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THE IMPACT OF CLIMATE CHANGE AND REGULATION OF THE WATER REGIME ON THE MORPHOLOGICAL STRUCTURE OF THE FLOODPLAIN FORESTS IN PETRŽALKA, SLOVAKIA

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Abstract

The main landscape-forming component has always been the forests in the lowlands. The devastation and disturbance of forest areas by anthropogenic activity change the ecological conditions in their environment. Climate and atmospheric changes affect the balance of the mutual relationships between individual components, as well as the existence of direct and feedback relationships in forest ecosystems. The transformation of bioclimatic and ecological conditions have caused the degradation of the Pannonian floodplain forest communities in Slovakia. Urbanization in Bratislava has caused the fragmentation of the surrounding forests. With changes in sunlight and heat conditions, floodplain communities are forced to become acclimatized to drier conditions, which lead to morphological and structural changes in their composition.

In this study we examined phytocenological records from 1999 to 2020 from various sources. The survey points to the impact of climate change and anthropogenic influences on biodiversity. The absence of floods and the drying of floodplain forest soils could have caused this change in the species' composition.

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Key words

- Forest morphology,
- Change of water regime,
- Climate change,
- Floodplains.

1 INTRODUCTION

Bratislava, the capital of Slovakia, and its surroundings have undergone many changes throughout their history. The first written mention of the territory of Petržalka, now a large neighborhood in Bratislava, dates from 1225. The first interaction of people with the floodplain biotopes was mainly economic. They used them for logging and hunting wild animals. Historical maps prove the intervention of the inhabitants in the vegetation of the floodplains, from which the transformation of the natural landscape into an economically viable urban region is evident (Reháčková, 2008).

A lack of production and accumulation of humus characterized the soils of the floodplain forests because floods and alluvial accretion disturbed them (Jurko, 1990).

The biotopes have been preserved in a fragmented form among the prevailing urban landscape. In connection with the operation of the nearby Gabčíkovo-Nagymaros dam and waterworks, socio-economic activities continue that still impact the development of biotopes in the area. During the dam´s construction, which began in 1977, a considerable area of these biotopes was devastated. The operation of the waterworks started in 1992. The waterworks disrupted the aquatic regime of the river and disrupted the flood regime and groundwater fluctuations.

The biotopes of the floodplain forests in the urbanized environment of Bratislava are subject to stress factors caused by anthropogenic factors. The development and urbanization of various locations in Petržalka pose the danger of disrupting the ecological stability and the biological balance, which signifi-

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cantly contribute to the fragmentation of the remnants of the Bratislava floodplain biotopes in the area studied.

Climate change, global warming, and the greenhouse effect are affecting the current state of the floodplain forests (Keszeliová et al., 2022). These global changes also impact forest communities in their structural composition or the variability of species in the biocenosis. The high concentration of greenhouse gases in the atmosphere (CO2, CH4, N2O, freon) is associated with human activity, specifically the burning of fossil fuels (Vološčuk et al., 2016).

According to climate change scenarios, biocenoses in lowland areas will be the most affected. Climate change disrupts the balance of the interrelationships of individual components and the existence of direct and feedback links in forest ecosystems (Ružička and Mišovičová, 2006). The increasing CO2 concentration and average temperature, changes in the amount and distribution of precipitation and subsequent changes in the water balance, increasing UV-B radiation, and changes in the frequency and intensity of extreme climatic events directly but also indirectly affect the composition of forest ecosystems (Minďáš and Škvarenina, 2000). Changes in bioclimatic conditions induced the transformation of forest communities along the Danube River.

The causes of the decline in the woody vegetation of floodplain forests and the decrease in the composition of autochthonous species are anthropogenic interventions and the inappropriate regulation of watercourses, which negatively affect surface water regimes and groundwater regimes, causing the absence of natural floods in river floodplains. The construction of roads and the urbanization of Petržalka have led to the fragmentation of its forest habitats. This phenomenon has affected changes in the sunlight and thermal conditions in its floodplain communities.

Plant communities react to the effect of external factors by changing the size of the assimilation organs or by undergoing various growth defects (Hutárová, 2011). These changes in the habitat of different plants are necessary for these biotopes to survive and live with the environment in balance. It is a response to a stimulus to which they have exposed the organism in different time intervals. The tolerance capacity of the species may vary with the factor being influenced (Forman and Gordon 1993).

We can consider floodplain communities as so-called ecotypes. This means that their optimal and tolerance limits correspond to local conditions. The regulation of natural conditions have changed the optimal tolerance limits of species, which have reduced the intensity of the vital activity of species typical of floodplain forests. A lack of production and the accumulation of humus characterize the soils of floodplain forests because floods and alluvial accumulation disturb them. Different textures and varied mineral compositions characterize these soil types. The absence of a natural flood regime has led to an increase in the formation of humus in the soil component, which has violated the limit values in which these biotopes can exist (Troll, 1939).

2 MATERIALS AND METHODS

We formulated a thesis based on which significant degradation of floodplain habitats is assumed in relation to climate change and anthropogenic influence. To determine the changes in the forest morphology and forest composition in Petržalka, we used a methodical procedure, which is based on comparing field data from several time horizons (using a time series of entries). During the selection of the areas monitored, the first step was a survey of the contemporary landscape cover to determine the selection of reference areas. For a survey of the territory, we used various map materials. Then we examined the phytocenological records from 1999 to 2020. These records come from the Joint Annual Reports on the Environment Monitoring (JAREM, 1999 - 2010), freely available biomonitoring data (Biomonitoring.sk, 2013, 2015), and our own field records (2020). All the areas monitored (Fig. 1) are located along the Slovak reach of the Danube. For our own field recording, thirteen reference areas (of approx. 675 m^2) in Petržalka were selected based on detailed analyses to correspond to different forest conditions. These areas are located in an urbanized environment that is cut off from surface water fluctuations. To preserve the homogeneity of the collected data, we also made phytocenological records in the field at the end of October 2020. A typical phytocenological record from the locality of Veľký Zemník (Tab. 1) describes information about the characteristics of the vegetation and the coverage of individual floors, which is important in the synthesis or diagnosis of the typological units.

Unlike Petržalka, all the JAREM and Biomonitoring reference areas (Fig. 1) are located in a natural environment, and some of the localities belong to an area with controlled flooding. With the help of these entries, we evaluated the average coverage of the individual floors in the reference sections of the Pannonian floodplain forests for the years 2000, 2010 and 2020, which helped us create a real picture of the changes in the forest morphology and forest composition.

When analyzing phytocenoses (vegetation), we describe them according to certain characteristic features, thereby resulting in a phytocenological record. The following characteristics are usually evaluated: the floristic composition (set of species), abundance (abundance), coverage (dominance), and sociability and vertical structure (vertical stratification in the biotope) (Križová and Nič, 2012). The area inventoried was measured using the Nautiz X6 GPS receiver and the MAPUJ program, which enabled us to edit the attributes of the individual reference areas and points directly in the field. According to the map analyses, we determined the coordinates of the reference area; they were corrected in the field because of the dense canopy of vegetation. The first step was to mark out the site directly in the MAPUJ application, which was followed by recording the GPS location of individual trees. The accuracy of the device ranged from 1.5m to 3.4m. We evaluated 21 trees in a dense canopy and approximately 9 shrubs. Inaccuracies could have occurred because of an incorrect determination by the ocular method or by different mappers of the percentage of cover.

3 RESULTS AND DISCUSSION

The status of the vegetation at the individual areas monitored was different, which can be attributed to the different locations of the individual sites. The average values of the coverage of the individual plant floors in 2000 can be seen in (Fig. 2).

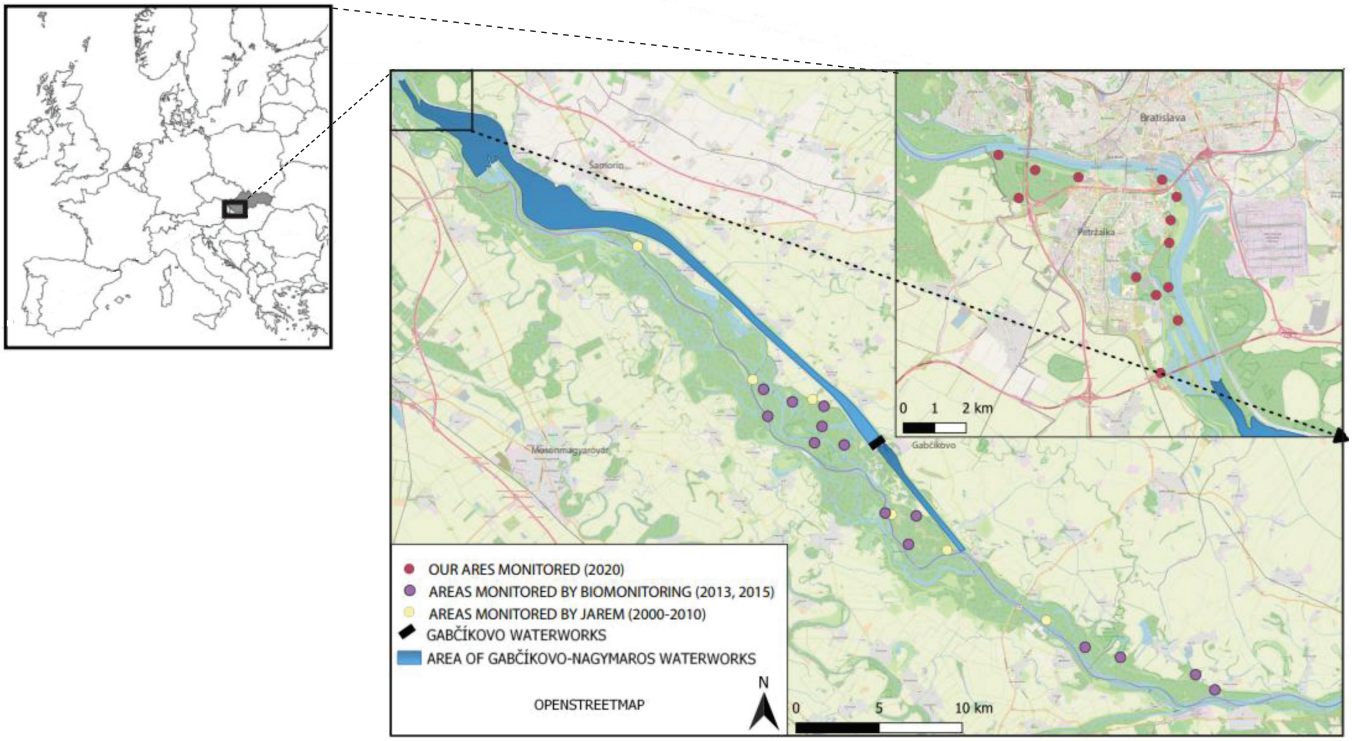


Fig. 1 *map of all the reference areas examined from 1990 to 2020*

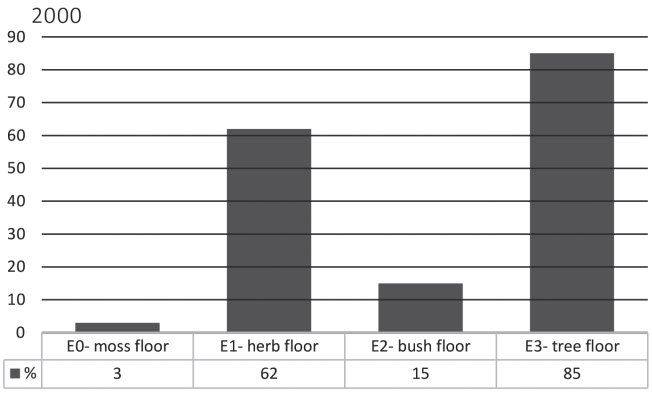


Fig. 2 *Average percentage value of plant floor coverage for the year 2000*

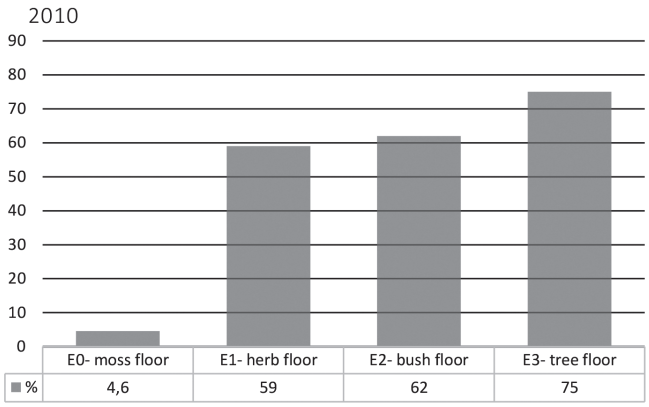


Fig. 3 *Average percentage value of the plant floor coverage for the year 2010*

In 2000, we noted considerable changes in the values of the ecological indices for the sunlight, moisture, and soil nitrogen. The absence of floods and the changes in the average annual temperature resulted in a violation of the ecological limits of the floodplains. Because of the stagnation of the water, the herbaceous layer was weakly connected and developed in a mosaic manner with a low diversity of species. We recorded an increase in its coverage and diversity in the summer months. At several locations, changes in the herbal composition and the appearance of the neophyte *Aster novi-belgii* were noted. On the sites that had an active water regime, which was characterized by the typical character of floodplain biotopes, the shrub layer was absent. Locations with an absence of flooding and water inflowing showed a trend of increasing coverage of a shrub layer dominated by *Cornus sanquinea*. The coverage of the tree layer did not change significantly compared to previous years. *Populus alba* was the dominant tree in several locations, but vital willows were also present in locations where the water level fluctuated (JAREM, 2000).

In 2010, because of high rainfall totals, regeneration of the tree floor occurred, specifically of the assimilation organs. In some locations, forest management and the planting of Canadian poplar monocultures began. Therefore, this year showed a meaningful increase in the coverage of the shrub layer since the monocultures had not yet reached a height of 5 m. Fig. 3 shows us the percentage of coverage of the individual plant floors, from which, compared to the year 2000 (Fig. 2) the changes are evident.

In several localities, the cutting down of willows and ash trees in a marginal part of the plots was recorded. Physiognomically, the composition of the shrub layer had not changed except for the abundant number of Canadian poplar samplings. In locations where flooding did not occur, there was a trend of strengthening the coverage of the plant layer, especially in shady locations where the herbaceous species had a lower amount of coverage. From the point of view of the composition of the species, changes were recorded only in the herbaceous layer (a decrease in the number of species), but the high

values of the similarity of the stand compared to the previous year showed stabilization of the layer. The lower coverage of the herbaceous layer and the reduction of a few nitrophilous species were caused by a spring flood. Nitrophilic species were again dominant, but some grasses were also present in the summer, although the dominant species was nettle (*Urtica dioica*) (JAREM, 2010).

At the Veľký Zemník 2/2 monitoring area, which is near Petržalka, we performed a detailed phytocenological recording of the herbaceous, shrub, and tree layers at the end of September 2020. By comparing this data with data from the phytocenological records from JAREM and the biomonitoring, we formulated a hypothesis based on which we found that changes in the structure of floodplain forests are influenced by changes in the ecological limits and the absence of floods. The changes in the dendrological composition and morphology of this floodplain forest precisely confirm this hypothesis. Urbanization and the construction of roads have disturbed the forest stands, which caused a change in the sunlight and microclimatic conditions of the forests.

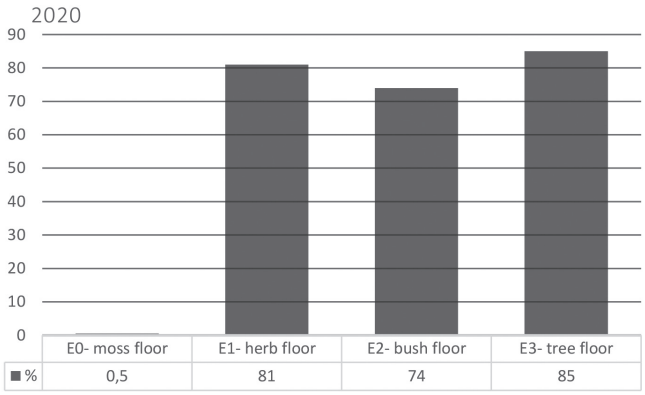


Fig. 4 *Average percentage value of the plant floor coverage in Petržalka for the year 2020*

These changes can be seen in Fig. 4. After evaluating the forms, we found that these changes caused the transformation of the floodplain habitats into a forest edge ecotone. After averaging the coverage of the monitoring areas located in the ur-

Tab. 1 *Phytocenological record from the Veľký Zemník 2/2 monitoring area (September 2020)*

Floor	Name Latin	English	invasive - non-invasive + invasive	Coverage (%)
tree	*Populus alba*	White poplar	-	15
	Fraxinus excelsior	Ash slender	-	6
	Acer campestre	Field maple	-	17
	Populus nigra	Black poplar	-	18
	Populus tremula	Aspen poplar	-	9
	Prunus avium	Bird cherry	-	0.5
	Acer platanoides	Norway maple	-	0.5
	Robidia pseudoacacia	Black locust	+	2
	Negundo aceroides	Ash maple	+	7
shrub	*Ligustrum vulgare*	Wild privet	-	-
	Crataegus monogyna	Common hawthorn	-	+
	Ulmus minor	Field elm	-	-
	Acer campestre	Field maple	-	+
	Sambucus nigra	Black elder	-	+
	Viburnum opulus	Guelder rose	-	–
	Populus alba	White poplar	-	1
	Negundo aceroides	Ash maple	+	-2/-4
	Rosa canina	Dog rose	-	+
	Fallopia japonica	Japanese knotweed	+	–
	Prunus spinosa	Blackthorn	-	–
herb	*Urtica dioica*	Stinging nettle	-	–
	Stellaria media	Chickweed	-	+[1]
	Parietaria officinalis	Upright pellitory	-	–
	Glechoma hederacea	Ground-ivy	-	-2/+2

Floor	Name Latin	English	invasive - non-invasive + invasive	Coverage (%)
herb	*Geum urbanum*	Wood avens	-	+
	Brachypodium sylvaticum	Lender false brome	-	–
	Impatiens glandulifera	Himalayan balsam	+	1
	Solidago canadensis	Canadian goldenrod	+	1/-2
	Populus alba	White poplar	-	3
	Fraxinus excelsior	Ash slender	-	+
	Acer campestre	Field maple	-	4/-4

ban environment of Petržalka, we can perceive a high percentage value of the shrub floor. Ideally, this value would be low, and shrubs would be found only on the edges of the floodplain habitats. Another fact that confirms our hypothesis about the changes in the ecological conditions is that *Acer campestre,* as well as other xerothermic species, is abundant in the given area on all the floors.

The absence of floods and the drying of floodplain forest soils could have caused these changes in the species' composition. Several JAREM annual reports mentioned that the presence of invasive species has been reduced in the reference sections that were flooded and that the regeneration of the habitat is occurring. Katz et al. (2005) investigated the delayed effects of flood control on a flood-dependent riparian forest in eastern Colorado, USA. They found that there was no significant difference between the regulated and unregulated sections of the South Fork River in the forest's structure. The reason for this fact is that there have been no major floods in any of the examined sections since the construction of the Bonny Dam. Scientists from the Slovak Academy of Sciences have studied long-term changes in the structure of softwood floodplain forests in our territory. They discovered these changes were mainly caused by the disturbance of the water regime. They concluded that, during the period monitored, there was a decline in autochthonous species and an increase in neophytes, which are slowly dominating domestic species (Mikulová et al., 2020).

In an annual agricultural report (Ministry of Agriculture and Rural Development of the Slovak Republic, 2010), the authors stated that the area of forest land in Slovakia has been increasing for a long time. In 2009, it reached 2,009,000 ha. Since 1950, it has increased by 238,000 ha (13.4%). The area of vegetation, i.e., the area of forest stands, has increased by 175,000 ha (9.9%) since 1950. Forest cover has been increasing for a long time as a percentage of the total area of forest land from the total area of Slovakia, which was approximately 41% in 2006. According to the results of the National Forest Inventory and Monitoring (NIML) of the Slovak Republic, which also included the so-called "white areas" (forests on non-forested land), Slovakia's forest cover is up to 44.3 ± 0.4%, which is positive, but they do not reflect the structural changes that have occurred during that period (Ministry of Agriculture and Rural Development of the Slovak Republic, 2010).

Mikulová et al. (2020) has stated that in the last 60 years, soft floodplain forests have been transformed considerably. The plant composition points to the indirect intervention of anthropogenic factors in the structure of the biotope. They concluded that the number and coverage of neophyte species have increased at the expense of native species. Their research shows that the territory of the Pannonian soft floodplain forests has changed from variable hygrophilic and mesophilic to homogenized mesophilic.

4 CONCLUSIONS

The survey points to the impact of climate change and anthropogenic influences on the biodiversity in a forested area in Bratislava, Slovakia. The current state and composition of the floodplains as shown in phytological records and field surveys, indicate an increase in the number of climate-sensitive species/habitats that have a narrow tolerance limit. Changes in the coverage of the plant floors show the sensitivity of floodplain habitats to changes in sunlight, climatic conditions, and the water regime.

By comparing the close-to-nature sections of alluvial forests with the urban environment of Petržalka, we can understand the stress that these biotopes are exposed to. The absence of floods in Petržalka have changed the ecological limits of soil moisture on which several taxa depend. There is also strong pressure on the forests due to urbanization as it has disrupted the compact area of the forest. Sunlight conditions have changed, and new transitional biotopes are formed. The violation of optimal and tolerance limits has led to changes in the environment, which is limiting for some species and restricts development, which is why the floodplains are regenerating into an ecotone on the edge of the forest. By changing the sunlighting conditions, the temperature in the growth increases, and evapotranspiration from the soil is higher, as a result of which these forests are drying out. The conditions created in this way are optimal for species that are not native to that environment.

The decline of autochthonous species in the structure of the forest communities in Petržalka can probably be attributed to anthropogenic interventions, improper management of these areas, and inappropriate regulation of watercourses, which have had a negative impact on the water regime. The alluvial ecosystems developed and were shaped according to human needs. The hydric function is quite variable because of the connection between the forests, water, and other components of the environment. Because of the individual factors that are necessary for the proper functioning of an ecosystem, the ecological conditions and structure of the forest play a central role.

By comparing the phytocenological records, the changes that affected the discussed area from 2000 to 2020 are clearly visible. According to Reháčková (2007), the original forest stands were preserved in locations that did not suit anthropogenic activities. From the map data, the fragmentation of the once continuous area of the floodplains is clearly perceptible. The field survey confirmed the hypothesis about the state and morphology of the floodplains near the built-up area of Petržalka.

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