Available online at www.HEFJournal.org

ISSN: 2785-2997

Journal of
Human, Earth, and Future

Vol. 3, No. 4, December, 2022

Parametric Assessment of Macrophytes Ecological Niches in Solving Problems of Sand Quarry Lakes Phytomelioration

Nataliia Mironova [1], Olesya Mateyuk [1], Halyna Biletska [1], Sergii Shevchenko [1], Liudmila Kazimirova [1], Boris Artamonov [1], Vasyl Kravchuk [2], Ihor Bloshchynskyi [2*]

[1] *Department of Ecology and Biological Education, Faculty of Humanities and Education, Khmelnytskyi National University, Khmelnytskyi, 29000, Ukraine.*

[2] *Bohdan Khmelnytskyi National Academy of the State Border Guard Service of Ukraine, Khmelnytskyi, 29000, Ukraine.*

Received 25 August 2022; Revised 03 November 2022; Accepted 17 November 2022; Published 01 December 2022

Abstract

Technogenic reservoirs, i.e., sand quarry lakes, appear when sand is extracted under the water column by dredgers or as a result of flooding of quarries. Studies of such reservoirs in the territory of Small Polissia (Ukraine) have shown that the devastated shoreline is like a neo-ecotope formed in the ecotone zone between the water environment of such reservoirs and natural areas upon completion of their operation. Changes in the ecotope within this zone lead to the formation of ecological niches with a set of new specific factors characteristic of aquatic and near-shore vegetation. It has been determined that the fundamental niche of macrophytes in the littoral area of sand quarry lakes in the conditions of Small Polissia is determined by the following parameters: illumination 2500-90000 lux; depth 0–5 m; and trophicity (humus content) – 0-5 %. The realized niches differ for plants of different ecological groups and make up about 50 % for helophytes, about 20 % for pleistophytes, and about 70 % for hydatophytes of the fundamental niche of aquatic vegetation. The volume of space in which the niches of all types of macrophytes in the technogenic lakes of Small Polissia overlay is 10%. The maximum overlay of niches is characteristic of areas covering a combination of factors in terms of illumination (in summer) 15000-90000 lux and depths of 1.3–2.8 m, which creates conditions for the formation of three-tiered phytocoenoses. The niche of submerged plants is the largest, which indicates their highly competitive potential, which is limited mainly by the illumination parameter. Under such conditions, the rapid development of submerged vegetation in the future may lead to the accumulation of its biomass and bogginess, which will limit the use of sand quarry lakes for recreational and other types of nature management. Phytomeliorative tree planting around sand quarry lakes is proposed to regulate illumination as a parameter of the ecological niche of submerged plants.

Keywords: Sand Quarry Lakes; Ecological Niche; Near-Shore and Aquatic Plants.

1. Introduction

Sand is one of the world's most popular types of mineral deposits. It is extracted using an open-pit mining method in dry or flood bypass quarries. Technogenic lakes with disturbed ecosystem components around the quarry field are formed upon completion of the operation of flood bypass quarries. As a result of the primary succession, the vegetation cover is restored by species whose niches correspond to the characteristics of the formed neo-ecotope. Studying the ecological niches of macrophytes in sand quarry lakes is an important issue for understanding succession processes and involving these water bodies in sustainable environmental management.

* Corresponding author: i.bloshch@gmail.com

http://dx.doi.org/10. 28991/HEF-2022-03-04-02

The conceptual framework of the research was based on the theory of the ecological niche [1–4], the concept of which has undergone certain changes over time and continues to evolve today. In our research, the ecological niche is considered by Hutchinson's theory [5-7] as a multidimensional model that takes into account the environmental factors to which a particular species should be adapted and is divided into a fundamental niche, which covers the entire set of environmental conditions in which a species can exist in the absence of enemies, and a realized niche, which is the set of conditions in which the species exists. In such a case, the realized niche is usually smaller than the fundamental niche.

It is known that to measure the dimension of a species' niche, it is necessary to describe all the parameters related to it (abiotic and biotic factors, physical and chemical environmental conditions), which is quite difficult to do. Some scholars investigated the influence of radioactive materials and objects, considering negative economic and social consequences to the person, society, state, and international community [8]. Therefore, researchers are interested in reducing the dimensionality of the niche as much as possible when the concept of a multidimensional niche is applied to the study of real natural communities. In this regard, the realized ecological niche has recently been increasingly identified with the spectrum of resource use by a species according to several of the most important niche factors. The fundamental study by Giller [6], Schenner [9], and other scientists [10, 11] has shown that the effective number of measurements of niche factors can be reduced.

Macrophytes are considered key components of aquatic ecosystems, providing about 26 types of ecosystem services [12]. Therefore, their ecological niches have been considered in various aspects; in particular, they have been studied under conditions of variable factors in the water regime of natural reservoirs [13]. The issues of overlaying niches in the context of competition for limited resources, including between natural and invasive species, have also been studied [14–16]. At the same time, the main focus of the studies has been on investigating niches in natural reservoirs, and technogenic water bodies have not been considered.

2. Materials and Methods

We have studied the parameters of macrophyte niches in sand quarry lakes formed in the territory of Small Polissia of Ukraine. Small Polissya is a physical and geographical region located in the western part of Ukraine and partially in Poland. The natural and climatic conditions, as well as the physical and geographical conditions of Small Polissia, have led to its specialization in certain industries such as agriculture, forestry, and mining. The formation of technogenic lakes in Small Polissia is associated with sand mining in water-bearing strata where groundwater is close to the soil surface. Most of the quarries that were produced before the mid-80s of the 20th century were 10–12 meters deep. Today's quarries are much deeper – up to 20–30 meters. Unlike natural lakes, sand quarry lakes lack a clear pattern in the distribution of depths and have an undeveloped area of shallow water. The water of these lakes is characterized by relative transparency and a low content of nitrogen compounds, and the littoral zone is represented by an unproductive sandy substrate.

The ecotone zone of technogenic reservoirs is subject to gradual self-overgrowth with the formation of a specific flora and vegetation cover upon the completion of the quarry operation. The species composition and distribution of plants in the ecotone of different lakes, and even in their areas, differ significantly and depend on the genesis (morphology of the basin and near-shore area), age, and several environmental conditions (properties of bottom sediments and near-shore substrate, transparency and chemical composition of water masses, its trophicity and mineralization, site illumination, etc.). In this context, changes in the natural ecotope of the Small Polissia area due to mining operations and the formation of technogenic lakes have led to the formation of ecological niches with a set of new specific factors, especially in the ecotone zone that has formed between the water environment of the lakes and areas that were not affected by mining operations.

The research program consisted of three stages. The first stage provided for the identification of plant species in different ecological groups characterized by the highest biomass accumulation and the selection of ecotone areas for the establishment of sample plots.

The second stage included the determination of the parameters of ecological niches. We used the rule of limiting factors, according to which not all vital factors were taken into account, but only those that, according to our research of the ecotone's phytocoenosis structure, may be critical for the species' survival and spread. The following factors were selected for this purpose: 1) illumination is a fundamental factor affecting plant development; 2) trophicity of the substrate of technogenic reservoirs, which is a product of the destruction of natural soil or its partial transformation; 3) depth of the littoral zone. The latter factor is the most important for attached plants, since a sharp drop in depth, which is characteristic of the specific shape of the hollow of sand quarry lakes, significantly limits the movement of plants from the shore towards the water area. The values of these parameters were measured along the transect in the sample plots.

The third stage involved graphical interpretation and analysis of the data.

The study of the species composition and structure of vegetation within the ecotone of technogenic lakes was carried out by route methods, with field documentation maintenance followed by desk-based processing of the collected materials. The illumination was measured with a Testo 540 lux meter. The study of ecotone substrates was carried out according to standard methods: taking and preparation of samples for analysis under GOST 28168-89 and DSTU ISO 11464-2007; humus content under DSTU 4289:2004.

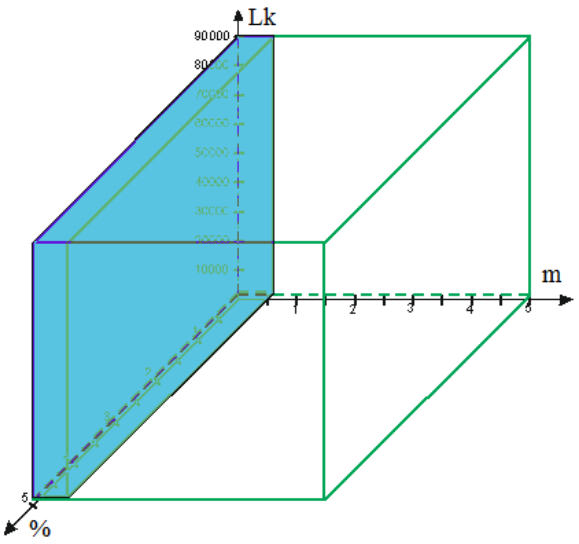
3. Results and Discussion

The peculiarities of the vegetation cover formation in the studied technogenic lakes are that the process of overgrowth is influenced not only by natural but also by economic and technological factors. These include, first and foremost, the slow pace of overgrowth due to the specific geochemical composition of the water and bottom sediments of sand quarry lakes, which are poor in nutrients. Another important factor is the heterogeneity of the microrelief, which was mostly formed by the technological factors of the quarry operation, resulting in a lack of a clear pattern in the depth distribution, i.e., deep water areas can gradually turn into shallow water not only from the center of the reservoir to the shores but also in other directions. This leads to the formation of a discrete cover of aquatic vegetation in addition to the traditional belt of near-shore water and aquatic vegetation.

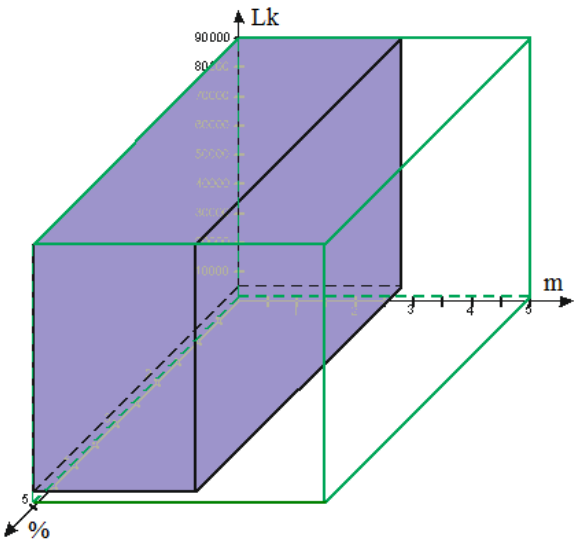
The formation of technogenic reservoirs has created conditions for the development of this territory by species with ecological niches that are completely different from the zonal ones. We consider the specificity of these niches in two aspects. The first one is related to the formation of a completely different ecological space in a certain area, i.e., the formation of lakes in forest ranges and floodplain meadows in Small Polissia, which puts the factor of changing the moisture gradient from the zonal value to the maximum in a water body forward to the leading place in the formation of vegetation cover. The second aspect is the change in the properties of the ecotope associated with mining activities, which distinguishes it from the natural one in terms of quantitative and qualitative indicators (change in soil cover, difference in the hydrochemical composition of lake water).

After analyzing the peculiarities of the vegetation cover of technogenic lakes, we determined that the main area of natural overgrowth in the conditions of absolute change of ecotope and its initial sterility is the littoral zone, which is filled with plants that can exist in conditions of excessive moisture or flooding. In this regard, we analyzed the formation of new ecological niches using the ecotope's aquatic and near-shore water plants.

Since we support the understanding of an ecological niche as a characteristic of a species rather than a set of environmental conditions, we defined ecological niches for the most common plant species of different ecological groups characterized by the largest projective cover and biomass, namely *Carex acuta* L., *Phragmites australis* (Cav.) Trin. ex Steud., *Potamogeton natans* L., and *Ceratophyllum demersum* L. As a result of the research, it was determined that the fundamental niche of littoral plants in technogenic lakes in Small Polissia, taking into account variations in trophicity, illumination, and depth, is determined by the following parameters: illumination – 2500-90000 lux; depth – 0-5 m; trophicity (humus content) – 0-5 %. Figure 1 shows the realized niches of macrophyte species in the hyperspace of the fundamental niche (shown in green) of sand quarry lakes.



niche *Carex acuta* L.



niche *Phragmites australis* (Cav.) Trin. ex Steud.

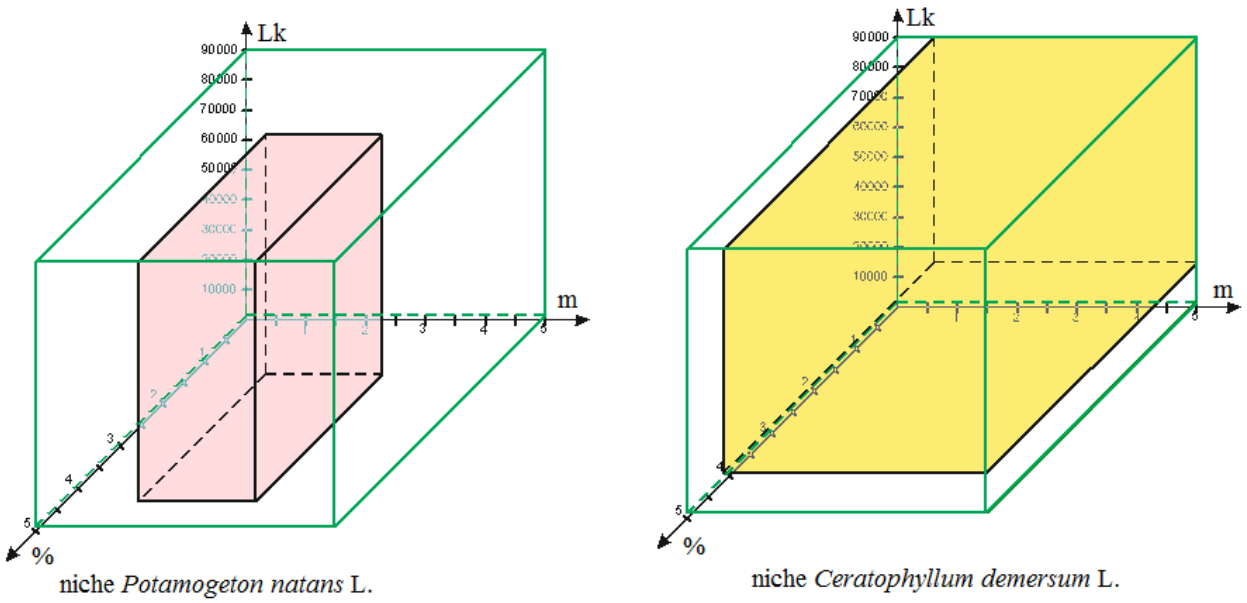


Figure 1. The niches of near-shore water plants and aquatic plants in the 3-dimensional volume ecotone zone of technogenic lakes (depth, illumination, trophicity of substrate)

It was found that at the first stages of overgrowth, in the absence of competition from other plants, the width of the fundamental and realized niches of aquatic and near-shore water plants in the ecotone coincided. With the further development of succession processes, the niche of *Carex acuta* decreases to 12% of the total volume of the ecological niche of aquatic and near-shore water plants in lakes. This value makes 53% for *Phragmites australis*, 23% for *Potamogeton natans*, and the highest value is characteristic of *Ceratophyllum demersum* at 73%. This, to some extent, explains the fact that the overgrowth of technogenic lakes is characterized by a significant presence of submerged vegetation.

The niches of littoral plant species are prone to a partial division of their fundamental niches, resulting in two or more species simultaneously claiming the same resource. In this case, according to Hutchinson, the hyperspace of niches for some species includes parts of the hyperspaces of niches for other species, i.e., it overlays them. In the conditions of technogenic lakes, the niches of *Carex acuta* and *Ceratophyllum demersum*, as well as *Carex acuta* and *Carex acuta*, do not overlay at all due to the differentiation of the niches of these species by depth.

The overlay of the fundamental niche of *Carex acuta* with *Phragmites australis* in the near-shore areas occurs in all parameters and amounts to about 97%. Only 3% of the space forms a non-competitive environment for *Carex acuta* due to unfavorable illumination for *Phragmites australis*. Such areas were observed on forest lakes, where shading at the water's edge is created by nearby forest vegetation. At the same time, sedge can occupy up to 21% of the total hyperspace in the reed niche.

On the waterside, the reed niche is overlaid by floating and submerged vegetation niches. For example, the *Phragmites australis* niche can overlay the *Potamogeton natans* niche by 20% and the *Ceratophyllum demersum* niche by 69%. This explains the spread of two-tiered associations between helophytic vegetation, which acts as dominant vegetation, and submerged vegetation, which acts as co-dominant vegetation, in medieval lakes. The niche of floating vegetation is almost completely overlaid by helophytic and submerged vegetation. For example, in the *Potamogeton natans* niche, almost half of the hyperspace (46%) can be occupied by *Phragmites australis*, and *Ceratophyllum demersum* can occupy up to 94% of its niche. Only a small proportion of it is not overlaid by niches of other species and, accordingly, can be occupied by pure, stable pleistophyte cenoses in the range of depths unfavorable for helophytes and under conditions of insufficient illumination for hydatophytes. Such areas were observed on medieval and young forest lakes with a sharp drop in depth under low illumination due to the proximity of the forest phytocoenoses to the water's edge. In the wide niche of *Ceratophyllum demersum*, reeds can occupy half of it (50%) and the pondweed up to 30%.

The volume of space in which the niches of all species overlay, except *Carex acuta*, is 10% of the ecological niche of aquatic and near-shore water plants (Figure 2).

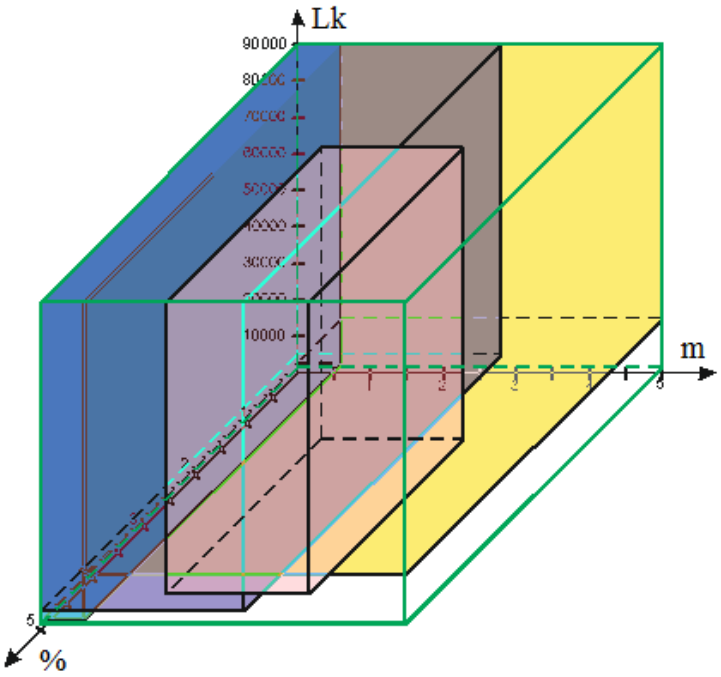


Figure 2. Overlay niches of macrophytes in ecotones of technogenic lakes of Small

As a result of the succession complications of phytocoenoses, new species occupy the distribution centers of already adapted species. Competition makes the dispersion of distribution narrow along the gradient. Hutchinson and MacArthur [2] and MacArthur [3] called this process the "packing" of an increasing number of species along the resource gradient. It has been shown that the main differentiation of niches occurs along the gradients of depth (or water layer height) and illumination, which in flat terms makes it possible to identify the most stressed areas and, as succession processes progress, the most "packed" areas with the maximum overlay of niches (Figure 3). These are areas that cover a combination of factors in terms of illumination (15000-90000 lux) and depth (1.3–2.8 m), where there is an overlay of niches of tall herbaceous helophytes, floating and submerged vegetation. However, floating vegetation will compete only in areas with a high humus content, the area of which will increase over time as a result of endoecogenetic succession of phytocoenoses.

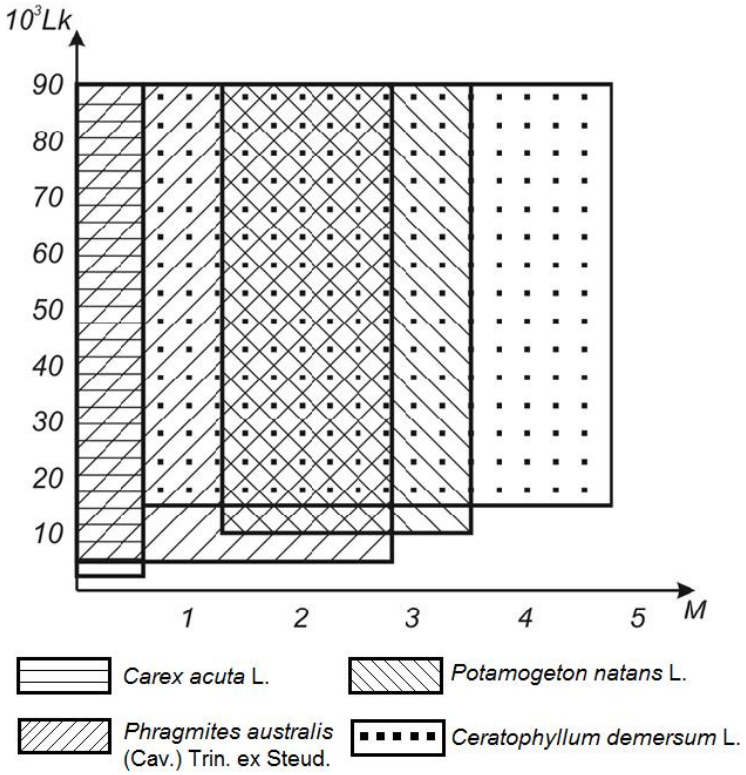


Figure 3. Two-dimensional model of overlay niches macrophyts in ecotones of technogenic lakes of Small Polissia depending on depth and illumination

4. Conclusions

The analysis of ecological niches makes it possible to state that, with time, the riverbanks and the littoral zones may actively overgrow, for example, with a cane, creating the conditions for the conversion of near-shore areas to boggy areas due to the accumulation of organic remains. Illumination is an important factor that can significantly restrain this process. To optimize the riverbank zone and avoid bogginess, it is expedient to use phytomelioration, i.e., conversion of the environment with the help of plants. The creation of riverbank plantations from the number of tree species that are characteristic of this natural-climatic zone will allow the formation of such an illumination regime in niches of macrophytes, which will regulate the phytoproduction of near-shore water and aquatic groups.

At the initial stage, the growth of near-shore phytomeliratory plantings will have a minimal influence due to the low height of trees, which will allow the phytocoenoses of aquatic and near-shore water vegetation to develop and provide artificial reservoirs with a natural appearance. As the projective cover of phytocoenoses of macrophytes increases, the need to limit the accumulation of their biomass to prevent the development of eutrophication processes in the reservoirs will arise. With the growth of near-shore plantations, the latter will act as a limiting factor for reducing the light flux, which, due to the formation of tree crowns, will provide the niche shading, especially for the cane and Ceratophyllum demersum, since they have the greatest potential for biomass accumulation with the increased illumination. The creation of phytomelioration plantations should ensure that the structure of natural phytocoenoses is consistent with the structure of natural phytocoenoses to trigger natural mechanisms of environmental optimization and the formation of sustainable plant communities.

Thus, our research highlights the peculiarities of macrophyte niches in sand quarry lakes associated with their technogenic genesis, namely: a rapid depth drop limits the niche of helophytes, and low trophicity in the initial stages of succession limits the niche of pleistophytes. Sufficient water transparency ensures the formation of a wide niche for submerged plants, which can lead to excessive accumulation of their biomass and gradual bogginess in shallow lake areas. To limit this process, it is advisable to regulate such a niche parameter as illumination by creating shoreline tree plantations.

5. Declarations

5.1. Author Contributions

Conceptualization, N.M. and I.B.; methodology, O.M.; software, H.B.; validation, S.S., L.K., and B.A.; formal analysis, VK; investigation, NM; resources, VK.; data curation, OM; writing—original draft preparation, HB; writing—review and editing, S.S.; visualization, L.K. and B.A.; supervision, I.B. and H.B.; project administration, N.M. and O.M. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article

5.4. Institutional Review Board Statement

Not applicable.

5.5. Informed Consent Statement

Not applicable.

5.6. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

6. References

[1] Senterre, B., Lowry Ii, P. P., Bidault, E., & Stévart, T. (2021). Ecosystemology: a new approach toward a taxonomy of ecosystems. Ecological Complexity, 47, 100945. doi:10.1016/j.ecocom.2021.100945.

[2] Hutchinson, G. E., & MacArthur, R. H. (1959). A Theoretical Ecological Model of Size Distributions among Species of Animals. The American Naturalist, 93(869), 117–125. doi:10.1086/282063.

[3] Qi, Y., Yao, Z., Ma, X., Ding, X., Shangguan, K., Zhang, M., & Xu, N. (2022). Ecological risk assessment for organophosphate esters in the surface water from the Bohai Sea of China using multimodal species sensitivity distributions. Science of the Total Environment, 820, 153172. doi:10.1016/j.scitotenv.2022.153172.

[4] May, R. M., & MacArthur, R. H. (1972). Niche overlap as a function of environmental variability. Proceedings of the National Academy of Sciences of the United States of America, 69(5), 1109–1113. doi:10.1073/pnas.69.5.1109.

[5] Lin, X., Tang, Z., & Long, H. (2022). Spatial and temporal research on ecological total factor energy efficiency in China: based on "Ecology-Economy-Geography" heterogeneity framework. Journal of Cleaner Production, 377, 134143. doi:10.1016/j.jclepro.2022.134143.

[6] Giller, P. S. (1984). Community structure and the niche. Chapman and Hall, London, United Kingdom. doi:10.1007/978-94-009-5558-5.

[7] Bornette, G., & Puijalon, S. (2011). Response of aquatic plants to abiotic factors: A review. Aquatic Sciences, 73(1), 1–14. doi:10.1007/s00027-010-0162-7.

[8] Nikiforenko, V. (2021). Combating Illegal Movement of Radioactive Materials and Objects across the State Border of Ukraine. Nuclear and Radiation Safety, 1(89), 30–35. doi:10.32918/nrs.2021.1(89).04.

[9] Schoener, T. W. (1983). Field experiments on interspecific competition. American Naturalist, 122(2), 240–285. doi:10.1086/284133.

[10] Pip, E. (1988). Niche congruency of aquatic macrophytes in central North America with respect to 5 water chemistry parameters. Hydrobiologia, 162(2), 173–182. doi:10.1007/BF00014540.

[11] Alahuhta, J., Virtala, A., Hjort, J., Ecke, F., Johnson, L. B., Sass, L., & Heino, J. (2017). Average niche breadths of species in Lake Macrophyte communities respond to ecological gradients variably in four regions on two continents. Oecologia, 184(1), 219–235. doi:10.1007/s00442-017-3847-y.

[12] Thomaz, S. M. (2021). Ecosystem services provided by freshwater macrophytes. Aquatic Ecosystem Services: Hydrobiologia, 1-21. doi:10.1007/s10750-021-04739-y.

[13] Veen, H., & Sasidharan, R. (2019). Shape shifting by amphibious plants in dynamic hydrological niches. New Phytologist, 229(1), 79–84. doi:10.1111/nph.16347.

[14] Verhoeven, M. R., Glisson, W. J., & Larkin, D. J. (2020). Niche models differentiate potential impacts of two aquatic invasive plant species on native macrophytes. Diversity, 12(4), 162. doi:10.3390/D12040162.

[15] Gettys, L. A. (2019). Breaking bad: Native aquatic plants gone rogue and the invasive species that inspire them. HortTechnology, 29(5), 559–566. doi:10.21273/HORTTECH04333-19.

[16] Matias, L. Q., Santos, L. I., Romero, R. E., & Menezes, B. S. (2022). Patchiness of aquatic plant assemblages in seasonal wetlands: Local abiotic factors explain the spatial distribution of growth forms. Austral Ecology, 47(7), 1495-1505. doi:10.1111/aec.13233.