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Biological Indication of Ecological Status of the Water Bodies within Kiev City Boundaries[1][†]

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On the basis of a series of indexes and quantitative characteristics of benthic and phytophilous macroinvertebrate communities, including diversity, criterial assessment of the water bodies located within boundaries of Kyiv city has been carried out. Possibility has been shown to find numerical values of reference characteristics in order to carry out comparative assessment of the water bodies' status. Typology of the water bodies has been given and reference characteristics of key biological elements for each type have been suggested.

KEYWORDS*:* *biological indication*, *water bodies*, *macroinvertebrates*, *biological diversity*, *reference conditions*.

Introduction

Aquatic ecosystems of the urbanized territories are exposed to intensive impact of anthropogenic factors, which cause transformations in biota and formation of new biological communities. At the same time their existence under wide diapason of the anthropogenic load of different types gives possibilities to develop and test methods of the aquatic ecosystems assessment. Actually exist some approaches to ecological assessment of the natural waters state, however many specialists recognize their imperfection, connected first of all with poor development of methods of the biological element assessment [2, 3, 8, 22]. The Water Framework Directive EC 2000/60 (WFD), accepted in EU [9], gives priorities to biological components in the ecosystem status assessment. WFD is also appropriate to be applied in Ukraine. Recently in Ukraine certain success has

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[1] The work was carried out within the frames of the Target program of the National Academy of Sciences of Ukraine "Development of technology of minimization of the ecological risks connected with technogenous and biological pollution of the surface waters in order to improve state of environment".

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been reached in development of methodological base of the water bodies' ecological status assessment [2, 3, 23–26, 36]. At the same time assessment of ecological status of the water bodies by biological quality elements is not still priority as compared with chemical assessment, as it is prescribed by WFD.

The aim of this work was to show possibility to find numerical values of reference characteristics at establishment of the so called "reference values of biological quality element" [9], used in the ecosystems' status assessment, by example of structural characteristics of the phytophilous fauna and macrozoobenthos as model communities.

Material and Method

Methodology of our study was based on conception "biological indication" [8, 28]. We used methods based on the aquatic systems indication with index-grade approach [2, 22, 24], methods of ecological assessment of the water quality and aquatic ecosystems' state [24, 29–31], principles of ecological status assessment provided by WFD [9].

Annex V WFD explicitly provides a set of quality elements to be used for the lakes' ecological status classification: composition, abundance and biomass of phytoplankton, composition and abundance of other aquatic flora, composition and abundance of bottom invertebrate fauna, composition, abundance and age structure of fish fauna [9].

As indexes within each element may serve individual species, groups, populations and communities of the aquatic organisms, which characteristics vary according to the aquatic medium (biotope) characteristics changes, caused first of all by anthropogenic load. As indexes (descriptors) may be used both individual features of species (saprobity index, indicative weight, etc.) or population (information diversity of size-age groups, sexual structure, etc.) and various biotic indexes, based on presence of indicative groups in the communities; and simple relation of species number in a community as well.

This work was based on seasonal sampling of phytophilous fauna and macrozoobenthos, carried out in 2004–2006 in 15 water bodies located within Kyiv city boundaries according to standard hydrobiological methods [16, 22]. As element for establishment ecological status of these water bodies we considered "composition and abundance of bottom invertebrate fauna" [9]. The follows descriptors were chosen: total numbers and biomass, Woodiwiss index (*TBI*), Shannon species diversity, presence of endangered and rare species, included into different protection lists. Quantitative development was characterized according to the known classification characteristics [31], modified into the five-grade scale to meet WFD requirements (Table 1).

On the basis of the literature data [4–7, 10–13, 18–21, 27; 29, 32, 35, 38–41], for other characteristics we suppose that the best values for the lakes of the Kyiv urbanized territories are those corresponding to the mesotrophic category. Limits of their variation for every case of the aquatic ecosystem assessment were established taking into account their variation in the anthropogenic load gradient. For assessment of the anthropogenic load rate the method was used based on analysis of the most obvious anthropogenic factors, their presence or absence in each water body. Thus, the water body where maximal number of factors and their impact were registered was considered as exposed to anthropogenic load to a maximal extent [42].

Results

General hydromorphological characteristic, type and purpose use of the considered water bodies are presented in the Table 2. Most of them are used for recreation purpose, including those without special conditioned beach zones and where recreation is prohibited by authorities. Results of assessment of the anthropogenic load on the lake ecosystems are presented in the Table 3.

Among considered water bodies the most number of anthropogenic factors was registered in the Vyrlitsa Lake, nearby this lake the combustion plant is located. The Berezka Lake, located in Hydropark was exposed to anthropogenic load to a minimal extent. The Teremkovskoye, Troyeshchinskoye and Solnechnoye lakes experience high anthropogenic load, the Lesnoye, Syretskoye, Red'kino lakes and Didorovskiy pond – low.

Numbers and biomass of invertebrates in the considered water bodies varied over wide range (Figure 1). Maximal numbers of zoobenthos was noted in the Syretskoye Lake, maximal numbers of phytophilous fauna – in the Berezka Lake. Maximal biomass of zoobenthos was noted in the pond № 15, and maximal biomass of phytophilous fauna – in the Lesnoye Lake. Development of phytophilous communities in all water bodies by total numbers corresponded to the grade "low – very high", and biomass "very low – moderate". For benthos these indexes varied from "low" to "high".

By numbers and biomass of invertebrates it is possible to mark out two groups of water bodies with similar relation of the phytophilous fauna and zoobenthos abundance. The first group comprised water bodies where biomass of phytophilous fauna and zoobenthos was similar: the Verbnoye, Red'kino, Berezka, Teremkovskoye and Lesnoye lakes and Didorovskiy pond. The second, more wide-spread group comprised water bodies where biomass of benthic communities exceeded biomass of the phytophilous communities: the Troyeshchinskoye, Vyrlitsa Malinovka, Solnechnoye, Sineye, Syretskoye lakes, ponds № 13, 14, 15.

Species richness of the considered water bodies comprised 291 taxa of invertebrates. The most diverse were Chironomidae larvae – 87 species. Also were found 36 species of Gastropoda; 31 – Oligochaeta; 17 – aquatic beetles; 15 – dragonflies larvae; 14 – Trichoptera larvae; 13 – Hemiptera; 10 – Ceratopogonidae and Ephemeroptera larvae; 9 – Hirudinea; 7 – Gammaridae and Bivalvia; 4 – Limoniidae; 3 – Bryozoa and Ephydridae, 2 – Isopoda, Lepidoptera larvae, Culicidae, Syrphidae and Muscidae; Misidae and Megaloptera included 1 species each. Two protected invertebrate species were found: aquatic Hemiptera *Ranatra linearis* (Linne) and Gastropoda *Lymnaea fusca* (C. Pfeiffer) [37]. The first was found in phytophilous communities of the Lesnoye, Sineye lakes and in the Pond № 15, the last – in benthos of the Lesnoye Lake.

Total species richness of macrofauna is presented in the Table 4. Maximal species number was found in the Lesnoye Lake, minimal – in the pond № 14.

Maximal values of the Woodiwiss index (*TBI*) [44], which is widely used for the water bodies' assessment by diversity of the indicative groups [2, 3, 26], were noted in the Verbnoye, Troyeshchinskoye and Malinovka lakes. Minimal values were registered for zoobenthos of the Didirovskiy pond, and for phytophilous fauna of the pond № 13 and the Solnechnoye Lake. Minimal TBI values by total macrofauna were also registered in these water bodies. In all lakes (except

Table 1

Quantitative characteristics of zoobenthos and phytophilous fauna in the water bodies of the urbanized territories of Kyiv

Rate of communities development	Zoobenthos				Phytophilous fauna		Class of trophity of the aquatic ecosystems (prevailing type)
	biomass, g/m^2			numbers (total), thousand specimens/m^2	biomass, g/kg	numbers, specimens/kg	
	total	without mollusks (“soft benthos”)	Oligochaeta and Chironomidae				
Very low	< 5.1	< 3.1	< 0.3	< 0.6	< 11	< 0.26	Oligotrophic
Low	5.1–50.0	3.1–15.0	0.3–1.5	0.6–2.0	11–100	0.26–1.00	Mesotrophic
Moderate	50.1–300.0	15.1–50.0	1.6–7.5	2.1–10.0	101–500	1.01–5.0	Eutrophic
High	300.1–1000.0	50.1–75.0	7.6–15.0	10.1–20.0	501–1000	5.10–10.00	Polytrophic
Very high	> 1000.0	> 75.0	> 15.0	> 20.0	> 1000	> 10.00	Hypertrophic

Table 2

General characteristics of the considered water bodies

Water bodies		Type	Water area, ha	Purpose use	Maximal depth, m	Transparence, m (summer)	Rate of overgrowth, %	Prevailing soil type
1	The Verbnoye Lake	1	13.2	d/r	14.0	1.38	20	Black mud, silted sand
2	The Red’kino Lake (Ministerskoye)	1	28.0	d/r	9.5	3.46	10	Silted sand, detritus
3	The Sineye Lake	3	2.8	d/r	3.0	1.64	35	Black mud, silted sand
4	The Lesnoye Lake)	2	8.2	d/r	2.7	0.87	35	Silted sand, detritus

Table 2 *(continued)*

General characteristics of the considered water bodies

Water bodies		Type	Water area, ha	Purpose use	Maximal depth, m	Transparence, m (summer)	Rate of overgrowth, %	Prevailing soil type
5	The Didorovskiy pond (in Golosiyevo park)	2	2.8	d/r	4.0	0.77	25	Silted sand, detritus
6	The Vyrlitsa Lake	3	98.0	d/r	13.0	2.10	20	Black mud, silted sand
7	The Troyeshchinskoye Lake	4	10.0	d/r	8.0	1.11	40	Gray silt, silted sand
8	The Malinovka Lake	1	2.2	d/r	5.0	1.71	35	Black mud, silted sand, detritus
9	The Syretskoye Lake	2	1.2	d	0.5	0.3	90	Black mud
10	The Teremkovskoye Lake	2	0.9	d/r	3.0	1.33	45	Gray silt, silted sand
11	The Solnechnoye Lake	4	13.8	d/r	14.0	0.70	10	Gray silt, silted sand
12	The Berezka Lake (in Hydropark)	1	3.44	d/r	6.0	1.38	15	Black mud, gray silt
13	Pond № 13 in zone “Kin’-Grust’”, Krasitskogo str.	2	0.24	d	2.0	0.80	25	Black mud
14	Pond № 14 in zone “Kin’-Grust’”, Kobzars’ka str.	2	0.4	d	2.5	1.10	70	Black mud
15	Pond № 15 in zone “Kin’-Grust’”, Krasitskogo str.	2	1.0	d	3.0	1.15	10	Black mud

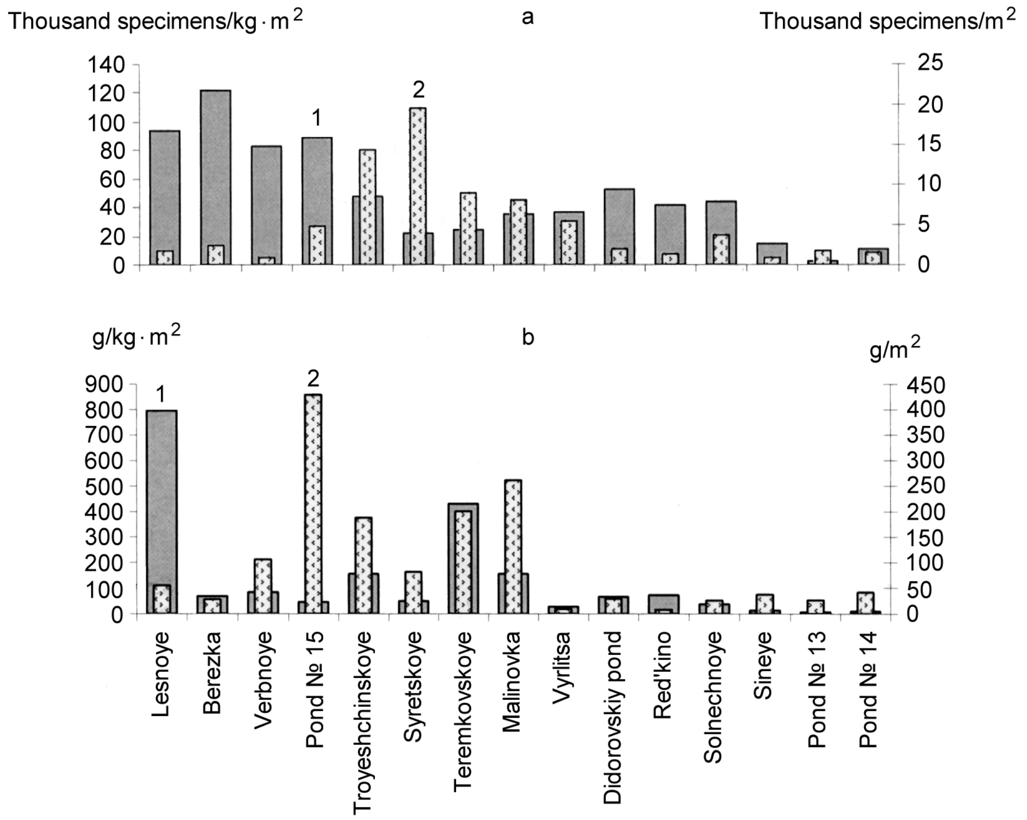
Note. Water bodies types and purpose use: 1 – flood land water bodies of the Dnieper River; 2 – ponds on the small rivers and streams; 3 – lakes supplied by groundwater and precipitations; 4 – artificial water bodies; d – decorative water bodies, d/r – decorative and recreational water bodies.

Table 3

Assessment of anthropogenic load on the considered water bodies

Anthropogenic impact factors	Water bodies														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Industrial and residential construction*	++	0	++	0	0	+++	++	+	0	++	++	0	+	+	+
Artificial alteration of morphometric characteristics**	0	0	0	0	+	0	0	0	0	+	0	0	++	++	0
Transport	+	+	0	0	0	+	+	0	+	+	+	0	+	+	+
Parkings	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0
Flood runoff from industrial construction	0	0	0	0	0	+	0	0	+	0	0	0	0	0	0
Flood runoff from residential construction	+	0	+	0	0	+	+	+	0	+	+	0	+	+	+
Recreation	+	+	+	+	+	+	+	+	0	+	+	0	0	0	0
Amateur fishing	+	+	+	+	+	+	+	+	+	+	+	+	0	0	+
Total	6	3	6	2	3	9	6	4	3	7	6	1	5	5	4

Note. 1–15 – names of the water bodies see in Table 1; «+» – presence of impact; «0» – absence of impact; impact rate: * «+» – weak (low-rise buildings), «++» – moderate (high-rise buildings), «+++» – heavy (industrial buildings); ** «+» – weak (partial alteration), «++» – heavy (total alteration). For other factors rate of impact was not evaluated.



1. Numbers (a) and biomass (b) of the phytophilous (*1*) and bottom (*2*) invertebrate macrofauna of the lakes of Kiev

Malinovka) maximal TBI values calculated by phytophilous fauna were higher than those calculated by zoobenthos.

Diversity of the considered communities was assessed on the basis of the average annual values of the Shannon diversity index. Maximal values of the Shannon index of zoophytos were registered in the Sineye Lake, of zoobenthos– in the Verbnoye Lake; minimal – in the pond № 14 and in Troyeshchinskoye Lake, correspondingly. On the whole, species diversity of the phytophilous complexes in most water bodies was higher than those of zoobenthos communities. From our point of view, Shannon index values 2.0 for zoobenthos and 2.5 for zoophytos can be considered as some mean value, conditional limit between "good" and "poor" state. By these characteristic all considered water bodies can be divided into four groups. The first group comprises water bodies with maximal Shannon index values of both zoobenthos and phytophilous fauna (Sineye, Malinovka, pond № 13, Lesnoye, Syretskoye, Red'kino). The second comprises water bodies where diversity of the phytophilous communities was low, though zoobenthos was quite diverse (Verbnoye, pond № 14). In the water bodies of the third group diversity indexes of the phytophilous communities were quite

Table 4

Characteristics of biological diversity of invertebrates of the considered water bodies

Water bodies		Species richness			*TBI*			Shannon biodiversity index, bit/specimen	
		Zoobenthos	Zoo-phytos	Total macrofauna	Zoo-benthos	Zoo-phytos	Total macrofauna	Zoo-benthos	Zoo-phytos
1	The Verbnoye Lake	46	59	87	7	8	8	2.55	2.50
2	The Solnechnoye Lake	25	45	60	4	6	6	1.70	2.46
3	The Vyrlitsa Lake	32	66	86	5	7	7	1.95	2.79
4	The Red’kino Lake	37	44	72	5	7	7	2.07	2.55
5	The Troyeshchinskoye Lake	40	73	94	7	7	8	1.57	2.86
6	The Berezka Lake	27	64	78	5	8	8	1.93	3.09
7	The Malinovka Lake	53	77	108	7	7	7	2.19	3.36
8	The Didorovskiy pond	41	50	83	2	7	7	1.93	2.31
9	The Sineye Lake	57	58	96	5	7	7	2.24	3.62
10	Pond № 15	24	52	64	5	7	7	1.75	2.66
11	The Teremkovskoye Lake	44	67	92	6	7	7	1.95	3.18
12	The Lesnoye Lake	63	90	130	4	8	8	2.37	2.78
13	Pond № 14	22	33	49	3	7	7	2.19	2.19
14	Pond № 13	22	41	60	5	6	7	2.31	2.98
15	The Syretskoye Lake	25	76	93	3	8	8	2.04	2.75

Note. Maximal *TBI* values are presented.

Table 5

Estimation scale of the ecological status of the water bodies of the urbanized territories of Kyiv

Descriptor		Class of ecological status				
		high, grade 5	good, grade 4	moderate, grade 3	poor, grade 2	bad, grade 1
Development rate by numbers	zoobenthos	moderate	high	low	very high	very low
	phytophilous fauna	high	moderate	very high	low	very low
Development rate by biomass		moderate	high	low	very high	very low
Species diversity		> 3.0	2.5–3.0	2.0–2.5	1.5–2.0	< 1.5
Species richness	zoobenthos	> 50	40–50	30–40	30–20	< 20
	phytophilous fauna	> 70	60–70	50–60	50–40	< 40
TBI		9–10	7–8	5–6	4–3	2–1
Presence of endangered, rare and protected species*		+	+	–	–	–

Note. Species richness means total species number for growing season in all water body; all other characteristics are average annual; * «+» – species of the Red book of Ukraine (grade 5) and in other protective lists (grade 4).

high, whereas these indexes of the benthic communities were low (Teremkovskoye, Berezka, Troyeshchinskoye, Vyrlitsa, pond № 15). The fourth group comprised water bodies where average annual values of the Shannon index were low in both communities (Solnechnoye, Didorovskiy pond).

Obtained data enabled to reveal descriptors' changes according to the anthropogenic load growth (without regard of the water body's genesis) and, consequently, to classify ecological status of the water bodies by invertebrate macrofauna according to the estimation scale (Table 5). We accept that grade 5 corresponds to the descriptor's characteristic that meets "high" status; 4 – "good"; 3 – "moderate"; 2 – "poor"; 1 – "bad".

Results of integrated assessment of ecological status of the considered water bodies' by six descriptors – numbers, biomass, species richness, species diversity, *TBI*, presence of absence of rare species are presented in the Table 6. At this maximal possible summary grade amounts to 30, it characterize "high" status. Integrated summary grade by quality element "invertebrate macrofauna" was calculated by summation of all descriptors' grades. Average grade was obtained by division of the integrated summary grade by six (number of descriptors), rounded to whole number, corresponded to the follows classes: 5 – "high"; 4 – "good"; 3 – "moderate"; 2 – "poor" and 1 – "bad"

Table 6

Grade score of structural characteristics of invertebrate macrofauna of the water bodies of Kiev

Water bodies	Biotic communities	Total numbers	Total biomass	Species richness	Species diversity	*TBI*	Rare species	Integral total grade		Average-grade index	*EQR**
								by group	by macrofauna		
Lesnoye	Zoobenthos	3	5	5	3	2	4	22.0	23.0	4	0.77
	Phytophilous fauna	2	5	5	4	4	4	24.0			
Malinovka	Zoobenthos	5	5	5	3	4	–	22	22.0	4	0.73
	Phytophilous fauna	5	3	5	5	4	–	22			
Pond № 15	Zoobenthos	5	4	2	2	3	–	16	21.5	4	0.72
	Phytophilous fauna	2	3	3	4	4	4	20			
Teremkovskoye	Zoobenthos	5	5	4	2	3	–	19	21.0	4	0.70
	Phytophilous fauna	5	5	4	5	4	–	23			
Sineye	Zoobenthos	3	4	5	3	3	–	18	19.5	3	0.65
	Phytophilous fauna	4	1	3	5	4	4	21			
Troyeshchinskoye	Zoobenthos	4	5	3	2	4	–	18	18.0	3	0.60
	Phytophilous fauna	2	3	5	4	4	–	18			

Table 6 *(continued)*

Grade score of structural characteristics of invertebrate macrofauna of the water bodies of Kiev

Water bodies	Biotic communities	Total numbers	Total biomass	Species richness	Species diversity	*TBI*	Rare species	Integral total grade		Average-grade index	*EQR**
								by group	by macrofauna		
Verbnoye	Zoobenthos	3	5	4	4	4	–	20	17.5	3	0.58
	Phytophilous fauna	2	4	2	3	4	–	15			
Syretskoye	Zoobenthos	4	5	2	3	2	–	16	17.5	3	0.58
	Phytophilous fauna	3	3	5	4	4	–	19			
Berezka	Zoobenthos	5	3	2	2	3	–	15	17.0	3	0.57
	Phytophilous fauna	3	3	4	5	4	–	19			
Vyrlitsa	Zoobenthos	5	3	3	2	3	–	16	17.0	3	0.57
	Phytophilous fauna	5	1	4	4	4	–	18			
Red’kino	Zoobenthos	3	3	3	3	3	–	15	15.0	3	0.50
	Phytophilous fauna	2	3	2	4	4	–	15			

Table 6 *(continued)*

Grade score of structural characteristics of invertebrate macrofauna of the water bodies of Kiev

Water bodies	Biotic communities	Total numbers	Total biomass	Species richness	Species diversity	*TBI*	Rare species	Integral total grade		Average-grade index	*EQR**
								by group	by macrofauna		
Pond № 13	Zoobenthos	5	3	2	3	3	–	16	14.5	2	0.48
	Phytophilous fauna	3	1	2	4	3	–	13			
Didorovskiy pond	Zoobenthos	3	3	4	2	1	–	13	13.5	2	0.45
	Phytophilous fauna	2	3	2	3	4	–	14			
Pond № 14	Zoobenthos	5	3	2	3	2	–	15	13.5	2	0.45
	Phytophilous fauna	3	1	1	3	4	–	12			
Solnechnoye	Zoobenthos	5	3	2	2	2	–	14	12.5	2	0.42
	Phytophilous fauna	2	1	2	3	3	–	11			

Note. «–» – not found; * *EQR* – Ecological Quality Ratio.

Table 7

Classification of the water bodies' ecological status by characteristics of invertebrate macrofauna (using material of the Table 6)

Water bodies	Ecological status of the water bodies by macrofauna	
	Average grade index	*EQR*
Lesnoye Malinovka Pond № 15 Teremkovskoye	Good status	Good status
Sineye Troyeshchinskoye Verbnoye Syretskoye Berezka Vyrlitsa Red'kino	Moderate status	Moderate status
Pond № 13 Didorovskiy pond Pond № 14 Solnechnoye	Poor status	

quality (or status). As it is obvious, maximal integral grade amounted to 23.0; it was registered in the Lesnoye Lake. Minimal integral grade was registered in the Solnechnoye lake – 12.5.

Available data enabled to calculate coefficient similar to ecological quality ratio (*EQR*) [9], as ratio of the obtained integrated summary grade and its reference value (grades of all descriptors are equal to 5). *EQR* values in the etalon (reference conditions, high status) are equal to 1 and in bad conditions they vanish. Scale of *EQR* values was divided into five classes according to the scheme: 5, 30, 30, 30 and 5% [40].

Integrated results of the water bodies' status assessment by macrofauna are presented in the Table 7. No case of "high" and "bad" ecological status was registered, from our point of view this is logical for the water bodies used for recreational and decorative purposes. "Good" status was determined in four water bodies: the Lesnoye, Malinovka, Teremkovskoye lakes and pond № 15. Status of most of the water bodies was assessed as "moderate". These water bodies were characterized by

Table 8

Characteristics of invertebrate macrofauna in different water bodies' types (summer)

Invertebrates groups	The Dnieper river floodplain water bodies without direct hydraulic connection	Lakes in the small rivers floodplains	Ponds in small rivers	Closed lakes
		Species richness		
Zoobenthos	11–30	20–40	5–34	40
Phytophilous fauna	32–54	38–40	13–82	51
Ephemeroptera	2–5	3–4	2–4	3
Trichoptera	3–6	1–4	1–6	3
Odonata	2–5	1–2	2–5	5
Bivalvia	–	2	1	–
		Development rate (by numbers)		
Zoobenthos	moderate	low	low – high	low
Phytophilous fauna	high – very high	very high	low – very high	moderate
		Development rate (by biomass)		
Zoobenthos	low – moderate	low – moderate	low – high	low
Phytophilous fauna	low – very low	low – moderate	moderate – very low	very low
		Biotic indexes		
TBI, macrofauna	7–8	7–8	7–8	7

various characteristics of the invertebrate macrofauna. By the average grade index four water bodies were considered as being in "poor" ecological status (the Didirovskiy pond and ponds № 13 and 14, the Lesnoye lake).

Discussion

According to WFD, state of the water body in the present or in the past where there are no, or only very minor, anthropogenic impact on its ecosystem is considered as etalon, or reference [2, 3, 9]. Reference conditions can be selected either by analysis and modeling of the retrospective data, or on the basis of expert assessment. In some cases paleolimnological data can be used for the reference conditions establishment. Principal provision of WFD is assessment of ecological status of the water body by comparison of its actual status (disturbance rate) regarding its conditional natural sta-

Table 9

Reference hydrobiological quality elements for different types of water bodies of Kiev (summer)

Hydrobiological characteristics	Water objects				
	The Dnieper river floodplain water bodies		Small rivers’ systems		
	without direct hydraulic connection with Dnieper	with direct hydraulic connection with Dnieper	lakes in the floodplains	ponds on rivers	stream sections of small rivers
BLOCK 1. Biotic indexes					
Biotic index of invertebrates macrofauna	8	8	9	8	7
Pantle-Buck saprobic index					
phytoplankton					
zooplankton	1.6–2.5	1.6–2.5	1.6–2.5	1.6–2.5	1.6–2.5
zoobenthos					
phytophilous fauna					
Trophity	mesotrophic	mesotrophic	mesotrophic	mesotrophic	mesotrophic
BLOCK 2. Communities’ structure (indicative and character for etalon conditions groups in main communities)					
Species richness					
zoobenthos	35	45	45	40	35
phytophilous fauna	50	55	45	85	45

Table 9 *(continued)*

Reference hydrobiological quality elements for different types of water bodies of Kiev (summer)

Hydrobiological characteristics	Water objects				
	The Dnieper river floodplain water bodies		Small rivers' systems		
	without direct hydraulic connection with Dnieper	with direct hydraulic connection with Dnieper	lakes in the floodplains	ponds on rivers	stream sections of small rivers
Number of species	Ephemeroptera – 6	Ephemeroptera – 6	Ephemeroptera – 4	Ephemeroptera – 5	Ephemeroptera – 4
	Trichoptera – 7	Trichoptera – 5	Trichoptera – 7	Trichoptera – 7	Trichoptera – 5
	Odonata – 6	Odonata – 5	Odonata – 5	Odonata – 6	Odonata – 4
	Bivalvia – 3	Bivalvia – 4	Bivalvia – 3	Bivalvia – 5	Bivalvia – 2
Number of aquatic plants species within indicative groups	rheophilous – 1	rheophilous – 2	rheophilous – 0	rheophilous – 2	rheophilous – 5
	limnophilous – 3	limnophilous – 3	limnophilous – 7	limnophilous – 5	limnophilous – 2
	paludous – 3	paludous – 1	paludous – 5	paludous – 3	paludous – 1
Number of the aquatic vegetation belts	3	1	3	3	2
Numbers					
zoobenthos	moderate	high	moderate	moderate	moderate
phytophilous fauna	moderate	moderate	high	high	moderate
Biomass					
zoobenthos	moderate	high	moderate	moderate	moderate

Table 9 *(continued)*

Reference hydrobiological quality elements for different types of water bodies of Kiev (summer)

Hydrobiological characteristics	Water objects				
	The Dnieper river floodplain water bodies		Small rivers' systems		
	without direct hydraulic connection with Dnieper	with direct hydraulic connection with Dnieper	lakes in the floodplains	ponds on rivers	stream sections of small rivers
phytophilous fauna	moderate	moderate	high	high	moderate
BLOCK 3. Biodiversity (indicative, character for etalon conditions, endemics and protected species)					
Invertebrate species, indicative and character for etalon conditions	*Eunapius fragilis*, *Pseudoanodonta complanata*, *Dreissena polymorpha*, *D. bugensis*, *Unio crassus*, *Dikerogammarus* sp.	*Spongilla lacustris*, *Dreissena bugensis*, *Unio tumidus*, *Plumatella emarginata*, *Astacus astacus*	*Pseudoanodonta complanata*, *Viviparus viviparus*, *Cristatella mucedo*	*Lymnaea stagnalis*, *Hirudo medicinalis*, *Sigara falleni*, *Tanypus vilipennis*, *Hydrobia tarda*, *Helophorus aquaticus*	*Hirudo medicinalis*, *Sigara falleni*, *Astacus astacus*, *Dreissena polymorpha*
Aquatic plant species, indicative and character for etalon conditions (requiring protection species are in bold)	*Butomus umbellatus*, *Schoenoplectus lacustris*, *Nuphar lutea*, *Potamogeton perfoliatus*, ***Nymphaea candida***	*Butomus umbellatus*, *Potamogeton perfoliatus*, *P. crispus*, *Sagittaria sagittifolia*, ***Salvinia natans***, *Nymphaea alba*, ***Trapa natans***, *Potamogeton*	*Butomus umbellatus*, *Nuphar lutea*, *Potamogeton perfoliatus*, *Utricularia vulgaris*, ***Aldrovanda vesiculosa***, ***Salvinia natans***, *Wolffia*	*Sparganium erectum*, *Stratiotes aloides*, *Hottonia palustris*, *Elodea canadiens*, *Potamogeton natans*	*Nuphar lutea*, *Potamogeton perfoliatus*, *P. natans*

Table 9 *(continued)*

Reference hydrobiological quality elements for different types of water bodies of Kiev (summer)

Hydrobiological characteristics	Water objects				
	The Dnieper river floodplain water bodies		Small rivers' systems		
	without direct hydraulic connection with Dnieper	with direct hydraulic connection with Dnieper	lakes in the floodplains	ponds on rivers	stream sections of small rivers
		compressus, *P. trichoides*	*arrhiza*, ***Nymphoides peltata***		
Fish species, indicative and character for etalon conditions	*Esox lucius*, *Scardinius erythrophthalmus*, *Carassius auratus*, *Tinca tinca*	*Abramis brama*, *Esox lucius*, *Perca fluviatilis*, *Leuciscus cephalus*, *Aspius aspius*, *Lota lota*	*Carassius carassius*, *Misgurnus fossilis*, *Cyprinus carpio*, *Tinca tinca*, *Anguilla anguilla*	*Carassius carassius*, *Misgurnus fossilis*, *Cyprinus carpio*	*Scardinius erythrophthalmus*, *Perca fluviatilis*, *Leuciscus idus*, *Carassius auratus*
BLOCK 4. Biotopes (relation of main types of biotopes, indicative and character for etalon conditions					
Rate of the riparian zone overgrowth, %	20–30	5–10	50	60	40
Average depth, m	4	5	4	3	2
Prevailing substrata type	Silted sand	Sand	Silted sand, sandy silt	Sandy silt, silt	Sand

tus. Ecological status assessment in fact is a classification of the water bodies on the basis of comparison of the survey (actual) data with reference characteristics specific for the given water body type. We consider possibilities of transition from the criterial approach to the comparative, or reference approach. First of all it is needed to establish benchmarks, so called reference conditions, for each type of the water bodies.

The first step in the water bodies' assessment is their typization. Within city of Kyiv and its neighborhood some types of the water bodies were divided [1]: the Dnieper River floodplain water bodies without direct hydraulic connection with the Dnieper River (the Malinovka, Berezka, Vyrlitsa lakes); floodplain water bodies with direct hydraulic connection (the Bobrovnia, Maliy Gidropark, Dolopetskaya); lakes in the small rivers floodplain (water bodies of the Vita River floodplain, the Opechen', Ptashinoye, Red'kino, Verbnoye lakes); ponds in the small rivers (the Lesnoye, Didorovka, Teremkovskoye, ponds № 15, № 14, № 13, Syretskoye) and stream sections of small rivers (the Vita, Lybid', Syrets rivers); artificial water bodies (the Troyeshchinskoye and Solnechnoye lakes) and closed lakes (the Sineye lake).

The next step consists in establishment of reference conditions for each type. Nowadays in Europe there is no single approved method of such data presentation. Recently the *RQBA* (River Quality Biological Assesment) tables [2, 3] are quite widely used for this purpose. They appeared to be quite suitable for rivers and other water bodies. These methods do not provide certain precise set of descriptors, however at tables' compilation it is needed to follow block principle. Particularly blocks "Communities' structure" and "Biodiversity" foreseen availability of data on indicative and character groups and species. Such data are not needed at criterial assessment, but they are important at comparative approach.

Table 8 comprises characteristics of the benthic and phytophilous communities taking into account requirements of the *RQBA* method. Taking into account anthropogenic load rates in each water body and determination of their state by criteria of the considered descriptors and literature data [4–7, 10–13; 18–21; 27; 29; 32; 35; 38–41], we derived reference values of the quality element "bottom invertebrate fauna" (Table 9).

On the basis of study of other groups, by literature data [4–7, 10–13; 18–21; 27; 29; 32; 35; 38–41], we have made an attempt to establish integrated "reference hydrobiological quality elements" according to method of assessment *RQBA* tables [2, 3] for some types of lakes and river systems of Kyiv and its neighborhood (see Table 9).

Poor quantity and quality of data on actual state of biota of the water bodies of Kyiv do not enable to carry out full assessment of their ecological status. However it is worth noting that by structural characteristics of macrofauna most of considered water bodies were referred to "moderate" status. At this none water body was characterized by "high" or "bad" ecological status. Comparative assessment by macrofauna enabled to determine the Didirovskiy pond, ponds № 13 and 14, and the Solnechnoye Lake as water bodies in "poor" status.

Suggested table "Reference hydrobiological quality elements" serve as a basis for assessment of the actual status of the water bodies. Certainly, many characteristics should be clarified; addition of other descriptors is quite possible, perfectly if each impact has its own descriptor. Probably, it is purposeful to include organisms of higher trophic levels, rare species of fish and birds, on the assumption of high ecological value of ecosystem able to provide their existence. Certainly, such assessment will need additional information on all blocks and simultaneous study of all biotic communities. Unfortunately, nowadays available material is not sufficient for the full-value assessment of all suggested blocks.

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Biotopic Distribution of Periphyton in the Cooling Pond of the Khmelnitskiy NPS[†]

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Data on the distribution of periphyton in the cooling pond of the Khmelnitskiy NPS are given in the paper. The peculiarities of the distribution of *Dreissena*, other invertebrates, and filamentous algae in various biotopes are discussed.

KEYWORDS: *periphyton*, *Dreissena*, *biotope*, *cooling pond*, *nuclear power station*.

Introduction

The presence of solid inorganic substrata and artificial temperature regime are favorable to the development of periphyton communities in cooling ponds [3]. Both these factors influence the composition and structure of periphyton communities. Changes in the temperature of water result in changes in the structure of periphyton communities [2, 11].

The main objective of the present work was to study the distribution and abundance of periphyton invertebrates in various biotopes of the cooling pond after putting into operation the second unit of the nuclear power station.

Material and Methods

The cooling pond of the Khmelnitskiy NPS is located in the northwestern part of Ukraine. It represents a water body formed in the Gniloy Rog River (the basin of the Pripyat River). A total of 5 regions differing in their conditions was distinguished in the cooling pond (Fig. 1). The dam 7 km long and 8 m deep paved with concrete is located in the north of the cooling pond. The water intake and discharge canals are located in the eastern part of the cooling pond. The water intake canal is

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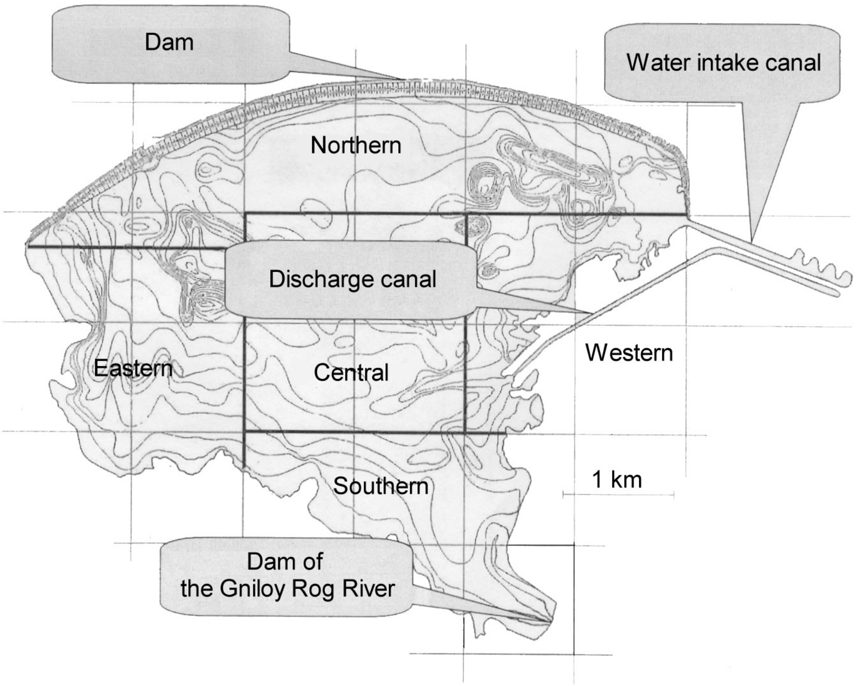

Fig. 1. Map-scheme of the cooling pond of the Khmelnitskiy NPS. The side of the square is 1 km long.

about 1.5 km long and 7–9 m deep. It is also paved with concrete. The speed of water flow in the canal is 0.3–0.4 m/sec. The discharge canal is 3.5 km long and about 4 m deep. It is paved with concrete and crushed stone. The first unit of the Khmelnitskiy NPS was put into operation in 1987, whereas its second unit – in 2004. For the first time *Dreissena polymorpha* Pallas was found in the cooling pond in 2002–2003 [8].

In 2006 the average temperature of water in the water intake canal was 23.5°C, whereas near the dam it was 24.4°C. In April and July, the temperature of water in the water intake canal differed from that in the discharge canal by 10°C, whereas in October this difference was 6°C. In the discharge canal in April – October, the average temperature of water was 31.6°C, whereas the maximal temperature of water accounted for 37.5°C (2006).

Periphyton was studied in 2005–2008 using the light diving equipment. This made it possible to assess the intensity of periphyton communities development, to determine dominant forms, and also to assess the area of their distribution. Visual assessment of the distribution of periphyton organisms using diving equipment was carried out in June and August 2005, in April, July, and October 2006, in July and October 2007, and in July and September 2008. A total of 12 observations were carried out within the dam and 14 observations – in the water intake canal. Samples were taken along transects about 30 m long directed from the water edge to the bottom. The samples of zooperiphyton were taken in June and August 2005 and in February, July, and October 2006. They were collected from concrete – on the dam and in the water intake and discharge canals, from metallic constructions – in the discharge canal, and also from stones – near the estuary of the Gniloy Rog River. The biomass of *Dreissena* was determined under field (12 measurements) and laboratory conditions (117 measurements).

The similarity between periphyton communities was determined by the method of Serensen and using the taxonomic analysis of Smirnov. The Shannon index was used in studies of species diversity [5]. The WaCo Program was used in processing the obtained material [12]. Invertebrates were identified to the species taxon, or to "the lowest determined taxon" [1].

Results

Visual observations of various substrata of the cooling pond have shown that the distribution and spatial structure of zooperiphyton were rather complicated. Macroforms, including filamentous green and blue-green algae, sponges, and *Dreissena*, formed their settlements at various depths in the form of zones. The character and density of such settlements varied over a wide range. One zone was represented mainly by empty shells of *Dreissena*, whereas another zone was covered by the settlements of *Dreissena*. In this case, the density of the cover was 100% (Fig. 2). During the period of investigations on the dam, the width of this zone gradually decreased, whereas in the canal its width increased. In both biotopes, the middle of this zone was registered at the depth of 5 m.

On the whole, 6 zones of the distribution of periphyton were distinguished in the water intake canal in June 2005. Green filamentous algae were observed to the depth of 4 m. To the depth of 1.3 m algae were attached to the concrete. Alive specimens of *Dreissena* were absent. The width of this zone was about 2 m. The second part of the zone was characterized by a more complicated structure. Green filamentous algae were attached to the settlements of *Dreissena* represented mainly by empty shells. The zone occupied by *Dreissena* with the cover of 80–100% was observed at the depths of 4–6 m. At the depth of more than 6 m, the settlements of *Dreissena* were represented by individual specimens with the cover of 60%.

On the vertical surface of the bridge, the settlements of *Dreissena* with the cover of 100% were observed at the depths of 1.3–1.5 m.

In summer 2005 on the dam, green filamentous algae (*Cladophora* sp.) with the cover of 100% were registered from the water edge to the depth of 0.3 m. The zone occupied by green filamentous algae (*Cladophora* sp.) and *Dreissena* was observed to the depth of 0.6 m. The zone occupied by *Dreissena* with the cover of 100% was registered at the depths of 1.9–2.5 m. In this case, green filamentous algae were almost absent. Green filamentous algae (*Ulothrix* sp.) and *Dreissena* with the cover of 80% were observed at the depths of 3.0–3.5 m. At the depth of 4 m, the cover of *Dreissena* was 80%, at the depths of 5–6 m – 50%, whereas near the bottom it was 15%. On the bottom (slightly silted sand) *Dreissena* occurred with the cover of 10%.

In August 2005 in the water intake canal, the empty shells of *Dreissena* occurred to the depth of 4 m. At the depths of 4–5 m, *Dreissena* occurred with the cover of 90%, whereas at the depths of 5–6 m it occurred with the cover of 100%.

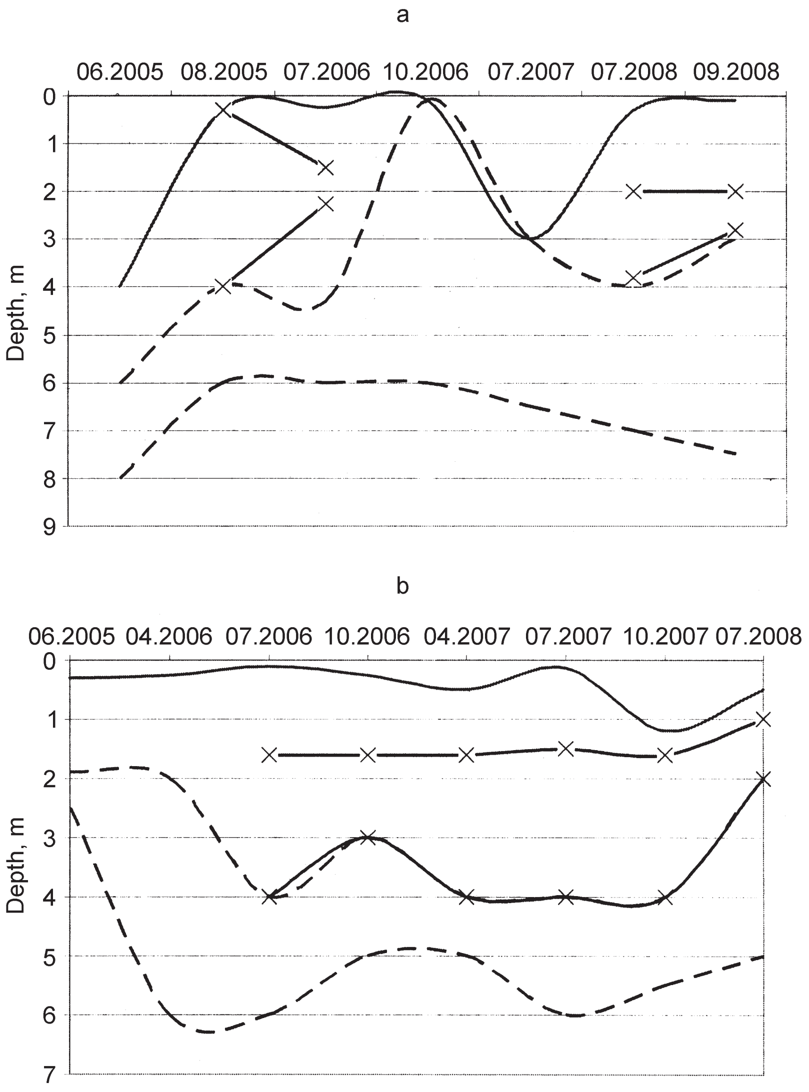

Fig. 2. Borders of the distribution of periphyton zones on the left bank of the water intake canal (a) and on the dam (b): the continuous line – the border of the autotrophic-heterotrophic zone; between the dotted lines – the zone occupied by the settlements of *Dreissena* with the cover of 100%; between the crossed lines – the zone occupied by the empty shells of *Dreissena*.

In April 2006 on the dam, diatoms were registered to the depth of 0.25 m. *Dreissena* with the cover of 100% occurred at the depths of 2–6 m. In July 2006, the numbers of *Dreissena* decreased at the depth of 3 m. In July 2006, the zone with the empty shells of *Dreissena* was registered at the depths from 1.5 to 3–4 m. The zone occupied by *Dreissena* with the cover of 100% was observed at the depths of 4–6 m.

In autumn 2005, the settlements of *Dreissena* were removed from the water intake canal. However, in July 2006 its settlements were observed from the depth of 0,3 m (10%) to the depth of 1.5 m (80%). It should be noted that the zone occupied by the empty shells of *Dreissena* was observed on the left more illuminated bank of the canal. On the right less illuminated bank of the canal, the settlements of *Dreissena* were observed to the depth of 0.9 m from the bottom. Its settlements with the cover of 100% were observed at the depths of 6–8 m. The vertical surface was totally occupied by the settlements of *Dreissena*.

In October 2006 and in April 2007, the settlements of *Dreissena* in the canal were observed from the depths of 10–15 cm. In April, the cover of *Dreissena* was 100%. In July on the banks of the canal, the zone occupied by the empty shells of *Dreissena* was observed at the depths of 0.9–3 m. In October it was also observed.

In October 2007 on the dam, the settlements of *Dreissena* with the cover of 100% were observed from the surface to the depth of 1.5 m, and also at the depths of 4–6 m. The zone occupied by the empty shells of *Dreissena* was observed at the depths of 1.5–4 m.

In July 2008, the dam was occupied by green filamentous algae to the depth of 5 m. The empty shells of *Dreissena* were observed at the depths of 1–2 m. The settlements of *Dreissena* with the cover of 100% were registered at the depths of 2–5 m.

In the water intake canal, the distribution of periphyton was non-uniform. On the left bank, the zone occupied by the empty shells of *Dreissena* was observed at the depths of 2–4 m, whereas on the right bank – at the depths of 1–3 m. The zone occupied by the settlements of *Dreissena* with the cover of 100% was observed to the bottom of the canal. The vertical surface of the bridge was occupied not only by the settlements of *Dreissena*, but also by the colonies of *Eunapius carteri* (Bowerbank, 1863) [10]. Its colonies occurred with the cover of 50–80%, whereas the settlements of *Dreissena* were registered with the cover of 40%. It should be noted that in the canal and on the dam the colonies of *Eunapius carteri* were not observed. In July 2008 in the water intake canal, its colonies occurred with the cover of 90%. At the depth of 3 m, relationship between *Eunapius carteri* and *Dreissena* was almost equal.

In July 2008 in the water intake canal at the depth of 7 m, the settlements of *Dreissena* were covered with fungi. In September 2008, this phenomenon was not observed.

In September 2008 on both banks of the water intake canal, green filamentous algae were observed at the depths of 2–4 m. On the left bank of the canal at the depths of 1–2 m, the settlements of *Dreissena* and green filamentous algae occurred with the cover of 100%. This zone was registered to the bottom. The frequency of occurrence of *Eunapius carteri* was very low. On the vertical surface of the water intake canal, the colonies of sponges occurred with the cover of 60%. The settlements of *Dreissena* were observed only at the depth of 5.5 m.

In the discharge canal at the depth of 0.5 m, Bacillariophyta dominated at a low temperature of water, green filamentous algae – in early summer, whereas blue-green algae – at the highest temperature of water. In this case, the width of the zone occupied by blue-green algae accounted for 1.5 m.

Table 1

Minimal (a) and maximal (b) number of the lowest determined taxa in different periods at the studied stations in various biotopes

Periods	Water intake canal		Dam		Southern region	
	a	b	a	b	a	b
June 2005	3	7	4	11	–	–
August 2005	2	13	9	11	8	17
February 2006	8	17	–	–	–	–
April 2006	4	10	9	14	–	–
July 2006	13	21	5	30	8	21
October 2006	2	22	11	30	16	21
April 2007	9	19	6	24	12	17
July 2007	7	20	4	20	7	14
October 2007	–	–	9	12	–	–
July 2008	14	22	11	19	–	–
September 2008	17	25	–	–	–	–

In the southern region in the estuary of the Gniloy Rog River, green filamentous algae occurred at the water edge. The zone occupied by *Dreissena* with the cover of 90–100% was registered to the depths of 1.5–2 m.

During the period of investigations, zooperiphyton of the cooling pond included 106 lowest determined taxa belonging to 21 groups. Oligochaeta and Chironomidae larvae were represented by the largest number of species (26 and 29, respectively). Gastropoda were represented by 13 taxa. Sponges, Hydrozoa, Naididae, Tubificidae, and Chironomidae larvae, including *Limnochironomus nervosus* Staeg., *Cricotopus* gr. *silvestris* Fabr., *Polypedilum convictum* Walker, and *Procladius ferrugineus* Kieff., were characterized by a high frequency of occurrence.

During the period of investigations in three studied biotopes (Table 1), the number of periphyton taxa changed. In the water intake canal, the minimal and maximal number of taxa constantly increased. On the dam, the number of taxa increased till October 2006, whereas at a later time it decreased. The same pattern of dynamics was observed in the southern region.

The main factors influencing the composition and abundance of zooperiphyton organisms are illumination, temperature, depth, and also the heterogeneity of the biotope conditioned by the character of macroforms settlements, including green filamentous algae and *Dreissena* [3, 9]. Illumination is responsible for the formation of two zones on the banks of the canals and on the dam. The first zone included green filamentous algae occurring at a high temperature of water and diatoms registered at a low temperature of water, whereas the second zone included the settlements of

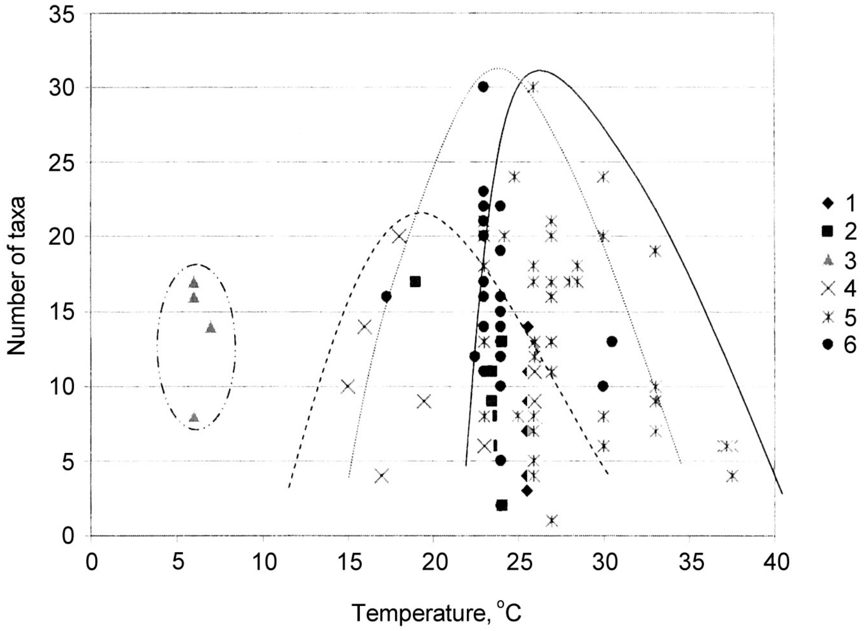

Fig. 3. Relationship between the number of the lowest determined taxa and the temperature of water at the studied stations in different seasons (enclosing lines: point, dotted line – February, dotted line – April, continuous line – July, points – October): 1 – 06.2005; 2 – 08.2005; 3 – 02.2206; 4 – 04.2006; 5 – 07.2006; 6 – 10.2006.

Dreissena. For the most part, the border between these two zones was observed at the depths of 3–4 m. In 2006 and 2007, green filamentous algae occurred in abundance at the depth of about 3 m in the western region of the cooling pond.

The number of zooperiphyton taxa depended on the temperature of water. Their lowest number was registered in wintertime. In February the number of taxa accounted for 8–17, whereas in July it was 5–30. Changes in the number of species depended on the temperature of water. However, this relationship was not linear (Fig. 3). In April the largest number of species was observed at 17°C, in July – at 23°C, whereas in October – at 27°C. At a high temperature of water, the number of taxa decreased (4–6 species at 37°C). A depth did not influence the number of species. As this takes place, the largest number of species was observed near the water edge.

The number of species depended not only on the temperature of water and season, but also on the abundance of *Dreissena*. The largest number of taxa was found at the biomass of *Dreissena* of about 13 kg/m^2 (Fig. 4). Near the water edge, green filamentous algae influenced the number of zooperiphyton taxa.

In wintertime the species diversity of zooperiphyton organisms was not high – not more than 1 bite/specimens. In April the highest species diversity was observed at 26°C – 2.5 bites/specimens. In summer the maximal species diversity was registered at 28°C – 3.3 bites/specimens, whereas at

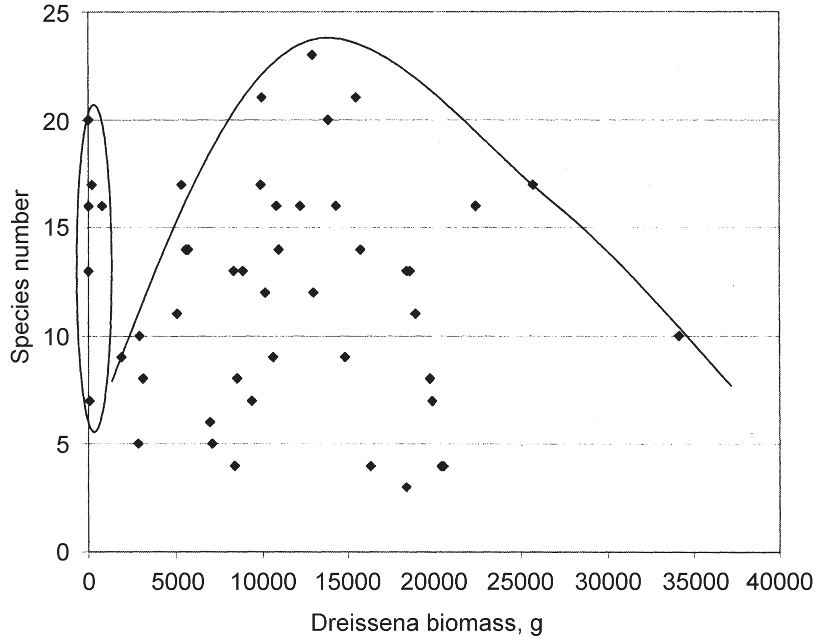

Fig. 4. Changes in the number of zooperiphyton species at different values of *Dreissena* biomass.

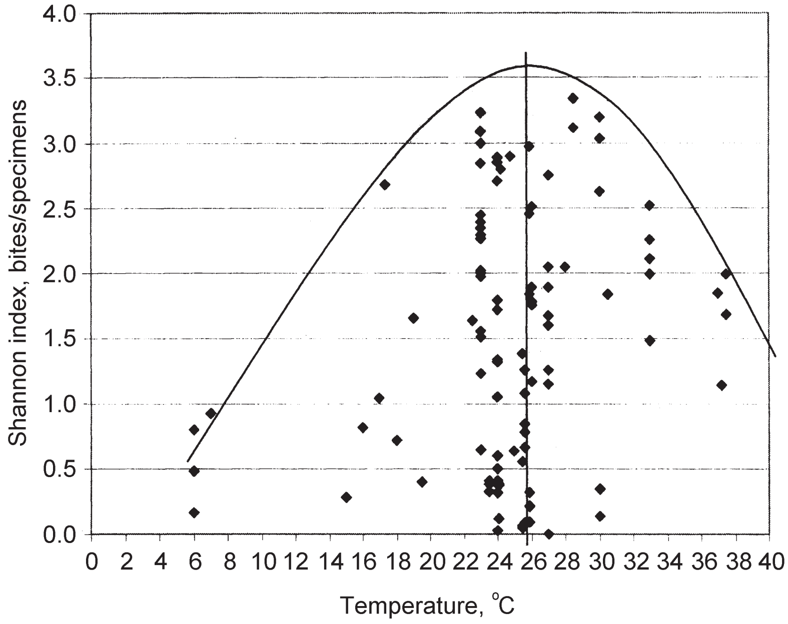

Fig. 5. Changes in the species diversity of zooperiphyton in terms of its numbers (bites/specimens) depending on the temperature of water.

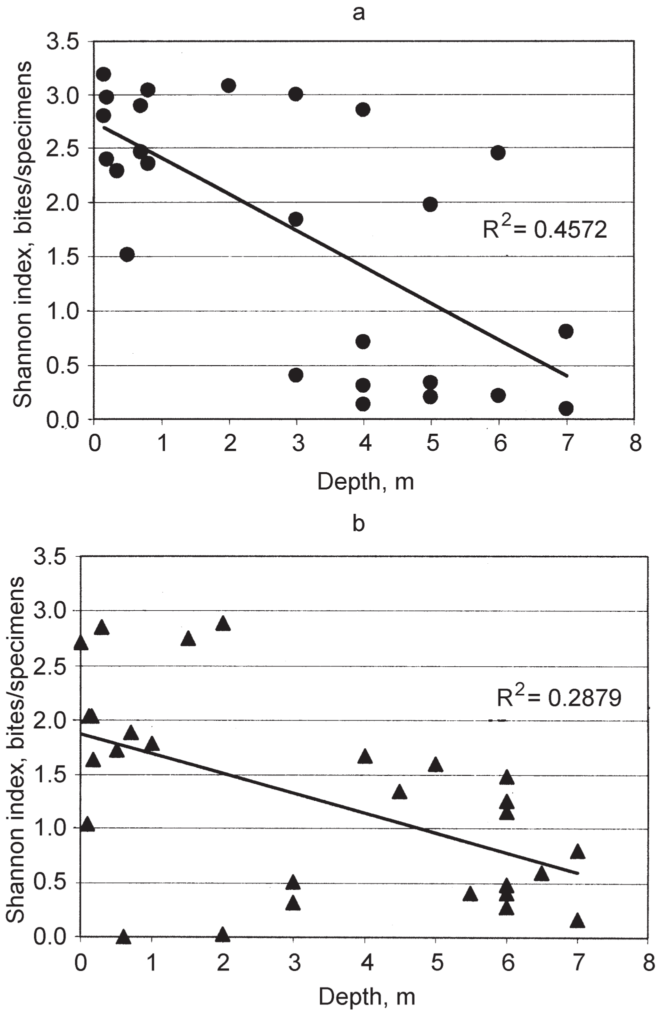

Fig. 6. Changes in the species diversity of zooperiphyton in terms of its numbers (bites/specimens) depending on the depth (with regard of *Dreissena*): a – dam; b – water intake canal.

37°C it decreased to 1.1 bites/specimens. The same pattern was observed in autumn: the maximal species diversity was observed at 23°C, whereas at 30°C it decreased. On the whole, the maximal species diversity was observed at the temperature of water of about 26°C (Fig. 5). The species diversity of zooperiphyton organisms changed with depth. At the water edge, their distribution depended on the intensity of development of green filamentous algae, whereas in deep water sections it depended on the development of *Dreissena*. On the whole, the species diversity of zooperiphyton organisms decreased with depth both on the dam, and in the canal (Figures 6 and 7).

The numbers of *Dreissena* in the water intake canal significantly differed from those on the dam. In the water intake canal, the density of *Dreissena* increased to the depth of 3 m and ranged

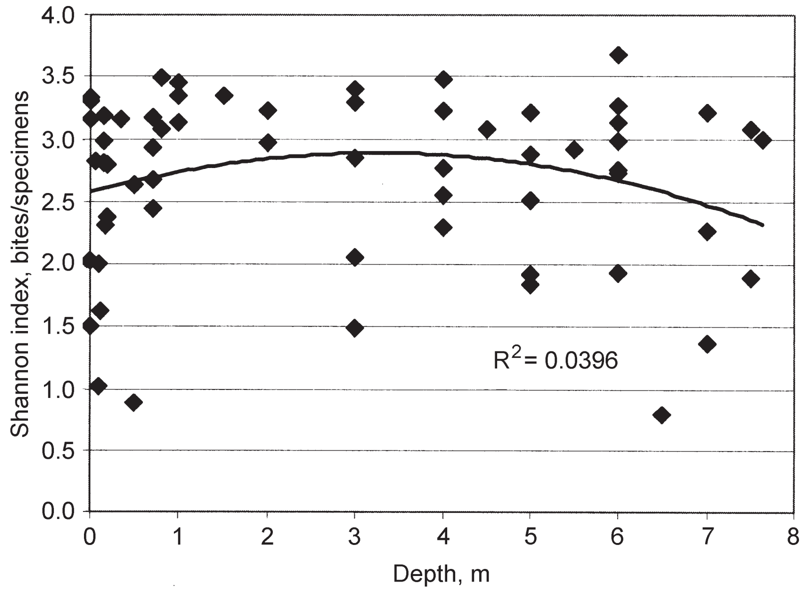

Fig. 7. Changes in the species diversity of zooperiphyton in terms of its numbers (bites/specimens) depending on the depth (without regard of *Dreissena*).

from 6 to 20 kg/m^2. On the average it accounted for about 13–15 kg/m^2. With regard of the cover these indices were somewhat lower (Fig. 8).

On the dam, relationship between the biomass of *Dreissena* and the depth was more complicated. Its biomass increased to the depth of 1 m, whereas at the depth of 2 m it decreased. At the depths of 3–6 m, the biomass of *Dreissena* increased to 20 kg/m^2 (with regard of the cover it was not more than 17 kg/m^2). After that from the depth of 4 m it sharply decreased. At the depth of 7 m, it was not more than 4 kg/m^2 (Fig. 9). Thus, the pattern of the distribution of *Dreissena* on the dam differed from that in the water intake canal.

On the dam in the estuary of the Gniloy Rog River, the distribution of *Dreissena* was uniform.

In the communities of zooperiphyton, *Dreissena* was not only dominant, but also edificator species (Fig. 10). At the biomass of *Dreissena* to 10 kg/m^2, the density of invertebrates increased, whereas at higher values of its biomass it decreased.

Discussion

The performed investigations have shown that in 1998, 1999, and 2001 periphyton macroforms were represented only by filamentous algae, sponges, and *Plumatella fungosa* Pall. [2, 7]. On the dam, the zone occupied by green filamentous algae occurred to the depths of 2.0–2.3 m, whereas in the water intake canal its width was not more than 0.8 m. A total of 60 taxa occurred in the thickets

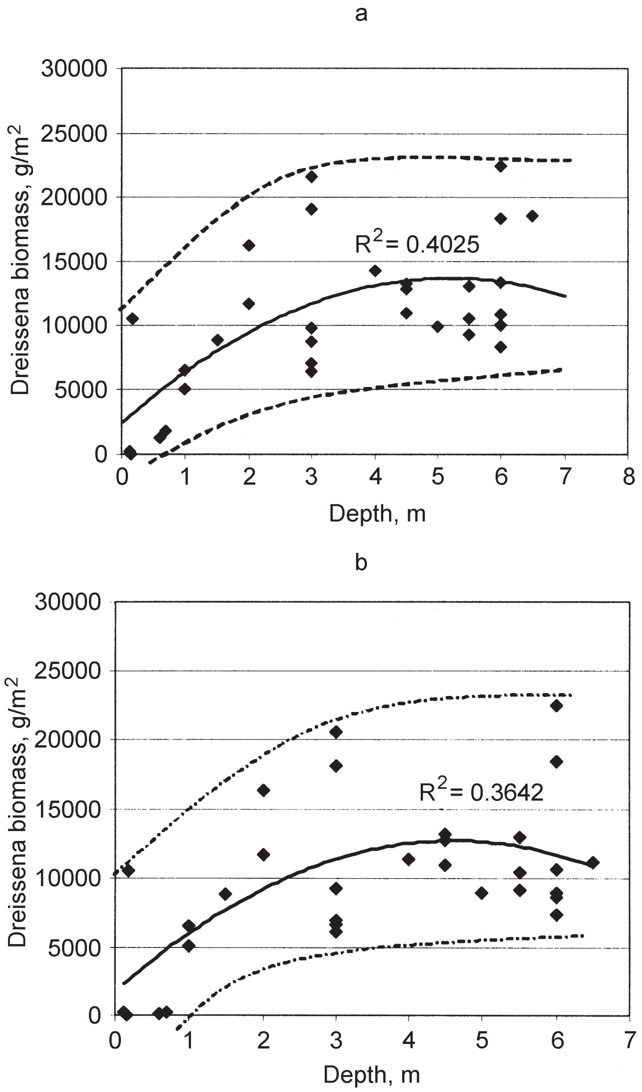

Fig. 8. Distribution of *Dreissena* biomass with depth in the water intake canal: without regard of the cover (a) with regard of the cover (b).

of green filamentous algae. The highest biomass of zooperiphyton was observed in the communities with a predominance of *Spongilla lacustris* L. – 238.7 g/m^2.

After the introduction of *Dreissena*, the biomass of periphyton was 1–2 orders of magnitude higher.

The formation of the zone occupied mainly by the empty shells of *Dreissena* was registered in the water intake canal in 2005. It was conditioned by intensive development of green filamentous algae. It is likely that their vegetation limited the development of *Dreissena*.

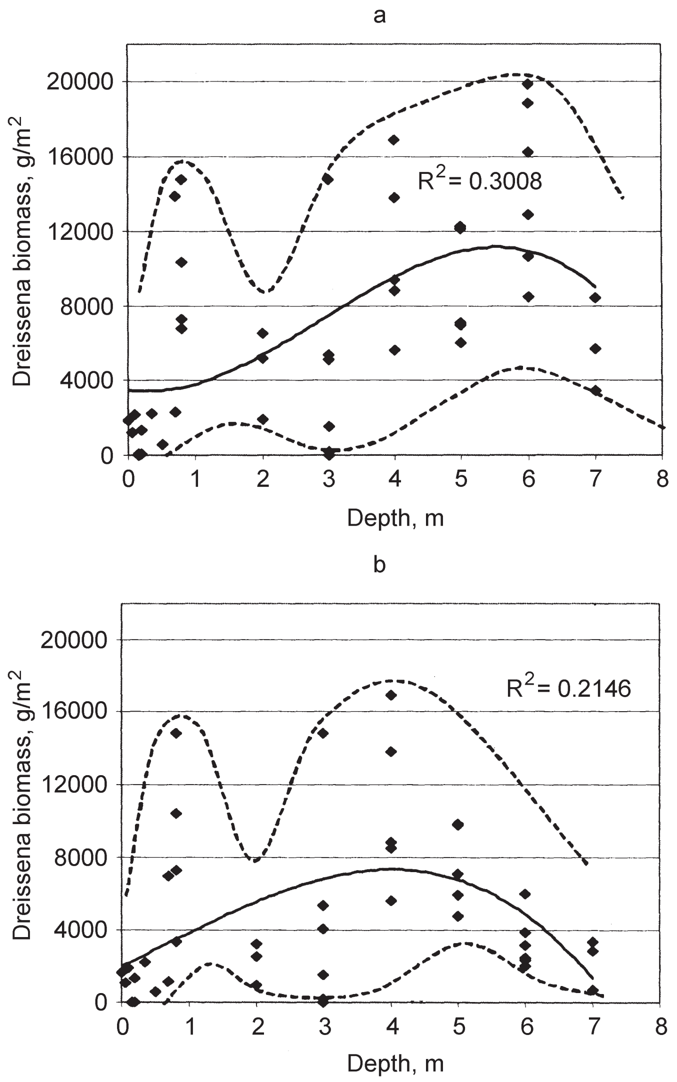

Fig. 9. Distribution of *Dreissena* biomass with depth on the dam: without regard of the cover (a) with regard of the cover (b).

The introduction of *Dreissena* into the cooling pond in 2004 resulted in serious hindrances to the water supply of the nuclear power station. In autumn 2005 the settlements of *Dreissena* were removed from the canal.

In the communities of periphyton, the biomass of *Dreissena* and its predominance were significant, as a result of which equalization in terms of biomass and species diversity of communities decreased. The biomass of *Dreissena* depended inversely on the species diversity of the community

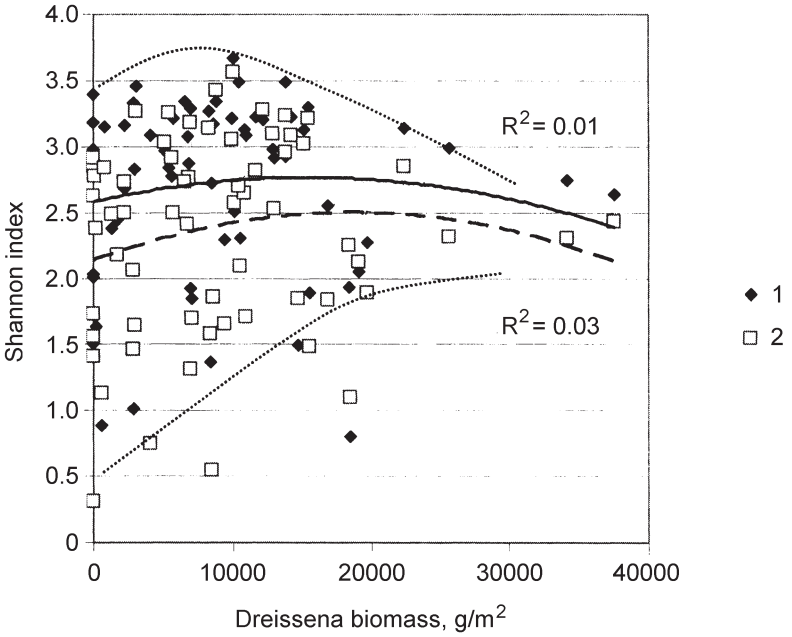

Fig. 10. Changes in the diversity of the consortium group of invertebrates depending on *Dreissena* biomass: 1 – *H*, bites/specimens (continuous line); 2 – *H*, bites/specimens (doted line).

on the whole. In summer 2006 the coefficient of correlation between these indices accounted for -0.651.

In the cooling pond of the Chernobyl NPS, the diversity of zooperiphyton communities calculated in terms of their numbers changed uni-modally with increasing *Dreissena* biomass. Their highest diversity was observed at the biomass of *Dreissena* of 7000 g/m^2 [6]. In the cooling pond of the Khmelnitskiy NPS, the highest species diversity of zooperiphyton communities was registered at the biomass of *Dreissena* of more than 10 kg/m^2.

Conclusion

It has been found that in the cooling pond of the Khmelnitskiy NPS the structure of periphyton communities varied over a wide range. The introduction of *Dreissena* into the cooling pond resulted in significant changes in the structure of periphyton communities. The increase in water transparency to 3–4 m in terms of the Secki disk at the expense of the filtration activity of mollusks resulted in the increase in the zone occupied by green filamentous algae. Their intensive vegetation inhibited the development of *Dreissena*. The highest diversity and abundance of zooperiphyton were observed at a rather high temperature of water.

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Hydrobiological Journal, 2010, Vol. 46, No. 4

Express-Method of Determination of Age Composition of the Black Sea Sprat Catches[†]

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Method of determination of populations' age structure based on normal fish size distribution within the same age group has been proposed. Proposed method is simple and can be used in express-analysis of the fish catches age composition. The experimental studies confirmed possibility to use the proposed method to determine age structure of the commercial fish stocks.

KEYWORDS*:* the Black Sea sprat, age-length key, age structure, law of normal distribution.

Introduction

Age structure of commercial stock, characterizing relation of the age groups (generations), is one of the main biological characteristics. Along with sexual, dimensional, spatial and other structure, it reflects important vital processes, such as reproduction intensity, mortality rate, generation change etc. [1, 2]. Age structure depends on both genetic peculiarities of species and concrete characteristics of its habitats; it sensitively responses to environmental changes.

Due to this property age structure can be considered as ecological indicator of the commercial stock state. On the basis of direction and velocity of the age structure it is possible to forecast further changes of the stock and, consequently, early determination and realization of measures of its management. So, it is clear that knowledge of the age structure is very important, and development and improvement of methods of the specimens' age are paid special attention [3–5].

Study of the age characteristics of the commercially valuable and mass species (age structure analysis) enables to obtain reference data to develop principles of the long-term rational exploitation of the commercial stocks and monitoring of ecological state of habitats.

Study of the age structure of the most species is quite complicated, labor- and time-consuming (sometimes days). By this reason assessment of the age structure is sometimes retrospective, it is

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carried out behindhand, that's why it significantly losses informational value as ecological indicator [3–6].

We consider methodic of the age-length key drafting, which can be used for express-analysis of the catches' age composition and obtaining operational information on biological state of commercial stocks. The Black Sea sprat *Sprattus sprattus phalericus* (Risso), which is one of the main commercial objects of the Black Sea and plays important role in ecosystem, was taken as an example.

Model conception. N.I. Chugunova [3] described methodic of the age-length key drafting, based on calculation of the "weighed" age structure, and determination of the age classes' distribution by lineal dimensions. This methodic is based on analysis of dimensional distribution over previous period, presented as stage histogram. This methodic was used to draft age-length keys for different fish species, which were applied for analysis of the age distribution [3, 7]. However real dimensional distribution within the same age class is not stage, but continual, this fact was not taken into account in the known age-length keys.

Continual normal dimensional distribution of fish within each age class was accepted as conceptual basis for the proposed method. So, dimensional structure of each age group can be described by fair curve of normal density distribution [8]:

$$p(l) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(l-l_{\text{ave}})^2}{2\sigma^2}}, \tag{1}$$

where: $p(l)$ – probability of appearance of fish of the length l; l_{ave} – average fish length, cm; σ – standard deviation of dimensional distribution.

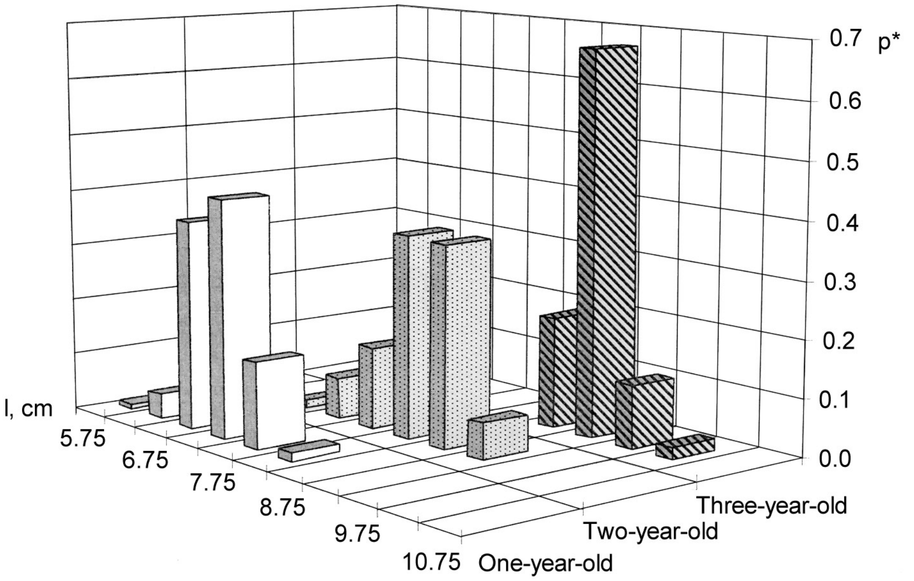
Material and Method

As material for the age-length key drafting and its reliability assessment were used specimens of the Blacks Sea sprat, taken in the cold months (from November to February 2001–2007) from the trawl catches of the south-west shelf of Crimea (from the Khersones cape to the town of Eupatorium). Catches were carried out by the different-depth trawl at the depth 50–80 m.

90–100 specimens were randomly taken, which reflected size and age structure of the catch. Material was processed either in fresh state or after freezing at –20°C. At biological analysis body length was measured to accuracy 0.1 cm, mass – to 0.01 g. Age was determined by otoliths [3]. Over considered period more than 50 thousand of the sprat specimens were processed. Data were statistically processed using Statistica, Excel and MathCAD software.

Methodic of the age-length key drafting. Results of processing of the winter catches of sprat over 2001–2002 were used as experimental reference data for the age-length key drafting.

At first frequency of fish of each dimensional class presence in each age group (one-, two- and three-year-old) was calculated by formula:



1. Histogram of the one- two- and three-year old sprats dimensional distribution in the winter catches 2001–2002.

$$p_{ik}^{*} = \frac{n_{ik}}{N_{k}}, \tag{2}$$

where: p_{ik}^{*} – frequency of presence of fish of the k^{th} age of the i^{th} dimensional group; n_{ik} – number of fish of the k^{th} age of the i^{th} dimensional group; N_k – number of fish of the k^{th} age class.

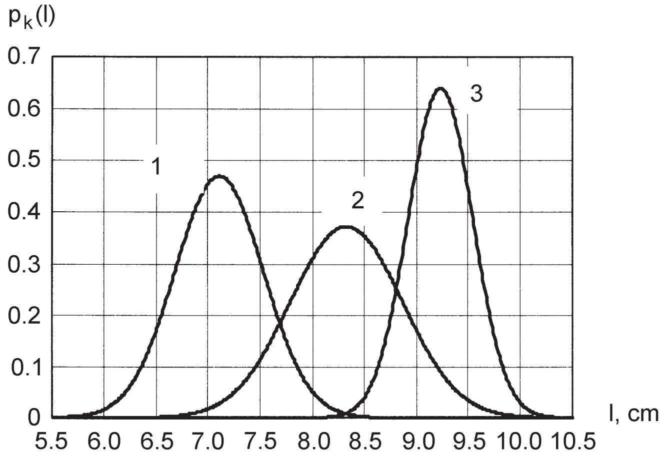
Stage histogram of the one-, two- and three-year old sprat appearance in the winter catches 2001–2002 is presented in the Figure 1.

Then on the basis of experimental data average fish length and standard deviation was calculated for each age class:

$$l_{\text{cpk}} = \sum_{i=1}^{n} l_i \, p_{ik}^{*}, \tag{3}$$

$$\sigma_k = \sqrt{\sum_{i=1}^{n} p_{ik}^{*} (l_i - l_{\text{avek}})^2}, \tag{4}$$

where: $l_{\text{ave}k}$ – average length of fish of the k^{th} age class, cm; n – number of dimensional groups; l_i – average size of the i^{th} dimensional group, cm; σ_k – standard deviation, calculated for the k^{th} age class.



2. Density of normal distribution of different age groups of the Black sea sprat: *1* – one-year-old; *2* – two-year-old; *3* – three-year-old.

Taking into account values obtained from formulae (3) and (4), formula (1) for calculation of the dimensional distribution density becomes the follows:

$$p_k(l) = \frac{1}{\sigma_\kappa \sqrt{2\pi}} e^{\frac{-(l-l_{cpk})^2}{2\sigma_k^2}}, \tag{5}$$

where: $p_\kappa(l)$ – dimensional distribution density of fish of the k^{th} age class.

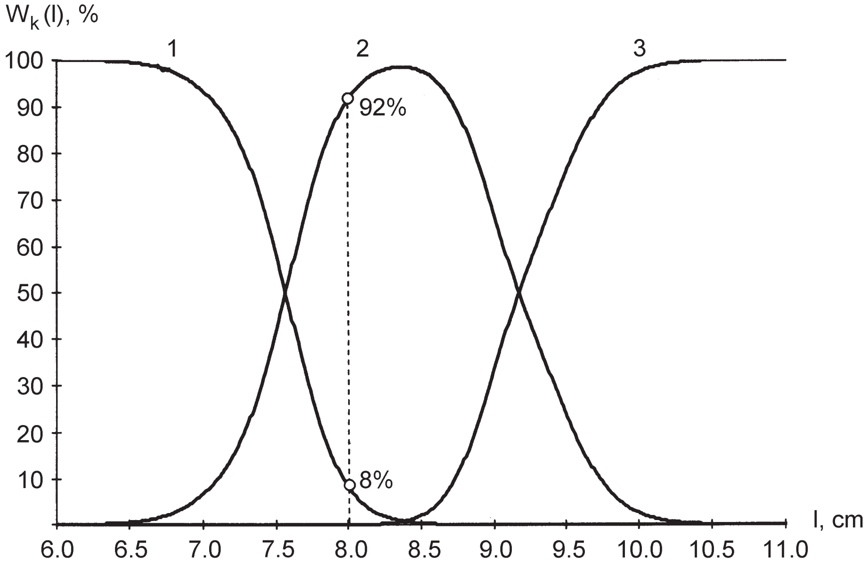
Figure 2 presents fair curves of normal dimensional distribution density for the one-, two and three-year-old specimens, plotted according to formula (5) and used for the age-length key drafting.

For the same-length specimens of each age group weight coefficients are calculated according to formula

$$a_k(l) = \frac{N_k}{\sum_{k=1}^{m} N_k p_k(l)}, \tag{6}$$

where: $a_k(l)$ – weight coefficient for the k^{th} age class, N_k – number of fish of the k^{th} age class, m – number of the age classes (for the Black sea sprat $m = 3$), $p_k(l)$ – value, calculated according to formula (5) for fish of the k^{th} age class of the length l.

Calculation of relative (expressed as a percentage) content of specimens of the k^{th} age class among specimens of the length l, was calculated according to formula



3. Age-length key for winter catches of the Black Sea sprat: *1* – yearlings; *2* – two-year-old; *3* – three-year-old.

$$W_k(l) = a_k(l)p_k(l) \cdot 100\%, \tag{7}$$

where $W_k(l)$ – relative content of specimens of the k^{th} age class among specimens of the length l.

Age-length key, drafted according to the mentioned method on the basis of the winter samples (2001–2002) processing, is presented in the Fig. 3.

Results and Discussion

Methodic of the age composition determination using age-length key is quite simple. Let us suppose that the taken sample contains 25 sprat specimens 8.0 cm long. Using Fig. 3 we determine that among fish 8.0 cm long 8% are one-year-old and 92% – two-year-old specimens; consequently, among these 25 fish there are 2 one-year-old specimens and 23 two-year-old specimens. Similarly, age distribution of each size group can be determined.

In order to compare age distribution calculated according to the age-length key and distribution determined by otoliths, the Pearson's criterion χ^2 was used [8]. This criterion enables to assess possibility to consider differences between experimental and designed data insignificant, within limits of random deviations.

Rate of agreement of the obtained results was calculated for winter season 2001–2002 (age-length key was also drafted by experimental data of this period) and for the next five winter seasons, including 2006–2007. For these seasons age distribution (one-, two- and three-year-old specimens) was determined by both drafted age-length key and by otoliths.

Calculation of the χ^2 criterion showed that for the considered period relative distribution of the age classes, determined using the drafted age-length key was in quite good agreement with distribution determined by otoliths. Probability of the results coincidence, calculated using χ^2 criterion, varied from 0.99 (winter periods 2001–2002 and 2002–2003) to 0.80 (for winter period 2004–2005). Average for six seasons probability of the results coincidence amounted to 0.94.

Conclusion

Drafted age-length key is simple to use, does not need long time to determine relative number of the age classes and can be used for the express-analysis of the Black sea sprat catches age structure; immediately on board of the commercial vessel as well.

Analysis of the experimental and designed data showed that with probability 0.94 differences are within the limits of random deviation.

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Algae Cenoses of Microphytobenthos in the Dnieper Reservoirs and in the Dnieper-Bug Estuarine Region[†]

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It has been found that in the Dnieper reservoirs, in the lower reaches of the Dnieper River, in the Southern Bug River, and in the Dnieper-Bug liman the formation of typical algae cenoses of microphytobenthos depends on the character of bottom sediments, and also on hydrodynamic factors. Characteristics of ecological and morphological structure of benthic algae cenoses, of the number of their species, and of the quantitative indices of their development under reference physical and chemical conditions are given in the paper.

KEYWORDS: *algae cenoses*, *microphytobenthos*, *physical and chemical conditions*, *the Dnieper reservoirs*, *the Dnieper-Bug estuarine region*.

Introduction

Various algae cenoses are formed in microphytobenthos of water bodies depending on ecological conditions [5, 8, 10]. The main ecological factors influencing the composition, structure, and quantitative indices of the development of benthic algae cenoses are as follows: the character of bottom sediments, hydrodynamic factors, trophic level, etc.

Algae cenoses of microphytobenthos are sensitive to changes in physical and chemical conditions of ecotopes subjected to the influence of both natural and anthropic factors. In this case, the structure of algae cenoses and the quantitative indices of their development can change. In some cases, specified algae cenoses gave way to other ones [6–8]. Thus, algae cenoses of microphytobenthos are rather reliable indicators of the deterioration of aquatic ecosystems under the influence of anthropic factors.

In the Water Framework Directive of the EC [2, 14], phytobenthos is among biological quality elements used for assessing the ecological state of water bodies. Based on this document, reference

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values of the indices typical to the composition and abundance of communities in the non-deteriorated or slightly anthropically changed ecosystems should be determined.

The main objective of the present work was to distinguish typical algae cenoses of microphytobenthos in the Dnieper reservoirs and in the Dnieper-Bug estuarine region, and also to study their composition, structure, and abundance depending on physical and chemical conditions of ecotopes.

Material and Methods

Material for the study included the samples of microphytobenthos taken in 1986–2005 in the Kanev and Kakhovka reservoirs, in the upper reaches of the Kremenchug Reservoir, in the lower reaches of the Dnieper and Gniloy Rog rivers, and in the Dnieper-Bug liman. Data on microphytobenthos of the Northern-Crimea and Ingulets canals, and also of the Ukrainian section of the Danube River delta, were used for comparison[1]. The samples of microphytobenthos were collected along the vertical profile of the bottom mainly from the depths of 0–6.0 m using the MB-TE micro-bottom sampler (40 cm^2) in three replicas. The samples were collected and processed following standard procedures [3]. The numbers of algae were determined using a special plate in the drop of 0.1 cm^3 volume. Diatoms were identified using constant preparations.

The following physical and chemical conditions of the studied water bodies were taken into account in characterizing microphytobenthos algae cenoses: types of bottom sediments, hydrodynamic factors, depth, bottom slope, trophic level, etc. [2, 14]. Cenological analysis was based on the ecological and floristic approach using the principles of the Braun-Blanquet method [4] adapted to microphytobenthos [8, 10]. Algae species found in microphytobenthos included both benthic and allochthonous organisms. The found algae species were representatives of ecological and morphological groups, including organisms similar in their ecological and morphological characteristics [9]. Ecological and morphological groups (EMG) of benthic organisms predominating in algae cenoses of microphytobenthos were: large diatoms (cells of more than 20 thousand μm^3 volume) – the B_{ld} EMG, eurytopic littoral diatoms – the B_{eld} EMG, small and middle diatoms – the B_{smd} EMG, blue-green filamentous algae – the B_{bf} EMG, and Chlorococcales – the B_{ch} EMG. Allochthonous organisms were represented by plankton (A_{pl}) and periphyton algae (A_{pr}).

The abundance of each species in the sample expressed in scale points was determined based on the data on algae numbers and biomass [8, 10]: + – numbers low, biomass of less than 10%; 1 – numbers high, biomass of less than 10%; 2 – numbers of no significance, biomass 10–25%; 3 – numbers of no significance, biomass 26–50%; 4 – numbers of no significance, biomass 51–75%; 5 – numbers of no significance, biomass of more than 75%. The contribution of each benthic organism to the total biomass of benthic organisms and the contribution of allochthonous organisms to the total biomass of microphytobenthos were taken into account. Algae species with the abundance of 3–5 scale points were assigned to dominants, whereas algae species with the abundance of 2 scale points were assigned to subdominants. The classes of species constancy were determined in terms of the frequency of their occurrence [8, 10]: I – less than 20%, II – 21–40%. III – 41–60%, IV – 61–80%, V – 81–100%. Diagnostic species reflecting the difference between ecological conditions in algae cenoses [4] were distinguished in terms of the frequency of their occurrence and abun-

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dance. The names of algae cenoses were given based on the main diagnostic species. To characterize the peculiarities of the ecological and morphological structure of algae cenoses, the multimetric index was used [16]. It represents the average arithmetic value of the contribution of the diagnostic ecological and morphological group (in %): 1) to the total number of species, 2) to the total numbers, and 3) to the total biomass of benthic organisms.

At present the classification of microphytobenthos algae cenoses similar in their composition and occurring under similar ecological conditions is urgent. In this case, the following preliminary scheme of microphytobenthos syntaxonomy can be used. The groups are formed by algae cenoses similar in the main diagnostic species (floristic feature) and specific conditions of their habitats (ecological feature). The groups can be subdivided into subgroups and variants differing in the second and third diagnostic species in the name of algae cenoses. The groups of algae cenoses form their types characterized by analogous ecological and morphological structure (physiognomic feature) and similar ecological conditions (ecological feature).

The groups and subgroups of algae cenoses can be considered as algae associations and algae subassociations, whereas their types – as the orders of algae cenoses [4].

Results and Discussion

A total of four groups of algae cenoses belonging to three types was distinguished in the Dnieper reservoirs and in the water bodies of the Dnieper-Bug estuarine region.

Group of algae cenoses *Cymatopleura elliptica*. Benthic algae cenoses of this group are typical to sands, slightly silted sands, and solid clayey silted bottom sediments (sometimes with the shells of mollusks) occurring in the Dnieper reservoirs, in the lower reaches and in the delta of the Dnieper River, in the lower reaches of the Southern-Bug River, and in canals.

The main diagnostic ecological and morphological group – large diatoms (B_{ld}) represented mainly by obligatory or facultative benthic organisms (Table 1). The main diagnostic species is *Cymatopleura elliptica* (Breb.) W. Sm. Diagnostic species are for the most part large diatoms with the cells of more than 20 thousand μm^3 volume. Thus, representatives of this ecological and morphological group are sensitive to hydrodynamic conditions. Intensive water motion and unstable bottom sediments adversely influence the development of large diatoms.

Under favorable hydrodynamic conditions, this group of algae cenoses was observed over the whole vertical profile of the bank. And vice versa under unfavorable hydrodynamic conditions, including significant fluctuations in water level, algae cenoses of this group occurred in the deep water section (2.0 m and more). In the shallow water zone they were absent.

The ecological and morphological group of small and middle diatoms (B_{smd}) included species of the genera *Navicula*, *Placoneis*, *Sellaphora*, *Aneumastus*, etc.

Algae cenosis *Cymatopleura elliptica* + *Surirella biseriata* occurs in the river sections of the Dnieper reservoirs. Diagnostic species include *Surirella biseriata* Breb., *S. tenera* Greg., *S. robusta* Ehr., etc. *Amphora ovalis* Kütz. represented mainly by large specimens is a constant species. A high frequency of occurrence is typical to species of the genus *Navicula*, including *N. reinhardtii* Grun. and *N. tripunctata* (O.F. Müll.) Bory, and also to *Diploneis smithii* (Breb.) Cl., *Gyrosigma*

Table 1

Diagnostic taxa (class of constancy and abundance) of the group of algae cenoses *Cymatopleura elliptica* in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Ecological and morphological groups	Algae	*C. e. + S. b.*			*C. e. + A. o.*		*C. e. + N. s.*		
		1	2	3	4	5	6	7	8
B_{ld}	*Cymatopleura elliptica*	II^{4}	II$^{2-3}$	IV^{+5}	IV^{+5}	III$^{2-5}$	V^{+3}	IV^{+3}	V^{+4}
	Nitzschia sigmoidea			IV^{+2}		III^{+}	V^{+3}	V^{+3}	V^{+2}
	Surirella biseriata	II$^{2-3}$	II^{+2}	II^{+3}			III^{+3}	II^{+}	
	S. tenera	I^{+}	II$^{3-4}$	I^{+}				I^{+}	II^{+2}
B_{ld}–B_{smd}	*Amphora ovalis*	III^{+4}	IV^{+3}	IV^{+}	V^{+5}	V^{+5}	V^{+}	V^{+}	V^{+}
B_{smd}	*A. libyca*					I^{+}	V^{+2}	V^{+3}	V^{+}
	Aneumastus tusculus		III^{+}		IV^{+2}		III^{+}	V^{+}	I^{+}
	Cymatopleura solea	II^{2}	IV^{+2}	IV^{+2}	II^{+}	IV^{+}	IV^{+2}	V^{+2}	V^{+}
	Diploneis smithii	III^{+}	V^{+2}		I^{+}				
	Gyrosigma acuminatum	II^{+2}	III^{+4}	III^{+3}	I^{+}	II^{+}	V^{+}	V^{+}	V^{+}
	Navicula reinhardtii	V^{3}	II^{+1}	II^{+3}	V^{+}	I^{+}	V^{+5}	V^{+}	V^{+2}
	N. tripunctata	IV^{+}	IV^{+}		V^{+}		V^{+2}	V^{+}	V^{+}
	Nitzschia vermicularis	II^{+}	II^{+3}	IV^{+4}		I^{+}	V^{+}		V^{+2}
	Surirella brebissonii var. *kuetzingii*	I^{+}		V^{+4}		III^{+}	V^{+2}	IV^{+}	V^{+2}
B_{eld}	*Melosira varians*	III$^{2-3}$	V^{+3}	II^{+2}	II^{+}	III^{+3}	V^{+2}	V^{+}	V^{+2}

Table 1 *(continued)*

Diagnostic taxa (class of constancy and abundance) of the group of algae cenoses *Cymatopleura elliptica* in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Ecological and morphological groups	Algae	*C. e.* + *S. b.*			*C. e.* + *A. o.*		*C. e.* + *N. s.*		
		1	2	3	4	5	6	7	8
B_{bf}	*Pseudostaurosira brevistriata*	I^{+}	II^{+}	I^{+}	II^{+}	I^{+}	V^{+}	IV^{+}	V^{+}
	Staurosira construens	IV^{+1}	V^{+1}	IV^{+2}	V^{+}	I^{+}	V^{+}	V^{+2}	V^{+}
	Oscillatoria amphibia		I^{+}	I^{+}			V^{+1}	IV^{+1}	
	O. geminata			IV^{+1}		III^{+1}	II^{+1}		
	O. limosa	I^{+1}		II^{+2}		III^{+3}	II^{+2}	I^{+}	I^{+}
	O. tenuis	I^{+1}	I^{+}	II^{+2}	I^{+}	IV^{+}	III^{+}	I^{+}	
	O. ucrainica	II^{+3}	III^{+1}		II^{+}		V^{+1}	IV^{+1}	II^{+}
	Oscillatoria Vauch	I^{+1}(3)	I^{+1}(4)	II^{+2}(9)	II^{+}(2)	II^{+3}(5)	II^{+1}(10)	II^{+1}(11)	I^{+}(5)

Note. Algae cenosis *C. e.* + *S. b.* (*Cymatopleura elliptica* + *Surirella biseriata*) – Kanev Reservoir, river section (depths 2.0–6.0 m): 1 – main riverbed near the town of Vyshgorod; 2 – old riverbed of the Desenka River; 3 – Northern-Crimea canal (0–1.0 m). Algae cenosis *C. e.* + *A. o.* (*Cymatopleura elliptica* + *Amphora ovalis*) – 4 – Kanev Reservoir, lake section, Buchak village (0–6.0 m); 5 – Kakhovka Reservoir, middle part, near the town of Nikopol, Pokrovskoye village (0–6.0 m). Algae cenosis *C. e.* + *N. s.* (*Cymatopleura elliptica* + *Nitzschia sigmoidea*) – 6 – lower reaches of the Dnieper River, near the town of Kherson (0–2.5 m); 7 – delta of the Dnieper River, Bakay branch (0–2.5 m); 8 – lower reaches of the Southern Bug River, near the Aleksandrovskaya dam, near the Rakovo village (0–5.0 m). Here and in Table 3, for the genus *Oscillatoria* Vauch. The figure in parentheses is a number of species.

acuminatum (Kütz.) Rabenh., *Cymatopleura solea* (Breb.) W. Sm., and *Nitzschia vermicularis* (Kütz.) Hant.

In the river section of the Kanev Reservoir, this algae cenosis occurred at a low (the Desenka River) and at an intermediate speed of water flow (near the town of Vyshgorod). It occurred mainly in the deep water zone (2.0–6.0 m), which was conditioned by an adverse effect of significant fluctuations in water level determined by the operation conditions of the Kiev Hydro-Electric Power Station. In the shallow water zone, this algae cenosis gave way to the communities of littoral diatoms (see below). Representatives of the B_{eld} ecological and morphological group, in particular *Staurosira construens* Ehr. and *Melosira varians* Ag., occurring in the shallow water zone in abundance were also registered in the deep water zone in the algae cenosis *C. elliptica* + *S. biseriata.*

A high speed of water flow inhibited the development of this algae cenosis (for example, in the main riverbed of the river sections of the Dnieper reservoirs, including the Kanev [6–8], Kremenchug, and Kakhovka reservoirs).

This algae cenosis was found in the Northern-Crimea canal, where it was registered in the upper section of the bank. The genus *Surirella* was represented by a large number of species, including *S. biseriata*, *S. tenera*, *S. robusta*, *S. gracilis* Grun., *S. brebissonii var. kuetzingii* Kram. et L.–B., etc. *Nitzschia sigmoidea* (Nitz.) W. Sm. was also found. In the Northern-Crimea canal, as well as in the other water bodies of the lower reaches of the Dnieper River, the number of species of blue-green algae (the B_{bf} ecological and morphological group) represented mainly by species of the genus *Oscillatoria*, including *O. amphibia* Ag., *O. tenuis* Ag., *O. geminata* (Menegh.) Gom., *O. limosa* Ag., etc., was higher than that in the upper reservoirs of the Dnieper cascade. This was conditioned by a higher temperature of water, and also by a higher trophic level. In this algae cenosis under reference conditions, the contribution of large diatoms to the total biomass of benthic organisms on the average accounted for 50–60%, to the total number of their species – 20–30%, and to their total numbers – 5–10%. The maximal values of these indices were 80–90%, 30–40%, and 20–30%, respectively. The multimetric index in terms of the average values of the quantitative indices of benthos development accounted for 25–30%, whereas in terms of its maximal values it was 40–50%.

A decrease in the contribution of the B_{ld} group in the algae cenosis can be indicative of the influence of unfavorable factors, including anthropic ones.

The B_{bf} group is also of considerable bioindicative importance. It has been known that anthropic contamination of water bodies by organic matter and nutrients results in the increase in the numbers and biomass of blue-green filamentous algae. In the Kanev Reservoir in this algae cenosis, the contribution of the B_{bf} group was not high: on the average 1–3% of the total biomass of benthic organisms, 4–5% of the total number of their species, and 15–20% of their total numbers. The multimetric index was about 5–10%.

Under reference conditions, the quantitative characteristics of the algae cenosis should correspond to the class "high ecological state" of the water body [2, 14, 16]. Within the class, the range of fluctuations of the values is 20% [13].

In the river section of the Kanev Reservoir, the number of species of benthic organisms and their numbers and biomass, as well as such characteristics of microphytobenthos on the whole, were rather low. This algae cenosis occurred at the depths of 2.0–6.0 m, whereas trophic level of the water body was not high. In the additional net characterized by a lower speed of water flow, these indices were somewhat higher (Table 2).

In the main riverbed at a high speed of water flow determined by the operation conditions of the Kiev Hydro-Electric Power Station, the structure of the algae cenosis was deteriorated, which resulted in the decrease in the number of benthic species. In the places contaminated by organic matter and nutrients, the quantitative indices of microphytobenthos development increased. Changes in the structure of algae cenoses resulted in the increase in the contribution of the B_{bf} group [6–8].

Algae cenosis *Cymatopleura elliptica + Amphora ovalis* is registered in the middle and lower parts of the Dnieper reservoirs characterized by the absence of significant fluctuations in water level. This algae cenosis is observed from the water edge to the bottom over the whole vertical profile of the bank.

In the lake section of the Kanev Reservoir, this algae cenosis occurred on sands and slightly silted sands. Constant species included *Navicula reinhardtii*, *N. tripunctata*, and *Aneumastus tusculus* (Ehr.) Mann. *Oscillatoria ucrainica* Vladim. was also characterized by a high frequency of occurrence.

In the Kakhovka Reservoir, this algae cenosis occurred mainly on sands and clayey silted bottom sediments with the shells of *Dreissena*. *Nitzschia sigmoidea*, and also representatives of the B_{bf} group, including species of the genus *Oscillatoria* (*O. geminata*, *O. limosa*, and *O. tenuis*) and *Surirella brebissonii var. kuetzingii*, were also of considerable importance. *Cymatopleura solea* was a constant species. *Melosira varians* occurred in abundance.

The contribution of the B_{ld} group to the total biomass of benthic organisms on the average accounted for 40–60%, to the total number of species – 15–20%, and to the total numbers – 5–10%. In this case, the maximal values were as follows: 80–90%, 20–25%, and 10–30%, respectively. The average values of the multimetric index were 20–30%, whereas its maximal values accounted for 40–50%.

In the southern reservoirs, the contribution of blue-green algae was higher than that in the northern reservoirs [1, 11]. In the Kanev Reservoir, their contribution to the biomass of benthic organisms on the average accounted for 1–3%, to the total number of species – 4–5%, and to their numbers – 15–20%. The multimetric index was 5–10%. In the Kakhovka Reservoir, their contribution to the biomass of benthic organisms on the average accounted for 3–4%, to the total number of species – 5–10%, to their numbers – 25–30%. The multimetric index was 10–15%.

Under reference conditions in this algae cenosis, the number of algae species was closely similar to that in the previous algae cenosis, whereas their abundance was essentially higher than that in the river section of the Kanev Reservoir (Table 2).

In the Kakhovka Reservoir characterized by a higher trophic level under reference conditions, the initial number of algae species and their numbers and biomass were essentially higher than those in the Kanev Reservoir.

Algae cenosis *Cymatopleura elliptica* + *Nitzschia sigmoidea*. This algae cenosis is typical to the riverbed water bodies of the Dnieper-Bug estuarine region. It occurs on sands and slightly silted

Table 2

Approximate values of the quantitative indices of the group of algae cenoses *Cymatopleura elliptica* under reference conditions in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Algae cenoses	Water bodies	Depth, m	Species number		Numbers, thousand cells/10 cm^2		Biomass, mg/10 cm^2	
			average	maximal	average	maximal	average	maximal
Cymatopleura elliptica + *Surirella biseriata*	**Kanev Reservoir**							
	river section							
	main riverbed	2.0–6.0	$\frac{15}{20}$	$\frac{25}{35}$	$\frac{20}{30}$	$\frac{40}{50}$	$\frac{0.08}{0.10}$	$\frac{0.12}{0.15}$
	additional net	2.0–6.0	$\frac{20}{25}$	$\frac{35}{40}$	$\frac{60}{50}$	$\frac{60}{70}$	$\frac{0.15}{0.17}$	$\frac{0.30}{0.40}$
Cymatopleura elliptica + *Amphora ovalis*	**Kanev Reservoir**							
	lake section	0–3.0	$\frac{15}{20}$	$\frac{25}{30}$	$\frac{60}{100}$	$\frac{100}{150}$	$\frac{0.11}{0.12}$	$\frac{0.17}{0.18}$
	Kakhovka Reservoir							
	middle part	0–6.0	$\frac{20}{30}$	$\frac{40}{50}$	$\frac{70}{100}$	$\frac{150}{300}$	$\frac{0.17}{0.20}$	$\frac{0.30}{0.40}$
Cymatopleura elliptica + *Nitzschia sigmoidea*	**Lower reaches of the Dnieper River**							
	near dam section	0–2.5	$\frac{30}{40}$	$\frac{40}{50}$	$\frac{500}{600}$	$\frac{2000}{2500}$	$\frac{0.70}{0.75}$	$\frac{1.20}{1.30}$
	branches of the delta	0–2.5	$\frac{30}{40}$	$\frac{40}{50}$	$\frac{500}{550}$	$\frac{1500}{1700}$	$\frac{0.40}{0.45}$	$\frac{1.00}{1.10}$
	Lower reaches of the Southern Bug River	0–5.0	$\frac{30}{40}$	$\frac{40}{50}$	$\frac{500}{550}$	$\frac{2000}{2300}$	$\frac{0.30}{0.35}$	$\frac{1.00}{1.00}$

Note. Here and in Tables 4 and 6: benthic organisms – above bar, benthic and allochthonous organisms on the whole – below bar; number of species in one sample taken from 40 cm^2 [4].

sands. Under reference conditions, this algae cenosis occupies the whole vertical profile of the bank. It is characterized by a predominance of large diatoms. A decrease in their abundance is indicative of an adverse effect of anthropic factors.

In the lower reaches of the Dnieper River (near the town of Kherson), large diatoms were represented by *C. elliptica* and *N. sigmoidea*, and also by species of the genus *Surirella* (*S. biseriata* and *S. robusta*). The species characterized by a high frequency of occurrence and abundance were *Amphora libyca* Ehr., *A. ovalis*, *Cymatopleura solea*, *Surirella brebissonii var. kuetzingii*, species of the genus *Navicula* (*N. reinhardtii*, *N. tripunctata,* etc.), *Oscillatoria amphibia*, *O. tenuis*, and *O. ucrainica.* The presence of vast shallow water zones, and also the influence of anthropic factors are favorable to the development of eurytopic littoral diatoms: *Staurosira construens*, *Melosira varians*, and *Pseudostaurosira brevistiata* (Grun.) Will. et Round.

The algae cenosis occurring in the delta of the Dnieper River in the Bakay branch was characterized by the presence of a large number of species of the genus *Surirella* (*S. biseriata*, *S. tenera*, *S. brebissonii var. kuetzingii*, *S. turgida* W. Sm., *S. robusta*, and *S. minuta* Breb.). The same phenomenon was observed in the Northern-Crimea canal. The constant species of the algae cenosis were *Amphora ovalis* and *A. libyca* occurring in abundance, and also *Gyrosigma acuminatum* and *Cymatopleura solea.* Species of the genus *Navicula* (*N. reinhardtii*, *N. tripunctata*, etc.) were widely distributed. Intensive development was typical to representatives of the B_{bf} group, including *Oscillatoria ucrainica* and *O. amphibia.* Eurytopic littoral diatoms were observed at the depths of 0–1.0 m.

In the lower reaches of the Southern Bug River (downstream of the Aleksandrovskaya dam and near the Rakovo village), the genus *Surirella* was also represented by a large number of species (*S. tenera*, *S. turgida*, *S. brebissonii var. kuetzingii*, *S. minuta, S. ovalis* Breb., *S. angustata* Kütz., *S. robusta*, and *S. splendida* (Ehr.) Kütz.). The constant species were *Navicula reinhardtii*, *Nitzschia vermicularis*; *Amphora ovalis*, *A. libyca*, *Gyrosigma acuminatum*, and *Navicula tripunctata.* The B_{ch} group was represented by *Pediastrum simplex* Meyen belonging to facultative benthic organisms. Eurytopic littoral diatoms were characterized by a high frequency of occurrence. However, they were not abundant.

Ecological and morphological structure was characterized by a predominance of large diatoms. Under reference conditions, the contribution of the B_{ld} group to the biomass of benthic organisms on the average accounted for 30–50%, to the total number of their species – 10–15%, and to their total numbers – 3–5%. In this case, the maximal values of these indices were 70–90%, 20%, and 10%, respectively. The multimetric index on the average accounted for 20–25%.

The contribution of blue-green filamentous algae to the structure of microphytobenthos was closely similar to that in the Kakhovka Reservoir in the algae cenosis *Cymatopleura elliptica* + *Amphora ovalis* under reference conditions. The contribution of the Bbf group to the biomass of benthic organisms on the average accounted for 3–4%, to the total number of their species – 5–10%, and to their total numbers – 20–40%. The multimetric index accounted for 10–15%.

Under reference conditions in this algae cenosis, the number of algae species and their numbers and biomass were higher than those in the algae cenoses of this group occurring in reservoirs (Table 2), which was conditioned by a high trophic level of the lower reaches of the Dnieper and Southern Bug rivers.

Group of alage cenoses *Campylodiscus hibernicus* was observed in the lake sections of reservoirs on stable sands and clayey silted bottom sediments with the shells of mollusks.

Algae cenosis *Campylodiscus hibernicus* + *Oscillatoria ucrainica* occurred in the near dam section of the lake part of the Kanev Reservoir in the deep water zone (2.0–4.5 m). In the shallow water zone, the motion of the water adversely affected its development. As a consequence, this algae cenosis gave way to the algae cenosis of eurytopic littoral diatoms.

Campylodiscus hibernicus Ehr. with very large cells was a differential species. The main diagnostic species included *Ellerbeckia arenaria* (Moore ex Ralfs) Crawf. [12] and *Oscillatoria ucrainica* [1]. *Cymatopleura elliptica* and *Surirella biseriata* were of considerable importance in the algae cenosis. Constant species were *Gyrosigma acuminatum*, *Amphora ovalis*, *Navicula reinhardtii*, *N. tripunctata*, *Nitzschia vermicularis*, and *Aneumastus tusculus.* Eurytopic littoral diatoms occurring in the shallow water zone in abundance were characterized by a high frequency of occurrence.

The contribution of the B_{ld} group to the total biomass of benthic organisms was 60 (sometimes 90)%, to the total number of their species – 35 (50)%, and to their numbers – 5 (10)%. The multimetric index accounted for 35 (50)%. The B_{bf} group was represented only by *Oscillatoria ucrainica.*

The quantitative indices of algae cenosis development were not high. The number of species varied from 15 species of benthic organisms (20 species on the whole) to 25 (30) species. The numbers of benthic organisms on the average were about 25 (40 on the whole) thousand cells/10 cm^2, whereas their maximal values accounted for 40 (60) thousand cells/10 cm^2. The average biomass of benthic organisms was about 0.10 mg/10 cm^2. However, sometimes it accounted for 0.25 mg/10 cm^2. In this case, the biomass of allochthonous organisms was not more than 0.01 mg/10 cm^2.

The groups of algae cenoses *Cymatopleura elliptica* и *Campylodiscus hibernicus* can be assigned to the same type of algae cenoses characterized by a leading role of large diatoms. Algae cenoses of this type occur on stable sands and slightly silted and clayey silted bottom sediments sometimes with the shells of mollusks occurring in different water bodies under favorable hydrodynamic conditions.

Group of algae cenoses *Staurosira construens.* The main diagnostic species – eurytopic littoral diatoms – are facultative benthic organisms. At first they occur in periphyton on various solid substrata and after that they occur in benthos and plankton. Many of them are capable of forming aggregations of various types. They can occur at a high speed of water flow and significant fluctuations in water level.

Algae cenoses of this group occurred mainly in the littoral zone of water bodies. In the shallow water zone, they were registered in abundance. In various water bodies, they were widely distributed on sands, and also on silted and clayey silted bottom sediments. In the deep water zone, they were also observed. On silted sands, they can occupy the whole vertical profile of the bank.

Algae cenosis *Staurosira construens* + *Melosira varians.* This algae cenosis is typical to the littoral zone of the Dnieper reservoirs. The main diagnostic species are representatives of the B_{eld} group, including *Staurosira construens* and *Melosira varians.*

In the Kanev Reservoir, this algae cenosis occurred in the shallow water zone of the river section subjected to the influence of intradaily fluctuations in water level and in the lake section of the reservoir. On silted sands, this algae cenosis occurred over the whole vertical profile of the bank. Constant species included *Amphora ovalis*, species of the genus *Navicula*, *Aneumastus tusculus*, *Gyrosigma acuminatum*, *Synedra ulna* (Nitz.) Ehr., and *Cymatopleura solea* (Table 3).

This algae cenosis was observed in the littoral zone of the upper reaches of the Kremenchug Reservoir. In the river section of the Kakhovka Reservoir, the algae cenosis was characterized by a high constancy of *Pseudostaurosira brevistriata.* Constant species included *Amphora ovalis* occurring in abundance, *Synedra ulna*, *Gyrosigma acuminatum*, *Navicula cryptocephala* Kütz., and also representatives of the B_{bf} group, including *Oscillatoria tenuis.*

The ecological and morphological structure of the algae cenosis was characterized by a predominance of the B_{eld} group. In the Kanev Reservoir, the contribution of this group to the number of benthic species was 25–30 (sometimes 60)%, to their numbers – 60–80 (95–100)%, and to their biomass – 40–50 (90–100)%. The multimetric index on the average accounted for 40–50%, whereas its maximal values were 75–85%.

In the upper reaches of the Kremenchug Reservoir and in the river section of the Kakhovka Reservoir, the contribution of the B_{eld} group to the number of benthic species was 25 (45)%, to their numbers – 30–50 (80)%, and to their biomass – 30–40 (80)%. The multimetric index on the average accounted for 30–35%, whereas its maximal values were 50–60%.

In the Kanev Reservoir, the role of blue-green filamentous algae in the structure of the algae cenosis differed from that in the Kakhovka Reservoir. In the Kakhovka Reservoir, their role was higher, which was conditioned by a higher trophic level. In the river sections of the Kanev and Kremenchug reservoirs under reference conditions, the contribution of the B_{bf} group in this algae cenosis to the total number of species on the average accounted for 2–4%, to their numbers – 8–12%, and to the biomass of benthic organisms – 1–2%. The multimetric index was 4–6%. In the lake sections, these values were essentially lower. The multimetric index was about 1%. In the Kakhovka Reservoir under reference conditions, the contribution of the B_{bf} group to the number of species of benthic organisms on the average accounted for 6–10%, to their numbers – 15–20%, and to their biomass – 2–3%. The multimetric index was 8–10%.

In the Kanev Reservoir, this algae cenosis was represented by a small number of species, whereas the quantitative indices of their development were rather low. In the additional net of the river section, the numbers and biomass of benthic organisms were higher than those in the main riverbed (Table 4). The lowest quantitative indices of microphytobenthos development were observed in the shallow water zone of the lake section of the reservoir.

In the river section of the Kakhovka Reservoir, the number of algae species was closely similar to that in the Kanev Reservoir, whereas the quantitative indices of their development were somewhat higher because of a higher trophic level.

Algae cenosis *Staurosira construens + Amphora libyca + Pseudostaurosira brevistriata*. This algae cenosis occurs in the littoral zone of the Dnieper-Bug liman. *S. construens, P. brevistriata*, and *Amphora libyca* occurring in abundance, and *A. ovalis* are of considerable importance (Table 3). Species of the genus *Amphora* are facultative benthic organisms occurring in the littoral zone of

Table 3

Diagnostic taxa (class of constancy and abundance) of the group of algae cenoses *Staurosira construens* in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Ecological and morphological groups	Algae	*S. c. + M. v.*					*S. c. + A. l. + P. b.*			
		1	2	3	4	5	6	7	8	9
B$_{eld}$	*Melosira varians*	IV^{+5}	V^{+5}	V^{+5}	V^{+4}	V^{+3}	IV^{+2}	I^{+}	II^{+}	
	Pseudostaurosira brevistriata	II^{+}	I^{+}	I^{+}	I^{+}	IV^{+}	I^{+}	V^{+4}	IV^{+5}	IV^{+5}
	Staurosira construens	V$^{3-5}$	V^{+3}	V^{+3}	V^{+2}	V^{+1}	V^{+5}	V^{+3}	V^{+2}	V^{+2}
	Synedra ulna	I^{+}	III^{+}	IV^{+1}	IV^{+}	IV^{+}	II^{+}	IV^{+2}	IV^{+}	III^{+}
B$_{smd}$	*Amphora libyca*					I^{+}	V^{+2}	V^{+3}	V^{+4}	V^{+3}
	A. ovalis	IV^{+4}	IV^{+3}	IV^{+3}	V^{+}	IV^{+4}	IV^{+}	V^{+2}	V^{+}	V^{+2}
	Aneumastus tusculus	II^{+}	I^{+}	IV^{+2}	III^{+}		II^{+}		I^{+}	
	Cymatopleura solea	II^{+3}	IV^{+4}	I^{+2}		II^{+}	V^{+}	III^{+}		II^{+}
	Gyrosigma acuminatum	I^{2}	I^{+}	III^{+}	II^{+}	III^{+2}	III^{+}	I^{+}	I^{+}	
	Navicula capitata	IV^{1}	IV^{+2}				IV^{+}	IV^{+}	III^{+}	IV^{+}
	N. cryptocephala	III^{2}	III^{+}	III^{+}	III^{+}	IV^{+}	III^{+}	IV^{+2}	V^{+4}	IV^{+2}

Table 3 *(continued)*

Diagnostic taxa (class of constancy and abundance) of the group of algae cenoses *Staurosira construens* in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Ecological and morphological groups	Algae	*S. c.* + *M. v.*					*S. c.* + *A. l.* + *P. b.*			
		1	2	3	4	5	6	7	8	9
	N. reinhardtii	III^{3}	IV^{+2}	II^{+}	V^{+}		V^{+2}	IV^{+2}		III^{+}
	N. tripunctata	IV^{1}	IV^{+2}	III^{+1}	III^{+}		II^{+}	II^{+}	I^{+}	II^{+}
	Surirella brebissonii var. *kuetzingii*	I^{+}	II^{+}			II^{+}	IV^{+}	II^{+}	IV^{+2}	III^{+5}
B$_{bf}$	*Oscillatoria amphibia*						I^{+}	I^{+}		II^{+1}
	O. tenuis	I^{+1}	I^{1}	I^{+1}		IV^{+1}				II^{+1}
	Oscillatoria Vauch.	I^{+1}(3)	I^{1}(2)	I^{+1}(4)	I^{+}(1)	II^{+1}(4)	I^{+}(3)	I^{+}(1)		I^{+1}(4)
B$_{Ch}$	*Desmodesmus communis*						V^{+1}	V^{+2}	V^{+}	IV^{+}

Note. Algae cenosis *S. c.* + *M. v.* (*Staurosira construens* + *Melosira varians*) – Kanev Reservoir, river section: main riverbed – 1 – near the town of Vyshgorod (depths 0–1.5 m), 2 – near the Moscow bridge, Navodnitskiy park (0–6.0 m), 3 – old riverbed of the Desenka River (0–1.5 m); 4 – lake wide section (0–1.5 m); 5 – Kakhovka Reservoir, river section, near the town of Zaporozhye, Nizhnyaya Khortitsa village (0–1.5 m). Algae cenosis *S. c.* + *A. l.* + *P. b.* (*Staurosira construens* + *Amphora libyca* + *Pseudostaurosira brevistriata*) – Dnieper-Bug liman (0–2.0 m): 6 – near the Stanislav village; 7 – near the Geroyskoye village; 8 – near the Kutsurub village; 9 – near the Luparevo village.

Table 4

Approximate values of the quantitative indices of the group of algae cenoses *Staurosira construens* under reference conditions in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Algae cenoses	Water bodies	Depth, m	Species number		Numbers, thousand cells/10 cm^2		Biomass, mg/10 cm^2	
			average	maximal	average	maximal	average	maximal
Staurosira construens + Melosira varians	**Kanev Reservoir**							
	river section							
	main riverbed	0–1.5*	$\frac{15}{20}$	$\frac{25}{35}$	$\frac{30}{50}$	$\frac{100}{150}$	$\frac{0.05}{0.06}$	$\frac{0.10}{0.10}$
	additional net	0–1.5	$\frac{15}{25}$	$\frac{25}{35}$	$\frac{40}{60}$	$\frac{150}{170}$	$\frac{0.06}{0.07}$	$\frac{0.20}{0.20}$
	lake section, near dam section	0–1.5	$\frac{10}{20}$	$\frac{20}{25}$	$\frac{15}{25}$	$\frac{30}{40}$	$\frac{0.03}{0.04}$	$\frac{0.10}{0.12}$
	Kakhovka Reservoir							
	river section	0–1.5	$\frac{15}{25}$	$\frac{25}{35}$	$\frac{50}{60}$	$\frac{170}{200}$	$\frac{0.08}{0.10}$	$\frac{0.12}{0.15}$
Staurosira construens + Amphora libyca + Pseudostaur-osira brevistriata	**Dnieper-Bug liman**							
	eastern part	0–2.0	$\frac{20}{35}$	$\frac{30}{50}$	$\frac{1500}{2000}$	$\frac{4000}{5000}$	$\frac{1.00}{1.00}$	$\frac{3.00}{3.00}$
	central, western, and Bug parts	0–2.0	$\frac{20}{30}$	$\frac{30}{45}$	$\frac{1000}{2000}$	$\frac{2000}{4000}$	$\frac{0.60}{0.80}$	$\frac{1.50}{2.00}$

* In the bays on silted sand at the depths of 0–6.0 m.

various water bodies of the lake type [9, 12]. *A. ovalis* occurs mainly in benthos of the littoral and deep water zones, whereas *A. libyca* occurs mainly in the littoral zone, where it is registered in benthos, plankton, and periphyton.

In the eastern part of the Dnieper-Bug liman (near the Stanislav village), the community of microphytobenthos was characterized by a high constancy of *Melosira varians.* On the other hand, it was closely similar to that registered in the central (near the Geroyskoye village), western (near the Vasilyevka and Kutsurub villages), and Bug (near the Luparevo village) parts (Table 3).

Intensive development of Chlorococcales was observed in the littoral zone of the Dnieper-Bug liman characterized by a high trophic level. The most abundant species were *Desmodesmus communis* (Hegew.) Hegew., *D. abundans* (Kirchn.) Hegew., *D. magnus* (Meyen) Tsar., *D. opoliensis* (P. Richt) Hegew., *Pediastrum boryanum* (Turp.) Menegh., and *P. duplex* Meyen. The number of constant species was rather low. They included *Navicula cryptocephala*, *N. capitata* Ehr., *N. reinhardtii*, *Surirella brebissonii var. kuetzingii*, etc.

The contribution of the diagnostic ecological and morphological group of eurytopic littoral diatoms to the structure of algae cenosis varied over a wide range. The contribution of the B_{eld} group to the numbers of benthic organisms on the average accounted for 30–80 (90)%, to their biomass – 25–75 (100)%, and to the number of their species – 25–50 (75)%. The average values of the multimetric index were 25–50%, whereas its maximal values – 45–75%. The contribution of blue-green filamentous algae to the number of species of benthic organisms on the average accounted for 8–10%, to their numbers – 15–20%, and to their biomass – 2–4%. The multimetric index accounted for 8–12%.

In the Dnieper-Bug liman under reference conditions, the abundance of algae was very high (Table 4). The highest values were registered in its eastern part. In the central, western, and Bug parts, their numbers and biomass were lower, whereas the number of their species was higher mainly at the expense of the presence of allochthonous organisms.

Group of algae cenoses *Nitzschia* Hass. is observed on silted bottom sediments in water bodies of various types. The main diagnostic taxon is the genus *Nitzschia*.

Blue-green filamentous algae represented by species of the genus *Oscillatoria* are of considerable importance in the algae cenoses of this group. A high content of organic matter and nutrients in silted bottom sediments is favorable to their development.

Algae cenosis *Nitzschia* Hass. + *Oscillatoria* Vauch. is observed on silted sands, and also on silted bottom sediments.

This algae cenosis was found in the main riverbed of the river section of the Kanev Reservoir. The genus *Nitzschia* was represented by a large number of species characterized by high constancy and abundance (Table 5): *N. palea* (Kütz.) W. Sm., *N. vermicularis*, *N. gracilis* Hantz., and *N. acicularis* (Kütz.) W. Sm. In this case, *Nitzschia acicularis* occurring in plankton was abundant on silts [15] as a facultative benthic organism. The genus *Oscillatoria* included *O. tenuis*, *O. limosa*, *O. redekei* van Goor, *O. chalybea* (Mert.) Gom., *O. ucrainica,* etc. Species of the genus *Navicula*, and also *Cymatopleura solea*, *Staurosira construens*, and *Synedra ulna,* are constant components of the algae cenosis.

Table 5

Diagnostic taxa (class of constancy and abundance) of the group of algae cenoses *Nitzschia* Hass. in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Ecological and morphological groups	Algae	*N. + O.*						*N. s. + O. u.*	
		1	2	3	4	5	6	7	8
B_{smd}	*Nitzschia acicularis*	III^{+2}		I^{+}	I^{+}	III^{+}	I^{+}	I^{+}	
	N. amphibia		V^{+}		I^{+}	II^{+}			
	N. dissipata		IV^{+}	I^{+}	I^{+}				
	N. gracilis	II^{+1}			II^{+2}	II^{+}	IV^{+}		
	N. linearis	I^{+}		II^{+}					
	N. palea	IV^{+3}	II^{+}	IV^{+}	I^{+}		II^{+}		
	N. recta	I^{+}		IV^{+}	I^{+}		II^{+}		
	N. sigmoidea	I^{+}	IV^{+3}	IV^{+4}	III^{+3}	IV^{+3}	II^{2}	V^{+2}	V^{3}
	N. sublinearis	I^{+}		II^{+}	IV^{+2}				
	N. vermicularis	III^{+4}			II^{+2}	V^{+2}	II^{+}	V^{+}	I^{+}
	Nitzschia Hass.	III^{+4}(10)	III^{+3}(6)	II^{+4}(7)	III^{+3}(12)	III^{+3}(6)	III^{+2}(5)	V^{+2}(3)	IV^{+3}(2)
	Amphora libyca		V^{+2}			V^{+}	V^{+}	V^{+}	V^{+}
	A. ovalis	II^{+2}	V^{+}	I^{3}	I^{3}	IV^{+}	II^{+}	V^{+}	V^{+2}
	Gyrosigma acuminatum	I^{+}	I^{+}	IV^{+4}	III^{+2}	V^{+}		I^{+}	I^{+}
	Navicula cryptocephala	III^{+1}	V^{+}	V^{+2}	IV^{+3}	II^{+}	V^{+}		III^{+}

Table 5 *(continued)*

Diagnostic taxa (class of constancy and abundance) of the group of algae cenoses *Nitzschia* Hass. in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Ecological and morphological groups	Algae	*N. + O.*						*N. s. + O. u.*	
		1	2	3	4	5	6	7	8
	Surirella brebissonii var. *kuetzingii*	I^{+}	III^{+}	III^{+2}	II^{+}	IV^{+}	II^{+}	V^{+}	V^{+}
B_{bf}	*Oscillatoria amphibia*		IV^{+}	II^{+2}		III^{+1}	IV^{+3}		II^{+1}
	O. geminata			III^{+3}	II^{+1}				
	O. limosa	I^{+}	I^{1}	I^{1}					
	O. tenuis	I^{+1}	I^{1}	$II^{1\text{-}2}$	II^{+1}			V^{+3}	II^{+}
	O. ucrainica	II^{+1}	V^{+1}	II^{+1}	I^{+}	IV^{+1}	IV^{+1}	III^{+1}	V^{+1}
	Oscillatoria Vauch.	$II^{+1}(7)$	$III^{+1}(8)$	$II^{+3}(7)$	$II^{+2}(5)$	$II^{+1}(4)$	$IV^{+3}(2)$	$IV^{+3}(3)$	$II^{+1}(3)$
B_{eld}	*Melosira varians*	II^{+3}	V^{+}	IV^{+5}	IV^{+}	IV^{+2}	V^{+3}	V^{+2}	
	Pseudostaurosira brevistriata	I^{+}	IV^{+}			II^{+}		III^{+}	
	Staurosira construens	III^{+}	$V^{2\text{-}4}$		I^{+}	V^{+3}	V^{+2}	V^{+}	
	Synedra ulna	III^{+}	V^{+}	I^{+}	III^{+2}	III^{+}	V^{+}	V^{+}	IV^{+}

Note. Algae cenosis *N. + O.* (*Nitzschia* Hass. + *Oscillatoria* Vauch.) – 1 – Kanev Reservoir, river section, strait (depths 0–6.0 m); 2 – Dnieper River delta, Rvach branch (3.0 m); 3 – Ingulets canal (0–1.5 m); 4 – Danube River delta, small and middle branches (0–1.0 m); Dnieper liman: 5 – near the Stanislav village (6.0 m); 6 – near the Geroyskoye village (6.0 m). Algae cenosis *N. s. + O. u.* (*Nitzschia sigmoidea* + *Oscillatoria ucrainica*) – Dnieper-Bug liman: 7 – near the Vasilyevka village (6.0 m), 8 – downstream of the town of Nikolayev (6.0 m). For the genera *Nitzschia* and *Oscillatoria,* the figure in parentheses is a number of species. *Nitzschia sigmoidea* was represented mainly by middle specimens.

Algae cenosis of the similar composition was observed in the Danube River delta in its small and middle branches at the depths of 0–1.0 m on silted sands and silted bottom sediments. The genus *Nitzschia* was represented by *N. sublinearis* Hust., *N. gracilis, N. vermicularis,* and *N. sigmoidea.* The genus *Oscillatoria* (*O. geminata*, *O. tenuis*, and *O. limnetica* Lemm.), and also *Phormidium foveolarum* (Mont.) Gom., *Lyngbya aestuarii* (Mert.) Liebm., and other representatives of blue-green filamentous algae occurred in abundance. Constant species were *Navicula cryptocephala*, *Gyrosigma acuminatum*, *Synedra ulna*, and *Melosira varians.* This algae cenosis was observed in the deep water zone of the branches of the Dnieper-Bug delta and in the eastern and central parts of the Dnieper liman, the bottom sediments of which were represented by clayey silts. In the Rvach branch at the depth of 3.0 m, species of the genera *Nitzschia* and *Oscillatoria* were rather abundant. The most frequent species were *N. amphibia* Grun., *N. dissipata* (Kütz.) Grun., *N. palea*, and *N. sigmoidea* (occurring in abundance), *O. ucrainica*, *O. amphibia*; and *O. limosa* and *O. tenuis* (characterized by high numbers). Constant species were *Navicula cryptocephala*, *N. reinhardtii*, *N. tripunctata*, *N. capitata, Amphora ovalis*, *Synedra ulna*, *Melosira varians*, *Pseudostaurosira brevistriata*, *Amphora libyca,* and *Staurosira construens.* The presence of littoral diatoms was conditioned by their intensive vegetation in the shallow water zone.

In the eastern and central parts of the Dnieper liman at the depth of 6.0 m on clayey silted bottom sediments, the algae cenosis was characterized by a high number of species, and also by their high abundance. The genus *Nitzschia* was represented by a large number of species, including *N. acicularis*, *N. amphibia*, *N. gracilis*, *N. palea*, *N. recta* Hantz., *N. sigmoidea*, *N. vermicularis,* etc. The number of species of the genus *Oscillatoria* was lower than that in the delta. Only *O. ucrainica* and *O. amphibia* were constant and occurred in abundance. *Lyngbya aestuarii*, *Phormidium foveolarum*, and *Ph. molle* (Kütz.) Gom. were also characterized by a high frequency of occurrence and abundance. In the eastern part, constant species included *Cymatopleura solea*, *Gyrosigma acuminatum*, *Navicula capitata*, *N. reinhardtii*, *N. viridula* Kütz., and *Surirella brebissonii var. kuetzingii*, in the central part they were *Cymatopleura solea*, *Navicula cryptocephala*, and *N. reinhardtii*, whereas in both parts of the liman they included *Amphora libyca*, *A. ovalis*, and representatives of eurytopic littoral diatoms vegetating in the shallow water zone.

Benthic algae cenosis of the same composition was registered in the Ingulets canal on clayey silted bottom sediments at the depths of 0–1.5 m. Constant species included *Nitzschia palea*, *N. recta*, and *N. sigmoidea* occurring in abundance. The frequency of occurrence of *N. linearis* (Ag.) W. Sm. and *N. sublinearis* was also rather high. The genus *Oscillatoria* was represented by a large number of species, including *O. amphibia*, *O. geminata*, *O. tenuis*, *O. ucrainica,* etc. *Navicula cryptocephala*, *Gyrosigma acuminatum*, *Surirella brebissonii var. kuetzingii*, and *Melosira varians* were characterized by high frequency of occurrence and abundance.

The ecological and morphological group of blue-green filamentous algae was of considerable importance in the structure of the studied algae cenosis. On silted sands (in particular in the main riverbed of the river section of the Kanev Reservoir) under reference conditions, the contribution of the B_{bf} group to the number of species of benthic organisms on the average accounted for 10%, to their numbers – 20%, and to their biomass – 4%. The multimetric index was about 12%. In water bodies with such type of bottom sediments, the B_{bf} group is among bioindicators of anthropic contamination.

On clayey silted bottom sediments (in the delta of the Dnieper River and in the Dnieper liman) under reference conditions, the contribution of the B_{bf} group was rather high, which was condi-

Table 6

Approximate values of the quantitative indices of the group of algae cenoses *Nitzschia* Hass. under reference conditions in microphytobenthos of the Dnieper reservoirs and of the Dnieper-Bug estuarine region

Algae cenoses	Water bodies	Depth, m	Species number		Numbers, thousand cells/10 cm^2		Biomass, mg/10 cm^2	
			average	maximal	average	maximal	average	maximal
Nitzschia Hass. + *Oscillatoria* Vauch.	**Kanev Reservoir**							
	river section, strait	0–6.0	$\frac{15}{20}$	$\frac{25}{40}$	$\frac{505}{70}$	$\frac{450}{750}$	$\frac{0.05}{0.06}$	$\frac{0.12}{0.14}$
	Dnieper River delta, branches	3.0	$\frac{35}{50}$	$\frac{40}{60}$	$\frac{600}{1000}$	$\frac{800}{1200}$	$\frac{0.15}{0.17}$	$\frac{0.20}{0.21}$
	Dnieper-Bug liman							
	eastern part	6.0	$\frac{25}{40}$	$\frac{30}{50}$	$\frac{400}{700}$	$\frac{1200}{1800}$	$\frac{0.12}{0.20}$	$\frac{0.30}{0.40}$
	central part	6.0	$\frac{20}{30}$	$\frac{25}{40}$	$\frac{700}{1000}$	$\frac{1500}{2000}$	$\frac{0.12}{0.20}$	$\frac{0.15}{0.30}$
Nitzschia sigmoidea + *Oscillatoria ucrainica*	**Dnieper-Bug liman**							
	western part	6.0	$\frac{20}{30}$	$\frac{25}{35}$	$\frac{350}{700}$	$\frac{500}{1000}$	$\frac{0.10}{0.20}$	$\frac{0.15}{0.30}$
	Bug part	6.0	$\frac{15}{25}$	$\frac{20}{30}$	$\frac{300}{700}$	$\frac{500}{1000}$	$\frac{0.10}{0.20}$	$\frac{0.15}{0.30}$

tioned by a high content of organic matter and nutrients. In the Dnieper liman, the contribution of the B_{bf} group to the total numbers of benthic organisms on the average accounted for 50–70%, to the number of their species – 15–20%, and to their biomass – 20–30%. The multimetric index was 30–40%. In the Rvach branch in the Dnieper River delta, the contribution of blue-green filamentous algae to the numbers of benthic organisms on the average accounted for 50%, to the number of their species – 12%, and to their biomass – 12%. The multimetric index was about 25%. In small and middle branches of the Danube River delta, these values were even higher. The contribution of the B_{bf} group to the numbers of benthic organisms was about 70%, to the number of their species – 30%, and to their biomass – 35%. The multimetric index was 45%. Under such conditions, the B_{bf} group can not be used as bioindicator of anthropic contamination.

Under reference conditions in the main riverbed of the Kanev Reservoir, the quantitative indices of algae cenosis development were not high. Only at some stations, its maximal numbers were rather high (Table 6). In the estuarine region of the Dnieper River, the algae cenosis was characterized by high number of species and abundance. Its highest average biomass was observed in the branch of the delta at the depth of 3 m (the Rvach branch). In the Dnieper liman at the depth of 6 m under reference conditions, the average biomass of algae was lower. In this case, in the eastern part of the liman its maximal values were higher than those in its central part, which was conditioned by the development of allochthonous organisms, including species of the genus *Aulacoseira* (*A. granulata* (Ehr.) Sim. and *A. italica* (Ehr.) Sim.), incoming from plankton.

Algae cenosis *Nitzschia sigmoidea* + *Oscillatoria ucrainica* was observed on silted sands of the deep water zone (6 m) of the Dnieper-Bug liman. It was registered in the central section of the western part of the Dnieper liman (in front of the Vasilyevka village) and in the Bug liman (downstream of the town of Nikolayev). It was represented by a lower number of species as compared to the above mentioned algae cenosis, which was probably conditioned by a lower content of nutrients in silted sands.

Nitzschia sigmoidea was a constant species. *Nitzschia vermicularis*; *Oscillatoria ucrainica*, *O. tenuis*, and *O. amphibia* were rather frequent. In the Dnieper-Bug liman, constant species included *Amphora ovalis*, *A. libyca*, *Surirella brebissonii* var. *kuetzingii*, and *Synedra ulna*. However, they were not abundant. The contribution of the B_{bf} group to the numbers of benthic organisms was 75–86%, to the number of their species – 15–20%, and to their biomass – 20–30%. The multimetric index was 40–45%.

In this algae cenosis under reference conditions, the number of algae species and their abundance were somewhat lower than those in the algae cenosis occurring on clayey silts (Table 6). The contribution of plankton organisms was rather high.

Conclusion

The algae cenosis *Cymatopleura elliptica* + *Surirella biseriata* characterized by a predominance of the ecological and morphological group of large diatoms occurring on sands and slightly silted bottom sediments is typical to river sections of the infracascade reservoirs of the Dnieper River. The algae cenosis is observed in the deep water zone (2.0–6.0 m). The algae cenosis *Staurosira construens* + *Melosira varians*. characterized by a predominance of eurytopic littoral diatoms is registered in the shallow water zone subjected to intradaily fluctuations in water level determined by the operation conditions of hydro-electric power stations. This algae cenosis is observed on silted sands. It is distributed over the whole vertical profile of the bank. The algae cenosis *Nitzschia* Hass. + *Oscillatoria* Vauch. is registered at the depth of more than 1 m on silts.

The algae cenosis *Cymatopleura elliptica* + *Amphora ovalis* occurring over the whole vertical profile of the bank both in the littoral and in the deep water sections on sands and solid clayey silted bottom sediments sometimes with shells of mollusks is typical to the middle sections of the reservoirs characterized by the absence of significant fluctuations in water level.

The algae cenosis *Campylodiscus hibernicus* + *Ellerbeckia arenaria* + *Oscillatoria ucrainica* forming in the deep water zone on solid clayey silted bottom sediments (with the shells of *Dreissena*) is observed in the wide lake near dam section of the Kanev Reservoir. The algae cenosis *Staurosira construens* + *Melosira varians* is observed in the shallow water zone.

The algae cenosis *Cymatopleura elliptica* + *Nitzschia sigmoidea* occurring on sands over the whole vertical profile of the bank is observed in the near delta section of the Dnieper River, and also in the branches of the Dnieper River delta. The algae cenosis *Nitzschia* Hass. + *Oscillatoria* Vauch. occurs on clayey silted bottom sediments on the bottom of the branches.

The algae cenosis *Cymatopleura elliptica* + *Nitzschia sigmoidea* occurring on sands, is observed in the lower reaches of the Southern Bug River. It is distributed over the whole vertical profile of the bank. This algae cenosis is characterized by intensive development of Chlorococcales (species of the genus *Pediastrum*).

Eurytopic littoral diatoms are registered in the shallow water zone of the Dnieper-Bug liman. The algae cenosis *Staurosira construens* + *Amphora libyca* + *Pseudostaurosira brevistriata* characterized by a high contribution of Chlorococcales (mainly species of the genus *Desmodesmus*) is typical to this region. The algae cenosis *Nitzschia* Hass. + *Oscillatoria* Vauch. is registered at the depth of 6.0 m on clayey silted bottom sediments, whereas the algae cenosis *Nitzschia sigmoidea* + *Oscillatoria ucrainica* characterized by lower quantitative indices of its development is observed on silted sands.

Under reference conditions, the number of species in all algae cenoses, as well as their abundance, increased downstream with increasing the trophic level of water bodies of the Dnieper River basin. In the Kakhovka Reservoir, the number of algae species and their numbers and biomass were higher than those in the same algae cenoses of the Kanev Reservoir. Under reference conditions, the highest quantitative indices of algae development were observed in the algae cenoses of the Dnieper-Bug estuarine region.

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Accumulation of Heavy Metals by *Anodonta anatina* (L.) in the Place of Household Sewage Release in the River Ecosystem[†]

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Accumulation of Ni, Zn, and Cu by soft tissues of *Anodonta anatina* (L.) was studied in the place of sewage release into the Dnieper River (the municipal wastewater treatment plant of Kiev) and into the Desna River (the municipal wastewater treatment plant of Chernigov). It has been shown that the content of Ni and Zn in mollusks reflects dynamics of metal concentration in the water downstream of the place of sewage release. The content of organic matter in bottom sediments influences the process of Cu accumulation by mollusks. Higher concentrations of Zn, Ni, and Cu in mollusks are registered within the distance of more than 9 km away from the place of sewage release. Thus, mollusks are sensitive indicators of the influx of non-purified sewage into river ecosystems.

KEYWORDS: *sewage*, *heavy metals*, *Bivalvia*.

Introduction

Household sewage of large cities is among dangerous pollutants. It is characterized by specific and unstable chemical composition. Heavy metals enter household sewage by different ways [22]. Thus, monitoring of aquatic ecosystems contaminated by household sewage is difficult to perform.

Changes in the chemical composition of the water in the place of sewage release are difficult to control. In this case, the methods of biological indication based on the bioaccumulative properties of some hydrobionts can be used with success. Literature data [8, 12, 16, 17, 20, 21] suggest that mollusks are widely used in performing biomonitoring. The content of pollutants in mollusks reflects the content of their biologically available forms, which characterizes their ecological threat to aquatic ecosystems [19].

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Special investigations using model objects with the known characteristics should be performed to elaborate the unified methods of determining the content of pollutants in aquatic ecosystems.

The main objective of the present work was to compare the content of heavy metals in soft tissues of *Anodonta anatina* (L.) with their content in the water and bottom sediments of large river ecosystems in the place of household sewage release. This species of mollusks is widely distributed in continental water bodies of Europe. It is capable of accumulating large amounts of heavy metals [5, 18].

Two model sections of the rivers differing in their hydrological parameters and peculiarities of sewage influx were chosen in performing investigations: the Desna River in the place of household sewage release (the municipal wastewater treatment plant of Chernigov) and the Dnieper River in the place of household sewage release (the municipal wastewater treatment plant of Kiev) [9]. Their contribution to the total content of sewage incoming into the basin of the Dnieper River accounts for 8.5 and 0.54%, respectively. In 2000 the following substances were released into the Dnieper River with sewage waters of Kiev: oil products –8.62 tons, suspended matter – 7.0 thousand tons, organic matter – 4.7 thousand tons, Cu – 4.2 tons, Zn – 8.4 tons, and Ni – 8.4 tons. During the same period the following substances were released into the Desna River with sewage waters of Chernigov: oil products – 1.4 tons, suspended matter – 0.3 thousand tons, organic matter – 0.2 thousand tons, Cu – 0.5 tons, Zn – 0.38 tons, and Ni – 0.41 tons [9].

Material and Methods

Samples were taken from 11 until 29 August 2008. Within the territory of Kiev, they were collected from 7 experimental stations on the left bank of the river: control station located 1 km upstream of the place of sewage release, 0.1 km downstream of the place of sewage release, 1.6 km, 3.1 km, 7.1 km, and 16 km downstream of the place of sewage release. Within the territory of Chernigov, samples were collected from 6 experimental stations: control station located 3.1 km upstream of the estuary of the Belous River (place of sewage release), 0.4 km downstream of the place of sewage release, 1.2 km, 1.8 km, 4.5 km, 9.6 km, and 15 km downstream of the place of sewage release. At the studied stations, the samples of *Anodonta anatina* (5 specimens), water (1 L), and the upper 5 cm layer of bottom sediments (2 samples) were taken in two replicas.

The samples of mollusks were collected from the depths of 1–2 m 5–20 m away from the bank. The specimens with standard dimensions (83–88 mm long weighing 61–70 g and 92–98 mm long weighing 75–80 g) were taken from the Dnieper and Desna rivers. Soft tissues of mollusks were separated and dried at 95^{o}C. Mineralization of samples was carried out using standard methods [3]. The concentration of metals was expressed in mg/kg of dry mass of the tissue.

The samples of water were filtered through the cellulose-acetate filter. After that 1 ml of 56% HNO_3 was added to the filtrate. The concentration of metals was determined after preliminary evaporation. The concentration of metals was expressed in mg/L.

The samples of bottom sediments were packed into the plastic bags of 50 ml volume. Under laboratory conditions, they were dried at 95^{o}C to constant mass. Heavy metals were extracted using 1 M HNO_3 following standard procedure [6]. It has been shown that this method reflects contamination of bottom sediments by heavy metals [23]. The concentration of metals was expressed in mg/kg of dry mass of bottom sediments.

The content of organic matter in bottom sediments was determined by the method of Gustafson at 600^{o}C [6]. The content of organic matter was expressed in % of mass.

The concentration of heavy metals was determined using the S115-M1 atom- absorption spectrophotometer (flame acetylene – air) with the deuterium corrector of the background and the KAS-11 computer analytical complex. The distribution of Zn, Cu, and Ni was analyzed.

The Mann-Whitney *U*-test was used in determining statistically valid difference in the concentration of heavy metals in the water, bottom sediments, and mollusks. Relationship between the content of heavy metals in soft tissues of mollusks and the chemical composition of the environment was determined by the method of correlation analysis using the Prison coefficient of linear correlation. The Statistica 4.3. StatSoft Inc. Program was used in processing the obtained data [10].

Results

In the studied rivers, the average concentration of Zn in the water of control stations varied insignificantly. In the Dnieper River, it accounted for 0.005 ± 0.003 mg/L, whereas in the Desna River – 0.003 ± 0.002 mg/L (Fig. 1). The influx of sewage resulted in a sharp increase in the concentration of the metal in the water. At the station located 0.1–1.6 km downstream of the place of sewage release, it was 0.03–0.04 mg/L. At the station located 1.6–1.8 km downstream of the place of sewage release, the concentration of the metal sharply decreased.

At the control station, the average content of Ni in the water of the Desna River was 1.6 times higher than that in the Dnieper River and accounted for 0.009 ± 0.001 and 0.006 ± 0.001 mg/L, respectively. The influx of sewage into the Desna River resulted in a more significant increase in the content of the metal as compared to the Dnieper River. At the stations located 1–3 km downstream of the place of sewage release, dynamics of Ni content in the Desna River were closely similar to those in the Dnieper River. At the stations located 1.8–3.1 km downstream of the place of sewage release, the concentration of Ni increased. In the Desna River 7 km away from the place of sewage release, the concentration of the metal decreased to the background level. In the Dnieper River at the station located 15 km away from the place of sewage release, its concentration was 2.2 times lower than that registered in the control variation.

The concentration of Cu in the water of the Desna River was not higher than 0.01 mg/L. In the Dnieper River at the control station, the average concentration of Cu accounted for 0.013 ± 0.009 mg/L. Downstream of the place of sewage release it gradually increased. In this case, the concentration of Cu increased with increasing the distance from the place of sewage release. At the station located 9.6 km downstream of the place of sewage release it was 0.10 ± 0.02 mg/L. The same pattern of the increase in the content of Cu was registered in the Don River [1].

During the whole period of investigations, the average content of Zn in bottom sediments of the Dnieper River was 1.3–2.0 times lower than that in the Desna River (Fig. 2). The influx of sewage of Kiev resulted in the statistically valid increase in the concentration of Zn in bottom sediments of the Dnieper River only at the station located 1.2 km away from the place of sewage release, where it

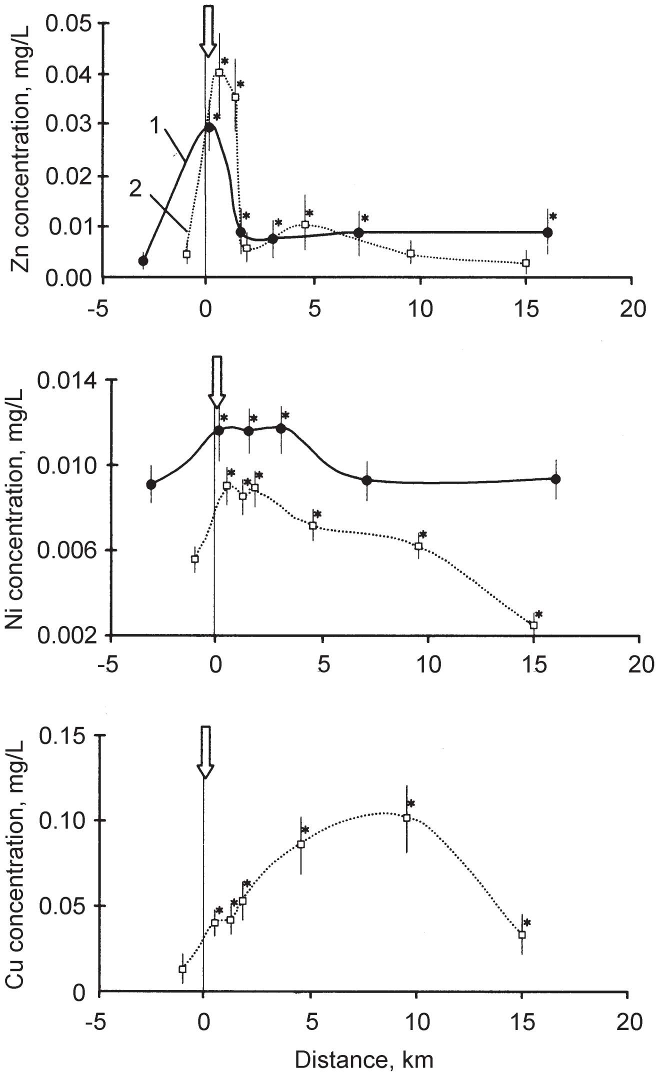

Fig. 1. Spatial dynamics of the content of Zn, Ni, and Cu in the water in the place of sewage release: 1 – Chernigov (the Desna River); 2 – Kiev (the Dnieper River). Here and in Figures 2 and 3: * statistically valid difference ($p < 0.05$); ⇓ – place of sewage release.

was 7.0 ± 2.1–12.4 ± 1.1 mg/kg. The concentration of Zn gradually decreased with distance from the place of sewage release. At the station located 9.6 km downstream of the place of sewage release it decreased to the background level. In the Desna River, the highest concentration of Zn (70.2 ± 4.6 mg/L) was observed at station located 100 m downstream of the place of sewage release within the territory of the town of Chernigov. However, 1.6 km away from the place of sewage release its content sharply decreased to the background level.

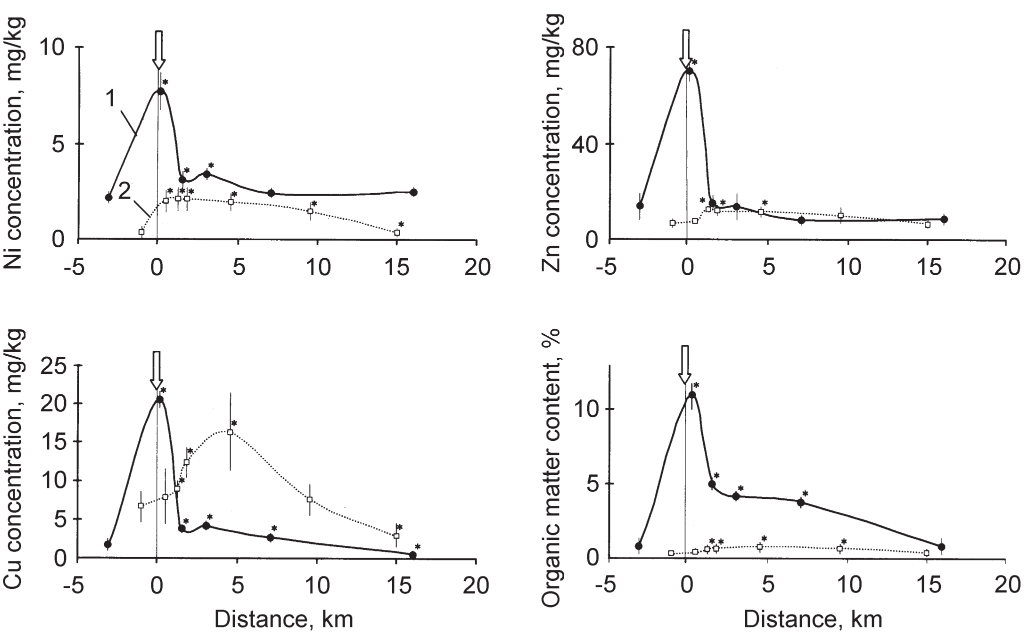

Fig. 2. Spatial dynamics of the content of Zn, Ni, Cu, and organic matter in bottom sediments of the Desna River (1) and of the Dnieper River (2) in the place of sewage release.

In the Dnieper River, the content of Ni in the surface layer of bottom sediments was 1.2–6.5 times lower than that in the Desna River. The influx of Ni with sewage into the Dnieper River resulted in the increase in its content in bottom sediments by a factor of 5.0–5.4. At the station located 16 km downstream of the place of sewage release, the content of the metal decreased to the control level. At the same time, in the Desna River in the place of sewage release the concentration of Ni was 3.6 times higher than that registered at the control station. At the station located 1.6 km downstream of the place of sewage release, the concentration of Ni was 1.5 times higher than that observed upstream of the place of sewage release.

In the Dnieper River, the average content of Cu in bottom sediments of the control station was 4 times higher than that in the Desna River and accounted for 6.6 and 1.6 mg/kg, respectively. In the place of sewage release, the concentration of Cu both in the water and in bottom sediments increased insignificantly. The maximal content of Cu was registered 4.5 km away from the place of sewage release, where it was 16 ± 5 mg/kg. It was 2.5 times higher than that observed at the control station. At the station located 9.6 km away from the place of sewage release, the concentration of Cu decreased to the control level. At the same time, in the Desna River a high content of Cu in bottom sediments was observed near the spill of sewage, where it increased from 1.6 to 20.4 mg/kg (by a factor of 12.4). At the station located 1.6 km away from the place of sewage release, it decreased to 3.7 ± 0.3 mg/kg. At the station located 16 km downstream of the place of sewage release, the content of the metal decreased to 0.6 ± 0.3 mg/kg, which was 2.6 times lower than that at the control station.

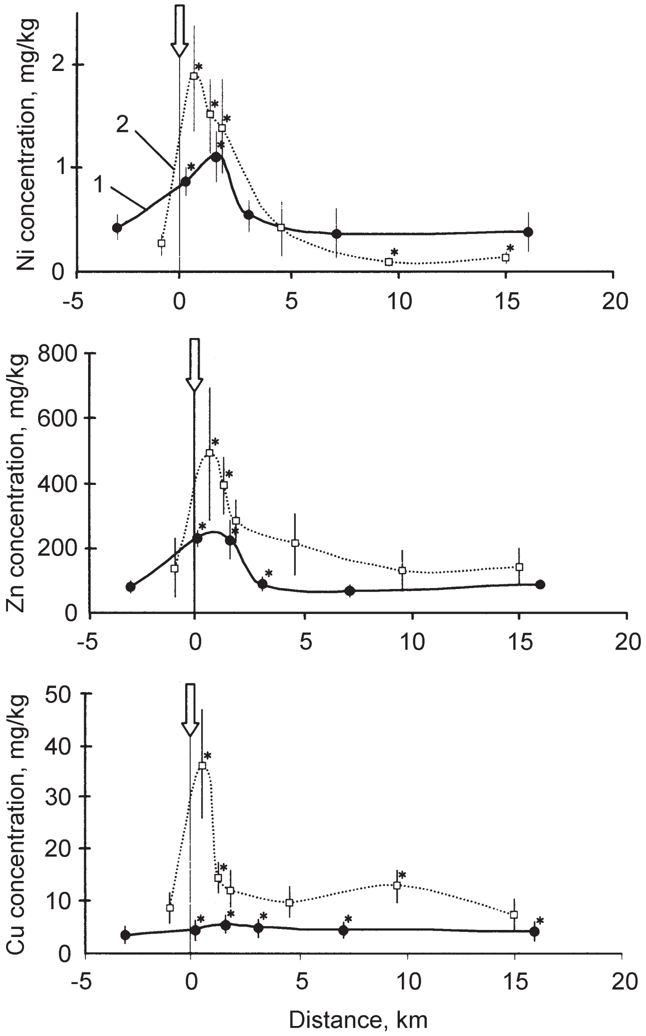

Fig. 3. Spatial dynamics of Zn, Ni, and Cu content in soft tissues of *A.anatina* in the Desna River (1) and in the Dnieper River (2) in the place of sewage release.

In both watercourses in the clean sections, the content of Zn in the tissues of *A. anatina* was closely similar. In the Dnieper River it on the average accounted for 140 ± 91 mg/kg, whereas in the Desna River it was 79 ± 19 mg/kg (Fig. 3). Near the spill of sewage of Kiev, the content of Zn in the tissues of mollusks increased by a factor of 3.5 as compared to the control station and accounted for 489 ± 204 mg/kg. The increase in the content of the metal by a factor of 3 was observed in the place of sewage release in the Desna River, where its concentration accounted for 228 ± 22 mg/kg. Dynamics of Zn content in the Dnieper River were closely similar to those in the Desna River. In the Dnieper River, a decrease in the concentration of Zn by a factor of 2.6 to the control level was observed at the station located 3.1 km downstream of the place of sewage release. In the Desna River, a decrease in the concentration of Zn by a factor of 2.3 to the control level was registered 4.5 km away from the place of sewage release. In the Desna River, relationship was established between the content of Zn in the tissues of mollusks and its content in the water and bottom sediments ($r = 0.70$ and $r = 0.69$, respectively). At the same time, in the Dnieper River relationship was established only between the content of Zn in the tissues of mollusks and its content in the water ($r = 0.93$). In the Desna River, the concentration factors of Zn in *A. anatina* accounted for 7600–25000, whereas in the Dnieper River they were 11000–47000.

At the control station of the Dnieper River, the average content of Ni in the tissues of *A. anatina* was 1.7 times lower than that at the same station of the Desna River and accounted for 0.26 ± 0.10 mg/kg and 0.43 ± 0.13 mg/kg, respectively. In the Dnieper River in the place of sewage release, the concentration of Ni in the tissues of mollusks increased more than by a factor of 7 and accounted for 1.9 ± 0.5 mg/kg. In the Desna River, a rather high content of Ni was registered at the station located 1.6 km away from the place of sewage release (1.12 ± 0.25 mg/kg). In the Dnieper River at the station located 4.5 km downstream of the place of sewage release, the content of Ni decreased by a factor of 4.5, whereas at the station located 16 km away from the place of sewage release its concentration decreased by a factor of 13.4 and accounted for 0.14 ± 0.45 mg/kg. In the Desna River at the station located 3.1 km downstream of the place of sewage release, the content of Ni decreased by a factor of 2, whereas at the station located 7.1 and 16 km downstream of the place of sewage release it decreased by a factor of 3 (to the background level). In the contaminated sections, dynamics of Ni content in mollusks corresponded to those in the water of the studied watercourses. A rather high content of Ni in the tissues of mollusks was registered at the stations located 1.6–1.8 km downstream of the place of sewage release. In the Desna River, the coefficient of correlation accounted for $r = 0.79$, whereas in the Dnieper River it was $r = 0.82$. In the Desna River, the concentration factor of Ni in *A. anatina* accounted for 40–96, whereas in the Dnieper River it was 15–207.

Analysis of the distribution of Cu content in the tissues of *A. anatina* at the control stations of the studied rivers has shown that in the Dnieper River it was 2.5 times higher than that in the Desna River (8.8 ± 3.0 and 3.6 ± 0.4 mg/kg, respectively). In the Dnieper River in the place of sewage release, the concentration of Cu in mollusks was 4 times higher than that at the control station and accounted for 36.3 ± 10.4 mg/kg. Downstream of the place of sewage release, the content of Cu in the tissues of mollusks rapidly decreased. Thus, at the station located 1.2 km away from the place of sewage release the concentration of Cu decreased by a factor of 2.5. In the Desna River at the station located 100 m away from the place of sewage release, the concentration of Cu in the tissues of mollusks increased to 4.7 ± 0.9 mg/kg (by a factor of 1.3), whereas at the station located 1.6 km away from the place of sewage release it increased to 5.7 ± 0.7 mg/kg (by a factor of 1.6). Only 3 km downstream of the place of sewage release, the content of Cu gradually decreased. Thus, in the Dnieper River the concentration of Cu in the tissues of mollusks decreased more rapidly than that in the Desna River. In the Dnieper River at the station located 1.8 km downstream of the place of sewage release, the content of Cu in the tissues of mollusks was closely similar to that registered at the control station. In the Desna River at the station located 16 km downstream of the place of sewage release, the content of Cu in the tissues of mollusks was 1.2 times higher than that registered at the control station. Dynamics of Cu content in mollusks did not coincide with its content in the water and bottom sediments. The concentration factors of this metal in *A. anatina* ranged from 0.6 to 4.5.

Discussion

Changes in the content of heavy metals in bottom sediments under the influence of sewage can reflect the processes of their accumulation by bottom sediments, and also the heterogeneity of the structure of bottom sediments in different sections of rivers. In this case, the studied watercourses differed in the pattern of dynamics of the distribution of heavy metals in bottom sediments.

Analysis of the peculiarities of the composition of bottom sediments has shown that in the Dnieper River they were represented by sands and silted sands, whereas in the Desna River – by clays. As a consequence, in the bottom sediments of the Dnieper River the content of organic matter was 8 times lower than that in the Desna River and on the average accounted for 0.5 and 4.2%, respectively (Fig. 2). Changes in the content of organic matter in bottom sediments coincided with the concentration of heavy metals. Relationship was established between the concentration of heavy metals and the content of organic matter in bottom sediments of the Desna River: Cu – $r = 0.94$, Zn – $r = 0.91$, and Ni – $r = 0.94$. In the Dnieper River, relationship between the content of heavy metals in bottom sediments and the concentration of organic matter was less distinct: Cu – $r = 0.87$, Zn – $r = 0.61$, and Ni – $r = 0.65$.

Thus, a rather high content of heavy metals in bottom sediments in the place of sewage release can be conditioned by a high content of organic matter. Downstream of the place of sewage release, the content of organic matter in bottom sediments and the concentration of heavy metals decreased. This fact suggests that the concentration of heavy metals in bottom sediments depends on the content of organic matter [2].

In both watercourses, the content of Zn and Ni in the tissues of mollusks reflected dynamics of the decrease in the concentration of the metals in the water. The difference in the content of Zn and Ni in the tissues of mollusks can be conditioned by the difference in the processes of dilution of the incoming amounts of metals by river waters. It has been found that the content of Zn in the sewage of the town of Chernigov is closely similar to that of Ni (0.38 and 0.41 tons/year, respectively). However, at the station located 1.2 km downstream of the place of sewage release the concentration of Zn sharply decreased, whereas a rather high concentration of Ni was observed even 3 km downstream of the place of sewage release. At the station located 3.1 km downstream of the place of sewage release, the content of Zn decreased by a factor of 2.6, whereas the content of Ni – by a factor of 2.0. At the station located 7.1 km downstream of the place of sewage release, the content of Zn decreased by a factor of 3.2, whereas the content of Ni – by a factor of 3.0. At the temperature of the river water of > 15°C, the coefficient of the rate of water self-purification from Zn accounted for 0.6 days^{-1}, whereas from Ni it was as twice as lower and accounted for 0.3 days^{-1} [11].

The same phenomenon was observed in the Dnieper River. At the station located 2 km downstream of the place of sewage release, the concentration of Zn in the tissues of *A. anatina* gradually decreased, whereas the content of Ni remained almost unchanged.

In the place of sewage release in the Desna River, the content of Ni in the tissues of mollusks increased by a factor of 2.5, whereas in the water it increased by a factor of 1.3. In the Dnieper River, its content in the tissues of mollusks increased by a factor of 7.0, whereas in the water it increased by a factor of 1.6. The influx of Zn with sewage resulted in a sharp increase in its concentration in the river water (more than by a factor of 8). However, at the station located 1.6–1.8 km away from the place of sewage release the concentration of Zn decreased to the background level. At the same time, in the tissues of mollusks a rather high content of Zn was registered at the station located 9 km downstream of the place of sewage release.

The influx of Cu with sewage of the town of Chernigov in the Desna River resulted in the insignificant increase in its content in the tissues of *A. anatina* and in a sharp increase in the concentration of Cu in bottom sediments. The influx of Cu with sewage of Kiev in the Dnieper River resulted in a sharp increase in the content of this metal in the tissues of mollusks. As this takes place, the concentration of Cu in bottom sediments remained almost unchanged. It is likely that the processes of Cu accumulation in bottom sediments enriched by organic matter limited its biological availability for mollusks. It has been known that Cu is capable of forming complexes with dissolved organic matter more intensively as compared to Ni and Zn [7]. As a consequence, 70–89% of the total content of Cu in bottom sediments are bonded with humic and fulvic acids of bottom sediments. In this case, the contribution of bounded Zn was not more than 30% [4, 21]. The same pattern of the accumulation of heavy metals by mollusks was observed in studies of the influence of sewage enriched by humic acids [14]. In the place of sewage release, the increase in the content of Cu in the tissues of *A. anatina* is a more sensitive indicator as compared to the chemical composition of the water or bottom sediments. A high rate of water self-purification from Cu (the coefficient of the rate of water self-purification at the temperature of water of > 15^{o}C accounts for 1.8 day^{-1} [11]) and the processes of its accumulation by bottom sediments result in the complicated relationship between the content of Cu in the water and the distance from the place of sewage release.

Thus, mollusks are more sensitive indicators of the influence of sewage on the river ecosystem as compared to the chemical composition of the water and bottom sediments, which is supported by literature data [15, 21]. However, in some cases a high content of suspended matter in sewage resulted in the decrease in the intensity of heavy metals accumulation in the place of sewage release [13].

Conclusion

In the Dnieper and Desna rivers, the spill of sewage resulted in the increase in the content of Zn, Ni, and Cu in the tissues of *A. anatina*. This fact is indicative of the presence of biologically available fraction of metals in the water. Thus, the chemical composition of soft tissues of mollusks reflects the influence of household sewage on river ecosystems.

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Physiological-Biochemical Response of Fish to the Pesticide Effect (a Review)†

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Paper deals with new literature data on some biochemical and physiological aspects of pesticide toxicity for fishes. Information on the pesticide effect on protein, lipid and carbohydrate metabolism, activity of enzymes, genetic apparatus, hematological indexes, immune status, reproductive function and elements of vital functions of fishes have been analyzed. The issues of forming of fish adaptation to the pesticide pollution of the water bodies have been considered.

KEYWORDS*:* *fishes*, *pesticides*, *toxicity*, *metabolism*, *enzyme activity*, *genetic apparatus*, *immune system*, *reproductive function*, *adaptation*.

Long-term, often not controlled and not ground use of pesticides in agriculture resulted in pollution of the water bodies by these hazardous pollutants and disturbance of natural balance in the water bodies. Because of cumulative properties, pesticides circulate and are accumulated in organisms of all hydrobionts, but especially high concentrations of pesticides and their metabolites are observed in fishes, because they are the uppermost link of the food chains of the water bodies [1, 17]. In this connection issue of toxic effect of pesticides on fishes, particularly peculiarities of their metabolism, responses to stress caused by impact of pesticides at physiological-biochemical level, were and still are quite actual; and significant number of papers are devoted to these issues. In this review the attempt has been made to comprehend and analyze scientific information on biochemical and physiological aspects of fish vital activity at pesticide pollution of the water bodies.

Structural-functional reorganization and genome expression in fish under the pesticide impact. Recently scientific papers pay more attention to the negative effect of pesticides on genetic apparatus of fishes. Thus, in experiments on the herbicide "Puma super" effect on the grass carp it was revealed that it caused disturbance of spectrum of amplification products with primers S12, S14 and S20. Conclusion was made about genotoxic potential of this herbicide [29]. Such potential was

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also revealed in some other pesticides (“aparan”, metribuzin) [28]. Study of effect of two organochlorine pesticides (dieldrin and DDE) on *Micropterus salmoides* enabled to state that they changed mRNA expression rate in some genes important for reproduction. Dieldrin also changed expression of genes of the sexual hormones synthesis and metabolism [32]. It was revealed that acetochlor-based herbicides induced increase of the micronuclei number and nuclear abnormalities in erythrocytes of *Misgurnus anguillicaudatus*, at this variation of the genetic index did not correlate with the herbicide dose [50].

So, experiments confirmed negative effect of pesticides on the genome expression and, consequently, on the protein synthesis, which in turn regulates metabolism and physiological functions on the whole.

Protein metabolism in fish. Many toxic substances, particularly pesticides, cause significant disturbances of the protein metabolism in fish. In this connection a series of the protein metabolism characteristics are used to predict consequences of the toxic stress and to assess pesticides’ toxicity rate [17]. Analysis of the literature sources uniquely testified to disturbances of the normal protein synthesis and suppression of the liver functional state in fish, empoisoned by pesticides.

Contamination of the aquatic environment by pesticide “actara” (1 and 3 mg/dm^3) caused changes in proteins’ and their fractions’ content in the skeleton muscles of the carp yearlings. As authors of this study considered, this fact probably indicated conformational dislocations of the protein molecules and testified to structural changes of the proteins [3]. Results of investigation [8] showed decrease of the total protein content in all carp tissues under the impact of pesticides; this was connected with use of proteins as energy substrates and their participation in adaptive structures forming.

Taking into account highly important role of transamination and oxidative deaminization reactions in normal protein metabolism support, data on activity of transaminases are successfully used in clinical biochemistry and toxicology for diagnostic purposes [17]. Study of acetochlor effect on transaminases’ activity in the liver and brain of the young carps showed increase of the enzyme activity at the beginning of the experiment and its drop at the end, this fact indicated changes in biochemical status of the liver and brain [6]. Insecticide “carbofuran” caused biochemical changes in the liver and muscle tissues of the freshwater fish *Clarias batrachus*, namely: growth of the ammonia content, increase of some enzymes activity (alanine transaminase, aspartate transaminase, glutamate dehydrogenase, glycogen phosphorylase *a*) [27].

In 12 hours after contact with herbicide “diquate” some changes of biochemical parameters in carp were observed: hypoproteinemia, growth of aspartate aminotransferase activity in the blood plasma, liver and muscles; and alanine aminotransferase activity growth in plasma and liver [25]. As it was stated, many organochlorine pesticides suppressed activity of the ATP-ases in the brain, gills, kidneys, which were activated by Na^+, K^+ and Mg^{2+} and play important role in osmoregulation, determine intensity and directivity of the water and ions transport in the marine and anadromous fishes [17]. Thus, increase of concentration and exposition of the pesticide “quinchlorac” lead to further suppression of the ATP-ase activity in the gills and liver of the *Carassius auratus* [46].

As it was mentioned in the paper [44], acute or chronic impact of the organochlorine, organophosphorus, carbamate or synthetic pyrethroid insecticides caused disturbance of the water balance in the bony fishes: increase or decrease of the Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and nonorganic phosphorus concentration.

Rate of the fish poisoning can be judged by activity of the certain enzymes and by changes of the main metabolites concentration. Thus, at pesticide load decrease of the pyruvate, oxaloacetate, lactate and malate content in tissues of the carp yearlings was revealed, at this activity of the malate dehydrogenase increased. Probably, at toxicosis transformation of ketoacids and other metabolites, connected with energetic detoxication processes, occurs more intensively [21].

Lipid metabolism in fish. Some characteristics of the lipid metabolism are widely used to assess responses of fish to the impact of the toxic substances, particularly pesticides. It was stated, that some pesticides possess ability to intensify processes of the lipids peroxidation. Because of metabolism, some of them are activated with forming of the free radicals. Similar properties are characteristic, particularly, to the pesticides “paraquate” and “diquate”. Under the impact of other pesticides, for instance, “lindane”, active forms of oxygen are formed more actively [16].

Study of the highly-toxic pesticides (“corbel”, “frontier”, “kharies”) on the sturgeon pre-larvae showed all of them to cause disturbances of the lipid metabolism. At this in the pre-larvae with high lipid content these disturbances were reversible, but if lipid content was below average level, these disturbances were irreversible; they affect plastic metabolism, caused changes of morphometric parameters [24]. Sublethal concentrations of hexachlorocyclohexane (HCCH) at four-day exposition suppressed lipid metabolism in catfish *Heteropneustes fossilis*. Content of phospholipids decreased in liver, gonads, blood plasma, this testified to lipogenesis suppression. Transformation of free cholesterol into etherified form was observed [45]. Significant growth (1.4 times) of the lipids concentration in the blood serum of the two-year-old carps and growth of the lipase activity under the effect of the pesticide “roundup” was revealed. According to the author, the main role of lipids probably consisted in accumulation of herbicides, especially derivatives of 2,4-D [8].

Carbohydrate metabolism in fish. Carbohydrates are one of the main energy source providing vital processes of the organism. In this connection characteristics of the carbohydrate metabolism, its intensity and directivity are of special interest in assessment of fish responses to the toxic substances.

Investigation of the carbohydrate metabolism in the European eel *Anguilla anguilla* demonstrated pesticide “lindane” in sublethal concentration to activate glycogenolysis and anaerobic glycolysis in animal tissues, similar to hypoxic stress [31]. Under the effect of pesticide “phenitrothion” level of protein, glycogen and, consequently, energy in body of the European eel decreased. The authors associated such effects with intensified synthesis of lipoproteins, which play protective role, and with intensive catabolism of glycogen at intoxication [42]. When fish were resettled into the clean water, energy metabolism in liver returned to normal level less than in a week [43].

Works of A.O. Zhydenko [8] showed herbicide load to change velocity and directivity of the carbohydrate metabolism in carp. Thus, in white muscles shift to aerobic oxidation was noted. In liver all herbicides, except “roundup”, caused misbalance towards anabolism. In the fish brain under the impact of 2,4-D stable level of glucose and macroergic substances content was maintained. Effect of “zenkor” on the two-year-old carps directed carbohydrate metabolism towards pentose phosphate shunt along with significant decrease of the macroergic substances forming [8].

Morphophysiological and histological modifications in the fish organism. The most drastic morphophysiological and histological modifications occur in the fish organs and tissues directly exposed to the toxicants' impact, for instance, in gills. They first suffer from the toxic impact, which disturbs structure of this vitally important organ of respiration and excretion [17]. According to the literature data [13], under the effect of toxic concentrations of herbicides on carp (2,4-D, "roundup", "zenkor") the most morphophysiological modifications occurred in liver and gills. On the whole, histological changes in the fish liver are connected with dystrophic processes, which irreversibly lead to hepatocytes dying. Respiratory lamellae swelling and gill filaments hypertrophy are mainly connected with adaptation to toxic conditions.

Effect of herbicide "simazine" (45 $\mu g/dm^3$) over 90 days in flowing system caused necrosis of haematopoietic tissue of kidneys and hyperplasia of interapinal branchial epithelium in carp, as well as appearance of necrosis focuses in liver and pancreas [40]. Impact of organophosphorus herbicide "diasinone" on fish *Melanotaenia dubaulayi* caused thickening of epithelium of the branchial lobes, proliferation of the chloride cells, hypertrophy, hyperplasia of gills, intensified mucus excretion and occlusion of the blood vessels [36]. Study of the herbicide "roundup" effect on the histological characteristics dynamics in the carp organs demonstrated that maximal histological modification occurred in liver and skeletal muscles, to a less extent – in intestine, and in gills and brain these modifications were insignificant [9].

At "diasinone" and "neopybutrine" intoxication ultrastructural modification in skeletal muscles of *Tilapia nilotica* were observed: swelling of sarcoplasmic reticulum and vacuolization of cytoplasm, fragmentation of myofibrils along all sarcomeres, exfoliation and disintegration of bundles of muscle fibers, decrease of chromatin content in nuclei [41].

Hematological characteristics in fish. The blood is known as highly informative indicator of the organism status. As investigation showed, effect of some herbicides on hematological characteristics of the two-year-old carps was ambiguous. Thus, effect of 2,4-D decreased time of blood coagulation and its viscosity, erythrocytes number, hemoglobin content. Effect of "roundup" was different; this herbicide caused growth of coagulation time, number of erythrocytes and decreased ESR. Negative effect of "zenkor" consisted in hypochromia, which resulted either from microcytosis, or from saturation of the normal-size erythrocytes by hemoglobin [7].

Investigation of A.O. Zhydenko [8] showed that at herbicides impact pathological deviations in the two-year old carps were noted in 7 days of intoxication, and in young fish – in 14 days. It was also stated that the 7th day was critical for forming of the compensatory response of the circulatory system in the two-year-old carps.

It was stated that chronic impact of the pesticide "actara" (thiametoxam) caused growth of bilirubin content in the blood serum of the carp yearlings. Thus, concentration 1 mg/dm^3, considered as ineffective for the fresh water bodies, changed biochemical characteristics; such changes can result in changes on physiological and population level [5, 18]. Effect of pesticides "tolban" and "tomilon" on the carp yearlings caused development of toxicosis, resulted in anemia, clearly expressed monocytosis and stop of the neutrophils production [2]. Pesticide carbophos (concentration 10 mg/dm^3) caused decrease of the leucocytes number in blood of young carps, release of significant amount of the young metamyelocytes into blood, and reliable lymphopenia and neutrophilia [14, 15].

Increase of the erythrocytes' deformation and fragility of their membranes at elevated dose and prolonged effect of the pyrethroid pesticides on the carp blood cells was also noted [34].

Neurotoxic effect of pesticides on fish. It is known that many pesticides of organophosphorus group, carbamate and organochlorine pesticides, have toxic effect on the warm-blooded animals and fishes by means of inactivation of acetylcholine esterase, which drives enzymatic hydrolysis of the very important mediator – acetylcholine. In this connection activity of acetylcholine esterase, which characterizes functional state of the nervous system, can serve as sensitive biochemical indicator of the pesticides toxicity [17]. It was revealed that growth of the pesticides diazinone and malathion caused significant decrease of the choline esterase activity in larvae of the rainbow trout *Oncorhynchus mykiss*, at the same time number of muscarinic cholinergic receptors decreased to a less extent. Changes in fish swimming behavior correlated with changes of the choline-esterase activity under the effect of both toxicants [26].

It is accepted that neurotoxic symptoms of acute poisoning by pyrethroid insecticides are conditioned by changes of electric activity of different departments of the nervous system. The main targets of their impact are potential-dependent Na^+-channels. Effect on these channels cause prolongation of Na^+-current at membrane excitation [49]. It was revealed, that pyrethroid insecticides suppress GABA-dependent (GABA: γ-aminobutyric acid) transport of $^{36}Cl^-$ into isolated synaptic neurosomes of the trout brain. According to authors' opinion, pesticides influence GABA-receptors' functions indirectly, through potential-dependent Na^+-channels [30].

It was stated, that under the toxic impact of pyrethroid insecticide "fenvalerate" neurotransmitter system of the carp brain suffered to the most extent; also disturbance of hormone regulation and motion coordination, cover pigmentation and hyperemia of gills was observed [38].

Reproductive functions of fish. As it was marked by L.P. Braginskiy, pesticides possess specific tropism as for reproductive system of the aquatic organisms; in future than can cause lethal mutations, abnormalities, stop ontogenesis and cause mortality at early development stages, birth of the low-viable generation, which, in turn, will give defective posterity with low reproduction potential [1]. Thus, under the effect of the pesticide carbofuran in the freshwater fish *Colisa lalia* (Hamilton – Buchanan) occurred ovaries atresia, change of the egg granules structure, decrease of oocytes' size and disintegration of the oviparous plates [48]. Keeping of *Carassius auratus* in medium with content of the herbicide atrazine caused decrease of testosterone and 11-ketotestosterone content and increase of 17 β-estradiol content in blood. Atrazine in concentration 1000 μ/dm^3 caused morphological abnormalities of testicles, and in concentration 100 μ/dm^3 caused ovaries' atresia [47]. Results of the experiment showed estrogen content in females and testosterone content in males to be in clear correlation with concentration of soluble pesticides [39].

Most of the gonad pathologies revealed in the Azov sturgeons, according to the authors' opinion, were a result of toxic effect of environment. Long-term observations showed that posterity of specimens with high content of pesticides in liver, gonads and kidneys was less viable, with wide range of functional abnormalities. Pathomorphological deviations caused decrease of reproductively valuable specimens' number, deceleration of maturation, and decrease of fertility [12]. Intoxication by the herbicide preparations "Puma super 100 EC" and "Puma super 75 EW" caused embryogenesis disturbance and embryos' death in fish. In solutions with maximal concentration of these pesticides disturbance of division and gastrulation processes was observed, this led to mass death of embryos at early neurula stage [23]. Impact of the pesticide methoxychlor on young rainbow trout *Oncorhynchus mykiss* caused suppression of the eggs growth already in 45 days after fertilization; in 140 days clear inverse relationship of the larvae length and mass and their survival rate with pesticide dose was observed [35].

As results of the experiments with sturgeons showed, these fishes are the most sensitive to the different pesticides effect at the most early stage of embryogenesis, especially at gastrulation stage, and the most stable they were at pulsating heart stage. Further toxic resistance decreased from the hatched embryos stage to larval stage [4].

Immune system of fish. Toxic effect, its expression and consequences are conditioned not only by chemical nature of the toxicant, it concentration and exposition time, but by peculiarities of the organism toxic resistance and state of its immune system as well.

It was shown that pesticides affect all levels of the immune system organization, without visible signs of poisoning. Relation and structure of immunocytes, their functional activity, characteristics of humoral link of immune were shown to be the most sensitive to the pesticide effect [10].

Carbophos caused structural-functional reorganization in tissues of the immune-competent organs of carp. Such reorganization was directed to neutralization of toxicant and its toxic effect. Intensity of pathological changes in fish tissues depended on toxicant dose [11].

Study of phagocytic function of the freshwater fishes in Australia showed that immune-toxicity of pesticides decreased in a consequence: organotin compounds > endosulfan > chlorpyriphos [33].

Fish adaptation to the pesticide effect. The most important factor influencing damaging rate of pesticides is an active physiological and biochemical response of fish, first of all their adaptive potential and resistance to toxicants [8].

As it is known, fishes establish relation between the organism and environment easier than the warm-blooded animals [22]. Impact of the herbicide 2,4-D caused energy metabolism activation in the one- and two-year-old carps, and under the impact of “zenkor” occurred exhaustion of the energy resources. At this, yearlings lost adenylates more intensively than two-year-old animals; by authors’ opinion this fact was explained by misbalance of the energy metabolism system in the yearlings. Among all studied tissues white muscles were affected to the most extent, and fish brain was affected to the less extent [20].

According to studies [8], relation of activity of the energy-production and energy-consuming reactions in young carps supported formation of the immediate adaptation under the “roundup” effect during 7 days and prolonged adaptation under the effect of the 2,4-D derivatives. Besides, under the effect of “roundup” adaptive growth of calcium concentration in the fish blood serum was revealed, due to this growth energy metabolism was stabilized.

Assessment of the oxidation-antioxidation activity of the muscle tissue in the carp yearlings under the effect of pesticide “actara”, carried out by malone dialdehyde accumulation, showed that prolonged stay of young fish in the polluted environment caused disturbance of the defensive-adaptive mechanisms and resistance decrease [19]. In fish *Oreochromis niloticus* and *Cyprinus carpio* rate of superoxide dismutase activity can be used as biomarker of the environment pollution by azine-phosmethyl and 2,4-D. Growth of this enzyme activity was considered as adaptive response to oxidative stress [37].

As it was shown in paper [8], one of the mechanisms of compensatory adaptation in the carp yearlings is synthesis of the ketone bodies in liver, which are formed as response to the low temperature and starving. Under the effect of toxicants, particularly herbicides, similar adaptation was not revealed in any age groups. In fish they caused only forming of compensatory responses, which provide organism tolerance to the non-specific impacts. Mechanisms of these responses are conditioned by physico-chemical characteristics of toxicants, peculiarities of their influx into the organism and age of fish.

Conclusion

Pesticides, which enter the water bodies, disturb normal vital activity of all aquatic organisms, especially fishes, because they are able to accumulate significant amount of pesticides.

Numerous scientific communications testify to significant physiological and biochemical modifications in fish organism under the toxic effect of different pesticides. They mainly affect protein, lipid and carbohydrate metabolism, activity of different enzymes and organism systems, hematological indexes, immune status, reproductive functions, genetic apparatus and other elements of vital activity of fishes. These modifications can be of adaptive character, or a result of pathological processes, which lead to death of fishes.

At the same time extensive experimental material on toxic effect of pesticides on fishes, particularly their physiological and biochemical processes, is not sufficiently analyzed and comprehended. Further researches in this field of the aquatic toxicology will contribute solution of issues of the fish toxic resistance and prognosis of their survival and biological productivity under the toxic load.

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Accumulation of ^{137}Cs by *Leuciscus cephalus* (L.)[†]

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The influence of various factors on the accumulation of ^{137}Cs by *Leuciscus cephalus* (L.) occurring in the cooling pond of the Chernobyl NPS, in the Pripyat River, and in the Kanev Reservoir was studied in 1987–2007. It has been found that the temperature of water and the age of specimens are the main factors influencing the content of ^{137}Cs in *L. cephalus* in water bodies similar in the degree of their radioactive contamination.

KEYWORDS: *cooling pond of the Chernobyl NPS*, *the Kanev Reservoir*, *Leuciscus cephalus*, *^{137}Cs accumulation*, *^{137}Cs content*.

Introduction

Leuciscus cephalus (L.) is a representative of the boreal zoogeographic complex. *L. cephalus* belongs to oxyphilous and rheophilous organisms. It occurs in rather cold waters with the bottom sediments represented by stones and/or sands. This species belongs to polyphagous organisms feeding on insects and their larvae. With age it becomes a facultative zoophagous or predatory organism.

Within the territory of Ukraine, *L. cephalus* occurs in all large rivers and reservoirs. However, the frequency of its occurrence is rather low.

Previously it was thought that *L. cephalus* is not used for fishery [4, 11]. However, in recent years its commercial importance increased.

In 1986–1988 in the cooling pond of the Chernobyl NPS, *L. cephalus* occurred rather rarely. At a later time, the number of its specimens increased. From 1991–1995 until 1997, the number of its specimens in the catches increased almost by a factor of 3 (from 3.4 to 11.0%).

In the Kanev Reservoir from 1988 until 2007, the number of *L. cephalus* specimens increased almost by a factor of 2.

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The study of radioecology of *L. cephalus* is of considerable importance because its numbers in the studied water bodies increased.

Material and Methods

The content of ^{137}Cs was studied in different organs and tissues of *L. cephalus*. The main attention was paid to its muscles.

In 1986–2006 *L. cephalus* was caught in the cooling pond of the Chernobyl NPS, in 1986–2007 – in the Kanev Reservoir, whereas in 1988–2005 – in the Pripyat River within the 30 km exclusion zone of the Chernobyl NPS. Mainly sexually mature specimens were caught.

The muscles were separated from the other organs and tissues and homogenized. The content of ^{137}Cs was determined by standard methods of γ-spectrometry. The specific radioactivity was calculated per net natural mass. The obtained data were statistically processed using the Excel 2003 Program (license N 42326439). For the most part measurements were carried out in three replicas.

The content of ^{137}Cs dissolved in the water of the studied water bodies is given according to the data of the “Ecocenter” and based on [9].

^{137}Cs concentration factors were calculated as the ratio between the averaged annual content of ^{137}Cs in the muscles of *L. cephalus* in the studied water body and the averaged content of ^{137}Cs dissolved in the water of this water body in the same year.

Results and Discussion

Distribution of ^{137}Cs over different organs and tissues of *L. cephalus*. The distribution of ^{137}Cs over different organs and tissues of *L. cephalus* was closely similar to that in the other species of fishes (Fig. 1).

In the cooling pond of the Chernobyl NPS, a higher content of ^{137}Cs was observed in the eggs of *L. cephalus,* and also in its spine. However, during this period the distribution of ^{137}Cs over different organs and tissues of *L. cephalus* was closely similar to that registered in the other representatives of the fish fauna occurring in this water body. The highest content of ^{137}Cs was observed in its muscles.

Accumulation of ^{137}Cs by males and females of *L. cephalus*. The content of ^{137}Cs in males was closely similar to that in females. However, according to the data of the “Ecocenter” in 1995 the content of ^{137}Cs in females of *L. cephalus* was reliable higher than that in its males. At a later time, this regularity was not observed. It is likely that this phenomenon was conditioned by changes in the temperature of water, and also in other characteristics of the cooling pond after the removal of the Chernobyl NPS from operation in 2000.

The place of *L. cephalus* among other fishes in terms of ^{137}Cs content. In the Kanev Reservoir, *L. cephalus* was characterized by a rather high content of ^{137}Cs (Fig. 2) registered in ichthyophagous species as compared to the other studied species of fishes.

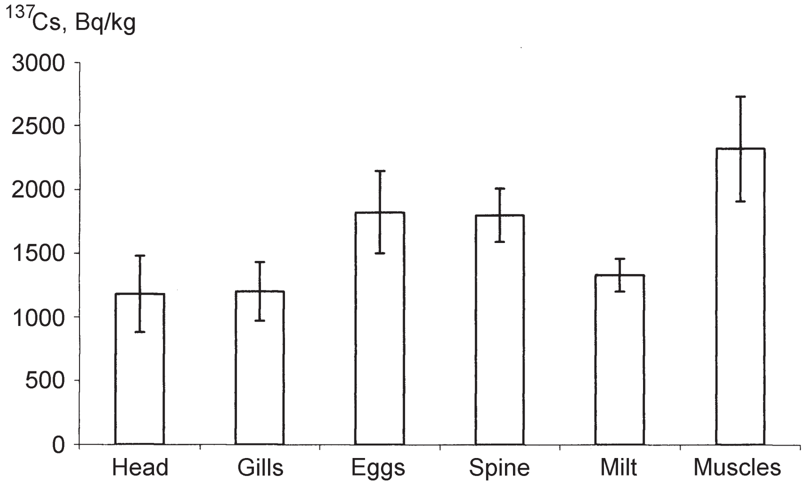

Fig. 1. Averaged content of ^{137}Cs in different organs and tissues of *L. cephalus* in the cooling pond of the Chernobyl NPS on 15 May 1999.

In the cooling pond of the Chernobyl NPS, *L. cephalus* occupied the intermediate place in terms of ^{137}Cs content as compared to the other studied species of fishes.

It is likely that this phenomenon was conditioned by the difference in some parameters of the studied water bodies, including the chemical composition of the water, dissolved oxygen content, speed of water flow, water temperature, etc. influencing the structure of trophic links and ^{137}Cs migration over these links.

Influence of food on the content of ^{137}Cs in *L. cephalus*. Almost 100% of ^{137}Cs enters the organism of freshwater fishes with food [7]. However, the contribution of plant and animal components into the food of polyphagous fishes under natural conditions is not clearly understood.

In the Kanev Reservoir, a higher content of ^{137}Cs was registered in the specimens of *L. cephalus,* in the gastro-intestinal tract of which animal components predominated over plant components.

On the contrary, in the cooling pond of the Chernobyl NPS a higher content of ^{137}Cs was observed in the specimens of *L. cephalus,* the gastro-intestinal tract of which contained mainly plant components.

Influence of water temperature on ^{137}Cs content in *L. cephalus*. In spring 1998 the content of ^{137}Cs in the specimens of *L. cephalus* caught in the section of the cooling pond with considerable heating was closely similar to that registered in its specimens caught in the section of the cooling pond with the minimal heating (Table 1).

However, in May and October 1999 the content of ^{137}Cs in the specimens of *L. cephalus* occurring in the discharge canal was higher than that in the specimens occurring in the water intake canal

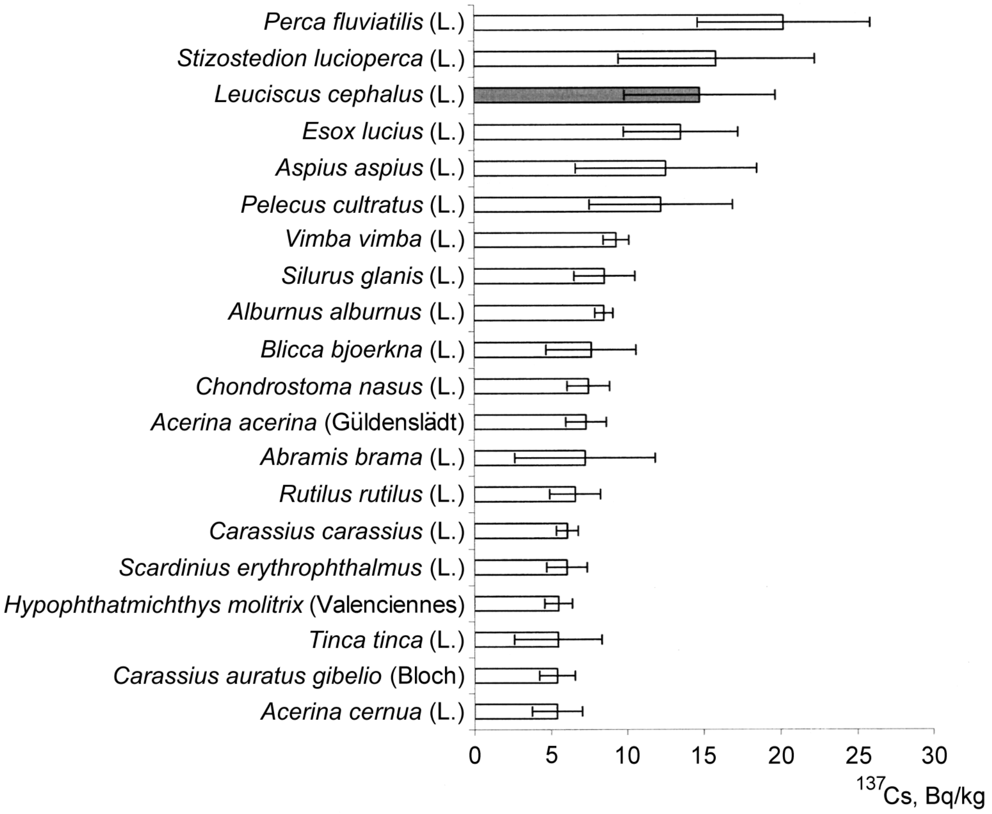

Fig. 2. Averaged content of ^{137}Cs in fishes of the Kanev Reservoir in 2007.

(Table 1). It has been known that in the discharge canal the temperature of water was higher than that in the water intake canal by 5–10°C depending on seasons.

Thus, the content of ^{137}Cs in *L. cephalus* increased with increasing the temperature of water.

Seasonal dynamics of ^{137}Cs content in *L. cephalus*. It is thought that seasonal dynamics of ^{137}Cs content depend on changes in the temperature of water, on the influx of radionuclides during the period of spring flood, on seasonal influx of ^{137}Cs into the water from bottom sediments, on changes in the spectrum of its nutrition, on seasonal dynamics of ^{137}Cs content in food, and also on other factors. Based on the data obtained by the "Ecocenter", the content of ^{137}Cs in *L. cephalus occurring in the cooling pond of the Chernobyl NPS decreased with increasing the concentration of inner fat.*

Based on the data of the "Ecocenter" (1995 and 1996), the content of ^{137}Cs in *L. cephalus* decreased from spring until autumn by a factor of 1.5–1.9. Our data obtained in 1998–2006 also suggest that the content of ^{137}Cs in *L. cephalus* occurring in the cooling pond of the Chernobyl NPS varied from season to season. However, the pattern of these changes was another (Fig. 3).

Table 1

Average content of ^{137}Cs in *L. cephalus* in various sections of the cooling pond of the Chernobyl NPS differing in the temperature of water and the average mass of a specimen

Sampling dates	Sampling stations	^{137}Cs, Bq/kg	Specimen mass, g
07–20.03.1998	Warm part of the cooling pond at the beginning of the separating dam	4560 ± 343	903 ± 251
20.03–02.04.1998	Cold part of the cooling pond at the beginning of the separating dam	4591 ± 1196	822 ± 116
06–16.05.1998	Warm part of the cooling pond at the beginning of the separating dam	5799 ± 2258	808 ± 320
10–17.05.1998	Cold part of the cooling pond at the beginning of the separating dam	4178 ± 329	1173 ± 329
14.05.1999	Water intake canal	2200 ± 173	377 ± 87
14.05.1999	Discharge canal	3500 ± 265	357 ± 80
12.10.1999	Water intake canal	4833 ± 208	112 ± 12
12.10.1999	Discharge canal	9140 ± 767	264 ± 75

In 1998 and 1999 seasonal dynamics of ^{137}Cs content in *L. cephalus* occurring in the cooling pond were not statistically valid. It is likely that this phenomenon was conditioned by artificial temperature regime of the cooling pond, and also by the additional influx of radionuclides.

After the removal of the Chernobyl NPS from service in December 2000, the temperature regime of the cooling pond depended on hydrometeorological conditions. In this case, the content of ^{137}Cs in *L. cephalus* increased in May and August and decreased in winter. In 2003 and 2004 seasonal dynamics of ^{137}Cs content in *L. cephalus* were statistically valid (Fig. 3). The same seasonal changes in ^{137}Cs content in *L. cephalus* were registered in the other studied specimens of fishes.

Dimensional effect or relationship between the content of ^{137}Cs and the age of *L. cephalus* specimens. After the accident at the Chernobyl NPS, it has been found that in larger specimens of the same species the content of ^{137}Cs was higher than that in their smaller specimens. This phenomenon is referred to as the “dimensional effect” [12].

In 2002 and 2003 in the Kanev Reservoir, in four specimens of *L. cephalus* the content of ^{137}Cs increased with increasing their mass.

In the cooling pond of the Chernobyl NPS, the content of ^{137}Cs in *L. cephalus* also increased with increasing the mass of its specimens. For the most part this increase was valid.

The most distinct dimensional effect is registered in the specimens weighing from 20 to 500–800 g. Within the next range, this effect is not distinct. However, at a later time the dimensional

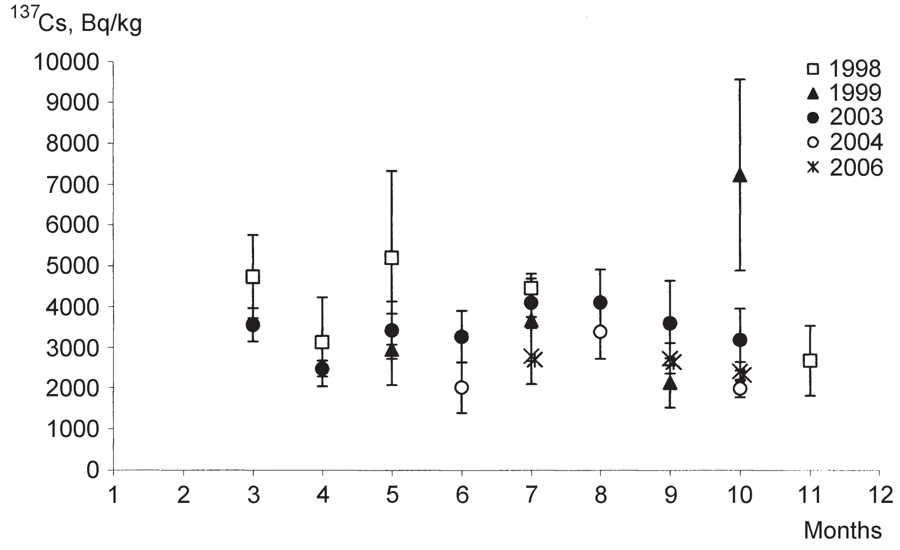

Fig. 3. Seasonal dynamics of ^{137}Cs content in *L. cephalus* in the cooling pond of the Chernobyl NPS (average per month ^{137}Cs content, Bq/kg).

effect is registered distinctly. In some cases, the dimensional effect is not observed. Within the range from 600–800 to 1000–1400 g, the content of ^{137}Cs in the specimens of *L. cephalus* can decrease with increasing their mass.

The content of ^{137}Cs in the specimens of *L. cephalus* occurring in the Pripyat River also increased with increasing their mass.

Only in the specimens of *L. cephalus* taken from the cooling pond of the Chernobyl NPS on 7 June 2004, the content of ^{137}Cs decreased with increasing their mass.

Influence of the non-uniform radioactive contamination of the area of water on the content of ^{137}Cs in *L. cephalus*. As a result of the accident at the Chernobyl NPS, the northern part of the Pripyat River proved to be most contaminated. Its bottom sediments were characterized by the highest specific radioactivity [5, 6], which decreased toward its southern part. In this case, the content of radionuclides in the attached and slightly mobile forms of hydrobionts decreased.

In 1998 the content of ^{137}Cs in *L. cephalus* taken from the northern part of the Pripyat River was higher than that in the specimens of this species taken from the southern part of the river by a factor of 10. It is likely that this difference was conditioned by the non-uniform radioactive contamination of the Pripyat River.

Long-term dynamics of ^{137}Cs content in *L. cephalus* in the Kanev Reservoir and in the cooling pond of the Chernobyl NPS are given in Figures 4 and 5.

Dynamics of ^{137}Cs content in *L. cephalus* of the Kanev Reservoir were closely similar to those registered in benthos-phagous species of this water body. During the first years after the accident,

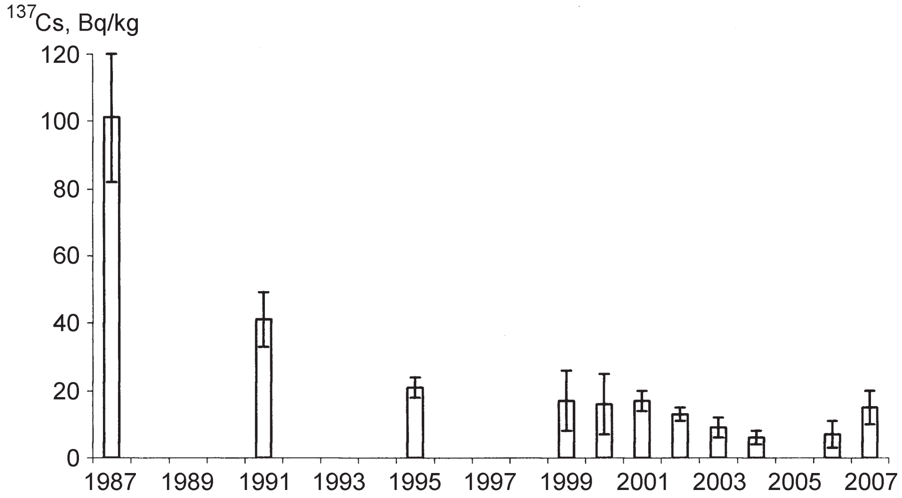

Fig. 4. Long-term dynamics of ^{137}Cs content in *L. cephalus* in the Kanev Reservoir in 1987–2007 (average per year content, Bq/kg).

the content of ^{137}Cs essentially decreased. However, from 1995 until 2007 its content was rather stable and accounted for 7–20 Bq/kg. It is likely that such changes in the content of ^{137}Cs were conditioned mainly by hydrometeorological factors influencing the influx of radionuclides into the water body. It should be noted that since 1999 the frequency of *L. cephalus* occurrence significantly increased. This fact is indicative of the increase in the numbers of *L. cephalus* in the reservoir in the recent decade.

Dynamics of ^{137}Cs content in *L. cephalus* of the cooling pond of the Chernobyl NPS were closely similar to those registered in benthos-phagous species of this water body. Since 1997 until 2006, the content of ^{137}Cs in this fish decreased (Fig. 5). However, the difference was not valid.

During the period of investigations, the content of ^{137}Cs in *L. cephalus* occurring in the cooling pond of the Chernobyl NPS was higher than that in this fish registered in the Kanev Reservoir by a factor of 1000–3000. Despite the fact that these water bodies differed in many characteristics, including the temperature of water, hydrochemical regime, the speed of water flow, and many other factors, the pattern of dynamics of ^{137}Cs content in *L. cephalus* found in these water bodies was closely similar.

Long-term dynamics of ^{137}Cs concentration factors in *L. cephalus* occurring in the Kanev Reservoir (Fig. 6) were closely similar to those registered in *Abramis brama* (L.) and *Rutilus rutilus* (L.) found in this water body.

The lowest value of ^{137}Cs concentration factor in *L. cephalus* was observed in 1987 – 441. In 2001 it increased up to 1700, whereas in 2003 it decreased to 1000 (Fig. 6).

In 1994–2003, dynamics of ^{137}Cs concentration factor in *L. cephalus* occurring in the cooling pond of the Chernobyl NPS were closely similar to those registered in benthos-phagous species oc-

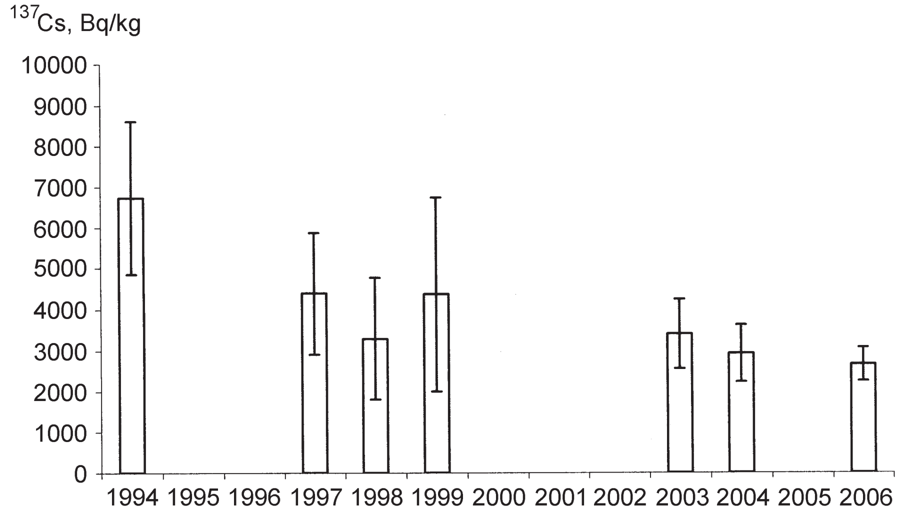

Fig. 5. Long-term dynamics of ^{137}Cs content in *L. cephalus* in the the cooling pond of the Chernobyl NPS in 1994–2006 (average per year content, Bq/kg).

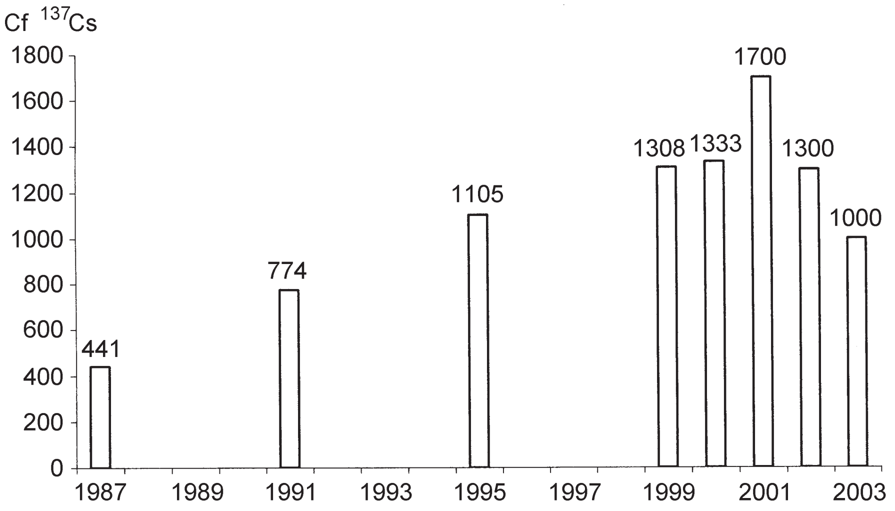

Fig. 6. Long-term dynamics of ^{137}Cs concentration factor in *L. cephalus* in the Kanev Reservoir (1987–2003).

curring in this water body, including *Abramis brama* (L.), *Rutilus rutilus* (L.), and *Blicca bjoerkna* (L.) (Fig. 7).

The values of ^{137}Cs concentration factor in *L. cephalus* occurring in the cooling pond of the Chernobyl NPS were somewhat higher than those observed in *L. cephalus* registered in the Kanev Reservoir (Figures 6 and 7).

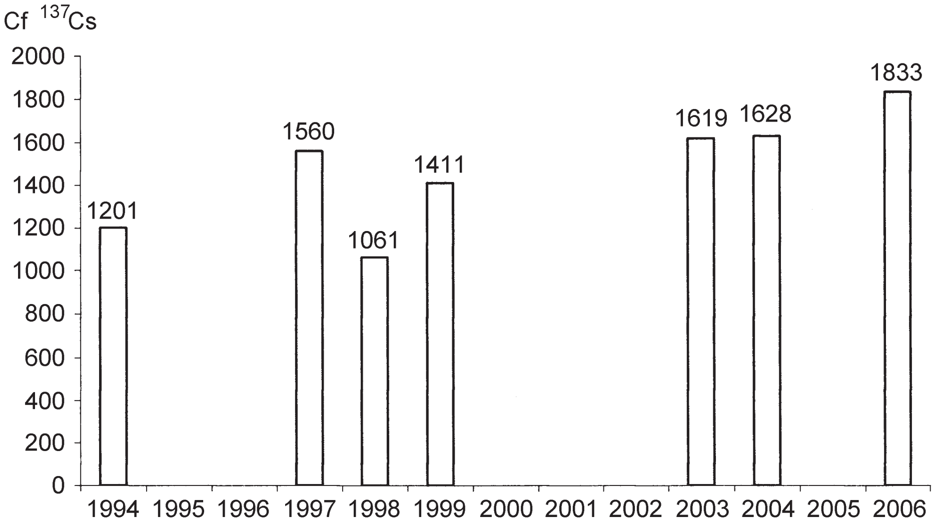

Fig. 7. Long-term dynamics of ^{137}Cs concentration factor in *L. cephalus* in the cooling pond of the Chernobyl NPS (1994–2006).

The content of radionuclides in the water of the Kanev Reservoir and of the cooling pond of the Chernobyl NPS decreased with time. Since 1987 until 2003 the content of ^{137}Cs in the water of the Kanev Reservoir decreased by a factor of ≈25, whereas in the water of the cooling pond it decreased by a factor of ≈ 33. It has been known that the main amount of ^{137}Cs enters the organism of fishes with food. However, the content of ^{137}Cs in the aquatic environment influences its content in fishes.

The process of ^{137}Cs accumulation by fish organism includes both rapid and slow components. Thus, based on the data of the experiment carried out in 2000–2001 in fishes taken from the clean zone and placed into the cooling pond of the Chernobyl NPS within 35 days the content of ^{137}Cs increased by a factor of 10 (rapid component). After that within 110 days it increased by a factor of 4 (slow component) [8]. The intensity of ^{137}Cs release from fish organism decreased with time [1–3, 10]. In this case, the intensity of ^{137}Cs release from fish organism was lower than the intensity of its accumulation.

It is likely that the increase in ^{137}Cs concentration factor in *L. cephalus* (and in some other species of fishes) can be conditioned by a predominance of the rate of ^{137}Cs accumulation over the rate of its release from fish organism.

Conclusion

The content of ^{137}Cs in *L. cephalus* occurring in the cooling pond of the Chernobyl NPS, in the Kanev Reservoir, and in the Pripyat River within the 30-km exclusion zone of the Chernobyl NPS was studied in 1987–2006. *L. cephalus* occupies the intermediate place in terms of ^{137}Cs content in its muscles.

The distribution of ^{137}Cs over the organs and tissues of *L. cephalus* was closely similar to that registered in the other species of fishes. Its highest concentration was observed in the muscles of this fish.

In the muscles of males of *L. cephalus*, the content of ^{137}Cs was closely similar to that registered in the muscles of its females.

Within the same section of the cooling pond, the content of ^{137}Cs in the muscles of *L. cephalus* did not depend on the type of its food.

For the most part the content of ^{137}Cs in the muscles of *L. cephalus* increased with increasing the temperature of water. Sometimes, this relationship was not distinct. However, the content of ^{137}Cs in the muscles of *L. cephalus* never decreased with increasing the temperature of water.

After the removal of the Chernobyl NPS from operation, the content of ^{137}Cs in *L. cephalus* increased in May and August and decreased in winter. In 2003 and 2004, the maximal content of ^{137}Cs in *L. cephalus* was observed in August.

Relationship was established between the content of ^{137}Cs and the mass of *L. cephalus*. Only in a set of samples taken on 7 June 2004, the content of ^{137}Cs decreased with increasing the mass of its specimens.

Within the same water body, the content of ^{137}Cs in *L. cephalus* can depend on the degree of its radioactive contamination. In the northern part of the Pripyat River heavily polluted by radionuclides, the content of ^{137}Cs in *L. cephalus* was several times higher than that in its specimens taken from the northern part of the river.

Dynamics of ^{137}Cs content in *L. cephalus* occurring in the Kanev Reservoir were closely similar to those registered in benthos-phagous species occurring in this water body. From 1987 until 1995, the content of ^{137}Cs in *L. cephalus* decreased from 100 to 20 Bq/kg. In 1995–2007 its content varied from 6 to 21 Bq/kg.

From 1994 until 2006 in *L. cephalus* occurring in the cooling pond of the Chernobyl NPS, the content of ^{137}Cs decreased by a factor of 2.

From 1987 until 2001 in *L. cephalus* occurring in the Kanev Reservoir, the values of ^{137}Cs concentration factor increased from 440 to 1700. Only after 2001 they somewhat decreased. In 1994–2006 in *L. cephalus* occurring in the cooling pond of the Chernobyl NPS, the values of ^{137}Cs concentration factor were somewhat higher (1000–1800). They also increased with time. It is likely that the increase in the values of ^{137}Cs concentration factor in *L. cephalus,* and also in some other species of fishes was conditioned by a predominance of the rate of ^{137}Cs accumulation over the rate of its release from fish organism.

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Effect of Microwave Irradiation on Growth and Photoluminescence Efficiency of the Green Alga *Chlamydomonas actinochloris*[†]

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Paper deals with the effect of the microwave irradiation of decimeter diapason on the green alga *Chlamydomonas actinochloris* Deason et Bold. Cells number dynamics and changes of luminescence spectra of samples after irradiation was studied. Dependence of these parameters on physiological state of the studied objects and radiation dose was revealed. Stimulating effect of the certain irradiation conditions was noted.

KEYWORDS*: algae*, *microwave irradiation*, *photoluminescence*.

Introduction

Microwave irradiation, as ecological factor, is increasingly common in daily life because of development of advance technologies, based on this type of radiation. However, along with profits of use of the cell phones, microwave ovens, and some other devices, it is important to take into account ecological risks resulting from such technologies.

Plants' response to irradiation depends on environmental factors and physiological state of the plant. For instance, dependently of the season, irradiation can bring the plant out of dormancy state and stimulate physiological processes, or lead to the depressive state or even to death [4].

The aim of this work was to study response of the green alga *Chlamydomonas actinochloris* to influence of the microwave irradiation of decimeter diapason. For this purpose we studied effect of different doses of microwave irradiation on the cells number in culture and their functional state (by photoluminescence efficiency of samples).

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Material and Method

Culture of the green alga *Chlamydomonas actinochloris* Deason et Bold (ACKU, № 706-06) was used in experiments. Effect of both low and high irradiation doses on samples in different physiological state was compared. Particularly, the first experimental group contained algae in the monad (mobile) state, and the second contained algae in the palmeloid state, that is cells were immobile.

Experimental samples (100 ml of the cell suspension in the glass vessel) were irradiated using standard household microwave oven. It was operated by magnetron with generation frequency $\nu = 2450$ MHz, which corresponded to frequency of some anthropogenic sources (wave length $\lambda \cong 12$ cm). Temperature of suspension was measured before and after irradiation. Absorbed dose D was calculated by the formula:

$$D = c\,(t_2 - t_1),$$

where: $c = 4.2$ J/(g·°C) – specific thermal capacity of water; t_1 and t_2 – initial and final temperature of suspension [2]. When samples where exposed to irradiation for 10, 20 and 30 sec, temperature increased to 35°, 45° and 55°C, correspondingly, and absorbed doses amounted to 45, 85 and 130 J/g, correspondingly. Samples not exposed to irradiation served as control.

Photoluminescence was excited by irradiation of the argon laser with the wave length 488 nm and power 19 mV. Spectra were measured on the 1st and 7th day after irradiation. In order to increase quantum efficiency of luminescence and, accordingly, to diminish experiment errors, studied samples were cooled to the temperature of the liquid nitrogen (80 K). In the studied spectra intensity was proportional to energy per unit of the spectral interval. Cells number in samples was calculated on the 1st, 2nd, 5th and 7th day of the experiment.

Results and Discussion

As it is known, photoluminescence intensity is connected with photosynthesis intensity in the plants; it may reflect their functional state [1]. In our experiments luminescence efficiency of culture in the monad state on the first day of the experiment, that is immediately after irradiation, depended on the absorbed dose. Particularly, irradiation led to decrease of the luminescence intensity (Fig. 1). In culture in palmeloid state, luminescence intensity of the experimental and control samples differed insignificantly. For all obtained spectra two stripes were character: relatively narrow one with maximum about $\lambda_1 = 685$ nm, and wide one with maximum within the interval $\lambda_2 \approx 710 \div 720$ nm. There is an opinion [1], that peak about $685 \div 692$ nm corresponds to chlorophyll *a* of photosystem II, at the same time stripe about $714 \div 726$ nm corresponds to photosystem I.

In the 7th day of experiment photoluminescence intensity of all samples increased, first of all because of algae biomass growth. Because algae numbers in different samples were different, obtained photoluminescence spectra were brought to the equal cell numbers in order to exclude effect of biomass growth on intensity (Fig. 2, 3). For this purpose numerical characteristics of each spectrum were divided by per cent index of cell numbers relative to control sample.

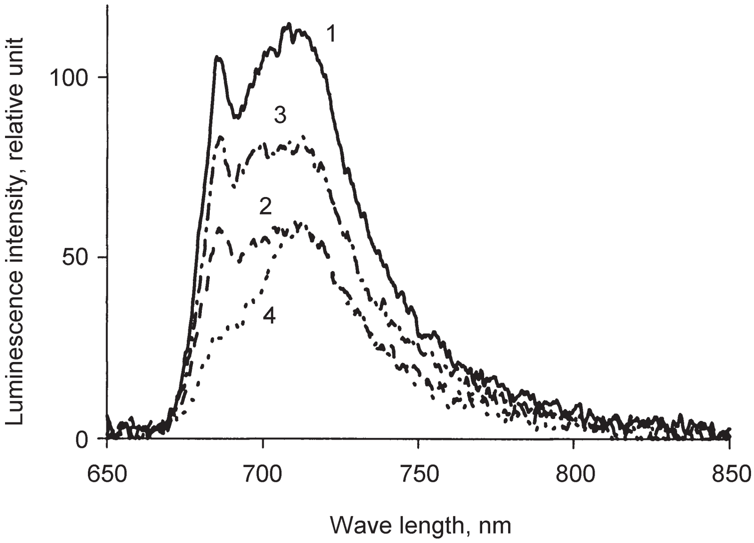

Fig. 1. Photoluminescence spectra of *Ch. actinochloris* (monad state) on the 1st day after microwave irradiation. Here and in the Fig. 2–5: *1* – control; *2* – exposition 10 sec (45 J/g); *3* – exposition 20 sec (85 J/g); *4* – exposition 30 sec (130 J/g).

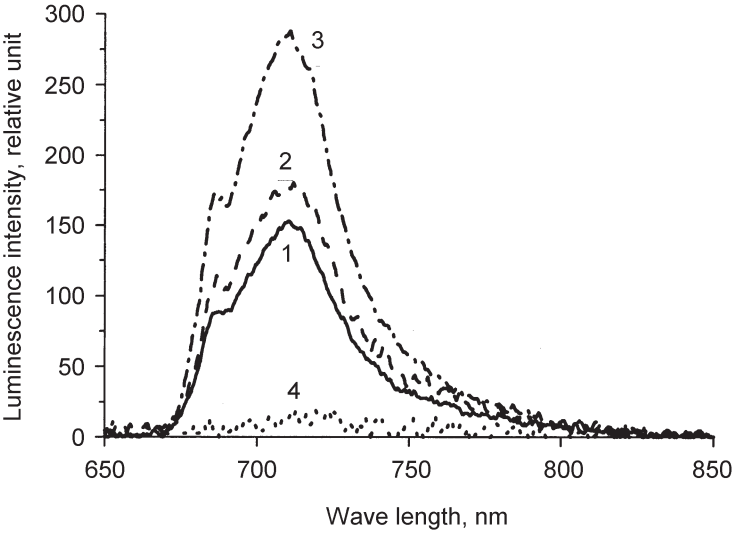

Fig. 2. Photoluminescence spectra of *Ch. actinochloris* (monad state) on the 7th day after microwave irradiation.

Effect of the 10-second irradiation depended on physiological state of cells. Thus, in cells in monad state occurred somewhat stimulation of intracellular processes and intensity of experimental

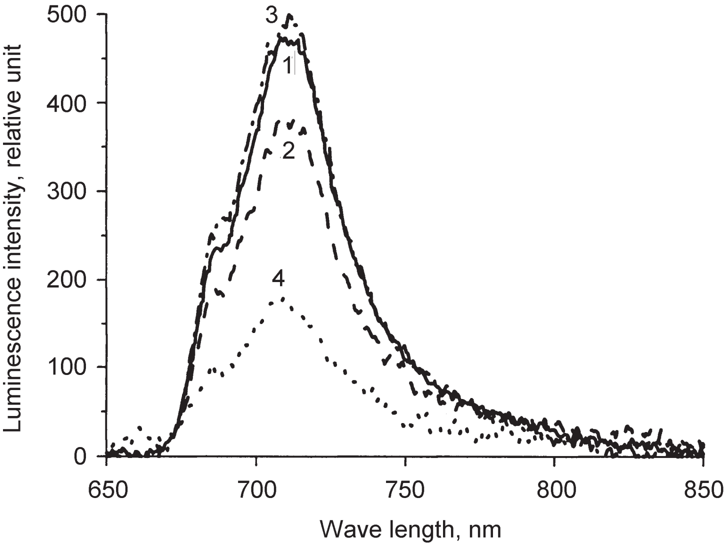

Fig. 3. Photoluminescence spectra of *Ch. actinochloris* (palmeloid state) on the 7th day after microwave irradiation.

spectra exceeded control one to some extent. In cultures in palmeloid state luminescence of the experimental sample was clearly lower than in control.

20-second irradiation of algae in the monad state significantly stimulated luminescent processes (see Fig. 2), because luminescence effectiveness of the experimental sample was significantly higher than control and irradiated during 10 seconds. On the contrast, 30-second irradiation practically totally suppressed luminescent processes. Luminescent intensity of samples in palmeloid state irradiated for 20 seconds to some extent exceeded control and other variants (see Fig. 3). In both cases at irradiation dose 130 J/g luminescence decreased as compared with control, and dose 85 J/g, on the contrast, increased it. Analysis of the obtained results with account of the cell numbers variability during the experiment was of special interest.

As results of the experiment showed, irradiation influenced luminescent processes and cell number dynamics as well. Thus, at exposition 20 seconds cell number in culture in the monad state increased in the 7th day of the experiment (Fig. 4). When this culture was affected during 30 seconds, cells number significantly decreased. Irradiation of culture in palmeloid state was not so damaging for its further development at maximal exposition (Fig. 5). Instead of somewhat decrease of the cell numbers immediately after irradiation, to the 7th day of experiment it notably increased. Gradual growth of the cell number was noted also in other variants, but there was no peak exceeding control. Probably, this can be explained by metabolism deceleration, character for plants in dormancy state.

Ambiguity of irradiation effect of small doses on functional state of algae in monad state can be explained by follows reasons. 20-second irradiation (85 J/g) was more damaging as compared with 10-second (45 J/g), it caused death of the cells and at least suppressed their reproduction. Only the

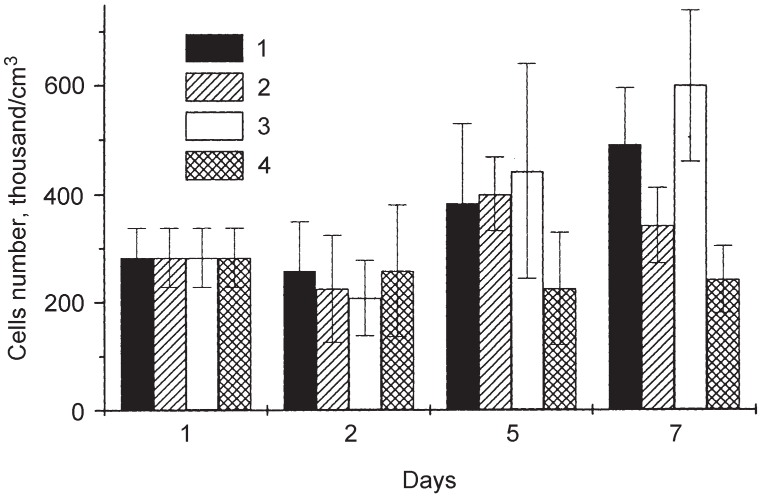

Fig. 4. Dynamics of *Ch. actinochloris* cell number (monad state) dependently on irradiation dose (duration).

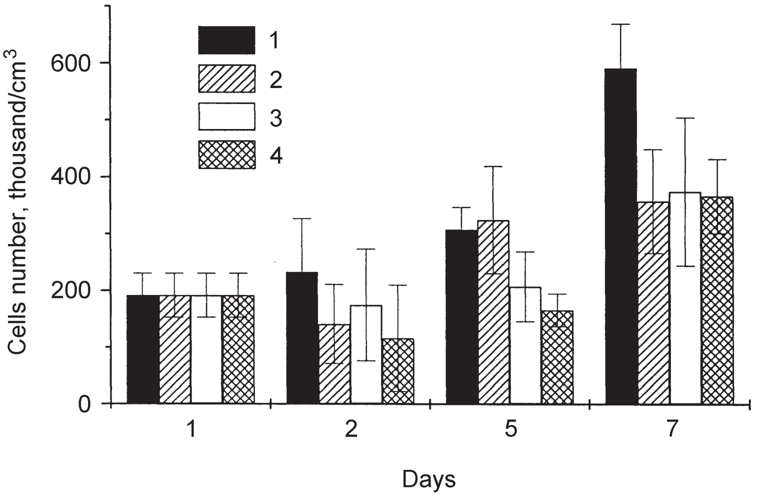

Fig. 5. Photoluminescence spectra of *Ch. actinochloris* (palmeloid state) on the 7th day after microwave irradiation.

most adapted cells survived, they quickly restored after stress and intensively reproduced, because there was no concurrence of the lysed cells. Consequently, they were in better functional state, and intensity of luminescence on average was higher. By this reason total number of cells in the monad culture, affected by 85 J/g in the 7th day was higher than those effected by 45 J/g, and luminescence intensity calculated in terms of cell number was even higher than in control group.

It is worth noting that similar results were obtained at investigation of the microwave irradiation effect on the egg sets of the mosquito *Culex pipiens molestus* Forskal [3]. Elevation of irradiation doses decreased portion of the survived larvae, however their development became more intensive. Thus, after irradiation of the maximal vital dose, larvae were the first who completed development cycle, however only 67% specimens reached imago stage, and in control – 89%.

Conclusion

Microwave irradiation influenced growth and luminescence properties of the green alga *Ch. actinochloris*. Peculiarities of influence depended on both absorbed dose and physiological state of the cell itself.

Irradiation dose 85 J/g stimulated intracellular processes. It was confirmed by increase of biomass and photoluminescence intensity.

Irradiation dose 130 J/g, on the contrast, suppressed cellular metabolism, led to sharp decrease of biomass and photoluminescence intensity.

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