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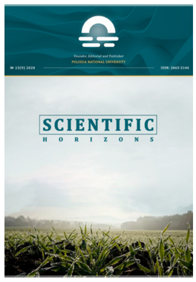

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Indicative Features of Macrophyte Communities in the Assessment of Anthropogenic Load on Aquatic Ecosystems

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Abstract. Studying structural and functional biodiversity in relation to various environmental factors is currently extremely relevant because aquatic ecosystems are a significant source of biological diversity and make up a significant part of the biological productivity of the Earth, they perform many functions, and they are valuable and important for the stability of biotic communities. With this in mind, the task to determine the floristic composition of the Teteriv ecological corridor as a prototypical river landscape in the northern part of Ukraine, to analyse the structural and functional features of the species diversity of macrophytes therein, and to dissect this diversity into its component parts according to its place of origin, its life form, and its relationship to environmental factors was set. The number of species and their predicted coverage in areas with different anthropogenic pressures within the Teteriv ecological corridor were analysed within ecological zones based on the study's findings. It was demonstrated that the integrated ecological indicator of water quality was crucial to the growth of phytocenoses in high-anthropogenic-load regions. The communities may survive in environments where dissolved oxygen is low, muddy sediments are abundant, and anaerobic processes predominate in the transformation of substances. Additionally, they can propagate in floodplains, wet swampy ecotopes, and other environments where water is present for extended periods of time. Most of these communities are not picky about their habitat, as they may thrive in a variety of situations, including slightly acidic or neutral substrates, varying amounts of nitrogen and minerals in the soil, and mild salinization of the plant life. An increase in the number of representatives of individual ecogroups can attest to changes in the ecological state of aquatic ecosystems and have practical significance in detecting increased anthropogenic pressure on aquatic ecosystems

Keywords: indicators, phytocenoses, biodiversity, species, ecogroups

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INTRODUCTION

Ecological monitoring of surface waters based on macrophyte reactions, as well as the study of the impact of various environmental factors on their diversitological and physiological indicators, is a common and proven area of hydrobiological research. The study of the reaction of macrophytes to the influence of anthropogenic factors can be attributed to the same direction. For example, using a diversitological approach to look at how stable the growth of higher aquatic plants is when water bodies get saltier may show early signs of deterioration.

Aquatic flora is a sensitive component of ecosystems that respond not only to environmental degradation but also to improvement (Elo *et al*., 2018). This is because, as the effects of humans on river ecosystems are lessened, the original species mix of macrophyte groups is brought back, and at the same time, some species whose growth was once caused by the displacement of more sensitive species from ecological niches are brought back.

Determining the diversity of organisms and any shifts in their physiological and morphological characteristics is an important part of evaluating the health of aquatic ecosystems. Phytoindicators are useful because they can, according to some sources, (a) react to relatively weak loads because of the effect of dose accumulation; (b) account for the total effect of various anthropogenic factors; (c) record an abundance of chemical and physical parameters that characterize the state of the environment; (d) establish the rate at which environmental changes are occurring; (e) track the evolution of biogeocenoses; and (e) pinpoint the entry points of toxicants (Isaienko *et al*., 2019; Hájek *et al*., 2020; Fedonyuk *et al*., 2020; Hu *et al*., 2021).

Due to varying methodological techniques and distinct natural environments in which this research was conducted, several writers ambiguously interpret the suggestive features of higher aquatic plants and their groups. Submerged macrophytes, or plants most closely associated with the aquatic environment, respond to changes in the composition of the water very quickly (O'Hare *et al*., 2018; Gurnell *et al*., 2020; Dong *et al*., 2022).

Species diversity is the main criterion for the state of aquatic ecosystems (Tanwir *et al*., 2020; Fedoniuk *et al*., 2020). Similar work was carried out in other parts of the world. Thus, similar studies noted the important role of imaging methods in the analysis of environmental quality (Fedoniuk *et al*., 2019; Xu *et al*., 2020).

The presence of *Isoëtes lacustris L.*, *I. echinospora Durieu*, *Lobelia dortmanna L.* and *Miriophyllum alterniflorum DC* indicate the purity and oligotrophy of natural waters. *Potamogeton pussilus*, *P. trichoides. Cham. et Schltdl.*, *P. gramineus L.* grow in the same water (Lindholm *et al*., 2021).

Areas of water bodies that do not currently undergo anthropogenic eutrophication are overgrown with *Catabrosa aquatica (L.) Beauv., Elatine alsinastrum L., Ceratophyllum submersum L.*, and reservoirs characterized by relatively clean water – *Gliceria plicata Fries. Aschers, Potamogeton alpinus Balb., and P. trichoides Cham. Et Schlecht*. The same group of plants includes *Potamogeton lucens L.* (Sand-Jensen *et al*., 2017). According to some sources, *Miriophyllum spicatum L.* very sensitive to industrial and municipal effluents (Rameshkumar *et al*., 2019; Ceschin *et al*., 2021). That is why other authors defined it as an indicator of reservoirs with high mineral content that were subject to strong anthropogenic eutrophication (Vardanyan & De, 2021; Lin *et al*., 2021).

The group of indicator plants that indicate the mesotrophic and eutrophic nature of water bodies is quite significant (Gil *et al*., 2020). Other groups of mesotrophic species include *Sparganium emersum Rehm.*, eutrophic species – *Equisetum fluviatile L., Typha angustifolia L., T. latifolia L., Potamogeton natans L., Sagittaria sagittifolia L., Utricularia australis* etc. (Roth *et al*., 2020; Orlov *et al*., 2021; Szpakowska *et al*., 2021). The rapid growth of duckweed could be a sign that pollution from agriculture and industry is hurting aquatic ecosystems (Fedoniuk *et al*., 2022).

The indicator potential of aquatic macrophytes is highly ambiguous (Fares *et al*., 2020). However, the prevalence of macrophytes – plant species with wide geographical ranges that may require various environmental conditions even within their range – cannot be relied upon as a reliable predictor of a certain degree of the environmental component. In phytocenoses, far fewer macrophytes than eurytopic ones often serve as accurate markers of any given natural situation. The development of an understanding of the level of water body pollution by the structure of macrophyte groups, the set of species, and their productivity appears to be the most promising route in light of this (Joniak *et al*., 2017; Reid *et al*., 2019; Kataki *et al*., 2021). Biomonitoring the dynamics of littoral overgrowth later can say a lot about how water quality changes both in the past and in the present.

The goal of this work was to figure out the structure and function of species diversity in the Teteriv ecological corridor in areas with different levels of development of the floodplain of the river landscape, and to find the most important ecogroups and biomorphs in relation to different environmental factors.

MATERIALS AND METHODS

The study was carried out from 2011 to 2020 in 78 sites within the wooded part of the ecological corridors of the Teteriv-River cascade. From among different types of water basins, the following rivers were chosen: the Teteriv River and its tributaries – the Gnylopiat, the Irsha, the Guiva, the Zdvyzh, as well as rather big water reservoirs – Chudniv, Vidsichne, Zhytomyr, Irshansk, Malyn (Fig. 1).

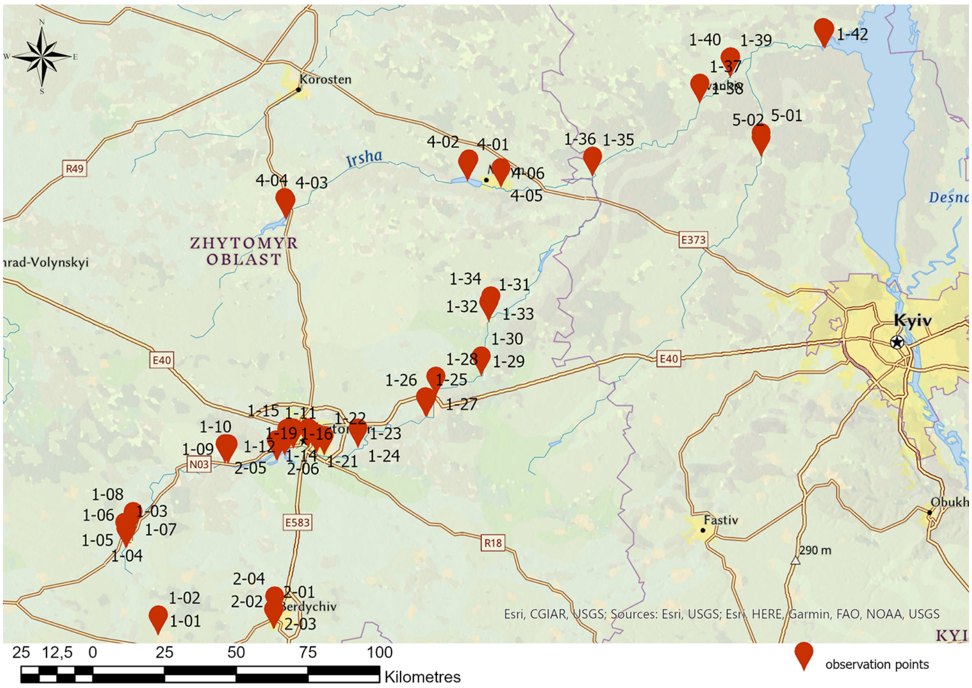

__Figure 1__. The distribution of higher aquatic vegetation metering points on the territory of Ukraine
***Source:** Google Earth 6.2.2.6613 (n.d.), aerial photo with author's tags*

Water samples were taken at the 78 points described above. The choice of research points was based on the following criteria: places of wastewater discharge and intensive surface runoff, etc.). The structural characteristics of the typical river ecosystems of the ecological corridors of the Teteriv-River cascade were analysed in the first stage of research. Retrospective data from the Ukrainian Hydrometeorological Center (n.d.) and the State Agency of Water Resources of Ukraine (n.d.) in the Zhytomyr region (from 1975 to 2010), as well as hydro-chemical and hydro-physical studies in the period 2011-2020, were used to conduct this research, obtained at monitoring sites No 1-01...1-10, 1-21...1-28, 1-31...1-34, 1-37...1-42, 2-01...2-04, 4-01...4-06 together with the State Agency of Water Resources of Ukraine (n.d.), survey data in points 1-11...1-13, 1-04, 1-15...1-20, 1-29, 1-30, 1-35, 1-36, 2-05, 2-06, 3-01 obtained individually.

At the same points as water sampling, descriptions of the species composition of plant organisms were carried out. Woodwiss's method (Woodiwiss, 1964) was used for research. When analysing a sample of higher aquatic plants from the accounting points, the data was compared with the list of indicator species, in which certain species have a certain class of water purity.

Life forms of macrophytes-indicators were analysed according to the classical classification of Hejny (1960). The distribution of aquatic macrophyte species by habitat type was carried out according to Meusel *et al.* (1965). Classification of aquatic macrophytes in relation to environmental factors was carried out based on indicator scales of Ellenberg *et al.* (1967) and unified scales of Didukh & Plyuta (1994), which are adapted to the geographical and territorial conditions of Ukraine, according to which the grouping of species was based on the value of ecological indices of plants in relation to light, thermal regime, continentality, humidity, acid, nitrogen and salt regimes.

RESULTS AND DISCUSSION

The structure and function of aquatic phytocenoses are an important way to figure out how stable they are. From 2011-2020, a study of some small rivers in the Zhytomyr region was conducted. As already mentioned, within the observation points, 43 species were described, which in total, from the point of view of taxonomy, belonged to 3 divisions, the most numerous of which was Magnoliophyta, which included 41 species. One species was observed within the Equisetophyta and Filicophyta divisions. 95.3% of the species in the Teteriv Ecological Corridor (TEC) belong to the Magnoliophyta division. When it comes to higher aquatic plants, this region has only one species of fern and one species of horsetail in its phytocenoses. This is in line with general trends in the development of higher aquatic plants in temperate-cool climates.

At the same time, the number of species in each department is about the same. There are 15 species in the class Liliopsida and 14 species in the class Magnoliopsida. The Equisetophyta and Filicophyta divisions remain with one species in each of these divisions (Table 1).

Table 1. Systematics of aquatic flora within the TEC

Division	Class	Order	Family	Genus	Number of species
Magnoliophyta - Angiosperms	Liliopsida - Monocotyledons	*Alismatales*	Alismataceae Vent.	Alisma L.	1
				Sagittaria L.	1
			Araceae Juss.	Acorus L.	1
			Butomaceae Rich.	Butomus L.	1
			Hydrocharitaceae Juss.	Elodea Michx."	1
				Hydrocharis L.	1
			Lemnaceae SF Gray	Lemna L.	2
				Spirodela Schleid.	1
			Potamogetonaceae Dumort.	Potamogeton	6
		Poales -	Cyperaceae Juss.	Carex L.	4
				Scirpus L.	2
			Poaceae	Glyceria R. Br.	1
			Poaceae Barnhart	Phragmites Adans.	1
			Typhaceae Juss.	Sparganium L.	1
				Typha L.	2
		Asparagus	Iridaceae Juss.	Iris L.	1
	Magnoliopsida -Dicotyledons	Asterales	Asteraceae Dumort.	Bidens L.	1
		Brassicales	Brassicaceae Burnett	Rorippa Scop.	1
		Saxifragales	Haloragaceae R. Br.	Myriophyllum L.	2
		Lamiales	Lamiaceae Lindl.	Lycopus L.	1
		Myrtales	Lythraceae Jaume	Lythrum L.	1
				Trapa L.	1
		Caryophyllales	Polygonaceae Juss	Polygonum L.	1
		Ranunculales	Ranunculaceae Juss.	Ranunculus L.	2
		Malpighiales	Salicaceae Mirb.	Salix L.	1
		Ceratophyllales	Ceratophyllaceae SF Gray	Ceratophyllum L.	1
		Nymphaeales	Melanthiaceae Batsch.	Nuphar Smith.	1
				Nymphaea L.	1
Equisetophyta - Horsetail	Equisetopsida - Horsetail	Equisetales	Equisetaceae Rich. ex DC.	Equisetum L.-	1
Filicophyta - Ferns	Polypodiopsida - Ferns	Salviniales	Salviniaceae Dumort.	Salvinia Seguier	1

Source: *compiled by the authors*

The most numerous, in terms of the number of species within the TEC, was the order *Alismatales*, within which 6 families and 9 genera were noted, which are represented by a total of 15 species. The order *Poales*, with 4 families and 6 genera, within which 11 species were recorded, was also numerous. It should be noted that both orders belong to the class Liliopsida. Within the class *Magnoliopsida*, orders *Saxifragales, Ranunculales, Nymphaeales*, and *Myrtales* are presented in the number of 2 species each. All other orders were counted within the studied phytocenoses of one species.

Thus, the distribution of hydrophytes by taxonomic parameters to identify general trends observed within the plant groups of temperate latitudes on the Eurasian continent was allowed (Dubina & Shelyag-Sosonko, 1984). The distribution of species represented by the minimum number within families and genera indicates the absence of polymorphism in the studied biocenoses, and biomorphs of the described species were practically not observed. In general, according to the species composition of vascular plants, most are angiosperms.

The species diversity of the TEC is spread out based on how closely they are related to growing conditions. The group of surface-water-air species is the most common, making up about 53.8% of all species. It should be noted that 100% of surface-water-air species were rooted plants. The group of flood-water-air plants was less numerous, occupying a total of 23.1%. Unlike the last group, this one had both rooted and floating species (10.3% and 12.8% of the total number of species, respectively). Submerged plants within the TEC were also represented only by rooted species (20.5%). And the least numerous was the group of submerged plants – 2.6%.

The distribution of species diversity of the TEC according to the spectrum of zonal chorological groups proposed by Meusel & Jäger (1989) showed that most phytocenoses belong to the boreo-meridional chorological group – 34.5%, plurizonal species – 25.6%, boreal-meridional – 18%, and submerdional type was about 10%. Three types of latitudinal areas: temperature-meridional, temperature-boreal, and boreal-tropical, are occupied by 7.7% and temperature-tropical type – about 5%. According to regional chorological groups by longitudinal habitats, the group of species with a circumpolar type of habitat was the most numerouss – 53.8, the chorological Euro-Asian group – 25.6%, and the European group – 10.3%.

Important, in terms of understanding the patterns of spatial distribution of aquatic macrophytes, is their classification by life forms. However, one of the most comprehensive and accurate, in authors' opinion, is the classification of Dubina *et al.* (1993), which optimally reflects the features of natural-territorial complexes within which the studied phytocenoses are formed, namely considering fluctuations in river ecosystems and floodplain drainage, several ecological and biological features of the ontogenesis of macrophytic species, etc. This classification assumes the division of macrophytes into deep-water, littoral shallow-water, limous marsh, and terrastic terrestrial ecotopes.

According to this classification, 5 groups and 9 types of biomorphs were noted within the TEC. The group of hydromorphic species turned out to be the most numerous, covering about 53.85% of all biomorphs belonging to it. The most numerous types (25.6%) of biomorphs within this class are aerohydatophytes (*Iris pseudacorus, Lycopus europaeus L., Myriophyllum spicatum L., M. verticillatum* etc.), which take place in the limnophase and coastal ecophase. The other two types of biomorphs of this class are quite numerous: euhydatophytes occupy 12.8% and pleistophytes – 15.38%.

The gelomorphic group of biomorphs occupies a smaller share of the total amount of species diversity – 38.5%. However, it should be noted that this group contains the most numerous types of biomorph-ochtohydrophytes – in which most of their existence is associated with coastal, swamp, and terrestrial ecophases and only for a short time – with the limnophase. This type covers about 31% of the entire species diversity of the TEC. The other two types of biomorphs of the gelomorphic group are present in small quantities: hydrochtophytes – 2 species and efochtophytes – 1.

The most common for the analysis of macrophytes are the Ellenberg indicator scales (1967) and the Didukh scales (2011), both adapted to the natural and climatic conditions of Ukraine. According to the distribution on the thermoclimatic scale of Ellenberg, almost three times fewer shares were occupied by species with ecological index 5 (*Alisma plantago-aquatica L., Lemna minor L., Lythrum salicaria L.*, etc), – 23% of the species diversity of phytocenoses. A significantly smaller share was occupied by species with ecological indices 7 and 8-15% (*Ceratophyllum demersum L., Schoenoplectus mucronatus (L.) Palla, Typha angustifolia L.*, etc) (Fig. 2).

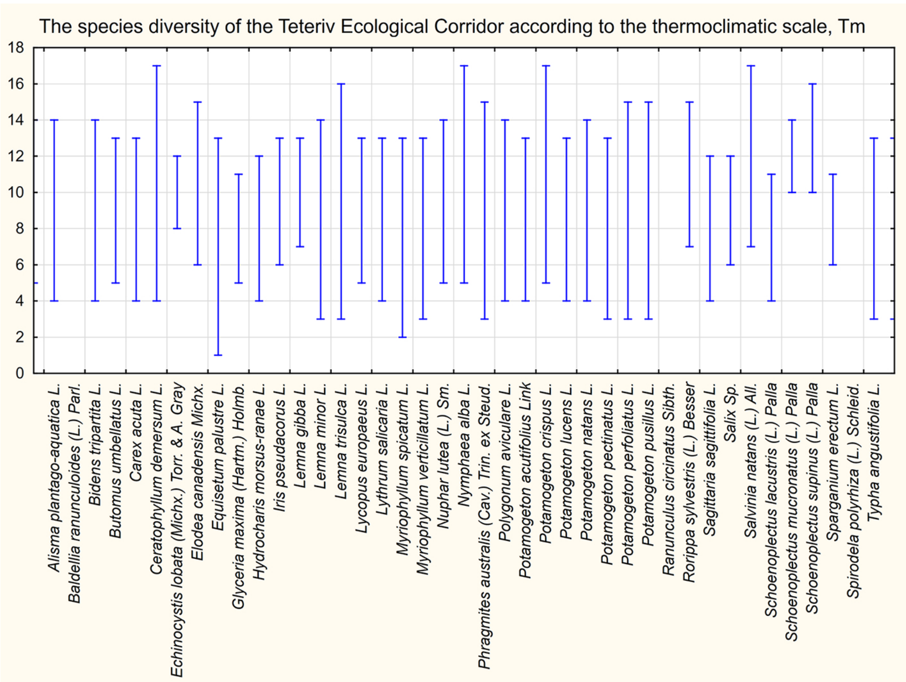

Figure 2. *Distribution of species diversity of the TEC according to the thermoclimatic scale, Tm*
Source: *compiled by the authors*

According to the Didukh scale, the largest share was occupied by species with tolerance ranges of 3-13 (9.76%), 4-13 (9.76%), and 4-14 (9.76%) (*Myriophyllum verticillatum L., Potamogeton pectinatus L., Typha angustifolia L.*). The distribution of the obtained data by ecogroups shows a significant predominance of submesothermic species, which occupied a total of 55%, with a larger share in this group occupied by hemievrytopic species (32.5%) than by eurytopic and hemistenotopic (10 and 12.5%, respectively). The group of submicrothermal hemievrytopic organisms was also significant (17.5%). Within the study area there are ecogroups and biomorphs of species characteristic of temperate latitudes with a wide range of tolerance to thermoclimatic regimes (stenotic species were not observed at all). Almost 77% of the total number of species are hemievrytopic and eurytopic species.

Thus, the development of submicrothermal species (*Equisetum palustre L., Myriophyllum spicatum L., Myriophyllum verticillatum L., Potamogeton pectinatus L.*, etc.) is suppressed by the deterioration of the overall integrated water quality index, with a clear tendency to reduce the coverage area of the observed species (r = -0.294) and their number (r = -0.506), (Table 2).

***Table 2**. Analysis of the relationship between the temperature patterns of macrophyte ecogroups and an integrated ecological index of water quality (N=5)*

Ecogroup	Correlation coefficient	$t_{Student's^*}$	Correlation conclusion	Correlation coefficient	$t_{Student's^*}$	Correlation conclusion
	by projective coating			by the number of species		
Submicrotherms	**-0.294**	-2,264	reverse	**-0.506**	-4,312	reverse
Submesotherms	-0.249	-1,886	missing	**-0.611**	-5,677	reverse
Mesotherms	0.097	0.717	missing	0.033	0.243	missing

Note: **in this table and all the following ones the weight of the relationship on the effectiveness of the feature is equated to the critical tabular value $t_{Student's}$=2.00*
Source: *compiled by the authors*

A decrease in the number of species under the influence of anthropogenic pressure occurs in the ecogroup of submesothermic species. However, unlike the previous ecogroup of submicrothermal species, in this one, projective coverage does not vary significantly due to the presence of more tolerant species. However, it should be noted that anthropogenic pressure has a clearly defined negative impact on the number of species in this ecogroup, which is confirmed by a close inverse correlation (r = -0.611). Mesothermal species had the most stable growth in the presence of pollution caused by humans, and there was no significant dependence on environmental degradation reactions.

The ombroregime is one of the most important environmental factors, which integrates the impact of precipitation, evaporation from the soil surface, and thermal resources of the territory. Most species of the TEC have a wide range of tolerance to the ombroregime. Thus, more than half of the species have such values for the upper and lower limits, the difference between which exceeds 10 units (*Elodea canadensis Michx., Lemna trisulca L., Ceratophyllum demersum L.*, etc.), (Fig. 3).

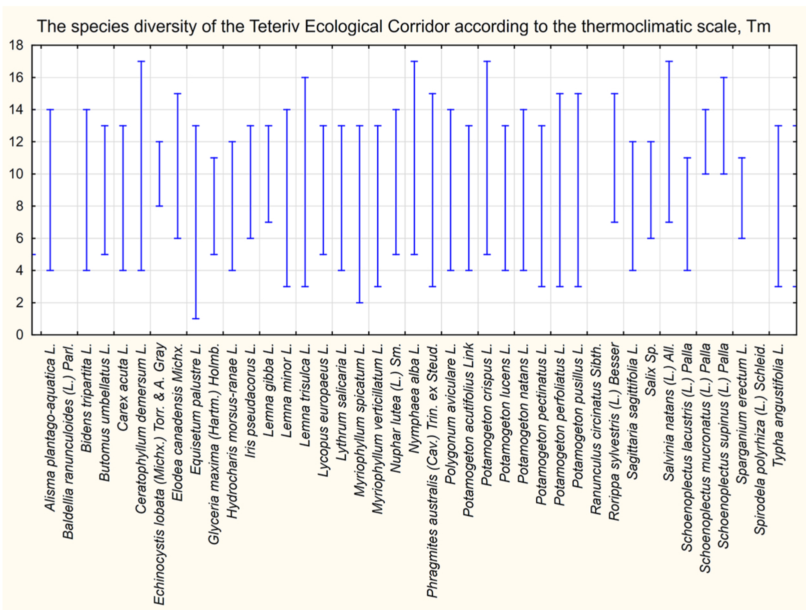

***Figure 3**. Distribution of species diversity of the TEC according to the thermoclimatic scale, Tm*
Source: *compiled by the authors*

Based on the ombre regime scale, all of the species in the TEC were put into 5 ecogroups. Of these, mesoaridophytes (20%), subaridophytes (37.5%), and subumbrophytes (27.5%) were the most common. In most ecogroups, the aridity-humidity of the climate did not cause significant changes, except for the mesoaridophyte ecogroup, where the overall decrease in projective coverage (r = -0.310) was accompanied by the loss of phytocenoses of some species (*Typha anphastifolia L., Typha angustitifia L., Potamogeton pectinatus L.*, etc.) (r = -0.210) (Table 3).

Table 3. *Analysis of the relationship between the aridity-humidity patterns of macrophyte ecogroups and an integrated ecological index of water quality (N=5)*

Ecogroup	Correlation coefficient	$t_{Student's}$	Correlation conclusion	Correlation coefficient	$t_{Student's}$	Correlation conclusion
	by projective coating			by the number of species		
Semiaridophytes	-0.258	-1,961	missing	**-0.490**	-4,126	missing
Mesoaridophytes	**-0.310**	-2,397	reverse	**-0.280**	-2,140	reverse
Subaridophytes	-0.254	-1,931	missing	**-0.501**	-4,249	reverse
Subombrophytes	-0.101	-0.745	missing	**-0.316**	-2,445	missing
Semiombrophytes	0.009	0.063	missing	0.046	0.339	missing

Source: *compiled by the authors*

In the subaridophyte ecogroup, the decrease in the number of species (r = -0.501) occurred against the background of the stability of projective coatings due to the presence of species sufficiently resistant to anthropogenic pollution species, which quickly filled the ecological niches freed from more sensitive species (*Potamogeton natans L., Potamogeton perfoliatus L., Schoenoplectus lacustris (L.) Palla, Carex acuta L.* etc). For other ecogroups, no significant dependencies on water quality were found. In terms of natural and climatic conditions, the Polissya region is a zone of significant temperature differences. This is especially true in the winter when sub-zero temperatures cause the formation of ice cover and cannot but affect the conservation of aquatic macrophytes. That is why their attitude to the cryoregime of the study area is also very important (Fig. 4).

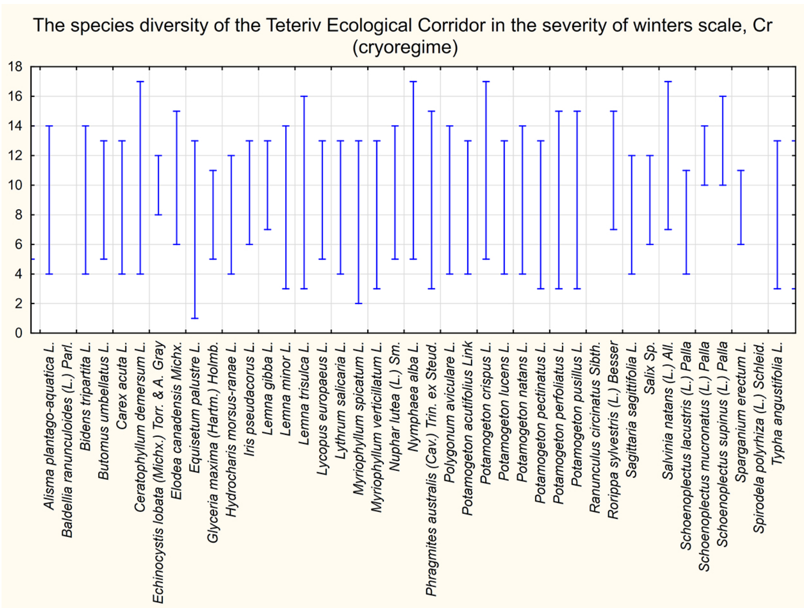

Figure 4*. The species diversity of the TEC in the severity of winters scale, Cr (cryoregime)*

Source: *compiled by the authors*

Thus, in accordance with the Didukh scale, most species were characterized by a significant range of tolerance to cryotherapy: 1-15 (*Ceratophyllum demersum L., Elodea canadensis Michx., Lemna trisulca L., Phragmites australis (Cav.) Trin. Ex Steud., Polygonum hydropiper L.*, etc) – 23.08%, 1-13 (*Alisma plantago-aquatica L., Lycopus europaeus L., Sparganium erectum L., Myriophyllum spicatum L.*) – 10.26%, 5-12 (Potamogeton acutifolius, Potamogeton lucens L. etc) – 10.26%.

The distribution of species diversity by ecogroups in relation to the cryotherapy showed that most species have a high amplitude, so the largest share in species diversity was occupied by subcryophytes – 53.84%, of which eurytopic species – 33.33 % and hemievrytopic – 17.95%. Slightly fewer hemievrytopic hemicryophytes – 12.82% and hemievrytopic cryophytes and acriophytes – 5.13% in each ecogroup, which are indicators of moderate and mild winter periods. In general, 97% of the species belong to the eco-groups of species, which can store seeds or other parts at very low temperatures and have a wide range of tolerance to the cryo-regime. According to research, the projective areas of the main ecogroups of macrophytes in relation to cryoregime did not vary under the influence of anthropogenic pressure on aquatic ecosystems (Table 4).

Table 4*. Analysis of the relationship between the cryotherapy patterns of macrophyte ecogroups and an integrated ecological index of water quality (N = 55)*

Ecogroup	Correlation coefficient	$t_{Student's}$	Correlation conclusion	Correlation coefficient	$t_{Student's}$	Correlation conclusion
	by projective coating			by the number of species		
Cryophytes	-0.132	-0.976	missing	-0.117	-0.866	missing
Subcryophytes	-0.197	-1,479	missing	**-0.457**	-3,777	reverse
Hemicryophytes	-0.165	-1,231	missing	**-0.298**	-2,297	reverse

Source: *compiled by the authors*

However, there is a pronounced negative impact of anthropogenic pressure and deterioration of water quality on ecological groups of subcryophytes and hemicryophytes, which is confirmed by the presence of close inverse correlations (r = -0.457 and r = -0.298, respectively). The decrease in the total number of species and the stability of coverage areas show that space is being taken up by species that are less affected by human activities. Many hemievrytopic (41.03%) and eurytopic (33.33%) species play a big part in these changes. According to Ellenberg's ecological scale, the range of scores ranged from 1 to 4. More than half of the species had a score of 4-51.5%, i.e., they were characterized by a wide range of tolerance to the continental climate. According to the Didukh scale, a similar trend was noted. The largest share of species was characterized by a wide range of tolerance: 1-17 (*Alisma plantago-aquatica L., Butomus umbellatus L., Ceratophyllum demersum L.*, etc) – 35% and others (Fig. 5).

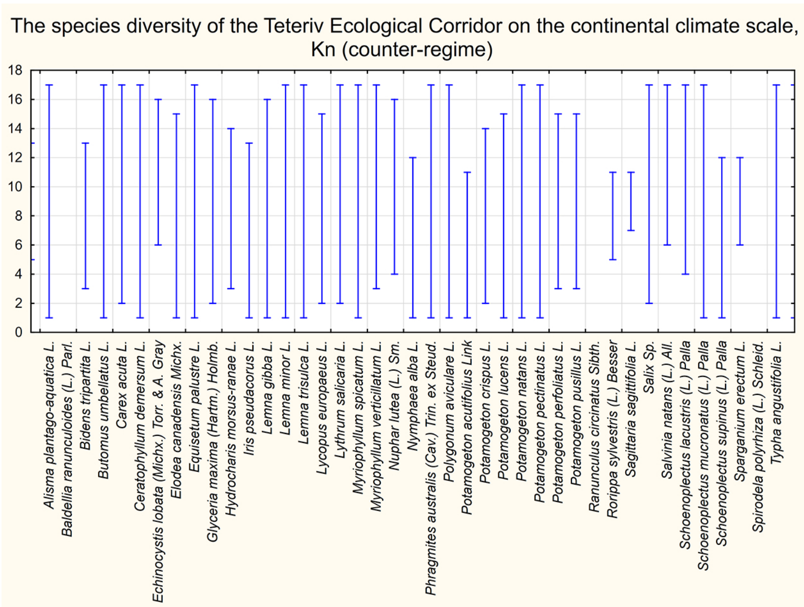

Figure 5*. The species diversity of the TEC on the continental climate scale, Kn (counter-regime)*
Source:*compiled by the authors*

In general, according to the continental scale, all species diversity in the TEC covered 4 ecogroups. The largest share of species belonged to the eco-group of hemicontinentals – 70.0%, less-homo-oceanic – 20.0%, and sub-oceanic and subcontinental together accounted for about 10%. In terms of ecological amplitude, the absence of stenotic species across all ecogroups should be noted. The largest share in both ecogroups was occupied by eurytopic species – 60% within the hemicontinental ecogroup and 10% by hemioceanists. Hemievritopic species accounted for 7.5%, 5%, and 5% of hemicontinentals, hemioceanists, and subcontinentals, respectively.

The influence of anthropogenic factors on projective coverings in terms of ecogroups on a continental scale did not show a consistent pattern. However, there was still a negative impact on the number of species (Table 5). Thus, it was most pronounced in the ecogroups of hemioceans and hemicontinentals (r = -0.461 and r = -0.581, respectively). The presence of a significant proportion of eurytopic species, which allows them to occupy free ecological niches in the fall of more sensitive to anthropogenic factors species, plays a significant role in maintaining the total number of individuals in terms of ecogroups, as it did in the previously described groups.

***Table 5.** Analysis of the relationship between the continentality patterns of macrophyte ecogroups and an integrated ecological index of water quality (N = 55)*

Ecogroup	Correlation coefficient	$t_{Student's}$	Correlation conclusion	Correlation coefficient	$t_{Student's}$	Correlation conclusion
	by projective coating			by the number of species		
Hemioceanists	-0.137	-1,016	missing	**-0.461**	-3,817	reverse
Hemicontinentals	-0.249	-1,893	missing	**-0.581**	-5,244	reverse
Subcontinental	-0.201	-1,508	missing	-0.155	-1,156	missing

***Source:** compiled by the authors*

Aeration is an important indicator that determines the nature of physicochemical processes in substrates. For the aquatic environment, this indicator is usually important because it determines the oxidation of organic and mineral substances, and thus determines the intensity of the self-cleaning processes. The most numerous groups of species with a tolerance range were: 12-15-17.5% (Fig. 6).

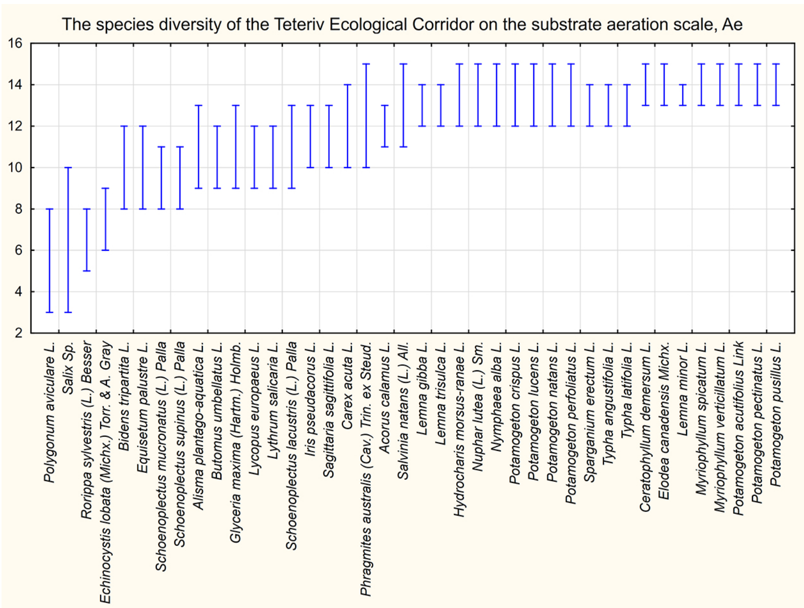

***Figure 6**. The species diversity of the TEC on the scale of substrate aeration, Ae*
***Source:**compiled by the authors*

All species of macrophyte diversity within the TEC in terms of substrate aeration were divided into 6 ecogroups. The largest share was occupied by stenotic hyperaerophobes – 48.8%, which indicates a low level of dissolved oxygen in water, the presence of silty deposits and the predominance of anaerobic processes of transformation of substances.

This is supported by data from hydrochemical analyses of water, where Biological Oxygen demand (BOD) and Chemical Oxygen Demand (COD) values exceeded the corresponding maximum permissible concentration (MPC) by 1.5-2.3 times in some cases. The share of subaerophobes, aerophobes, and megaaerophobes was significant in the studied phytoceoses – 9.8%, 19.5%, and 14.7%, respectively. The presence of these species is due to the processes of glaciation of coastal soils and constant excessive moisture of the territory with an unsatisfactory aeration regime, which inevitably leads to waterlogging of the floodplain. The total share of species adapted to exist in sufficient aeration regimes – subaerophiles and hemiaerophiles, accounted for a small share – just over 7%. All species diversity had a rather narrow range of ecological amplitude, as evidenced by a significant percentage of stenotic (53.7%) and hemistenotopic (46.3%). In response to anthropogenic pollution of aquatic ecosystems, the parameters of different ecogroups in relation to the aeration of the substrate varied differently (Table 6).

Table 6. *Analysis of the relationship between the substrate aeration (Ae) patterns of macrophyte ecogroups and an integrated ecological index of water quality (N = 55)*

Ecogroup	Correlation coefficient	$t_{Student's}$	Correlation conclusion	Correlation coefficient	$t_{Student's}$	Correlation conclusion
	by projective coating			by the number of species		
Subaerophiles	**-0.443**	-3,631	reverse	**-0.499**	-4,236	reverse
Hemiaerophobes	**-0.501**	-4,257	reverse	**-0.424**	-3,444	reverse
Subaerophobic	-0.033	-0.242	missing	-0.142	-1,054	missing
Aerophobic	**-0.382**	-3,042	reverse	**-0.313**	-2,423	reverse
Megaaerophobes	-0.148	-1,102	missing	-0.251	-1,905	missing
Hyperaerophobic	-0.056	-0.411	missing	-0.379	-3,009	reverse

Source: *compiled by the authors*

Close correlation with inverse links and negative effects have been established between the deterioration of water quality and the number of subaerophiles, hemiaerophobes, and aerophobes, which manifested itself in both a general reduction in the number of species and a general suppression of populations as well as a reduction in the overall projective coverage of relevant ecogroups. Under conditions of anthropogenic pressure, the physicochemical composition of the habitat of species is of great importance. Thus, especially in places of wastewater inflow, there are significant variations in the pH of the aquatic environment. The largest share of species of aquatic phytocenoses had the Ellenberg scale values indices 6, 7, and 8, which indicate the confinement of such species to neutral, slightly alkaline, and alkaline substrates. Their share was almost 90% of all species' diversity. The values of ecological indices according to Didykh acidity scale showed a wide range of changes (Fig. 7).

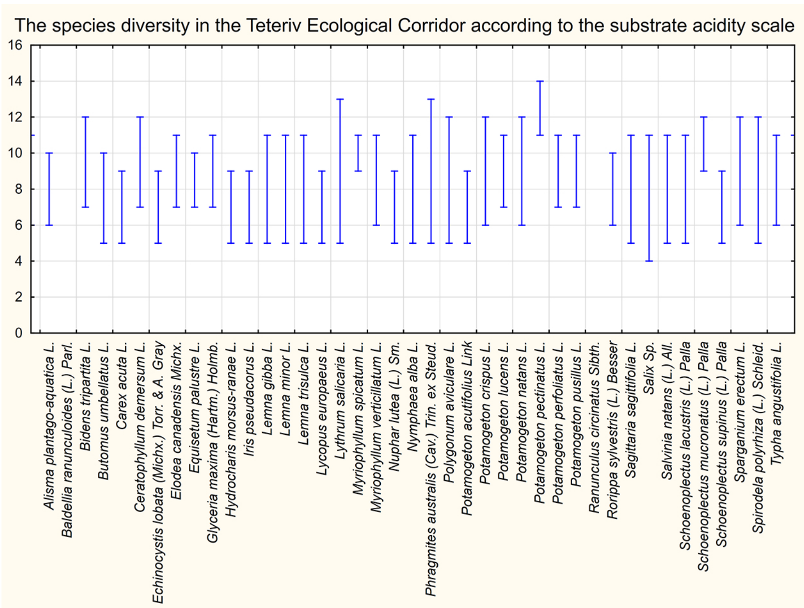

Figure 7*. The species diversity in the TEC according to the substrate acidity scale*

Source:*compiled by the authors*

Most species had a wide range of tolerance to environmental acidity – from 5 to 9 points, or 17 %. Although a retrospective analysis of water quality data for the period since 1947 showed an average pH value of 7.49 and the presence of a significant proportion of hemistenotopic subacidophiles (26.3%), the negative impact of contaminated effluents associated with significant pH variations within the study area. It should be noted that most of the species in these ecogroups are hemistenotopic and hemievrytopic biomorphs. The presence of neutrophilic and basophilic species is more like how the conditions and chemical properties of water have changed over time. The inflow of acidified wastewater in recent decades has significantly adjusted the diversity of this area, and thus the sensitivity of individual ecogroups to the acidity of the substrate is obvious. As the correlation analysis of the relationships between total projective coverings and the number of species of individual ecogroups showed, they all changed due to the transformation of the aquatic environment under the influence of anthropogenic factors. In particular, subacidophiles and basophiles saw a decrease in the total projective cover (Table 7), as well as a decrease in the number of species (r = -0.519 and r = -0.284, respectively).

Table 7. *Analysis of the relationship between the substrate acidity (Rc) patterns of macrophyte ecogroups and an integrated ecological index of water quality (N = 55)*

Ecogroup	Correlation coefficient	$t_{Student's}$	Correlation conclusion	Correlation coefficient	$t_{Student's}$	Correlation conclusion
	by projective coating			by the number of species		
subacidophiles	**-0.371**	-2,936	reverse	**-0.519**	-4,458	reverse
neutrophils	-0.122	-0.904	missing	**-0.516**	-4,430	reverse
basophils	**-0.271**	-2,071	reverse	**-0.284**	-2,179	reverse

Source: *compiled by the authors*

In the neutrophil ecogroup, where the projective cover was stable, there was a decrease in the number of species and an increase in species that were less affected by pollution from humans, such as *Potamogeton lucens L., Potamogeton perfoliatus L, Elodea canadensis Michx*, etc. Aquatic plant species with a significant range of ecological indices in relation to the nitrogen supply of the environment have been recorded. According to the Ellenberg scale, the most numerous were groups of plants with indices 6, 7, and 8 (27.0%, 29.7%, and 27.0%). An oligotrophic type of nutrition is observed for almost 8% of species (2 and 3 ecological indices). According to the Didukh tolerance scale JP (2011), most species had narrow ranges: 3-7 – 14.6%, 5-10 – 19.5% (Fig. 8). The distribution of species by ecogroups in relation to nitrogen supply showed that the largest shares are nitrophils (61%) and heminitrophils (37.8%), which tend to place with high concentrations of nitrogen compounds in water.

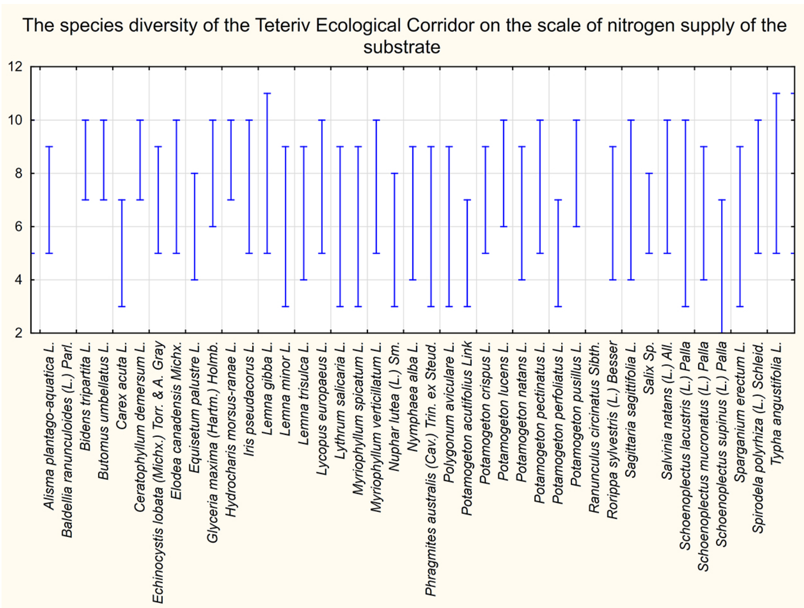

Figure 8. *The species diversity of the TEC on the scale of nitrogen supply of the substrate*
Source: *compiled by the authors*

Hemievritopic species occupy the largest share within both ecogroups, at 63.41%. The presence of species belonging to such a variety of ecogroups in terms of nitrogen supply indicates a significant variation in plant living conditions on this indicator of significant anthropogenic pressure within the TEC, namely intensive agricultural production, and wastewater from urban areas. The ecogroups of geminitrophiles and nitrophiles were the most sensitive to the influence of anthropogenic factors, but the nature of reactions within these ecogroups differed. In heminitrophils with deteriorating water quality, there is a decrease in the number of species (r = -0.352) against the background of stability of the total projective cover of the ecogroup. In nitrophiles, the general decrease of species (r = -0.555) with deterioration of water quality was accompanied by a decrease in projective coverings (r = -0.391) (Table 8).

Table 8. *Analysis of the relationship between the ratio of digestible forms of nitrogen in the substrate of macrophyte ecogroups and an integrated ecological index of water quality (N=55)*

Ecogroup	Correlation coefficient	$t_{Student's}$	Correlation conclusion	Correlation coefficient	$t_{Student's}$	Correlation conclusion
	by projective coating			by the number of species		
Heminitrophils	-0.069	-0.507	missing	**-0.352**	-2,765	reverse
Nitrophiles	**-0.391**	-3,117	reverse	**-0.555**	-4,902	reverse
Eunitrophiles	-0.056	-0.413	missing	-0.183	-1,366	missing

Source: *compiled by the authors*

Analysis of species diversity on a scale relative to the salt regime showed that a significant proportion of species have a wide range of tolerances: 5-11 – 8.2% and 5-13 – 8.2% (Fig. 9).

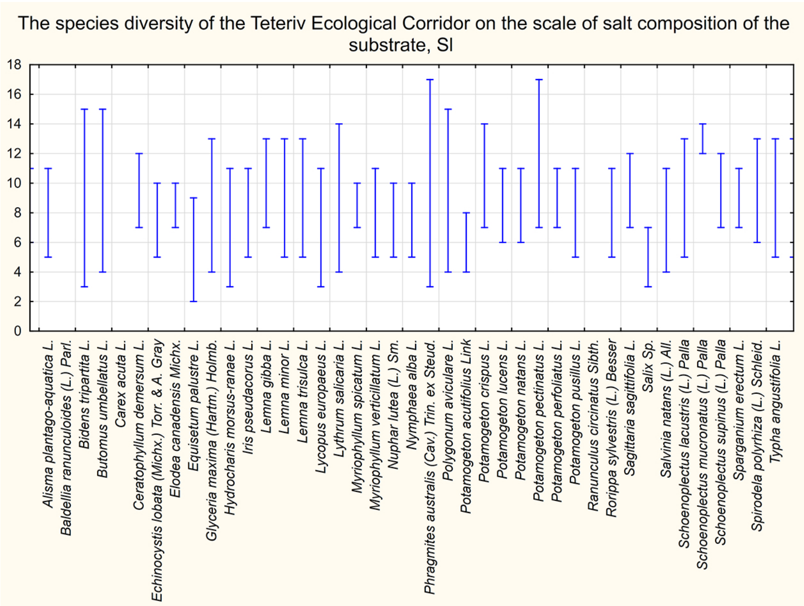

Figure 9*. The species diversity of the TEC on the scale of salt composition of the substrate, Sl*
Source:*compiled by the authors*

Based on how the plant ecogroups were spread out in relation to the salt content in the TEC, semievtrophs (22.0%) and eutrophs (58.6%) were the most common, which tend to have high salt concentrations in their substrates. In both groups, hemistenotopic species occupy a larger share (56.1%) than less-hemievrytopic (31.7%). Eurytopic species are represented only within the eutrophic ecogroup (4.9%), stenotic-only within the eutrophic (4.9%), and glycotrophic (2.4%).

A small share of the total species diversity was occupied by species that tend to salt-poor substrates or mesotrophic substrates –12.2%. In general, the distribution of macrophyte species by industry shows that species adapted to existence in mineral-rich substrates predominate, and the presence of subglycotrophic and glycotrophic species indicates the presence of excess HCO3-, SO42-, and Cl-salts and traces of salt salinity in the substrate.

Different ecogroups of macrophytes were affected by the deterioration of water quality in different ways, according to the industry. Projective coverage of ecogroups varied slightly, except for subglycotrophs and glycotrophs. In particular, the first group showed a decrease in the total projective coverage of the ecogroup (r = -0.271) against the background of a stable number of species, and for the second, the deterioration of water quality led to an increase in the number of species (r = 0.567) and the expansion of their projective coverage (r = 0.607) (Table 9).

Table 9. *Analysis of the relationship between the salt regime of the substrate (Sl) of macrophyte ecogroups and an integrated ecological index of water quality (N=55)*

Ecogroup	**Correlation coefficient**	$t_{Student's}$	**Correlation conclusion**	**Correlation coefficient**	$t_{Student's}$	**Correlation conclusion**
Mesotrophs	-0.179	-1,338	missing	-0.219	-1,645	missing
Semievtrophs	-0.169	-1,263	missing	**-0.323**	-2,509	reverse
Eutrophies	-0.242	-1,833	missing	**-0.550**	-4,842	reverse
Subglycotrophs	**-0.271**	-2,071	reverse	-0.250	-1,897	missing
Glycotrophs	**0.607**	5,618	direct	**0.567**	5,056	direct

Source: *compiled by the authors*

For semieutrophic and eutrophic ecogroups, the deterioration of water quality led to a decrease in the number of species against the background of insignificant variations in the total groups of projective coatings. Mesotrophs were found to be the least sensitive to anthropogenic pressure, with no significant dependencies on the number of species or their projective coatings within the study area. The information on the distribution of macrophyte species diversity in relation to soil carbonate content is intriguing. Most species have narrow ranges of ecological valence to this factor. And the most represented ranges, 4-7 and 4-9, cover almost 30% of species (Fig. 10). Carbonatephobes (2.44%) and hemicarbonaphobes (68.29%) are prevalent.

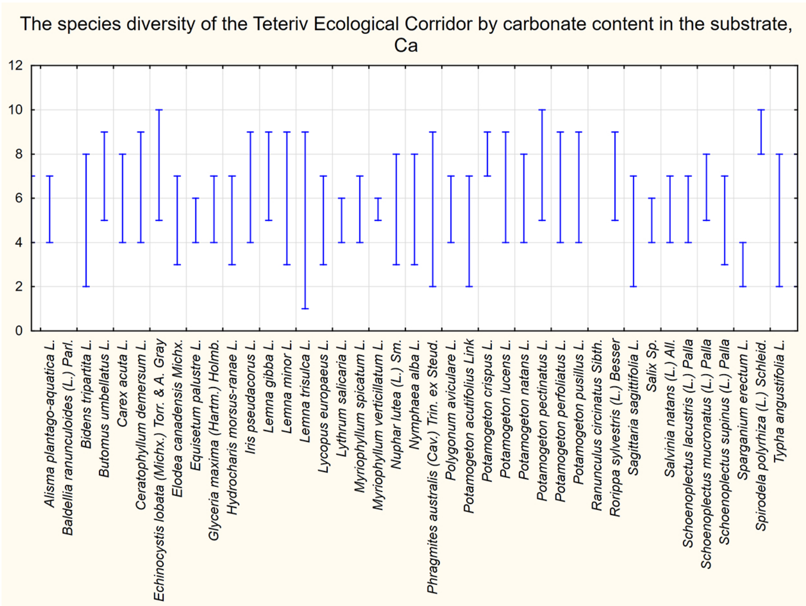

Figure 10*. The species diversity of the TEC by carbonate content in the substrate*

Source:*compiled by the authors*

Stenotic and hemistenotopic biomorphs are more common in ecogroups, which also shows that carbonate salinization isn't allowed in the study area. Different ecogroups were affected by deteriorating water quality in relation to the presence of carbonates. (Table 10).

Table 10. *Analysis of the relationship between the carbonate content in the substrate (Ca) of macrophyte ecogroups and an integrated ecological index of water quality (N = 55)*

Ecogroup	Correlation coefficient	$t_{Student's}$	Correlation conclusion	Correlation coefficient	$t_{Student's}$	Correlation conclusion
Carbonatophobes	-0.118	-0.875	missing	-0.118	-0.875	missing
Hemicarbonatephobes	**-0.331**	-2,581	reverse	**-0.578**	-5,211	reverse
Acarbonate	-0.128	-0.950	missing	**-0.323**	-2,510	reverse
Hemicarbonate	-0.196	-1,469	missing	-0.116	-0.863	missing

Source: *compiled by the authors*

Thus, the most sensitive group was the hemicarbonate ecogroup, where, along with a decrease in the number of species, there was a decrease in their projective coverage. On the other hand, in the acarbonate group, the loss of water-sensitive *Rorippa sylvestris (L.) Besser* was accompanied by overgrowth of *Potamogeton lucens L.* and *Schoenoplectus mucronatus (L.) Palla*. So, research has shown that there are a few ecogroups and species that have changed the most in response to changes in water quality (Fig. 11).

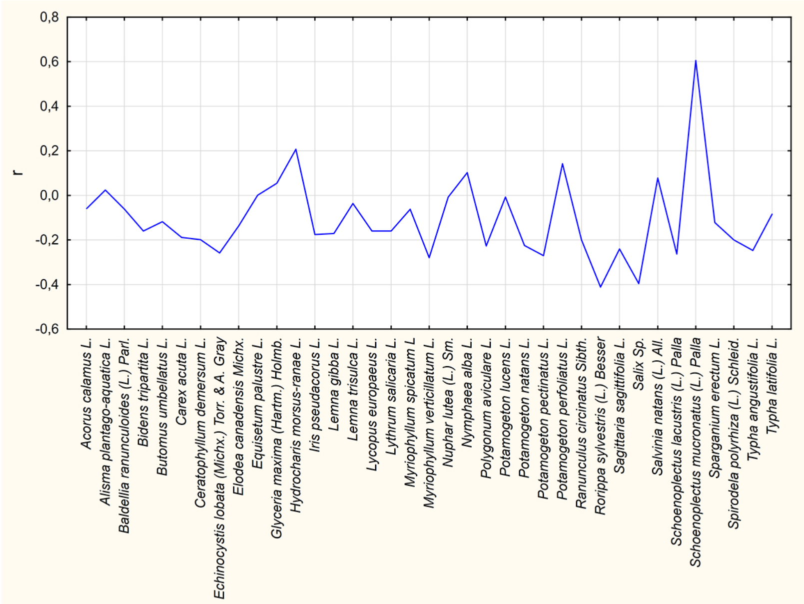

Figure 11. *Correlation relationships (r) of macrophyte distribution in terms of projected coverage based on the integrated environmental water quality index (IE)*

Source:*compiled by the authors*

Thus, the negative impact and close feedback between these indicators for the species *Trapa natans L. (Michx.) Torr. & A. Gray, Myriophyllum verticillatum L., Rorippa sylvestris (L.) Besser, Salix Sp.* etc. In addition, the positive effect of deteriorating water quality on the increase of projective coatings of some species of macrophytes, in particular, *Hydrocharis morsus-gapae L., Potamogeton perfoliatus L., Salvinia natans L., Schoenoplectus lacustris L.* etc.

Wetlands are vital, self-sufficient ecosystems that aid in the dispersal of a wide variety of plant life. Related research supports this claim (Finlay *et al*., 2020; Cruz *et al*., 2020). According to Vestergaard *et al.* (2000), these aquatic communities play a crucial role in conservation efforts over the long run. Wetlands operate as natural pollution filters and store water after heavy rains, so it's no surprise that Khan *et al.* (2022) found that they also help reduce pollution.

Wetland vascular plant diversity has been categorized in numerous ways based on the findings of different studies. For instance, Khan *et al.* (2022) categorized wetland plants using Cook's (1996a) taxonomy. Although Ellenberg's systems are widely recognized for the European region, they are missing several of the species that was discovered in the research. As a result, Didukh's system was heavily utilized, albeit modified to better suit Polissya Ukraine.

Members of the Potamogetonaceae and Cyperaceae families, which thrive in open places because to favourable factors like strong light, are disproportionately common, according to certain authors (De Oliveira *et al*., 2020; Haq *et al*., 2021). This research uncovered similar patterns.

Through this investigation, it was possible to deduce the relationships between species' ecological characteristics and their growing environment. There is a lack of research on this problem in wetlands, even though it is generally accepted that ecological development conditions affect species richness through decreased nutrient availability and slower rates of nitrogen mineralization and nitrification (Rajilesh *et al*., 2016; Cruz *et al*., 2020). The relevance of water composition and lighting conditions for their maintenance was highlighted by the current study, which showed a correlation between practically all ecogroups of macrophytes and the ecological parameters of locales. Vestergaard and Sand-Jensen (2000), two other authors, validate these findings as well.

Analysis of species distribution patterns revealed that aquatic habitats, home to species with a wide variety of thermoregime, ombroregime, continentality, and cryoregime tolerances, was predominant in the Teteriv ecological corridor. They are adaptable to a wide variety of environments, including those with a constant over wetting of the floodplain, wet swamp ecotopes, and places with temporary over wetting, low levels of dissolved oxygen in the water, the presence of muddy sediments, the predominance of anaerobic processes of transformation of neutral or, in some cases, slightly acidified substrates, a diverse supply of nitrogen and mineral composition, and the presence of traces of phosphorus. The following ecogroups are particularly vulnerable because of the degree to which their evolution is altered by the effect of anthropogenic factors.

CONCLUSIONS

The conducted studies showed the presence of species belonging to 3 divisions, and Magnoliophyta was the most numerous (41 species). The number of species is distributed almost evenly among the divisions – 15 and 14 species within the classes Liliopsida and Magnoliopsida. The group of surface-aquatic-aerial species was the most numerous, accounting for about 53.8% of the total number of species. Most phytocenoses belong to the boreo-meridional chorological group with a circumpolar range type. Thus, because of phytoindication analysis of macrophytes, a significant diversity of ecomorphs and groups of species in response to major abiotic environmental factors, formed mainly on nutrient-rich, acid-neutral, and nitrogen-rich substrates. The analysis of the distribution of species diversity showed that the Teteriv ecological corridor is dominated by aquatic ecosystems inhabited by species with wide ranges of tolerance to thermoregime, ombroregime, continentality, and cryoregime, which are able to exist in ecotopes of constant over wetting of the floodplain, wet swamp ecotopes, and places with temporary over wetting, a low level of dissolved oxygen in the water, the presence of muddy sediments and the predominance of anaerobic processes of transformation of substances neutral in acidity, and in some cases slightly acidified substrates, with a significant range of nitrogen supply and mineral composition, with the presence of traces of salt salinization of the substrate, but unable to exist in the conditions carbonate salinity.

The development of various ecological groups is significantly adjusted by the influence of anthropogenic factors, so the ecogroups are defined as sensitive: in relation to the thermal regime – submicrothermal and submesothermal; by aridity-humidity – mesoaridophytes and subaridophytes; in relation to the cryoregime – subcryophytes and hemicryophytes; according to the scale of continentality – hemioceanists and hemicontinentals; according to soil moisture – hygromesophytes, hydrophytes, hygrophytes and subhydrophytes; in relation to aeration of the substrate – subaerophiles, hemiaerophobes and aerophobes, hyperaerophobes; according to the reaction of the environment – neutrophils, heminitrophils and nitrophils; according to substrate branching – subglycotrophs, glycotrophs, semieutrophs and eutrophs; according to the content of carbonates in the substrate – hemicarbonatophobes and acarbonatophiles.

The prospects of further research are related to the determination of morphological features of species belonging to different ecogroups, which can be used for bioindication of anthropogenic pressure on aquatic ecosystems.

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Індикаційні особливості макрофітних угруповань в оцінці антропогенного навантаження на водні екосистеми

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Анотація. Вивчення структурно-функціонального біорізноманіття у взаємозв'язку з різними екологічними чинниками наразі є надзвичайно актуальним, оскільки водні екосистеми є вагомим джерелом біологічного різноманіття і складають значну частину біологічної продуктивності Землі, виконують багато функцій, є цінними і важливими для стабільності біотичних угруповань. З огляду на це, було поставлено завдання визначити флористичний склад Тетерівського екологічного коридору як прототипового річкового ландшафту північної частини України, проаналізувати структурно-функціональні особливості видового різноманіття макрофітів у ньому та розчленувати це різноманіття на складові частини за місцем походження, життєвою формою та відношенням до факторів середовища. За результатами дослідження проаналізовано кількість видів та їх прогнозоване покриття на ділянках з різним антропогенним навантаженням в межах Тетерівського екологічного коридору в розрізі екологічних зон. Показано, що інтегральний екологічний показник якості води є визначальним для зростання фітоценозів у регіонах з високим антропогенним навантаженням. Угруповання можуть виживати в умовах низького вмісту розчиненого кисню, великої кількості мулистих відкладів та переважання анаеробних процесів у перетворенні речовин. Крім того, вони можуть поширюватися в заплавах річок, вологих болотистих екотопах та інших середовищах, де вода присутня протягом тривалого часу. Більшість цих угруповань не вибагливі до середовища існування, оскільки можуть процвітати в різних ситуаціях, включаючи слабокислі або нейтральні субстрати, різний вміст азоту та мінеральних речовин у ґрунті, а також помірне засолення рослинного покриву. Збільшення чисельності представників окремих екоугруповань може свідчити про зміни екологічного стану водних екосистем та мати практичне значення при виявленні посилення антропогенного тиску на водні екосистеми

Ключові слова: індикатори, фітоценози, біорізноманіття, види, екоугруповання