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The structural analysis of the flora of water bodies of Poltava city

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The species composition of the flora of water bodies and watercourses of Poltava city (174 species of higher macrophytes) was clarified and its structural analysis was carried out. The leading role of synanthropization processes of riparian biotopes in the forming of water bodies floristic diversity was noted. The typical and specific features of aquatic flora, related with natural conditions and anthropogenical influence on the urbanized area, were determined. Among 55 species of higher aquatic flora 2 ones are new for the researched region.
Keywords: flora of water bodies, aquatic flora, higher plants, structural analysis, urbanized area, Poltava city.

Установлен видовой состав флоры водоемов и водотоков г. Полтавы (174 видов высших макрофитов) и проведен ее структурный анализ, отмечена ведущая роль процессов синантропизации околоводных местопроизрастаний в формировании разнообразия флоры водных объектов. Выделены типичные и особенные черты водной флоры в связи с природными условиями и антропогенным влиянием на урбанизированной территории. Среди 55 видов водной флоры 2 являются новыми для района исследований.
Ключевые слова: флора водных объектов, водная флора, высшие растения, структурный анализ, урбанизированная территория, г. Полтава.

Introduction. The intensity of human impact on natural systems is particularly high in urban areas. One of the main, but also the most vulnerable and often not sufficiently investigated components of urban landscape are polytypic water bodies, which ecosystems are constantly deteriorating. In conditions of urbanization it is caused by both direct (pollution of water, hydrotechnical constructions, recreation) and indirect (transformation of catchment areas) forms of anthropogenic influence. The reactions of autotrophic component of urban hydroecosystems, first of all communities of higher aquatic vegetation, are the most typical markers of environmental violations. This is reflected in disproportionate overgrowth of water areas, depletion of phytobiota's species and coenotic composition, growth of filamentous algae coenotical activity etc. The first stage in cognition the ecological state of urban reservoirs and streams is the study of their flora.

The study of vegetation of urban water bodies was carried out in the cities of Kyiv (by G.A. Karpova, L.N. Zub, A.L. Savitsky, D.V. Dubyna et al.), Lvov (R.N. Danylyk), Samara (V.V. Solovyova), Rybinsk (O.G. Krylova), Tomsk (I.V. Sukhanova), towns of Udmurtia (O.A. Kapitonova) and some others.

The aim of this work is structural analysis of higher flora of Poltava city water bodies.

The literature with scattered data on the flora and vegetation of water bodies in the city of Poltava was accumulated. The most complete study of flora and vegetation of the city and its suburban neighborhoods was held in the first quarter of the 20th century by S.O. Illytchevsky, who among of 972 identified species of vascular plants noted 26 species of aquatic and 48 ones of riparian habitats [1]. At present stage some data on the flora of Poltava city presented in floristic summaries by natural [2] and administrative [3], [4] regions, as well as in materials of researches of urbanoflora of Poltava [5]. However, no special study of the flora of Poltava water bodies and streams until recently was conducted.

Materials and methods. Poltava (49º15' N 34º33' E) is the administrative center of the Poltava region, significant industrial and cultural center of the Middle Dnieper Area. The city area is 103,5 km^2 and the number of its population is 295,0 thousand people (2015). According to geobotanical zoning [6], the city is located within the Dykan'sko-Kotelevsky geobotanical region, the Romensko-Poltavsky geobotanical district, the Left-Bank Dnieper Area subprovince, the Eastern Europe province, Euro-Siberian Forest-Steppe area.

The hydrographic network of Poltava city is based on the average river Vorskla with the system of its small tributaries, most of which are regulated by dams. Our survey covered 22 water bodies of different types: the average river (urbanized segment of the river Vorskla about 9 km in length), the

small river, the ox-bow lake, the quarry-type reservoirs, earth reservoirs and ponds. Floristic data collection occurred during field seasons 2011–2013 by traditional methods [7]. According to the conventional approach [8], [9], [10], we have studied flora of water bodies in a broad sense as a totality of species of aquatic and coastal plants that come in into the water, i. e., growing not only in water but also on dry off shallow water and on the shore in the temporary flooding zone.

Results and their discussions. Researched flora of urban waterbodies and watercourses of Poltava includes 174 species of higher plants from 115 genera, 52 families and 37 orders, 5 classes, 4 divisions. Higher spore plants are presented by 5 species (2,9 %) from 3 divisions (*Briophyta* – 1, *Equisetophyta* – 3, *Polypodiophyta* – 1), angiosperms – by 169 species, including 111 species (63,8 %) – *Magnoliopsida*, 58 species (33,3%) – *Liliopsida*. Vascular plants are 173 species, representing 10,8 % of the Left Bank Dnieper Area's flora [2] and 29,4 % of urbanoflora of Poltava city [5].

In accordance with the ecological classification of V.G. Papchenkov [9], studied flora represented by five ecotypes (table 1): hydrophytes – 25 species (14,4 %), helophytes – 13 species (7,4 %), hygrohelophytes – 17 (9,8 %), hygrophytes – 55 (31,6 %), hygromeso- and mesophytes – 64 species (36,8 %). Thus, aquatic flora that formed by plants of first three ecotypes, together account for 55 species, or 31,6 % of the flora list. While the species of coastal flora, that only indirectly related to the aquatic environment (hygrophytes, hygromeso- and mesophytes), significantly prevail (119, or 68,4 % of the flora list).

Table 1 – The ecological structure of higher flora of water bodies of Poltava city

Group of ecotypes	Ecotype, ecological group	Number of species		
		absolute	% of flora of water bodies	% of aquatic flora
True aquatic plants	*Hydrophytes*	*25*	*14,4*	*45,5*
	Aquatic mosses	1	0,6	1,8
	Hydrophytes free floating in the water	5	2,9	9,1
	Rooted submerged hydrophytes	11	6,3	20,0
	Rooted hydrophytes with leaves floating on the water	4	2,3	7,3
	Hydrophytes free floating on the water	4	2,3	7,3
Riparian-aquatic plants	*Helophytes (air-water plants)*	*13*	*7,4*	*23,6*
	Low-grass helophytes	6	3,4	10,9
	High-grass helophytes	7	4,0	12,7
	Hygrohelophytes (water's edge plants)	*17*	*9,8*	*30,9*
Total of aquatic flora		55	31,6	100,0
Coastal plants	*Hygrophytes*	*55*	*31,6*	–
	Hygromeso- and mesophytes 64 36,8			–
Total of flora of water bodies		174	100,0	–

However, according to some authors [11], [10], the share of coastal component in the flora of natural reservoirs normally does not exceed 40–50 %, i. e. the disproportion between aquatic and coastal components for the flora of water bodies of Poltava city is approximately 8–18 %. The explanation for this, in our view, may be two reasons.

Firstly, it is the prevalence among the studied water bodies typical for the urbanized landscape small artificial reservoirs (ponds, earth reservoirs) and gain the influence of heterogeneous conditions of ecotonic zone in the formation of floral diversity of hydroecosystems, which aquatic environment is more unvaried (a small water volume, simple bottom relief, sharp drop of depths) and often less favorable in their hydrological (emergency water level fluctuations) and hydrochemical (high contamination with low water exchange) features. This is confirmed by the similarity in the distribution of species by ecotypes for studied flora and floras of small artificial water bodies in certain areas within the temperate zone of the Russian Federation [8], [12] (table 2).

Table 2 – The ecological spectra of floras of Poltava city water bodies (A), pasture earth reservoirs of Yaroslavl region (B, [8]) and technical and natural reservoirs of the Middle Volga Area (C)

Ecotype	Relative number of species (%)		
	A	B	C
Hydrophytes	14,4	12,3	20,1
Helophytes	7,4	7,7	7,3
Hygrohelophytes	9,8	16,1	5,2
Total of aquatic flora	31,6	36,1	32,6
Hygrophytes	31,6	38,1	34,9
Hygromeso- and mesophytes	36,8	25,8	32,5
Total of coastal flora	68,4	63,9	67,4
Total of flora of water bodies	100,0	100,0	100,0

Secondly, the high species diversity of coastal flora caused by the participation of more xerophilous synanthropic plants, that actively capture the secondary habitats widespread in the urban environment on the area of temporary flooding (due to trampling, breeding bonfires, resettlement places for fishing and other infringement of natural vegetation cover). The part of synanthropic species increases sharply from ecotypes of aquatic flora to ecotypes of coastal flora (table 3). It indicates on xerophytization processes of natural coastal flora under the influence of human activities [13].

Table 3 – The ecological structure of synanthropic component of higher flora of water bodies of Poltava city

Ecotype / Synanthropic component	Aquatic flora			Coastal flora	
	Hydrophytes	Helophytes	Hygro-helophytes	Hygrophytes	Hygromeso- and mesophytes
Apophytes	–	–	–	16	33
Alien species	1	1	1	8	18
Archaeophytes	–	–	1	2	6
Kenophytes	1	1	–	6	12
Total	1	1	1	24	51
	3			76	

To enable more adequate comparison of floras of various water objects is important a study and structural analysis of not only the full list of plants, but first of all that its part, which combines species of aquatic flora immediately (in the understanding of V.G. Papchenkov [9]) – true aquatic plants (hydrophytes) and riparian-aquatic plants (helophytes and hygrohelophytes). The plants of these ecotypes in the flora of water bodies are the most dependent on the state of aquatic environment, so they can reflect ecological status of aquatic ecosystems and their main ecological processes.

The systematic structure of higher aquatic flora of water bodies of Poltava city is presented by 55 species, which belong to 36 genera, 25 families, 19 orders, 5 classes, 4 divisions – *Briophyta*, *Equisetophyta*, *Polypodiophyta* (by one species) and *Magnoliophyta* (52 species, or 94,5 %), among that 15 species (27,3 %) are dicotyledonous and 37 species (67,3 %) are monocotyledonous.

Thus, the proportion of monocotyledonous and dicotyledonous is approximately 1:2, which is quite typical for hydrophylic flora [14]. Vascular plants are 54 species, which represents 75,0 % of selected by us the aquatic component of flora the city of Poltava and its surroundings [1], and 50,5 % of the flora of the Left-bank Forest-steppe reservoirs.

Ratio of families, genera and species of studied higher aquatic flora determines its proportion as 1:1,44:2,2 and describes it as a relatively young and poorly differentiated, which is also reflected in the range of leading families and genera. Thus, in the six leading families there are 29 species, or 52,7 % of studied aquatic flora: *Cyperaceae* (8 species), *Potamogetonaceae* (7), *Poaceae* (5), *Lemnaceae*, *Lentibulariaceae*, *Typhaceae* (by 3 species). Another 7 families contain on 2 species (25,5 % of aquatic flora), the remaining 12 families have only by one species and form 21,8 % of aquatic flora. This distribution of families at the first three ranked places fully corresponds to aquatic flora of water bodies of Tomsk [15], situated in zone of subtaiga, what emphasize the azonal

character of aquatic floras and similar way of their formation in conditions of urbanized environment. The qualitative composition of the first three families (without rank accordance) coincide with those for hydrophylic flora of the Lvov city [16], as well as flora of the Left-bank Forest-steppe reservoirs [12].

In genera spectrum there are four leading ones, which represented by 18 species, or 32,7 % of studied aquatic flora: *Potamogeton* (7 species), *Carex* (5), *Utricularia*, *Typha* (by 3 species); 5 genera have by 2 species (*Myriophyllum, Sium, Phragmites, Lemna*, *Sparganium*) – they account for 10 species, or 18,2 %; most genera (27) contain only one species, forming 49,1 %.

Ecologically among ecotypes of studied aquatic flora the true aquatic plants (hydrophytes, or fraction of «water core») naturally dominate (25 species, 45,5 %). The only representative of aquatic mosses is *Drepanocladus aduncus* (Hedw.) Warnst. Among vascular true water plants the group of rooted submerged hydrophytes quantify prevails (*Batrachium trichophyllum* (Chaix) Bosch, *Myriophyllum spicatum* L., *M. verticillatum* L., *Potamogeton crispus* L., *P. lucens* L., *P. pectinatus* L., *P. perfoliatus* L., *P. trichoides* Cham. & Schlecht., *Elodea canadensis* Michx., *Caulinia minor* (All.) Coss. & Germ., *Najas major* All.) – 11 species, or 20,0 %. The ecological group of submerged hydrophytes free floating in the water (*Ceratophyllum demersum* L., *Utricularia australis* R. Br., *U. minor* L., *U. vulgaris* L., *Lemna trisulca* L.) presented by 5 species, or 9,1 % of studied aquatic flora. There is equal number of species in ecological groups of rooted hydrophytes with leaves floating on the water (*Nuphar lutea* (L.) Smith, *Persicaria amphibia* (L.) Delarbre f. aquatica, *Potamogeton natans* L., *P. nodosus* Poir.) and hydrophytes free floating on the water (*Salvinia natans* (L.) All., *Hydrocharis morsus-ranae* L., *Lemna minor* L., *Spirodela polyrrhiza* (L.) Schleid.) – by 4 species, or by 7,3 %. In part of detected species of «water core» of the flora the indicators of eutrophic low flow water, prone to waterlogging, prevail [17].

The ecological type of helophytes, or air-water plants, is the least numerous in studied flora and contains 13 species (23,6 %), including 6 species (10,9 %) from the group of low-grass helophytes (*Equisetum fluviatile* L., *Butomus umbellatus* L., *Alisma plantago-aquatica* L., *Sagittaria sagittifolia* L., *Sparganium emersum* Rehman, *S. erectum* L.) and 7 species (12,7 %) from the group of high-grass helophytes (*Scirpus lacustris* L., *Glyceria maxima* (C. Hartm.) Holmberg, *Phragmites altissimus* (Benth.) Nabille., *Ph. australis* (Cav.) Trin. ex Steud., *Typha angustifolia* L., *T. latifolia* L., *T. laxmanii* Lepech.).

The ecological type of hygrohelophytes, water's edge plants, presented by 17 species (30,9 % of studied flora) (*Rumex hydrolapathum* Huds., *Rorippa amphibia* (L.) Besser, *Lythrum salicaria* L., *Sium latifolium* L., *S. sisaroideum* DC., *Veronica anagallis-aquatica* L., *Iris pseudacorus* L., *Bolboschoenus maritimus* (L.) Palla, *Carex acuta* L., *C. acutiformis* Ehrh., *C. pseudocyperus* L., *C. riparia* Curtis, *C. vesicaria* L., *Eleocharis palustris* (L.) Roem. et Schult., *Agrostis stolonifera* L., *Catabrosa aquatica* (L.) P. Beauv., *Acorus calamus* L.).

The prominent role in aquatic flora of riparian-aquatic plants, which are presented by the last two ecotypes (whole 30 species, or 54,5 %), is determined by spreading in the studied water bodies appropriate habitats – shallow water, wetlands, waterlogged banks, due to both natural causes and hydrotechnical transformation of urban area.

On the life-form spectrum by the system of I.G. Serebryakov studied flora fully formed by herbaceous plants, that is quite reflects the specific of aquatic floras. For the duration of the life cycle the vast majority are perennials (48 species, or 87,2 %), 3 species (5,5 %) are annuals (*Salvinia natans*, *Caulinia minor*, *Najas major*) and 4 species (*Hydrocharis morsus-ranae*, *Potamogeton crispus*, *P. pectinatus*, *P. trichoides*), or 7,3 % of aquatic flora, depending on conditions can be both biennials and perennials. Aquatic macrophytes are often the perennials, because (due to inhibition of sexual process in often adverse conditions of temperature of water) vegetative reproduction significantly predominates over generative.

According to the classification of life forms by K. Raunkiaer, hemicryptophytes are the most widely presented (16 species, 29,1 %), slightly less geophytes (15 species, 27,3 %), helophytes (11 species, 20,0 %) and hydrophytes (10 species, 18,2 %), terophytes are only 5,4 % of all studied flora. The prevalence of hemicryptophytes is typical for moderately cold areas and monitored in many hydrophilic floras of Ukraine, including the hydrophilous flora of Forest-steppe of Ukraine [18].

In establishing the geographic structure of studied aquatic flora it was composed the chorological spectra of species in accordance with their zonal and regional position and oceanic-continental attachment, based on botanical-geographical zoning of the world [19] and its adaptation for the flora of reservoirs of Ukraine [20].

At zonal chorological spectrum among nine selected geographical elements of the flora the representatives of plurizonal group significantly prevail (23 species, 41,8 %), the representatives of boreal-submeridional and boreal-meridional groups also provide a notable contribution (10 species, or 18,2 %, and 8 species, or 14,6 %, appropriately). Other groups considerably depleted: temperate-meridional and temperate-submeridional – by 5 species (by 9,1 %), boreal, boreal-temperate, temperate-tropic and submeridional-meridional – by 1 species (by 1,8 %). The quantitative prevalence of species of plurizonal and boreal-submeridional chorological groups also is characteristic for floras of the Left-bank Forest-steppe reservoirs [12] and the reservoirs of Ukraine [20] (table 4).

Table 4 – The chorological spectra of aquatic flora of water bodies of Poltava city (A), the flora of the Left-bank Forest-steppe reservoirs (B, [21]), the flora of reservoirs of Ukraine (C, [20])

The chorological spectra of floras		A	B	C
Zonal chorological groups	plurizonal	41,8	34,9	22,5
	boreal	1,8	–	–
	boreal-submeridional	18,2	23,0	17,9
	boreal-temperate	1,8	7,3	7,6
	boreal-meridional	14,6	9,2	7,2
	temperate-tropic	1,8	4,6	4,6
	temperate-meridional	9,1	7,3	11,8
	temperate-submeridional	9,1	11,9	17,4
	submeridional-meridional	1,8	1,8	10,8
Regional chorological groups	cosmopolite	12,7	8,3	5,1
	circumpolar	43,7	47,7	35,8
	european	1,8	7,3	14,3
	eurasian	29,1	25,7	32,8
	eurosiberian	12,7	11,0	7,2
	euro-northamerican	–	–	4,8
Climatic types of areals	euoceanic-suboceanic and suboceanic – 1,8 7,7			
	euryoceanic	30,9	32,1	32,3
	suboceanic	–	–	3,6
	eucontinental-subcontinental and subcontinental	–	2,8	5,1
	eurycontinental	10,9	8,3	13,8
	indifferent	58,2	55,0	37,4

Boreal group as a whole is not characteristic for mentioned hydrophilous floras, allocated at the level of vascular plants, in the studied flora of higher macrophytes represented by hydrophilic spices of mosses, for which in bryoflora of Left-bank Forest-steppe [22] boreal origin is rather typical. Low share of species of submeridional-meridional group in the studied flora and flora of Forest-steppe reservoirs on the whole explained by atypicity to this physical-geographical zone of southern species, that quite numerically found (10,8 %) in the flora of reservoirs of Ukraine [20] mainly through the steppe zone. In particular, the sole representative of this southern group at the studied flora is alien helophyte *Phragmites altissimus*, which in recent years has active promotion to north of Europe [23]. The temperate-tropical group also has low representation in all compared floras, mainly because it includes more southern and rare in Ukraine species. So the only representative of this group at the studied flora is *Utricularia australis*, which is listed in the third edition of the Red Book of Ukraine and for the forest-steppe zone was given by us at first [24].

At regional chorological spectrum among five selected types of areals on a regional spread the species of circumpolar (43,7 %) and eurasian (29,1 %) groups make up the majority. Mentioned chorological groups similarly lead in the floras of the Left-bank Forest-steppe reservoirs and the reservoirs of Ukraine. Cosmopolite, eurosiberian (by 12,7 %) and european (1,8 %) species presented significantly fewer. The leading positions of species with wide areals are typical for hydrophilic floras, because the aquatic environment is conservative and only slightly dependent on zonal-climatic factors.

At oceanic-continental chorological spectrum it was identified 3 types of areals, that in order to reduce the number of species are located as follows: indifferent type (58,2 %), euryoceanic (30,9 %), eurycontinental (10,9 %). In other words, in the highest participation of species with areals without specific climatic attachment, among other oceanic species almost triple prevail over continental, that corresponds to the distribution of species by climatic types of their areals in the flora of reservoirs of Ukraine.

So studied higher aquatic flora of water objects of Poltava city is heterogeneous in its origin: there are species of 9 zonal, 5 regional and 3 climatic chorological groups. The main role in formation of studied flora belongs to species with wide areals: plurizonal, boreal-submeridional and boreal-meridional (as a whole 74,6 %), among that there are circumpolar and eurasian species of indifferent and euryoceanic climatic attachment.

During the research it was discovered 2 new taxa for the region: *Utricularia australis* – for the Forest-steppe of Ukraine [24], *Phragmites altissimus* – in the rank of species to Ukraine [25], [24]. The alient component in studied aquatic flora presented by three species: 1 achaeophyte (*Acorus calamus*) and 2 kenophytes (*Phragmites altissimus* – eurosiberian species of Iranian-Turanian origin and *Elodea canadensis* – plurizonal cosmopolite of North American origin).

Six species of higher aquatic plants have the sozological value in studied flora: 3 species – *Utricularia australis*, *U. minor*, *Salvinia natans* – listed in the third edition of Red Book of Ukraine, the last species there is in first supplement to Bern Convention, 4 species (*Nuphar lutea*, *S. natans, U. minor, Potamogeton trichoides*) – included to Red List of macrophytes of Ukraine [17], 2 species (*S. natans, Nuphar lutea*) are rare within the Forest-Steppe zone [18], 2 species (*U. vulgaris* and *U. minor*) are rare within the Poltava region. 2 species (*Nuphar lutea, S. natans*) are the dominants of communities, listed in the Green Book of Ukraine. The absolute majority of rare plant species timed to ecotops of the river Vorskla, that may indicate a higher resistance of average river's ecosystem to anthropogenic transformation under the influence of urban environment.

Conclusions. Thus, the flora of water objects of Poltava city has a high degree of synanthropization due to the active participation of species, timed to disturbed areas of coastal zone, particularly alien floral elements. The aquatic flora, picked out as a totality of true aquatic plants and riparian-aquatic plants, is quite typical by its geographical and biomorphological indices but depleted in comparison with hydrophilic natural flora of the region and of the historical data, which may indicate its high vulnerability in the current conditions of urban environment. Ecological structure of studied aquatic flora reveals the prevalence in water bodies of Poltava city processes of shallowing and waterlogging.

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