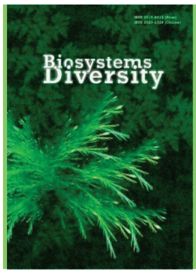

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Geographical distribution and spatio-temporal changes in the occurrence of invasive plant species in Slovak Republic

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Biological systems are subject to a dramatic increase in invading species in the 21st century due to increasing globalization around the world. In the near future, these species will cause more extensive ecological as well as socio-economic damage. Biotic invasions will result not only in a reduction of the original biodiversity, but also total loss, particularly degradation of natural habitats – especially Natura 2000 habitats. This study aims to understand the processes of spread of invasive plant species, their way of life, adaptation to environmental changes and displacement of native species. Without the local level, it is not possible to understand these processes on the regional and continental dimensions and thus implement scientific facts and findings into the prediction of the development of global biosystems. The research was conducted during the vegetation period in the years 2017–2021 in the studied areas of non-forest and forest habitats in the central part of Slovakia. We recorded 242 localities in the area with the occurrence of invasive plant species in an area of 3.057 km^2 out of the total mapped area of 169.024 km^2. We recorded the highest number of localities and the most expansive distribution for the species *Stenactis annua*, *Robinia pseudoacacia*, *Solidago canadensis*, *Impatiens glandulifera* and *Fallopia japonica*.

Keywords: invasive species management; non-native plants; predicting invasive plants; implications for conservation; Slovakia.

Introduction

The issue of invasive plant species is becoming an increasingly discussed topic in our society. The introduction of non-native plant species from other continental biogeographical regions into Europe (Alpine and Pannonian biogeographical region in Slovakia) has a significant impact on the native flora, leading to an overall loss of phytodiversity especially rare and endangered species. Other problems caused by invasive species: health – allergies, non-immunological reactions, economic burden in land management, damage to agricultural, forestry and water management sectors (i. e. damage to agricultural production, changes in the structure of the tree composition, make it difficult to manage watercourses and reservoirs), biological change in the structure of phytocenoses, displacement of indigenous species, geographical changes in natural terrestrial complexes (Lykholat et al., 2018; Burda & Koniakin, 2019; Dubovik et al., 2019). These problems of invasive plants species are of concern to the European Union (Alston & Richardson, 2006; Blackburn et al., 2014; Bacher et al., 2018).

European legislation has adopted international conventions that address the issue of invasive species at the international level. There is the effective regulation of the European Parliament and of the Council (EU) No. 1143/2014 on the prevention and management of the introduction and spread of invasive non-native species. Pursuant to Article 4 of Commission Regulation (EU) (Sopsr, 2014) a list of invasive non-native species of Union concern has been compiled pursuant to Regulation (EU) No. 182/2011 of the European Parliament and of the Council 1143/2014. Another European Union document is Council Directive 92/43/EES (Sopsr, 2016) on the conservation of natural habitats and of wild fauna and flora, which aims to contribute to ensuring biological diversity in the European Union through the conservation of natural habitats and species of wild fauna and flora. This also means preventing the spread of any species that may endanger native organisms. These EU documents indicate the need for regular monitoring, summarization of sites and data on the occurrence of allochthonous invasive species. The discovery of non-native species, whether animals, plants, fungi or microorganisms, in new places is not always a cause for concern. However, a significant subset of non-native species can become invasive and can have serious adverse effects on biodiversity and related ecosystem services, as well as other social and economic impacts that should be avoided. Approximately 12,000 species in the EU environment and in other European countries are non-native, of which an estimated 10–15% are invasive (Eur-lex Europa, 2021). The national legislation of the Slovak Republic on invasive species is governed by the Regulation of the Government of the Slovak Republic No. 449/2019 Coll. (Nariadenie Vlády, 2021), which issues a list of invasive species of concern to the Slovak Republic. Methods of removal of individual invasive species are regulated by the Decree of the Ministry of the Environment of the Slovak Republic No. 450/2019 Coll., which establishes the conditions and methods of removal of invasive species (Sopsr, 2021).

Research from abroad now also points to a broad overview of the interactions between invasive plants and climate change. Climate change and the invasion of exotic plants are the result of human activity and can cause major environmental and socioeconomic damage in the near future. Climate change can facilitate the invasion of exotic plants by changing the basic environmental conditions. All plants, whether autochthonous or allochthonous, are likely to be affected by changes in the environment, and it is generally expected that climate change will favour invasive allochthonous plants over autochthonous plants. The way in which invasive exotic plants affect the environment (e.g. modification of hydrology and soil properties, change of fire regimes) (Turbelin & Catford, 2021; Puchałka et al., 2021) can to some extent either contribute to or exacerbate the impact on climate change (Sádlo et al., 2017; Wagner et al., 2017; Dyderski et al., 2018). The main factor in the spread of invasive species is the globalization of trade and travel, which has facilitated the spread of non-native species not only in Europe, but also throughout the Earth (Pyšek et al., 2012). As a long-term trading center, Europe has seen a significant impact of invasive species, which have major adverse effects in all of Europe's biogeographical regions. Therefore, it is important to understand the process of invasion, the changes that invasive species cause to ecosystems (habitats), and how the problems of invasive species can be reduced. This research addresses the process and drivers of species invasions in Europe, the socioeconomic factors that make some regions particularly vulnerable, and the ecological factors that make some species particularly invasive

(Keller et al., 2011). Invasive species are one of the worst threats to biodiversity and ecosystems worldwide. According to the Rio Convention on Biological Diversity (1992) (Convention of Biological Diversity, 2021), invasive non-native species ranked second with the highest risk of biodiversity loss. Control of invasive plant species is very demanding and expensive. Various methods are available for control, such as mechanical, chemical and biological. Climate change further exacerbates the spread of invasive non-native species. Therefore, it is important to learn how to control them with modern tools and techniques (Brooks et al., 2004; Braun et al., 2016; Biró et al., 2019; Sahu et al., 2020). Monitoring spatiotemporal changes in the environment as well as ecological environmental factors is one of the basic methods to help understand the spread of invasive plant species, their way of life, adaptation to environmental changes, displacement of native species and overall succession in plant communities (Gonzáles-Moreno et al., 2013).

The aim of the paper is to point out the importance of regular mapping and monitoring of non-native and invasive plant species and their spatiotemporal changes, which are associated with bad, respectively inappropriate management of these species in the country, as well as noncompliance with legal obligations to regulate non-native and invasive species. The study aims to understand the processes of spread of invasive non-native plant species, their way of life, adaptation to environmental changes and displacement of native species. Without the local level, it is not possible to understand these processes on the regional and continental dimensions and thus implement scientific facts and findings into the prediction of the development of global biosystems. The study identified the main causes of the spread of invasive non-native plant species (mainly environmental and economic factors, which are more closely related to inappropriate human management in the country) and pointed to ways of effective management.

Materials and methods

Definition of the studied area. The studied area (Fig. 1) is located in the western part of the Revúcka Highlands (48°26' N 19°35' E). It is located on the upper course of the Kriváнský brook and in the area of its tributaries, the Budínský and Dobročský brooks. The Ružiná Reservoir has been built in the central part and the whole area belongs to the Ipeľ river basin. The studied area is surrounded by the northwestern mountain range Ostrôžky, the northern border Sihlianska Planina (subunit of the Veporské Mts.), the northeastern and Málinské Mts. (subunit of the Stolické Mts.). The valley of the Krivánské brook continues south to the Lučenská basin, where the Novohradské terraces and the Poltár uplands lie (Kočický & Ivanič, 2014). These include the cadastral districts (hereinafter c. d.) of Píla, Divín, Ružiná, Mýtna, Dobroč, Kotmanová, Lovinobaňa and Podrečany. The wider background is formed by c. d. Budiná, Tuhár, Cinobaňa and Točnica. The area is a typical example of biocenoses affected by anthropogenic activity (mining, construction, land management). This research deals with a local study with an area of 169.024 km^2 with an altitude profile from 200 to 750 m above sea level.

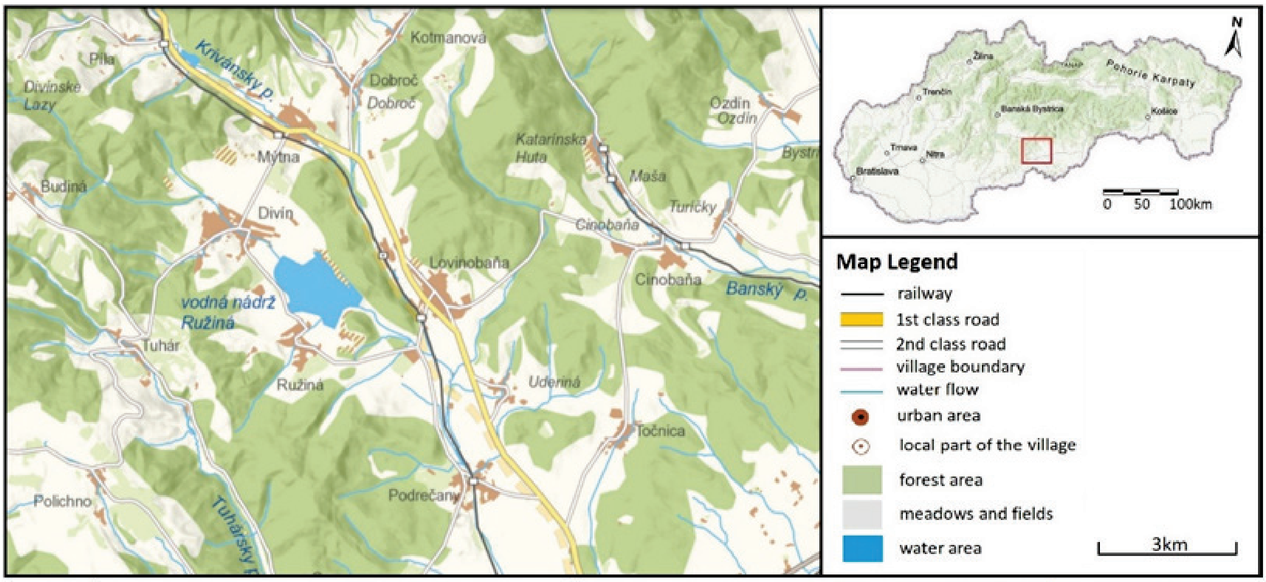

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Fig. 1. Map of the studied area – Western Carpatians of Slovakia (Revúcka Highlands) (Zbgis, 2021)

Complex geographical characteristics of the studied area. The area is built of molasse sediments and tertiary volcanics, covered by Quaternary sediments. Pre-tertiary formations are represented in two tectonic units – Gemericum and Veporicum (Vass & Elečko, 1992). The studied area for the most part belongs to the Lovinobanská furrow, which represents a slightly large basin depression in the northwestern part of the Cinobanské foothills, which was formed by erosion-deduction processes as a significantly excavated form of surface. There are mainly two soil types of sandy-aluminous and aluminous in the area. The soil cover consists of cambisols modal acid, accompanying cultisols and ranks; from weatherings of acidic to neutral rocks; modal podzols, accompanying litozems and ranks; from quartzite weatherings and from tertiary sediments with a significant proportion of quartz skeleton; gley luvisols, accompanying gley from carbonate and non-carbonate alluvial sediments; luvisols pseudogley, accompanying pseudogley luvisols from loess clays, local cambisols from Quaternary and Tertiary skeletal sediments (Vupop, 2021). The affected area belongs to the warm climate area (lower interval of amplitude of average monthly temperatures 21 °C with lower interval of annual total precipitation 600 mm) (Kočický & Ivanič, 2021). According to the Hrašna & Klukanová (2014) map of engineering-geological zoning of the territory of Slovakia, the studied area belongs to the region of core mountains, the crystalline subregion, the area of sandstone-conglomerate rocks. According to the map of the main hydrogeological districts, the area of interest belongs to the hydrogeological district No. 89 – crystalline of Revúcka Mts. and Stolické Mts. in the Ipeľ basin (Malík & Švasta, 2002).

Within the phytogeographical division of Europe, the territory belongs to the Holarctic region, the Eurosiberian subregion, the Atlantic-European province and the Pontic Pannonian. From the phytosociological point of view, the studied area belongs to the oak zone, the mountain subzone, the crystaline-Mesolithic area, the Revúcka Mts. district and the Lovinobanské foothills sub-area (Plesník, 2002). The original potential natural vegetation of the area would be formed by *Alnenion glutinoso-incanae* Oberd. 1953; *Salicion triandrae* Th. Müller et Görs 1958 pp; *Salicion eleagni* Moor 1958), *Carici pilosae-Carpinenion betuli* J. et M. Michalko 1986, *Quercetum petraeae-cerris* Soó 1957 s. l. (Michalko et al., 1986).

Methodology and data analysis. We obtained floristic data during the vegetation period during the years 2017 to 2021, when we performed extensive mapping and monitoring of invasive plant species. Most of the mapped localities cover nature reserves and one area of European importance (PR Príbrežie Ružinej, PR Ružinské jelšiny and ÚEV Uderinky).

We performed the mapping by field biogeographic research at selected localities according to the established methodology and frequency (at the time of the reproductive phase of the plants in every year). We monitored non-forest and forest habitats and plant species from the List of Invasive Species of Concern to the Slovak Republic (Gojdičová et al., 2002).

The number of monitored localities where we recorded the occurrence of invasive plant species was 242. We obtained basic data on the distribution of invasive plants from the Comprehensive Information System of the State Nature Protection of the Slovak Republic and the currently registered occurrence of invasive plant species of the Slovak Republic, which is available on the interactive map of Slovakia (Biomonitoring, 2021).

The mapping and control included systematic and targeted monitoring, which was based on the existence and functioning of permanent research areas located in the open country, but also in selected protected areas. Monitoring at the local as well as regional level is justified. The mapping method included the activities needed to detect the presence of invasive plants. We performed the mapping of invasive species at the end of July and then in August and early September, as most species were in the phenological phase of flowering, which allowed us to better identify specific invasive species in the field. In addition to mapping the occurrence of invasive species, we recorded their horizontal distribution (growth area in m^2), number and density of populations. The density of smaller populations was determined by counting the individuals in a given population, in the case of a larger population we counted the number of individuals per 1 m^2 or determined it by estimation.

Subsequently, we verified the data by reconnaissance in the field. We recorded all the findings with photographs and a GPS records (WGS 84). We present the scientific names of taxa in the sense of the work (Marhold & Hindák, 1998). Map data are presented in the program Zbgis (2021) and Biomonitoring (2021). The size of the area was recorded by GPS with conversion of the average number of individuals per m^2. The ZBGIS program and the Forest Geographic Information System (Lgis, 2021) were used for the analysis of spatial data with a digital relief model for areas over 500 m^2 with the help of reference geodetic points. To determine the size of the population, we used the method of direct counting of all individuals (smaller areas) and the method of estimating the size of the population (abundance) on selected areas. In the results for a detailed overview of the characteristics of the distribution of species, we present the identification of invasive species in the form of lists. We consider a good knowledge of the origin of the species and its natural range in terms of rapid adaptations, but also of the current climate change, to be an important step in the selection of appropriate methods for the management of invasive species. Subsequently, we can take the right measures to prevent the introduction of non-native species of organisms in new areas in order to stop, reduce, respectively to guide the invasion process to such an extent that natural ecosystems and habitats are not disturbed and damaged. Occurrence in Europe and in the world is presented in terms of the work (Ružek & Noga, 2015). Occurrence in Slovakia comes within our own field research, map portal and from the work (Galko et al., 2018). It is important to protect the natural species composition of ecosystems, which includes, among other things, regulating the deliberate spread of non-native species. We used the following scale to represent invasive species: 1 – rare/uncommon (1–4 individuals/m^2), 2 – isolated (5–9 individuals/m^2), 3 – common (10–29 individuals/m^2), 4 – very common (30–49 individuals/m^2) and 5 – abundant (< 50 individuals/m^2). The localities were continuously expanded throughout the period, except for some years when no new site was recorded. The proposal for the removal and management of invasive plant species in the country is based on publications (Cvachová & Gojdičová, 2003; Secretariat of the Convention on Biological Diversity, 2009; Minzp, 2019).

Remote sensing of invasive plant species. Effective and accurate reporting of the presence of invasive plant species requires detailed and accurate maps of their distribution. This data can be obtained by remote sensing of the Earth. Based on these data, we can not only accurately identify specific populations, but we can also predict their further spread.

Complex mapping of invasive plant species represents, even on small local scales, demanding data processing (determination of invasive species, location, area size, threat, causes, current state, protection of original biodiversity and prediction of further spread). Therefore, the Remote Sensing of Invasive Plants Species method is currently being used. As this is a new way of mapping vegetation, its structural and spatio-temporal changes and predictions of further spread, some authors specify the correct mapping by remote sensing. In our work, we used Remote Sensing of Invasive Plants Species, only for some species, which are difficult to map in terms of rapid spread, not to mention the rapid enlargement of areas with the occurrence of these species. In our case, these were species such as *Fallopia japonica*, *Helianthus tuberosus*, *Impatiens glandulifera*, *Robinia pseudoacacia*, *Solidago canadensis* and *Stenactis annua*. The mapping in this case consisted of four phases: 1 – preparatory (identification of possible sites with invasive plant species using by Remote Sensing of Invasive Plants Species), 2 – reconnaissance (field survey of identified sites and retrospective confirmation, validity), 3 – data (recording of obtained data into selected digital systems) and 4 – management (practical care of habitats and size regulation of specific populations).

All data can significantly contribute to accurate and timely management as well as to the eradication itself. Figure 2 shows an example of a comparison of two sites with the occurrence of *Solidago canadensis* in the years 1950, 2010 and during imaging in the years 2017–2019. *Solidago canadensis* is a suitable model species for mapping sites subject to biological invasions, as this species usually has other accompanying invasive species, such as *Solidago canadensis* and *Stenactis annua*. It is also a species that is easy to identify by remote optical scanning from space. Older black and white images are not suitable for the analysis of this data, but can be used to compare already identified sites from older periods, for example in our case from 1950.

Some authors used the spectral diversity of the individual species in a study (Andrew & Ustin, 2008) in the mapping of *Lepidium latifolium* (perennial pepperweed), which is a noxious Eurasian weed invading riparian and wetland areas of the western US. Remote detection of plant species is most likely to be viable if the target plant species has a unique growth form or phenology (He et al., 2015). Study evidence suggests that the success of a remote sensing analysis declines as site complexity increases (species, structural, and landscape diversity; spectral variability; etc.), although this relationship is complex, indirect, and may be phenology-dependent. Novel products derived from multispectral and hyperspectral sensors, as well as future Light Detection and Ranging (LiDAR) and RADAR missions, may play a key role in im-proving model performance. To successfully fight plant invasions, new methods enabling fast and efficient monitoring, such as remote sensing, are needed. In an ongoing project, optical remote sensing (RS) data of different origin (satellite, aerial and UAV), spectral (panchromatic, multispectral and colour), spatial (very high to medium) and temporal resolution, and various technical approaches (object, pixelbased and combined) (Müllerová et al., 2013). Several authors have done similar research (Jarnevich et al., 2011; Liu et al., 2020; Singh et al., 2020; Anderson et al., 2021). The method of comparison involved comparing the results obtained from the mapping with already existing results published in publications by other authors. The aim was to identify the basic characteristics and possible forms of invasive behaviour to better understand their behaviour.

Results

During 5 years of regular mapping and monitoring of invasive plant species, we recorded 11 target taxa of concern from 8 families. The largest part of the species belongs to the invasive taxa – neophytes. Only one species belongs to the potential (regional) invasive taxa – *Datura stramonium*. Each of species was included in the association (Table 1). In terms of habitat communities with invasive species dominated on rivers and their banks. During the vegetation period 2017–2021, we recorded a total of 242 localities with the occurrence of invasive plant species. We can state that the number of localities recorded a rapid increase in species wqith 8 species being recorded in by 2019 and 11 species in 2021 (Table 2). To a significant extent, there are also area changes that are visible in all parts of the studied area. Most localities with the occurrence of invasive species are represented by *Stenactis annua* (21%). Other species with the largest representation of localities include *Robinia pseudoacacia* (19%). In a large part of the territory, *Solidago canadensis* (17%) has the ability to significantly occupy new habitats. *Impatiens glandulifera* (13%) and *Fallopia japonica* (13%) show middle representation The smallest representation is by *Ailanthus altissima* (2%), *Asclepias syriaca* (2%) and *Negundo aceroides* (1%) (Chart 1, 2).

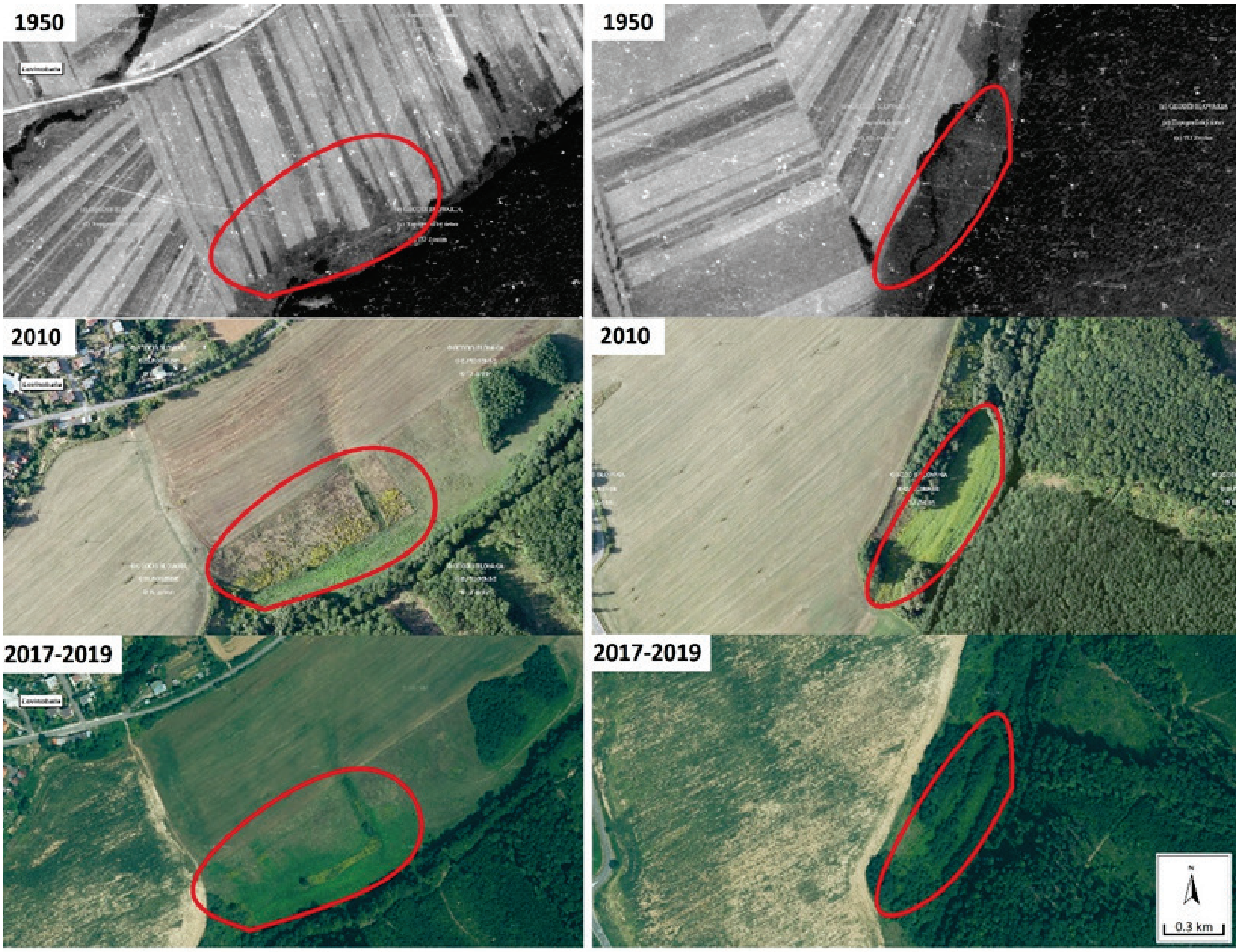

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Fig. 2. Remote optical sensing of *Solidago canadensis* from Space (Eurosense, 2017)

Table 1
Mapped neophyte species, their categories and syntaxonomy (Gojdičová et al., 2002; Pladias, 2021)

Taxon	Agriophyte of Central Europe	Potentially (regionally) invasive taxon	association
Ailanthus altissima	+	–	*Chelidonio majoris-Robinietum pseudoacaciae* Jurko 1963
Asclepias syriaca	–	–	*Asclepiadetum syriacae* Láníková in Chytrý 2009
Datura stramonium	+	+	*Mercurialietum annuae* Kruseman et Vlieger ex Westhoff et al. 1946
Fallopia japonica	+	–	*Reynoutrietum japonicae* Görs et Müller in Görs 1975
Helianthus tuberosus	+	–	*Oenothero biennis-Helianthetum tuberosi* de Bolòs et al. 1988
Impatiens glandulifera	+	–	*Calystegio sepium-Impatientetum glanduliferae* Hilbig 1972
Impatiens parviflora	+	–	*Stellario nemorum-Alnetum glutinosae* Lohmeyer 1957
Negundo aceroides	+	–	*Sambuco nigrae-Aceretum negundo* Exner in Exner et Willner 2004
Robinia pseudoacacia	+	–	*Chelidonio majoris Robinietum pseudoacaciae* Jurko 1963
Solidago canadensis	+	–	*Rudbeckio laciniatae-Solidaginetum canadensis* Tüxen et Raabe ex Anioł Kwiatkowska 1974
Stenactis annua	–	–	*Asteretum lanceolati* Holzner et al. 1978

The population biological and spatio-temporal characteristics of the individual non-native plant species were diametrically different. This fact was influenced by several factors (mainly environmental and economic factors).With *Ailanthus altissima* the increase in area was up to 15,900% by 2021. We recorded the highest percentage increase in the years 2018–2019 by 700%. *Asclepias syriaca* was recorded in the studied area for the first time in 2020 and the area in which it occurs increased by 60% year-on-year. For the species *Datura stramonium*, we recorded an increase of 2,150% in 2021 compared to the values from 2017. We recorded the highest year-on-year percentage increase in the years 2017–2018, by 300%. *Fallopia japonica* represents one species that spreads exponentially around watercourses. In this case, we recorded an increase of 507% compared to the values measured in 2017. The highest year-on-year percentage increase was recorded in the years 2017–2018, namely by 167% while the lowest was recorded in the years 2020–2021 (22.4%). *Helianthus tuberosus* was registered for the first time in 2018. The increase in area in 2021 was up to 119%. For *Impatiens glandulifera* we recorded an increase until 2021 up to 833%. Year-on-year growth was highest in years 2018–2019 for 119%. *Negundo aceroides* did not increase its area or the number of individuals in the area. The area with the occurrence of *Robinia pseudoacacia* increased by 487% from 2017 to 2021. The highest year-on-year increase was recorded in 2018–2019 by 84.6%. *Solidago canadensis* and *Stenactis annua* represent species that occupy new sites very intensively, also because of their ability to spread seeds quickly in their surroundings. For *S. canadensis*, it represented an increase from 2021 to 93.3% and *S. annua* 44.8%.

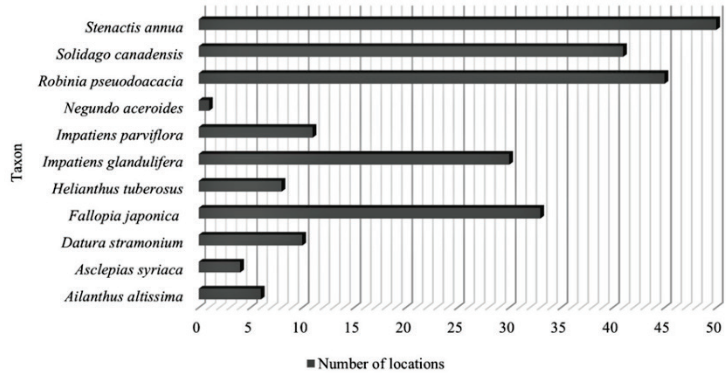

Chart 1. Number of localities of mapped neophyte species (17.07.2021)

Table 2
Spatial-temporal changes of mapped species, increase in area in m^2 (local level) in period 2017–2021

Taxon	2017	2018	2019	2020	2021
Ailanthus altissima	5	10	80	320	800
Asclepias syriaca	–	–	–	25	40
Datura stramonium	2	8	25	30	45
Fallopia japonica	13 500	36 000	51 500	67 000	82 000
Helianthus tuberosus	–	800	1 100	1 400	1 750
Impatiens glandulifera	4 500	8 000	17 500	26 000	42 000
I. parviflora	230	350	510	690	900
Negundo aceroides	1	1	1	1	1
Robinia pseudoacacia	460 000	650 000	1 200 000	1 800 000	2 700 000
Solidago canadensis	75 000	92 000	118 000	134 000	145 000
Stenactis annua	5 000	13 000	20 000	58 000	84 000

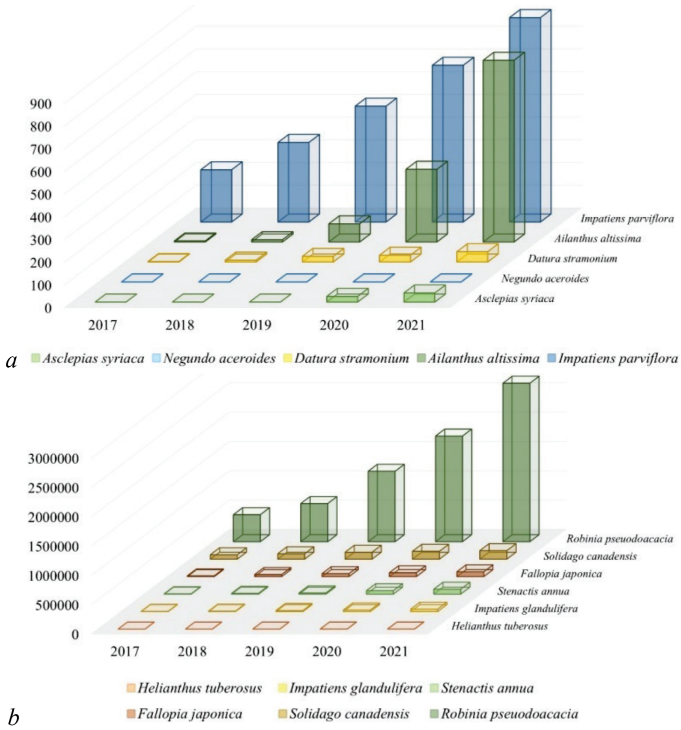

Chart 2. Extension of the territory by the occurrence of invasive plant species in the years 2017–2021: *a* – species represented in the area 1–900 m^2, *b* – species represented in the area of 1,000–3,000,000 m^2

Appropriate uses and regular management are important prerequisites for preventing the spread of non-native plant species. To reduce areas with the occurrence of invasive plant species, respectively to reduce the number of individuals in the population as well as the habitats themselves, it is best to use mechanical methods of removal (plucking, mowing, sawing, intensive and extensive grazing). One of the possibilities is a chemical method of removing invasive plant species, but we recommend this in the studied area only to a very small extent, as most of the habitats are located either directly or in close proximity to protected areas and hydrologically important watercourses. In all cases, it is important to mitigate the impact on the original vegetation of the area.

Ailanthus altissima (Mill.) Swingle (fam. Simaroubaceae). General distribution: it was introduced to Europe, Africa, the USA, South America, Australia and the rest of Asia. Distribution in Slovakia: the southwestern part of the Malé Carpathians (Mts.), the Danube Plain (around Bratislava and Nové Zámky), the Danube Uplands and part of which occurs in Zemplín (Fig. 3). New distribution data (local level): surroundings of ÚEV Uderinky (c. d. Lovinobaňa), peripherally intervenes in the undergrowth of ÚEV. Dissemination to the central part without regulatory management is expected in the near future. Habitat characteristics: 95% of the invasions occupies the forests. 5% of the species occupying habitats with bush vegetation in the forests. The occurrence is characterized by a high intensity of expansion, which is also related to the geographical location in the warm region of Slovakia. Its ability to grow is also characterized by the soil type on which it grows – cambisols, podzols and luvisols. Occurrence is also characteristic on waterlogged soils. Average representation: common. Proposal for management in the country: mechanical method of removal, sawing, plucking roots from the soil, chemical injection.

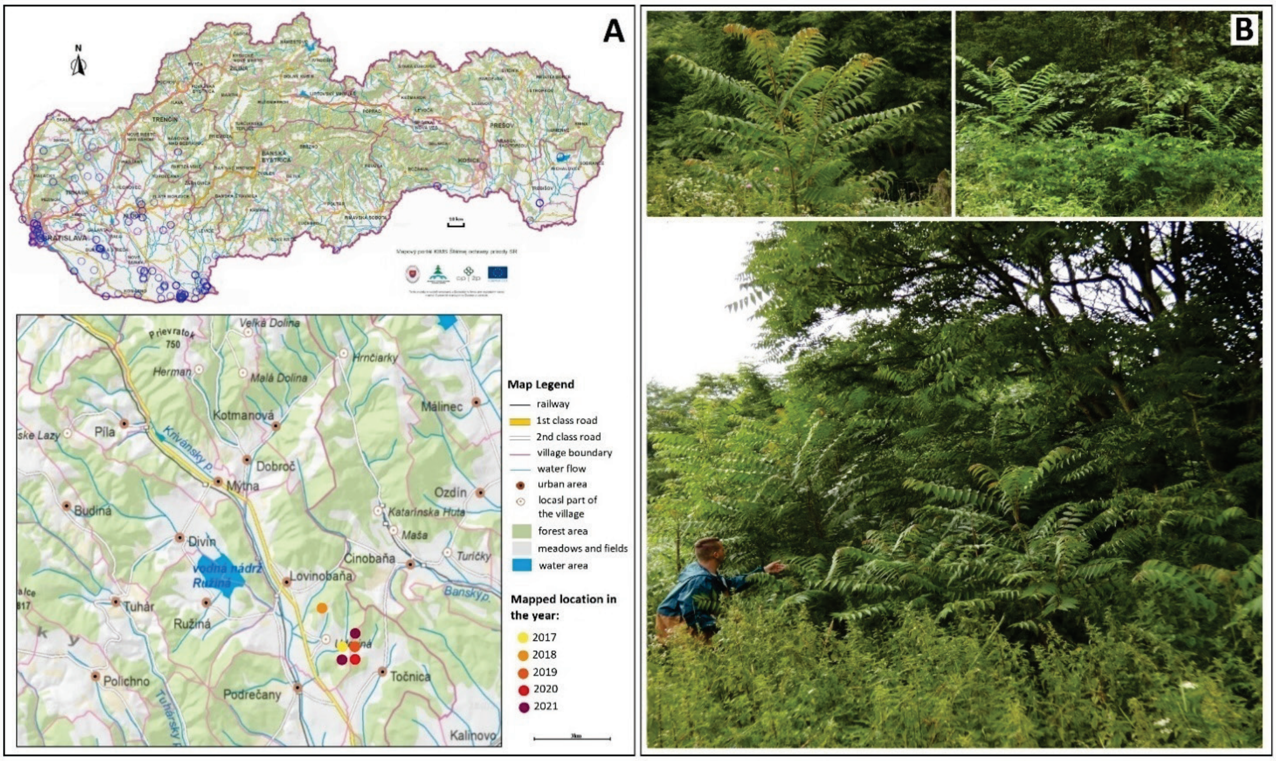

Fig. 3. Distribution map of *Ailanthus altissima* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

Asclepias syriaca L. (fam. Asclepiadaceae). General distribution: in Europe, it is naturalized mainly on dry grasslands in several parts of Central and Southern Europe. Occurrence is also recorded on the eastern edge of the Asian continent. Distribution in Slovakia: Podunajská rovina (around Komárno), Podunajská pahorkatina, Juhoslovenská kotlina, Cerová vrchovina and Východoslovenská rovina (Fig. 4). New distribution data (local level): local part Medzi potôčkami (c.d. Lovinobaňa) and the surroundings of the road from the direction Lovinobaňa – Cinobaňa (980 m from the village Lovinobaňa). It is the northernmost mapped locality within the competence of the territorial scope of the Cerová vrchovina Protected Landscape Area Administration. Habitat characteristics: the occurrence is linked to the warm and dry meadow habitat of permanent grasslands with the management of extensive mowing. It also expands extensively into parts of the bush layer with the occurrence of *Prunus spinosa* and the tree floor with the occurrence of *Robinia pseudoacacia* in the vicinity of the recorded localities with a predominance of clayey and aluminous-sandy soils. Average representation: common. Proposal for management in the country: fruit picking and subsequent mechanical plucking of the whole plant, biomass disposal, extensive grazing and mowing.

Datura stramonium L. (fam. Solanaceae). General distribution: it occurs in North, Central and South America, Europe, Asia and Africa. Distribution in Slovakia: Danubian Plain (around Bratislava, Nitra and Komárno), Danubian Uplands, Borská nížina, Myjavská Uplands, Javorníky, Juhoslovenská kotlina and Východoslovenská rovina (Fig. 5). New distribution data (local level): c. d. Lovinobaňa, local part Uderiná, Horné and Dolné Fafáky, Hrbáky. Habitat characteristics: 100% occurrence is mainly related to ruderal communities with intensive feeding of wild animals, from where it spreads to other parts of the mapped area. These are mainly bright and warm places with acid-base properties. Average representation: isolated. Proposal for management in the country: fruit picking and subsequent mechanical plucking of the whole plant, biomass disposal, extensive grazing and mowing.

Fallopia japonica (Houtt.) Ronse Decr. (fam. Polygonaceae). General distribution: it is invasive in most European countries, Canada and the USA, as well as in Australia and New Zealand. Distribution in Slovakia: almost the whole territory of Slovakia (Biele Carpathians, Strážovské vrchy, Podunajská pahorkatina, Horehronské podolie, Javorie, Revúcka vrchovina, Spišsko-šarišské mezihorie and Východoslovenská pahorkatina) (Fig. 6). New distribution data (local level): Krivánsky potok (c. d. Mýtna, Lovinobaňa, Podrečany), Budinský potok (c. d. Divín), c. d. Ružiná, Tuhár, Píla, Ružiná Reservoir. Habitat characteristics: 80% of the invasion occupies the surroundings of watercourses with a transition to the accompanying vegetation (hydrophilic communities of bushes). 20% of the invasion occupies habitats outside water bodies and watercourses – which causes significant environmental damage with significant suppression of the development of native plant communities. The species causes shading of habitats, which leads to complete succession. It occupies areas with predominant disturbance of the soil cover, especially near synanthropic habitats (human settlements, roads and railways). In the studied area, it acquires an alarming state of expansive anthropophytization. Average representation: abundant. Proposal for management in the country: mechanical uprooting of the whole plant, biomass disposal, extensive grazing and mowing, mulching, chemical spraying.

Helianthus tuberosus L. (fam. Asteraceae). General distribution: secondarily widespread in many areas of North and South America, Europe, Asia and New Zealand. Distribution in Slovakia: Dolnomoravský úval, Borská nížina, Javorníky, Žilinská kotlina, Podunajská pahorkatina, Revúcka vrchovina, Beskydské predhorie a Východoslovenská rovina (Fig. 7). New distribution data (local level): c. d. Lovinobaňa, Podrečany. Habitat characteristics: Occurrence is mainly related to agricultural areas with intensive management. In some parts it occupies the edges of forests in a higher degree of humidity. In the near future, the species will cause economic damage, as it occupies areas of arable land, where it spreads rapidly through regular plowing and plowing of tubers. Average representation: very common. Proposal for management in the country: mechanical uprooting of the whole plant, biomass disposal, extensive grazing and mowing, mulching, chemical spraying.

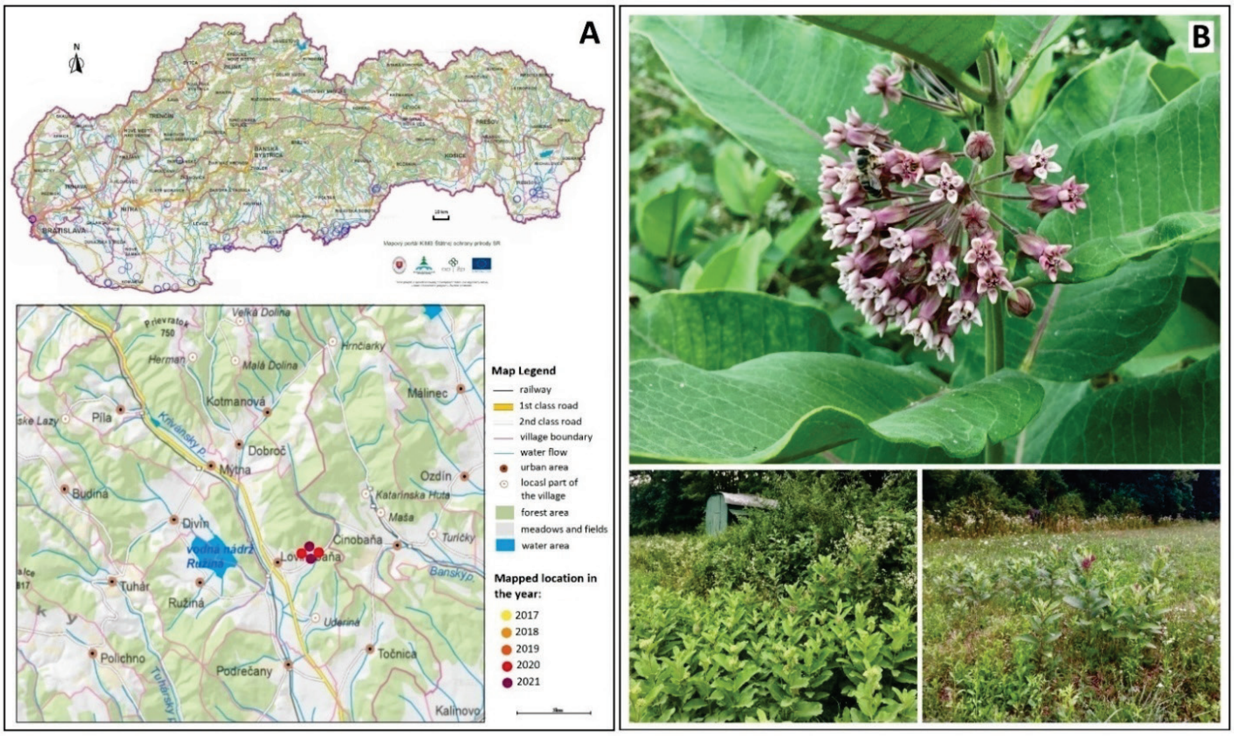

Fig. 4. Distribution map of *Asclepias syriaca* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

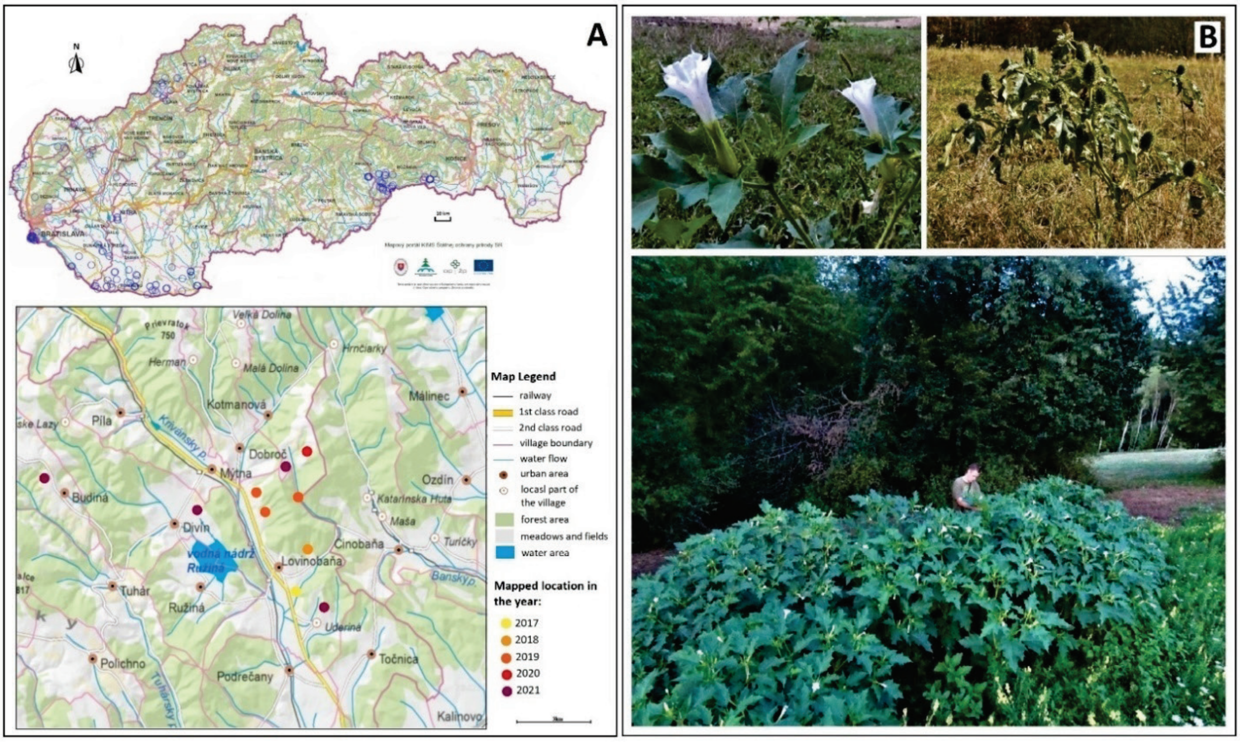

Fig. 5. Distribution map of *Datura stramonium* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

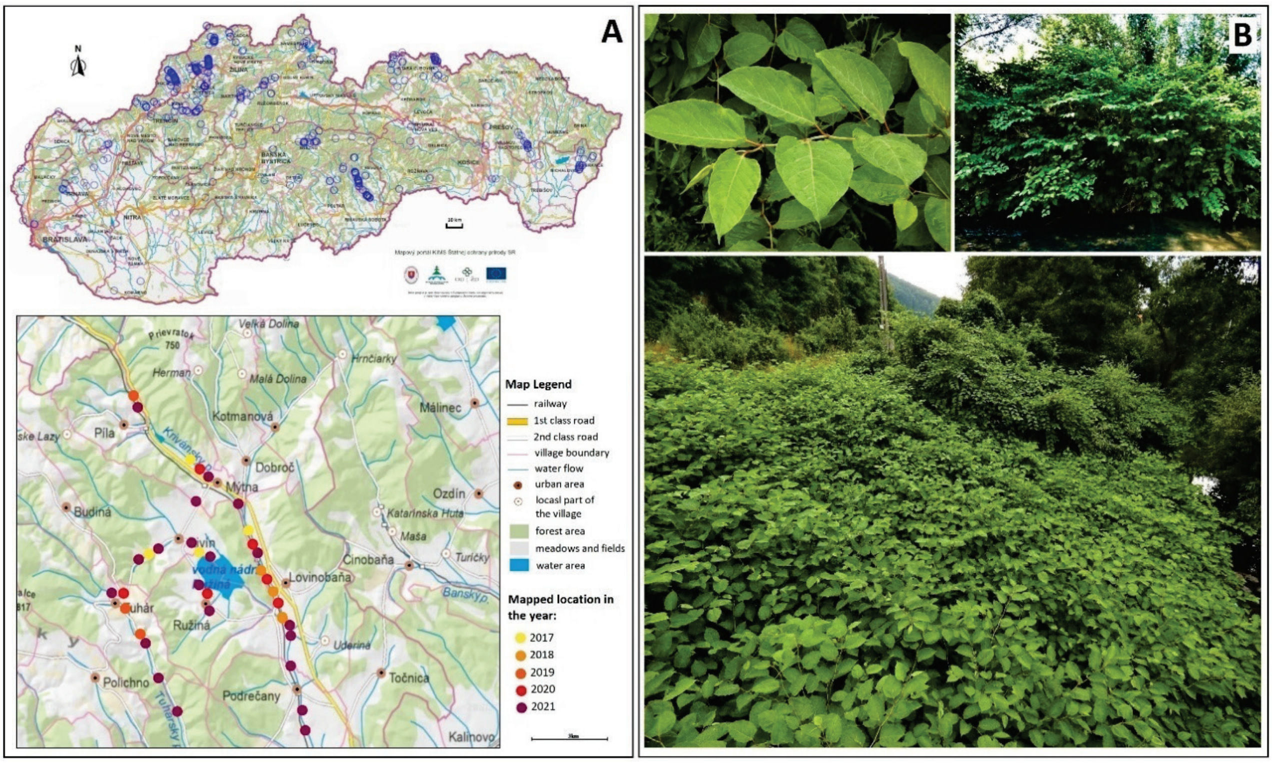

Fig. 6. Distribution map of *Fallopia japonica* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

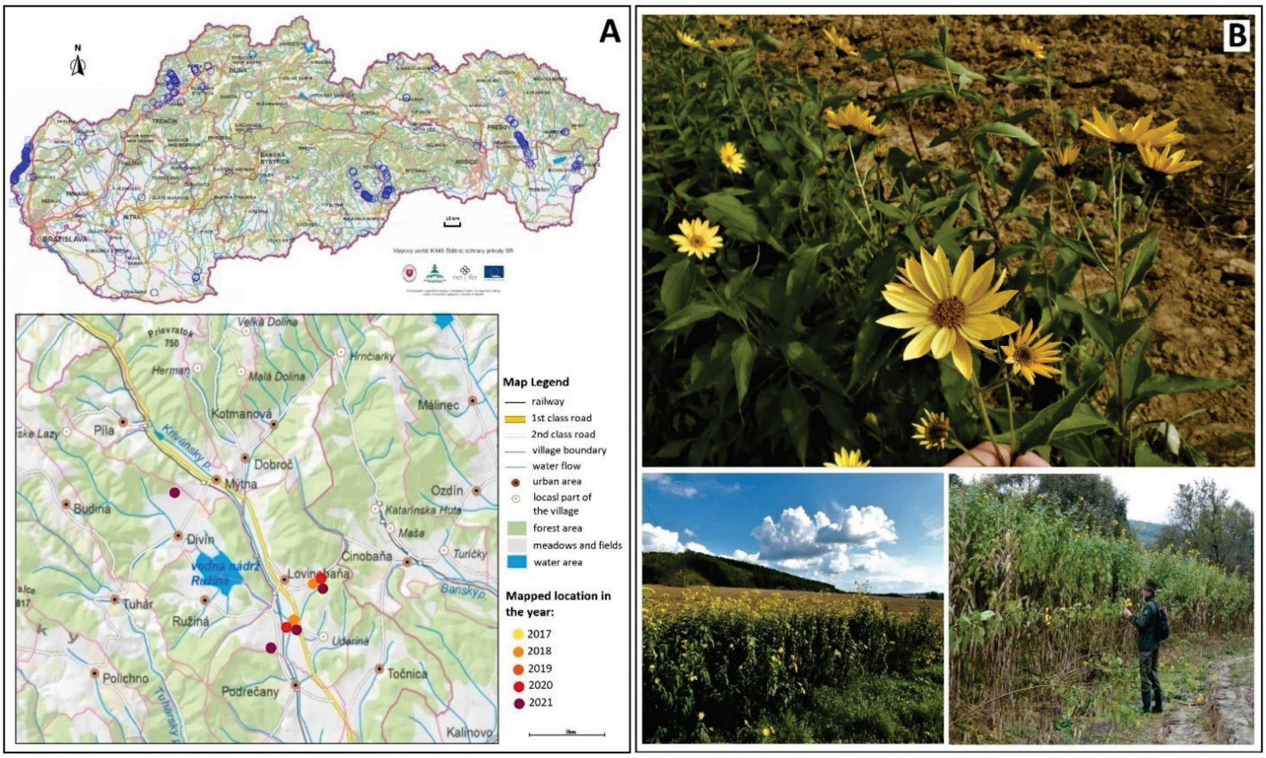

Fig. 7. Distribution map of *Helianthus tuberosus* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

Impatiens glandulifera Royle (fam. Balsaminaceae). General distribution: it is currently invasive in large areas of Europe, as well as in the western and southeastern regions of the United States. In Europe, it is mainly linked to coastal vegetation. Distribution in Slovakia: southern and southeastern part of Slovakia, central part of Podunajská pahorkatina a Podunajská rovina, Západné and Východné Tatry, Podtatranská kotlina, Oravské Beskydy and Biele Karpaty (Mts.) (Fig. 8). New distribution data (local level): around watercourses Krivánsky potok, Budínsky potok, Ružiná Reservoir, Mýtna Reservoir, Salajka brook. Habitat characteristics: occurs mainly in humid places on the banks of watercourses, resp. water reservoirs. In some parts it enters the communities of floodplain forests, where it quickly spreads, which suppresses native species of the herbaceous layer. In some parts it grows up to 3 m. Present in ruderal habitats with dry skeletal soil where this species can grow. Continuous and permanent vegetation is visible in the area of road and rail communications. This species has an alarming prognosis with expansive spread in the area, especially in small protected areas, where it threatens rare species of flora and fauna. Average representation: abundant. Proposal for management in the country: mechanical uprooting of the whole plant, biomass disposal, extensive grazing and mowing, mulching, chemical spraying.

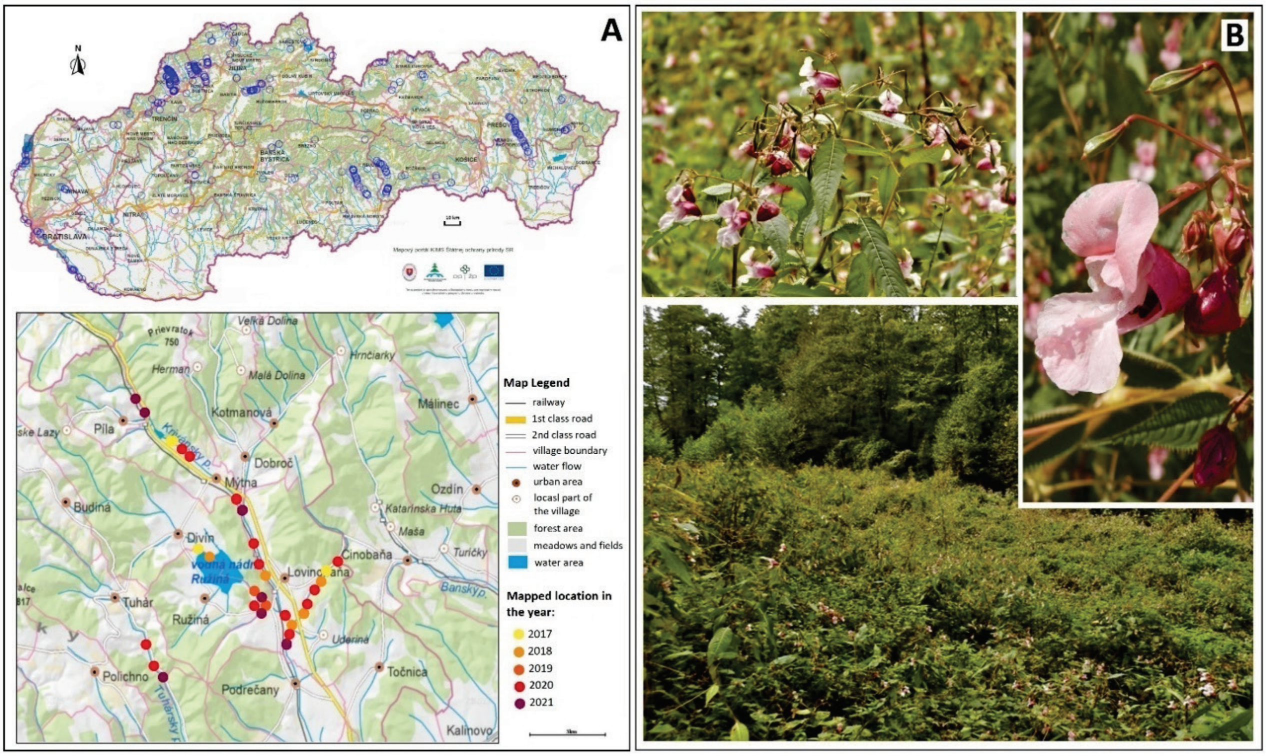

Fig. 8. Distribution map of *Impatiens glandulifera* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

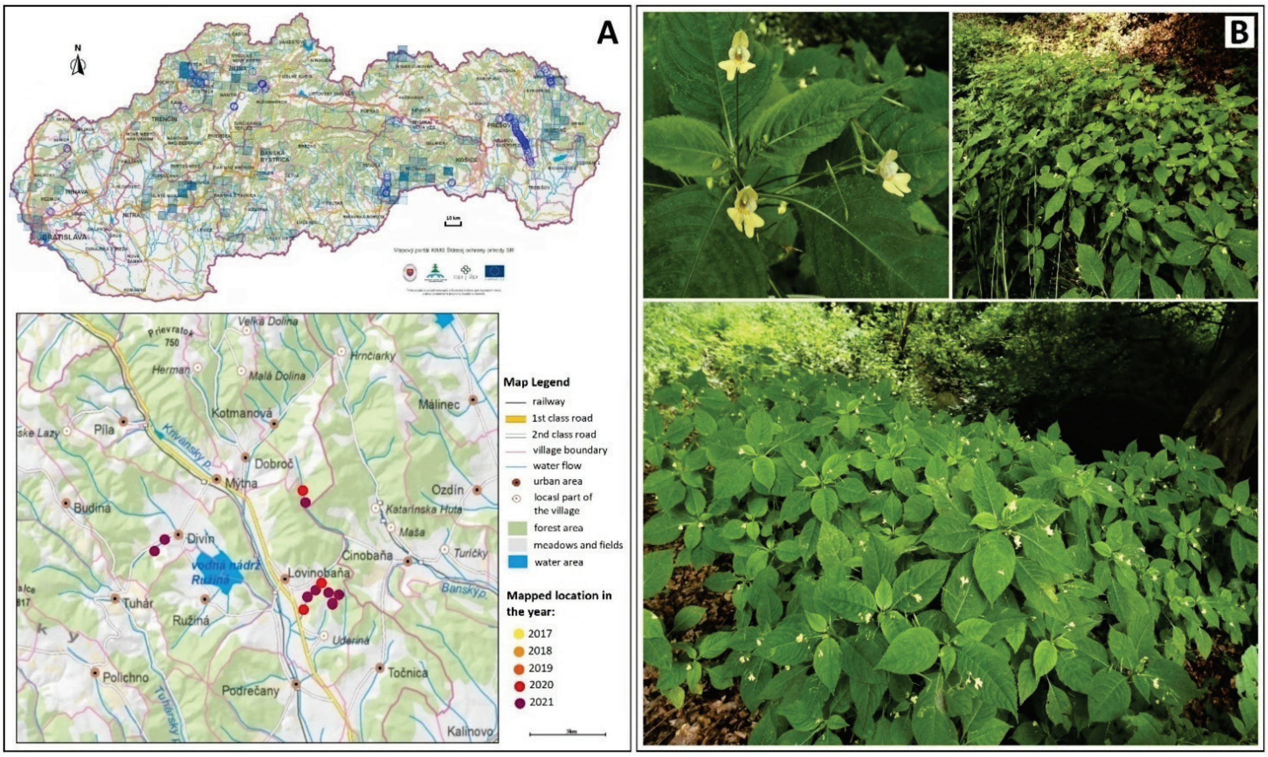

Fig. 9. Distribution map of *Impatiens glandulifera* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

Impatiens glandulifera Royle (fam. Balsaminaceae). General distribution: it is currently invasive in large areas of Europe, as well as in the western and southeastern regions of the United States. In Europe, it is mainly linked to coastal vegetation. Distribution in Slovakia: southern and southeastern part of Slovakia, central part of Podunajská pahorkatina a Podunajská rovina, Západné and Východné Tatry, Podtatranská kotlina, Oravské Beskydy and Biele Karpaty (Mts.) (Fig. 9). New distribution data (local level): around watercourses Kriványsky potok, Budínsky potok, Ružiná Reservoir, Mýtna Reservoir, Salajka brook. Habitat characteristics: occurs mainly in humid places on the banks of watercourses, resp. water reservoirs. In some parts it enters the communities of floodplain forests, where it quickly spreads, which suppresses native species of the herbaceous layer. In some parts it grows up to 3 m. It is interesting to note its presence in ruderal habitats with dry skeletal soil where this species can grow. Continuous and permanent vegetation is visible in the area of road and rail communications. This species has an alarming prognosis with expansive spread in the area, especially in small protected areas, where it threatens rare species of flora and fauna. Average representation: abundant. Proposal for management in the country: mechanical uprooting of the whole plant, biomass disposal, extensive grazing and mowing, mulching, chemical spraying.

Negundo aceroides Moench (fam. Aceraceae). General distribution: it is introduced in most European countries (Scandinavia, the Baltic countries, Russia, Central and Western Europe). Distribution in Slovakia: Borská nížina, Podunajská rovina, Burda a Východoslovenská rovina (Fig. 10). New distribution data (local level): mapped one locality c. d. Lovinobaňa. Habitat characteristics: occurrence is recorded in one habitat with dry and oligotrophic soil. This species resists the shading of the accompanying bushes *Prunus spinosa*, *Rosa* sp. In the studied locality, it does not currently pose a risk, there is no assumption of aggressive behavior. Average representation: rare. Proposal for management in the country: mechanical method of removal, sawing, plucking roots from the soil, chemical injection.

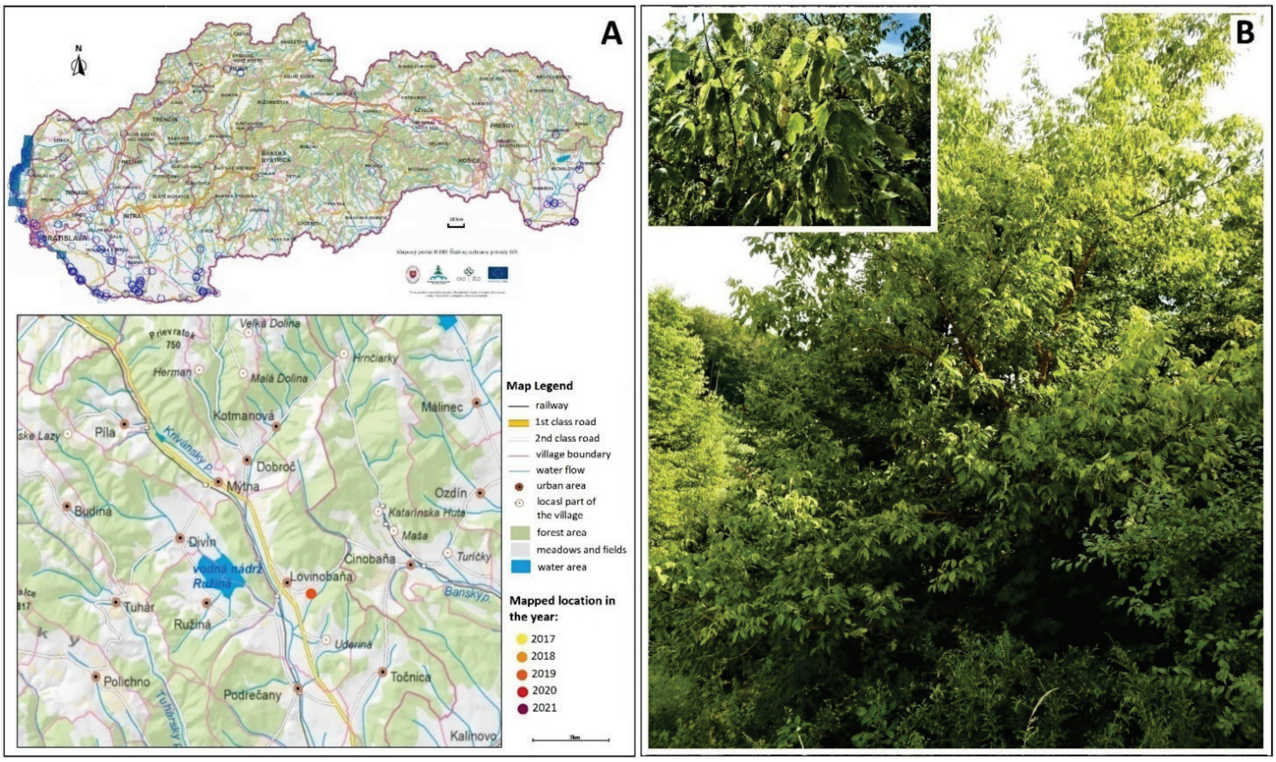

Fig. 10. Distribution map of *Negundo aceroides* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

Robinia pseuodoacacia L. (fam. Fabaceae). General distribution: the expansion area covers most of Europe, Asia, Africa, Australia and New Zealand. Distribution in Slovakia: almost the whole territory of Slovakia (Borská nížina, Podunajská rovina, Podunajská pahorkatina, Tribeč, Javorníky, Juhoslovenská kotlina, Cerová vrchovina, Revúcka vrchovina, Starohorské vrchy and Východoslovenská rovina) (Fig. 11). New distribution data (local level): almost all forest habitats and forest management units of the studied area. At present, its occurrence also affects areas of non-forest habitats (c. d. Tuhár, Divín, Mýtna, Píla, Lovinobaňa, Dobroč, Kotmanová, Lovinobaňa, Podrečany). Habitat characteristics: 85% of the population is located in forests, 15% occupy non-forest habitats, where it creates continuous swathes, especially in linear formations around transport communications. This species is characterized by expansive spread mainly in forestry areas, where there is a complete reduction in the area of vegetation cover. Good conditions are created by disturbed soil cover after use of heavy mining equipment. The species occupies all soil types – cambisols, luvisols, podzols and fluvisols. *Robinia* sp. creates extensive undergrowths of woody species *Quercus* sp., *Fagus sylvatica*, *Carpinus betulus*. The main negative ecological factor is the enrichment of the soil with nitrogen by symbiotic nitrifying bacteria, which causes changes in the species composition in the herbaceous layer – expansion of nitrophilous vegetation. Undergrowth of *Robinia* sp. is impenetrable to other species. At present, this species is causing extensive economic damage in the area. Its current state is alarming. Average representation: abundant. Proposal for management in the country: mechanical method of removal, sawing, plucking roots from the soil, chemical injection.

Solidago canadensis L. (fam. Asteraceae). General distribution: it is non-native in the western United States and introduced in Europe, Asia, Australia, and New Zealand. Distribution in Slovakia: south Slovakia, Borská nížina, Podunajská rovina and Podunajská pahorkatina, Západné Beskydy, Veľká Fatra, Turčianska, Zvolenská, Hornonitrianska and Juhoslovenská kotlina, Slovenský kras, Košická kotlina, Laborecká vrchovina and Východoslovenská rovina (Fig. 12). New distribution data (local level): almost all non-forest habitats of the studied area. In some parts, it also exceptionally affects forest habitats (c. d. Tuhár, Divín, Mýtna, Píla, Lovinobaňa, Dobroč, Kotmanová, Lovinobaňa, Podrečany). Habitat characteristics: 95% of the population is located in non-forest habitats with disturbed vegetation (rubbles, irregularly mowed unmown pastures). A smaller part (5%) is located in the vicinity of watercourses, roads, railways and in illegal landfills. It creates shady places in the meadows, where other species lose their ability to exist. Associated species also include *Stenactis annua*. The areas with their occurrence degrade alarmingly, as such meadows lose their biological as well as economic significance (potential pastures, silage for livestock). Average representation: abundant. Proposal for management in the country: mechanical uprooting of the whole plant, biomass disposal, extensive grazing and mowing, mulching, chemical spraying.

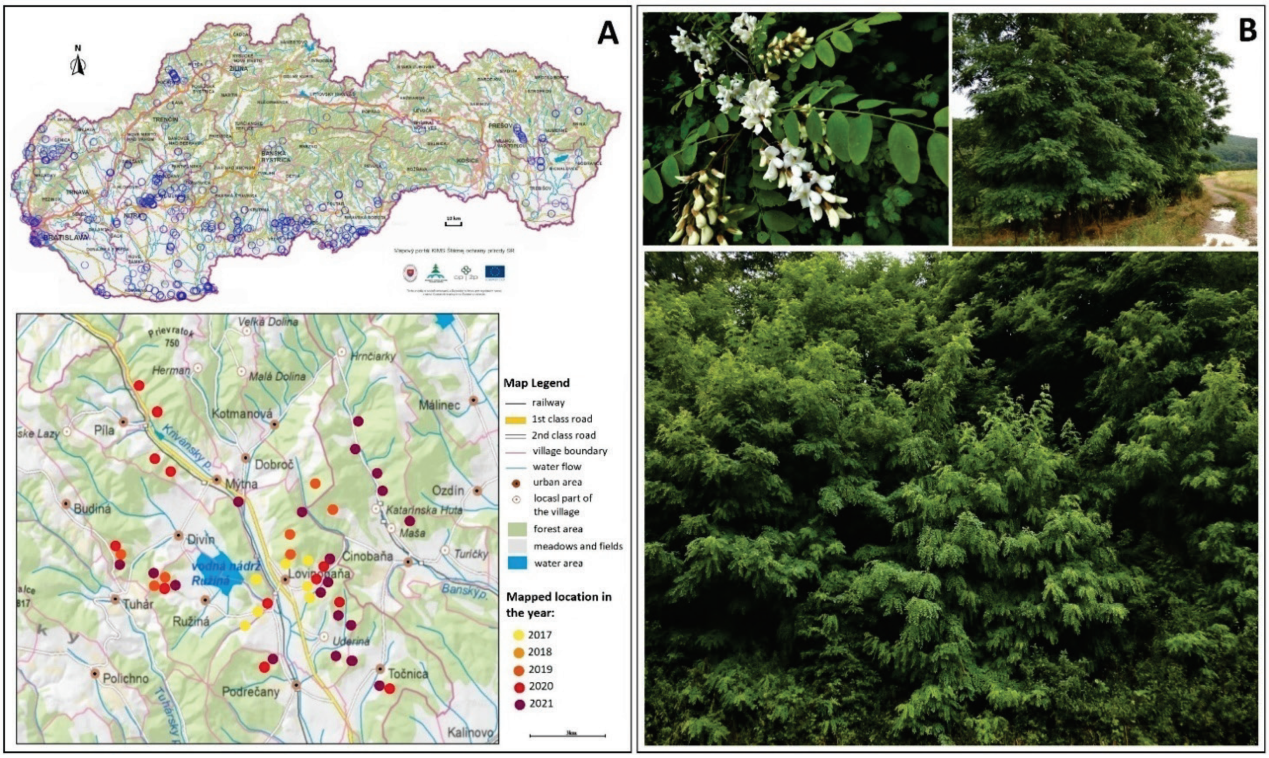

Fig. 11. Distribution map of *Robinia pseudoacacia* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

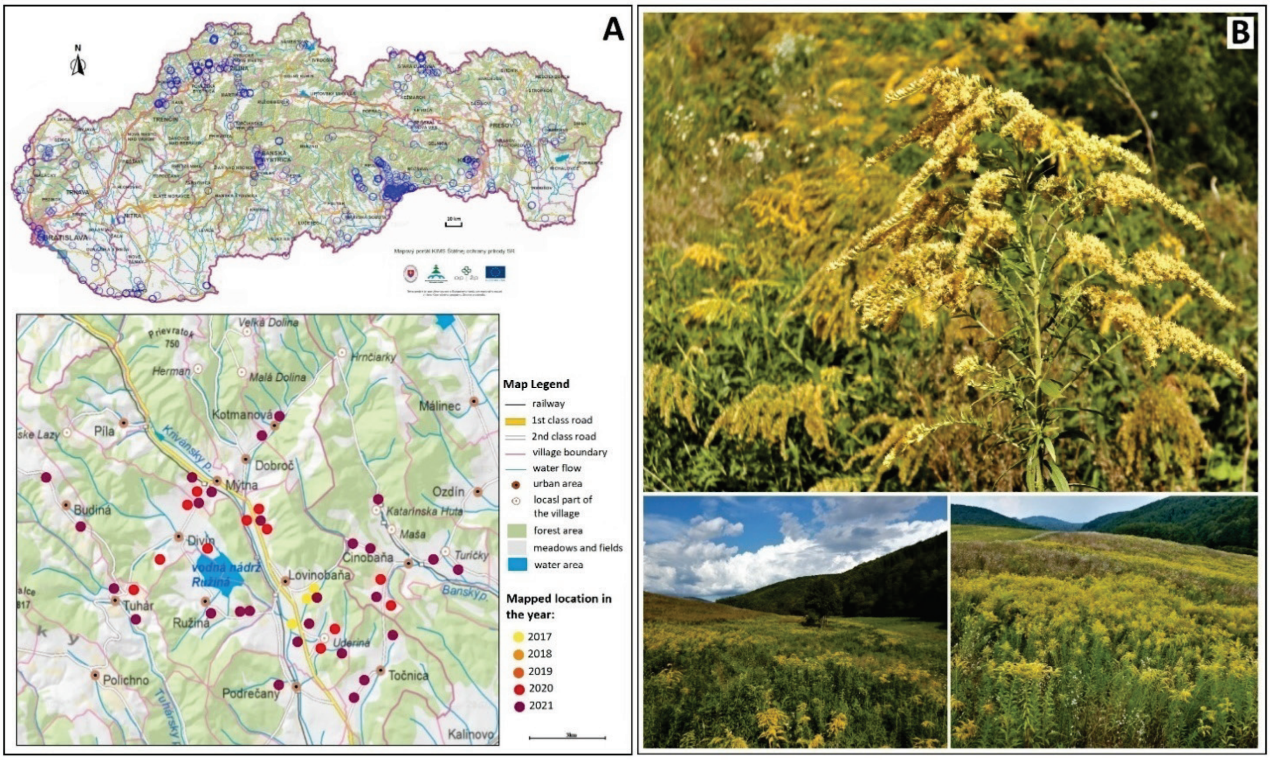

Fig. 12. Distribution map of *Solidago canadensis* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

Stenactis annua (L.) Nees. (fam. Asteraceae). General distribution: secondarily widespread in Europe but also in Asia. Dstribution in Slovakia: almost the whole territory of Slovakia (mainly in Podunajská rovina, Podunajská pahorkatina, Juhoslovenská kotlina, Cerová vrchovina, Revúcka vrchovina and Východoslovenská rovina) (Fig. 13). New distribution data (local level): almost all non-forest habitats of the studied area. In some parts, it also exceptionally affects forest habitats (c. d. Tuhár, Divín, Mýtna, Píla, Lovinobaňa, Dobroč, Kotmanová, Lovinobaňa, Podrečany). Habitat characteristics: most of the population is located in non-forest habitats with disturbed vegetation (rubbles, irregularly mowed unmown pastures). A smaller part is located around watercourses, roads, railways and in illegal landfills. Areas with their occurrence degrade alarmingly, as such meadows lose their biological as well as economic significance. Average representation: abundant. Proposal for management in the country: mechanical uprooting of the whole plant, biomass disposal, extensive grazing and mowing, mulching, chemical spraying.

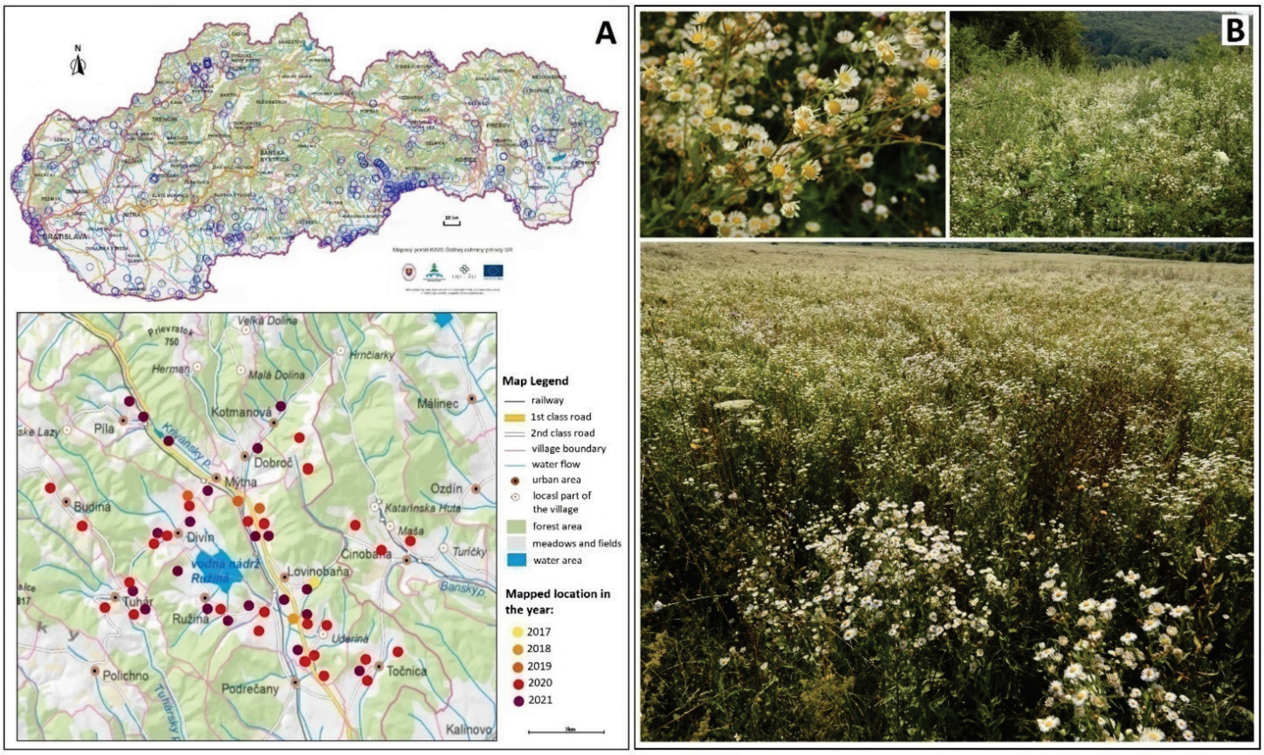

Fig. 13. Distribution map of *Stenactis annua* in Slovakia (*A*) and species during the growing season (*B*): map portal KIMS of the State Nature Protection of Slovakia, 2021; botanical occurrence records

Discussion

The occurrence of invasive plant species is mainly related to the same habitats, which facilitates the prediction of their further possible spread, respectively their assumption of occurrence. In other field mappings (Christen & Matlack, 2009; Franc et al., 2015) report that invasive plant species more easily penetrate and occupy ecosystems (habitats) created, altered or disturbed by human activity, abandoned and disused areas, areas where chemistry has changed (eutrophication) and areas with poor species composition. This statement is also based on the fact that, in comparison with our field findings, non-native plant species are capable of rapid adaptation to the environment, without significant demands on the environment. An important question is: "How will these species react to climate change in the near future in comparison with our indigenous plant species and what impacts will it have on the overall phytodiversity of Slovakia?" Research on non-native species in the US (Sofková & David, 2016; Končeková et al., 2020) confirms the common occurrence of these species along roadsides and assumes that populations will attack larger areas by spreading along the road axis. To distinguish between road functions as movement corridors and habitats, non-native plant species have been studied along roadsides in deciduous forest localities. It appears, therefore, that roads function as habitat and at the same time as a means of expanding population, the rate of the spread depends on the life history of individual species. These results suggest a hierarchical process of regional invasion with different propagation mechanisms operating at different spatial scales. The study area confirmed, similarly to a foreign study, the occurrence of invasive plants in the vicinity of transport routes (roads and railways). The probability of spreading within the corridor depends on the management and maintenance of roads, which corresponds to the fact of easy spreading of seeds with the help of technical facility, which are mainly used for mowing around roads and railways.

Turbelin & Catford (2021) point to the importance of understanding the relationship between invasive plants and climate change. Climate change can facilitate the invasion of plants by changing the basic environmental conditions. Authors like Kleunen et al. (2015) and Flory & Clay (2010) state that one of the defining features of the anthropocene epoch is the erosion of biogeographical barriers by the spread of human-mediated species to new areas where they can naturalize and cause ecological (succession, threat to native phytodiversity), economic (agricultural damage to crops) and social damage (medical). The authors consider the absence of a comprehensive analysis of the global accumulation and exchange of non-native plant species between continents to be a significant problem, mainly due to the lack of data. This deficiency is caused precisely by the predominance of higher theoretical and methodological work largely without direct field findings, which are an important basis for evaluating the current state of the global scales. For an accurate assessment of the direct effects of invasions on the structure and composition of native communities, there is a relationship between the different responses of native and non-native species to environmental conditions and the direct effects of invasions on native communities. This statement was confirmed by Flory & Clay (2010) by establishing experimental localities, where they deployed their 12 original species. They then added seed of non-native invasive grass to half of the area and compared the responses of native plant communities between control and affected areas. During the three growing seasons, the invasion reduced the original biomass by 46% and 58%. After the second year of the experiment, the affected areas had 43% lower species richness and 38% lower diversity. The results of this study confirmed how a non-native invasive plant inhibits the establishment and growth of native species after disturbance and that native species will not gain competitive dominance after several growing seasons.

The threat in the studied area is the occurrence of several invasive species in one association and their uncontrollable spread through transitional associations to the surrounding associations with the displacement of naturally occurring plant species. It reaches deforested areas through the anemochoria *Solidago canadensis*, where its shading prevents the growth of young undergrowth of *Carpinus betulus*, *Fagus sylvaticus* and *Quercus* sp. Changes are also visible in the structure of the soil where the predominant erosion-denudation processes are in the degradation phase. *Fallopia japonica* and *Impatiens glandulifera* spread uncontrollably along watercourses. Most often they form large dense undergrowth under which other species of plants cannot exist. The waterborne spread of plant seeds threatens to spread these species to other parts of the territory in the Lučenec district. The agricultural landscape is most often affected by *Solidago canadensis*, *Stenactis annua* and *Helianthus tuberosus*, which can affect agricultural production. *Datura stramonium* is found mainly on feeding areas for wildlife and hunting facilities.

Disturbance is an important component of many ecosystems, and variations in disturbance regime can affect ecosystem and community structure and functioning. The "intermediate disturbance hypothesis" suggests that species diversity should be highest at moderate levels of disturbance. However, disturbance is also known to increase the invasibility of communities. Disturbance therefore poses an important problem for conservation management (Hobbs & Huenneke, 1992; Tkalich et al., 2021; Yorkina et al., 2021). Our study confirmed that up to 90% of the mapped sites represent significantly disturbed habitats with a high degree of anthropogenic influence.

We believe that the differences in the number of invasive species between localities, respectively regions, is mainly caused by land management, the capture of seeds by agricultural machinery and the associated transfer to other territories. This case of introduction is hypothetically related to the management in the country, e.g. maintenance of road surroundings, watercourses, etc. Within the concept of the hypothesis, we think that biological invasions affect the most intensive area of aquatic and meadow ecosystems, where other environmental factors (anemochoria and hydrochoria) also come to the forefront of active spread.

The studied area largely forms according to Corine (2018) landcover broad-leaved forest, mainly agriculture areas, with significant areas of natural vegetation, meadows and pastures, non-irrigated arable land and water bodies. The landcover is variously differentiated and in this respect the area is highly susceptible to the spread of invasive plants in relation to current anthropogenic influences. This fact is also confirmed by a Mediterranean study (Gonzáles-Moreno et al., 2013), alien tree species in floodplain forests and Slovenian forests (Kutnar & Pisek, 2013; Höfle et al., 2014). Even though temperate forests have lower non-native plant species richness and cover in comparison to some other habitats, such as anthropogenically influenced habitats or some grassland habitats, several recent studies from Central Europe suggest that there has been an increase in the numbers and proportions of non-native species in forests. Previous studies on the level of invasion in forest habitats were usually conducted on a relatively coarse scale (Medvecká et al., 2018; Krigas et al., 2021).

Our field research confirmed 242 localities with the occurrence of these species, representing 3.057 km^2 of the total studied area of 169.024 km^2, which represents 1.8% of the area. We recorded 11 representatives from 8 families in the area, with 100% of species belonging to invasive neophyte taxa. *Datura stramonium* as the only mapped species belongs to the potential (regional) invasive taxa. The number of localities has increased by 520.5% since 2019, which is an alarming precondition for further spread and increase in the degree of anthropophytization of the area, as no regulatory mechanisms are currently in place to suppress the occurrence and overall spread of these species. *Stenactis annua* occupies the greatest number of localities holding invasive species. Other species with the largest representation of localities include *Robinia pseudoacacia*. In a large part of the territory *Solidago canadensis* has the ability to significantly occupy new habitats. *Impatiens glandulifera* and *Fallopia japonica* occupy a medium area of territory. *Ailanthus altissima*, *Asclepias syriaca* and *Negundo aceroides* occupy the smallest areas of territory. The physiognomy of these localities is characterised mostly by monodominant undergrowth of invasive species, while the floristic composition contains only a small amount of other native species. These are mainly diagnostic types of associations that occur in communities with invasive neophytes and agriophytes.

The results of the mapping can be used to prepare reports on the status of habitats and species of European importance to the European Commission, thus meeting international and national legislative requirements. The results should be used to meet the requirements of the Ministry of the Environment of the Slovak Republic (No. 543/2002 Collection of Laws on nature and landscape protection) for the creation and maintenance of a territorial system of ecological stability and the protection of the natural species composition of ecosystems.

Conclusions

Thus the field research carried out by us confirmed 242 localities with the occurrence of the studied invasive species, which represents 3.057 km^2 of the total studied area of 169.024 km^2. We recorded 11 representatives from 8 families in the area. The number of localities with these species has increased by 520.5% since 2019, which gives an alarming prognosis for their further spread and increase in the extent of anthropophytization of the area, since there are no regulatory mechanisms currently in place to suppress the occurrence and overall spread of these species.

The prognosis in the near future assumes that due to the constant human activity, these associations will continue to expand dynamically in the territory. Based on the literature, we have proposed the most optimal management solutions. We propose the overall regulation and elimination of these invasive plant species using chemical and mechanical methods of removal. We recommend removal of invasive plants, for example by spraying, injecting herbicide solutions directly into the plants, intensive mowing, grazing by livestock or digging up (*Fallopia* sp.) the whole plant, which reproduces vegetatively.

The study confirmed the fact that in 90% of cases man is responsible for the spatial distribution of invasive and non-native associations.

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The authors declare no conflict of interest.

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