THE CHANGES IN THE FOREST VEGETATION ON THE DANUBE RIVER AGGRADEMENT MOUND AFFECTED BY WATER REGIME CHANGES

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Abstract


This article is focused on the specific vegetation, which has formed from the floodplain forests on the aggradation mound (elevated sediment deposition) along the original Danube river in Slovakia in the part affected by Gabčíkovo waterworks that was put in operation in 1992. As a result of water regime changes, when a major part of the Danube water flow was redirected to the Gabčíkovo hydroelectric power plant, original floodplain forests on the aggradation mound began to suffer from a water deficit, which is also supported by shallow soils formed mostly on the gravel sediments with limited capillary rise of groundwater. It has triggered successional processes leading to the degradation of forest with changes in all layers. To identify these changes and development trends, we analyzed vegetation data from 2002, 2012, and 2022. The results indicate that the process of secondary succession of the original floodplain forest continues. This includes mainly an increase in the number of species, especially those typical for grasslands and synanthropic habitats. From an environmental point of view, the spread of some invasive species is striking. Ordination method (canonical-correlation analysis [CCA]) confirmed light, moisture, number of species, and Shannon–Wiener index as the main factors determining relevés’ variability.

Key words: floodplain forests, Danube river aggradation mound, changes, trends.

Introduction

The Danube, with its 2580 km, is the second longest river in Europe. Its character is largely influenced by human interventions. A total of 41 dams have been built along the Danube between its spring and the Slovak border. The upper Danube is thus significantly interrupted (Schmid et al., 2023). This, hand in hand with other measures, such as river regulations and modifications, had an essential impact on the Danube water regime and ecosystems. In Slovakia, the last crucial impact to the Danube water regime is dated back to 1992, when Gabčíkovo hydroelectric power plant was put into operation. In the part between the cities of Bratislava and Gabčíkovo, most of the Danube water was transferred to the supply channel leading to the hydroelectric plant. Thus, the original average flow of 2025 m\(^3\)/s (at Bratislava–Devin station) was reduced to only 400 m\(^3\)/s under normal conditions (Martinka et al., 2004). The subsequent water deficit has become particularly noticeable in the aggradation mound along the river bed with its shallow gravel soils (fluvialsols), where groundwater does not rise by capillary action. Therefore, the main source of water here is only precipitation. The original floodplain forests (Jurko, 1958) gradually began to change their structure and composition (Somšák et al., 2003; Kocinger et al., 2004). Several authors have addressed these changes from a phytosociological and an ecological point of view (Uherčíková, 1995; Somšák et al., 2003; Minarič, 2012). However, the processes of secondary succession continue and require additional attention. The aim of this paper is, therefore, to evaluate the changes and development trends in this vegetation, which took place over the last 20 years.

Methods

Study area

The study area includes the aggradation mound (elevated sediment deposition) along the Danube river with reduced flow between the cities of Bratislava and Gabčíkovo (Fig. 1). Its length is about 40 km. The average temperature is about 20 °C in July and 2.5 °C in January. The average annual temperature is 10.6 °C. Annual precipitation is about 590 mm. Shallow fluvialsol formed on gravel sediment is the typical soil here (Kocinger et al., 2004). Gravel is usually in a depth up to 30 cm. Willow–poplar floodplain forests of alliance Salicion albae Soó 1930 are the potential vegetation (Michalko et al., 1987).
Data collection

Vegetation data from three time periods were used: i) 10 phytocoenological relevés from 2002 provided by Šomšák et al. (2003), ii) five phytocoenological relevés from 2012 sampled by Minarič (2012), and iii) original data (Kollár, Palaj, 2021), which included nine phytocoenological relevés sampled in 2021. All vegetation data were sampled in compliance with the methods of Zurich–Montpellier School using the seven-point cover-abundance scale (Braun-Blanquet, 1964). In the original dataset, we tried to relocate and resample older plots, but we were able to do so only in four plots from 2012. Data from 2003 were not localized by Global Positioning System (GPS), and some of the stands from 2012 disappeared. Smaller number of original relevés resulted from a limited number of existing stands with appropriate area and quality. The obtained data were stored in the Turboveg program database (Hennekens, Schaminée, 2001) and further edited in the Juice program (Tichý, 2002). The vascular plant nomenclature complies with Marhold, Hindák (1998).

Data analysis

The evaluation of changes was based on the comparison of nine current original relevés (Kollár, Palaj, 2021), five relevés from 2011 (Minarič, 2012), and 10 from 2002 (Šomšák et al., 2003). Regarding the missing GPS localization data in Šomšák et al. (2003), we evaluated the differences between these three time periods only by comparing the frequency of species and by ordination methods. Due to the length of the first Detrended correspondence analysis (DCA) axis (<3.0), we used canonical-correlation analysis (CCA) as an ordination method. As environmental variables, we used diversity parameters (number of species, Shannon–Wiener index) and unweighted Ellenberg indicator values (Ellenberg et al., 1992) for light, temperature, moisture, and soil reaction. Indicator values for soil nutrients were excluded because of high correlation with moisture (<0.85). Then, the differences in indicator values were evaluated by analysis of variance and Tukey’s range test. For a more exact determination of changes, we did pairwise comparison of Ellenberg indicator values and diversity parameters of four current relevés and four relevés from 2011 (Minarič, 2012) sampled on the same plots. The differences were tested by paired t-test and are graphically presented in the form of boxplots. For data analysis and creation of graphic outputs, we employed the RStudio program and R packages (Wickham, 2016; Oksanen et al., 2020; RStudio Team, 2021).

Results

Floristic composition

During all observed periods, the sampled vegetation had transitional character between forest and non-forest vegetation. It was formed by the processes of secondary succession from original floodplain forests, which were triggered by water regime changes. It was classified as a newly proposed association Aristolochio–Populetum nigrae by Šomšák et al. (2003). Tree layer of the studied vegetation was thin in all time periods, ranging from 40 to 60%. It was dominated by Populus nigra. Constant tree species included Populus x canescens and invasive Negundoaceroides. However, these were supplemented by invasive Fraxinus pennsylvanica (44% frequency) in the original data from 2021. Higher current frequency, compared to earlier periods, was also recorded for Acer campestre, which is a thermophilous and drought-tolerant species. The shrub layer did not show any clear dynamic pattern and was mainly dominated by Swida sanguinea; also, Crataegus monogyna was very common. The participation of vine-like species (Clematis vitalba, Humulus lupulus), often growing into the tree layer, was also noticeable. The herb layer was made of ecologically diversified species. Important components during all the observed periods included the nitrophilous species of floodplain forests and their edges, especially Aristolochia clematitidis, Clematis vitalba, Galium aparine, Glechoma hederacea, Rubus caesius, and Urtica dioica. An ecologically important feature observed was the high presence of grassland species. Constant grassland species included Achillea millefolium agg., Dactylis glomerata, Galium mollugo, and Poa pratensis agg. Interestingly, the typical mesophilous grassland species Arrhenatherum elatius was not recorded in 2002, while its frequency was 80% in 2011 and 89% in 2021. In addition, an increase in some synanthropic species was clear, such as Calamagrostis epigejos, Cirsium arvense, and Ellytrigia repens. Some of the synanthropic species were identified only in 2021, with higher frequency of mainly Bromus sterilis (frequency 78%), Anthriscus cerefolium (frequency 56%), and Cymoglossum officinale.
(frequency 56%) and lower frequencies of *Arenaria serpyllifolia* agg., *Bromus hordeaceus*, *B. tectorum*, *Dipsacus fullonum*, *Erysimum diffusum*, and *Rubus fruticosus* agg.

**Ecological analysis**

The distribution of the individual relevés in the ecological space is shown in the CCA biplot (Fig. 2). The main factors determining relevés variability included light ($F = 2.139, p = 0.001$), moisture ($F = 1.760, p = 0.016$), number of species ($F = 1.884, p = 0.003$), and Shannon values–Wiener index ($F = 1.581, p = 0.002$). Analysis of variance showed that the most significant differences over time were in the number of species in the relevé ($F = 10.42, p = 0.0007$). On average, the current dataset was richer by 11 species compared to 2011 ($p = 0.027$) and by almost 15 species compared to 2002 ($p = 0.0006$). A significant increase in the number of species was also confirmed by the pairwise comparison of the herb layer of the same four stands sampled in 2011 and 2021 (Fig. 3), which was evaluated as statistically significant by the $t$-test ($t = 5.78, p = 0.010$). Pairwise comparison also showed some differences in environmental conditions based on Ellenberg ecological indicators, including a decrease in the values for light, soil moisture, and nutrients and an increase in the values of soil reaction (Fig. 4), but these changes were not found to be statistically significant.

**Discussion**

The impact of construction of Gabčíkovo waterworks on the Danube floodplain ecosystems was studied in detail. There have been running complex biomonitoring since 1990 (Matečný, 2010) and its results are included in annual reports (Ministry of Environment of the Slovak Republic, 2023). One of the monitoring sites referred to as MP-06 is located close to our plots (relevés 1 and 3). This part is most affected by the water regime changes, as it is located above the water supply facility at the Dobroňov village. However, this site does not have the same location as our plots and is of different size. It is hardly comparable with our data. Nevertheless, in compliance with our findings, the ongoing process of tree layer decaying has been reported. Our most important results include changes in phytodiversity. Increase in the number of species results from changes in water regime, which trigger secondary regression processes. Thus, vegetation
Fig. 4. Pairwise comparison of Ellenberg ecological indices (Ellenberg et al., 1992) on the same 4 plots sampled in 2011 and 2021. Average values are marked with a red dot.

is a successional stage formed by a mixture of species typical for ecologically different habitats. There still persist species of floodplain forests, and these are supplemented by the newcomers, mainly the non-forest species. Similar processes were reported from the area along the Váh river (the longest Danube tributary in Slovakia) affected by the waterworks systems, where such vegetation covers large areas (Ábrahámová et al., 2014). In addition, neophytes including invasive species are an important vegetation component here and deserves particular attention. Their increasing abundance and presence correspond well with a generally known fact that habitats along rivers are among those having higher susceptibility to invasion (Chytrý et al., 2008), including riparian forest (Medvecká et al., 2018). Invasive species composition complies with all studies focused on this issue in the region (e.g., Uherčíková, 2001). Interestingly, invasive Impatiens glandulifera, being frequently dominant in adjacent willow–poplar softwood forests and poplar monocultures, is almost missing in our data. The reason is that this species prefers deeper soils well supplied by water and nutrients (Uherčíková, 1997). When compared to earlier studies focused on tree species (e.g., Benčaf et al., 1984), it seems that some of the invasive tree species are expanding in the study area, especially Fraxinus pennsylvanica. According to our field research, Ailanthus altissima also is expanding, despite the fact that it is not included in our relevés since it usually forms separate stands outside the sampled vegetation. The trend of expansion of A. altissima in the study area was also reported by Pauková et al. (2019). Therefore, management of the area should particularly focus on this issue. We confirmed that successional processes gradually change original floodplain forests into other vegetation types, and the issue requires continual attention. In compliance with Somšák et al. (2003), it can be expected that the studied vegetation, especially stands in the upper part of the study area with the shallowest soils with gravel substrate, will more and more resemble a specific forest steppe vegetation described from the vicinity of Bratislava as Asparago–Crataegetum (Jurko, 1958) Mucina 1985 association with a high environmental value (Šremr, 1985).

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References


