – indicators of pH also changed compared to the 1970s-1980s (Fig. 5). In this case, the contribution of alkaliphiles and alkalibionts increased (from 40.4% to 44.6% and from 1.8% to 3.6%, respectively). In this case, the contribution of indifferent organisms remained unchanged, whereas the contribution of acidophiles decreased from 16.1% to 10.1%. It has been known that the processes of eutrophication and alkalization are interdependent. A decrease in the concentration of nutrients in water bodies is responsible for more intensive development of planktonic algae, and, thus, for an increase in the intensity of photosynthesis. As a consequence, the values of pH significantly increase especially in the surface water layer (Denisova 1979). The literature data (Timchenko et al. 2013) suggest that the pH values in the Kiev Reservoir increased up to 8.3-8.9 in the summertime, i.e. in the period of mass development of planktonic algae.

Thus, the obtained results suggest that in 2010-2013 major changes occurred in the ecosystem of the Kiev Reservoir compared to the 1970s-1980s. They consisted in the increase in the intensity of eutrophication, alkalization and thermofication processes. All these processes along with a rather high content of radionuclides in abiotic and biotic components of the ecosystem of the Kiev Reservoir can exert an adverse effect on the water quality in the main watercourse of Ukraine.

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