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The distribution of the tree of heaven (*Ailanthus altissima* (Mill.) Swingle) in the settlements and forests of Southern Börzsöny, Hungary

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Key words: artificial canopy gap, forest road, Nagymaros, non-native invasive plant, road network, Zebegény.

Abstract: In this study, we investigated the occurrence of the invasive alien tree of heaven (*Ailanthus altissima*) in the approximately 2,100-hectare area of Southern Börzsöny, along the road network in settlements Zebegény and Nagymaros and in forests. The survey was carried out according to the abundance and location of the species (for all occurrences), the maintained or neglected status of the area (for settlements), and the open or closed nature of the stand (for forests). Individuals or more coherent stands of the tree of heaven were recorded using handheld GPS. A new point was taken when the distance between two individuals or stands exceeded 10 m. We recorded 482 occurrences of tree of heaven in the two settlements and found that it occurs most frequently in neglected public green areas (38%) and neglected gardens (21%), and often shows up along railway lines (18%). In forested areas between the two settlements, we recorded 193 occurrences and found that the tree occurs mainly along regularly used forest roads (42%), and most frequently in open stands (especially in artificial gaps) (69%). Our study also points out that the Hungarian National Forest Inventory data indicate significantly fewer occurrences (covering 23 subcompartments) than our forest mapping survey or earlier ones by other researchers (56 and 60 subcompartments, respectively). Based on our results, anthropogenic impacts are crucial for the spread of the species. The tree is expected to spread exponentially in the future, so in order to prevent this, we recommend that treatments are carried out as soon as possible, with the immediate eradication of seed-producing individuals. The issue of social perception and knowledge is also crucial, as the majority of the society generally has little knowledge of both the tree of heaven and the dangers posed by invasive plant species. Targeted education of the public can therefore be an important element of prevention.

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Introduction

The tree of heaven is native to Southeast Asia (mainly China) but is now widespread on all continents except Antarctica (Kowarik and Säumel 2007). In Europe, it is present in 18 countries (Wohlgemuth et al. 2022). It was probably brought to the continent (first to Paris) in the 1740s (Hu 1979), and to Hungary in the early 1800s (Korda 2018). The online database of vascular plant species of Hungary (Atlas Florae Hungariae) currently indicates it in almost three quarters of the survey quadrats (Horváth et al. 2008, Bartha et al. 2022), but it is likely to be present in additional cells as well. According to a questionnaire survey conducted in 2017 among nature conservation specialists, the tree of heaven ranks 3rd in the country among the most problematic species present in protected natural areas (Kézdy et al. 2017).

Its spread and transformative effects are largely determined by its root system, which branches out in a fan-like shape below the soil surface. The roots develop adventitious buds, from which the tree produces sprouts that emerge to the surface. Glandular hairs on the upper and lower surface of the leaflets produce an unpleasant smelling volatile oil, which plays a major role in the species' resistance to pests (Udvardy 2004). Its flowers can be hermaphroditic and staminate which grow on separate individuals, and open in late June or early July. The tree disperses its samara from early September until spring of the following year. In a seed burial experiment, an average of 79% germination rate was found after 5 years of burial, indicating a long-term persistent soil seed bank for the species (Rebbeck and Jolliff 2018). The tree can become seed-bearing as early as 4–5 years old, and able to produce samaras beyond the age of 100 years. Seed-bearing individuals can produce up to 10 million seeds in 40 years, and up to 52 million seeds in 100 years (Wickert et al. 2017). The shape of the samara allows it to move laterally even in calm air, and this contributes greatly to the efficient dispersal of the species. The distance travelled by the samara can easily exceed 100 m in wooded areas, reaching small open areas (gaps). It can also travel long distances along roads and linear landscape elements (Landenberger et al. 2007). Anthropogenic dispersal, such as seeds stuck to the wheel drums of motor vehicles or the soles of boots, also plays an important role (Wichmann et al. 2009). A mature tree of heaven is about 25–30 m tall and has a lifespan of up to 150 years (Udvardy 2004, Udvardy and Zagyvai 2012).

The impact of tree of heaven on the vegetation is significant. As a pioneer species with a high capacity for expansion, it can spread rapidly on bare ground surfaces. Its expansion also affects the composition and diversity of the shrub and canopy layers (Demeter et al. 2021). Its growth and development are vigorous with young shoots growing up to 3 m in a year (Udvardy 2004). Where the species emerges and reproduces, degradation and transformation of native vegetation can be observed (Demeter and Czóbel 2016), but it does not always affect the seed bank of native herbaceous vegetation (Brooks et al. 2021). The impact on vegetation can be divided into two phases: first, the release of allelopathic compounds from the plant roots into the soil (which inhibit germination, shoot growth and root expansion of native plants), followed by changes in vegetation due to increased shading and nitrogen enrichment from the decomposition of large amounts of leaf litter. Thus, nitrophilous, disturbance-tolerant and shade-tolerant species emerge in the surrounding area (Udvardy 2004, Csiszár 2009). Its most abundant allelopathic compound is ailanthone ($C_{20}H_{24}O_7$) (Heisey 1996). The allelopathic effects are felt relatively close to the plant and are more pronounced around younger shoots and in the early stages of invasion by the species (Gómez-Aparicio and Canham 2008). Previously, it was widely accepted that the tree has a low tolerance to shading (Kowarik and Säumel 2007), but more recent research shows that it is viable – both in terms of growth and reproduction – when spreading by shoots, even under fully closed canopy (Knüsel et al. 2017).

Due to its deliberate planting and rapid spontaneous spread, the tree of heaven is now widespread in Hungary (Korda 2018) and can be found in all landscape units of the country. It is most commonly encountered along linear structures (roads, railways, canals, etc.) and can occur in virtually any neglected area within a settlement, often emerging from narrow gaps in facades and pavements (Kowarik and Säumel 2007). Neglected public and private areas are potential colonisation sites for the species (Fotiadis et al. 2011). It also easily colonises natural areas – either open areas, forest edges, or sometimes even closed stands (Kowarik and Säumel 2007). Although in recent decades it has mainly spread in lowland areas in Hungary, its occurrence in hilly and mountainous areas is equally threatening and is an increasingly urgent problem nowadays (Szmorad et al. 2021). The distribution of Forestry Aridity Index (FAI) values for the occurrences of the tree of heaven is similar to that of its frequent sympatric native trees: downy oak (*Quercus pubescens*) and manna ash (*Fraxinus ornus*). Thus, the tree of heaven threatens the semi-natural habitats of potential basiphilous and thermophilous oak forests (Zagyvai and Bartha 2022). Some forestry activities (such as thinning or felling) are particularly conducive to its spread (Brundu et al. 2020, Erdélyi et al. 2021). In Southern Börzsöny, the use of artificial canopy gaps is a common practice in several forest subcompartments. This type of forest management usually involves creating circular clearings, while maintaining a continuous forest cover, giving the impression that the gap in the forest is natural. The physical environment of a clearing differs significantly from that of the surrounding forest, which is mainly due to greater exposure to light and, in small clearings, greater soil moisture (Gálhidy 2016, Kovács et al. 2020). However, such clearings also serve as potential colonisation sites for the tree of heaven, even in forests of protected natural areas in the mountains.

Based on our previous observations, the tree of heaven is present in high abundance in the neglected parts of two settlements in Southern Börzsöny, Nagymaros and Zebegény, therefore its invasion into the surrounding forest areas is almost certain under current forest management practices (Erdélyi et al. 2021). Kowarik and Säumel (2007) have shown that the tree of heaven can easily reach uninfested areas along linear structures, so we considered it necessary to map the settlement routes. The situation is complex, with several factors influencing dispersal, and a thorough investigation of these is needed to understand the site-specific distribution of the species.

The aim of our work was to map the occurrence of the tree of heaven in detail along the road network of the villages of Nagymaros and Zebegény, both in the inner and outer areas of the settlements, and along the road network and gaps in the forests of Southern Börzsöny, by characterising the distribution and abundance of the species.

Material and methods

Description of the study area

The site of our work is the southernmost stretch of the Börzsöny, which belongs to the Börzsönyi-peremhegység microregion (Dövényi 2010), while according to the more recent landscape classification it is part of the Börzsöny and Visegrád Gorge microregions of the Danube Bend Region microregion group (Csorba et al. 2018). The study area overlaps with the administrative areas of Zebegény and Nagymaros, and covers an area of about 2,100 hectares. Within this area, our actual survey focused on different types of routes (Fig. 1).

The south-facing slopes of the study area are dominated by downy oak, while the parts less exposed to sunlight are covered by Turkey oak (*Quercus cerris*) forests and sessile oak-hornbeam (*Quercus petraea–Carpinus betulus*) woodlands. In the cooler, shady parts, mostly in valleys, beech (*Fagus sylvatica*) stands are found. Several protected plant and animal species rare to the country are present in the surveyed area (Bartha and Nagy 2014). 57% of the study area overlaps with the core area of the Danube–Ipoly National Park.

The area suffers from heavy disturbance by big game (browsing, rooting, trampling etc.). The mouflon (*Ovis gmelini orientalis*), red deer (*Cervus elaphus*), wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*) are present in significant numbers. Their impact on vegetation regeneration is confirmed, among others,

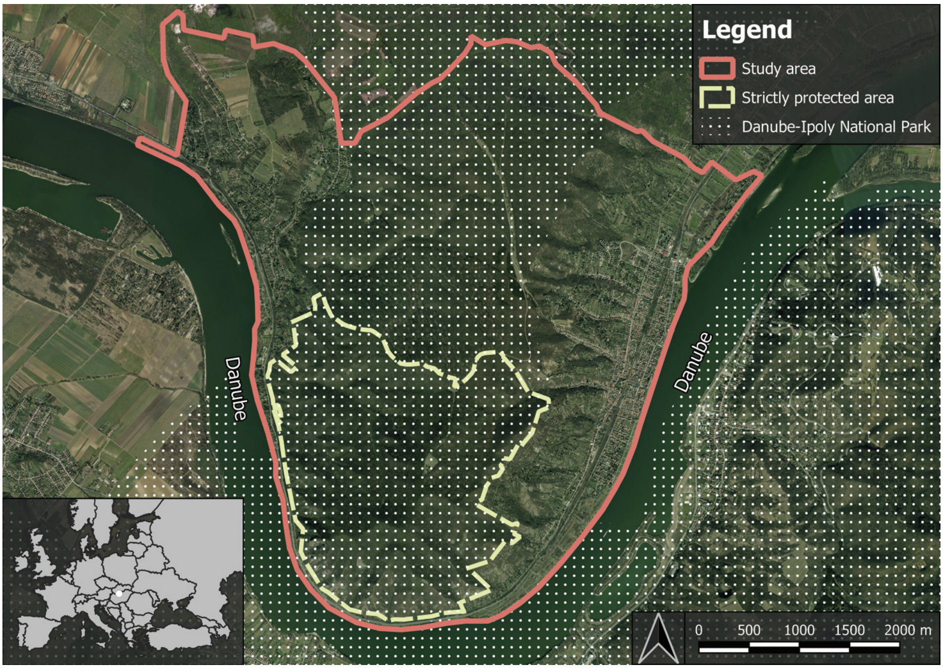

Fig. 1. The study area and the strictly protected area within it. (Base map: ESRI Satellite, 2021.)
1. ábra. A vizsgálati terület és a benne található fokozottan védett természeti terület. (Alaptérkép: ESRI Satellite, 2021.)

by a complex, detailed forest condition survey carried out in 2014–2016, which showed that the most common condition for saplings was "heavily browsed" (Standovár et al. 2017). In our study area, the lack of herbaceous vegetation on steep south-facing slopes with completely bare soil surfaces in some places should definitely be noted. This is mainly caused by mouflon.

Our forest area surveys were carried out in the Danube–Ipoly National Park, on 1,235 hectares, of which 558 hectares are strictly protected (Fig. 1). The asset manager of the forest area is Nagymaros Forestry of the Ipoly Erdő state forestry company. In the majority of the strictly protected natural area there is no timber extraction, while the forests north from it are partly in conversion and partly in felling mode. Here, from the Remetekereszt Crag and its ridge northwards to the Csizmadia Valley, are the forest areas where artificial canopy gaps have been created since 2012 (Fig. 2). The current gaps have been created over several years, the latest ones in 2019. The gaps are located in 17 forest subcompartments which covers a total area of 136.6 hectares.

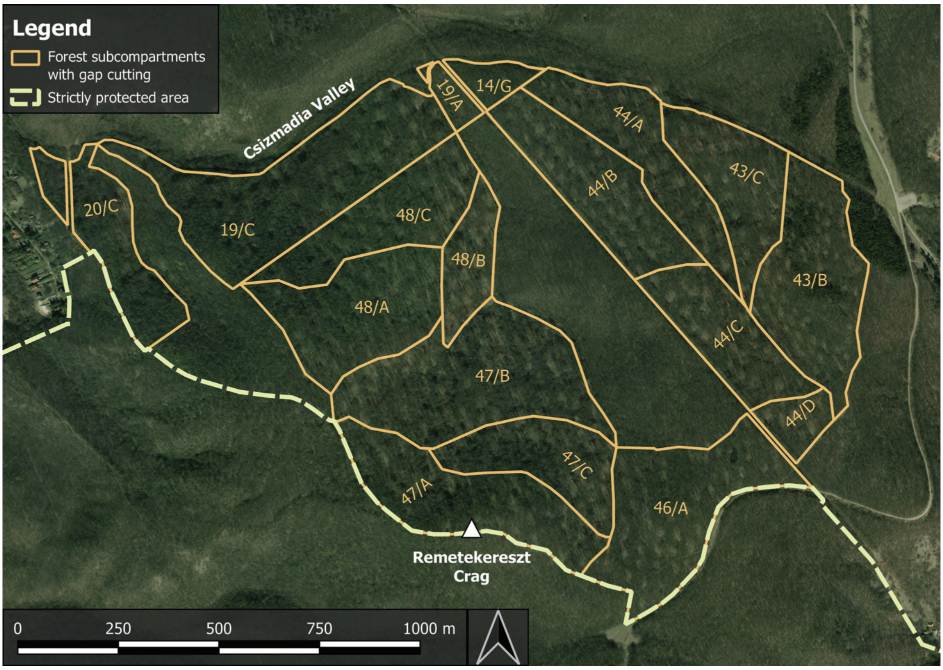

Fig. 2. Satellite image of the forest subcompartments with gap cuttings between Remetekereszt Crag and Csizmadia Valley. (Basemap: Google Satellite, 2020.)
2. ábra. Lékes felújítással érintett erdőrészletek műholdképen. (Alaptérkép: Google Satellite, 2020.)

Road network survey in the settlements

The road network survey in the administrative area of Zebegény covered all types of public spaces (roads, streets, paths, squares, stairs etc.) and also partially included a small section of the EuroVelo 6 cycle path connecting Zebegény and Szob, in the administrative area of Szob. For Nagymaros, the northern boundary of the survey was the Sólyom Island and the Köbölvölgy road, and to the south of it, all types of public land were also covered (Fig. 3, Vig et al. 2023).

The survey was conducted between November 2021 and April 2022, and the data were recorded using a Huawei P30 phone and Locus GIS application. The accuracy of the GPS signal was between 3–5 m. During the site visits, we recorded the path (Fig. 3) and the location of the observed tree of heaven stems directly along the roads and in visible private gardens. Where the coordinate could not be determined at the actual location of the occurrence (in the case of private land), the location of the view was indicated, with a note describing the location of the stems. Each contiguous patch was marked as a point where the maximum distance between edge stems was within 10 m. Where this distance was greater than 10 m, a new point was recorded. For larger groups of stems and patches with many individuals, we tried to keep the map point in the middle of the patch, but in some cases the map point could be placed only at the edge of the patch due to impassability.

Fig. 3. Every surveyed road (green line) of the settlements and forest area combined. (Basemap: ESRI Satellite, 2021.)
3. ábra. A települési és az erdőterületi felmérések során bejárt útvonalak együttesen. (Alaptérkép: ESRI Satellite, 2021.)

After recording the location, we determined the abundance in four categories: 1: 1–9 stems; 2: 10–99 stems; 3: 100–999 stems; 4: 1000 or more stems. The first two categories were differentiated by counting the number of stems; the other categories were separated by visual inspection and estimation. We considered a stem as an independent piece of the tree growing directly from the soil, so ramets were taken into account separately during counting or estimation. The number of seed-bearing individuals at a given coordinate was recorded in two categories: 1–9 and 10 or more. As this part of the survey was carried out outside the growing season, we considered those individuals to be seed-bearing on which samaras or at least pedicels were visible. Specimens of at least 30 cm diameter at breast height (DBH) as well as old polycorms were recorded separately. The latter represents one or a few long-established individuals that may have been cut back several times, resulting in an elongated group of many shoots due to their considerable lateral expansion. The categories listed in Table 1 were used for the description of the environment of each occurrence.

Table 1. Categories and definitions used to describe the distribution of *Ailanthus altissima* in the settlements survey. (Own criteria.)
1. táblázat. A települési felmérés során használt, a bálványfa megjelenési helyére vonatkozó kategóriák és definícióik. (Saját szempontrendszer.)

Place of occurrence	Definition
Maintained garden	Gardens and similar private areas used for residential or regular purposes
Neglected garden	Abandoned or apparently very rarely used gardens and similar private spaces
Maintained public green area	Public open spaces that are regularly maintained, e.g., flower gardens, mown lawns, pruned shrubs, wooded strips, patches
Neglected public green area	Public spaces that are visibly neglected for a long time, weedy, with spontaneously growing shrubs and trees
Cables and power lines	Typically, vegetated areas under and adjacent to overhead power lines and support structures, with vegetation cut back at intervals
Gap	Gaps and cracks in buildings, plinths, pavements and other built structures
Drains and ditches	Deepened linear structures, ditches for draining
Railway	Railway embankments and their immediate surroundings, which are periodically managed by cutting back vegetation
Other linear object	Other, not common linear objects, e.g. scarps, walls or stone barriers
Other occurrence	Other, not common occurrences, e.g. rooftops, abandoned buildings, vehicles

The data collected during the survey most likely do not include all the tree of heaven individuals or their groups present in the two settlements, but the accessible areas were surveyed in an exhaustive manner, so the data collected are likely to be a good approximation of reality.

Road network survey in the forest area

As in the settlements, the forest area between Zebegény and Nagymaros was first mapped for tree of heaven cover by road surveys between February and May 2022 (Fig. 3). The current maps (tourist map, OpenStreetMap, cadastral map) did not show all actual roads. Older roads that are no longer or rarely used may have contributed to the spread of the tree of heaven (especially considering that the uneven surface of such roads makes it easier for seeds to be released from tyre grooves, wheel arches and boot soles), so we also included roads shown on topographic maps from 1964 and 1969 (http1, Fig. 4).

The coordinates of the tree of heaven individuals and their groups along the surveyed routes were recorded. In line with the method used in the settlements, a new coordinate was recorded for each instance where the nearest stem was more than 10 m away from the edge shoot. However, in contrast to the settlement survey, only occurrences within 10 m of both sides of the central axis of the route were recorded. For those stands positioned exactly on the edge of the 10 m line, the parts extending beyond the 10 m boundary were included in the abundance value. Of the variables used, abundance, seed-bearing individuals, individuals with a minimum DBH of 30 cm, and old polycorms were the same as those used in the municipal survey. Our own criteria were used to record road type and canopy closure (Table 2).

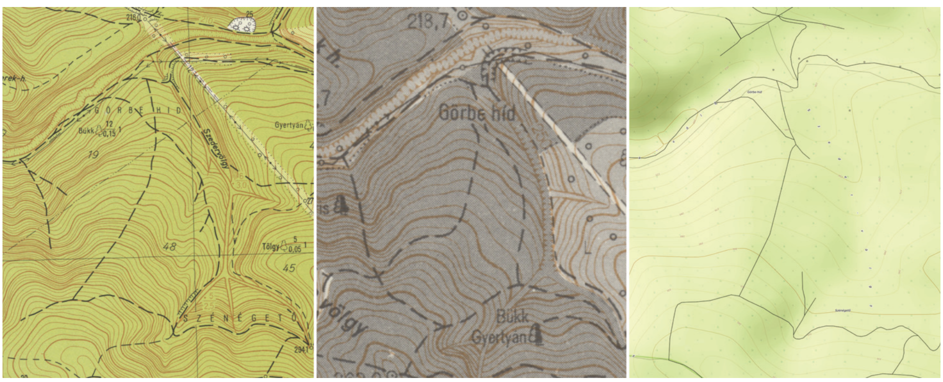

Fig. 4. Example for the road density within the same area from 1964, 1969 and on a recent map (OpenTopoMap).

4. ábra. Az úthálózat sűrűsége egyazon területen 1964-es, 1969-es és aktuális térképen (OpenTopoMap).

Table 2. Categories and definitions used to describe the distribution of *Ailanthus altissima* in the forest survey. (Own criteria.)
2. táblázat. Az erdőterületi felmérés során használt, a bálványfa megjelenési helyére vonatkozó kategóriák és definícióik. (Saját szempontrendszer.)

Place of occurrence	Definition
Regularly used forest road	A frequently used and regularly maintained road that is part of a permanent extraction network, covered with scattered gravel or compacted, eroded forest soil
Abandoned forest road	Unused or infrequently used road, typically covered with a thicker layer of forest litter
Tourist paths, tracks	Footpaths and trails, not used by vehicles
Forest glade	Straight cuts and their narrow surroundings, usually not used as roads, but for power lines or fire protection, where vegetation is cut back from time to time
Skid trail	Temporary road constructed only for logging/felling operations in the area
Crossroads	Road crossings, typically with open canopy
Other road	Old cart tracks, typically running on the contour lines of the slopes.
Open	Exposed gaps greater than one tree height, other cuts or clearings
Edge	Forest edges, clear felled areas and margins of uncut forest stands
Open (gap)	Gaps, openings no greater than one tree-height length
Closed	Fully closed canopy

In order to provide a more comprehensive description of the site-specific situation of the tree of heaven, we used data from the National Forestry Database (http2) and relevant data from the 2014–2016 forest surveys “Multipurpose assessment serving biodiversity conservation in the Carpathian region of Hungary” (registration number SH/4/13) (Standovár et al. 2017, Szmorad et al. 2021) and from the 2021 surveys within the Interreg Centralparks CE1359 project. The spatially consistent data sets from the latter two surveys were used in a consolidated manner, generalised to 50 m × 50 m quadrats (hereafter referred to as previous forest mappings).

Results

Results of the municipal road network survey

During the municipal road surveys, 482 points were recorded, of which 142 were in the administrative area of Zebegény and 330 in Nagymaros (Fig. 5). A further 10 points were recorded in the administrative area of Szob, along the

Zebegény-Szob cycle path, and these were assigned to Zebegény in the following analyses.

In the Zebegény area we found 78 stands with 1–9 stems (51%), 57 stands with 10–99 stems (38%) and 17 stands with 100–999 stems (11%). Of the coordinates recorded, 61 sites had up to nine seed-bearing individuals, and a further 14 sites had ten or more. Individuals with a minimum DBH of 30 cm were recorded at 12 sites, and older polycorms at 10 sites. Of the 152 sites, there were 10 cases of tree of heaven growing from some kind of a gap, 11 sites in a disturbed area under an overhead power line, and 36 in private gardens that were visible from the street, with 30 in private gardens considered neglected. In urban green spaces 37 sites were recorded, 34 of which were found to be neglected. We have recorded the presence of the tree of heaven at 34 sites along the railway embankment, including the Szob cycle-path section.

In the area of Nagymaros, 52 of the 330 points recorded were outside the residential area, all of them were encountered along the railway, at the southern

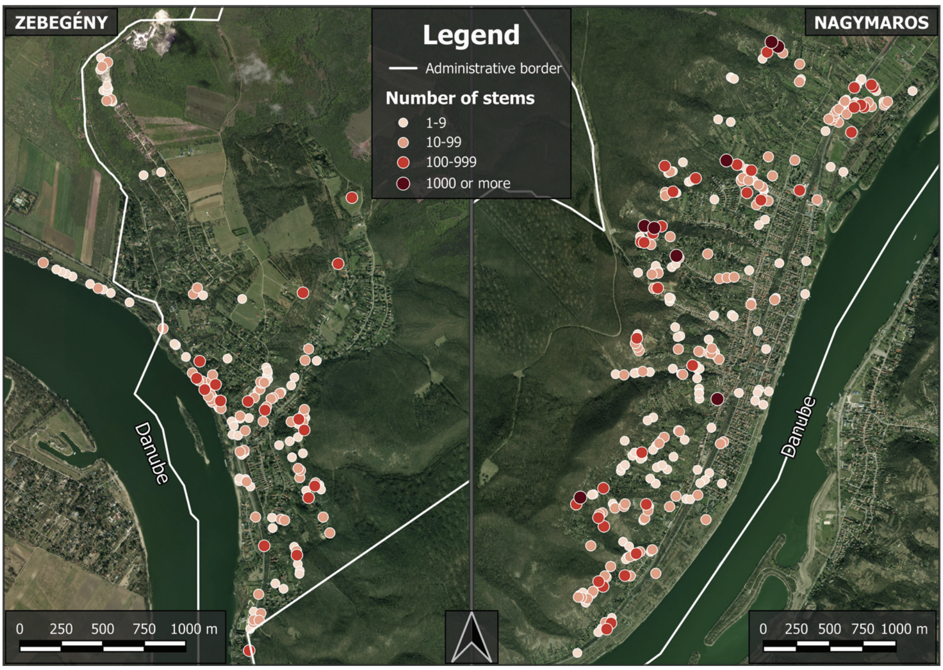

Fig. 5. Occurrences of *Ailanthus altissima* by abundance groups in the settlements. The white line indicates the administrative boundaries. (Basemap: ESRI Satellite, 2021.)
5. ábra. A települési felmérések során rögzített bálványfa-előfordulások területi eloszlása tömegességi csoportok szerint. A fehér vonal a közigazgatási határokat jelzi. (Alaptérkép: ESRI Satellite, 2021.)

and south-western foot of the hill (Fig. 6). It is important to note that several of these recorded coordinates also indicate occurrences within forest areas, as the groups of shoots sometimes extend several tens of metres upwards on these steep southern slopes. The data presented below for Nagymaros exclude these 52 points and describe the remaining 278 settlement points, which are shown in Fig. 5. In terms of abundance, 141 of these sites have 1–9 stems (51%), 94 sites have 10–99 stems (34%), 35 sites have 100–999 stems (12%), while 7 sites have more than 1,000 stems (3%) of the tree of heaven. We recorded up to nine seed-bearing individuals at 111 sites and ten or more at 37. Individuals with at least 30 cm DBH were recorded at 36 sites, and old polycorms at 37 sites. We found specimens growing out of a gap at 22 sites, and occurrences under an overhead power line at 24 sites. 107 sites were observed in the private gardens of Nagymaros, 73 of which were neglected. 154 sites were recorded in urban green spaces, of which 147 were considered as neglected. On railway embankments, we recorded 25 sites within residential areas.

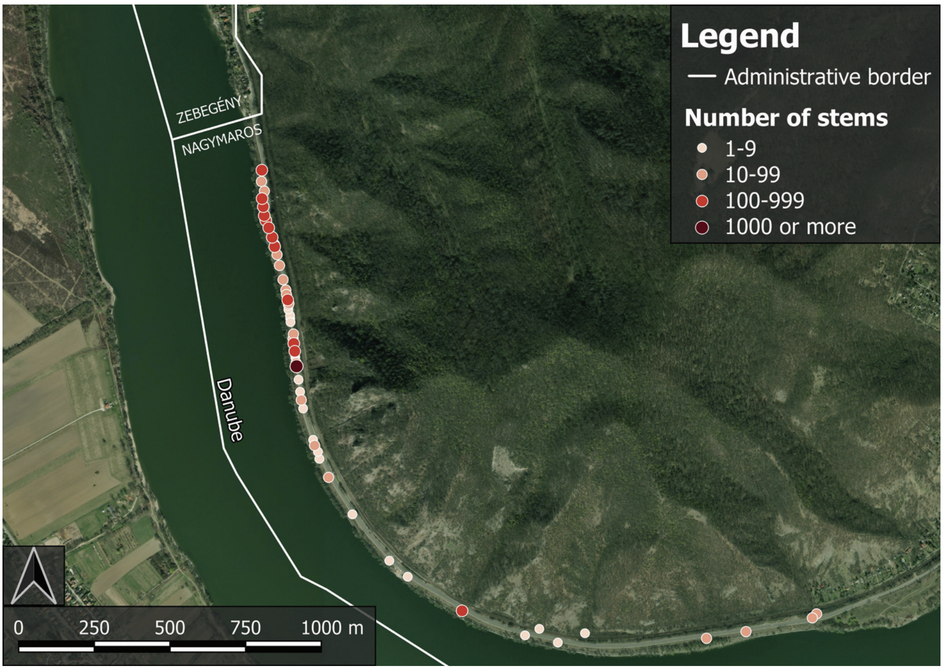

Fig. 6. The 52 occurrences of *Ailanthus altissima* outside the residential area of Nagymaros, next to the railway, the main road and on the adjacent mountain foot. The white line indicates the administrative boundaries. (Basemap: ESRI Satellite, 2021.)

6. ábra. Az 52 bálványfa előfordulás Nagymaros lakott területén kívül, a vasút, illetve közút mellett és a kapcsolódó hegylábi részeken. A fehér vonal a közigazgatási határokat jelzi. (Alaptérkép: ESRI Satellite, 2021.)

Of the 52 points outside the residential area (Fig. 6), 26 were recorded on the railway embankment and a further 26 on the Danube side of the cycle path along the main road No. 12, which runs parallel to the railway line. In the latter case, most of the tree of heaven individuals were located right next to the cycle path, and in some cases on the upper third of the embankment between the river and the cycle path. Of the 52 points, 19 were marked with 1–9 stems (37%), 20 with 10–99 stems (38%), 12 with 100–999 stems (23%) and 1 with more than 1,000 stems (2%). At 21 sites we found 1-9 seed-bearing individuals, while at 10 additional sites we found 10 or more. We recorded individuals with a minimum DBH of 30 cm at 8 sites and old polycorms at 17 sites.

The distribution data in Fig. 7 show the combined results of Zebegény and Nagymaros for 482 points. There are several cases of overlap in the categories of occurrences, so that when all the values are added, the result is greater than 482. For example, there were several cases where a group of shoots covered both sides of a fence separating a private garden from an urban green area, with an overhead power line running above.

The three most frequent places of occurrence were the neglected public green areas (181 cases, 38%), neglected gardens (103 cases, 21%), and along railway lines (85 cases, 18%). The most notable of these is the neglected public green area category, where we also recorded the highest number of tree of heaven poly-

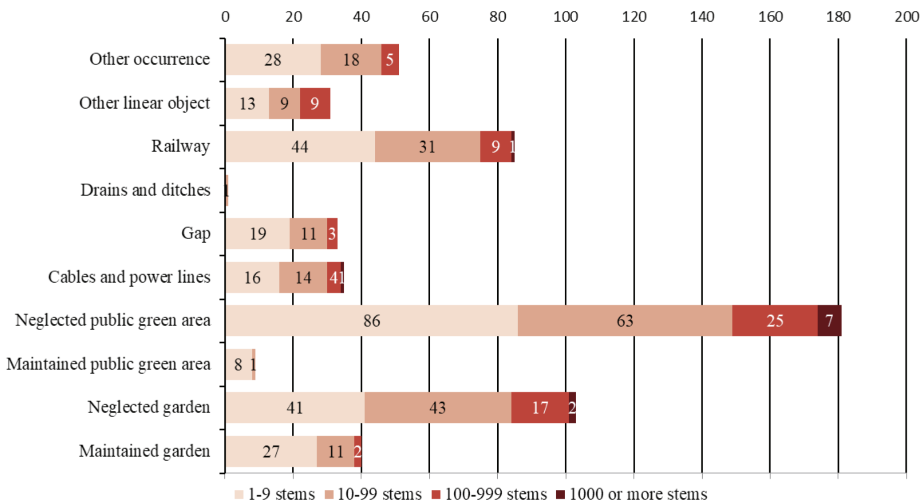

Fig. 7. The number of occurrences of *Ailanthus altissima* in the two settlements in relation to the abundance categories and location variables.

7. ábra. Bálványfa előfordulások tömegességi kategóriák szerinti megoszlásban a két település egyesített adatsorában, a megjelenés helyét leíró változók szerint csoportosítva.

corms with 1,000 or more stems. We found 7 such locations, all of them in the administrative area of Nagymaros.

For the two settlements, it was not possible to calculate relative frequencies for the individual categories, as this would require a separate characterisation of each land unit (more than 10,000 land units). However, it is safe to say that Nagymaros and Zebegény are not among the depopulating settlements in Hungary, which means that the proportion of maintained plots (with a significant proportion of inhabited ones) and maintained public green areas may be much higher than the national average. Nevertheless, the tree of heaven was found noticeably more often in various neglected areas and was typically more abundant in these areas.

The 'other' category should also be mentioned, which in our surveys was mainly suburban, neglected, non-greenspace sites, such as an abandoned sports ground (with concrete cover) or a disused built-up area.

In the two settlements combined, we found 1–9 seed-bearing individuals in 193 cases, and 10 or more in 61 cases. Their spatial distribution according to the two categories is shown in Fig. 8.

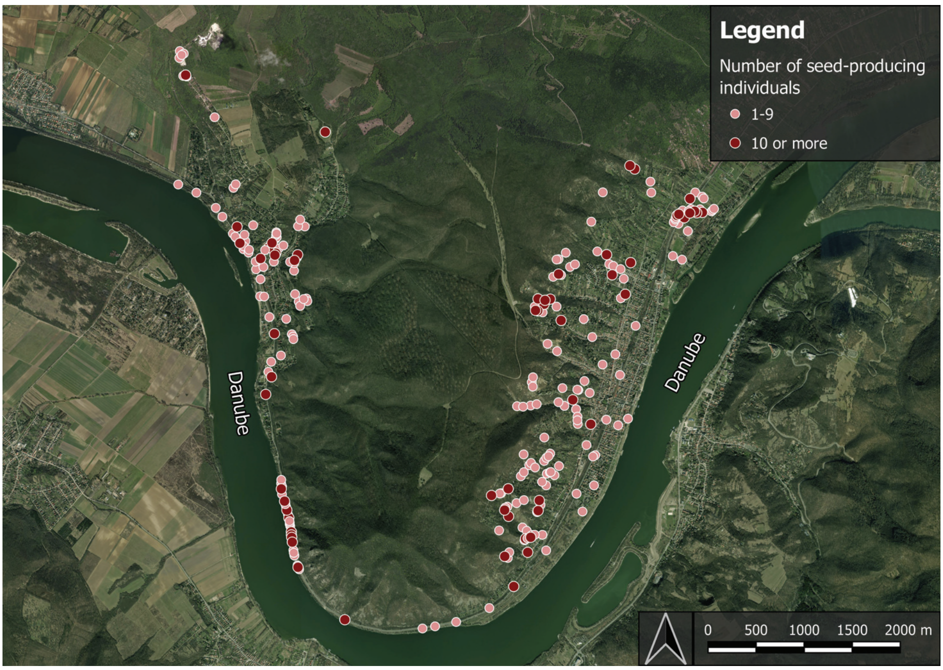

Fig. 8. Seed-producing individuals by their number in the settlements. (Basemap: ESRI Satellite, 2021.)

8. ábra. A magtermő egyedek térbeli eloszlása a két településen. (Alaptérkép: ESRI Satellite, 2021.)

Results of the forest road network survey

193 occurrences were recorded in the forest area: 82 (42%) on regularly used forest roads, 47 (24%) on abandoned forest roads, 27 (14%) on paths, 9 (5%) in forest glades, and 11 (6%) on skid trails. The type of road for the further 17 (9%) sites was given as 'other' – these are old cart tracks, typically running on contour lines. 24 occurrences were recorded at crossroads. In terms of abundance, we observed 1–9 stems in 109 cases (56%), 10–99 stems in 75 cases (39%), 100–999 stems in 8 cases (4%), and 1,000 or more stems in 1 case (1%) – the latter near a path leading to a hunting stand. At 17 points there were 1–9 seed-bearing individuals on the site, while at 2 recorded coordinates there were 10 or more. At 8 sites we encountered individuals with a minimum DBH of 30 cm, while at 14 sites we found older polycorms. In terms of stand closure, 133 points (69%) were recorded in open (gap) areas (typically at the confluence of a road and an artificial gap), 25 points (13%) in forest edge situations, 12 (6%) in open (not forested) areas, and 23 (12%) in closed stands. The vegetation around the recorded points was dominated by beech in 56 cases, sessile oak in 44 cases, Turkey oak in 20 cases and hornbeam in a further 20 cases. The remaining 53 occurrences can be characterised as fringe vegetation, bramble (*Rubus fruticosus* agg.), or open areas.

Our results indicate that the tree of heaven occurs in the highest proportion in open stands (especially in artificial gaps) in terms of closure, and is most abundant along regularly used forest roads (Fig. 9).

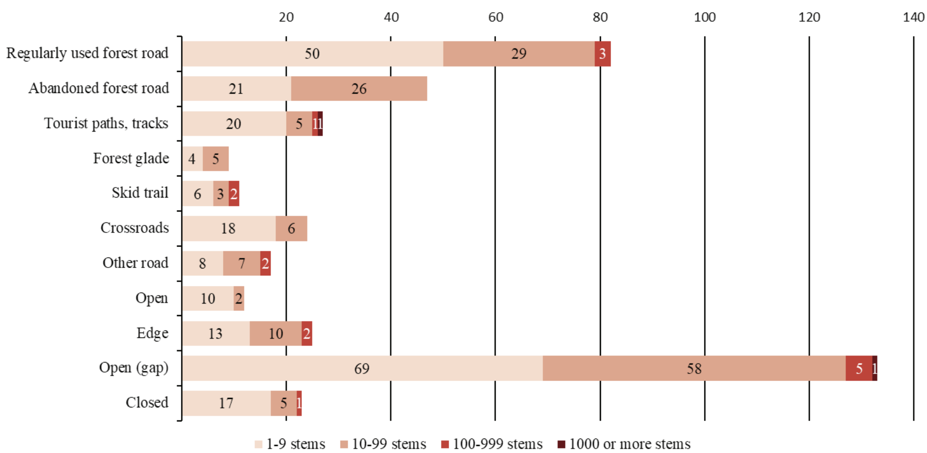

Fig. 9. The number of occurrences of *Ailanthus altissima* in the forested area in relation to the abundance categories and location variables.

9. ábra. Bálványfa előfordulások a felmért erdőterületeken tömegességi kategóriák szerinti megoszlásban, az utak jellegét, valamint a záródást jellemző változók szerint csoportosítva.

Combining our results with the data from the National Forestry Database and previous forest mappings, we can conclude that the tree of heaven is definitely present in a total of 88 of the 238 forest subcompartments concerned. Of the 88 forest subcompartments, 66 are protected (national park) and 21 are strictly protected. In the administrative area of Zebegény, the number of forest

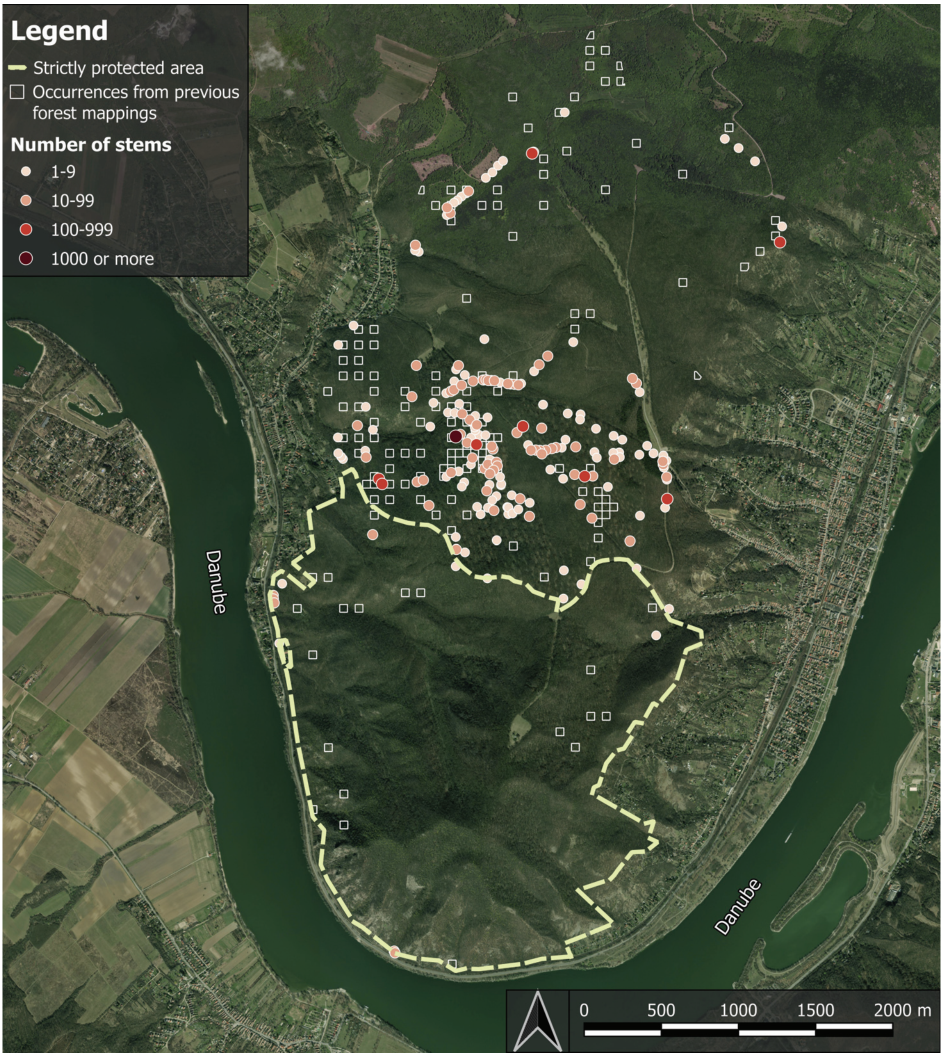

Fig. 10. Locations of *Ailanthus altissima* in Southern Börzsöny according to our survey data (by the categories of the number of stems) and the previous forest mappings, in relation to the strictly protected area. (Basemap: ESRI Satellite 2021.)
10. ábra. Bálványfa-előfordulások a Dél-Börzsönyben, saját felméréseink és a korábbi erdőtérképezések adatai alapján, a fokozottan védett terület viszonylatában. (Alaptérkép: ESRI Satellite, 2021.)

subcompartments infected by the tree of heaven are 17, 23 and 24 according to the National Forestry Database, previous forest mappings and our own survey, respectively. The same figures for Nagymaros are 6, 37 and 32. Regarding the overlap of these data sets, in the two settlements combined, all three of them indicate the presence of the tree of heaven in 10 forest subcompartments, two in a further 31 and only one data source in 47 forest subcompartments. In terms of the forestry mode, 44 of the forest subcompartments infected by the tree of heaven are used for logging, 20 are not used for timber production and 15 are in conversion mode. In addition to these, 9 other subcompartments (forest clearings, bare unproductive areas, cuts) host this invasive species.

Figure 10 shows a summary of the data recorded by us and from previous forest mappings. Most of the occurrences were recorded on the hillsides between Zebegény and Nagymaros from the Remetekereszt Crag to the Csizmadia Valley. It is precisely the very area where artificial gaps have been created over the past few years. In contrast, the tree of heaven is much less common in the strictly protected areas, where no felling has taken place for decades.

Discussion

Summarising our results and previous data, it is clear that the spread of the tree of heaven is largely determined by anthropogenic impacts. In settlements, the tree of heaven was conspicuously more frequent and abundant in neglected, abandoned areas than in maintained areas. This applies to both public and private areas. A study carried out in 10 settlements in Greece showed similar results (Fotiadis et al. 2011), where the tree species was also the most abundant in abandoned areas, overtaking e.g., roadsides and footpaths. Once an area has been abandoned, the initial conditions are usually most favourable for pioneer species, so that within a few years some weedy species may become dominant. In addition to those, other herbaceous plants prevailing in the area may naturally emerge, followed by woody plants with better dispersal abilities. As our study area lies in a forest climate, woody plants can spread relatively quickly, and the area can be completely overgrown by shrubs or can even become forested within a few decades. At the same time, if the tree of heaven is introduced into the abandoned area in the early years, its individuals can grow up very quickly and by forming new shoots and seed-derived new individuals further reduce the chances of other plants establishing, surviving and spreading (Udvardy 2004). We recommend starting the control of this species in settlements by treating seed-bearing individuals and groups of shoots with numerous stems as soon as possible. In both Zebegény and Nagymaros, there are dominant sources of propagules, and their effective elimination can limit the further rapid spread of the tree. This is also important because in rainy weather, the samaras of the tree of heaven can easily be picked up by vehicles (e.g., wheel drums) and fall out farther in the forest. So, by managing the hotspots, the chances of them getting into the forest area can be reduced.

Based on our surveys of road networks in the forest area, the tree of heaven occurs with substantially greater frequency and abundance along regularly used roads and in cuts (in our case generally in forest stands with artificial canopy gaps) than in areas affected by other uses. For example, in the strictly protected area, which is free of forestry intervention, its occurrence was spectacularly lower. Consequently, it can be said that any disturbance of closed vegetation paves the way for its emergence. This is in line with the results of a study in a lowland forest-steppe forest (Erdélyi et al. 2021) and several studies in other countries (e.g., Carter and Fredericksen 2007, Radtke et al. 2013, Rebbeck et al. 2017). It is also important to emphasise that there are significantly fewer regularly used forest roads and skid trails in the strictly protected area. The routes observed in this area were mainly tourist paths and abandoned forest roads or other roads (old cart roads). It is important to note, however, that the spread of the tree of heaven is not only occurring in oak stands that are typically exposed to light, but also in cooler, shadier beech stands. According to Korda (2018), there were attempts to cultivate the species in beech-growing areas in Hungary in the 19th century, e.g. in the Pilismaróth manor (Hoffmann 1875). With regard to Börzsöny, only one work published in 1963 provides some information (Danszky 1963). However, in this work, as in most of the literature on the use of this species, it was only recommended as a companion species for the driest habitats (in this area, with resident manna ash and mahaleb cherry (*Prunus mahaleb*) scrubs). It is likely that there was no significant introduction of the tree of heaven into the forests of Southern Börzsöny, and that its advance, as seen in our study, can only be considered as the result of a combination of spontaneous processes and anthropogenic disturbance. Until now, the nature conservation and forestry problem caused by the tree of heaven was typically dominant in the plain areas, but due to climate change, this is no longer necessarily true. This is illustrated by a study carried out in Italy (Motti et al. 2021), which found that the limit of expansion of the tree species was 11.1 °C mean annual temperature, which corresponds to an average altitude of 900 m above sea level under the local climatic conditions. As our mountain forests are not immune to the effects of climate change, further spread of the tree of heaven is likely. The low number of the tree of heaven occurrences in open areas in our survey contrasts with the literature, since the study area is essentially a forest, where open areas larger than one tree height across are rare.

The 193 occurrences in forest areas indicate the presence of the tree of heaven in 56 of the 238 forest subcompartments in the survey area, while the data of the National Forestry Database indicates its presence in only 23 subcompartments – 20 of which are mentioned in the notes and another 3 in the dominant species section (with a proportion of 5-5-10%). Of the 23 subcompartments, 17 belong to Zebegény, and 6 to Nagymaros. The data of previous forest mappings indicate the presence of the tree of heaven in 60 forest subcompartments out of the 238 forest subcompartments concerned, in a total of 152 different quadrats (50 m × 50 m). Of these quadrats, only 15 cases coincide with the points we recorded. The low correspondence can be explained by the fact that while the routes we surveyed very often follow the boundaries of forestry compartments, the two previous mapping exercises have a consistent point data survey covering the whole forestry compartment.

Damage from big game species is also significant and is most drastic on south-facing slopes. The bare soil surfaces created in a short time by big game species, and the resulting numerous problems should be addressed first by changing local game management practices. The identification and management of old seed-bearing individuals is of key importance, as they can play a central role in the invasion of gaps. In parallel with the reduction in the populations of big game species, the spread of the tree of heaven would thus be drastically reduced, as fewer conditions would be conducive to its establishment.

A relatively new area of knowledge about the tree of heaven, and biological invasions in general, is the assessment of societal attitudes. The importance of this under-researched topic is being increasingly recognised. While the problems posed by invasive species are well known and obvious to those involved in invasion biology, conservation, forestry and agriculture, the majority of society has little knowledge of the problem. A more widespread and centralised approach to invasive species would contribute significantly to the effectiveness of solutions. A recent survey in Berlin showed that, although most respondents recognise the tree of heaven by sight, only a few knew its name, and its presence in planned and designed green spaces was generally accepted by the majority, while escaped specimens were considered inappropriate in urban environments. Furthermore, survey respondents who identify themselves as fond of nature have a generally positive view of the tree of heaven, and are mainly in favour of 'leaving it alone' when it comes to management (Kowarik et al. 2021). In the Hungarian context, questionnaire-based research on the issue of the species includes a survey of national park directorates and state forestry departments to explore the economic importance of the species and the costs of its control (Demeter et al. 2015), and another survey of local authorities' attitudes towards the species (Demeter et al. 2017), but the exploration is far from complete (Meinhardt et al. 2022). Therefore, informal and easy-to-understand communication with an ecological perspective can also be effective in reducing the stands of this species on a voluntary basis. Awareness-raising and the involvement of society to bring the problem to the public's attention is therefore an important task.

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A mirigyes bálványfa (*Ailanthus altissima* (Mill.) Swingle) előfordulásai a Dél-Börzsöny településein és erdeiben

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Összefoglalás: Munkánkban az idegenhonos, inváziós mirigyes bálványfa (*Ailanthus altissima*) elterjedését térképeztük fel és jellemeztük a Dél-Börzsöny mintegy 2100 hektáros területén, a települési és erdei úthálózat mentén. A felmérést alapvetően a tömegesség, az elhelyezkedés, települések esetében a gondozott-gondozatlan jelleg, erdőt illetően a nyílt-zárt állomány viszonyainak függvényében végeztük. A bálványfa egyedeit vagy összefüggőbb állományait kézi GPS segítségével rögzítettük. Új pont akkor került letételre, ha a két egyed vagy állomány közötti távolság meghaladta a 10 métert. A településeken (Zebegény és Nagymaros) összesen 482 előfordulási pontot rögzítettünk. Megállapítottuk, hogy a bálványfa elsősorban a gondozatlan zöldterületeken (38%) és a gondozatlan kertekben (21%) jelenik meg leggyakrabban, illetve jelentős előfordulást rögzítettünk a vasút menti területeken is (18%). A két település közti erdőben folyta-

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tott felmérésünk során 193 előfordulási pontot rögzítettünk. Eredményeink szerint a faj elsősorban a rendszeresen használt erdészeti utak mentén jelenik meg (42%), valamint a legtöbbször felnyílt állományokban (mesterséges lékekben) fordul elő (69%). Vizsgálatunk rámutat arra is, hogy az erdészeti üzemtervi adatok számottevően kevesebb erdőrészletben jeleznek előfordulást (23 db), mint az általunk végzett (56 db), illetve korábban lezajlott erdőtérképezések felmérései (60 db). Eredményeink alapján az antropogén hatások meghatározóak a faj terjedésében. A jövőben exponenciális terjedése várható, így ennek megelőzése érdekében mielőbbi kezelések végrehajtását javasoljuk, a magtermő egyedek gócpontjainak azonnali felszámolásával. Sarkalatos továbbá a társadalmi megítélés és tudás kérdésköre is, mivel a társadalom nagy része általánosságban csekély ismerettel rendelkezik mind a bálványfáról, mind az inváziós növényfajok jelentette veszélyekről. Az ismeretterjesztés ennek következtében potenciális útja lehet a megelőzésnek.

Idézés: Vig T., Erdélyi A., Malatinszky Á. 2023: The distribution of the tree of heaven (*Ailanthus altissima* (Mill.) Swingle) in the settlements and forests of Southern Börzsöny, Hungary. [A mirigyes bálványfa (*Ailanthus altissima* (Mill.) Swingle) előfordulásai a Dél-Börzsöny településein és erdeiben]. Bot. Közlem. 110(2): 167–190. DOI: 10.17716/BotKozlem.2023.110.2.167 (in English with Hungarian abstract)