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AQUATIC VEGETATION IN THE SYRA POGONIA MASSIF, RIVNENSKYI NATURE RESERVE (POLISSIA, UKRAINE): CLASSIFICATION AND ECOLOGICAL SPECIFICITY

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Background. Aquatic vegetation is a sensitive indicator of wetland ecosystem conditions, particularly peat bogs. In the Syra Pogonia protected area, vegetation reflects the effects of past anthropogenic impacts (land reclamation). Given the current climate change and hydrological instability, a detailed study of aquatic vegetation is necessary. Such research helps assess the current state of phytocoenoses and supports evidence-based conservation and restoration efforts under changing environmental conditions.

Materials and Methods. The study applied the phytosociological method of J. Braun-Blanquet using 14 geobotanical relevés. Data analysis involved TURBOVEG, JUICE, and RStudio. Plant communities (syntaxa) were identified via indicator species analysis with the fidelity coefficient (*phi*). Ecological gradients and vegetation–environment relationships were examined using PCA and NMDS.

Results. The aquatic vegetation segment of the Syra Pogonia massif was studied, and the floristic structure of the inundated localities was analyzed using cluster analysis methods. Based on 14 geobotanical relevés, three associations were delineated, belonging to different classes of aquatic vegetation (*Lemnetea*, *Potamogetonetea*, *Littorelletea*). The results indicate ecological and syntaxonomic diversity among the aquatic communities formed under the influence of trophic status, acidity, and changes in the hydrological regime of the environment. Clear ecological gradients were revealed that divide the aquatic vegetation into three groups: oligotrophic, mesotrophic, and eutrophic communities.

Conclusions. The identified aquatic vegetation communities exhibit a distinct ecological specialization and a narrow affinity to specific ecotopes, shaped by abiotic environmental factors. Their spatial segregation highlights a strong indicative potential, making these communities valuable tools for biomonitoring and assessing the condition of wetland ecosystems.

Keywords: wetland plant communities, ecological gradients, vegetation dynamics, Ukrainian Polissia

INTRODUCTION

Aquatic vegetation within peat-bog complexes constitutes an important component of biodiversity (Fontaine *et al.*, 2007). Such phytocoenoses are highly sensitive to changes in water chemistry, pH, and trophic level, and are regarded as good indicators of the ecological state of wetland ecosystems (Tomaselli *et al.*, 2018; van Wirdum, 1991). Stable aquatic communities occupy distinct ecological niches formed along trophic and hydrological gradients in peatland habitats (Bergmeier, 2020; Drzymulska *et al.*, 2013; Fijałkowski, 1959; Rodwell, 1995; Spałek, 2008;). Their study is crucial both for understanding successional processes in ombrotrophic and minerotrophic mires, and for developing conservation strategies in the face of climate change, eutrophication, and anthropogenic transformation of landscapes (Lastrucci *et al.*, 2025; Wołek, 1991).

The vegetation cover of the Syra Pogonia massif in the Rivnenskyi Nature Reserve developed under the influence of both natural and anthropogenic factors. Despite the protected status of the area, the legacy of drainage works-dating back to the early 1960s-continues to affect the contemporary vegetation by causing fluctuations in groundwater levels (Andriienko *et al.*, 2006). This has facilitated the emergence of degraded zones where eu-mesotrophic plant communities atypical for bogs appear (Yuskovets *et al.*, 2024). In addition, unregulated amber mining in adjacent territories exerts further pressure (Kovalevskyi *et al.*, 2019, 2021). Moreover, meteorological data from Sarny station show recent changes in precipitation amount and seasonal patterns, along with increases in mean annual temperatures, leading to disturbances in the hydrological balance of the massif (*Meteopost: Weather forecast for Sarny,* 2022). All these factors act synergistically to degrade natural plant communities and destabilize wetland ecosystems (Yuskovets *et al.,* 2024).

Within the vegetation structure of Rivnenskyi Nature Reserve, aquatic vegetation is the most diverse component, comprising 26.9 % of the phytocoenotic repertory (*Litopys pryrody Rivnenskoho pryrodnoho zapovidnyka*, 2007). However, these figures characterize the entire reserve and do not specifically emphasize the Syra Pogonia massif. A review of the research history on both the broader bog complexes and the Syra Pogonia peat-bog vegetation was presented in our previous work (Yuskovets *et al.*, 2024). Given that past studies of the Syra Pogonia peat-bog complex did not account for recent shifts in vegetation community formation driven by changing hydrological regimes, fires in 2015–2020, and fragmentation of wetland habitats, detailed studies of the aquatic vegetation fraction are warranted for refining and deepening data interpretation in view of changing inundation conditions of the massif.

The aim of the study is to assess the condition and indicator value of aquatic vegetation in the Syra Pogonia peat-bog massif under disturbed hydrological regime and an increasing impact of climate change.

MATERIALS AND METHODS

Study area. The Syra Pogonia peat-bog massif is a part of the Rivnenskyi Nature Reserve (Polissia, Ukraine), with a total area of 9,926 hectares, located near the villages of Hrabun and Bilsk in the Sarny District of Rivne Region (**Fig. 1**).

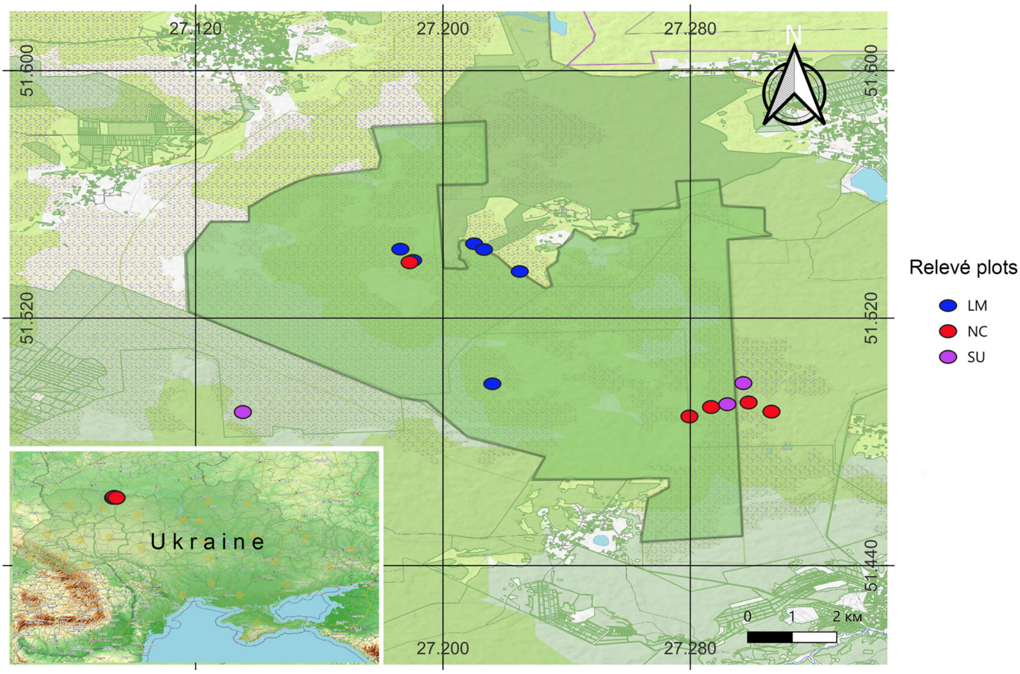

Fig. 1. Syra Pogonia massif (WGS-84), relevé plot locations: LM – *Lemnetum minoris*, NC – *Nymphaeetum candidae*; SU – *Scorpidio scorpioidis-Utricularietum*

Methods. The research was conducted following the methodology of J. Braun-Blanquet (Chytrý & Otypkova, 2003), based on the analysis of 14 phytosociological relevés collected on sample plots ranging from 1 to 16 m² from 2020 to 2022. The classification of syntaxonomic units of aquatic vegetation was carried out in stages. In the first stage, cluster analysis methods were applied to distinguish groups of relevés with similar floristic structure. The next step involved interpreting the resulting clusters using up-to-date syntaxonomic concepts and typological schemes (Mucina *et al.*, 2016; Chytrý, Ed., 2011). The identification of syntaxonomic units of aquatic vegetation enabled the characterization of their ecological and floristic specificity within the context of contemporary phytosociological classification. Plant species names are given according to the Plants of the World Online database (2025).

Data analysis. The data were processed using TURBOVEG 2.79 software in combination with JUICE 7.0.83 (Tichý, 2002). Phytocoenoses were identified using a modified two-way indicator species analysis algorithm (Roleček *et al.*, 2009). The pseudospecies cut levels were set at 0, 5, 15, and 25 %. Diagnostic species of syntaxa were determined based on the fidelity coefficient *phi* (Chytrý *et al.*, 2002), with a threshold value of more than 25%. The statistical significance of the coefficient was assessed using Fisher's exact test at P <0.001. To determine ecological optima in relation to key environmental factors, statistical analyses were performed in the RStudio 4.4.1 integrated environment using the R programming language, based on refined indicator values developed by J. Dengler *et al*. (2023). The Principal Component Analysis (PCA) was used to identify the main ecological factors shaping the spatial structure of wetland vegetation (Jolliffe & Cadima, 2016). To visualize differences in plant community composition based on ecological indicators, the non-metric multidimensional scaling (NMDS) was applied. The dataset was transformed using the Gallagher method, which reduced the influence of dominant species and balanced the contribution of less common species, ensuring a more accurate representation of species structure in statistical analysis (Legendre & Gallagher, 2001).

RESULTS AND DISCUSSION

As a result of the relevé analysis, three clusters were identified, which fall into two groups based on the waterbody trophic status: the first group includes associations 1 and 2, characterized by species typical of oligo- and oligomesotrophic conditions, while the second – association 3, whose species occur in eutrophic waterbodies (**Fig. 2**).

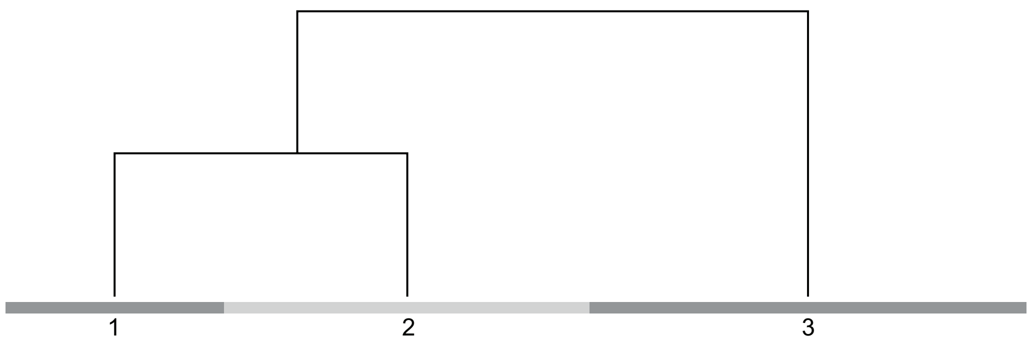

Fig. 2. Dendrogram of aquatic community distribution: 1 – *Scorpidio scorpioidis-Utricularietum*; 2 – *Nymphaeetum candidae*; 3 – *Lemnetum minoris* associations

Three associations were identified, belonging to three alliances, three orders, and three classes (**Table**):

Cl. *LEMNETEA* O. de Bolòs et Masclans 1955.

Ord. *Lemnetalia minoris* O. de Bolòs et Masclans 1955.

All. *Lemnion minoris* O. de Bolòs et Masclans 1955.

Ass. *Lemnetum minoris* von Soó 1927.

Cl. *POTAMOGETONETEA* Klika in Klika et Novák 1941.

Ord. *Potamogetonetalia* Koch 1926.

All. *Nymphaeion albae* Oberd. 1957.

Ass. *Nymphaeetum candidae* Miljan 1958.

Cl. *LITTORELLETEA UNIFLORAE* Br.-Bl. et Tx. ex Westhoff *et al.* 1946.

Ord. *Littorelletalia uniflorae* Koch ex Tx. 1937.

All. *Sphagno-Utricularion* T. Müller et Görs 1960.

Ass. *Scorpidio scorpioidis-Utricularietum* Ilschner ex T. Müller et Görs 1960

Synoptic table of aquatic vegetation associations of the Syra Pogonia massif

Associations No	1	2	3
No of relevés	3	5	6
No of species	7	19	8
Ass. *Scorpidio scorpioidis-Utricularietum*			
Utricularia minor	66.1	9.4	-
Sphagnum cuspidatum	50.0	50.0	-
Carex limosa	50.0	46.0	
Lusimachia thyrsiflora	46.0	6.6	-
Rhynchospora alba	28.8	4.1	
Ass. *Nymphaeetum candidae*			
Nymphaea candida		100.0	
Potamogeton natans		70.7	
Hydrocharis morsus-ranae		70.7	
Ceratophyllum demersum		63.2	15.8
Elodea canadensis		63.2	15.8
Jungus bulbosus		55.5	
Carex rostrata		37.8	
Menyanthes trifoliata		37.8	
Utricularia intermedia		37.8	
Spirodela polyrhiza		36.3	41.0
Ass. *Lemnetum minoris*			
Lemna minor	-	28.9	57.7
Alisma plantago-aquatica	-	6.6	46.6
Glyceria fluitans		15.4	30.9

Note: the table presents *phi*-coefficient values multiplied by 100; dark green highlights highly diagnostic species, while light green indicates diagnostic species

Relevés assigned to cluster 1 are identified as belonging to the class *Littorelletea uniflorae*, alliance *Sphagno-Utricularion*, and association *Scorpidio scorpioidis-Utricularietum* (**Fig. 3*C*,*D***). Diagnostic species include *Utricularia minor*, *Sphagnum cuspidatum*, and *Carex limosa.* Constant species are *Sphagnum cuspidatum*, *Lysimachia thyrsiflora*, and *Rhynchospora alba*. Dominant species are *Utricularia minor* and *Sphagnum cuspidatum*. The communities are mostly two-layered: the emergent layer is dominated by *Lysimachia thyrsiflora*, with occasional *Carex limosa*, while the submerged layer is formed by *Utricularia minor* and *Sphagnum cuspidatum*. *Vaccinium oxycoccos* and *Scheuchzeria palustris* occur sporadically due to their morphological traits (elongated shoots) that spread toward the water body edges and reach the peripheral limits of this association.

According to K. Dierssen (1999), two main types of communities can be distinguished within this association, depending on ecotope characteristics: those with *Utricularia minor* and *Sphagnum* species in acidic pools of oligotrophic bogs, and those with *Utricularia intermedia* and mosses from the genera *Scorpidium*, *Straminergon*, and *Drepanocladus* in neutral or slightly acidic waters of lowland fens. W. Matuszkiewicz

(2008) describes this association as having a wide ecological amplitude. E. Oberdorfer (1994) considers phytocoenoses with *Utricularia* and *Sphagnum* to be rankless communities, as he believes they are not yet fully developed. D. Fijałkowski (1959) notes that *Utricularieto-Sphagneum* communities form in strongly acidic waters. This association typically occurs in oligo-mesotrophic waters at the edges of peat bogs on peat soils with low water mineralization and a pH between 4.0 and 6.0. Key factors influencing its formation include constant or periodic inundation.

Cluster 2 consists of species from the class *Potamogetonetea*, alliance *Nymphaeion albae*, and association *Nymphaeetum candidae* (**Fig. 3*A,B***). Diagnostic species include *Nymphaea candida*, *Potamogeton natans*, and *Hydrocharis morsus-ranae*. Constant species are *Spirodela polyrhiza* and *Sphagnum cuspidatum*. The dominant species is *Nymphaea candida*. The communities are mainly two-layered, occasionally three-layered. The emergent layer includes *Carex rostrata* and *Juncus bulbosus*. The floating layer is dominated by *Nymphaea candida* (up to 85 %), accompanied by *Hydrocharis morsus-ranae*, *Spirodela polyrhiza*, and *Potamogeton natans* (each 1–5 %). The submerged layer includes *Ceratophyllum demersum* (up to 15 %) and *Elodea canadensis* (up to 5 %).

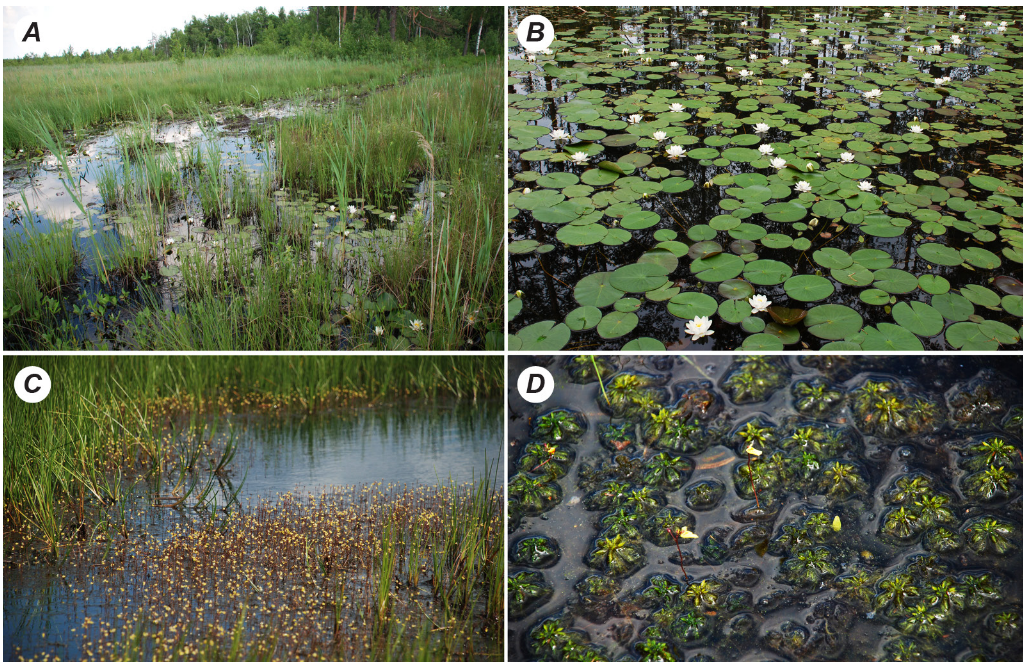

Fig. 3. ***A*, *B*** – *Nymphaeetum candidae*; ***C*, *D*** – *Scorpidio scorpioidis-Utricularietum*

This community develops in stagnant or slightly flowing waters with sandy or muddy-peat substrates, such as bog margins and drainage channels, under full sun or partial shade. *Nymphaea candida*, the edifying species, is a regionally rare aquatic geophyte with a Eurasian distribution. It is sensitive to significant water level fluctuations and cannot withstand prolonged drying. Although the optimal conditions are nutrient-poor waters, this community may also occur under a broader range of conditions – from oligo-mesotrophic and dystrophic to slightly eutrophic. The pH of the environment ranges from slightly acidic to neutral (pH 6.0–7.0).

Cluster 3 includes six relevés assigned to the class *Lemnetea*, alliance *Lemnion minoris*, and association *Lemnetum minoris*. The diagnostic species of the association is *Lemna minor*. Constant species include *Alisma plantago-aquatica* and *Glyceria fluitans*. Dominant species are *Lemna minor* and *Alisma plantago-aquatica*. Total vegetation cover within the phytocoenoses ranges from 70 % to 100 %. The main dominants are *Lemna minor* (over 75 %) and *Alisma plantago-aquatica* (up to 5 %). A total of eight species were recorded in the relevés. In addition to *Lemna minor*, high fidelity (*phi*) values were noted for *Alisma plantago-aquatica* and *Glyceria fluitans* (*Table*). Other species, such as *Ceratophyllum demersum* and *Elodea canadensis* (class *Potamogetonetea*) and *Phragmites australis* (class *Phragmitetea-Magnocaricetea* Klika in Klika et Novák 1941), were occasionally present, but they played no significant role in the community structure. This association occurs in enclosed or weakly flowing, well-illuminated and water-saturated, primarily eutrophic parts of waterbodies, such as puddles on forest roads, shallow canal margins, or edges of bogs.

The PCA results (**Fig. 4**), incorporating vector representation of ecological factors and macrophyte species clustering, revealed distinct ecological gradients that determine the primary structure of the aquatic vegetation.

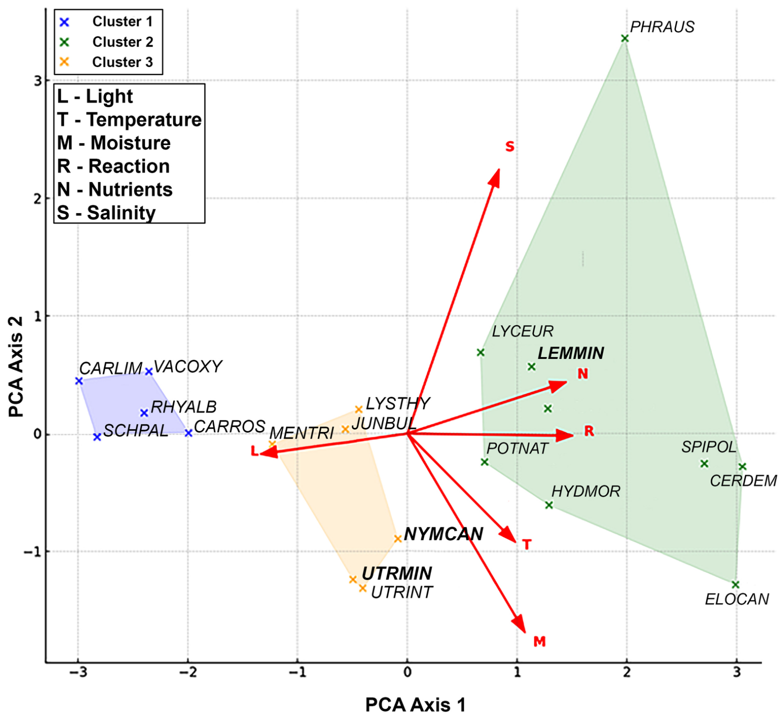

Fig. 4. PCA ordination of species along ecological gradients: ALIPLA – *Alisma plantago-aquatica*, CARLIM – *Carex limosa*, CARROS – *Carex rostrata*, CERDEM – *Ceratophyllum demersum*, ELOCAN – *Elodea canadensis*, GLYFLU – *Glyceria fluitans*, HYDMOR – *Hydrocharis morsus-ranae*, JUNBUL – *Juncus bulbosus*, LEMMIN – *Lemna minor*, LYCEUR – *Lycopus europaeus*, LYSTHY – *Lysimachia thyrsiflora*, MENTRI – *Menyanthes trifoliata*, NYMCAN – *Nymphaea candida*, PHRAUS – *Phragmites australis*, POTNAT – *Potamogeton natans*, RHYALB – *Rhynchospora alba*, SCHPAL – *Scheuchzeria palustris*, SPHCUS – *Sphagnum cuspidatum*, SPIPOL – *Spirodela polyrhiza*, UTRMIN – *Utricularia minor*, UTRINT – *Utricularia intermedia*, VACOXY – *Vaccinium oxycoccos*

Three clusters were identified, each corresponding to different environmental condition types: the first cluster includes oligotrophic, acidophilic species typical of acidic, waterlogged ecotopes; the second cluster is represented by species tolerant to moderate levels of light, moisture, and nutrient availability, characteristic of transitional conditions; the third cluster consists of eutrophic, light- and thermophilic species that prefer neutral to slightly alkaline waters with elevated nutrient content. The directional orientation of the ecological vectors confirms the presence of three habitat types: natural wetland areas, anthropogenically transformed eutrophic waterbodies, and transitional zones that combine features of both and are characterized by a mosaic vegetation cover.

The results of the additional application of the NMDS method (**Fig. 5**) indicate a clear separation of plant species according to their ecological requirements and also allowed for the identification of three main groups. The first group comprises hydrophytic species associated with eutrophic conditions of standing or slow-flowing waters. The second group is represented by species typical of oligotrophic peat bogs with acidic, nutrient-poor soils. The third group includes species occupying an intermediate position, occurring under mesotrophic conditions.

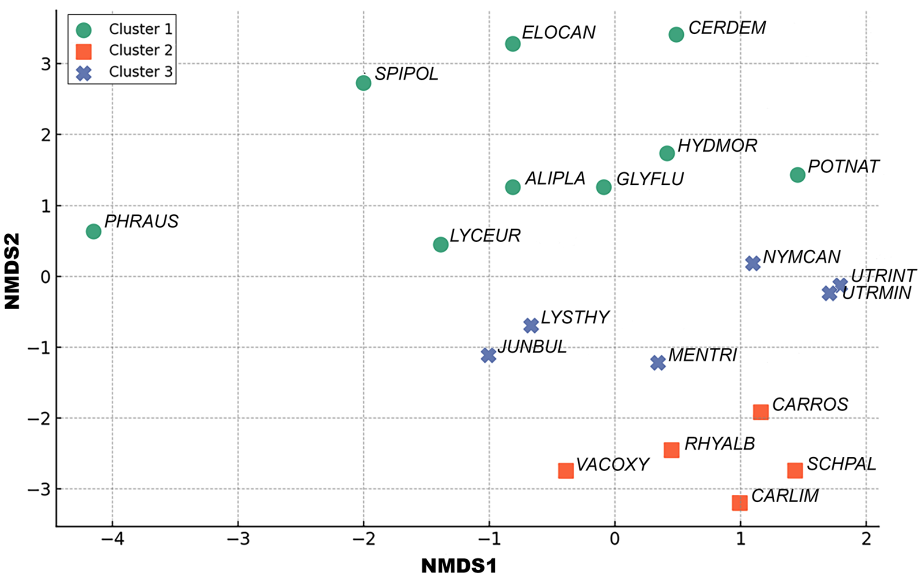

Fig. 5. Non-metric multidimensional scaling (NMDS) of bog flora species based on ecological similarity. Species symbols on the scale as in Fig. 4

CONCLUSION

The identified associations of aquatic vegetation in the Syra Pogonia peat-bog massif are characterized by distinct ecological amplitudes, which generally do not overlap. This indicates a relatively narrow affinity of each plant community to specific ecotopes and demonstrates that their spatial distribution is closely linked to a set of abiotic environmental factors – primarily the hydrological regime of waterbodies, trophic status, and acidity. The structural organization of the studied aquatic communities allows them to be regarded as indicative units that reflect specific habitats within wetland ecosystems. Therefore, the classification boundaries established between the communities may serve as a basis for the typology of wetland biocenoses and for assessing the ecological condition of protected areas. The stability and relative narrowness of the ecological amplitudes of the species make these communities reliable markers of both natural and anthropogenically altered environments, which is of critical importance for biomonitoring, biodiversity conservation, and sustainable natural resource management.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHORS CONTRIBUTIONS

Conceptualization, [I.D.; O.K.]; methodology, [I.D.; O.K.; I.R.; M.Y.]; data analysis, [I.R.]; investigation, [I.D.; O.K.; M.Y.]; data curation, [I.D.]; writing – original draft preparation, [I.D.; O.K.; I.R.; M.Y.]; writing – review and editing, [I.D.; I.R.; O.K.]; visualization, [I.D.; I.R.]. All authors have read and agreed to the published version of the manuscript.

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ВОДЯНА РОСЛИННІСТЬ МАСИВУ СИРА ПОГОНЯ РІВНЕНСЬКОГО ПРИРОДНОГО ЗАПОВІДНИКА (ПОЛІССЯ, УКРАЇНА): КЛАСИФІКАЦІЯ ТА ЕКОЛОГІЧНА СПЕЦИФІКА

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Обґрунтування. Водяна рослинність є чутливим індикатором стану водно-болотних екосистем, зокрема, торфовищ. У межах заповідної території Сира Погоня структура рослинного покриву відображає наслідки минулих антропогенних впливів, особливо меліоративних робіт 1960-х років. З огляду на сучасні кліматичні зміни та нестабільність гідрологічного режиму, детальне вивчення водяної рослинності є актуальним. Такі дослідження сприяють оцінці сучасного стану фітоценозів і розробці науково обґрунтованих заходів охорони й відновлення екосистем в умовах змін довкілля.

Матеріали та методи. Дослідження проведено за фітоценологічним методом Ж. Браун-Бланке на основі 14 геоботанічних описів. Аналіз даних здійснювали з використанням програм TURBOVEG, JUICE і RStudio. Виділення рослинних угруповань (синтаксонів) виконано методом індикаторних видів із використанням коефіцієнта вірності (*phi*). Для виявлення екологічних градієнтів і аналізу зв'язку рослинності з умовами середовища застосовували аналізи PCA та NMDS.

Результати. Досліджено водну фракцію рослинності масиву Сира Погоня, проаналізовано флористичну структуру обводнених локалітетів із використанням методів кластерного аналізу. Виділено три асоціації, що належать до різних класів водяної рослинності (*Lemnetea, Potamogetonetea, Littorelletea*). Отримані результати свідчать про екологічну та синтаксономічну різноманітність водяних угруповань, сформованих під впливом трофності, кислотності та змін гідрологічного режиму середовища. Виявлено чіткі екологічні градієнти, що розділяють водяну рослинність на три групи: оліготрофні, мезотрофні й евтрофні угруповання. Дослідження демонструє важливість аналізу водяної фракції рослинності для оцінки стану болотних екосистем та їхньої екологічної динаміки.

Висновки. Виділені угруповання водяної рослинності характеризуються чіткою екологічною спеціалізацією та вузькою приуроченістю до певних типів екотопів, що зумовлено відповідними абіотичними факторами середовища. Їхнє просторове розмежування свідчить про значний індикаційний потенціал таких угруповань, які можуть бути використані для біомоніторингу й оцінки стану водно-болотних екосистем.

Ключові слова: водно-болотні рослинні угруповання, екологічні градієнти, динаміка рослинного покриву, Українське Полісся

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Supplement 1. **Header data of the authors' relevés**

Relevé	Date, year/month/day	Latitude	Lontitude	Relevé area, m^2	Cover shrub/herb layer, %	Height schrub/herb layer, м	Cover moss layer, %
1	2020/07/21	51.5440680	27.2101020	15	95	1.15	
2	2020/07/21	51.5421970	27.2132690	20	45	0.38	
3	2020/07/21	51.4987950	27.2159860	25	98	1.60	
4	2020/07/20	51.5386840	27.1903620	10	80	0.38	
5	2020/07/20	51.5423140	27.1862110	12	60	0.41	
6	2020/07/20	51.5350890	27.2248380	20	40	0.36	
7	2020/07/21	51.4990240	27.2971620	15	20	0.15	70
8	2022/07/20	51.4896540	27.1352820	12	85	0.51	40
9	2022/08/22	51.4921900	27.2919910	10	60	0.34	80
10	2022/07/22	51.4882290	27.2797230	50	30	0.33	90
11	2022/07/22	51.4912700	27.2867300	25	40	0.30	20
12	2021/07/21	51.5380730	27.1892270	15	50	0.62	80
13	2022/07/22	51.4897850	27.3062630	30	50	0.60	85
14	2020/08/23	51.4927440	27.2988780	25	40	0.34	90

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Supplement 2. **Vegetation table of the authors' relevés**

Species \ Associations	*Scorpidio scorpioidis-Utricularietum*			*Nymphaeetum candidae*					*Lemnetum minoris*					
Relevé	8	9	7	12	10	11	13	14	3	2	5	1	4	6
Sphagnum cuspidatum	3	3	4	2	3	2	4	3	-	-	-	-	-	-
Utricularia minor	3	5	4	r	+	-	-	+	-	-	-	-	-	-
Lysimachia thyrsiflora	+	-	+	+	-	1	-	-	-	-	-	-	-	-
Scheuchzeria palustris	2	-	2	-	-	-	-	-	-	-	-	-	-	-
Vaccinium oxycoccos	1	-	1	-	-	-	-	-	-	-	-	-	-	-
Rhynchospora alba	1	-	-	-	-	+	-	-	-	-	-	-	-	-
Carex limosa	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Nymphaea candida	-	-	-	3	5	3	5	4	-	-	-	-	-	-
Ceratophyllum demersum	-	-	-	2	1	+	+	1	-	+	+	1	1	-
Elodea canadensis	-	-	-	1	2	+	+	1	+	-	1	-	1	2
Potamogeton natans	-	-	-	-	2	1	+	-	-	-	-	-	-	-
Spirodela polyrhiza	-	-	-	-	1	+	+	1	1	2	-	+	2	2
Juncus bulbosus	-	-	-	-	2	-	+	-	-	-	-	-	-	-
Hydrocharis morsus-ranae	-	-	-	r	-	+	-	+	-	-	-	-	-	-
Menyanthes trifoliata	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Carex rostrata	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Utricularia intermedia	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Lycopus europaeus	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Lemna minor	-	-	-	-	1	+	+	+	5	5	5	5	4	4
Alisma plantago-aquatica	-	-	-	-	1	-	+	-	+	+	-	-	1	1
Glyceria fluitans	-	-	-	-	+	-	-	+	+	-	-	-	+	1
Phragmites australis	-	-	-	+	-	-	-	-	-	-	-	-	1	-