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Research Article

Plants along roads in Slovakia: current spread of *Amorpha fruticosa* L. around motorways and expressways

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Abstract

Amorpha fruticosa is a non-native invasive species of Slovak flora spreading along waterways. In the past, it was planted to strengthen road embankment soil. These plantings on the edges of motorways and expressways are potential seed sources. A survey of the distribution of *A. fruticosa* along all motorways and expressways in Slovakia was carried out in June 2023 (tracking while driving, counting *A. fruticosa* sites). In total, 519.42 km of motorways and 252.19 km of expressways were covered in both directions. The species was recorded on 40.01% of motorway and expressway sections. The highest frequency of occurrence was recorded in warm regions, at elevations up to 300 m a.s.l. (1900 records, 99.16%) and along the oldest sections of motorways and expressways (completed by the year 2000 – 1833 records, 95.67%). At higher elevations in northern Slovakia, the occurrence of the species was rare (16 records, 0.84%). *Amorpha fruticosa* spreads from existing plantations to nearby surrounding plant communities. Its spread into the open landscape is effectively prevented by regular mowing, mulching, grazing or ploughing of stands on cultivated agricultural land around road embankments.

Key words: distribution, false indigobush, invasive species, management, non-native species, outlander plant, roadside

Introduction

Amorpha fruticosa is a deciduous shrub native to North America (POWO 2023). It was introduced to southern and eastern Asia and southern South America and to western and eastern European countries (POWO 2023). In Europe, the species became popular mainly through its cultivation as an ornamental and honey plant and for the production of false indigo (dye manufacturing from yellow anthers) and for medical applications (e.g., in diabetic disease) and due to its ability to stabilize the soil via its extensive root system (Kozuharova et al. 2017; Chrtek 2019; Li et al. 2022). Due to its well-developed root system, exuberant growth of branches and leaves, rapid establishment, drought resistance, and endurance in lean soil, *A. fruticosa* has been used in the hardening of road verges and vegetation

recovery on road slopes (Yang et al. 2016). In addition, it has strong salt-alkali tolerance (Chytrý et al. 2018; Gao et al. 2024a, b), and it is highly resistant to vehicle emissions (Li et al. 2012). Due to these properties, it has been planted not only in areas of its natural range (Zak et al. 1972) but also in countries where it was introduced, e.g. China (Zhang and Li 2010; Yang et al. 2016; Cao et al. 2018), Russia (Kolyada and Kolyada 2018) and Slovakia (Mereďa et al. 2021).

The ability of the species to grow in the specific habitat conditions of roadsides results from its wide ecological amplitude (Supplementary material Table S1) and its adaptive capacity to survive and develop tolerance to stress (Mitrović et al. 2012; Gao et al. 2024a, b). It prefers habitats with increased soil moisture (Dyakov and Zhelev 2013), however it is also able to grow on mesic to dry soils. For example, in Hungary, *A. fruticosa* was identified in 10 different habitats, including steppe woodlands and mesic deciduous woodlands on hills and mountains (Botta-Dukát 2008). Moreover, it does not avoid halophytic habitats (Botta-Dukát 2008), which explains its tolerance to saline soils near roads.

Amorpha fruticosa is registered as an invasive plant in almost all European countries (Seebens et al. 2017; Roy et al. 2020; EPPO 2021). Its occurrence is reported in Lithuania (Gudžinskas and Žalneravičius 2015), Poland (Danielewicz et al. 2020), Czech Republic (Pyšek et al. 2012), Hungary (Szigetvári 2002; Török et al. 2003; Szigetvári and Tóth 2008), Ukraine (Kucher 2015; Konaikova and Vakarenko 2020), Russia (Vinogradova et al. 2021), Serbia (Blagojević et al. 2015; Petrović et al. 2016; Radovanović et al. 2017; Litavský et al. 2018), Croatia (Pandža 2010; Seibold and Fischer 2013; Batanjski et al. 2016), Romania (Sărățeanu 2010; Dumitrașcu et al. 2011; Ferus et al. 2015), Bulgaria (Aneva et al. 2018), Montenegro (Hadžiablahović et al. 2011), Italy (Pellegrini et al. 2021; Praleskouskaya and Venanzoni 2021), Greece (Papachristou and Papanastasis 1994; Arianoutsou et al. 2023), Turkey (Uludağ et al. 2017), as well as in Tajikistan (Nobis et al. 2015), Georgia (Kalníková et al. 2020), China (Wang et al. 2021), South Korea (Kim et al. 2023) and Japan (Takagi and Hioki 2013).

Amorpha fruticosa is expanding successfully along waterways and terrestrial transport ways, as well as in grassland vegetation (Sărățeanu 2010). The potential for the spread of *A. fruticosa* under temperate zone conditions was confirmed by Šerá et al. (2023) through a study on reproductive capacity. Prerequisites for species spread include regular high production of fruits and seeds and high seed germination. In addition, *A. fruticosa* is capable of wide dispersal via vegetative reproduction (Möllerová 2005; Kolyada and Kolyada 2018). The plant is especially easily dispersed within the watersheds of large rivers (Shevchyk et al. 2021; Grabić et al. 2022). The invasive spread of *A. fruticosa* is facilitated by its ability to fix nitrogen (Boscutti et al. 2020; Pellegrini et al. 2021; Vujanović et al. 2022) and allelopathy (Csiszár 2009;

Novak et al. 2018; Krstin et al. 2020). Climate and land use changes also contribute to the spread of *A. fruticosa* (Kiss and Sándor 2009; Nagy et al. 2018), as do land cover and management changes (Szigetvári et al. 2002).

Amorpha fruticosa was introduced to Slovakia in 1850 (Medvecká et al. 2012). Since the second half of the 19th century, it has been cultivated in parks, gardens, and streets as an ornamental shrub (Chrtková 1988). It also has been planted on the edges of motorways and expressways (Mereďa et al. 2021). In Slovakia, *A. fruticosa* is a naturalized neophyte (Medvecká et al. 2012). Due to its biological and physiological properties, as the ability to spread rapidly, replacement of native flora, reduction of biodiversity and change the soil chemical properties, since 2014, it has been considered an invasive species (Government Regulation No. 158/2014).

The occurrence of *A. fruticosa* in Slovakia is primarily linked to targeted plantings around motorways and expressways. Little is known about its current occurrence around these transport corridors. In addition, it is likely that *A. fruticosa* spreads from motorways and expressways further into the natural landscape. In this context, the main aim of this study was recorded the occurrence of *A. fruticosa* along motorways and expressways in Slovakia.

Materials and methods

Study area

The motorway and expressway network in Slovakia has been under construction since 1969 (https://historiadialnic.sk/; accessed 18 July 2023). By the end of 2022, 519.42 km of motorways and 252.19 km of expressways were in operation in Slovakia. They have been distributed throughout the entire territory of Slovakia, with the highest proportion occurring in the western region.

Motorways and expressways are mainly situated in plains and basins. In the northern part of Slovakia, these roads are partly situated in uplands and highlands (Mazúr and Lukniš 1986). The monitored motorways and expressways were located across Slovakia. For this reason, a brief description of the entire state follows. The altitudes vary from 100 to 800 m a.s.l. The geology of Slovakia is heterogeneous. Quaternary sediments accumulate in the highest amounts along rivers and valleys and locally reach a significant thickness (Maglay et al. 2009). Neogene sediments (clays, sands and gravel) prevail in lowlands and basins, and Paleogene sediments (claystones and sandstones) prevail in some intermountain basins. The mountain ranges of the Western Carpathian Mountain system consist of various crystalline (granites and crystalline schists) and sedimentary (limestones, dolomites, sandstones and shales) rocks. The Slovenské stredohorie Mts. are formed by volcanites (mostly andesites and by rhyolites and basalts to a lesser extent) (Biely et al. 1996; Hók et al. 2019). There is a moderately transitional climate characterized by frequent alternations between humid oceanic air

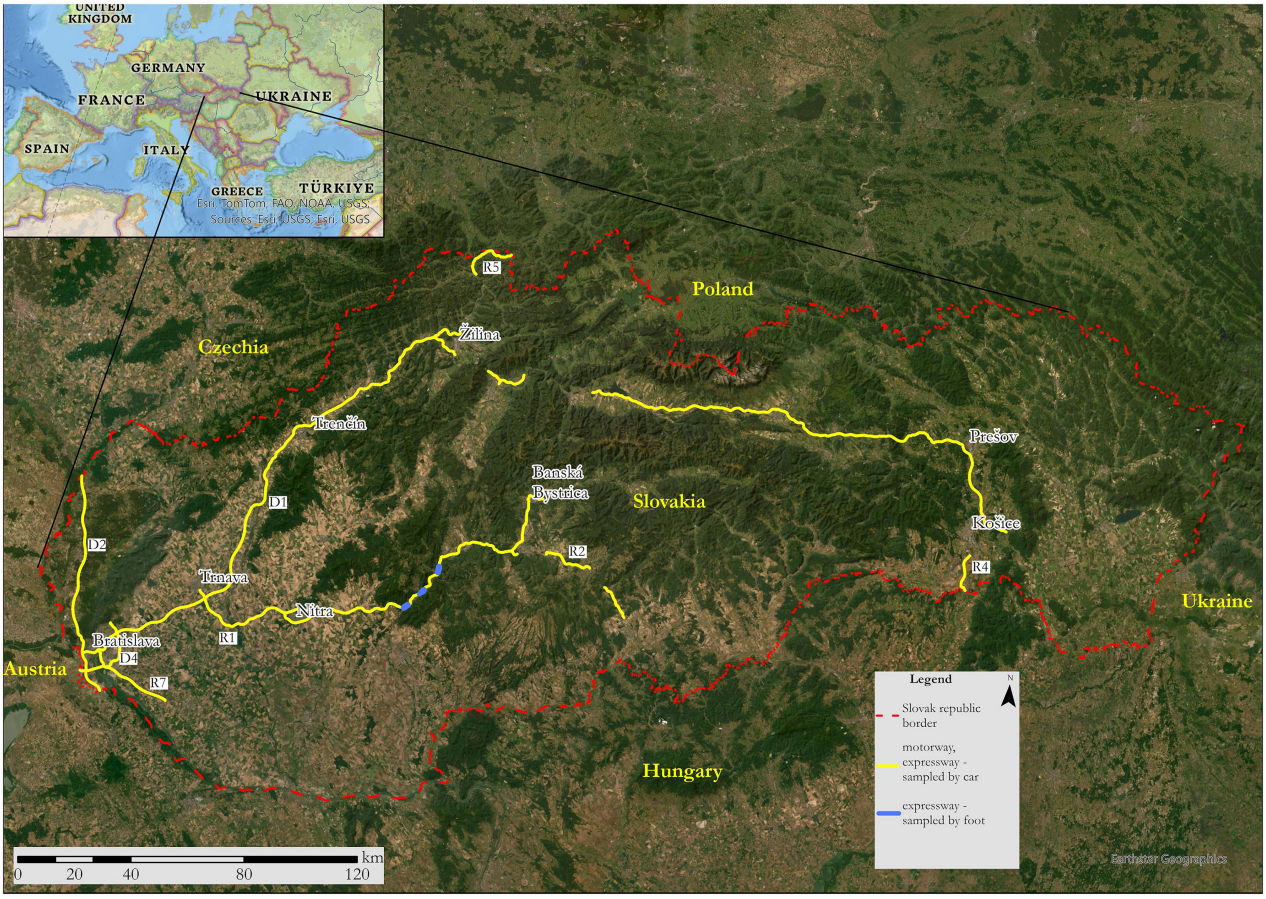

Figure 1. Motorways (D1, D2, D4) and expressways (R1, R2, R4, R5, R7) where the car survey and the foot survey were conducted.

and dry continental air (hot in summer, cold in winter). In the west, south, and east, motorways and expressways traverse warm (50 or more summer days annually on average) and moderately warm (fewer than 50 summer days annually on average and a July mean temperature of 16 °C or more) regions. In central and especially in northern Slovakia, these roads pass through cool regions (July mean temperature less than 16 °C) (Lapin et al. 2002). The annual precipitation in these areas ranges from approximately 500 mm to 800 mm (Faško and Šťastný 2002).

Field procedures, data collection and visualization

The survey of occurrence of *A. fruticosa* along all motorways and expressways in Slovakia was conducted on D1, D2 and D4 motorways and on R1, R2, R4, R5 and R7 expressways (Figure 1). A total of 519.42 km of motorways and 252.19 km of expressways were sampled in both directions (total 1543.22 km). The occurrence of the species was recorded at the end of June 2023. This time frame was suitable considering the characteristic timing of flowering or fruit-bearing in *A. fruticosa*.

The data on the occurrence of *A. fruticosa* were collected through a car survey. The data were recorded from the front passenger seat. The car was driving in the slowest traffic lane along the edges of motorways and

expressways. The average speed was 90 km per hour. The occurrence of the species in the central strip of roads was not recorded. The coordinates of the species occurrence were recorded using the GPS device Garmin 62st in the degrees, minutes, and seconds format (in Table S2, they are provided in degrees). A motorway or expressway section was a part of a road divided by direction, forming a line. A higher concentration of records indicated the relative frequency of the species in a given section of the road (at least one individual). However, the records did not represent the exact location of individuals of *A. fruticosa*. The relative species frequency was expressed as the number of records per 1 km of the road section.

Errors in records may arise from both botanical and technical reasons:

i. Similarities with the taxa *Robinia pseudoacacia*, *Fraxinus* sp., *Caragana arborescens*, *Rhus typhina*, and *Ailanthus altissima*, with which *A. fruticosa* often forms mixtures.
ii. Difficult identification of nonflowering individuals.
iii. Overtaking slow-moving vehicles (especially trucks).
iv. Occurrence of the species behind noise barriers and on slopes.
v. Technical limitations of the GPS device.

The locations of the sections delimited in the text by marker posts can be found at https://ismcs.cdb.sk/mapviewer/ (accessed 11 July 2023).

The Figures 1–3 were created in ArcGIS Pro 3.1.0 software (ESRI 2023). We used the imagery data obtained by the ArcGIS Imagery basemap. The motorway and expressway data (type of road, altitude, year put into operation) were obtained from https://data.gov.sk/ (accessed 10 September 2023). The information on the GPS coordinates of *A. fruticosa* occurrence was added to the figures using the Excel Table and Display XY data tools. The *A. fruticosa* data were coloured according to the labels of the motorways and expressways, or according to the frequency of records.

The nomenclature of vascular plants followed Roskov et al. (2006), and the syntaxa names were provided by Mucina et al. (2016).

Verification of records from the car survey

The objective of the verification was to determine the accuracy of the records obtained from the car survey by comparing them with the data obtained from the foot survey. Foot surveys are considered the most accurate method for conducting roadside surveys (Barone et al. 2021). They provided a greater level of data accuracy than car surveys or more modern methods (camera, photointerpretation of Google Street View, and photointerpretation of Google Earth aerial images) (Barone et al. 2021; Kotowska et al. 2021; Lourenço et al. 2021).

For verification, three sections of expressway R1 were selected: Hronský Beňadik–Tekovská Breznica (87.5–89.2 km), Nová Baňa bypass (95.5–97.8 km) and Žarnovica bypass (107.3–109.4 km) in both directions. The total length of the sections was 6.1 km. The survey involved walking along the base of

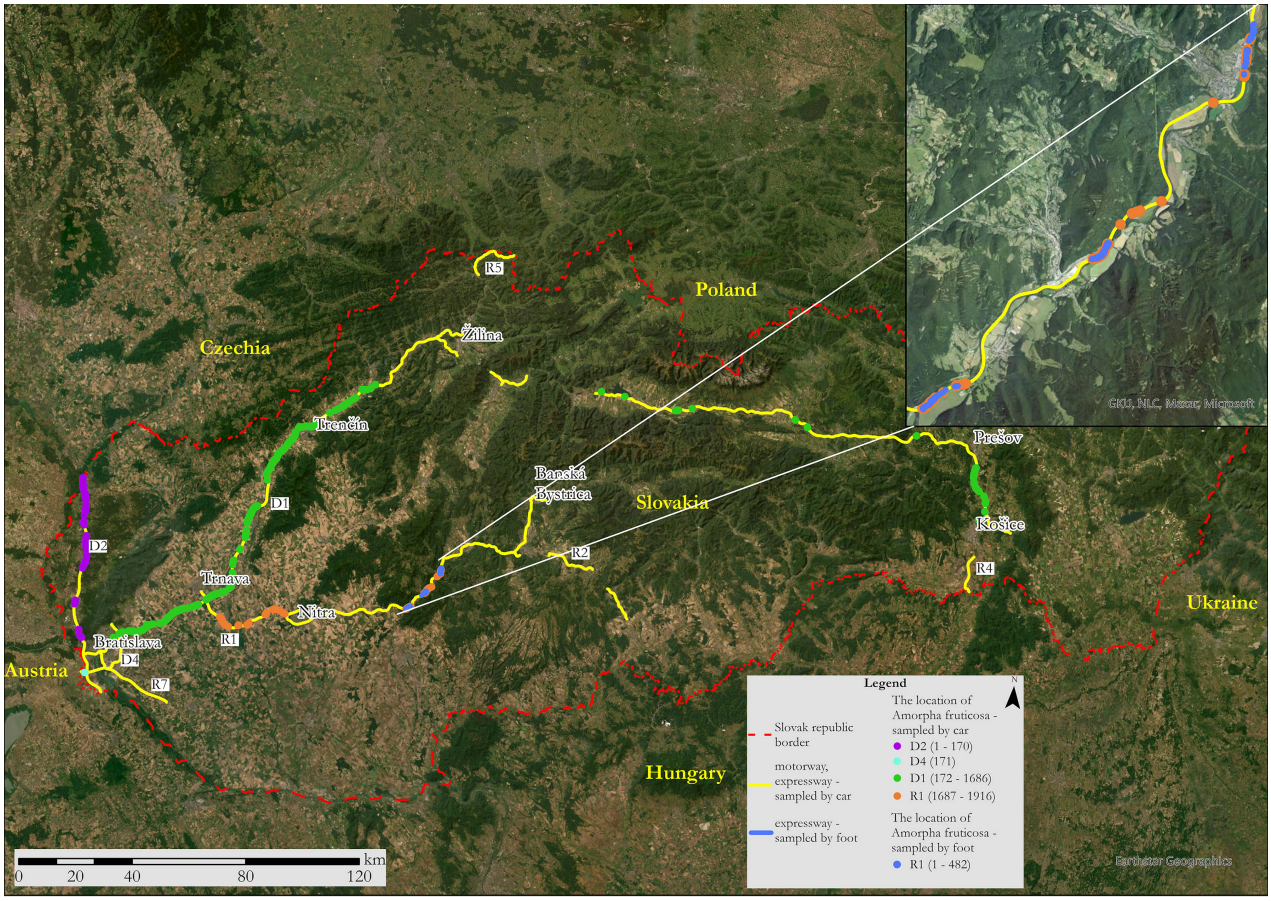

Figure 2. Spatial distribution of *A. fruticosa* plantings on the edges of motorways and expressways in Slovakia.

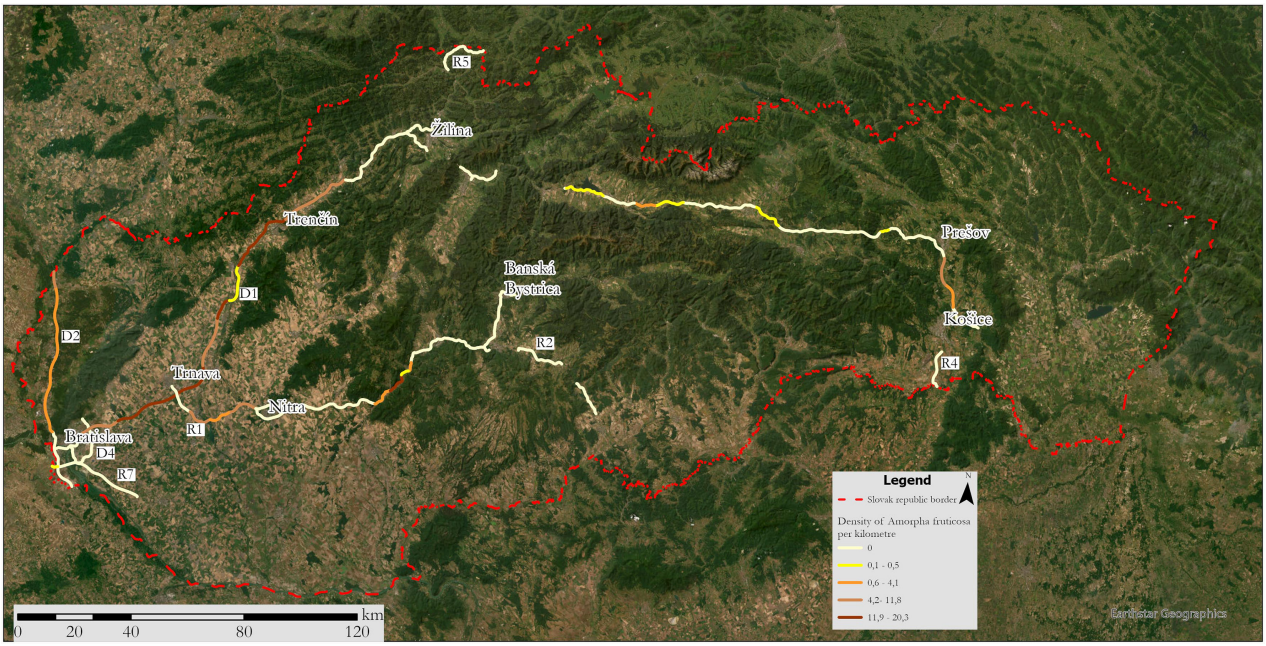

Figure 3. The occurrence of *A. fruticosa* on motorways and expressways in Slovakia according to the frequency of records.

road embankments of the selected expressway sections at a speed of approximately 2 km per hour, and the presence of *A. fruticosa* was noted using a GPS device. The *A. fruticosa* presence/absence data obtained by both methods on 10-m segments of the road (12.2 km = 1200 segments) were

Table 1. Results of the comparison of the *A. fruticosa* presence/absence data obtained from the car survey and the foot survey on verification sections of expressway R1.

Car survey/Foot survey	Direction towards	No. of segments	YY	YN	NY	NN	Agreement %	Difference %
Hronský Beňadik–Tekovská Breznica	Zvolen	170	6	3	22	139	85.29	14.7
	Bratislava	170	4	1	21	144	87.06	12.94
Nová Baňa bypass	Zvolen	230	13	2	50	165	77.39	22.6
	Bratislava	230	11	5	32	182	83.91	16.09
Žarnovica bypass	Zvolen	210	10	5	42	153	77.62	22.38
	Bratislava	210	0	0	20	190	90.48	9.52
Total		1220	44	16	187	973	–	–
Average		–	–	–	–	–	83.63	16.37

Y – yes, N – no

compared. A similar approach for surveying the distribution of plants along roadsides was also used by Shuster et al. (2005), Abella et al. (2009) and Kotowska et al. (2021).

By comparing data on the presence/absence of *A. fruticosa* obtained from car and foot surveys, an average agreement of 83.63% was found (Table 1). The car survey method was therefore used as a suitable method for this research.

Results

We recorded 1916 occurrences of *A. fruticosa* on 265.41 km of motorways and 44.19 km of expressways (40.01% of the studied roads) (Table S2). The highest concentration of records was associated with older sections of motorways and expressways completed by the year 2000 (1833 records, 95.67%). These mainly included sections of motorway D1 Senec–Trnava (30–50 km), Piešťany–Horná Streda (83.5–91.2 km), Nové Mesto nad Váhom–Chocholná (105.9–119 km) and Chocholná–Skala (119–130 km). The species had the highest frequency at lower altitudes, at elevations up to 300 m a.s.l. (1900 records, 99.16%). The length of these road sections was a total of 523.06 km (67.79%). In the northern part of Slovakia (D1 sections Ivachnová–Liptovský Mikuláš, Liptovský Hrádok–Hybe, Hybe–Važec, Mengusovce–Jánovce and Fričovce bypass), the occurrence of the species was rare (16 records, 0.84%). The length of the studied road sections at an elevation above 300 m a.s.l. was a total of 248.55 km (32.21%) (Tables 2, 3, Figures 2, 3, Table S2).

Discussion

A comparison of the *A. fruticosa* presence/absence data obtained from the car survey and from the foot survey methods revealed an average agreement of 83.63% (Table 1). A greater data inaccuracy degree was found for roads with steep road embankment slopes (Nová Baňa bypass and Žarnovica bypass – towards Bratislava). Deus et al. (2016) noted that the accuracy of records decreased when the survey was conducted via the car method on steeper slopes. The advantage of the car survey method is that it allows covering larger areas in shorter periods with fewer resources (Shuster et al. 2005; Catry et al. 2015).

Table 2. Occurrence of *A. fruticosa* along the edges of motorways (D) and expressways (R) in Slovakia obtained from the car survey. The colours in the first column correspond to the colours of motorways and expressways used in Figure 2.

Motorway, expresway	Motorway or expressway sections with occurrence of *A. fruticosa*	Year of finish	Section length* (km)	No. of records	Records density (per km)
D1	Bratislava Senecká road–Senec	1975	16.8	107	6.37
	Ivachnová–Liptovský Mikuláš	1977	14.33	4	0.28
	Senec–Trnava	1978	19.31	368	19.06
	Trnava–Hlohovec	1982	18.46	227	12.29
	Prešov south–Ličartovce	1982	8.64	50	5.79
	Hlohovec–Piešťany	1985	15.13	94	6.21
	Piešťany–Horná Streda	1988	8.33	169	20.30
	Ličartovce–Budimír	1988	10.5	14	1.33
	Liptovský Hrádok–Hybe	1990	7.87	8	1.02
	Chocholná–Skala	1996	11.2	177	15.80
	Horná Streda–Nové Mesto nad Váhom	2000	14.1	7	0.50
	Nové Mesto nad Váhom–Chocholná	2000	13.1	214	16.34
	Nemšová–Ladce	2000	16.63	74	4.45
	Hybe–Važec	2000	10.66	1	0.09
	Fričovce bypass	2003	3.17	1	0.32
	Mengusovce–Jánovce	2009	11.62	2	0.17
D2	Bratislava Lamačská road–Malacky	1973	29.34	39	1.33
	Malacky–Kúty	1978	24.18	78	3.23
	Kúty-state border Slovak republic–Czech Republic	1979	4.49	53	11.81
D4	Bratislava Jarovce state border Slovak Republic-Austria	2002	7.55	1	0.13
R1	Báb–Nitra west	1980	10.37	63	6.08
	Šoporňa–Báb	1998	9.47	19	2.01
	Sereď–Šoporňa	1998	6.8	67	9.86
	Hronský Beňadik–Nová Baňa	2003	4.36	18	4.13
	Nová Baňa–Rudno nad Hronom	2003	3.23	43	13.33
	Rudno nad Hronom–Žarnovica	2006	5.49	2	0.36
	Žarnovica bypass	2006	4.47	16	3.58
Total	–	–	309.6	1916	–

*The section length represents the length of a directionally divided road, forming a line

A survey of *A. fruticosa* occurrence along motorways and expressways in Slovakia indicated that it is most common in the oldest sections of these roads. Occurrences of *A. fruticosa* along sections of roads completed by the year 2000 confirm the ability of the species to survive long-term in the climatic conditions of Slovakia. In the colder regions of Slovakia, the occurrence of *A. fruticosa* is rare. At altitudes above 300 m a.s.l., we recorded only 16 occurrences, which represent a total of 0.84% of all records (Table 3). It is a thermophilic species that is predominantly distributed in lowland areas (Chytrý et al. 2018). Therefore, its low frequency in colder regions was not surprising.

With respect to the invasive status of *A. fruticosa* in Slovakia, its planting is currently banned. Since 2001, planting on road embankments has significantly decreased, e.g., a total of 83 (4,33 %) of all records (Table 2). Sections R1 Hronský Beňadik–Žarnovica (87.5–109.4 km), which were completed between 2003 and 2006, are an exception. A foot survey was conducted in these sections.

The existing plantings of *A. fruticosa* along roadsides are potential sources of dispersal, enabling its penetration into adjacent habitats as well as from ornamental plantations in cities and botanical gardens and arboretums

Table 3. Occurrence of *A. fruticosa* along the edges of motorways and expressways of Slovakia according to vegetation zones (according to Futák 1972; Zlatník 1976).

Vegetation zone	Altitude	Number of records	Number of records (%)	Length (km)	Length (%)
Oak	up to 300 m a.s.l.	1900	99.16	523.06	67.79
Beech-oak	300–500 m a.s.l.	1	0.05	137.66	17.84
Oak-beech	500–700 m a.s.l.	5	0.26	64.04	8.30
Beech	700–1000 m a.s.l.	10	0.52	46.85	6.07
Total	–	1916	–	771,61	–

(Chindyaeva et al. 2018; Ferus et al. 2020). During the foot survey, we observed that *A. fruticosa* is able to spread from road embankments to adjacent phytocoenoses. But it is not yet recorded in the syntaxa of Slovakia. We compiled an overview of syntaxa in which the *A. fruticosa* occurrence was confirmed in different Central and Southern European countries (Table S1). The list of mentioned syntaxa confirms that *A. fruticosa* does not occur exclusively in wetland habitats but can also establish itself in habitats at the opposite end of the moisture gradient. The rather wide coenotic range of *A. fruticosa* was noted by Shevchyk et al. (2020). Considering the biotope diversity of the areas where motorways and expressways are located in Slovakia, it can be expected that *A. fruticosa* will successfully establish itself in various types of plant communities in the vicinity of the invaded roads.

Amorpha fruticosa is not very widespread in natural communities and had not been recorded in the Central Database of Phytocenological Relevés of Slovakia until 2023 (Hegedüšová 2007; Šibík 2012). Despite that, the occurrence of *A. fruticosa* is known e.g. from wetland habitats in the Podunajská nížina Lowland (Jehlík et al. 2005; Vétek and Rédei 2014; Bača 2019; Malovcová-Staníková 2021; Somogyi 2023), Zvolenská kotlina Basin (Hrivnák et al. 2019), Východoslovenská rovina Plain (Lustyk 2009), from xeric meadow in the Krupinská planina Plain (Králik 2019), from the field road along the railway track in the Zemplínske vrchy Hills (Hrouda 2009a), from built up area of town in the Východoslovenská pahorkatina Uplands (Hrouda 2009b). It means that the species has already been recorded in Slovakia not only in areas with motorways and expressways.

A foot survey found that *A. fruticosa* did not grow in areas near road embankments (meadows, pastures, fields) regularly managed by mowing, mulching, grazing, or ploughing (Table 4). Dissemination of *A. fruticosa* was not recorded on these farmed sites. Mechanical mowing appears to be the most effective measure for spreading control.

Doroftei et al. (2005) experimentally demonstrated the capacity for intensive regeneration after mechanical cutting. Our observations also confirmed that single or irregular mechanical mowing or mulching management leads to the successful regeneration of the aboveground organs of the species. This phenomenon was observed, e.g. during the foot survey in the vicinity of bridge constructions or sections inaccessible to machinery. According to the recommendation of the State Protection of Nature of the Slovak Republic,

Table 4. Management measures used in adjacent habitats of the verification sections of expressway R1.

Verification section	Direction towards	Length (km)	Management measure (%)			
			Mowing/Mulching	Grazing	Ploughing	No management
Hronský Beňadik–Tekovská Breznica	Zvolen	1.7	100	–	–	–
	Bratislava	1.7	100	–	–	–
Nová Baňa bypass	Zvolen	2.3	82	18	–	–
	Bratislava	2.3	30	–	70	–
Žarnovica bypass	Zvolen	2.1	83	–	–	17
	Bratislava	2.1	86	–	–	14
All verification sections together	–	12.2	78.07	3.39	13.2	5.34

it is necessary to apply herbicide in addition to the mechanical removal of individuals (https://invaznedruhy.sopsr.sk/amorpha-fruticosa-l-beztvarec-krovity/; accessed 20 July 2024). Regular mowing and continuous grazing can be considered as the most effective long-term measure for spread control of *A. fruticosa* (Demeter et al. 2021). This also applies in areas where the adjacent habitats along the edges of roads with the presence of *A. fruticosa* are floodplain forests (e.g., verification sections of R1), where the species has optimal conditions for survival (Shevchyk et al. 2021; Grabić et al. 2022). Insufficient management or the absence of management promotes the spread of the species (Sărățeanu et al. 2007; Nagy et al. 2018). Even though *A. fruticosa* plantings are located primarily around motorways and expressways, understanding the distribution of this shrub along roads provides essential information about its potential spread locations. This knowledge is crucial for planning preventive management measures to prevent the species from spreading into the landscape.

Conclusions

It was found that tracking *A. fruticosa* by a moving car is similarly effective as a standard field survey (foot survey). Car survey confirmed the occurrence and long-term survival of *A. fruticosa* plantings on the edges of roads and road embankments on motorways and expressways in Slovakia. The species was recorded on 40.01% of motorway and expressway sections. The highest frequency of the species was recorded in the oldest sections of these corridors, which are located above all in the warmer lowlands. On the other hand, the occurrence of this species was sporadic in cooler areas at higher elevations. It was observed that *A. fruticosa* can spread from the original plantings to the surrounding stands. Its spread into new habitats is prevented by regular management (mowing, mulching, grazing, or ploughing) of the surrounding landscape. The absence of management can support the expansion of the originally planted shrubs and the spread of *A. fruticosa* into the immediate vicinity.

Authors' contribution

Conceptualization: BŠ, HŽ; formal analysis: HŽ, BŠ; investigation: HŽ, BŠ; methodology: HŽ, BŠ, IH; visualization: MG; writing and editing: HŽ, BŠ, MG, KH and IH.

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Supplementary material

The following supplementary material is available for this article:

Table S1. List of syntaxa with *Amorpha fruticosa*.

Table S2. List of records of the occurrence of *Amorpha fruticosa* along the edges of motorways and expressways in Slovakia.

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