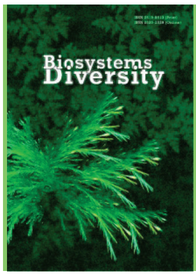

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Diversity and dynamics of hydrophilic flora of Lowland Polissya (on the example of the Sluch River basin)

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Study and analysis of hydrophilic flora diversity are important parts of environmental research due to various functions of vascular macrophytes in freshwater ecosystems, which deteriorate under the influence of anthropogenic activity and climate change. The aim of this study is to analyze the hydrophilic flora diversity (taxa, biology, ecology, and conservation status of species) and current population trends in the Sluch River basin, the largest tributary of the Horyn River (the Pripyat River basin), within the Polissya Lowland in the northern-west region of Ukraine. The list of hydrophilic flora is based on materials of the authors' field researches in 2014–2020 within the upper and middle parts of the river basin, herbarium materials, and archive data. The study shows that the natural flora consists at least of 105 species of vascular plants belonging to 66 genera, 36 families, and 22 orders. Structural analysis shows the predominance of a few families in the systematic structure of the flora (Cyperaceae, Potamogetonaceae, Poaceae, Ranunculaceae, Plantaginaceae, and Typhaceae) and genera (*Potamogeton*, *Carex*); the dominant categories are hemicryptophytes and geophytes, entomophiles and anemophiles, heliophytes and hygrohelophytes. C- and S-strategists are dominant. This is the generally typical taxonomic and ecological structure of the hydrophilic flora of water bodies in the Pripyat River basin. The list of rare species includes 20 species from 15 genera and 12 families, for instance, species listed as vulnerable in The Red Book of Ukraine (*Juncus bulbosus*, *Utricularia intermedia*, *Nymphoides peltata*). Even rare and vulnerable species can form numerous populations in some localities, for example, *Nymphoides peltata* and *Calla palustris*. Five alien species were identified (*Acorus calamus*, *Elodea canadensis*, *Zizania latifolia*, *Bidens frondosa*, and *Echinocystis lobata*), some of which tend to expand and displace aboriginal species. In the future, it will be important to further study the structure and changes in the hydrophilic flora of the region under conditions of anthropogenic impact, to monitor the dynamics of populations of alien species, and to develop conservation measures for rare species and communities.

Keywords: vascular macrophytes; rare species; alien species; the Pripyat River basin.

Introduction

Vascular macrophytes perform various functions in aquatic ecosystems: the plants synthesize primary organic matter, release oxygen into water, and fix atmospheric carbon; they are an organic substrate for river biocenoses generally. Communities of vascular aquatic plants are highly productive centers of biodiversity (French & Chambers, 1996; Gross et al., 2001; Grenouillet et al., 2002; Elser et al., 2007), create heterogeneous conditions in the aquatic environment and, accordingly, increase the number of ecological niches for animals, allow prey to avoid contact with predators (Harrel & Dibble, 2001; Rennie & Jackson, 2005; Dibble et al., 2006; Casartelli & Ferragut, 2018; Law et al., 2019). Rare species generally increase the aesthetic, cultural, and taxonomic value of biodiversity (Papchenkov, 2001; Mouillot et al., 2013; Adamec, 2018). In addition, macrophytes neutralize anthropogenic pollution of water bodies – they actively participate in self-purification processes, perform a barrier function by obstructing the flushing of organic and mineral pollutants from the catchment area into rivers and streams (Dhote & Dixit, 2009; O'Hare et al., 2018; Lv et al., 2019; Ganzha et al., 2020). At the same time, among the aquatic macrophytes, there are the most dangerous invasive weeds in the world due to their high productivity, wide ecological tolerance, ability to rapidly spread seeds and propagules (Pieterse & Murphy, 1993; Fleming & Dibble, 2015; Aronson et al., 2017). The analysis of the dynamics of distribution of rare and alien plant species is an important component of phytomonitoring of water bodies, with the ultimate goal of regulating their numbers and preventing negative changes (Protopopova et al., 2006; Bilz et al., 2011; The IUCN Red List of Threatened Species, 2014; Fleming & Dibble, 2015).

Study and analysis of hydrophilic flora diversity is an important part of environmental researches due to current trends of human impact and climate change. It is known from the literature that the greatest threat to aquatic plants in Europe is the direct loss of habitat as a result of ecosystem transformation (Bilz et al., 2011; Jones et al., 2020; Zarfl & Lehner, 2020); some wetlands and parts of them, or entire wetland complexes have been drained for agricultural needs in Europe and certain regions (Tena et al., 2017; Water and agriculture: towards sustainable solutions, EEA Report 17/2020). According to scientists, as a result of the drainage, Europe probably lost almost half of its wetlands, and this has necessitated the development of protection measures and implementation of projects to restore drained wetlands (Hughes, 2003; Dugan, 2005; Keddy, 2010). Among the anthropogenic threats to aquatic flora in Central and Eastern Europe, drainage reclamation and anthropogenic eutrophication are especially dangerous for the vegetation cover of water bodies (Dubyna et al., 1993; Smith, 2003; O'Hare et al., 2018). For example, the hydrophilic flora in the southern part of the Rivne region in Ukraine has been poorer than in its northern part as a consequence of the complex influence of abiotic conditions and anthropogenic impact on the water bodies, which include eutrophication and pollution (Grokhovskaya & Volodymyretc, 2015). Today, scientists in Western and Central Europe pay much attention to the study of the dynamics of invasive aquatic and wetland plants. A set of publications has been devoted to this topic (Havel et al., 2015; Hussner et al., 2017; Ribaudo et al., 2018; Bolpagni et al., 2020). They primarily draw attention to the spread of new species, analyze the factors that contribute to this process. This study aims to analyze the hydrophilic flora diversity (taxa, biology, ecology, and conservation status of species) and current population trends in the Sluch River basin within the Polissya Lowland in Ukraine.

Materials and methods

The objects of the study were water bodies in the Sluch River basin (within the upper and middle parts of the river) in the northern-west region of Ukraine. The Sluch River, the largest right-bank tributary of the Horyn River (the Pripyat River basin), flows through Zhytomyr and Rivne regions (Zhytomyr Oblast and Rivne Oblast). The basin is within the 16th European ecoregion by the Water Framework Directive (2000). The list of hydrophilic flora is based on materials of the authors' field researches, herbarium materials, and archive data. The collection and processing of material were carried out according to generally accepted methods (Katanskaja, 1981; Abakumov, 1983). Data for this study were collected in 2014–2020 during the period from May to September. The studies were conducted based on the Department of Aquatic Bioresources at the National University of Water and Environmental Engineering. The 8 sites were located on the main river (Sluch) and two of its tributaries (Korchyk and Chorna, Fig. 1, Table 1).

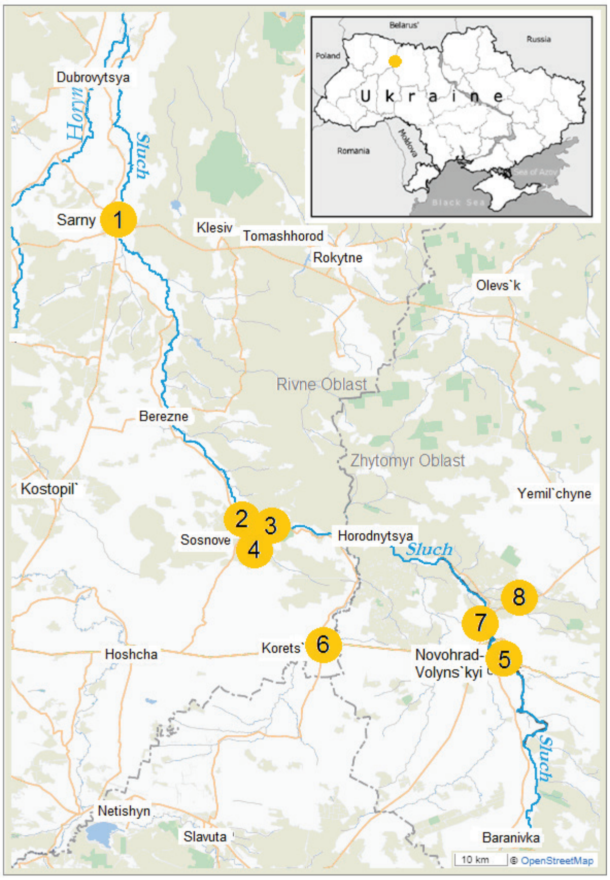

Fig. 1. Sampling sites in the Sluch River basin: rivers and sampling sites are listed in Table 1

The frequency of species occurrence was estimated based on sample plot descriptions (10 x 10 m) at a rate of 7 to 15 depending on local conditions. By scientific data, the hydrophilic flora includes all species that are typical aquatic and coastal aquatic plants. The list of macrophytes of Ukraine (Dubyna et al., 1993) and the world aquatic flora by Raspopov et al. (2011) was taken as a basis. The classification of flowering plants was given by the system of Angiosperm Phylogeny Group (2016). Conservation status of species was established by the Red Book of Ukraine (Didukh et al., 2009), a regional Red List (Danylyk & Volodymyrets, 2018), and The Red List of Water Macrophytes of Ukraine (Dubyna et al., 1993). Belonging to biological and ecological groups, the category of life strategies was established mainly due to scientific sources (Sculthorpe, 1967; Grime, 1977; Dubyna et al., 1993; Papchenkov, 2000, 2001; Raspopov et al., 2011). Alien species were analyzed according to generally accepted criteria (Protopopova & Shevera, 2005). Groups of alien plants by chronoelement were identified on the classification of Kornaš (1968).

Results

Taxonomic diversity. The natural hydrophilic flora of the river basin consists of at least of 105 species of vascular plants, which belong to 66 genera and 36 families (Table 2). The largest number of taxa was found in the middle part of the river (Table 1, sites 2–4).

Biomorphs. According to the classification of life forms, all species identified within the basin belong to the group of herbaceous plants. Of these, two species (*Callitriche palustris* and *Limosella aquatica*) are annual (1.9%), *Ranunculus sceleratus* – annual or biennial plant, and 102 are perennial (97.1%). Most higher aquatic plants are capable of vegetative propagation, which often predominates; some species under the conditions of the studied region reproduce exclusively in a vegetative way (alien *Acorus calamus* and *Elodea canadensis*). However, generative reproduction is in the first place for a few species such as *Caltha palustris* and *Ranunculus lingua*.

Climamorphs. According to plant life-form system, the species are distributed as follows: hemicryptophytes – 54 species (51.4%), cryptophytes – 46 species (geophytes – 36 species / 34.3%, hydrophytes – 10 species / 9.5%, and therophytes – 5 species / 4.8% (Fig. 3a).

Pollination. By the method of pollination, entomophily, or insect pollination, predominates – 50 species, which make up 48.5% of 103 flowering plants species (Fig. 3b). Anemophilous species (wind pollination) make up almost one-third (32 species / 31.1%). There is only one hydrophilous species (pollen is distributed by the flow of water) – *Ceratophyllum demersum*. Among the identified species, there are 20 species (19.4%) capable of pollination by several agents. For example, *Hottonia palustris* is pollinated with the help of wind and insects, *Stuckenia pectinata* – by wind and water flow, *Sparganium emersum* is usually pollinated by the wind, but also capable of self-pollination (autogamy).

Spreading. In terms of spread plant seeds and propagules method, the largest group is hydrochores (dispersal by water) – 72 species (68.6%). The next group by the number of species is zoochores (dispersal by animals) – 58 species (55.2%). The rest of the species can disperse seeds and propagules by wind – anemochory (28 species / 26.7%), by gravity alone – barochory (14 species / 13.3%), by humans – anthropochory (5 species / 4.8%), and without any help from an external vector – autochory (5 species / 4.8%). Only 31 species (29.5%) spread seeds and propagules in one way, such as hydrochory in *Utricularia intermedia*, or anemochory in *Phragmites australis*. Other plant species are capable of propagation by various agents (Fig. 3c).

Table 1
Sampling sites in the Sluch River basin

Site No.	Administrative location and site description	The distance from the mouth, km	The geographical coordinates	
1	The Sluch River near the city of Sarny, Rivne region	50.5	51°19'02" N	26°38'10" E
2	The Sluch River near the town of Sosnove in Berezne district, Rivne region	134.0	50°49'43"N	27°00'50"E
3	The Sluch River near village Hubkiv in Berezne district, Rivne region	137.0	50°49'19"N	27°03'18"E
4	The Sluch River near vil. Marynyn in Berezne district, Rivne region	143.0	50°49'03"N	27°06'55"E
5	The Sluch River in the city of Novohrad-Volynskyi, Zhytomyr region	201.7	50°35'51"N	27°37'28"E
6	The Korchyk River near the city of Korets, Rivne region	38.3	50°36'15"N	27°08'11"E
7	The Vershnytsya River near vil. Chyzhivka in Novohrad-Volynsky district, Zhytomyr region	0.9	50°40'59"N	27°36'59"E
8	Wetlands in the Sluch River basin, near an unnamed stream in between vil. Chyzhivka and Vilshanka in Novohrad-Volynsky district, Zhytomyr region	2.1	50°41'46"N	27°37'26"E

Table 2
Diversity of hydrophilic plants in the Sluch River basin

Order	Family	Species	Frequency of occurrence	Ecotype	Conservation status	Native / Alien
Equisetales	Equisetaceae	*Equisetum fluviatile* L.	2	II	–	N
Polypodiales	Thelypteridaceae	*Thelypteris palustris* (A. Gray) Schott	1	IV	–	N
Nymphaeales	Nymphaeaceae	*Nuphar lutea* (L.) Smith	3	I	C3	N
		Nymphaea alba L.	1	I	C3, RLR	N
		N. candida J. Presl	2	I	C3, RLR	N
Acorales	Acoraceae	*Acorus calamus* L.	1	II	–	Alien / Arch.
Alismatales	Alismataceae	*Alisma plantago-aquatica* L.	4	II	–	N
		Sagittaria sagittifolia L.	4	II	–	N
	Araceae	*Calla palustris* L.	1	II	C3	N
		Lemna minor L.	4	I	–	N
		L. trisulca L.	3	I	–	N
		Spirodela polyrrhiza (L.) Schleid.	4	I	–	N
	Butomaceae	*Butomus umbellatus* L.	3	II	–	N
	Hydrocharitaceae	*Elodea canadensis* Michx.	2	I	–	Alien / Ken.
		Hydrocharis morsus-ranae L.	3	I	–	N
		Stratiotes aloides L.	1	I	–	N
	Potamogetonaceae	*Potamogeton acutifolius* Link	1	I	NT↓	N
		P. alpinus Balb.	1	I	C1, RLR	N
		P. berchtoldii Fieber	2	I	–	N
		P. crispus L.	3	I	–	N
		P. friesii Rupr.	1	I	RLR	N
		P. gramineus L.	1	I	C3	N
		P. lucens L.	3	I	–	N
		P. natans L.	2	I	–	N
		P. nodosus Poir.	3	I	–	N
		P. perfoliatus L.	3	I	–	N
		Stuckenia pectinata (L.) Böerner	4	I	–	N
Asparagales	Iridaceae	*Iris pseudacorus* L.	2	III	–	N
Poales	Cyperaceae	*Carex acuta* L.	3	III	–	N
		C. acutiformis Ehrh.	4	III	–	N
		C. elata All.	2	IV	–	N
		C. pseudocyperus L.	2	IV	–	N
		C. riparia Curtis	2	IV	–	N
		C. rostrata Stokes	3	III	–	N
		C. vesicaria L.	3	III	–	N
		Eleocharis acicularis (L.) Roem. & Schult.	2	III	–	N
		E. palustris (L.) Roem. & Schult.	3	III	–	N
		Schoenoplectus lacustris (L.) Palla	3	II	–	N
		S. tabernaemontani (C.C. Gmel.) Palla	2	II	–	N
		Scirpus sylvaticus L.	4	IV	–	N
	Juncaceae	*Juncus bulbosus* L.	1	IV	Vul.	N
		J. effusus L.	2	IV	–	N
	Poaceae	*Agrostis stolonifera* L.	3	V	–	N
		Catabrosa aquatica (L.) P. Beauv.	2	V	–	N
		Glyceria fluitans (L.) R. Br.	4	III	–	N
		G. maxima (C. Hartm.) Holmb.	5	II	–	N
		G. notata Chevall.	2	III	–	N
		Leersia oryzoides (L.) Sw.	2	IV	–	N
		Phalaroides arundinacea (L.) Rausch.	4	IV	–	N
		Phragmites australis (Cav.) Trin. ex Steud.	4	II	–	N
		Zizania latifolia (Griseb.) Turcz. ex Stapf.	1	II	–	Alien / Euken.
	Typhaceae	*Typha angustifolia* L.	3	II	–	N
		T. latifolia L.	3	II	–	N
		Sparganium emersum Rehmann	2	II	–	N
		S. erectum L.	3	II	–	N
		S. natans L.	1	II	NT↓, C2, RLR	N
Ceratophyllales	Ceratophyllaceae	*Ceratophyllum demersum* L.	4	I	–	N
Ranunculales	Ranunculaceae	*Caltha palustris* L.	2	III	–	N
		Batrachium aquatile (L.) Dumort.	1	I	RLR	N
		B. circinatum (Sibth.) Spach	2	I	RLR	N
		Ranunculus flammula L.	2	IV	–	N
		R. lingua L.	1	IV	–	N
		R. sceleratus L.	2	III	–	N
Saxifragales	Haloragaceae	*Myriophyllum spicatum* L.	4	I	–	N
		M. verticillatum L.	3	I	–	N
Rosales	Rosaceae	*Comarum palustre* L.	2	III	–	N
Cucurbitales	Cucurbitaceae	*Echinocystis lobata* (Michx.) Torr. et Gray	3	V	–	Alien / Euken.
Myrtales	Lythraceae	*Lythrum salicaria* L.	4	III	–	N
	Onagraceae	*Epilobium hirsutum* L.	3	IV	–	N
		Epilobium parviflorum Schreb.	4	IV	–	N
Brassicales	Brassicaceae	*Cardamine pratensis* L.	3	V	–	N
		Rorippa amphibia (L.) Besser	2	III	–	N
		R. palustris (L.) Besser	4	IV	–	N

Order	Family	Species	Frequency of occurrence	Ecotype	Conservation status	Native / Alien
Caryophyllales	Caryophyllaceae	*Myosoton aquaticum* (L.) Moench	3	IV	–	N
	Polygonaceae	*Persicaria amphibia* (L.) Delarbre	3	I	–	N
		P. hydropiper (L.) Delarbre	3	IV	–	N
		Rumex hydrolapathum Huds.	3	III	–	N
Ericales	Primulaceae	*Hottonia palustris* L.	1	II	C3	N
		Lysimachia vulgaris L.	3	IV	–	N
		Naumburgia thyrsiflora (L.) Rchb.	2	IV	–	N
Boraginales	Boraginaceae	*Myosotis palustris* (L.) L.	3	IV	–	N
Gentianales	Rubiaceae	*Galium palustre* L.	3	IV	–	N
		G. rivale (Sibth. & Sm.) Griseb.	2	IV	–	N
Solanales	Convolvulaceae	*Calystegia sepium* (L.) R. Br.	3	V	–	N
	Solanaceae	*Solanum dulcamara* L.	2	IV	–	N
Lamiales	Lamiaceae	*Lycopus europaeus* L.	4	IV	–	N
		Mentha aquatica L.	2	IV	–	N
		M. verticillata L.	3	IV	–	N
	Lentibulariaceae	*Utricularia intermedia* Hayne	1	I	Vul., C3	N
		U. vulgaris L.	1	I	–	N
	Plantaginaceae	*Callitriche palustris* L.	2	I	C3	N
		Hippuris vulgaris L.	1	III	RLR	N
		Veronica anagallis-aquatica L.	3	III	–	N
		V. anagalloides Guss.	2	IV	–	N
		V. beccabunga L.	1	III	RLR	N
	Scrophulariaceae	*Limosella aquatica* L.	1	IV	RLR	N
Asterales	Menyanthaceae	*Menyanthes trifoliata* L.	1	III	–	N
		Nymphoides peltata (S.G. Gmel.) Kuntze	1	I	Vul., C2	N
	Asteraceae	*Bidens cernua* L.	1	IV	–	N
		B. frondosa L.	4	V	–	Alien / Euken.
		B. tripartita L.	2	IV	–	N
Apiales	Apiaceae	*Berula erecta* (Huds.) Coville	1	III	C4	N
		Cicuta virosa L.	1	III	–	N
		Oenanthe aquatica (L.) Poir.	2	III	–	N
		Sium latifolium L.	3	III	–	N

Notes: frequency of occurrence of species according to route researches in 2014–2020: 1 – rare (single localities) and sporadic species, which have been identified on less than 20% plots; 2 – uncommon species which could be found on 20–40% plots; 3 – common species which occur on 40–60% plots; 4 – common species which occur frequently, on 60–80% plots; 5 – the most common species, which have been found on more than 80% plots; ecotypes: I – hydrophytes, II – helophytes, III – hydrohelophytes, IV – hygrophytes, V – hygromeso- and mesophytes (Papchenkov, 2000, 2001); conservation status: NT – near threatened, ↓ – decreasing current population trend by IUCN (2021); Vul. – vulnerable, by The Red Book of Ukraine (Didukh et al., 2009); C1–C4 – by The Red List of Aquatic Macrophytes of Ukraine (Dubyna et al., 1993): C1 – critically endangered species, C2 – species under severe threat, C3 – threatened species, C4 – species that are currently not rare, but tend to reduce their range and, therefore, need conservation attention; RLR – Red List of Rivne Region (Danylyk & Volodymyrets, 2018): "–"– without conservation status; N – native (resident), Alien (introduced): Arch. – archaeophyte, Ken. – kenophyte, Euken. – eukenophyte; as can be seen from the table above, the most numerous orders are Poales (28 species / 26.7%), Alismatales (21 species / 20.0%), Lamiales (11 species / 10.5%), Ranunculales (6 species / 5.7%), Asterales (5 species / 4.8%), Caryophyllales and Araliales (4 species / 3.8%); the most numerous families turned out to be Cyperaceae (12 species / 11.4%), Potamogetonaceae (11 species / 10.5%), Poaceae (9 species / 8.6%), Ranunculaceae (6 species / 5.7%), Plantaginaceae and Typhaceae (5 species / 4.8%), Araceae and Apiaceae (4 species / 3.8%); together, these families comprise 53.3% of the total plant species composition; the share of the remaining 28 families is 46.7%, of which 14 are represented by only single species. In terms of the number of species, the richest are such genera as *Potamogeton* (10 species / 9.5%) and *Carex* (7 species / 6.7%) (Fig. 2).

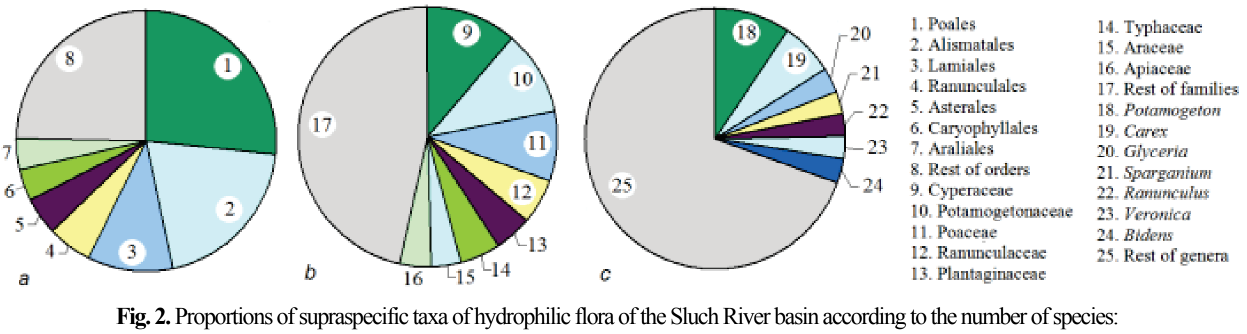

Fig. 2. Proportions of supraspecific taxa of hydrophilic flora of the Sluch River basin according to the number of species: *a* – spectrum of orders; *b* – spectrum of families; *c* – spectrum of genera

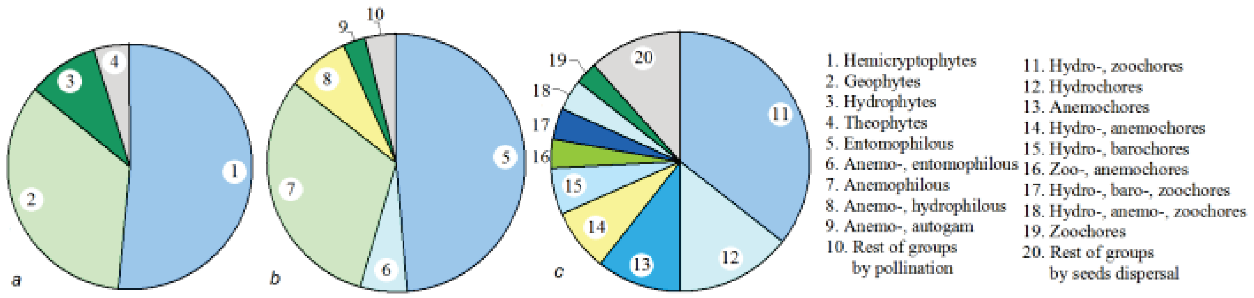

Fig. 3. Proportions of ecobiomorph of hydrophilic flora in the Sluch River basin according to the number of species (I): *a* – spectrum of plant life-forms by Raunkiær system (1934); *b* – spectrum of the method of pollination; *c* – spectrum of the method of seeds and propagules dispersal

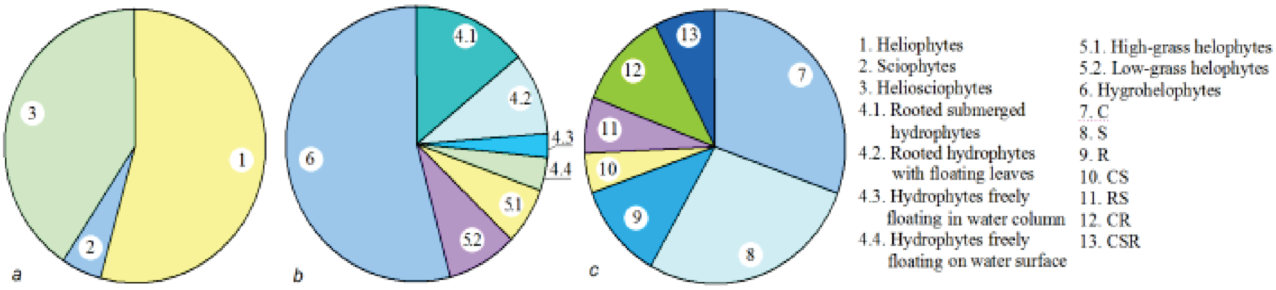

Fig. 4. Proportions of ecobiomorph of hydrophilic flora in the Sluch River basin according to the number of species (II): *a* – spectrum in relation to lighting; *b* – spectrum of hydromorphs; *c* – spectrum of plant strategies; C – competitors, S – stress tolerators, R – ruderals

Heliomorphs. The spectrum of the region's hydrophilic flora concerning lighting has shown the heliophytes and heliosciophytes groups dominate (54.3% and 41.0%, respectively, Fig. 4a). Representatives of the genus Utricularia (2 species), as well as *Equisetum fluviatile*, *Calla palustris*, *Carex pseudocyperus* belong to a small group of sciophytes (4.7%).

Hydromorphs. The spectrum of ecotypes in the flora of the Sluch River by Papchenkov (2000, 2001) is as follows: hydrophytes – 30 species (28.6%), helophytes – 17 species (16.2%), hydrohelophytes – 23 species (21.9%), hygrophytes – 29 species (27.6%), hygromeso- and mesophytes – 6 species (5.7%, Table 2). In addition, the volume of ecotypes has been determined based on the floristic list by Raspopov et al. (2011) (Fig. 4b). There are 32 species (30.5%) of hydrophytes in the flora. These aquatic plants are divided into four ecological groups: submerged, rooted with floating leaves, or without them, as well as free-floating on the surface of the water or in its column. Submerged rooted species predominate quantitatively – 15 species (14.3%). The next ecological group – hydrophytes rooted with floating leaves – 10 species (9.5%). Of the group of hydrophytes that float freely in the water column, 4 species have been identified (3.8%), and 3 species are floaters on the water surface (2.9%). Helophytes include 16 species (15.2%). The ecotype is divided into two ecological groups – low-grass helophytes, which are plants with a height of 60–100 cm and less (9 species / 8.6%), and high-grass helophytes (7 species / 6.7%). There are 57 species of hygrohelophytes in the flora (54.3%).

Plant strategies. According to C-S-R scheme, the species of the flora were distributed as follows (Fig. 4c): C-competitors – 32 species (30.5%), S-stress tolerators – 29 species (27.6%), R-ruderals – 12 species (11.4%), and transitional between two or three strategic types – 32 species (30.5%). Thus, the dominant plant life strategies are C- and S-strategists (58.1% in total).

Conservation status of species. The flora includes three species (*Juncus bulbosus*, *Utricularia intermedia*, and *Nymphoides peltata*) which belong to the Red Book of Ukraine (Didukh et al., 2009), and also representatives of four categories by the Red List of Aquatic Macrophytes of Ukraine (Dubyna et al., 1993):

– (C1) critically endangered species – *Potamogeton alpines*;

– (C2) species under severe threat – *Nymphoides peltata*, *Sparganium natans*;

– (C3) threatened species – *Calla palustris*, *Callitriche palustris*, *Hottonia palustris*, *Nuphar lutea*, *Nymphaea alba*, *N. candida*, *Potamogeton gramineus*, *Utricularia intermedia*;

– (C4) species that are currently not rare but tend to reduce their range and therefore need conservation attention – *Berula erecta*.

Of the 258 species listed as regionally rare and endangered (Danylyk & Volodymyrets, 2018), 10 species are included in the list of hydrophilic flora. In general, the list of rare species includes 20 species from 15 genera and 12 families.

Distribution of species. Analysis of the species occurrence frequency has shown that 25 species (23.8%) of vascular macrophytes were quite rare (up to 20% plots). A very low frequency is primarily characteristic of most rare species, including *Batrachium aquatile*, *Hippuris vulgaris*, *Hottonia palustris*, *Juncus bulbosus*, *Limosella aquatica*, etc. However, even rare species, that are protected by the law via the national and Regionnal Red Lists, can form numerous populations in some water bodies, such as *Nymphoides peltata* in the Sluch River between the settlements of Sosnove and Marynyn, Rivne region (Fig. 5; sites 2–4 in Table 1), or *Calla palustris* in wetlands within Zhytomyr region (Fig. 6; site 8 in Table 1).

The frequency of occurrence of 20–40% plots is characteristic of 30 species (28.6%). Uncommon species were *Equisetum fluviatile*, *Elodea canadensis*, *Eleocharis acicularis*, *Iris pseudacorus*, *Nymphaea candida*, *Potamogeton natans*, *Schoenoplectus tabernaemontani*, *Sparganium demersum*, *Solanum dulcamara*, etc.

32 species (30.5%) were found on 40–60% plots, for instance, *Butomus umbellatus*, *Glyceria fluitans*, *Hydrocharis morsus-ranae*, *Lemna trisulca*, *Nuphar lutea*, *Persicaria amphibia*, *Potamogeton perfoliatus*, *P. crispus*, *Rumex hydrolapathum*, *Schoenoplectus lacustris*, *Sparganium erectum*, *Typha angustifolia*, etc.

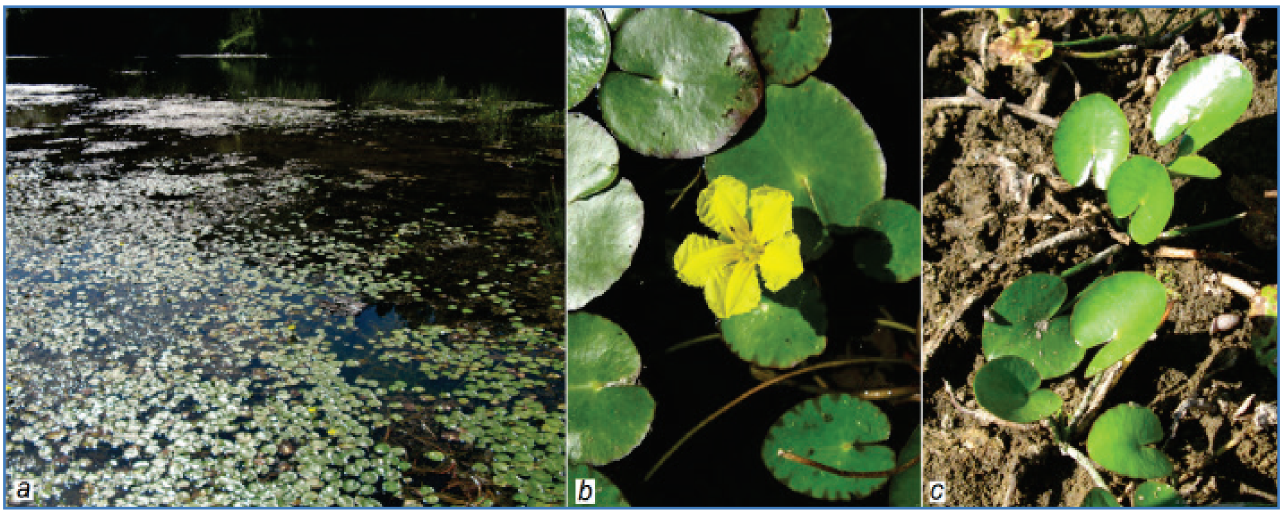

Fig. 5. *Nymphoides peltata* (S. G. Gmel.) Kuntze is listed as a vulnerable species in the Red Book of Ukraine (Didukh et al., 2009); the Sluch River is the only reliably known locality of the species within Rivne region: a numerous population in shallow waters in Sarny district (*a*), aquatic (*b*) and terrestrial (*c*) forms (2015)

Fig. 6. *Calla palustris* L. is a threatened species listed in the Red List of Aquatic Macrophytes of Ukraine (Dubyna et al., 1993); a population of the species on a wetland in the Sluch River basin, Novohrad-Volynskyi district, Zhytomyr region (2014)

17 species (16.2%) were found on 60–80% plots, in particular *Alisma plantago-aquatica*, *Ceratophyllum demersum*, *Lemna minor*, *Myriophyllum spicatum*, *Phragmites australis*, *Sagittaria sagittifolia*, *Scirpus sylvaticus*, *Spirodela polyrrhiza*, *Stuckenia pectinata*, etc.

Glyceria maxima is the most common species, dominant of communities, and was found on more than 80% of plots.

Discussion

This study has shown that spontaneous hydrophilic flora of the Sluch River basin turned out to be relatively rich and typical for such water bodies in terms of taxonomic and ecological structure (Dubyna et al., 1993; Papchenkov, 2000, 2001; Chambers et al., 2008). These results are in line with those of previous studies. In particular, the flora makes up almost 54% of the total species composition of the hydrophilic flora of Rivne region and indicates a significant species diversity of the studied basin (Grokhovskaya & Volodymyretc, 2015a; Grokhovska & Volodymyretc, 2015b). The same families (Cyperaceae, Potamogetonaceae, and Poaceae) are also in the spectrum of numerous families of the hydrophilic flora of the region and the species composition of small rivers in the forest-steppe part of the Horyn River basin. The genera *Potamogeton* and *Carex* also turned out to be the most numerous in the composition of the hydrophilic flora of the region. The only reliably known locality of *Nymphoides peltata* within the Rivne region is within the studied territory.

A possible explanation for these results may be that the vegetation cover of the water bodies is least disturbed in comparison with other landscapes of the region, despite anthropogenic pressure due to economic activity. In particular, this study has identified rare and endangered species, which were included in international, national, and regional Red Lists. Two species (*Sparganium natans* and *Potamogeton acutifolius*) were assessed as near threatened (NT) (The IUCN Red List of Threatened Species, 2014). Most species of the flora have the IUCN (2021) conservation status – least concern (LC) and stable population trend. *Juncus bulbosus*, *Utricularia intermedia* and *Nymphoides peltata* are included in the Red Book of Ukraine as vulnerable in terms of conservation status. These species are quite rare in the study area and known only from separate isolated localities. The most numerous populations are characteristic of *Nymphoides peltata*. Among the species subject to regional protection (Danylyk & Volodymyrets, 2018), the rarest were *Nymphaea alba*, *Potamogeton alpinus*, and *Sparganium natans*.

On the other hand, changes in the vegetation cover of water bodies occur as a result of natural and anthropogenic factors, and the state of aquatic vegetation is an objective indicator of the processes occurring within the catchment area and aquatic ecosystems. Anthropogenic transformation is primarily manifested in the distribution of submerged hydrophytes, which are known to be most sensitive to the state of the aquatic environment and are used as its bioindicators (Dubyna et al., 1993; Zub et al., 2018; Fedonyuk et al., 2020; Mushtaq et al., 2020). For example, the current population trend of *Sparganium natans* is decreasing in Europe and globally; threats: natural system modifications and pollution (agricultural & forestry effluents) (The IUCN Red List of Threatened Species, 2014). The reasons for the decline in the population of *Potamogeton acutifolius* are not entirely clear, but it seems likely that this species does not withstand anthropogenic hyper-eutrophication (Preston et al., 2002; Kaplan, 2010). That is, the threat to this pondweed is the intensification of agriculture and aquaculture.

Significant transformation of plant communities with the participation of hydrophilic species in the region is similar to processes that are happening in other parts of the world. This is due to a decrease in water content, fragmentation of the river network, eutrophication of aquatic ecosystems, spreading and naturalization of alien plant species. The anthropogenic impact is aggravated by climatic changes that have been taking place in the region in recent decades (Smith, 2003; Tena et al., 2017; Ivanyuta et al., 2020). In particular, within the city of Novohrad-Volynskyi (site 5 in Table 1) there has been an expansion of the populations of *Nuphar lutea* and *Potamogeton nodosus*, as well as free-floating representatives of the Araceae family – duckweeds. This is due to the slowing of the current and the shallowing of the river in recent decades.

Anthropogenic homogenization of the vegetation cover to a certain extent is also characteristic of aquatic ecosystems. In total, five alien plant species (4.8% of the flora) occur in the Sluch River basin: archaeophyte *Acorus calamus*, kenophyte *Elodea canadensis*, eukenophytes *Zizania latifolia*, *Bidens frondosa*, and *Echinocystis lobata*. It should be noted that all alien plant species are agrioepecophytes or agriophytes by the degree of naturalization and already have overcome environmental barriers in natural or seminatural vegetation (Kornaš, 1968; Richardson et al., 2000; Protopopova & Shevera, 2005; Protopopova et al., 2006). *Acorus calamus*, *Bidens frondosa*, and *Echinocystis lobata* are included in the list of the highly invasive plant species threatening forest, steppe, and submediterranean zones of Ukraine (Protopopova et al., 2006).

Our research in the Sluch River basin shows the current trend of *Acorus calamus* and *Elodea canadensis* populations as decreasing in the past decade. At the same time, there has been a rapid spread in the Pripyat River basin of alien coastal species *Bidens frondosa* and *Echinocystis lobata*. These species have an increasing population trend in the region. Moreover, invasive *Bidens frondosa* (North American origin) quickly displaces other native aboriginal species of this genus in hydrophilic communities, and the species is currently in a state of expansion. The predominance of eukenophytes in the list of alien plants indicates the intensification of the invasion processes and growth of anthropogenic pressure on the aquatic ecosystems.

Conclusion

This study has identified that the hydrophilic flora in the Sluch River basin consists at least of 105 species of vascular plants, which are typical of aquatic ecosystems in the Pripyat River basin. This is reflected in the results of structural analysis, which show the predominance of a few families and genera in the systematic structure, the dominance of hemicryptophytes and geophytes, entomophiles and anemophiles, and heliophytes. In the spectrum of hydromorphs, the first place in the number of species is taken by hygrohelophytes (53%), the second – hydrophytes (31%), the third – helophytes (15%). The dominant strategies according to Grime's C-S-R scheme are C- and S-strategists (58% in total). The flora also includes rare and endangered species listed in The Red Book of Ukraine, representatives of 4 categories of the Red List of Aquatic Macrophytes of Ukraine, and 10 species listed as regionally rare and endangered. The present study adds to the growing body of research on alien species: there are five alien species, some of which tend to expand and displaces aboriginal species. Further research should be undertaken to explore a larger area of the Sluch River basin, primarily its other tributaries, to identify new localities of rare and alien species, to monitor the dynamics of populations of these species, and to develop the conservation measures for rare species and communities.

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