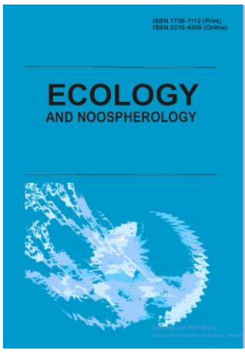

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Ecological and structural transformation of floodplain forests of Khortytsia island under post-catastrophic disruption of the hydrological regime

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The article presents the results of a comprehensive study of transformation processes in the floodplain forest ecosystems of Khortytsia Island caused by the destruction of the Kakhovka Hydroelectric Power Plant dam in June 2023. The relevance of the study is determined by the unprecedented scale of the hydrological disaster, which resulted in severe dehydration of the middle reaches of the Dnipro River and a radical alteration of floodplain habitat conditions. The aim of the research was to identify key features of ecological and landscape restructuring of vegetation cover and to reveal patterns of secondary succession during the post-disaster period. The methodology combined remote sensing techniques and field-based geobotanical surveys. Sentinel-1 SAR data were used to accurately map changes in water surface area, while Sentinel-2 imagery was applied for spectral index analysis (NDVI). The results show that the total water surface area of floodplain lakes decreased by more than 170 times (from approximately 793,200 m^2 to 4,630 m^2), which effectively indicates the collapse of aquatic ecosystems in the southern part of Khortytsia Island and the onset of intensive terrestrial succession processes. Field investigations enabled a comparative analysis of the floristic composition of the primary bank and newly formed terrestrial areas on the sites of former water bodies. The dendroflora of the primary bank (33 species) proved to be relatively more stable; however, it exhibits clear signs of mesophytization and xerophytization caused by groundwater level decline. Degradation of hygrophilous edificators (*Salix alba*, *Populus nigra*) was recorded, manifested by reduced vitality, extensive crown dieback, and damage by stem-boring insects. The most critical condition was observed in species of the genus *Ulmus*, associated with disruption of their ecological optimum and the development of secondary phytopathological processes. On the exposed beds of former water bodies, pioneer communities of early successional stages have developed, dominated by ecologically plastic and invasive species (*Amorpha fruticosa, Salix × rubens, Populus nigra*). Special attention is drawn to the expansion of *Amorpha fruticosa*, which forms monodominant thickets and inhibits the natural regeneration of native tree species. Ecomorphic analysis revealed a shift in phytocenosis structure towards xeromesophytic and synanthropic forms, indicating a gradual loss of typical functional characteristics of floodplain forests. The scientific novelty of this study lies in the quantitative real-time assessment of landscape transformation on Khortytsia Island using satellite monitoring verified by field observations. The practical significance of the results involves their application in developing adaptive management strategies for protected areas during the post-disaster period, forecasting fire hazards, and planning measures to limit recreational pressure on degraded ecosystems. The obtained data provide a basis for long-term ecological monitoring of ecosystem recovery in the Dnipro River basin.

Keywords: Khortytsia Island; Kakhovka HPP; floodplain forests; succession; dehydration; NDVI; invasive species; *Amorpha fruticosa*; remote sensing; ecological disaster.

Introduction

Floodplain forests are a key component of river landscapes, ensuring biodiversity conservation, hydrological regulation, and ecosystem stability in large river valleys (Capon et al., 2013; Johnson et al., 2016). They form specific habitats dependent on seasonal water-level dynamics and are among the most vulnerable ecosystems, being highly sensitive to anthropogenic impacts and alterations in hydrological conditions (Havrdová et al., 2023; Borsukevych et al., 2022). In Ukraine, the conservation and adaptive management of floodplain forests are particularly relevant within the framework of the habitat-based approach to nature conservation (Borsukevych, 2023).

Khortytsia Island is a unique natural area located in the middle Dnipro floodplain, where floodplain, ravine, and steppe ecosystems coexist, resulting in high floristic diversity and significant conservation value (Okhrimenko & Shelegeda, 2016; Okhrimenko & Tkach, 2019). The vegetation cover of the island has been studied for several decades, with particular attention paid to dendroflora and the structure of ravine (balka) and floodplain communities (Popovych et al., 1992; Yakovleva-Nosar & Bessonova, 2018, 2020, 2025). At the same time, anthropogenic regulation of the Dnipro River flow during the 20th century, associated with the construction of a cascade of reservoirs, substantially transformed the natural hydrological regime, leading to structural changes in floodplain biotopes and the spread of adventive species (Abduloieva & Karpenko, 2009; Klisz et al., 2019).

The destruction of the Kakhovka Hydroelectric Power Plant dam in June 2023 was an unprecedented ecological disaster that caused an abrupt alteration of the Dnipro hydrological regime and large-scale transformations of floodplain ecosystems (Afanasiev, 2023; Kvach et al., 2025; Shumilova et al., 2025). The catastrophic drainage of the Kakhovka Reservoir resulted in the formation of new dry and waterlogged ecotopes, triggered intensive successional processes, and led to profound restructuring of the vegetation cover (Dovhanenko et al., 2024; Didukh et al., 2024). It has been shown that already within the first year, various pioneer communities developed on the exposed reservoir bottom, including willow–poplar cenoses capable of restoring key ecosystem functions of the floodplain (Didukh et al., 2024; Tutova et al., 2025c).

For Khortytsia Island, located upstream of the former dam, the reduction in water level resulted in the shallowing of floodplain water bodies, disruption of soil moisture regimes, and rapid restructuring of coastal vegetation (Mikhina, 2025; Domnich et al., 2024). Field surveys and remote sensing analyses revealed pronounced spatial differentiation of these transformations: coastal zones experienced a sharp increase in hemeroby and in the proportion of ruderal and adventive species, whereas the central parts of the island remained relatively stable (Lisovets et al., 2025; Tutova et al., 2025b). Analysis of spectral indices and remote sensing data confirmed structural and functional changes in phytocenoses associated with dehydration, increased xerophyticity, and disruption of trophic links (Tutova et al., 2025b). Generalized floristic data for Khortytsia Island and adjacent territories collected after the disaster indicate the formation of new spatial vegetation patterns combining elements of degradation and recovery (Tutova et al., 2025a; Lisovets et al., 2025).

In this context, a comprehensive study of the ecological and structural transformation of floodplain forests on Khortytsia Island following the abrupt hydrological changes caused by the destruction of the Kakhovka Hydroelectric Power Plant is highly relevant. Such a study should include the application of remote sensing methods, which allow assessment of the condition and recreational functions of green areas (Ivanchenko et al., 2022; Denysenko et al., 2025). The aim of this study is to identify changes in the vegetation cover of the island’s floodplain areas, determine the leading ecological drivers of these transformations, and assess potential successional trajectories of phytocenosis development. This provides a necessary scientific basis for substantiating measures for the conservation, restoration, and adaptive management of floodplain forests under new hydrological conditions.

Materials and methods

The study was conducted in 2025 using a combination of remote sensing methods and field geobotanical and ecological studies. The methodological basis was provided by generally accepted approaches to the analysis of vegetation cover and the ecological structure of phytocenoses (Kuzemko et al., 2018).

To assess the spatial and temporal changes in the hydrological regime and vegetation cover, Sentinel-2 and Sentinel-1 satellite data for 2020, 2023-2025 were used, obtained through the Copernicus Browser platform (https://browser.dataspace.copernicus.eu/). The analysis of the coastline, water areas, and vegetation condition was performed based on True Color visualization. To quantitatively assess the productivity and moisture content of the vegetation cover, the NDVI vegetation index was calculated using the QGIS software environment. A quantitative assessment of changes in the area of floodplain reservoirs on Khortytsia Island was performed based on Sentinel-1 radar images for 2023 and 2025. The use of SAR data made it possible to reliably identify water surfaces regardless of cloudiness and lighting conditions. In the SNAP program, after standard image preprocessing (radiometric and orthotransformation correction), the water surface was selected and discrete cartographic models were constructed. Water areas were identified using threshold segmentation based on backscatter values σ^0, which made it possible to separate water surfaces from land and calculate the area of water bodies.

Field studies were conducted during the 2025 growing season. To analyze the structure of tree and shrub communities, 205 sample areas measuring 4 × 4 m were established on the native shore and 224 similar areas on drained areas of former water bodies. In each sample area, the species composition of tree and shrub species, the projective cover of seedlings in the herbaceous layer, and the canopy closure of the tree and shrub layer were determined. The vitality of trees was assessed based on a set of morphological characteristics, including the condition of the crown, foliage, trunk, and skeletal branches, taking into account signs of desiccation, mechanical damage, and damage by plant diseases and insect pests.

The ecological structure of tree and shrub communities was assessed using an ecomorphic approach, analyzing the hygro-morphic, tropho-morphic, and light structure of the dendroflora. For each species, membership in the corresponding ecomorphological groups was determined according to ecological scales (Tarasov, 2012), after which their share in the composition of communities of the native shore and drained areas of former reservoirs was summarized.

Results and discussion

1. Changes in the hydrological regime and their impact on floodplain ecosystems in the southern part of Khortytsia Island

To analyze changes in the coastal zone of floodplain lakes on Khortytsia Island and in the Dnipro River channel, Sentinel-2 images acquired in August 2020, 2024, and 2025 were used. This temporal selection made it possible to minimize seasonal effects and to trace spatial and temporal dynamics of the observed transformations. The year 2020 was chosen as the baseline due to dry weather conditions comparable to those recorded in 2024.

Comparative analysis of Sentinel-2 images using True Color visualization (Fig. 1) revealed pronounced spatial changes in the shoreline configuration of floodplain lakes and the Dnipro River channel. A substantial reduction in water surface area was observed, accompanied by exposure of former reservoir bottoms and the formation of extensive sandy–silty coastal zones, indicating a significant decrease in water levels. Simultaneously, fragmentation and attenuation of the green spectral signal within floodplain forests and coastal areas were recorded, reflecting transformation of vegetation cover under disturbed hydrological conditions. The detected changes are predominantly qualitative in nature and indicate a general trend toward dehydration and structural reorganization of floodplain ecosystems.

To assess spatio-temporal dynamics of the functional state of vegetation cover in the southern part of Khortytsia Island, the NDVI was analyzed for August 2020 and 2024 (Fig. 2A, B). The results demonstrate an overall decrease in NDVI values in 2024 relative to 2020, indicating a decline in total vegetation productivity within the study area. Higher NDVI values were mainly confined to meadow–marsh vegetation associated with former floodplain lakes, where moisture conditions remained relatively stable.

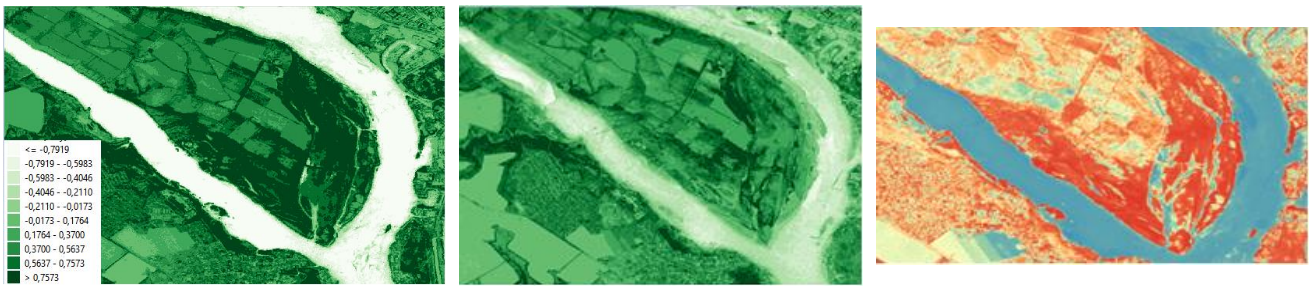
29 August 2020 *23 August 2024* *28 August 2025*

Fig. 1. Changes in the shoreline of floodplain lakes and the Dnipro River and in the intensity of green coloration based on Sentinel-2 satellite images (True Color visualization)

To further detail spatial patterns of change, a map of NDVI differences (ΔNDVI) between 2020 and 2024 was constructed (Fig. 2C). Areas characterized by negative ΔNDVI values are clearly localized within zones that experienced the most pronounced hydrological alterations. These areas exhibit reduced green cover density, degradation of plant communities, or substantial restructuring of their internal organization, indicating a weakening of vegetation ecological functions under dehydration stress.

Analysis of radar imagery revealed that by 2025 the total water surface area of floodplain lakes had decreased from approximately 793,200 m² in 2023 to 4,630 m², representing a reduction of more than 170-fold. Consequently, less than 1% of the water surface area recorded prior to the destruction of the Kakhovka Hydroelectric Power Plant remained within the study area.

The floodplain lake area in May 2023, estimated using Sentinel-1 data, was approximately 20% smaller



A. 25 August 2020 *B. 26 August 2024* *C. Difference in NDVI values between 2020 and 2024*

Fig. 2. Dynamics of the NDVI within the southern part of Khortytsia Island

than generalized values reported in the literature (Kompanets & Kazantsev, 2025). This discrepancy can be attributed to the inherent variability of floodplain hydrological regimes, as open water surface areas fluctuate in response to water-level regulation and hydrological conditions (Wohl, 2025; Opperman et al., 2010). In this context, radar-derived estimates reflect the minimum actual extent of open water, whereas literature data typically represent averaged or maximum seasonal values.

The obtained quantitative indicators confirm the critical scale of floodplain ecosystem dehydration on Khortytsia Island and are consistent with results derived from optical imagery and vegetation index analyses. It should be noted that threshold-based SAR classification may slightly underestimate water surface areas in shallow, vegetated, or partially waterlogged zones characterized by increased backscatter. However, given uniform processing conditions and the comparative nature of the analysis, this limitation does not affect the reliability of the detected trends in water surface dynamics.

2. Structural and functional characteristics of tree vegetation on the native shore and former floodplain reservoirs

Field surveys corroborated the remote sensing results and revealed characteristic indicators of floodplain ecosystem transformation on Khortytsia Island. These include strip-like overgrowth of shallow floodplain lakes, the formation of continuous stands of pioneer herbaceous species and tree–shrub clusters, as well as intensive soil processes such as cracking of exposed bottom sediments and subsequent plant colonization of these fissures. The combination of these features indicates the onset of hydroserial succession and the transition of floodplain biotopes into a new, structurally unstable state.

For comparative analysis of tree and shrub vegetation, two contrasting ecotopes were examined: (1) the native shore located between the system of floodplain lakes (205 sample plots of 4 × 4 m), and (2) drained areas that functioned as the bottom of floodplain lakes until 2023 (224 plots of 4 × 4 m). This design allowed assessment of differences in phytocenosis structure, tree species regeneration, and the role of pioneer and invasive species in habitats with contrasting hydrological histories.

On the native shore, the tree layer exhibits pronounced vertical stratification and comprises a mixture of native and naturalized species. *Quercus robur*, *Populus alba*, *Celtis occidentalis*, and *Acer negundo* play a dominant role in the tree stand (Table 1). The highest crown closure values were recorded for *Q. robur* (33.8 ± 3.0%) and *P. alba* (26.9 ± 2.6%), which determines their leading coenotic role and their influence on local microclimatic conditions. In the most humid coastal microhabitats, the contribution of *Salix alba* increases locally, where it forms dense thickets; however, overall it remains a secondary component of the tree layer.

The shrub layer is dominated by *Amorpha fruticosa* and *Crataegus fallacina*, while intensive regeneration of *C. occidentalis* and *Acer tataricum* indicates active renewal processes within the tree stand.

Synanthropization is clearly expressed in the structure of the native shore. The presence of invasive taxa (*Amorpha fruticosa*, *Gleditsia triacanthos*, *Robinia pseudoacacia*) and the dominance of pioneer and invasive species (*A. fruticosa*, *Populus* spp., *Acer negundo*) within the regeneration layer indicate their pronounced competitive advantages. In contrast, natural regeneration of native forest-forming species (*Quercus robur*, *Ulmus laevis*, *Rhamnus cathartica*) remains weak. The occurrence of seedlings of *Ailanthus altissima* and *Parthenocissus quinquefolia* represents an additional indicator of synanthropic element penetration into forest communities.

Table 1
Species composition and structural parameters of tree and shrub vegetation in native shore communities and former floodplain water bodies

Latin name	Native shore (n = 205)		Former water bodies (n = 224)	
	Occurrence, %	Crown closure / projective cover, % (Mean ± SE)	Occurrence, %	Crown closure / projective cover, % (Mean ± SE)
1	2	3	4	5
I. Tree layer				
Acer negundo L.	17,1	15,7±1,7	0,9	33,4±17,1
Celtis occidentalis L.	17,6	19,4±3,0	1,3	20,0±5,8
Fraxinus pennsylvanica Marshall	6,3	11,9±1,9	0,4	20,0
Morus alba L.	13,7	16,4±2,1	0,4	10,0
Morus nigra L.	1,5	20,0±5,8		
Populus alba L.	17,1	26,9±2,6	0,9	15,0±2,2
Populus nigra L.	13,7	14,8±2,5	3,1	25,3±5,2
Pyrus communis L.	9,3	13,4±1,8		
Quercus robur L.	18,5	33,8±3,0	0,4	40,0
Robinia pseudoacacia L.	2,4	12,0±3,4		
Salix alba L.	5,4	28,2±5,5	0,9	5,0±0,0
Styphnolobium japonicum (L.) Schott	0,5	15,0		
Ulmus glabra Huds.	9,3	9,7±1,2	0,9	15,0±5,0
Ulmus laevis Pall.	13,2	10,8±1,8		
Ulmus minor Mill.			0,4	5,0
II. Shrub layer				
Acer campestre L.			0,4	3,0

1	2	3	4	5
Acer negundo L.	4,4	6,7±0,8	2,2	7,6±1,5
Acer tataricum L.	5,4	9,6±1,6		
Amorpha fruticosa L.	35,6	11,2±1,0	20,1	24,4±2,5
Berberis vulgaris L.	1,0	6,0±4,0	0,9	2,5±0,5
Celtis occidentalis L.	9,3	6,1±1,3		
Cornus sanguinea L.	6,3	6,9±1,8		
Crataegus fallacina Klokov	20,5	7,9±1,4	0,4	5,0
Crataegus monogyna Jacq.	2,0	7,5±2,5		
Euonymus europaeus L.	0,5	2,0		
Frangula alnus Mill.	1,5	3,3±0,9		
Fraxinus pennsylvanica L.	2,4	8,6±3,1	0,4	2,0
Gleditsia triacanthos L.	1,0	2,0±0,0		
Populus alba L.	3,9	6,8±2,3	3,6	39,4±9,0
Populus nigra L.			11,2	19,2±2,8
Prunus spinosa L.	0,5	5,0		
Pyrus communis L.	0,5	5,0		
Quercus robur L.	0,5	30,0		
Rhamnus catartica	2,0	2,0±0,4		
Robinia pseudoacacia L.	1,0	10,0±0,0		
Rosa canina L.	1,0	2,0±1,0		
Salix × rubens Schrank			17,4	32,8±4,1
Salix alba L.	0,5	5,0	0,4	5,0
Sambucus nigra L.	1,5	2,0±0,6		
Ulmus glabra Huds.	0,5	5,0		
Ulmus laevis Pall.	0,5	1,0		
Ulmus minor Mill.	2,9	5,8±2,9		
Ulmus pumila L.	1,5	3,0±1,0		
III. Tree and shrub seedlings (herb layer)				
Acer negundo L.	7,3	2,0±0,3	7,1	2,0±0,3
Acer tataricum L.	0,5	5,0		
Ailanthus altissima (Mill.) Swingle			0,4	3,0
Amorpha fruticosa L.	12,7	3,2±0,5	19,6	8,4±1,9
Celtis occidentalis L.	22,0	1,9±0,2	6,3	1,6±0,3
Cornus sanguinea L.	4,4	1,2±0,2	1,8	5,8±4,8
Crataegus fallacina Klokov	2,9	1,2±0,2		
Crataegus monogyna Jacq.	0,5	1,0		
Euonymus europaea L.	1,5	2,3±1,3		
Fraxinus pennsylvanica Marshall	2,9	1,3±0,3	1,8	1,3±0,3
Gleditsia triacanthos L.	2,4	1,0±0,0		
Morus alba L.	1,5	1,3±0,3	3,6	1,0±0,0
Parthenocissus quinquefolia (L.) Planch.	2,0	3,0±1,4		
Populus alba L.	9,8	1,8±0,3	8,5	1,6±0,2
Populus nigra L.	2,0	1,8±0,5	12,9	4,8±1,7
Prunus armeniaca L.	0,5	1,0		
Prunus spinosa L.	1,0	1,5±0,5		
Pyrus communis L.	2,0	1,5±0,5		
Quercus robur L.	5,9	1,8±0,7	0,4	3,0
Rhamnus cathartica L.	1,0	1,0±0,0	0,4	1,0
Robinia pseudoacacia L.	1,0	1,0±0,0		
Rubus caesius L.	13,7	4,8±1,4	0,9	3,5±1,5
Salix ×rubens Schrank			7,1	4,0±1,8
Salix triandra L.			0,4	1,0
Sambucus nigra L.	2,0	1,5±0,3		
Ulmus laevis Pall.	1,5	2,3±1,3	0,4	1,0
Ulmus minor Mill.	5,4	1,4±0,2	3,6	1,0±0,0
Vitis riparia Michx.	1,0	1,0±0,0	0,9	1,0±0,0

In drained areas of former water bodies, the tree layer is fragmented and represented by isolated individuals of *Populus nigra*, *P. alba*, *Celtis occidentalis*, and *Acer negundo*. Despite their low frequency, some species are capable of forming locally high projective cover (notably *A. negundo*, 33.4 ± 17.1%), resulting in pronounced spatial mosaicism. Overall, the tree stand is open, sparse, and structurally unstable, whereas the shrub layer plays a decisive role in community organization. The absolute dominant species is the invasive *Amorpha fruticosa* (20.1% occurrence; 24.4 ± 2.5% cover), which forms dense thickets and suppresses the development of other taxa. A substantial contribution is also made by *Salix × rubens* (17.4%) and juvenile individuals of *Populus nigra* and *P. alba*, which actively colonize exposed substrates.

The regeneration layer in drained areas is predominantly composed of pioneer and invasive taxa

(*Amorpha fruticosa*, *Populus* spp., *Acer negundo*, *Salix* × *rubens*), whereas recovery of native floodplain species (*Quercus robur*, *Ulmus laevis*, *Rhamnus cathartica*) is minimal. The detection of *Ailanthus altissima* and *Vitis riparia* further indicates the rapid incorporation of synanthropic elements into early successional communities.

Overall, the native shore retains features of a relatively well-formed forest phytocenosis with higher structural stability, whereas drained former water bodies represent early stages of secondary succession and are characterized by a mosaic, ecologically unstable organization dominated by pioneer and invasive species. These contrasts reflect differences in hydrological history between the ecotopes and highlight the decisive role of hydrological regime disruption in restructuring tree and shrub vegetation.

The native shore is characterized by higher taxonomic richness of woody plants, with 33 species belonging to 15 families, compared to 21 species from 13 families in drained former water bodies, corresponding to an approximate difference of 36% (Fig. 3). The family structure of the native shore is more balanced, with a substantial contribution from Rosaceae (7 species), as well as Fabaceae and Ulmaceae (4 species each), reflecting the presence of developed undergrowth and a combination of autochthonous and naturalized components. In contrast, the floristic spectrum of drained areas is more condensed and typical of early successional stages: Salicaceae dominates (5 species), indicating the prevalence of moisture-demanding, fast-growing taxa capable of rapid colonization of unstable substrates; Ulmaceae is represented by three species, while most other families are represented by single species and do not form a stable floristic core. The presence of Simaroubaceae, represented by *Ailanthus altissima*, serves as an additional indicator of synanthropization in these young communities.

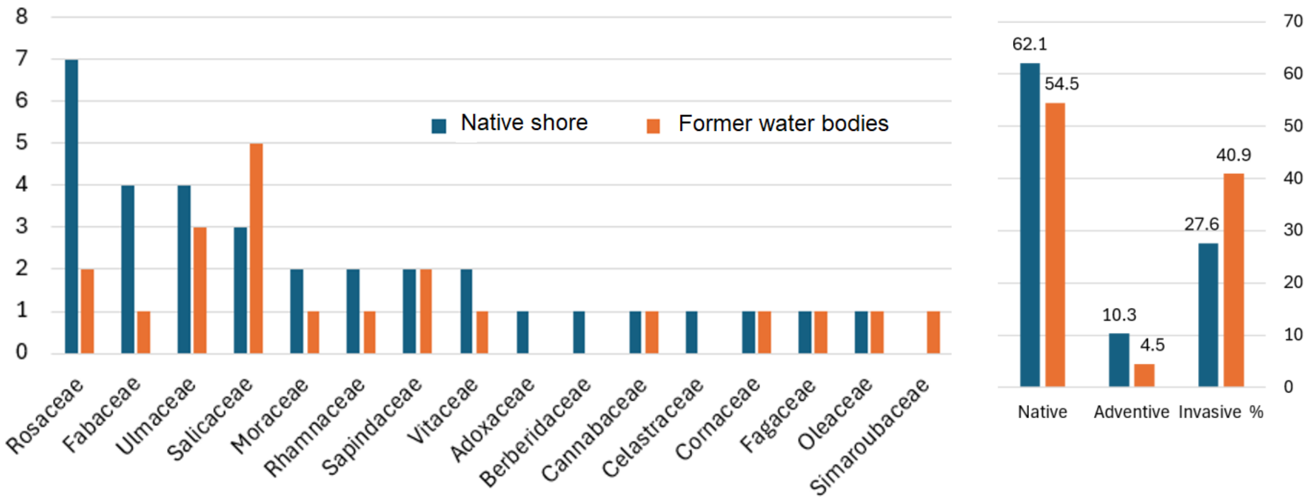


Fig. 3. Floristic structure of the dendroflora of the floodplain forests of Khortytsia Island

With respect to the origin of its tree and shrub flora, the native shore retains a predominantly autochthonous character, represented by species typical of floodplain and forest-steppe forests (*Quercus robur*, *Ulmus laevis*, *U. minor*, *U. glabra*, *Populus alba*, *P. nigra*, *Salix alba*, *Cornus sanguinea*, *Crataegus* spp., *Prunus spinosa*, *Rosa canina*, etc.). An adventive component is also present; however, it is largely confined to the regeneration and lower strata and is mainly represented by North American and East Asian introductions (*Acer negundo*, *Amorpha fruticosa*, *Robinia pseudoacacia*, *Gleditsia triacanthos*). This pattern reflects prolonged anthropogenic pressure and gradual naturalization processes. At the same time, the native shore hosts a higher number of invasive species (13 vs. 7), which can be interpreted as a consequence of a longer "time window" available for their establishment under relatively stable edaphic and hydrological conditions.

Drained areas of former water bodies are characterized by a markedly greater contribution of adventive and invasive taxa, associated with abrupt hydrological regime disruption, substrate exposure, and the formation of open ecotopes. Species exhibiting high ecological plasticity and rapid recovery potential (*Acer negundo*, *Fraxinus pennsylvanica*, *Amorpha fruticosa*, *Vitis riparia*, *Parthenocissus quinquefolia*, *Morus alba*, *Ailanthus altissima*) are actively represented, along with *Salix* × *rubens*, which is typical of anthropogenically transformed floodplains. Autochthonous species (*Salix alba*, *Populus* spp., *Ulmus* spp.) are also present; however, they frequently fail to form well-developed regeneration layers and are outcompeted by adventive shrubs and lianas.

Comparison of the two biotopes shows that the native shore is dominated by indigenous species (62.1%), whereas drained areas exhibit a substantially higher proportion of invasive taxa (40.9%). Consequently, the native shore functions as a relatively stable refuge for forest vegetation, while drained former water bodies represent dynamic early successional communities with a high likelihood of further synanthropization. These patterns are consistent with generalizations for post-catastrophic floodplain landscapes, where drainage and substrate exposure promote rapid pioneer vegetation development and enhance the role of invasive species (Didukh et al., 2024; Dovhanenko et al., 2024). Similar trends are reflected in index-based assessments of vegetation hemeroby following the destruction of the Kakhovka Reservoir (Lisovets et al., 2025; Tutova et al., 2025b). In a broader context, war-induced hydrological disturbances are increasingly recognized as drivers of long-term biodiversity change and shifts in restoration trajectories toward synanthropic components (Kvach et al., 2025).

3. Assessment of tree community vitality and the level of damage caused by plant diseases and insect pests

Assessment of tree community vitality revealed pronounced differentiation among taxa, driven by species-specific ecological traits as well as contrasting moisture conditions across the studied biotopes. The most severely depressed condition was recorded in representatives of the genus *Ulmus*, which exhibited the lowest vitality indicators. Numerous exit holes and bark deformations typical of damage caused by trunk-dwelling entomophages, presumably bark beetles, were observed on *Ulmus* spp. trunks (Fig. 4). Such damage is commonly associated with the development of Dutch elm disease and indicates substantial weakening of the tree stand. Despite severe damage to generative individuals, intensive vegetative regrowth was frequently observed, which may be interpreted as a compensatory population response to declining vitality.

Symptoms of reduced vitality–including partial crown dieback, mortality of individual branches, decreased leaf area, and crown fragmentation–were also recorded in *Salix alba* and *Populus nigra*. These symptoms were most pronounced in individuals growing on drained former water bodies under conditions of severely disturbed hydrological regimes. Such manifestations are likely associated with physiological stress caused by rapid soil dehydration.

In contrast, *Quercus robur* populations located in the central parts of floodplain forests exhibited these symptoms much less frequently. Most oak individuals maintained satisfactory to good vitality, indicating a relatively high resistance of this species to combined abiotic and biotic stressors. In some individuals, localized foliar damage was observed in the form of light spotting and diffuse discoloration of leaf blades. These symptoms were mosaic in distribution, were not accompanied by extensive necrosis or premature leaf abscission, and were likely associated with fungal phytopathologies or general physiological weakening. The detected damage was sporadic and did not exhibit a systemic character.

Fig. 4. Damage to elm (*Ulmus* sp.) trunks caused by trunk entomophages (numerous exit holes and bark deformation)

The abrupt disruption of the hydrological regime following the destruction of the Kakhovka Hydroelectric Power Plant created favorable conditions for the development of secondary trunk pests, particularly jewel beetles (Buprestidae), which may accelerate the decline of weakened trees. Larvae of these insects create galleries in the bark and sapwood, disrupting water and nutrient transport and, in combination with hydrological stress, potentially leading to rapid tree mortality. In addition, trunk-dwelling entomophages act as potential vectors of *Ophiostoma ulmi* spores, thereby increasing the risk of Dutch elm disease spread in transformed floodplain communities.

The highest overall vitality was observed in *Morus alba* and *Celtis occidentalis*. These species were characterized by well-developed crowns, the absence of significant trunk damage, and low levels of phytopathological and entomological injury. Their high vitality reflects considerable ecological plasticity and effective adaptation to transformed environmental conditions.

The regeneration and shrub layers were generally in satisfactory condition, exhibiting minimal signs of pathogen or pest damage. This indicates relative stability of the lower phytocenotic layers even under conditions of overall ecological stress.

4. Compliance of existing tree plantations in the floodplain forests of Khortytsia Island with environmental factors

The formation of tree and shrub communities in the floodplain forests of Khortytsia Island occurred through close interaction with abiotic factors, primarily moisture regime, soil trophic properties, and light conditions. The current state of these plantations reflects a combination of long-term natural processes and abrupt anthropogenic disturbances that have substantially altered key environmental parameters. In this context, ecomorphic analysis provides a tool for assessing the degree to which the contemporary species composition and community structure correspond to the prevailing ecological factors and for identifying potential directions of further successional transformation.

Analysis of the hygromorphic structure (Fig. 5A) demonstrated that both studied biotopes are predominantly formed by species with a broad ecological amplitude with respect to moisture availability; however, the patterns of hygromorph dominance differ markedly. On the native shore, xeromesophytic and mesophytic species prevail: the MsX group accounts for 33.3%, while mesophytes (Ms) constitute 24.2%, together representing more than half of the total species composition. Transitional hygromorphs (XMs, MsX–HgMs, MsX–MsHg) are moderately represented, whereas the proportion of distinctly hygrophilous elements (MsHg) is minimal. This structure corresponds to well-drained, relatively stable conditions of the native shore, characterized by predominantly moderate moisture availability.

In contrast, communities developing on former water bodies exhibit a shift of the hygrophilous spectrum toward moisture-demanding and transitional groups (Fig. 5A). The share of MsX decreases to 19.0%, while the contribution of hygrophilous and transitional elements (XMs–Hg, MsHg, MsX–HgMs) increases, reflecting the persistence of zones with elevated moisture and heterogeneous substrates following drainage. Overall, these communities are characterized by ecological instability and correspond to early stages of secondary succession.

Trophomorphic analysis (Fig. 5C) revealed pronounced differences in trophic structure between the studied biotopes. On the native shore, mesotrophic and meso-eutrophic species dominate, indicating relative stability of the trophic regime and a well-established soil nutrient cycle. The presence of an eutrophic component is associated with long-term accumulation of organic matter in developed undergrowth and sustained functioning of the tree layer. Oligotrophic and transitional trophomorphs are represented only marginally and do not determine the overall community character.

In former water bodies, the trophic structure is less balanced and shifted toward mesotrophic and eutrophic groups (Fig. 5C), which can be attributed to mineralization of organic bottom sediments after drainage and a temporary surplus of available nutrients. Such conditions favor rapid development of pioneer and invasive species and are typical of early successional stages, when trophic regimes are not yet integrated into stable biogeochemical cycles.

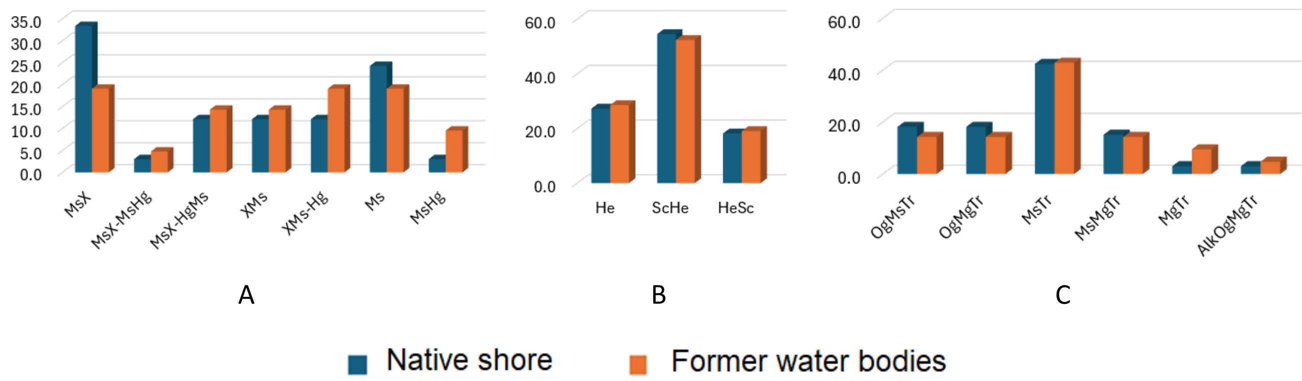


Fig. 5. Proportional composition of hygromorphs (A), heliomorphs (B), and trophomorphs (C) among tree and shrub species in the studied biotopes

The light structure of the communities (Fig. 5B) is generally similar in both biotopes. Semi-shade-tolerant species (ScHe) dominate, reflecting the floodplain origin of the vegetation and the prevalence of diffuse light conditions. However, in former water bodies, the proportion of light-demanding semi-shade-tolerant species (He) slightly increases, which is associated with the sparse tree layer and more open vegetation structure. Conversely, on the native shore, a somewhat higher proportion of shade-tolerant species (HeSc) reflects greater canopy closure and a more stable light regime.

Despite relatively high tree and shrub species diversity, the current condition of the plantations indicates ongoing degradation processes primarily driven by hydrological regime disturbance. On the native shore, widespread decline of hygrophilous and mesohygrophilous species (*Salix alba*, *Populus nigra*, *Ulmus* spp.) is observed, manifested as crown dieback, reduced growth intensity, and increased susceptibility to stem-dwelling insect pests. This suggests that these species have exceeded their ecological optima under prolonged drainage conditions.

In former water bodies, degradation processes exhibit a somewhat different trajectory. After an initial phase of successful colonization of exposed substrates by hygrophilous pioneer species (*Salix* × *rubens*, *Populus nigra*), gradual weakening and drying of these populations occurs as soil moisture continues to decline. Thus, even typical floodplain pioneer species appear unstable under conditions of long-term hydrological transformation.

Overall, the obtained results indicate a decreasing correspondence between the current species composition of tree plantations and the classic ecological conditions of floodplain forests. In the absence of restoration of the natural hydrological regime, further successional restructuring can be expected, characterized by a decline in the role of hygrophilous species and increasing dominance of ecologically plastic mesophytic and mesoxerophytic taxa. In the long term, this will lead to transformation of the floodplain forests of Khortytsia Island and a gradual loss of their characteristic ecological features and conservation value.

5. Prospects for recreational use of the floodplain forests of Khortytsia Island

The floodplain forests of Khortytsia Island constitute an important component of the recreational potential of the protected area due to the mosaic character of the landscapes, pronounced vertical stratification, and high aesthetic value of sites with preserved tree layers and well-developed undergrowth (Liashenko et al., 2022). These forests also provide microclimatic comfort through shading and mitigation of temperature extremes and enhance the perception of the island's historical and cultural heritage as an integrated landscape. Given the protected status of the territory, the recreational function of these communities should be considered primarily cognitive and educational rather than oriented toward mass recreation.

A key constraint is the need to minimize impacts on vegetation cover and soil environments. In floodplain forests, trampling, soil compaction, damage to undergrowth and understory layers, as well as the introduction and spread of adventive and invasive species along paths and forest edges represent major threats. Areas with disturbed hydrological regimes and weakened tree stands are particularly vulnerable, where any additional anthropogenic pressure may accelerate degradation processes (Fig. 6). Consequently, even seemingly "moderate" recreational use without regulation can result in disproportionately large ecological impacts.

The current ecological condition of floodplain forests further restricts acceptable recreational scenarios. Declining vitality of tree species, the presence of deadwood, and accumulation of dry phytomass increase fire hazard, making uncontrolled visitation during the warm season undesirable. In drained areas of former floodplain reservoirs, vegetation cover remains successional and structurally unstable and is especially sensitive to mechanical disturbance. Trampling and soil surface disruption in these areas promote substrate exposure, localized erosion, and further intensification of synanthropization processes.

An additional limiting factor is the set of security restrictions associated with wartime conditions. The potential presence of explosive hazards, including UAV debris, unexploded ammunition, and related fragments, in remote forested and floodplain areas objectively constrains recreational use in the absence of specialized inspection and verification of route safety. Under such circumstances, the priority shifts from recreational development to strictly controlled provision of safe access to clearly designated areas.

Fig. 6. Signs of ecological stress and degradation of tree and shrub communities in the floodplain forests of Khortytsia Island (July 2025)

Within the protected area, emphasis should be placed on regulated, environmentally compatible forms of recreation, such as short educational routes, ecological trails, thematic guided excursions, seasonal vegetation observation, and interpretive programs focused on ecosystem restoration processes and current environmental risks. Spatially, this necessitates zoning, including designation of areas with restricted access and zones where recreational use is undesirable or unacceptable, such as weakened tree stands, early successional and unstable ecotopes, and potentially hazardous sites.

In the long term, any expansion of recreational practices will depend on three key conditions: stabilization of the security situation, reduction of fire hazard, and ecological stabilization of floodplain communities following hydrological transformation. Even under these circumstances, recreational use must remain subordinate to conservation objectives and should not conflict with the preservation of the natural structure and ecological integrity of floodplain forests.

Conclusions

The floodplain forests of Khortytsia Island have undergone profound ecological transformation as a result of abrupt hydrological regime disruption caused by the destruction of the Kakhovka Hydroelectric Power Plant. Integration of remote sensing data with field-based geobotanical observations revealed large-scale dehydration of floodplain water bodies, an almost complete loss of open water surfaces, and restructuring of vegetation cover toward secondary, structurally unstable communities.

The native shore within the floodplain lake system retains characteristics of relatively stable forest phytocenoses with a pronounced vertical structure and predominance of native tree species. At the same time, clear signs of degradation of hygrophilous taxa, reduced tree vitality, and an increasing contribution of invasive and ecologically plastic species were recorded. In contrast, drained areas of former water bodies represent early stages of secondary succession and are characterized by pronounced spatial mosaicism, dominance of pioneer and adventive species, unstable hydrological and trophic regimes, and limited natural regeneration of native floodplain taxa.

Ecomorphic analysis demonstrated that the current structure of tree and shrub communities on the native shore reflects a shift from hygrophilous toward mesophytic and mesoxerophytic conditions, accompanied by an increased role of transitional ecological groups. Exceedance of ecological optima has resulted in declining tree vitality–particularly in *Ulmus* species–and has created favorable conditions for the development of secondary phytopathologies and trunk-dwelling insect pests, thereby accelerating degradation processes.

Overall, the obtained results indicate that, in the absence of restoration of the natural hydrological regime, transformation of the floodplain forests of Khortytsia Island will be long-term and associated with progressive loss of typical floodplain ecosystem features, intensification of synanthropization, and reduction of their natural ecological value. Under these conditions, floodplain forests should be regarded not as stable recreational systems but as dynamic, ecologically vulnerable communities requiring priority conservation measures, continuous monitoring, and scientifically grounded management.

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