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Assessment of the ecological state of surface waters of the Luga River, in the town of Volodymyr, by macrophytes

Ocena stanu ekologicznego wód powierzchniowych rzeki Ługi na terenie miasta Włodzimierza na podstawie makrofitów

Abstract. The objectives of our research were an ecological assessment of the quality of the Luga River water in the town of Volodymyr (Volyn region, Ukraine) by physico-chemical and phyto-indicative parameters, analysis of the species composition of the flora of aquatic and coastal aquatic plants by ecotypes, identification of protected species and indicator species. The studies were made during the 2022–2023 growing season at four test sites within the town of Volodymyr. According to the results of field floristic studies of selected test sections of the Luga River in Volodymyr, 25 species of aquatic and coastal-aquatic plants were found, belonging to the division of *Magnoliophyta*, two classes (*Magnoliopsida* and *Liliopsida*), and include sixteen families and twenty-two genera. The most represented class *Liliopsida* includes 16 species (64%) belonging to 13 genera and 8 families. The class *Magnoliopsida* consists of 9 species belonging to 9 genera and 8 families.

During the research, 13 types of macrophyte indicators were found at test site no. 1 (Old Cathedral), 19 indicator species at test site no. 2 (Hydrological station), eight species at test site no. 3 (Lyceum boarding school), and eight species on site no. 4 (Shistivsky Bridge).

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The Macrophyte Index for Rivers (MIR) of the Luga River in the town of Volodymyr varies generally from 30.75 to 36.71, which corresponds to water quality Class III, satisfactory ecological condition; except at test site no. 2 where water quality is class II, good ecological condition.

Keywords: ecological assessment of rivers, macrophyte index MIR, the Luga river

INTRODUCTION

Phytoindication methods, along with physico-chemical methods, are used to assess the level of anthropogenic pollution of surface waters. Aquatic communities are susceptible to changes in environmental factors, including anthropogenic ones, and the reaction to such changes can be observed visually [Didukh 1994, Klymenko, Grokhovska 2005]. Aquatic and coastal-aquatic plants are constantly exposed to the external environment and react to changes in its parameters; thus, knowing their sensitivity to certain pollutants, one can find out the average level of pollutants. Chemical and physical methods of assessing the quality of surface water provide a one-time determination of the degree of pollution during the study. In contrast, biological methods determine the impact of pollutants in the long-term perspective, which is especially relevant for aquatic ecosystems under anthropogenic load [Ciecierska et al. 2013].

During research using phytoindication methods, the floristic composition of aquatic and coastal aquatic plants is studied, species under protection and indicator species are identified, and the ecological state of surface waters is assessed. Also, multi-year observations follow the dynamics in the species composition of the flora of aquatic ecosystems, in the projective coverage of species, in changes in the ecological state of surface waters under natural and anthropogenic factors. Therefore, for a comprehensive ecological assessment of rivers, we used biological methods in addition to physical and physico-chemical research.

A detailed study of the flora in the surroundings of the town of Volodymyr, near which the northern border of the Volyn Highlands is marked, was made for the first time by J. Pachosky [Pachosky 1888]. Based on the materials collected in 1890, the scientists compiled a list of 455 plant species. In our time, the flora of the city outskirts was studied by Kuzmishina I.I. and Kotsun L.O. [Kuzmishyna 2005, Kuzmishyna 2008, Kotsun, Kuzmishyna 2016].

The goals of our research were analysis of the species composition of the flora of aquatic and coastal aquatic plants by ecotypes, identification of indicator species, and ecological assessment of the quality of the Luga River water in the town of Volodymyr was performed based on phyto-indicative parameters and Macrophyte Index for Rivers.

MATERIALS AND METHODS

The Luga River is the right tributary of the Western Bug, a tributary of the 3rd order of the Vistula River, and belongs to the Baltic Sea basin. The catchment area is 1351.4 km^2, and the length is 89.1 km. The Luga originates from the Volodymyr district near the village of Kolpytiv, at an altitude of about 221 m above sea level. The spring coordinates are 50°35'31"N latitude and 24°46'22"E longitude. In the upper course, the Luga flows from east to west; in the middle and lower course, it flows to the northwest. In the town of Ustylug, Volodymyr District, it flows into the Western Bug River, 569 km from its mouth. The coordinates of the Luga River mouth are 50°52'4"N latitude and 24°8'52'E longitude, altitude above sea level is 178.3 m. The largest right tributaries are the Luga-Svynoryika, the Rylovytsia, and the Svynoryika rivers, the left one is the Strypa River [Luga River Passport 2012].

Part of the Luga River basin is located in the west of the Volyn Upland, part is within the Volyn Polissia zone. Most of the basin has a clay-loam cover and is used in agriculture.

The floodplain of the river is meadow, in some places shrubby, its width increases with the length of the river by an average of 0.4–0.8 km. The average height of the floodplain above the river cut is 0.6–0.7 m, the banks are low and gentle.

The bottom of the river is flat and loamy. The channel is very winding. From the source to the village of Stary Porytsk, the width does not exceed 5 m, the depth is 1.5 m. In the town of Volodymyr, the river is already 10–25 m wide and 0.4–1.5 m deep. Later, the river branches forming an island of considerable size (more than 150 ha). There are many bays and islands between Ustylug and Volodymyr. The floodplain of the river is mountainous, about 200 meters wide, cut by many channels [Regional Office of Water Resources, 2023].

The Luga riverside flora, within the town of Volodymyr (lower course of the river), during the 2022–2023 growing season was studied. The floristic composition of plants was studied in 4 test sites, 100 m long each, on either bank of the river (Fig. 1). The coordinates of the centre of the plots are shown in Table 1.

Table 1. Coordinates of test sites

Number of site	Name	Latitude	Longitude
1	Old Cathedral, Naberezhna St.	50°51'3.72"	24°17'21.30"
2	Hydrological station, Volodymyra Monomakha St.	50°51'2.96"	24°17'56.26"
3	Lyceum, Filotova St.	50°49'35.55"	24°19'45.24"
4	Shistivsky Bridge, Taras Shevchenko St.	50°49'1.62"	24°19'58.77"

For biological research, we used the phytoindication methods, namely the Macrophyte Method for River Assessment (MMRA), in its Polish adaptation of Macrofitowa Metoda Oceny Rzek (MMOR), which is the official state method of river assessment in Poland [Ciecierska et al. 2013] and has already been tested in Ukraine, in the Volyn region to assess the tributaries of the upper reaches of the Pripet and the Western Bug and in the Kharkiv region for the Siverskyi Donets. The choice of the above method for use on the territory of Ukraine is explained by the significant agreement of the floristic lists of the studied sections of the rivers and the set of indicative species of macrophytes used for calculating the MIR index [Korobkova 2017, Boiaryn and Tsos 2019, Nekos et al. 2021, Tsos 2021, Malovanyy et al. 2022].

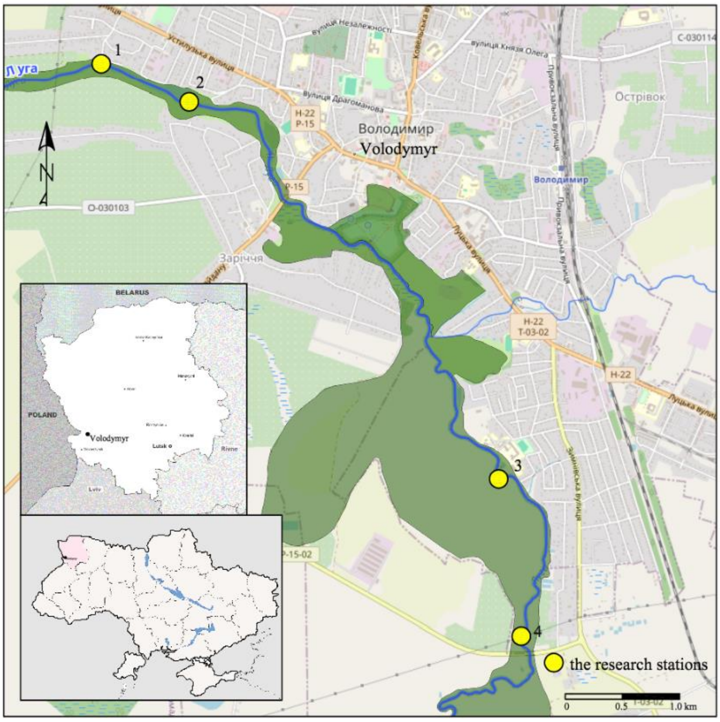

Fig. 1. Distribution of test sites in the town of Volodymyr and its location in the Volyn region (top insert) and Ukraine (bottom insert)

The methodology included several stages. The first stage was preparatory. At this stage, experimental sites were determined. The sites were chosen so that they were representative of the given area and were conveniently accessible for researchers.

The second stage was a trip to the research site to select a site. Test plots were representative, with well-developed vegetation. The geobotanical description involved compiling the species lists and was carried out on 100-meter stretches of the river, within 4–5 m from the riverbank.

According to the methodology, certain types of aquatic plants are assigned two index numbers. The first index, L, indicates the average trophic level of the environment in which the species exists. The value of L index ranges from 1 (for developed eutrophic processes) to 10 (for oligotrophic waters). The second indicator number is the weight coefficient W. This is an indicator of ecological tolerance of species (from steno- to eurytopic). The weight factor W varies from 1 for eurytopic species to 3 for stenotopic species. The Macrophyte Index calculation uses 153 types of macrophytes [Ciecierska et al. 2013, Szoszkiewicz 2020].

The number of indicator species from 11 to 15 is considered sufficient for the research. The study reliability requires at least eight indicator species in the area. There can be fewer if they are primarily stenobiont species, i.e. the most sensitive. These are plants with a W score of 2 or 3.

Also, the coefficient of projective coverage P is determined. It is specified on a nine-point scale for each species [Holmes et al. 1999, Szoszkiewicz et al. 2007]: <0.1%, 0.1–1%, 1–2.5%, 2.5–5%, 5–10%, 10–25%, 25–50%, 50–75%, and >75%.

In the next stage, the Macrophyte Index for Rivers (MIR) was determined, and the ecological state of the water was assessed. The MIR was calculated based on data from field studies using the following formula [Szoszkiewicz et al. 2007]:

$$\mathrm{MIR} = \frac{\sum_{i=1}^{n} L_i \cdot W_i \cdot P_i}{\sum_{i=1}^{n} W_i \cdot P_i} \cdot 10$$

where MIR is the value of the Macrophyte Index for Rivers at the test site; n is the number of species at the test site; L_i is the indicator value for the i-th taxon; W_i is the weighting factor for the i-th taxon; P_i is the projective coverage of the i-th taxon according to the nine-point scale.

The Water Framework Directive 2000/60/EC [WFD] introduced a water assessment system consisting of five classes of the ecological status of surface waters, which correspond to excellent, good, satisfactory, bad, and very bad status. The calculated values of the MIR correspond to a particular class of the water assessment system introduced by the Water Framework Directive. The classification of the studied section of the river requires matching the calculated MIR value and the range of limiting values assigned to the corresponding type of river (Tab. 2).

Table 2. Values of the MIR macrophyte index for different types of lowland rivers [Ciecierska et al. 2013]

River type according to the phytocenotic composition of macrophytes (for lowland rivers, ≤200 m above sea level)		Ecological status (class)				
		excellent (i)	good (ii)	satisfactory (iii)	bad (iv)	very bad (v)
M–VI	sandy rivers	≥46.8	(46.8 – 36.6)	(36.6 –24.6)	(26.4 – 16.1)	≤16.1
M–VII	stone-gravel rivers	≥47.1	(47.1 – 36.8)	(36.8 –26.5)	(26.5 – 16.2)	≤16.2
M–VIII	organic rivers	≥44.5	(44.5 – 35.0)	(35.0 –25.4)	(25.4 – 15.8)	≤15.8
M–IX	large rivers of the lowlands	≥44.7	(44.7 – 36.5)	(36.5 –28.2)	(28.2 – 20.0)	≤20.0

RESULTS AND DISCUSSIONS

According to the results of field studies of the flora of selected test sites of the Luga riverbed in the town of Volodymyr, 25 species of aquatic and coastal-aquatic plants were found belonging to the same division *Magnoliophyta*, two classes (*Magnoliopsida* and *Liliopsida*), which include sixteen families and twenty-two genera (Tab. 3). The species names by The International Plant Names Index [IPNI 2022] were given.

The *Liliopsida* class is the more represented of the species of macrophytes found on the test sites, which includes 16 species (64%) belonging to 13 genera and 8 families. The most numerous are the families *Cyperaceae* (4 species) and *Typhaceae* (3 species) which together make up 28% of all presented species. Class *Magnoliopsida* consists of 9 species belonging to 9 genera and 8 families. Family *Polygonaceae* features two species, while other families (e.g. *Apiaceae, Boraginaceae, Nymphaeaceae*) have one each species.

Indicative species for calculating the environmental index MIR were determined in the test sites presented in Figure 1. In test site no. 1 (Old Cathedral), 13 species of macrophytes indicative of the ecological state were found. Of these, only 2 species (15.39%) belong to truly aquatic plants, hydrophytes. Rooted hydrophytes with floating leaves include *Nuphar lutea*, and free-floating ones have *Lemna minor*. Three species belonged to tall herbaceous helophytes, specifically *Glyceria maxima*, *Typha angustifolia* and *Typha latifolia*. One species, *Sagittaria sagittifolia*, belonged to low-herbaceous helophytes. Four species were hydrogelophytes (*Oenanthe aquatica*, *Rumex hydrolapathum*, *Carex acuta* and *Carex riparia*). Three more species were hygrophytes: *Mentha aquatica*, *Myosotis scorpioides* and *Polygonum persicaria* (Tab. 4).

Table 3. Species composition and projective coverage of macrophytes at the test sites of the Luga River, in the town of Volodymyr

Species	Test site, projective coverage			
	no. 1	no. 2	no. 3	no. 4
Oenanthe aquatica (L.)	0.1%	0.1%	–	–
Myosotis scorpioides L.	1%	1%	0.5%	0.5%
Rorippa palustris (L.) Bess.	0.1%	0.1%	–	–
Ceratophyllum demersum L.	–	2%	0.1%	0.1%
Mentha aquatica L.	1%	1%	1%	1%
Nuphar lutea (L.) Smith.	10%	60%	–	10%
Polygonum persicaria L.	0.5%	–	–	–
Rumex hydrolapathum Huds	1%	1%	–	–
Lysimachia nummularia L.	–	0.1%	–	–
Sagittaria sagittifolia L.	1%	2%	–	–
Butomus umbellatus L.	–	< 0.1%	–	–
Lemna minor L.	5%	3%	3%	2%
Elodea canadensis Michx.	–	1%	–	–
Vallisneria spiralis L.	0.1%	0.1%	–	–
Potamogeton crispus L.	–	0.1%	–	–
Potamogeton natans L.	–	0.1%	–	–
Carex acuta L.	1%	1%	–	–
Carex riparia Curtis	1%	0.5%	0.5%	1%
Scirpus sylvaticus L.	–	1%	0.1%	0.1%
Eleocharis palustris (L.) Roem. & Schult.	–	0.1%	–	–
Glyceria maxima (Hartm.) Holmb.	10%	10%	10%	5%
Phragmites australis (Cav.) Steud.	–	–	10%	5%
Sparganium erectum L.	–	1%	–	–
Typha angustifolia L.	4%	20%	30%	–
Typha latifolia L.	5%	–	–	–
Total	15	22	9	9

The largest projective coverage at test site No. 1 belongs to *Nuphar lutea* (10%), *Glyceria maxima* (10%), *Typha angustifolia* (4%), *Typha latifolia* (5%) and *Lemna minor* (5%) – Table 3.

Test site no. 2 (Fig. 2) features the largest number of indicative macrophytes compared to other sites, namely 19 species. Of them, 6 species (31.58%) are truly aquatic plants. Specifically, submerged rooted species include *Elodea canadensis* and *Potamogeton crispus*; the rooted ones with floating leaves are *Nuphar lutea* and *Potamogeton natans*; *Lemna minor* is a free-floating species, *Ceratophyllum demersum* is a submerged, unrooted species.

Fig. 2. Test site no. 2 [photo V. Radzii, 15.06.2023]

Another 5 species belong to helophytes, of which three species, *Sagittaria sagittifolia*, *Butomus umbellatus*, and *Sparganium erectum*, are low-herbaceous helophytes. Two species, *Glyceria maxima* and *Typha angustifolia*, are tall herbaceous helophytes. Five more species are hydrogelophytes, specifically, *Oenanthe aquatica*, *Rumex hydrolapathum*, *Carex acuta*, *Carex riparia*, and *Eleocharis palustris*. Lastly, three hygrophyte species are *Myosotis scorpioides*, *Mentha aquatica*, and *Scirpus sylvaticus* (Tab. 4).

Table 4. Indicator species of macrophytes of the Luga River in the city of Volodymyr

Species	Coefficients		Projective coverage coefficient, *R*			
			test site			
	L	*W*	no. 1	no. 2	no. 3	no. 4
Oenanthe aquatica (L.)	5	1	1	1	–	–
Myosotis scorpioides L.	4	1	2	2	2	2
Ceratophyllum demersum L.	2	3	–	3	1	1
Mentha aquatica L.	5	1	2	2	2	2
Nuphar lutea (L.) Smith.	4	2	5	8	–	5
Polygonum persicaria L.	2	2	2	–	–	–
Rumex hydrolapathum Huds	4	1	2	2	–	–
Sagittaria sagittifolia L.	4	2	2	3	–	–
Butomus umbellatus L.	5	2	–	1	–	–
Lemna minor L.	2	2	4	4	4	3
Elodea canadensis Michx.	5	2	–	2	–	–
Potamogeton crispus L.	4	2	–	2	–	–
Potamogeton natans L.	4	1	–	2	–	–
Carex acuta L.	5	1	2	2	–	–
Carex riparia Curtis	4	2	2	2	2	2
Scirpus sylvaticus L.	5	2	–	2	1	1
Eleocharis palustris(L.) Roem. & Schult.	6	2	–	2	–	–
Glyceria maxima (Hartm.) Holmb.	3	1	5	5	5	4
Sparganium erectum L.	3	1	–	2	–	–
Typha angustifolia L.	3	2	4	6	7	–
Typha latifolia L.	2	2	4	–	–	–
Total	21		13	19	8	8

The highest projective coverage at the test site No. 2 was observed for Nuphar lutea (up to 60%), Typha angustifolia (20%) and Glyceria maxima (10%).

Test site no. 3 is located near the Lyceum boarding school. Its survey found a significantly smaller number of indicative species of aquatic and coastal aquatic plants, only 8. Of these, there are only 2 species of true aquatic plants, hydrophytes: Ceratophyllum demersum belongs to submerged unrooted hydrophytes, and Lemna minor is a free-floating hydrophyte. Only one species, Carex riparia, belongs to hydrogelophytes, and three species are hygrophytes:Myosotis scorpioides, Mentha aquatica, and Scirpus sylvaticus (Tab. 4). The two species of tall herbaceous helophytes, Glyceria maxima (10%) and Typha angustifolia (up to 30%), have the highest projective coverage of indicative plant species (Tab. 3).

During the study of test site no. 4 (Shistivskyi Bridge), only 8 species of indicator macrophytes were also found. Three species are truly aquatic plant hydrophytes. These are Ceratophyllum demersum which belongs to submerged unrooted hydrophytes, Nuphar lutea which is rooted with floating leaves, and Lemna minor which is a free-floating hydrophyte. One species belongs to tall herbaceous helophytes, Glyceria maxima, and another species, Carex riparia, is a hydrogelophyte. Three hygrophyte species are Myosotis scorpioides, Mentha aquatica, and Scirpus sylvaticus (Tab. 4).

Among the indicator species, Nuphar lutea (10%) and Glyceria maxima (5%) have the largest projective coverage (Tab. 3). Coefficients L and W were determined according to the MMOR method [Ciecierska 2013].

The results of the calculation of the Macrophyte Index for Rivers MIR and the estimate of the ecological state of surface waters of the Luga River are presented in Table 5 and Figure 3.

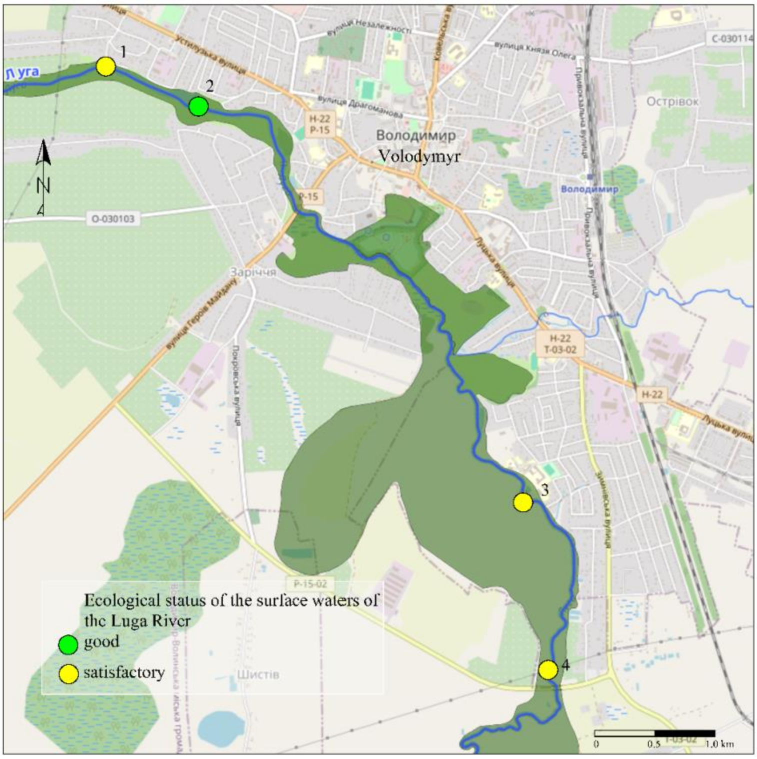

Fig. 3. Ecological status of surface waters in the test sites

Table 5. Ecological status of the surface waters of the Luga River, in the town of Volodymyr, according to the MIR index

Number of site	Location along the river	MIR	Class	Status	Trophic status
1	Old Cathedral	32.00	III	satisfactory	eutrophic
2	Hydrological station	36.71	II	good	mesotrophic
3	Lyceum boarding school	30.75	III	satisfactory	eutrophic
4	Shistivskyi bridge	34.54	III	satisfactory	eutrophic

CONCLUSIONS

1. Twenty-five species of aquatic and coastal-aquatic plants belonging to the division *Magnoliophyta*, two classes, *Magnoliopsida* and *Liliopsida*, sixteen families, and twenty-two genera were found in the test sites of the Luga River in the town of Vo-

lodymyr. Their numbers differed significantly between test sites – fifteen species at site no. 1, twenty-two at site no. 2, nine species at sites no. 3 and no. 4.

2. According to the division by ecotypes, seven species each belong to true aquatic plants (hydrophytes) and to helophytes, six species belong to hygrophytes, and five species to hydrogelophytes.

3. Twenty-one indicator species were found. The largest number of species, nineteen, at the test site no. 2, with thirteen species at site No. 1, and eight species each at sites no. 3 and no. 4 were found.

4. The largest projective coverage was observed for the species *Nuphar lutea* (from 10% at sites no. 1, 3 and 4 to 60% at the site no. 2), *Glyceria maxima* (from 5% at site no. 4 to 10% at sites no. 1, 2 and 3) and *Typha angustifolia* (absent at site no. 4, from 4% at site no. 1, up to 20% at site no. 2 and to 30% at site no. 3).

5. According to the results of the calculation of the macrophyte index of rivers MIR, the best water quality in the Luga River in the town of Volodymyr was found at the test site no. 2 (Hydrological station) and corresponds to class II of water quality, at other test sites the water quality is class III. In our opinion, the better water quality at the test site no. 2 is the consequence of the fact that:

– the river before this site has a wide, boggy floodplain,

– the channel is divided into branches,

– the current is slow,

– there is an island between the branches. The species composition of this territory is rich. As a result, the water is cleaner and the species composition is richer at the test site no. 2 compared to other test sites.

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