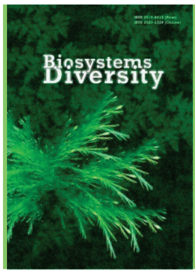

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Distribution and management of *Fallopia japonica* in riparian biotopes in Slovakia and Austria

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Globally, invasive species represent a serious threat to biodiversity and to the ecosystem. As an undesirable part of riparian ecosystems, invasive plants form continuous growths on the banks of watercourses. One of the biggest problems at river bank sites is Japanese knotweed, *Fallopia japonica* (Houtt.) Ronse Decr, which is an extremely invasive and aggressive weed. The topic of the interaction of flow and invasive plant species in shore stands is rich and presents a wide range of possibilities for research. The presented paper brings the results of our studies on the invasions of *F. japonica* in chosen riparian vegetation sites in Austria and Slovakia from 2011–2020 (36 stands). Our research was aimed at the survey on the changes in the distribution (spread) of *F. japonica* at the selected river sites; assessment of the impact of the watercourse regime on the spread of *F. japonica*; monitoring of the population growth dynamics of *F. japonica* and assessment of possibilities for effective eradication of *F. japonica* in context of the riparian vegetation management. We used standard techniques of field survey, mapping, flow modeling/simulation, and laboratory experiments. Our research results showed that water streams are not primary invasion starters until there is a flood. As long as flooding does not exceed the critical speed of the water stream, there is no direct damage to the invasive plant. The water body can be a secondary trigger for plant invasion at normal speeds. In addition, *F. japonica* reproduction ability directly conditions its population dynamic growth. We can report that selective invasion removal adapted to local conditions can be most suitable and beneficial for municipalities.

Keywords: biological invasions; *Fallopia japonica* spread; water flow regime; population growth dynamics; eradication.

Introduction

Invasive plants are non-native species that are characterized by their massive expansion and negative impact on biological diversity. They can form new populations or stands that are spreading rapidly and at long distances from parent plants (Richardson et al., 2000; Thompson, 2014). These plants occupy a large amount of space in invaded habitats and are expected to negatively impact the native vegetation (Blackburn et al., 2014). Furthermore, invasive plants have an unambiguously negative influence on ecosystems. This influence can be expressed directly by affecting the dynamics of nutrients and soil biota (Weidenhammer & Callaway, 2010; Jo et al., 2017; Zhang et al., 2019), as well as by producing allelochemicals to eliminate plant competitors (Kalisz et al., 2021). The indirect effect of plant invasions includes negative impacts on species composition and diversity (Hejda et al., 2009; Powell et al., 2011), ecosystem conditions (Gilioli et al., 2014; Vaza et al., 2017), as well as on the food webs and the physical structure of the biotic environment (Davis, 2009). Invasive plant species pose a risk of undermining the ecological stability and biological balance of the landscape (Ivan et al., 2014). Additionally, the negative effects of plant invasions include social and cultural dimensions and, in many cases, a threat to human health and safety. Ultimately, their negative impact is also economic (Head, 2017).

The main factors affecting plant invasions can be divided into the following four categories (Eschtruth & Battles, 2009): (1) changes in plant cover (disturbance or removal of native vegetation), (2) propagule pressure, (3) species diversity, and (4) herbivory. The first of the above-mentioned factors has been an important topic in the past decade (Lembrechts et al., 2016; Haeuser et al., 2017; Byun et al., 2018). Several factors affect the means, intensity, and success of their propagation. These factors include the suitability of habitat, human influence, and various biotic and abiotic barriers. Many works (Myers & Bazely, 2003; Pyšek & Richardson, 2007; Thuiller et al., 2007; Valéry et al., 2008; Holzmueller, 2013) summarize the most important traits of invasive species. According to them, the most relevant characteristics of invasive plant species include (a) high competitive ability (vitality, resistance to stress, rapid vegetative growth), ability to survive adverse periods (droughts, floods), ability to grow in various types of habitats, good reproductive properties and effective propagation mechanisms, as well as the absence or limited frequency/density of native natural enemies (predators, parasites, diseases).

According to the accessible summary data for Europe (Daisie, 2009), most species classified as non-native (including invasive species) occur in industrial habitats (more than 60%). These habitat types are followed by arable land, gardens, and parks (more than 50%), and by grasslands, forests, and woodlands (about 30%). The human-influenced areas are therefore considered the most susceptible to plant invasions. These kinds of habitats were reported as the most invaded in a previous large-scale study from Slovakia and Austria (Medvecká et al., 2014; Ružek & Noga, 2015). Besides the industrial areas, however, the consequences of plant invasions significantly impact rural territories with managed vegetation as well (villa et al., 2010). Another paper (Vilá & Ibaňez, 2011) reported that the fragments of natural habitats are more invaded if they are surrounded by a human-made landscape. Due to globalization, geographical distances are no more a problem for plant species, and thanks to the global market, new species are easily transported to habitats that are not natural for them. The uncontrolled growth of invasive plants is dangerous and there is a need to find a solution to this issue (Vaseková & Majorošová, 2017). Trade, traffic, and travel associated with globalization increase the random or focused spread risk of invasive plants (Maľová et al., 2014).

Nevertheless, several authors (Hynes, 1983; Stanford & Ward, 1988; Richardson et al., 2007) studied the invasive plants in riparian biotopes that are also considered highly invaded. Many invasive species show a temporary river corridor distribution pattern, primarily in the early periods of their invading history (Burkart, 2001; Tokarska-Guzik, 2005; Andrew & Ustin, 2008). As an undesirable part of riparian ecosystems, invasive plants form continuous growths on the banks of watercourses. Thanks to the water regime, they quickly occupy new locations from the source area to the delta. Stands situated directly on the slope cause soil erosion because of their shallow root system. As a result, there is water concealment in the shoreline. The erosion is also intensified by the drying of these ecosystems in the winter months, causing the soil surface to become exposed and unstable (Aguiar & Ferreira, 2013). The topic of the interaction of flow and invasive plant species inshore stands is rich and presents a wide range of possibilities for research.

The EU spends approximately EUR 10–15 billion annually to control and eradicate invasive plants and to remove damage caused by invasive species. The USA spends, even more, EUR 80–100 billion annually (Vaseková & Majorošová, 2017). Municipalities in Central Europe deal with the problem of invasive species in their natural ecosystems. In addition, invasive plant species that have naturalized in the natural vegetation of Central Europe are often found in riparian vegetation (Zaimes, 2019). Invasive species with larger coverage are mainly *Ambrosia artemisiifolia* L., *Asclepias syriaca* L., *Heracleum mantegazzianum* Sommier et Levier, *H. sosnowskyi* Manden., *Impatiens glandulifera* Royle, *I. parviflora* L., *Solidago canadensis* L., *S. gigantea* Ait., *Fallopia japonica* (Houtt.) Ronse Decr., *F.* × *bohemica* Chrtek et Chrtková, *F. sachalinensis* Nakai, *Ailanthus altissima* (Mill.) Swingle, *Amorpha fruticosa* L., *Lycium barbarum* L. and *Negundo aceroides* Moench (Lecerf et al., 2007; Liendo et al., 2016; Van Oorschot et al., 2017).

However, the biggest problem at river bank sites is Japanese knotweed, *F. japonica*, which is an extremely invasive and aggressive weed, even though it lacks extensive sexual reproduction in most of the countries where it has been introduced. It can sprout from small sections of rhizomes and is often spread via the movements of topsoil or construction traffic (Grzedzicka, 2022). Rhizome fragments as light as 7 g fresh weight can regenerate, provided a node is present. Some clones of *F. japonica* can persist in localities for up to 130 years. Only one piece of *F. japonica* of the female clone was introduced and spread over Europe, earning it the nickname of the "world's largest female". Nevertheless, its flowers (more than 190,000 per stem) can be fertilized by the pollen of *F. sachalinensis*. In that case, the winged achenes are transported by wind and water, dispersing viable embryos of *F.* × *bohemica*, or of the congeneric climber *F. aubertii* (L. Henry) Holub, in which case only a low percentage are fertilized and the establishment of seedlings is inefficient (Shaw, 2013). Dead *F. japonica* stems can persist for 2–3 years, producing large quantities of debris and slowly decomposing litter, which also leads to reduced floristic diversity. Climate change also favors various plant invasions (Beerling, 1991; Bradley et al., 2009, 2010; Parepa et al., 2009; Clements & Di Tomasso, 2011) including the spread of *F. japonica* (Bombino et al., 2019). As is the case with many invasive species, the impact of *F. japonica* on biodiversity is often referred to, but seldom studied. A riverbank that used to support a wide range of native species but now supports a monoclonal stand of *F. japonica* certainly has less biodiversity. Its early emergence and great height combine to shade out other vegetation and prohibit the regeneration of other species (Gonzales et al., 2010; Aguiar, 2018). The invasions of *Fallopia* spp. affect largely negatively the counts, as well as the species richness of birds (Hajzlerová & Reif, 2014).

The presented paper brings the results of our studies on the invasions of *F. japonica* in chosen riparian vegetation sites in Austria and Slovakia from 2011–2020. Our research was aimed at the survey on the changes in the distribution (spread) of *F. japonica* at the selected river sites; assessment of the impact of the watercourse regime on the spread of *F. japonica*; monitoring of the population growth dynamics of *F. japonica* and assessment of possibilities for effective eradication of *F. japonica* in context of the riparian vegetation management. We can hypothesize that a) water body regime (flow hydraulics/increased discharges) is the main driver of propagation and distribution changes of *F. japonica* in riparian ecosystems and therefore, the greatest development of the invasion can be expected in the sections when the river stream is stronger and bends hitting the shore; b) the flooding can have an impact on invasive plants reduction or the other hand, helps them to spread faster, c) *F. japonica* reproduction ability directly conditions of its population dynamic growth, d) selective invasion removal adapted to local conditions can be most suitable and most beneficial for municipalities.

Materials and methods

Study area. Research on *F. japonica* was carried out at reference sections in Austria (the Schwechat River near Traiskirchen) and Slovakia (the Malé Karpaty area, where we selected 6 water streams for our study: Vydrica, Gidra, Blatina, Limbašský Stoličný a Jurský water streams, Fig. 1). Water streams were selected based on their characteristics (mainly topography and natural river banks).

The study site at River Schwechat is located in the Baden district in the southeastern part of lower Austria about 20 km south of Vienna. Our reference site is located near the Traiskirchen village (47°59'53.5" N 16°16'55.3" E). The area is part of the floodplain forest around the river Schwechat and is protected as a natural protected site. Schwechat flows through most of the southeastern part of lower Austria. The highest point is at Schwechat Schöpfl at 893 m above sea level. With a slight bow, it flows from its origin in the north-east ending at Mannswörth (Schwechat) at 162 m above sea level with its water mouth into the Danube. River Schwechat is 62 km long, average flow rate is 7.9 m^3/s (at Schwechat).

Vydrica site at 48°11′21″ N 17°04′55″ E is a stream in Southwestern Slovakia. It has a length of 17 km and an average flow rate of 0.22 m^3/s in the estuary. The area of the Vydrica basin is 32 km^2. It originates in the Little Carpathians near the White Cross (190 m above sea level) and flows into the Danube near the Lanfranconi Bridge as its left-hand tributary. It is one of the few Slovak streams directly flowing into the Danube. 3 European protected areas in the Natura 2000 system have been declared on the Vydrica stream. The forests, especially on the upper reaches of the Vydrica, have a predominantly natural character, which was, however, influenced by forestry (mainly logging).

Gidra watercourse (48°13′14″ N 17°38′12″ E) is a right-hand tributary of the Lower Dudváh. It has a length of 38.5 km. It originates in the Malé Karpaty (Little Carpathians) below Baďurka (547 m above sea level) at an altitude of about 470 m above sea level. It flows mainly in a south-easterly direction. It flows through an area with several holiday cottages, then through the village of Píla and enters the Danube Upland. On the right bank, it bypasses the PR Lindava (the original forest community of the Danube uplands) and on the left bank the PR Alúvium Gidra (marsh communities). The average annual flow rate is 0.68 m^3/s.

Blatina (48°09′15″ N 17°15′44″ E) is a stream in the Danube lowland, flowing through the territory of the districts of Hlohovec and Nitra. It originates in the Nitra Upland, at an altitude of about 200 m above sea level. It flows in a south-easterly direction through a marshy area with the Lukáčovský pond on the right bank, then flows through the village and southeast of the village it flows at an altitude of about 148.5 m above sea level into Andac. The average annual flow rate is 0.14 m^3/s.

Stoličný stream (48°21′05″ N 17°18′37″ E) is a watercourse in Southwestern Slovakia, flowing through the districts of Pezinok, Senec and Galanta. It is a left-hand tributary of the Black Water with a length of 38.9 km and is a stream of the III order. The average forest cover of the basin reaches 20%. It originates in the Little Carpathians, in the Pezinské Carpathians subdivision, on the eastern slope of the Great Homole (709.2 m above sea level) at an altitude of about 470 m above sea level. The average annual flow rate is 0.68 m^3/s.

Limbašský stream (48°17′20″ N 17°13′19″ E) is a watercourse with a length of 9.2 km. The stream flows through the village of Limbách. On the territory of the village there are two tributaries Račí potok and Lúčanku stream. The village of Limbach (152–181 m above sea level) is located in the southern foothills of the Little Carpathians (the western part of the cadastre of the village extends into the Protected Landscape Area of the Little Carpathians). Limbašský stream creates a bio corridor of regional importance. The average annual flow rate is 0.12 m^3/s.

Jurský stream (48°15′07″ N, 17°12′56″ E; 180–594 m above sea level) springs on the eastern side of the wooded slopes of the Little Carpathians above the town of Svätý Jur at an altitude of about 180 m above sea level. The territory through which it flows belongs to the Danube river basin. The catchment area of the stream is about 6.3 km^2. The average annual flow rate is 40–50 L/s. The stream flows through the city in the direction SV-JV and flows into the Šurský Canal.

Field survey and distribution mapping. Prior to the field survey, we conducted a theoretical analysis of *F. japonica* morphology (inflorescences, stems, stalks, reproduction ability, shoots, rhizome parts) and ecology (mainly soil horizons conditions and water flow factors) as well as of the history of *F. japonica* invasion in Slovakia and Austria. In Slovakia, we continued to find detailed information on this plant occurrence based on State Nature Conservancy of the Slovak Republic (ŠOP SR) databases. After deciding on localities, we started with fieldwork focused on monitoring *F. japonica* occurrence. This monitoring was undertaken from 2014 to 2020. The field monitoring started with the determination of the location of the first occurrence of an invasive plant on a stream in a riparian stand from the source area. Then, the identification of other habitats and targeting was conducted, followed by a geodetically targeted location. Invasive species were determined based on morphological characteristics). Following the field observations, we updated the database of localities presented in the research of the State Nature Conservancy of the Slovak Republic (SOP SR) and we identified new locations of *F. japonica.*

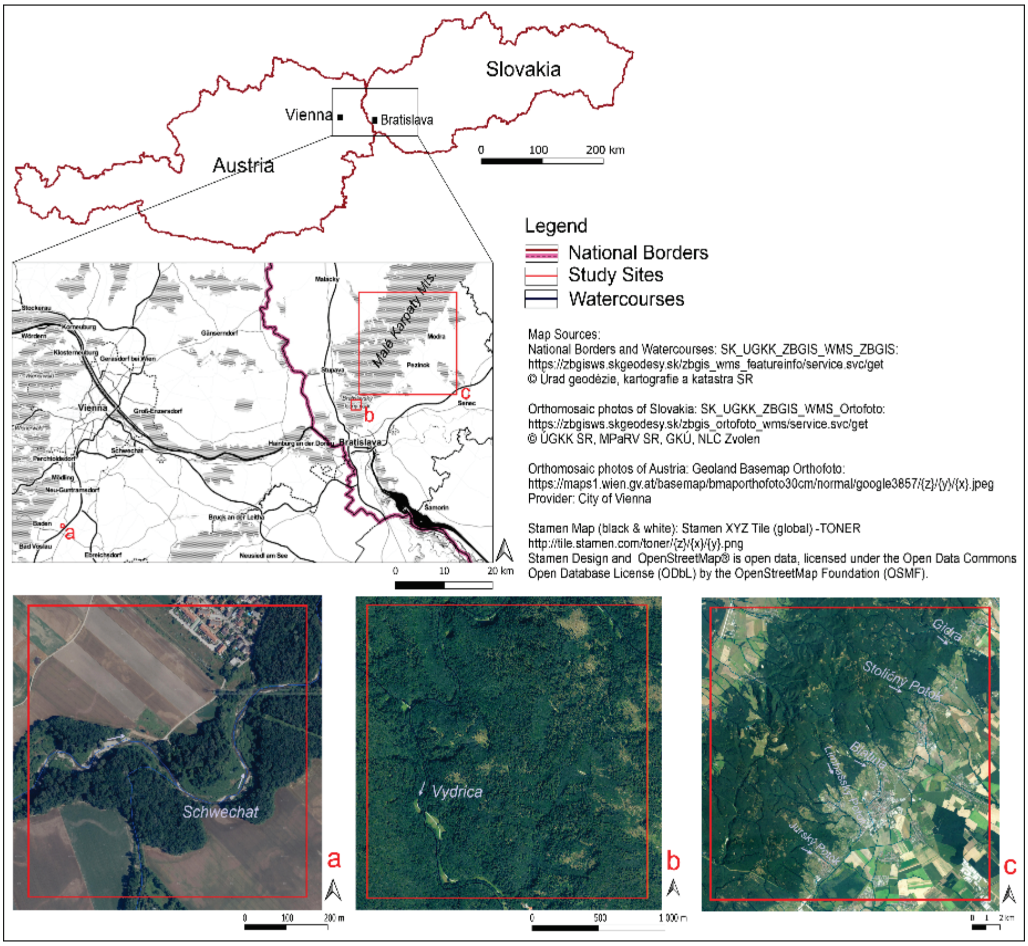

Fig. 1. Study sites selected in Austria and Slovakia

In Austria, the field survey followed at sites selected from previous research where the monitoring occurred from 2011 to 2016. Riparian vegetation including the occurrence of invasive species with larger coverage was mapped. The research started in June and July 2013. The survey continued in May and June 2014. Data obtained in May 2014 were used to capture the state before the flood while data measured in June 2014 were used for defining the changes after the flood. The first step was to estimate total vegetation cover. The key for the mapping units is based on the characterization of polygons in the aerial photo. The delimitation of the polygons with similar land cover was done before starting the mapping in the field. The data collection was focused on structural features. The dominant species and their cover percentages were recorded. Furthermore, maximum plant height, median plant height, vegetation coverage, and humus horizon thickness were measured. One of the most important parts of the research was vegetation mapping provided by a series of phytocoenological relevés, which were conducted not only in the measured stand but in the whole surrounding area. That gave us quite a clear idea about vegetation types present in the area of interest. As riparian areas are considered to be valuable ecosystems because of their biodiversity and functions, special attention was paid to the invasive species which can significantly lower the biodiversity and other important functions of these ecosystems.

In Schwechat, after 2013, *F. japonica* was quickly spreading, especially to flooded areas. We decided to measure the differences in the area of distribution before and after flooding. Measurements were performed in our area of interest. We geodetically distinguished the edge of the area covered by *F. japonica* before and after a flood and calculated the difference in cover.

Mapping of *F. japonica* distribution growth was carried out using new methods of vegetation mapping. Technological devices for 3D digital modeling of objects were used for the research. Three devices were used: a 3D scanner, a quadcopter with a mounted camera, and a GPS locator. The purpose of mapping was to determine the dynamics of *F. japonica* distribution.

Fixed points were set in selected reference sections to be used as georeferenced points for redetermination of the same points in cyclically repeated measurements during the growing seasons, in the environment of a coordinate system created by us for the given sections. During the mapping, the same groups of *F. japonica* invasive plants were monitored. The measurements were aimed at determining the borders of the invasive species in different ways.

The measurements were repeated over 5 growing seasons, between 2013 and 2017 (usually in summer and autumn). In each growing season, one measurement was performed. The only exception was the year 2015 when two measurements were performed. We wanted to monitor the changes between two measurements in one growing season. In comparison, the results from one growing season were almost the same, so we decided to repeat the measurements once in the growing season only. An annual gain was determined based on each year.

The 3D models of the areas of interest were created using 3D Laser Scanner. The scans were used to create altitudes from which it is possible to clearly read the border of *F. japonica* plants. The borders of each *F. japonica* group in the Austria section were also recorded by the GPS device, where continuous lines from the points measured at the border sections between the herbaceous vegetation and the *F. japonica* plants were formed.

Each stand was documented by photos at the same time. In locations where the invasive species were more widespread, species were measured as polygons. The solitary individuals were measured as points. In some places, parts of the plants directly touch the water level.

The outputs from the measured data from the 3D scanner were subsequently modified by post-processing in Scene and CivilCAD 3D. GPS coordinates of the points outlining the border of the monitored vegetation in Schwechat, altitudes from scans, and aerial images were further edited in CivilCAD 3D, where it was possible to compare individual measurement types. The 3D scanner creates a highly detailed 3D image consisting of millions of points (point cloud) assigned to all 3 coordinates (x, y, z). Post-processing results in a 3D photorealistic colour scan.

Furthermore, we obtained an orthophotograph to be used to determine the plan view of the plants by photographing the reference sites using a Dji Phantom 2 quadcopter with a mounted GoPro camera. After post-processing from the GoPro camera in Agisoft PhotoScan Professional, we found that scanning the studied object was imperfect because of the breeze and an incomplete image that had been created. Quadcopter scanning had to be repeated. For that reason, the first measurement was undertaken in 2014 at the beginning of the vegetation period, and the second one was conducted at the end of the vegetation period.

Evaluation of water regime impact on F. japonica distribution and its expansion dynamics. The interactions between the water body and invasive plants were evaluated at the Gidra and Blatina water streams. This location was selected in order to assess the impact of water body characteristics (water level regime, water speed, and *F. japonica* occurrence) on the expansion dynamics of invasive plants. The reference sections were chosen so that it was possible to follow the propagation of the studied species. This means that there was an abundant occurrence of *F. japonica* in the reference section, and it did not occur below the reference section. Furthermore, one of the reasons for choosing the Gidra River for research was the flood in this area in 2011. The aim of this research was to find out the impact of individual water stream factors on invasive plants' distribution, i.e., to verify the hypothesis of whether the water body regime (the increased discharges) can be the main initiator of *F. japonica* distribution/expansion in riparian vegetation.

During this evaluation, a number of methodological steps were utilized: topographic measurements, detailed measurements of characteristic transverse water stream profiles determining the flow level regime and height connection of individual transverse profiles in order to obtain an accurate map for the hydraulic model, focusing on the flow at which the flow level was measured and laboratory experiment on vegetation dynamic growth of *F. japonica*.

Field measurements were performed in several stages at the Gidra and Blatina water streams. During the first measurement (24.11.2016), the occurrence of *F. japonica* species was detected in order to determine the location of the first occurrence of invasive plants on the flow in the riparian vegetation in the flow direction from the spring area towards the mouth. Subsequently, it was necessary to find out other habitats and to forecast the reason for the spread. The measurement was performed in order to obtain real data, with which it would be possible to confirm the hypothesis on the spread of the species. In principle, the measurement was focused on obtaining data, from which it would be possible to derive the causes of propagation, namely the influence of flow hydraulics on invasive plants' propagation.

Vegetative material is created in the period of higher flows, when there are velocities in the flow, which we called the critical velocity. A hydraulic model was used to verify the effect of stream hydraulics on the spread of the invasive species of *F. japonica*. Specifically, cross-sectional profiles of the flow area of interest were topographically oriented. The level regime was targeted by leveling, and based on hydrometering, the flow was determined, which corresponded to the targeted level regime. This was the basis for the verification of the hydraulic model. All these measurements were used for the hydraulic model created with Hydrocheck software in order to verify the impact of flow hydraulics on the spread of *F. japonica*. From the hydraulic model, a critical velocity was determined for the target level and extent of plant damage.

In order to detect the reproduction ability of vegetative fragments of *F. japonica*, we decided to conduct a laboratory experiment. It is known that the expansion of this invasive plant is accompanied by intensive regeneration of stems, rhizomes, roots, and nodes on the dying below-ground parts of plant organisms (Grzedicka, 2022). Therefore, the expansion dynamics of the plant are closely related to its vegetative reproduction ability. Under favourable conditions, the stems of *F. japonica* produce adventive roots (Shaw, 2013). Then, Japanese knotweed reproduces and expands by enrooting. In the laboratory, we tried to simulate the real conditions of the outer environment (moisture conditions, light).

During the experiment on the vegetation dynamic growth of *F. japonica*, the above-ground parts of *F. japonica* were sampled from the investigated reference section of the Blatina water course. The sampled stems were divided into cuttings with lengths of 3–10 cm. Individual cuttings were put horizontally into Petri dishes with water. Observations of the progression of the regeneration of individual cuttings were taken at weekly intervals.

F. japonica eradication. The eradication research was based on data obtained from field measurements and laboratory experiments. The possible methods were selected according to the previously ascertained plant predispositions.

Focusing on the possibilities for eradication of *F. japonica* in riparian ecosystems, our aim was to find the most suitable eradication techniques for these species. The research was conducted at the Blatina River in Pezinok and Stoličný creek in Modra, Slovakia. At the Blatina River, the reference section was located on the border of the built-up area of the city of Pezinok, and at the Stoličný creek the reference section was located in the peri-urban area. The focus was on individual localities of occurrence of the investigated invasive plant.

Two eradication techniques, mechanical and combined chemical-mechanical treatment, were carried out in the riparian stands of both watercourses.

Individual localities with the occurrence of *F. japonica* were positioned by LeicaVIVA GPS locator. Localities under 1 m^2 were positioned as points. The other ones, larger than 1 m^2, were measured and positioned as polygons. The primary results of measuring and positioning were used for the preparation of field maps. Mapping of individual localities was carried out from the spring area downwards and the length of the reference section was 1 km. Geographical positioning and measurement were repeated three times during the vegetation period. The total cover areas of *F. japonica* were recorded on both banks.

After their assessment, we performed a comparison with the findings of other research teams (following the published materials, e.g., the Beskidian method).

We started with mechanical removal when two selected localities were cut. In the next growing season, an increase in the population of *F. japonica* was recorded, and one new location was created.

At first, *F. japonica* eradication by mowing was carried out in a locality with a total area of about 150 m^2. This locality consisted of two partial plots, the first on the right and the second on the left bank of the water course. The mowed parts of the plants were not raked, i.e., they were left on the sites where they grew. To eliminate the risk of another spread of Japanese knotweed by enrooting plant fragments, we tried to minimize the downward water transport of mowed plant material. Nevertheless, mowing is effective only when repeated several times during the vegetation period, at 14-day intervals at best. The plants should be cut just at the base of the stem or even better, 10–15 cm below the surface. In our case, the first possibility was chosen due to the maintenance of the relatively steep bank and its stability. The consequences of the mechanical eradication were assessed during the following vegetation period. At the time of the culminating vegetation period, the combined chemical-mechanical eradication was carried out as the second possible technique for controlling Japanese knotweed. The chosen locality with an area of approximately 50 m^2 was treated by Roundup Biaktiv. The leaves were sprayed upright from above, with the utmost possible effort to eliminate contamination of the environment.

After the death of the above-ground biomass, it was removed mechanically in order to improve light and moisture conditions for the growth of the natural vegetation. The chemical treatment was carried out in accordance with regulations for the eradication of invasive plants in Slovakia. For chemical eradication, spraying based on the Invasive Plant Removal Guidelines for the Slovak Republic was used.

The next step was the comparison of vegetation cover after mechanical and chemical eradication. In order to verify the influence of eradication on the stability of banks, soil pits were dug in the two chosen localities. The first represented the site after the mechanical eradication and the second one represented the place where the combined chemical-mechanical treatment had been carried out. Samples of plant roots were taken from both soil pits. Subsequently, we assessed the viability of the root system and its stabilization function with regard to the erosion of banks. The situation after eradication of the Japanese knotweed was evaluated quantitatively.

Results

Field survey and distribution mapping. At the Schwechat reference site, 10 vegetation types were distinguished in the whole research area. *F. japonica* is mostly replacing the habitat of willow shrubs. It is not possible to find much willow shrub vegetation here, even though it is a natural transition between herb vegetation closer to the river and woody vegetation at a greater distance from the water body. In some places, parts of the plants directly touch the water level. Examples of phytocenological characterization are presented in Table 1.

On the River Vydrica, the length of the area examined was 0.7 km, 1 *F. japonica* stand was recorded. On the River Gidra, the length of the area examined was 7.8 km, there were 15 separate sites. The reference section was chosen from the first site, the closest to the spring area, to the last habitat of the part of the river under examination. On the Stoličný stream, a section 2.5 km long was examined with 10 separate sites recorded. On the Blatina stream, a section 9.8 km long was examined with 5 separate sites. On the Limbašský stream, a section with a length of 5.3 km was examined. Only two separate sites were measured. Along the Jurský stream, a 1.2 km long section was explored. Two locations were measured in close proximity to each other, we can even talk about only one locality divided by a road bridge.

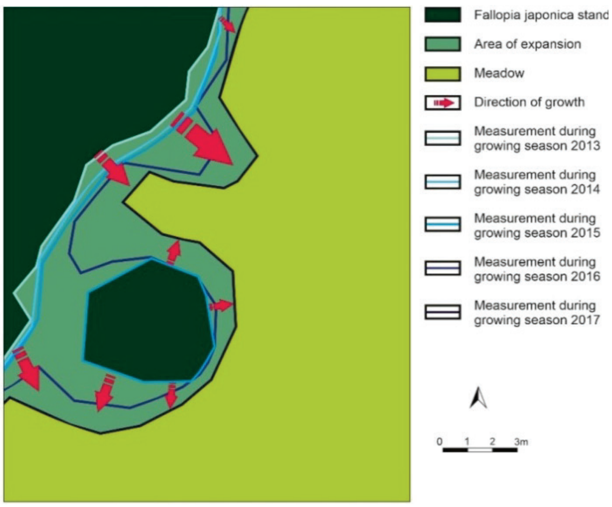

Fig. 2. The border lines of the *Fallopia japonica* vegetation species at the Schwechat River: the borders were measured by a GPS device and it shows the growth between 4 growing seasons; the annual growth is evident and the red arrows show the direction of the growth

Table 1
Phytocoenological table with relevés (1–5) made in the observed *Fallopia japonica* stands, crack and white willow forest and crack willow forest

Relevé No.	1	2	3	4	5
Tree layer-high					
Robinia pseudoacacia	–	–	3	2	–
Ulmus laevis	–	–	–	–	–
Salix alba	–	–	2	–	–
S. fragilis	–	–	1	3	4
Vitis vinifera	–	–	2	2	2
Aesculus hippocastanum	–	–	–	2	–
Shrub layer					
Fallopia japonica	5	5	5	4	2
Robinia pseudoacacia	–	–	1	–	–
Vitis vinifera	–	–	2	1	2
Salix fragilis	–	–	–	–	1
Impatiens glandulifera	–	–	–	–	1
Herb layer					
Fraxinus excelsior	–	–	–	1	–
Ranunculus repens	–	r	–	–	–
Impatiens glandulifera	–	2	2	–	3
Phalaris arundinacea	–	–	–	–	+
Plantago major	–	–	–	–	–
Saponaria officinalis	–	1	1	–	+
Urtica dioica	–	–	–	–	2
Clematis vitalba	–	–	–	–	–
Fallopia japonica	–	+	+	+	2
Rubus caesius	–	–	+	–	–
Bromus sterilis	–	r	+	–	–
Arrhenaterum elatius	–	+	–	–	1
Melilothus albus	–	r	–	–	–
Vitis vinifera	–	r	–	+	+
Arctium species	–	r	–	–	–
Poa trivialis	–	+	–	–	–
Scrophularia umbrosa	–	–	–	–	+
Fallopia convolvulus	–	–	–	–	+
Impatiens parviflora	–	r	–	–	–
Alliaria petiolata	–	r	–	–	–
Brachypodium sylvaticum	–	r	–	–	–
Galeopsis species	–	r	–	–	–
Acer platanoides	–	–	–	1	–

Note: Relevé No. 1: 16.06.2013, relevé area – 16 m^2, cover total – 100%, cover tree layer – 0%, cover shrub layer – 100%, cover herb layer – 0%, height tree layer – 0 m, height low tree layer – 0 m, height shrub layer – 5.0 m, height herb layer – 0 cm, max. height herb layer – 0 cm, richness – 1, Shannon – 0, Eveness – 0, Simpson – 0; Relevé No. 2: 16.06.2013, relevé area – 8 m^2, cover total – 80%, cover tree layer – 0%, cover shrub layer – 80%, cover herb layer – 10%, height tree layer – 0 m, height low tree layer – 0 m, height shrub layer – 4.0 m, height herb layer – 20 cm, max. height herb layer – 40 cm, richness – 14, Shannon – 1.06, Eveness – 0.40, Simpson – 0.42; Relevé No. 3: 26.07.2013, relevé area – 150 m^2, cover total – 100%, cover tree layer – 40%, cover shrub layer – 100%, cover herb layer – 10%, height tree layer – 0 m, height low tree layer – 12 m, height shrub layer – 3.5 m, height herb layer – 100 cm, max. height herb layer – 100 cm, richness – 9, Shannon – 1.55, Eveness – 0.70, Simpson – 0.71; Relevé No. 4: 16.06.2013, relevé area – 16 m^2, cover total – 70%, cover tree layer – 80%, cover shrub layer – 70%, cover herb layer – 5%, height tree layer – 0 m, height low tree layer – 20 m, height shrub layer – 2.5 m, height herb layer – 20 cm, max. height herb layer – 30 cm, richness – 7, Shannon – 1.52, Eveness – 0.78, Simpson – 0.72; Relevé No. 5: 17.08.2013, relevé area – 150 m^2, cover total – 50%, cover tree layer – 70%, cover shrub layer – 30%, cover herb layer – 40%, height tree layer – 40 m, height low tree layer – 20 m, height shrub layer – 2.5 m, height herb layer – 100 cm, max. height herb layer – 150 cm, richness – 11, Shannon – 1.74, Eveness – 0.782, Simpson – 0.77.

Using the GPS device in Schwechat reference site, continuous lines from the points measured at the border sections between the herbaceous vegetation and the *F. japonica* species were formed as presented in Figure 2.

When adding individual measured vegetation borders from different years to one file, it was possible to evaluate the annual growth of the monitored vegetation groups. It can be estimated from the results that the average annual gain was from 0.37 m up to 1.11 m. Analysis of the measured lines confirmed the spreading of the *F. japonica* habitat. The results showed growing dynamics. It can be said that the longer it is prospering in its habitat, the faster it expands. The results from the GPS device and hypsometry from the 3D scanner were compared. The results were almost identical, implying that both methods give equivalent results. The measurements showed a gradual attachment of a single group of individuals to the main habitat of this invasive plant (Fig. 3).

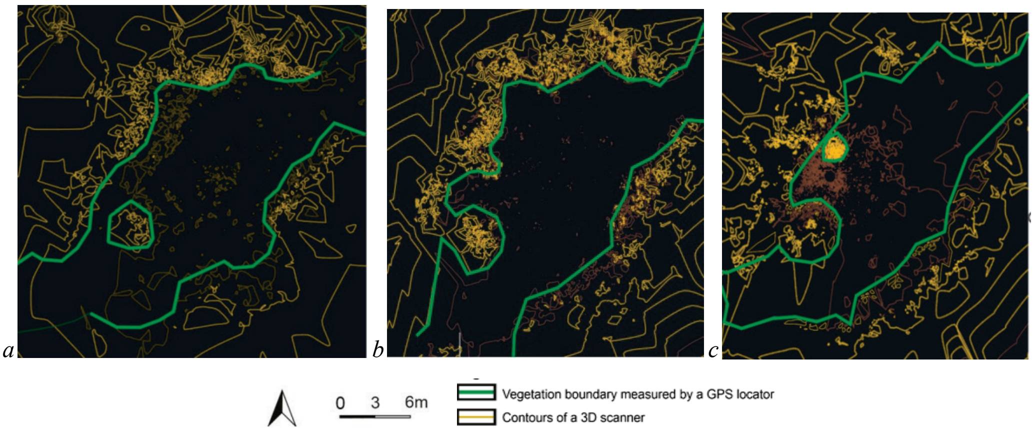

Fig. 3. GPS border lines of the *Fallopia japonica* species added into hypsometry from the 3D scanner at Schwechat on (*a*) 5 May 2014), (*b*) 6 November 2015 and (*c*) 19 May 2016

During our research at Schwechat, the flood occurred in May 2014 (peak May 16th, 2014). The maximum discharge that occurred during the flood was 91.7 m^3/s (http://ehyd.gv.at) which corresponds to the 4.5-year discharge. It is known that flooding events can facilitate the spread of *F. japonica*; therefore, we tried to capture the difference in the stand areas of this species at our research locality. In addition, rapidly growing *F. japonica* can actually disrupt the integrity of flood defense structures.

Figure 4 presents the comparison of stand area occupied by *F. japonica* before and after the flood. We can see the measured edges of the areas and differences calculation. The increase one month after the flood was 98 m^2. Based on the measurements, we can see a relationship between riverbank vegetation and rivers. Due to repeated measurements, we found that the reproductive material is transported. Fragments of plants are transported over long distances downstream, thanks to the water flow.

When mapping the propagation dynamics of *F. japonica* in Slovakia, a quadcopter with a mounted GoPro camera and a 3D scanner were used. The GPS signal was jammed by the high-grown vegetation found in close proximity to the monitored *F. japonica* group.

In addition, the results showed that the aerial photography of *F. japonica* is more appropriate in autumn when there is a clearly visible contrast between the orange autumn colours and the surrounding herbaceous vegetation, which is predominantly green (Fig. 5). The colour contrast makes it possible to determine the border of the invasive plant.

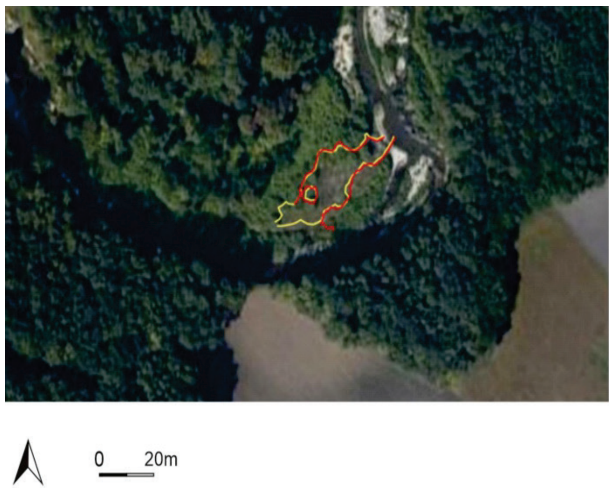

Fig. 4. Difference in the areas of *F. japonica* stands (red line indicates the border lines before flood and the yellow one after the flood in 2014)

The border of *F. japonica* in the orthophotograph of 7 October 2015 (Fig. 6) was compared with a 3D scan from which hypsometry was prepared. Using hypsometry, the border can be clearly defined because *F. japonica* produces compact habitats of approximately the same height. The surrounding herbaceous level is visible on hypsometry due to lower growth than *F. japonica* and the tree level was significantly higher, which was also reflected in hypsometry (Fig. 7).

Fig. 5. Aerial photography measured in the autumn at the Vydrica reference site

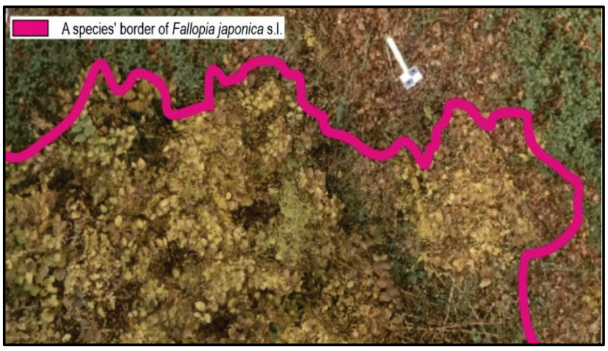

Fig. 6. Aerial photography indicating the border line of *Fallopia japonica*: it is not easy to recognize the individuals at the herbaceous level that are separated from the main homogenous stand

The results of the measurement analyses proved that all three procedures had comparable results since the mutual overlap of the borders obtained by the three methods showed considerable consistency. It can be said that it is possible to use a GPS locator, 3D scanning, and orthophotographs for mapping the invasive species *Fallopia japonica*.

Evaluation of water regime impact on F. japonica distribution and its expansion dynamics. For this part of our research, measurements were made to map the occurrence of plant invasions on Gidra and Blatina rivers. During the first measurement in the autumn of 2016, *F. japonica* was found to occur in fifteen habitats on the Gidra River and 5 stands on the Blatina River. The first place of occurrence was measured in the village intravilan where the planting of the first individual is attributed to anthropogenic activity. The average size of the stands 1–5 on the site was 25 m^2.

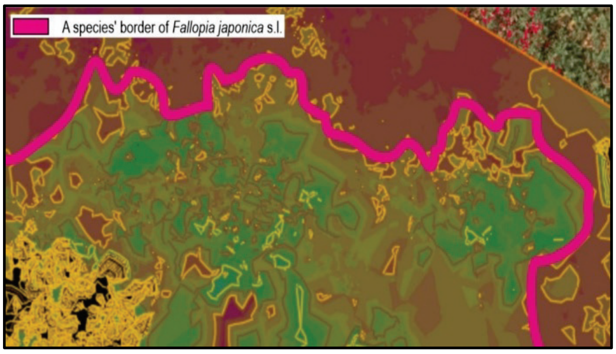

Fig. 7. A 3D scan from which hypsometry was prepared where the border of *Fallopia japonica* can be clearly defined: it is possible to recognize the individuals separated from the main group

The second measurement was conducted as an additional measurement. Another section of the municipality's intravilan was measured, in which no further occurrence of the observed species was confirmed. Access the riverbed, the village intravilan is limited by the boundaries of private land that are in direct contact with the shore zone. Therefore, the uncontrolled spread of the observed species in this section could not be considered. In this case, the measurement was carried out downstream from the spring area towards the mouth. A fixed point was specified at each stand with respect to the targeted area of invasive species' vegetation cover. Consequently, photo documentation was provided. For the habitat of the species *F. japonica* for selected 5 locations out of 15, transverse profiles of riverbed No. 2185, 2121, 2005, 1974, and 1910. The coordinates of fixed points are presented in Table 2.

Table 2
Coordinates of the Gidra water stream cross-section

Stand	Coordinates		Cross-sections
1	48°23.669 N	17°19.491 E	2185
2	48°23.646 N	17°19.524 E	2121
3	48°23.600 N	17°19.569 E	2005
4	48°23.591 N	17°19.589 E	1974
5	48°23.576 N	17°19.589 E	1910

In the case of increased discharges at the Gidra reference section from 2016–2020, the water level should be recorded (either directly or according to the traces left by the level). The aim here was to measure all water stream sections where the monitored plant was damaged with a note on the extent of damage (initial condition, a fragment of the stem, etc., up to damage to the plant). Following the hydraulic model, we were able to determine the critical flow velocity under which the vegetative material of *F. japonica* can be produced. Cross-sections 1–5 correspond to stands where the occurrence of *F. japonica* was evident during the first measurement. Figure 8 shows transverse profiles that represent the area of occurrence of *F. japonica*.

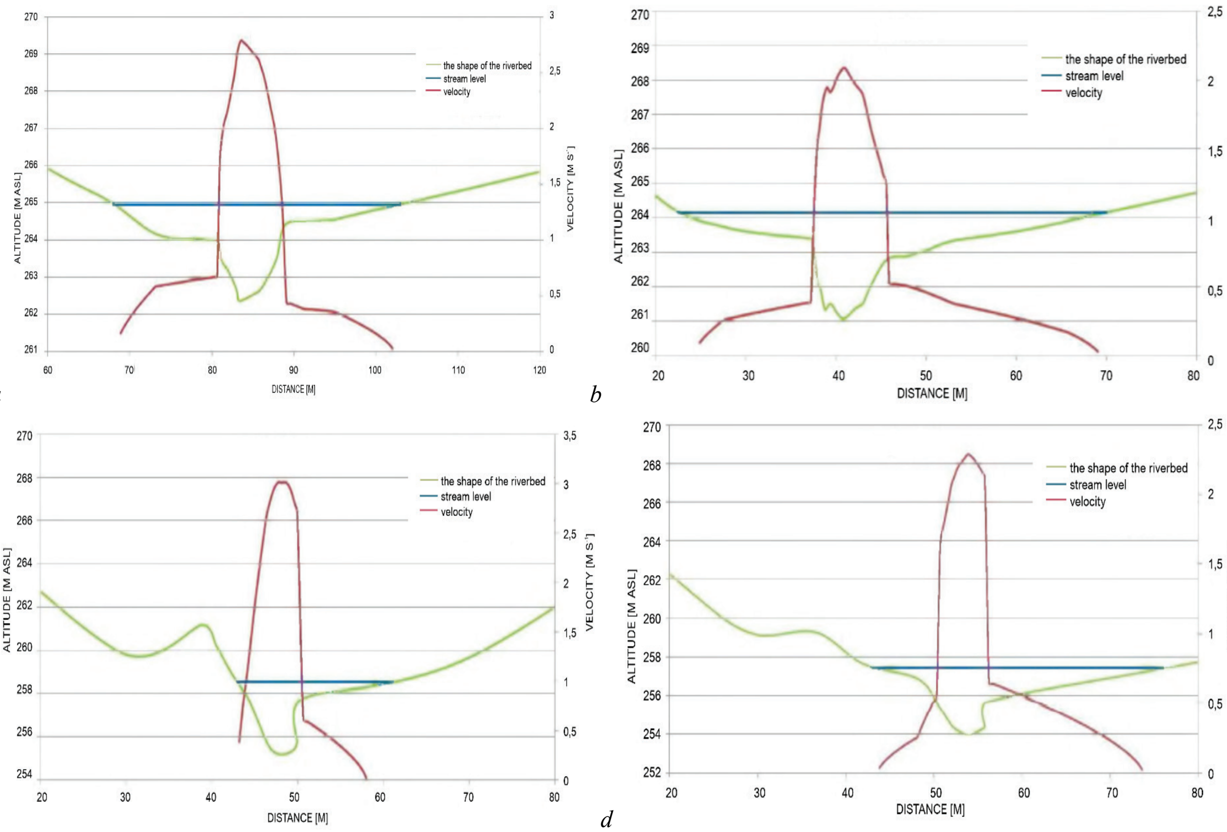

Fig. 8. Examples of flow speed at full bed capacity – flow 24.4 m/s in cross-section: *a* – No. 2,185, *b* – No. 2,121, *c* – No. 2,005, *d* – No. 1,974

In the period of 2016–2020, an increased flow was not observed on the Gidra River, which would disrupt the above-ground structure or the root system of the species *F. japonica*.

A natural river bed usually has a capacity in the region of one to two years' flow Q1 to Q2. The flow of a full bed has the greatest influence on the morphological development of the bed, this means that with these flows the riparian vegetation is already significantly eroded. The flow level Q1 to Q2 = 24.4 m^3/s was fixed on the gauge profile of the Gidra River. This flow occurred on June 9, 2011. A hydraulic model was developed to simulate the velocity field of the Gidra flow in the area of interest. Specifically, cross-sectional profiles of the flow area of interest were topographically focused. The level regime was targeted by leveling, and based on hydrometering, the flow was determined, which corresponded to the targeted level regime. This was the basis for the verification of the hydraulic model for the area of low flows. The area of higher flows was verified at the level that was recorded on June 9, 2011. Thus, the model was verified for a wider range of flows. The course of the surface regime for Q' = 24.4 is shown in Figure 10. It follows from the transverse profiles that the maximum flow speed is in the region of 2.5 m/s. These are speeds that are significantly higher than the degree of stability of the vegetation material. As can be seen from Figure 9, these velocities occur in the middle of the trough, where Japanese knotweed does not occur. In the riverbank area, the velocities are around 1 m/s. This is the speed at which *F. japonica* can already be damaged. Overall, it can be assumed that the flow of a full channel is a critical flow, at which vegetative material is already formed.

By combining the results from simulation on hydraulic models and from field measurements of the presence of invasive plants between 2016–2020, we know that a watercourse is not the primary trigger for invasion until a flood state occurs (flash or another flooding). As long as it is not reached and exceeds the critical speed, there is no direct damage to the plant by the water flow. At normal speeds, a watercourse can be a secondary trigger. In this case, the primary trigger is anthropogenic activity (e.g. vegetation material formed after improper mechanical removal) or climatic conditions (e.g. strong winds).

Water level monitoring also took place on the Blatina watercourse in 2017–2020. We wanted to note the effect of increased water status on damage to the plant. There was no direct damage to the plant during the observation period. Increased flows were recorded, with no negative impact on riparian vegetation.

Based on the laboratory experiment on *F. japonica* growth dynamics we observed that directly after sampling, the fragments have fresh ends with a high capacity to receive water and the young axillary leaves were slightly withered. After the first week, the darkening of cut areas became visible. The older leaves were removed immediately after the sampling, but their stalks remained green for several days. After one week, they were no longer nourished and withered and died. Contrarily, new axillary sprouts with young leaflets appeared in the axils of branches. After the second week, these sprouts became markedly elongated and branched. The leaves without terminal stalks became enlarged, but after two weeks, they subsequently died. After 3 weeks of cultivation, the cuttings seemed to be still viable, but adventive roots were not observed. Nevertheless, the success of enrooting was only 20%. Thus, as many as 80% of cuttings did not produce adventive roots.

Therefore, the successful spreading of *F. japonica* by flowing water requires the capture of vegetative fragments on the bank and their consecutive enrooting in soil. When we assume a water flow velocity of 0.1 m/s, the viable vegetative fragments could be transported at a distance of about 70 km. Under ideal conditions, this maximum distance could represent the length of the entire water course.

The results of our laboratory experiment show that the vegetative fragments of *F. japonica* stay viable for at least 3 weeks. During that time, they can be safely transported by flowing water. Nevertheless, the adventive roots do not appear during that period. Enrooting seems to be more successful in the vegetative fragment of the below-ground parts of the plant (roots, below-ground parts of stems).

Fallopia japonica eradication. After mechanical eradication, the expansion of the Japanese knotweed continued. The total covered area increased in its total size and width, and one new locality was registered. The main advantages of mechanical eradication are its (1) instant effect, (2) low adverse effect on the environment, and (3) low costs.

The effectiveness of chemical eradication was much stronger. The important finding is that the efficacy of chemical eradication depends on the sprayed leaf area more than on the concentration of the sprayed solution. The larger the total leaf area treated, the better the infiltration of the active substance into the plant. We used a solution with a concentration of 5%, which is 3% less than the recommended value (8%). The practical carrying out of the chemical eradication at the culminating growth period is relatively difficult because the plants are approximately 2.5 m high. In compact thickets of Japanese knotweed, the spraying is less effective due to the difficult accessibility. In such cases, chemical eradication could be carried out, exceptionally, at the beginning of the vegetation period. As Figure 9 shows, after the combined chemical–mechanical eradication, the herbal layer started to regenerate due to the removal of the withered stems. When compared to the purely mechanical treatment, the growth of the herbal layer is slowed down and delayed.

After the mechanical treatment, the ability to germinate again was expressed in one-third of plants, on average. This represents approximately 1.5% of the observed area, whereas the remaining 98.5% remained empty. Contrarily, the lack of ability to germinate again was registered after the combined chemical-mechanical eradication. Therefore, the below-ground organs of Japanese knotweed withered after chemical treatment as well. After the combined chemical-mechanical eradication (chemical treatment and mechanical removal of withered stems), the invasive plant started to be replaced by native vegetation as early as the same year.

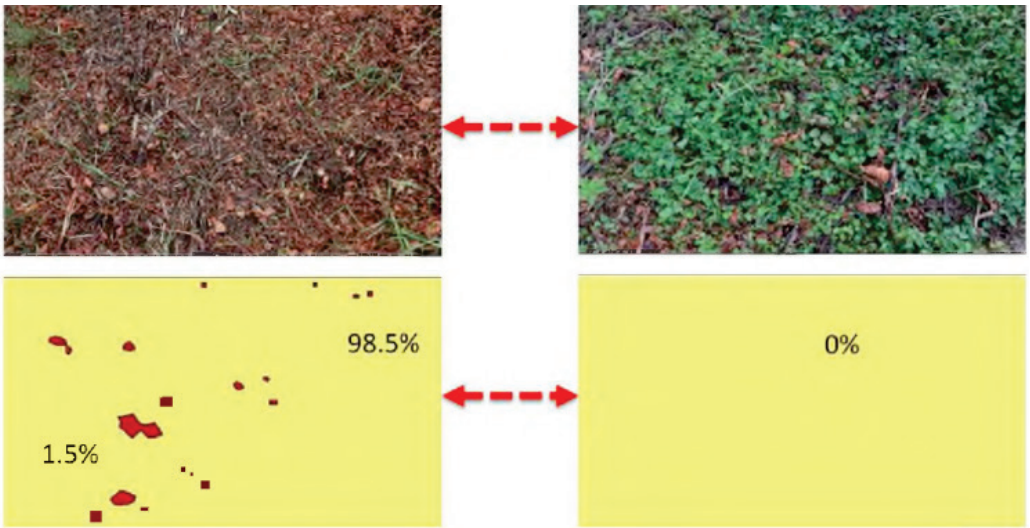

Fig. 9. Vegetation cover after mechanical and combined chemical-mechanical eradication: on the left is the area after mechanical eradication, on the right after combined mechanical-chemical eradication, in a given phase of time; the percentage designation indicates the viability of the individual after eradication; the red colour indicates a re-growth of an invasive individual, yellow colour indicates a free area with the desired growth

Discussion

Field survey and distribution mapping. In recent decades, the issue of mapping, monitoring, and management of the invasive species *F. japonica* has started to appear intensively in research topics not only in Slovakia. *F. japonica* is considered as one of the 100 most invasive plant species in Europe (Medvecká et al., 2012). One of the aspects of the field work was the correct identification of this invasive plant. It is related to that based on findings determined by botanists (Eliáš, 2008), we believe that most of the data on *F. japonica* belongs to the species *F.* x *bohemica*. Botanists also point out that it is necessary to focus not only on the size of the area and on habitat preference, but also on the number of populations (Pauková et al., 2018). The data obtained from occurrence mapping can be the basis for modeling their potential occurrence (Van Oorschot et al., 2017).

The intention for mapping the occurrence of *F. japonica* in the Lesser Carpathian region (SR) along watercourses was to confirm or addition of already existing information about the occurrence of this species in Slovakia. Following the field observations, we updated the database of localities presented in the research of the State Nature Conservancy of the Slovak Republic (ŠOP SR) and we identified new locations of *F. japonica*. In this country, a comprehensive assessment of non-native plant species has not yet been developed. We noted an increase in find data (sites) in the period from 1995 to 2005 (68% of finds). The next increase in mapped locations came after 2015. *F. japonica* collections in individual periods are not uniform (Wittlinger et al., 2022).

On the Austrian side near the Schwechat River, mapping the occurrence and distribution of *F. japonica* was part of the riparian vegetation analysis in the surveyed area. The records were processed in the form of a phytocenological survey as part of the research focused on the dynamics of morphological changes in a streambed stabilized by natural vegetation. In some reference sections of this research, *F. japonica* prevented the growth of the original riparian vegetation and thus a strong monoculture was created, which was an incentive for further investigation.

In connection with the occurrence and distribution of *F. japonica*, several experts are following several aspects, specifically the preference of this invasive plant for altitude. A proven statistically significant regression is at an altitude from 100 to 500 m above sea level (Pauková et al., 2018), which was also confirmed by our research.

From the results of measuring the increase in the area of *F. japonica* in time periods, it can be assessed that a significant increase occurred after the flood. This corresponds with several studies suggesting that *F. japonica* needs to be near a watercourse or high groundwater level to survive and flooding is an important factor in its propagation (Merritt et al., 2010). The fragments of stalks and roots are washed away to new locations during floods, and since *F. japonica* is a particularly aggressively spreading plant, as a 2 cm fragment is enough to take root, flooding can be a driver of establishing new invasion sites.

Evaluation of water regime impact on F. japonica distribution and its population growth dynamics. This part of our research followed the idea that there is a relationship between the water regime and invasive plant expansion. The aim of our research was to assess the influence of the water flow regime on the spread of *F. japonica* and to monitor the dynamics of its population growth in order to find a way to prevent its spread along the stream in riparian vegetation. A new idea was created, which results from the relationship between the flow's hydraulics and the plant's vegetative reproduction. We assumed that the water regime of the flow helps in the vegetative method of reproduction in the case of the species *F. japonica*. Thanks to hydraulic model simulations and field measurements, we have come to the conclusion that water flow is not the primary trigger of invasion until flood conditions occur. As long as the critical flow rate is not exceeded, there is no direct damage to the invasive plant. At normal speeds, water flow can be a secondary trigger.

In this context, some authors noted that disturbance theories, theories of diaspore supply, and theories of fluctuation of resource availability have the greatest importance for the successful establishment of invasive species in riparian vegetation. An important phenomenon that conditions the extraordinary dynamics of floodplain ecosystems are regular floods (Davis et al., 2000; Hierro et al., 2005). Their importance from the point of view of the spread of organisms lies in the acceleration of the possibility of moving their propagules. Regular floods disrupt successional development and thereby increase the strength of competitive relationships. This is the reason for the high species diversity of floodplains or river ecosystems. As a result of regular floods, the successional process slows down, even stops, or returns to the early successional stages. In this way, a colorful mosaic of ecosystems is created in the area of the floodplain, which is one of the prerequisites for high species diversity. However, these factors can also increase the susceptibility of the floodplain ecosystem to the spread of invasive species, whose spread in this area is facilitated precisely by frequent disturbances. This spread is also contributed by the increase in the supply of diaspores, the spread of which is in many cases made possible thanks to water courses (Hood & Naiman, 2000). In addition to the size of the flood, expressed by the extent of the flooded area, the height of the water column, flow, and time, the season is important for vegetation. If a flood occurs outside the growing season, the flood has less impact on the vegetation than in the growing season. A large number of diaspores are transferred during seed maturation. A characteristic feature of flash floods is their short onset time or duration. These are mostly local floods in the upper sections of the streams, on a relatively small area of the basin. They are caused by intense precipitation of short duration; 10 mm or more in less than 3 hours is most often reported; some sources report flash floods on relatively larger areas.

In the case of floods, the stalks and other parts of the plant are often fragmented, and their subsequent washing away causes the fragments to be distributed to new places where they subsequently root and form new invasive groups (Johnson, 2000; García-Arias, 2012). Moreover, dead stems can be swept away and cause blockages downstream. We aimed to find out if flooding of this intensity has a positive effect and is reducing the amount of these plants or on the other hand is helping them to spread faster. The research suggests that with increased flow rates, the quantity of material transported is increased. Invasive plants spread not only in the direction of flow but also in a particular location (Egger et al., 2013; Scalera et al., 2016).

Our research confirmed that the underground parts of *F. japonica* have a greater reproductive capacity than the above-ground ones, which means that a fragment of the root is more likely and easier to take hold than a fragment from an above-ground stem. After being caught on the edge of the bank, the plant can establish a population in a new habitat through the vegetation fragment. According to other research (Maťašová, 2015), the success rate of their capture is about 75%. In the case of *F. japonica*, the below-ground adventive rhizome buds are formed in autumn and early winter and new young sprouts start to develop in mid-April. Their height growth is completed in early summer and is strongly affected by weather conditions between mid-April and mid-June. In this way, the plant produces a lot of vegetative sprouts. Their broken fragments are transported by water, and on suitable sites, enrooting takes place by adventive roots.

F. japonica management. Several authors from Central Europe have already dealt with the management of the dangerous invasive species as well as its possible use as phytomass or nature-based engineering solution (Šrubař & Albín, 2005; Cvachová & Gojdičová, 2008; Barták et al., 2010; Fehér et al., 2016; Hoerbinger & Rauch, 2019; Dudáš et al., 2020).

The best ways to limit the distribution of invasive vegetation in riparian ecosystems are monitoring, preventive measures, maintenance, eradication, and control. It should be noted that the elimination of non-native species from natural communities is extremely expensive. It is necessary to be cautious when handling such a dangerous plant for native ecosystems. It is important that the removal near a watercourse always takes place by first removing the top group along the watercourse, and, at the same time, the last location along the watercourse, to prevent possible spreading during removal (Fibichová et al., 2014).

The best solution to the problem of the spread of *F. japonica* species is to eradicate them. Localities, where eradication was carried out (regardless of the method), should be marked in order to facilitate the necessary regular checking in the future. In addition, such localities are characterized by cumulating dead organic material as a result of the removal of invasive plant bodies. Therefore, the possibilities for the liquidation of dead biomass should be considered before choosing the most suitable eradication method (Ulrych & Gojdičová, 2014).

The most optimal way is to remove the plant at the early stage of the growing cycle when the leaf area is smaller. The result is then ecologically and economically more advantageous. After chemical eradication, it is necessary to remove dead plant residues in the autumn to create optimal light and wet conditions for the growth of potential natural vegetation. In this context, the necessary step after the removal of the species is the subsequent monitoring and inspection of the treated areas, and checking the vegetation regeneration after removing the plant is necessary. An expert inspection of treated areas should focus on new coppices and distribution zones, which must be removed as soon as possible in order to detect the whole process of rooting in a new site at an early stage to prevent invasion. Monitoring focused on finding new habitats is necessary to prevent invasion, and the inhabitants of a given cadastral territory can be helpful in this regard (Child & Wade, 2000; Roy et al., 2014; Ainsworth & Weiss, 2022).

When we evaluate the ways and methods described by us within the research of other scientists (Šrubař & Albín, 2005; Fibichová et al., 2014; Ulrych & Gojdičová, 2014) we come to the conclusion that eradication is effective with a combined chemical-mechanical method. When determining the time of spraying, we are inclined to the so-called spraying Beskydy method (Pergl et al., 2016). The subject of the Beskydy method is the application of herbicide spraying in the fall. During this period, plants retract into underground organs. In this way, the plant treated by the sprayed preparation, so to speak, "drinks", and the destructive components get directly into the root system faster. The leaves of plants in the vegetative peak cover their flat soil, so less of the sprayed substance reaches the soil and the surrounding area.

We verified the effectiveness of eradication after spraying in the summer. This method can be used in a combined way. The combined method is effective because it gives more space for the immediate restoration of potential natural vegetation. This is one of the other proofs of the effectiveness of combined chemical-mechanical eradication, even if we do not consider the Beskydy method. The Beskydy method recommends spraying in autumn. The combined method allows spraying in spring, summer and autumn. With this method, we are not limited by time, as much as with other methods. Thanks to it, it is possible to use the advantages of each growing season. In spring, this method takes advantage of the accessibility to extensive homogeneous stands. In summer, it uses the peak stage of the plant. The continuous canopy of the plant ensures that the soil surface is covered, which eliminates the amount of sprayed substance that reaches the soil and the surrounding area. In autumn, this method uses the principle of the Beskydy method. The plant pulls into the underground organs and the destructive components reach the root system faster.

Conclusions

The findings and results of the research presented in this article can contribute to mapping the occurrence and distribution of the selected invasive species *F. japonica* in the natural environment of Slovakia and Austria. We have added information on the spread of *F. japonica* in riparian ecosystems at the local level. The process of invasion is progressing and the force of the invasive *F. japonica* species can be well illustrated by the systematic monitoring to show how enormous expansion can be formed by this invasive plant. Research on the structure and growth dynamics of this invasive species can be used to address relevant management issues. The methods used in our research are directly applicable in practice for the successful prevention, control, and revitalization of riparian ecosystems invaded by *F. japonica*. In addition, results could also be useful as a comparison study for other parts of Central Europe as they are presented in a way that could be used directly in practice.

We confirmed the hypothesis that the water streams can be a driver of propagation and distribution changes of *F. japonica* in riparian ecosystems and that the reproduction ability of this invasive plant directly conditions its population dynamic growth. Furthermore, based on both the flow model simulation and field mapping, we can conclude that water streams are not primary invasion starters until there is a flood. We verified the methods of *F. japonica* eradication in the conditions of Slovakia and the hypothesis on selective invasion removal adapted to local conditions as the most suitable and most beneficial for municipalities was confirmed by our research.

We should stress the necessity of educating the professional and general public in the field of biotic invasions A well-designed manual dealing with complex designing of the revitalization of riparian vegetation invaded by the invasive *F. japonica* species would serve as a helpful management tool-kit for local and regional authorities. Furthermore, it has to be said that further studies are necessary to investigate the structure, population size, and growth dynamics of populations of invasive species especially in protected areas so that the issue of their systematic management can be addressed.

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