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Railway network of Southern Bulgaria as a pathway for the introduction and spread of alien invasive plants

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Abstract. The railway networks and its adjacent areas represent important corridors for the introduction and secondary spread of alien plant species. Most of them possess high adaptive potential and expand rapidly into non-native environments. As a result, they often become invasive and cause substantial ecological disruption on a global scale. Therefore, the aim of this study was to document the floristic composition of 37 railway stations in Southern Bulgaria and to identify alien invasive plants (AIP). As a result of observation, a total of 413 vascular plant taxa were recorded. The species richness was recorded in Asteraceae (67 species), followed by Poaceae (45 species) and Fabaceae (33 species), respectively. A moderate level of species was observed in Brassicaceae (20 species), Lamiaceae (18 species), Plantaginaceae (17 species), and Rosaceae (17 species). Based on phytogeographic characteristics, predominant Euro-Asian (17.05%) and Euro-Mediterranean (15.01%) elements, while AIP were 11.45% from total recorded flora. Overall, the highest numbers of AIP were recorded at stations by intensive railway traffic, the presence of abandoned wagons, and poorly maintained surrounding areas. Most of alien taxa originated from North America (40.91%), followed by Asia (13.64%) and South America (11.36%). Generally, the high proportion of AIP identified confirms that the railway network is a major route for plant invasions. The results of this study provide scientific information for future monitoring and the development of management measures targeting alien plant species.

Key words: alien plants, biological invasions, railway corridors, synanthropic flora.

Introduction

The alien invasive plants (AIP) are the most serious threats to biodiversity, ecosystem functioning and socio-economic stability worldwide (Williams & Newfield, 2002). Increasing globalization and urbanization in society are the cause of intensive trade and transport. Cross-border travel and exchange of goods are increasing the transfer of plant species outside their natural distribution areas (Williams & Newfield, 2002). Once in new habitats, some of them develop mechanisms (ecological plasticity, high seed productivity, allelopathic action, vegetative propagation) that allow them to spread rapidly (invasion). The consequences of these invasions are as follows: (1) loss of biodiversity; (2) degradation of soil and water resources; (3) economic consequences for agriculture, forestry, and infrastructure (Simberloff et al., 2013; Pyšek et al., 2020).

Transport networks are key corridors for the transport and spread of alien species (Gelbard & Belnap, 2003; Hulme, 2009). Of these, railway tracks and stations are some of the first synanthropic habitats of these species (Hulme, 2009). Along linear structures - rails, embankments and adjacent terrains - ruderal and weedy species associated with habitats disturbed by anthropogenic activity are found (Ascensão & Capinha, 2017). AIP thrives in these habitats. Their success comes not only from vegetative propagation but also through the formation of large amounts of seed banks. They are also unaffected by pesticide treatment and mowing, recovering quickly afterwards. This is due to the ability of these species to produce phytochemicals that allow them to survive under adverse conditions. The problem of invasive species is increasing, as is the search for solutions to preserve existing flora (Simberloff et al., 2013; Capinha et al., 2015). This has led to the consideration of this problem on a global scale (Borda-de-Água et al., 2017).

Despite the growing importance of biological invasions, floristic investigations of railway networks in Bulgaria remain limited (Latowski, 1993; Raycheva et al., 2021). In general, in Bulgaria, systematic inventory and monitoring of the flora at railway stations, especially in areas with high anthropogenic and climatic variability, has not been conducted.

The present study aims to establish the floristic diversity along the railway network of Southern Bulgaria and to assess the participation of alien invasive species. Conducting such a study would serve as a scientific basis for developing management and monitoring strategies.

Materials and methods

Field studies were conducted during the period 2023–2025 at 37 railway stations in Southern Bulgaria (Table 1). The railway stations were selected based on pedestrian accessibility. Each railway station was researched in different seasons (from two to four visits) to record the full plant species composition. The study focused on the vegetation at railway stations, with an emphasis on alien invasive species.

The plant species were identified according to Stoyanov et al. (2022) based on morphological characters. Voucher specimens from field work were deposited in the SOA Herbarium (numbers 063630, 063631, 063632, 063633 and 063634). According to available databases and reports of Ministry of Enviroment and Water (MOEW) were classified taxa as alien and invasive species (Petrova et al., 2013; Vladimirov & Petrova, 2023).

Life forms were determined following Raunkiaer (1934), biological types and ecological groups were assigned according to Stoyanov et al. (2022). Floristic elements were classified following Assyov & Petrova (2012).

Results

From the field work, 413 plant species were identified (Table 2), of which 21 were assigned to genus and 392 to species. Of the identified species, 44 species were introduced to the Bulgarian flora. Of these, 31 species were invasive plants.

Flora of the study area

The analysis of the taxonomic structure of the flora along the railway network of Southern Bulgaria showed that the Equisetophyta division is represented by 1 family, 1 genus and 2 species. The species were found at 9 stations (Belovo, Voluyak, Vladaya, Kostinbrod, Kumaritsa, Kurilo, Pazardzhik, Podkova, Razlog), where places with higher humidity were registered. Polypodiophyta are represented by only one species *Cystopteris fragilis* (L) Bernh. The identified species is from the Vladaya station. Pinophyta includes 1 family, 2 genera and 2 species – *Abies alba* Mill. and *Pinus sylvestris* L. found at the Dobrinishte and Kalotina railway stations.

The largest share of the identified taxa belongs to Magnoliophyta. Of these, dicotyledons occupy 92.19% of the flora, and monocotyledons are represented by 5 families, 31 genera and 51 species or 7.81%. The families with the highest number of species were Asteraceae (67 species), Poaceae (45 species), Fabaceae (33 species), Brassicaceae (20 species), Lamiaceae (18 species), Plantaginaceae (17 species) and Rosaceae (17 species). Families containing many weedy and ruderal species were also present in high proportions along the railway network: Amaranthaceae with 15 species, Euphorbiaceae with 9 species and Polygonaceae with 8 species.

From the observations received, the largest number of species were found in stations with frequent trains and those with abandoned wagons and unmaintained terrain. These were the following stations: Kardzhali – 108 species, Karlovo – 99 species, Dupnitsa - 89 species, Kyustendil - 89 and Karnobat with 89 species. These stations had disturbed and unmaintained terrains around them and active human activity, which may explain the presence of the largest number of species found there. The most frequently recorded species include *Amaranthus albus* L., *Avena fatua* L., *Bromus tectorum* L., *Centaurea diffusa* Lam., *Chenopodium album* L., *Chondrilla juncea* L., *Crepis foetida* L., *Cynodon dactylon* (L.) Pers., *Digitaria sanguinalis* (L.) Scop., *Erigeron canadensis* L., *Euphorbia maculata* L., *Galium aparine* L., *Hordeum murinum* Huds., *Lactuca serriola* L. and *Tribulus terrestris* L. The species

Convolvulus arvensis L., *E. canadensis*, *H. murinum*, *L. serriola*, *Portulaca oleraceae* L., *Tragopogon dubius* Scop. and *T. terrestris* were absent from only two of the railway stations.

Table 1. List of studied railway stations in Southern Bulgaria.

Train station	Coordinates (begin and the end of the study area)		Altitude
Asenovgrad	42.01460°N 24.86850°E	42.01410°N 24.86990°E	205 m
Bankya	42.70609°N 23.14972°E	42.70681°N 23.15381°E	630 m
Blagoevgrad	42.21565°N 24.01870°E	42.21540°N 24.01900°E	322 m
Belovo	42.01390°N 23.08490°E	42.01340°N 23.08545°E	360 m
Burgas V. Pavlov	42.50120°N 27.45760°E	42.05103°N 27.45775°E	7 m
Burgas central	42.49110°N 27.47260°E	42.49090°N 27.47290°E	19 m
Vladaya	42.62310°N 23.18095°E	42.62358°N 23.18688°E	850 m
Voluyak	42.75751°N 23.24155°E	42.75240°N 23.24784°E	545 m
Dimitrovgrad	42.07235°N 25.57731°E	42.07027°N 25.57149°E	125 m
Dobrinishte	41.81770°N 23.55985°E	41.81753°N 23.56035°E	850 m
Dupnitsa	42.26110°N 23.11590°E	42.26070°N 23.11710°E	525 m
Ihtiman	42.49370°N 26.45765°E	42.49338°N 26.45815°E	106 m
Zimnitsa	42.46670°N 23.60990°E	42.46638°N 23.61034°E	656 m
Kazanlak	42.61660°N 25.41000°E	42.61635°N 25.41055°E	244 m
Kalotina	42.82590°N 22.95190°E	42.82555°N 22.95240°E	183 m
Karlovo	42.70235°N 24.87495°E	42.70205°N 24.87545°E	374 m
Karnobat	42.57595°N 26.99505°E	42.57570°N 26.99555°E	111 m
Kostinbrod	42,80431°N 23,20185°E	42,81016°N 23,19463°E	560 m
Kulata	41.39486°N 23.36099°E	41.38890°N 23.36173°E	186 m
Kumaritsa	42.80025°N 23.34146°E	42.79945°N 23.34128°E	95 m
Kardzhali	42.82007°N 23.36130°E	42.81460°N 23.35214°E	520 m
Kyustendil	41.64190°N 25.36555°E	41.64155°N 25.36610°E	210 m
Nowi iskar Kurilo	42.28180°N 22.68870°E	42.28145°N 22.68920°E	490 m
Pazardzhik	42.19290°N 24.33330°E	42.19258°N 24.33385°E	325 m
Panagyurishte	42.50040°N 24.14355°E	42.50005°N 24.14410°E	430 m
Pernik distrubution	42.61045°N 23.03340°E	42.61010°N 23.03395°E	703 m
Pernik central	42.61708°N 23.02890°E	42.61675°N 23.02935°E	695 m
Petrich	41.43598°N 23.19920°E	41.43565°N 23.19970°E	431 m
Peshtera	42.04955°N 24.31515°E	42.04920°N 24.31570°E	470 m
Plovdiv depot Trakia	42.13300°N 24.77615°E	42.13265°N 24.77615°E	160 m
Podkova	42.43468°N 23.40105°E	42.43434°N 23.40150°E	650 m
Razlog	41.88588°N 23.46825°E	41.88555°N 23.46875°E	831 m
Slivnitsa	42.85063°N 23.03585°E	42.85030°N 23.03640°E	545 m
Stara zagora	42.41944°N 25.63429°E	42.41687°N 25.63111°E	196 m
Tulovo	42.61690°N 25.64665°E	42.61660°N 25.64720°E	331 m
Harmanli	41.93272°N 25.90411°E	41.92205°N 25.87516°E	61 m
Haskovo	41.93305°N 25.58411°E	41.92310°N 25.38012°E	194 m

Table 2. The established number of genera and species by families, classes and divisions.

№	Division Class Family	Genera		Species	
		Number	% of total species found	Number	% of total species found
	Equisetophyta				
1.	Equisetaceae	1	0.29%	2	0.48%
	Polypodiophyta				
2.	Aspleniaceae	1	0.29%	1	0.24%
	Pinophyta				

3.	Pinaceae	2	0.58%	2	0.48%
	Magnoliophyta				
	Magnoliopsida				
4.	Amaranthaceae	7	2.04%	15	3.63%
5.	Anacardiacea	2	0.58%	2	0.48%
6.	Apiaceae	9	2.62%	9	2.18%
7.	Apocynaceae	1	0.29%	1	0.24%
8.	Araliaceae	1	0.29%	1	0.24%
9.	Asteraceae	36	10.50%	67	16.22%
10.	Betulaceae	2	0.58%	2	0.48%
11.	Bignonaceae	1	0.29%	1	0.24%
12.	Boraginaceae	7	2.04%	10	2.42%
13.	Brassicaceae	14	4.08%	20	4.84%
14.	Campanulaceae	1	0.29%	2	0.48%
15.	Cannabaceae	2	0.58%	2	0.48%
16.	Caprifoliaceae	5	1.46%	8	1.94%
17.	Caryophyllaceae	8	2.33%	14	3.39%
18.	Celastraceae	1	0.29%	1	0.24%
19.	Convolvulaceae	4	1.17%	6	1.45%
20.	Cornaceae	1	0.29%	1	0.24%
21.	Crassulaceae	1	0.29%	2	0.48%
22.	Cucurbitaceae	2	0.58%	2	0.48%
23.	Euphorbiaceae	2	0.58%	9	2.18%
24.	Fabaceae	15	4.37%	33	7.99%
25.	Fagaceae	1	0.29%	1	0.24%
26.	Geraniaceae	2	0.58%	9	2.18%
27.	Hypericaceace	1	0.29%	1	0.24%
28.	Juglandaceae	1	0.29%	1	0.24%
29.	Lamiaceae	12	3.50%	18	4.36%
30.	Malvaceae	3	0.87%	6	1.45%
31.	Moraceae	2	0.58%	2	0.48%
32.	Nyctaginaceae	1	0.29%	1	0.24%
33.	Oleaceae	3	0.87%	5	1.21%
34.	Onagraceae	2	0.58%	8	1.94%
35.	Oxalidaceae	1	0.29%	2	0.48%
36.	Papaveraceae	4	1.17%	5	1.21%
37.	Paulowniaceae	1	0.29%	1	0.24%
38.	Phytolaccaceae	1	0.29%	1	0.24%
39.	Plantaginaceae	8	2.33%	17	4.12%
40.	Plantanaceae	1	0.29%	1	0.24%
41.	Plymbaginaceae	1	0.29%	1	0.24%
42.	Polygonaceae	4	1.17%	8	1.94%
43.	Portulacaceae	1	0.29%	2	0.48%
44.	Primulaceae	1	0.29%	1	0.24%
45.	Ranunculaceae	5	1.46%	5	1.21%
46.	Resedaceae	1	0.29%	1	0.24%
47.	Rhamnaceae	1	0.29%	1	0.24%
48.	Rosaceae	8	2.33%	17	4.12%
49.	Rubiaceae	2	0.58%	5	1.21%
50.	Salicaceae	1	0.29%	1	0.24%
51.	Sapindaceae	2	0.58%	4	0.73%
52.	Saxifragaceae	1	0.29%	1	0.24%
53.	Scrophulariaceae	3	0.87%	8	1.94%
54.	Simaroubiaceae	1	0.29%	1	0.24%

55.	Solanaceae	2	0.58%	3	0.73%
56.	Ulmaceae	2	0.58%	3	0.73%
57.	Urticaceae	1	0.29%	1	0.24%
58.	Verbenaceae	1	0.29%	1	0.24%
59.	Viburnaceae	1	0.29%	1	0.24%
60.	Violaceae	1	0.29%	2	0.48%
61.	Vitaceae	2	0.58%	2	0.48%
62.	Zygophyllaceae	1	0.29%	1	0.24%
	Liliopsida				
63.	Alismataceae	1	0.29%	1	0.24%
64.	Araceae	1	0.29%	1	0.24%
65.	Asparagaceae	1	0.29%	3	0.73%
66.	Commelinaceae	1	0.29%	1	0.24%
67.	Poaceae	27	7.87%	45	10.90%
	Total	**343**		**413**	

Ecological-biological structure of floral elements

Most species are heliophytes, adapted to open, well-lit habitats. Some show xeromorphic traits in drier microhabitats, e.g. *Ballota nigra* L., *Lotus corniculatus* L., *Potentilla argentea* L. and *Eryngium campestre* L.

Herbaceous vegetation was dominant, while trees and shrubs were mostly restricted to the periphery of stations and abandoned lines. The most found species included *Ailanthus altissima* (Mill.) Swingle, *Acer negundo* L., *Rosa canina* L., *Rubus* sp., *Robinia pseudoacacia* L., *Populus nigra* L. and *Gleditsia triacanthos* L. Seedlings of these species were often observed between the rails and on the periphery of the railway lines. It was observed that anthropogenic activity, such as afforestation around railway stations, promoted the spread of tree and shrub species.

Grass communities typical of ruderal habitats were widespread, including *Cynodon dactylon* (L.) Pers., *Poa bulbosa* L., *Galium aparine* L., *Bromus sterilis* L., *Capsella bursa-pastoris* (L.) Medicus, *Melilotus officinalis* (L.) Pall. and *Centaurea diffusa* Lam. The distribution by biological type is shown in Fig. 1. Annual herbaceous species predominate (38.78%), followed by perennial herbaceous species (31.12%).

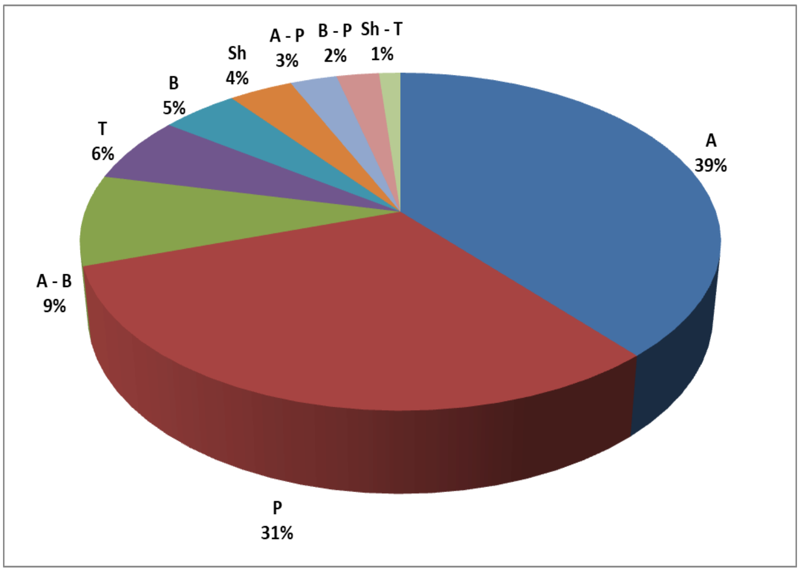

Fig. 1. Distribution of species by biological type in % of the species found at the railway stations. (A-annual herbaceous plants, P-perennial herbaceous plants, A-B-annual and biennial herbaceous plants, T-tree type, B-biennial herbaceous plants, Sh – shrub, A-P-annual and perennial herbaceous plants, B-P-biennial to perennial herbaceous plants, Sh-T-shrub to tree type).

Distributed by life forms, therophytes had the largest proportion, representing 42.67% of the detected species (Fig. 2). Their high proportion was explained by the frequent disturbances on the railway lines (mowing, herbicide treatment, trampling by trains), which favored short-lived species capable of forming seed banks. Hemicryptophytes represented 32.90%, mainly perennial plants, while phanerophytes were 12.08%. Hamephytes and geophytes were less common, with 2.06% and 1.80%, respectively.

A total of 37 floristic elements were recorded (Table 3). European-Asian (17.05%) and European-Mediterranean (15.01%) elements predominated, indicating the prevalence of species with wide ecological amplitudes. Alien (adventive) species comprised 11.45% of the flora, ranking third. No endemic species were observed in the area studied.

Invasive alien species at railway stations

A total of 44 introduced species for Bulgaria were identified on the surveyed railway stations. Of these, 31 species were classified as invasive. Six species were among the ten most problematic invasive plants in Bulgaria: *Acer negundo*, *Ailanthus altissima*, *Ambrosia artemisiifolia* L., *Amorpha fruticosa* L., *Bidens frondosa* L. and *Robinia pseudoacacia* according to data from the MOEW (2026). The most of them are originate from North America (40.91%), followed by Asia (13.64%) and South America (11.36%).

Invasive species were predominantly identified within inter-track spaces, on station platforms, and throughout derelict or unmanaged zones. The most frequent species in these habitats were *Amaranthus albus*, *Erigeron canadensis*, *Portulaca oleracea*, *Tribulus terrestris*, and *Euphorbia maculata*. Along railway edges, seedlings of *Robinia pseudoacacia*, *Amorpha fruticosa*, *Ailanthus altissima* and *Gleditsia triacanthos* were developing, while *Morus alba* L. and *Tilia* sp. were less frequent.

Stations with the highest proportion of AIP were Karlovo, Petrich, and Kardzhali. This was explained by the intensive movement of passengers and freight at these stations, as well as the maneuvering and stopping of freight trains. The lowest proportions were recorded at Ihtiman, Podkova, Peshtera, and Kumaritsa, corresponding to the low workload of these stations, the lack of maneuvering, loading and unloading activities, the better maintenance of the area around the station.

Vegetation control (mowing and herbicide application) was carried out at all stations, which was reported by the traffic managers. Effectiveness was not achieved due to single treatments or applications at inappropriate phenological stages, often after seed maturation.

Overall, these results support previous studies (Latowski, 1993; Raycheva et al., 2021) demonstrating that railway networks serve as corridors for the introduction and establishment of alien plant taxa.

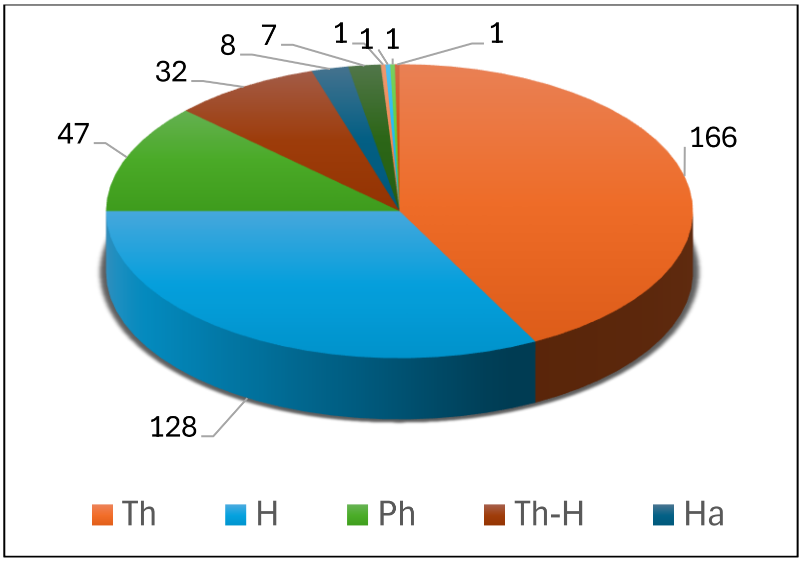

Fig. 2. Distribution by life forms (according to Raunkiaer).
(Th therophytes; H hemicryptophytes; Ph phanerophytes; Th-H therophytes – hemicryptophytes; Ha hamefites; G geophytes; A aquatic; Ha-Ph hamephytes – phanerophytes; H-G hemicryptophytes – geophytes; H-Ha hemicryptophytes – hamephytes).

Table 3. Distribution by flora elements.

Flora elements	Number of species	% of species found at railway stations
Eur-As	67	17.05 %
Eur-Med	59	15.01 %
Adv	45	11.45 %
subMed	42	10.69 %
Boreal	23	5.85 %
Kos	22	5.60 %
Med	22	5.60 %
Eur-Sib	21	5.34 %
subBoreal	21	5.34 %
Eur	12	3.05 %
Pont-Med	10	2.54 %
sPont	6	1.53 %
Eur-subMed	6	1.53 %
Med-Cas	4	1.02 %
Ap-Bal	3	0.76 %
Med-As	3	0.76 %
Casual	2	0.51 %
Eur-Cas	2	0.51 %
Pann-Bal	2	0.51 %
Pont-Cas	2	0.51 %
subMed-As	2	0.51 %
Arct-Alp	1	0.25 %
As	1	0.25 %
Bal-Anat	1	0.25 %
CSEur	1	0.25 %
Eur-As/Paleo	1	0.25 %
Eur-Med-CAs	1	0.25 %
Eur-OT	1	0.25 %
Med-Atl	1	0.25 %
Med-TO	1	0.25 %
NAm	1	0.25 %
Ornament	1	0.25 %
Pont	1	0.25 %
Pont-OT	1	0.25 %
Pont-Sib	1	0.25 %
subSib	1	0.25 %
Bal	1	0.25 %
Total	392	

Discussion

Generally, Equisetophyta and Polypodiophyta are underrepresented. Their limited distribution is probably due to specific ecological constraints, which is in line with the observations of Raycheva et al. (2021). Pinophyta are probably present due to the location of the stations, near which there are coniferous forests.

Magnoliophyta has the largest number of species, with the families Asteraceae (67), Poaceae (45), Fabaceae (33), Brassicaceae (20) prevailing. The high species richness of the families Asteraceae, Poaceae and Fabaceae are not accidental, because they have the richest species composition and wide ecological plasticity, which allows them to successfully develop in disturbed habitats.

Regarding life forms, annual and perennial herbaceous plants constitute the largest part of the flora. These biological types are well adapted to the strong light intensity and frequent disturbances characteristic of railway environments, often developing xeromorphic traits under adverse conditions.

Field studies have shown that the most common species are plants with small anemochoric seeds, which are easily dispersed by air currents created by moving trains. This determines their successful spread along the railway network. Similar results have been reported in the literature by Paiaro et al. (2011) and Májeková et al. (2014) for the territory of Central Argentina and the stations Chop (Ukraine) and Čierna nad Tisou (Slovakia).

The spread of species along railway sections occurs through different mechanisms. Over long distances, passing trains and human activity play a major role. Local dispersal of diaspores occurs through zoochory (ants, rodents and birds), anemochory (wind) and hydrochory during intense rainfall. Furthermore, anthropogenic disturbances, such as construction and repair activities, contribute to further spread, as was observed during the repair of Belovo station.

Invasive alien species are most found on embankments and adjacent areas of stations, which confirms the findings of the authors (Özaslan et al., 2016; Matevski, 2017; Neblea & Marian, 2022). Their presence highlights the high vulnerability of railway habitats to biological invasions.

Railway networks represent a linear element in the landscape, connecting separate urban areas, which facilitates the spread of invasive species. For a large part of the alien plants, the lines and the embankments around them serve as a starting point for further spread. This is confirmed by field studies for the species *A. altissima*, *R. pseudoacacia* and *A. fruticosa*, whose presence was recorded at multiple stations along the lines. Similar results have been reported in international studies that determine railway networks as effective distribution corridors (Helldin et al., 2019; Májeková et al., 2021; Nilsson, 2022; Xiong et al., 2025).

Despite the disturbed habitats of railway networks, they sometimes serve as habitats for rare or endemic species. Such cases were reported by Heneidy et al. (2021) where endemic, rare and threatened species were identified for the territory of Egypt. In the Czech Republic, 85 Red List taxa with different categories of threat were identified (Kutlvašr et al., 2024), and in Slovakia, 17 threatened species were identified and another 9 were considered rare (Májeková et al., 2014). In the present study, no rare or threatened species were identified on railway networks. This is likely due to strong anthropogenic transformation, regular habitat maintenance, and high levels of disturbance, which favors mostly widely adapted and invasive species.

Conclusions

The present study showed that the vegetation around the railway stations is characterized by high floristic diversity and a significant participation of alien invasive species. It also showed the presence of species with different origins and ecological requirements. This may define the railway network as a significant route for the entry and spread of introduced plants into the Bulgarian flora, which poses a potential risk to the surroundding natural ecosystems.

The obtained results emphasize the need for regular monitoring and implementation of integrated measures for management and limitation of the impact of alien invasive species to protect the surrounding natural ecosystems.

Acknowledgments

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