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SEASONAL VEGETATION CHANGES ON A SELECTED SECTION OF A RAILWAY LINE IN THE SOUTH MORAVIAN REGION (CZECH REPUBLIC) – A CASE STUDY

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ABSTRACT

Railways constitute a pivotal component of linear transport infrastructure. The monitored section is part of the line connecting Vienna and Kraków, the construction of which began in 1837. The objective of the study was to assess the species composition of vegetation in a designated section of the railway. The evaluation was executed through the implementation of the phytocoenological relevé method, with the assessment conducted in the year 2021, during the months of April, June, August, and October. During the monitoring process, a total of 31 plant species present within the trackbed of the designated section were documented. The results indicate that the section under observation is distinguished by relatively abundant and species-diverse vegetation, the composition and coverage of which undergoes changes during the vegetation period. The impact of vegetation on the structural stability of railway lines is a matter of concern, as it can also adversely affect the fluidity and safety of rail transport. Consequently, the regular monitoring and evaluation of vegetation should be an integral part of the operational maintenance of railway infrastructure.

Keywords: plant, diversity of plant species, anthropogenic area, anthropogenic vegetation, railway

INTRODUCTION

Railways constitute a linear transport infrastructure that exhibits a number of common habitat characteristics, irrespective of geographical area or climate zone. These habitats are entirely of anthropogenic origin, involving the removal of original vegetation and the preparation of a new substrate for the construction of embankments and the laying of rails (Borda-de-Água, Ascensão, Sapage, Barrientos & Pereira, 2017; Borda-de-Água et al., 2019). The linear habitats thus created are characterised by extreme environmental conditions, including dry, rocky, and sun-exposed substrates with often high levels of pollution, especially heavy metals (Wiłkomirski, Galera, Sudnik-Wójcikowska, Staszewski & Malawska, 2012). These stress factors have been identified as a primary cause of the decline in biodiversity, particularly among plant species (Kalusová et al., 2017).

Transport infrastructure, including railways, also significantly contributes to the spread of plant diasporas to new areas (von der Lippe & Kowarik, 2008; Winkler et al., 2024). Railway corridors frequently serve as conduits for the migration of flora, thereby facilitating the traversal of natural and ecological barriers (Rashid et al., 2021). In the past, several species, e.g. *Geranium purpureum*, have spread to new regions across Europe thanks to railway transport and subsequently colonised other urban habitats (Büscher, Keil & Loos, 2008; Eliáš, 2011).

Furthermore, railway environments are characterised by the presence of diverse microhabitats, which are conducive to the proliferation of species with divergent ecological requirements. Rocky and exposed

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surfaces tend to be inhabited by xerophilic and thermophilic species, while mesophilic and hygrophilic species thrive in shady and wetter microdepressions with less permeable surfaces (Wittig & Lienenbecker, 2003; Fornal-Pieniak & Wysocki, 2011).

Railways have been demonstrated to have a substantial impact on the environment, manifesting in two principal ways. Firstly, the construction phase involves a notable disruption to the existing topography, a consequence that is subsequently compounded by the operational and maintenance demands of the railway infrastructure. The processes by which plant communities are re-formed after disturbance have been a long-standing topic of ecological research (Götzenberger et al., 2012). Nature conservation must move beyond the traditional notions of wild and cultivated nature (Kueffer & Kaiser-Bunbury, 2014) and embrace new hybrid approaches to protect biotopes that exhibit biological diversity, many of which have been shaped by human civilisation (Burney & Burney, 2007; Winkler et al., 2021). Respect for spontaneous vegetation can support biodiversity in urban environments (Reif & Kreß, 2014).

Each phase of railway construction and operation has a substantial impact on the proliferation of vegetation. Furthermore, plant communities in railway areas are exposed to constant disturbance pressure due to the intensive transport of people and goods, as well as management interventions (e.g. mowing or herbicide application) aimed at suppressing unwanted vegetation (Rutkovska, Pučka, Evarts-Bundersanta & Paidere, 2013).

Disturbed railway habitats can serve as sites for the propagation of plant material originating from various local and regional sources. These species then interact ecologically, adapt to the new environment, and can affect the biodiversity of the entire area (Rutkovska et al., 2013). As railway networks traverse a variety of landscape uses, ranging from agricultural and urban areas to sites of high ecological value or intact forests, they facilitate the propagation of non-native species, even into relatively pristine habitats. This phenomenon has the potential to disrupt the species composition of surrounding ecosystems, particularly adjacent communities (Hansen & Clevenger, 2005; Fornal-Pieniak & Wysocki, 2010).

In the Czech Republic, the railway infrastructure is characterised by a network configuration that encompasses an area of approximately 30,128 ha. A total of 9,566 km of operational railway tracks have been constructed, with the cumulative length of all railway tracks reaching 15,570 km (Krejčířiková, 2017).

The segment of the railway that is under observation is part of the line from Vienna to Kraków, the construction of which commenced in 1837. The railway was known as the Northern Railway of Emperor Ferdinand. The inaugural test run occurred on 15 April 1841, in the segment designated Břeclav–Staré Město u Uherské Hradiště, with the official opening of the line to traffic occurring on 5 May of the same year. The town of Rohatec was not established until 1866. In 1872, the Northern Railway underwent an expansion that included the addition of double tracking. Beginning in 1907, the utilisation of trains for the transportation of mail has also been documented. In 1934, a new five-kilometre line was constructed from Ratíškovice to Rohatec. This line was used to transport lignite from the recently opened Tomáš (later Theodor) mine. During World War II, significant destruction occurred, particularly on 10 April 1945, when the railway bridge in Rohatec towards Sudoměřice was destroyed. In the aftermath of the war, the railway line was reinstated, and in 1948, a new arch bridge was constructed (Bíza & Skácel, 1973).

Between 1960 and 1965, a new railway stop was constructed in Rohatec, and the route of the Rohatec––Kolonie station underwent expansion, facilitating the passage of trains transporting lignite from Ratíškovice to Hodonín. In 1973, the Břeclav–Otrokovice rail line experienced the passage of approximately 20 passenger trains and 4 express trains on a daily basis. From 1995 to 1998, the line underwent a comprehensive reconstruction, during which the tracks were replaced, and the signalling equipment was modernised. Presently, switching operations are managed automatically (Bíza, 2012).

A fundamental ecological consequence of railways is a set of changes that occur in the adjacent natural vegetation (Wang, Gillespie, Liang, Mushkin & Wu, 2015; Pollock, Nielsen & St. Clair, 2017).

The aim of the work was (i) to evaluate the species composition of vegetation in a selected section of the railway, (ii) to monitor changes in vegetation composition during the growing season, and (iii) to evaluate potential interactions between vegetation and railway operations.

MATERIAL AND METHODS

Characteristics of the study area

The selected section of the railway line is located in the cadaster of the municipality of Rohatec in the South Moravian Region, at an average altitude of approximately 185 m above sea level. The territory falls within the Pannonian province and the Intracarpathian Depression system, specifically into the Lower Moravian Valley unit and the Dyje-Moravian Alley sub-unit. The bedrock is composed of Neogene sediments, primarily calcareous clays with a mixture of silty and sandy components. These sediments are slightly impermeable to impermeable. Rohatec is located on the periphery of the Moravian Sahara, a geographical region characterised by the presence of sand dunes and blown sands. The landscape around the Morava River was shaped by alluviums of gravel, sand, and loess, with a maximum thickness of 18 m in certain areas. The territory is part of the Morava River basin, which in the past experienced unregulated fluvial activity, resulting in the formation of numerous meanders and side branches. The most prevalent rock formations are loess and loamy sands, which are characterised by a preponderance of fine quartz grains. According to the climatic regionalisation, the area is classified as a warm and dry climatic zone, characterised by protracted hot summers and brief, mild winters. The spring and autumn seasons are marked by short and warm periods, respectively. Spring frosts are a common occurrence in the lowlands surrounding the river. The average annual temperature is 9.5–9.7°C, with July being the warmest month, reaching 19.8°C. The annual precipitation in this region is approximately 585–600 mm, and the predominant wind directions are from the southeast and northwest (Culek et al., 1996; Czech Geological Survey [CGS], 2017; CGS, 2018). Figure 1 shows the location of the study railway line (GPS 48.8914683N, 17.1950708E).

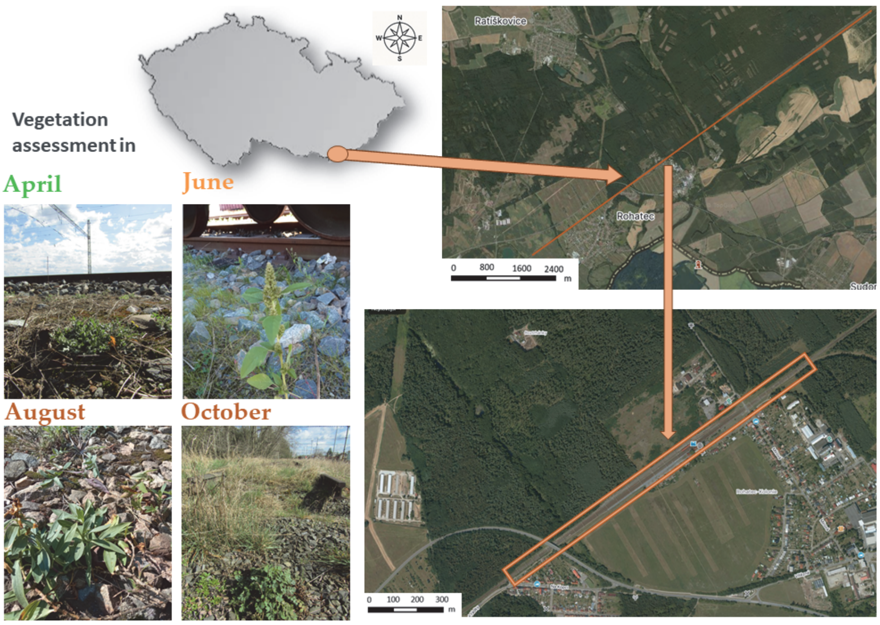

Fig. 1. Map of the railway line and the monitored periods

Source: own work.

Vegetation assessment methodology

The vegetation assessment was executed through the implementation of the phytocoenological relevé method (Westhoff & van der Maarel, 1978). These phytocoenological relevés were captured within the right-of-way of a designated railway segment. A total of 10 relevés were recorded, each measuring 2 × 2 m (i.e. 4 m²). The assessment was conducted on four occasions during 2021, with the same areas surveyed on each occasion. The initial procedure was conducted in April, the subsequent procedure in June, the third procedure in August, and the final procedure in October. The extent of coverage for individual species was determined through direct estimation in percentages. The nomenclature of plant species was derived from the Pladias database (Pladias, 2021).

Statistical analysis

The relationships between individual assessment dates and the coverage of the identified plant species were evaluated using multivariate analyses of ecological data. First, a segmental analysis detrended correspondence analysis (DCA) was performed, in which the length of the gradient was determined. Subsequently, the influence of the management method on vegetation was tested using redundancy analysis (RDA). The statistical significance of the results was verified by a Monte Carlo test with 999 permutations. The Canoco 5.0 program (Braak & Šmilauer, 2012) was used for all calculations.

RESULTS AND DISCUSSION

During the assessment, a total of 31 plant species were recorded as occurring in the trackbed of the selected railway section. Table 1 provides an overview of the plant species found, as well as an overview of floristic regions and elevational belts. As illustrated in Figure 2, the representation of individual species is contingent upon the total coverage, while Figure 3 demonstrates the proportion of biological plant groups in individual assessment dates.

Table 1. Overview of found plant species and an overview of their floristic areas and altitudinal zones in the Czech Republic

Species	Abbreviation	Biological groups	Floristic region	Elevational belt in the Czech Republic
Anagallis arvensis	*AnaArve*	annual dicotyledons	circumpolar	lowlands, colline belt (submontane belt)
Amaranthus retroflexus	*AmaRetr*	annual dicotyledons	Western America	lowlands, colline belt (submontane belt)
Arrhenatherum elatius	*ArrElat*	perennial monocotyledons	Europe	lowlands, colline belt, submontane belt, montane belt
Bromus inermis	*BroIner*	perennial monocotyledons	circumpolar	lowlands, colline belt (subalpine belt)
Bromus tectorum	*BroTect*	annual monocotyledons	Europe, Western Asia	lowlands, colline belt (submontane belt)
Calamagrostis epigejos	*CalEpig*	perennial monocotyledons	Europe, Asia	lowlands, colline belt, submontane belt, montane belt
Capsella bursa-pastoris	*CapBurs*	annual dicotyledons	circumpolar	lowlands, colline belt, submontane belt, montane belt
Centaurea jacea	*CenJace*	perennial dicotyledons	Europe	lowlands, colline belt, submontane belt
Centaurea stoebe	*CenStoe*	perennial dicotyledons	Europe	lowlands, colline belt, submontane belt
Convolvulus arvensis	*ConArve*	perennial dicotyledons	Europe, Asia, circumpolar	lowlands, colline belt, submontane belt
Digitaria sanguinalis	*DigSang*	annual monocotyledons	Asia, Africa, circumpolar	lowlands, colline belt (submontane belt)
Echium vulgare	*EchVulg*	perennial dicotyledons	Europe, Western Asia	lowlands, colline belt, submontane belt
Elymus hispidus	*ElyHisp*	perennial monocotyledons	Europe, Western Asia	lowlands, colline belt (submontane belt)
Epilobium adenocaulon	*EpiAden*	perennial dicotyledons	Europe, Asia, Americas	lowlands, colline belt, submontane belt, montane belt, subalpine belt

Table 1 (cont.)

Species	Abbreviation	Biological groups	Floristic region	Elevational belt in the Czech Republic
Erodium cicutarium	*EroCicu*	perennial dicotyledons	Europe, Western Asia, circumpolar	lowlands, colline belt, submontane belt
Geranium robertianum	*GerRobe*	annual dicotyledons	Europe, Asia	lowlands, colline belt, submontane belt, montane belt
Chenopodium album	*CheAlbu*	annual dicotyledons	circumpolar	lowlands, colline belt, submontane belt, montane belt
Leontodon hispidus	*LeoHisp*	perennial dicotyledons	Europe	lowlands, colline belt, submontane belt, montane belt, subalpine belt
Medicago falcata	*MedFalc*	perennial dicotyledons	Europe, Asia	lowlands, colline belt, submontane belt
Melica transsilvanica	*MelTran*	perennial monocotyledons	Europe	lowlands, colline belt
Panicum miliaceum	*PanMili*	annual monocotyledons	Asia	without information
Portulaca oleracea	*PorOler*	annual dicotyledons	circumpolar	lowlands, colline belt (submontane belt)
Potentilla argentea	*PotArge*	perennial dicotyledons	Europe, Western Asia	lowlands, colline belt, submontane belt, montane belt
Rubus sp.	*RubSp.*	perennial dicotyledons	Europe, Caucasus, Eastern America	without information
Rumex thyrsiflorus	*RumThyr*	perennial dicotyledons	Europe, Asia	lowlands, colline belt
Saponaria officinalis	*SapOffi*	perennial dicotyledons	Europe, Western Siberia	lowlands, colline belt, submontane belt
Senecio viscosus	*SenVisc*	annual dicotyledons	Europe	lowlands, colline belt, submontane belt, montane belt
Stellaria media	*SteMedi*	annual dicotyledons	circumpolar	lowlands, colline belt, submontane belt
Trifolium arvense	*TriArve*	annual dicotyledons	Europe, Western Siberia	lowlands, colline belt, submontane belt
Trifolium repens	*TriRepe*	perennial dicotyledons	circumpolar	lowlands, colline belt, submontane belt, montane belt, subalpine belt
Urtica dioica	*UrtDioi*	perennial dicotyledons	circumpolar	lowlands, colline belt, submontane belt, montane belt
Vicia sepium	*VicSepi*	annual dicotyledons	Europe, Western Siberia	lowlands, colline belt, submontane belt, montane belt, subalpine belt

Source: own work according to floristic regionalisation by Klotz, Kühn and Durka (2002).

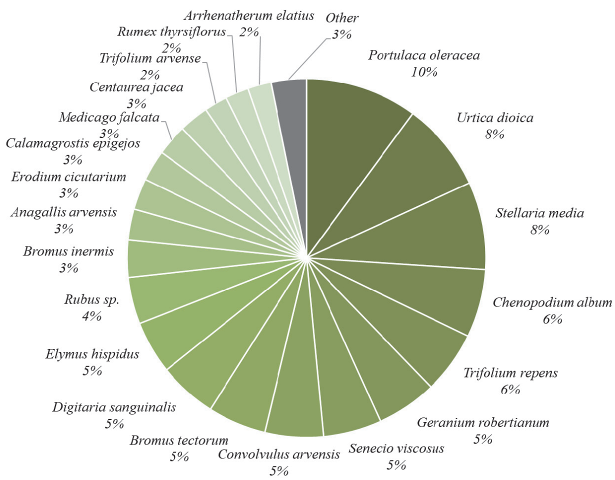

Fig. 2. Representation of plant species found in the trackbed of the monitored railway section

Source: own work.

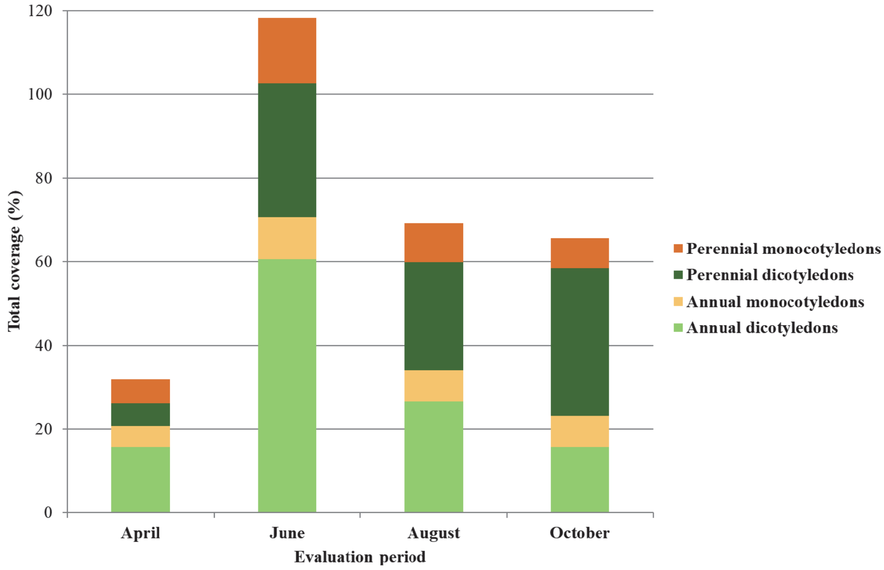

Fig. 3. Contributions of biological groups to vegetation cover in assessment terms

Source: own work.

RDA analysis defines the spatial arrangement of individual plant species and the evaluation term. The results of the RDA analysis are significant at the significance level of $\alpha = 0.04$. The results are therefore statistically highly significant. According to the ordination diagram (Fig. 4), the plant species can be divided into four groups.

The first group of species had a more significant coverage in April and was the species *Epilobium adenocaulon* (*EpiAden*).

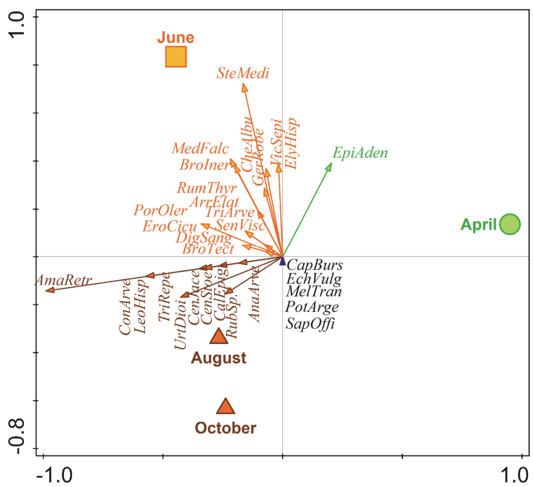

Fig. 4. Ordination diagram expressing the relationship between the found plant species and the terms evaluated on the trackbed of the selected railway section (RDA analysis results; pseudo $F = 0.5$; $p = 0.04$)

Source: own work.

The second group had more significant coverage in June: *Arrhenatherum elatius* (*ArrElat*), *Bromus inermis* (*BroIner*), *Bromus tectorum* (*BroTect*), *Digitaria sanguinalis* (*DigSang*), *Elymus hispidus* (*ElyHisp*), *Erodium cicutarium* (*EroCicu*), *Geranium robertianum* (*GerRobe*), *Chenopodium album* (*CheAlbu*), *Medicago falcata* (*MedFalc*), *Portulaca oleracea* (*PorOler*), *Rumex thyrsiflorus* (*RumThyr*), *Senecio viscosus* (*SenVisc*), *Stellaria media* (*SteMedi*), *Trifolium arvense* (*TriArve*), *Vicia sepium* (*VicSepi*).

The third group had more significant coverage in August and October: *Amaranthus retroflexus* (*AmaRetr*), *Anagallis arvensis* (*AnaArve*), *Calamagrostis epigejos* (*CalEpig*), *Centaurea jacea* (*CenJace*), *Centaurea stoebe* (*CenStoe*), *Convolvulus arvensis* (*ConArve*), *Leontodon hispidus* (*LeoHisp*), *Rubus* sp. (*Rub*Sp.), *Trifolium repens* (*TriRepe*), *Urtica dioica* (*UrtDioi*).

The fourth group consists of species that were more influenced by factors other than the assessment date. These are the species: *Capsella bursa-pastoris* (*CapBurs*), *Echium vulgare* (*EchVulg*), *Melica transsilvanica* (*MelTran*), *Potentilla argentea* (*PotArge*), *Saponaria officinalis* (*SapOffi*).

Habitats created by human civilisation represent a significant component of the Central European landscape (Lososová et al., 2006). These habitats also include transport infrastructure, which significantly changes environmental conditions and landscape character (Wiłkomirski et al., 2012). The upper portion of the railway track is composed of a system of transversely laid sleepers that support the rails. These elements are then placed in a gravel bed, where they coalesce to form the frame structure of the track. The lower portion of the railway track is engineered to ensure its stability and to transmit the static and dynamic pressures that are generated by the movement of trains. The embankment of the track is composed of a material whose properties must ensure stability and long-term load-bearing capacity. Non-cohesive soils are the most suitable, as they are characterised by their ability to retain their physical properties despite climatic variations, such as freezing during winter months, and they exhibit higher load-bearing capacity than cohesive soils (Plášek, Zvěřina, Svoboda & Mockovčiak, 2004).

The section of railway that is subject to monitoring and observation therefore constitutes an environment that has been altered through anthropogenic influence, exhibiting substantial disparities when compared with the adjacent natural habitats. The aforementioned conditions exert a profound influence on the composition and structure of vegetation. Only species that possess the capacity to withstand extreme temperatures, drought, and mechanical disturbance will prevail within the designated area. The site is situated in the warmest region of the Czech Republic, where the onset of spring is rapid, summers are hot and dry with low rainfall, and autumns are warm. Consequently, there is extreme overheating of stony and sandy subsoils, the surface temperature of which often exceeds 50°C. In the context of such habitats, heliophytes – that is, species that demonstrate a preference for sunny and dry environments – are dominant. The low overall vegetation coverage is related to the structure of the gravel bed, which consists of coarse crushed aggregate with a thickness of over 0.3 m. The species *Rubus* sp. has a powerful root system, capable of drawing water from greater depths. Due to its dense growth, this species poses a significant challenge in terms of removal, as it can threaten the stability and structural integrity of the railway track base.

Portulaca oleracea is a low, prostrate plant with fleshy leaves, found in abundance on sandy soils, wastelands, and roadsides (Pladias, 2022). It has been observed to establish itself on the railway superstructure, where its biomass accumulates. Bromus tectorum is an annual herb that propagates through seeds and is frequently observed in anthropogenically influenced habitats and sandy soils (Pladias, 2022). This species presents a challenge in the context of railway superstructure.

The development of railways and the associated transportation infrastructure has contributed to the dissemination of non-native and exotic plant species (Galera et al., 2011). Herbicide-resistant species include *Equisetum arvense*, *Galium* spp., and *Conyza canadensis* (Torsterson, 2001). Railway sites are home to native and introduced ruderal species, which occur not only in railway yards but also on embankments, sidings, and turntables. These sites function as ecological corridors for plants with specific environmental requirements (Galera, Sudnik-Wójcikowska, Wierzbicka & Wiłkomirski, 2011).

The species recorded in this study were *Amaranthus retroflexus*, *Digitaria sanguinalis*, *Calamagrostis epigejos*, and *Epilobium adenocaulon*.

Regression tree analysis identified two main factors influencing the species richness of vascular plants – average annual temperature and the number of freight trains. The richness of native species was higher in sites with temperatures below 8.65°C, while non-native species were more numerous in areas with intensive freight transport (> 7,640 trains). Higher transport volume also positively affected the richness of archaeophytes and neophytes (threshold values of 2,524 and 7,640 trains). Red Book species were more common at warmer sites (> 9.04°C). In terms of life forms, the richness of therophytes increased with temperature, while hemicryptophytes and chamaephytes were more abundant in colder areas (Májeková et al., 2025). In our study, the endangered species *Melica transsilvanica* was recorded.

There are many reasons why it is necessary to limit the growth of vegetation on railways and thereby ensure the safety of railway transport. The main objective is to maintain the quality and stability of the railway track. Vegetation control contributes to the stability of the ballast bed, the protection of wooden sleepers, the safety of employees and the prevention of fires caused by dry vegetation (Torstensson, 2001).

If the gravel bed is not cleaned regularly, weed residues and organic material can fill its cavities, which worsens drainage. In winter, freezing water can cause the track to shift or deform. Vegetation on the tracks also increases the risk of wheel skidding, lengthens braking distances and thus endangers traffic safety. The properties of herbicides used on railways can vary depending on the composition of the soil. In soils with a higher content of clay and organic matter, they adsorb, which reduces microbial activity and slows down decomposition, thereby increasing the persistence of herbicides in the environment (Torstensson, 2001).

Another issue is the clogging of drainage systems by vegetation, which leads to water retention and can cause the collapse of embankments or railway banks (Hutniczak, Urbisz, Urbisz & Strzeleczek, 2022).

Vegetation growth is further influenced by the annual distribution of precipitation. The monitored area is characterised by dry and hot summers with uneven precipitation. The greatest vegetation growth occurs in spring and early summer (April–June), when precipitation is more frequent. On the contrary, in late summer and autumn (August–October), plants do not grow or dry out, which leads to the accumulation of dry biomass. This can negatively affect the braking distance of train sets and traffic safety. For these reasons, vegetation regulation in railway yards is necessary not only to maintain the quality of the infrastructure, but above all to ensure the safe operation of railway transport.

CONCLUSIONS

The results of the study demonstrate that the trackbed of the selected railway section exhibits a relatively rich and diverse vegetation community. In the study of plant ecology, it has been observed that species that demonstrate a preference for sunny locations, as indicated by their extensive root systems or high seed production, are often dominant in such environments. However, the growing roots of these plants have the potential to disrupt the structural integrity of the railway line. The results also demonstrate that the species composition and amount of vegetation undergo changes during the growing season.

From the perspective of vegetation assessment, the most opportune period appears to be June, when the highest levels of biomass production and the greatest species diversity occur. Vegetation has been shown to exert a significant influence on the structural stability of railway tracks. Additionally, its impact on the smoothness and safety of railway transport has been demonstrated. This phenomenon not only poses a potential fire hazard but also exerts an influence on the composition of the surrounding vegetation. Consequently, regular monitoring and assessment of vegetation along railway lines should be a standard component of railway operational maintenance.

Authors' contributions

Conceptualisation: J.W.; methodology: J.W. and A.M.; validation: J.W., M.H. and A.M.; formal analysis: J.W.; investigation: J.W.; resources: J.W. and M.M.; data curation: J.W.; writing – original draft preparation: J.W. and M.H.; writing – review and editing: J.W. and M.H..; visualisation: J.W.; supervision: J.W.; project administration: J.W.; funding acquisition: J.W. and A.M.

All authors have read and agreed to the published version of the manuscript.

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ZMIANY ROŚLINNOŚCI W ZALEŻNOŚCI OD PORY ROKU NA WYBRANYM ODCINKU LINII KOLEJOWEJ W REGIONIE MORAW POŁUDNIOWYCH (CZECHY) – STUDIUM PRZYPADKU

STRESZCZENIE

Linie kolejowe stanowią ważny element liniowej infrastruktury transportowej. Monitorowany odcinek jest częścią linii łączącej Wiedeń z Krakowem, której budowa rozpoczęła się w 1837 roku. Celem pracy była ocena składu gatunkowego roślinności na wybranym odcinku linii kolejowej. Ocenę przeprowadzono metodą obrazowania fitocenologicznego w 2021 roku w miesiącach kwiecień, czerwiec, sierpień i październik. Podczas monitoringu odnotowano łącznie 31 gatunków roślin występujących w podtorzu danego odcinka. Wyniki wskazują, że monitorowany odcinek charakteryzuje się stosunkowo bogatą i różnorodną gatunkowo roślinnością, której skład i pokrycie zmieniają się w trakcie okresu wegetacyjnego. Roślinność wpływa nie tylko na stabilność strukturalną linii kolejowej, ale może również wpływać na płynność i bezpieczeństwo transportu kolejowego. Z tych powodów regularny monitoring i ocena roślinności powinny stanowić integralną część utrzymania eksploatacyjnego infrastruktury kolejowej.

Słowa kluczowe: roślina, bioróżnorodność, obszar antropogeniczny, roślinność antropogeniczna, kolej