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Quantitative description and modelling of spatio-temporal patterns of invasive tree species in the forest-steppe forests of the Felső-Kiskunság region

Theses of doctoral (PhD) dissertation

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1. Background and objectives

Biological invasions are now an inescapable problem worldwide. In addition to negative impacts on conservation and ecosystems, agriculture and public health are particularly affected, and significant costs can also be realised in the infrastructure construction and maintenance sectors (Schwoerer et al. 2019; Crystal-Ornelas et al. 2021; Fantle-Lepczyk et al. 2022). Damage from invasive species has reached US $ 1.3 trillion over the past five decades, and costs continue to rise at an exponential rate (Diagne et al. 2021). To date, 37 000 introductions of non-native species have been described, and of these, 3 500 species are confirmed highly invasive (Roy et al. 2023). For plants, new introductions have been documented for 4 700 species (Laginhas et al. 2023). However, this is a low number, as more than half of the world's known vascular flora is found in botanical, domestic and other gardens outside their original ranges (van Kleunen et al. 2018).

Without exception, woody plant species have reached other continents through deliberate introductions. All of the tree species of current concern arrived in Europe by the end of the 18th century at the latest (Nyssen et al. 2018), but in many cases invasions took place after a long time (Kowarik 1995). These include the tree species examined in this thesis, the Tree of heaven (*Ailanthus altissima* (Mill.) Swingle), the Common hackberry (*Celtis occidentalis* L.), the Black cherry (*Prunus serotina* Ehrh.) and the Boxelder (*Acer negundo* L.). In Hungary, the interest in them declined only in the second half of the 20th century. After 150 years of planting and spontaneous spreading, they have become common throughout the country (Bartha et al. 2015; Korda 2018). Their invasion has affected most of Hungary’s lowlands and hilly landscapes, and in the near future the tree species are expected to spread to the mountainous forests as well (Vig et al. 2023).

A number of tested mechanical and chemical methods are now available for the control of invasive tree species (Csiszár and Korda 2017; Weidlich et al. 2020). Interventions are typically costly and therefore almost exclusively carried out within the framework of tenders. Volunteer work is also becoming increasingly popular (Dechoum et al. 2019), which can help in particular with post-treatment regarding tree species. However, the success of controlling efforts is largely determined by how much we know about these species. The planning of interventions can actually determine the outcome, and if we lack knowledge of past and present conditions, this can easily lead to sub-optimal use of resources and reduced effectiveness of interventions. It is therefore necessary to produce data series that describe current occurrence and abundance relationships in a spatially realistic way. Based on these data, management plans can be developed to reduce or even eliminate the threat of invasive tree species in the longer term and at lower cost. In addition to provide a realistic description of current conditions, it is also worth exploring past events, as this provides the basic framework for interpreting a biological invasion and identifying the invasive behaviour of a species. It is also important to understand in detail the characteristics of dispersal dynamics, including the causal relationships of often abrupt changes in abundance, and the identification of factors that inhibit or significantly restrain dispersal. The doctoral thesis addresses the tasks outlined above, and thereby seeks to contribute to nature conservation efforts on the one hand, and on the other hand to propose, by means of quantitatively supported arguments, proposals for rethinking certain elements of conventional forest management.

The main objectives of the PhD research were the following:

1. to investigate the spreading history of the four invasive tree species studied using six different approaches at the local scale
2. to assess and describe the occurrence and abundance relationships of the invasive tree species at a fine scale (spatially realistic), with particular attention to the problems arising from sampling intensity
3. to assess variables explaining the spread of invasive tree species - with particular attention to propagule pressure, host environment and disturbance
4. to investigate the possibilities for control using a set-up experiment for the Tree of heaven and the Common hackberry.

2. Materials and methods

Study site

In the Felső-Kiskunság region there are still fragments of forest-steppe forests of high conservation value. The study was carried out in the Peszér-forest and, to a lesser extent, in the Kunadacs-forest. In both areas, there are several valuable habitats, of which the stands of the Euro-Siberian steppic woods with *Quercus* spp. (91I0) are outstanding. In addition to these, there are diverse sandy grasslands, fens and marshes with shrublands and forests of different composition. Besides oaks, Grey poplar (*Populus* x *canescens*) and Black locust (*Robinia pseudoacacia*) make up the majority of the forests, with Common hawthorn (*Crataegus monogyna*) as the leading shrub. The Peszér-forest has a longer "forested" history, while the greater part of the Kunadacs-forest originates from the new plantations in the 19th and 20th centuries. A common problem in both places is the four invasive tree species, which are able to spread and dominate in all closed forest and forest-steppe habitat types except the densest shrublands.

Exploring the spreading history of the four invasive tree species in the Peszér-forest

The historical reconstruction of the spread of the tree species was carried out using a combination of six following methods:

1. a literature survey assessing a summary work (Korda 2018) and all the relevant journals
2. processing and mapping of archival and recent forestry data of the area
3. processing of data from the full-coverage survey of the Peszér-forest (see next subsection) and additional field data collection for dense stands
4. identification of the oldest tree individuals, and annual ring counts
5. hotspot analyses using the data from the full-coverage survey
6. collection of local knowledge.

The problem of estimating the occurrence and abundance of invasive tree species

The occurrence and abundance of the four invasive tree species were surveyed in the Peszér-forest and Kunadacs-forest between 2017 and 2019. Data were collected according to a 25 × 25 m grid, which therefore represented a full-coverage survey instead of sampling. The survey covered 450 forest subcompartments (60 forest compartments) with 24 905 survey units of 625 m^2, defined by the grid. Abundance data were collected by two groups per tree species. Individuals belonging to the group dbh ≥ 5 cm were counted and the mean diameter for the group was recorded, and the number of vital saplings belonging to the group dbh < 5 cm (excluding seedlings) was estimated. The data collected at nearly 100% resolution allowed to perform simulations at lower sampling intensities and to compare the resulting estimates with the results of the full-coverage survey. I investigated the problem at the spatial scales of forest subcompartments, compartments and the two forest blocks, according to the two diameter classes of the four tree species, using a resampling procedure (500 replicates, back-sampling) and spatially uniform point distribution. The simulated sampling intensities were 2%, 5%, 10%, 25% and 50%.

Investigating cause and effect relationships in the spread of invasive tree species

I examined the occurrence and abundance patterns of invasive tree species in relation to propagule pressure, vegetation structure and, in the case of the Tree of heaven, silvicultural practices. For the assessment of propagule pressure, I used the data from the full-coverage survey. The explanatory variable was approximated by the product of the number of individuals and mean diameter recorded in the dbh ≥ 5 cm group. The dependent variable was the number of individuals recorded in the dbh < 5 cm group. Data were analysed using generalized linear models by three spatial scales (survey units, surrounding 8 and 24 survey units, or a combination of these) and three groupings (complete dataset, stands older than 20 years, stands not disturbed since the 1990s), for a total of 60 different cases.

Causal relationships related to vegetation structure were explored using data from 563 quadrats (5 × 5 m) in five first-round treatment stands of the Peszér-forest of different ages and use histories. Dependent variables were the number of individuals of the four invasive tree species counted in five height classes, and explanatory variables were recorded in eight groups using continuous or categorical estimates. Data were analysed using descriptive statistics and generalized linear models for 62 different cases.

The relationships between the spread of the Tree of heaven and silvicultural practices were investigated by comparing pre- and post-cut conditions (BACI approach) and the role of stump deposits. In the former case, the survey method was adapted to the full-coverage survey, while in the latter case, data were collected according to an individual layout using transect sampling. Data were analysed using simple statistics (e.g. Kruskal-Wallis, Dunn test).

Investigating the possibilities to control the Tree of heaven and the Common hackberry

I investigated the dynamics of the (re)spreading of the Tree of heaven and the Common hackberry, and also their seed bank behaviour in an *in situ* experiment in a stand of the Peszér-forest, which has not been disturbed since the 1990s.

The experiment was set up in 2019, in 12 quadrats of 625 m^2 in 3 replicates as follows: 1) single treatment (2019), 2) continuous treatment (2019–2022), 3) continuous treatment (2019–2022) with buffer zone establishment, 4) control (no treatment). In all cases, treatments consisted of complete removal. Invasive tree species were counted by five height classes in a central arrangement of 9 plots per quadrat in each year. In addition to variables describing the experimental setting, 13 environmental explanatory variables were recorded and additional analyses were performed for mortality and herb layer in an individual sampling design. Data were analysed with descriptive statistics, generalized linear and generalized mixed models (using variable-interactions).

3. Results and discussion

Reconstructing the spreading history of the four invasive tree species

The first localities of the introductions of the four tree species in the Peszér-forest have been identified with a high degree of accuracy, most notably the northern forestry house and its surroundings (e.g. experimental forest, former nursery). Only the Black cherry was known with certainty, but the other three species were likely to have been present in the area by the late 1930s at the latest. Based on the circumstances of the first occurrences, accidental introduction could be excluded with a high probability, so that the first introduction of the species was by man. The first introduction sites and dates were determined from the literature for the Tree of heaven and the Black cherry, from counts of the annual rings of old trees for the Common hackberry, and from forestry records for the Boxelder. The Tree of heaven and the Boxelder were certainly not planted after the 1950s, but the Common hackberry and the Black cherry were still used occasionally until the 1990s. In addition to field data, this was supported by local knowledge and hotspot analysis. Among the recurrent hotspots identified by hotspot analyses, the strongest were found in the same locations as the first introductions of the Tree of heaven and the Boxelder. However, for the Black cherry and the Common hackberry, these partly fell on the locations of identified or probable later plantings. An important finding was that the rapid invasion (population burst) of the four tree species happened simultaneously only at the turn of the millennium. Although the frequency of the tree species has increased somewhat over the decades, forestry data and local knowledge suggested that their exponential spread started only 60–70 years after their first (known) occurrence. Local knowledge suggested that this may be due to climate change and rapid changes in game and forest management. Finally, the results (together with the second topic) also highlighted the multiple under-representation of invasive tree species in recent forestry data.

Relationships between sampling intensity and estimation error

The results suggested that the estimation of real occurence and abundance values at the spatial scale of forest compartments and forest subcompartments using low sampling intensities (≤ 10%) is subject to unacceptably high error. The probabilities of estimation error were generally high even at sampling intensities of 25%, and in some cases even simulations at 50% gave unacceptably poor results. At these spatial scales, the probability of "not found" cases (failure to find the species in a given forest compartment/ subcompartment in a simulation) was also extremely high, e.g. ranging from 60-80% at a sampling intensity of 2%. The patterns of error probabilities did not differ between tree species, i.e. the estimation problem is not species dependent. At the forest block scale, however, the estimation error was found to be acceptable even at low sampling intensities, so it can be stated that at the scale of several hundred hectares, data can be collected with sampling intensities of a few %, which give a good approximation. However, this only applies to abundance, not to spatial patterns, because the largly aggregated spatial distribution of invasive tree species – despite correct abundance values – cannot be reproduced with low sampling intensities either. Comparing the estimation error with area size, abundance and frequencies at the forest compartment and subcompartment spatial scales gave significantly negative results in most cases. However, the correlation was much stronger with abundance and frequency than area size.

Cause-effect relationships in the spread of invasive tree species

Examination of the relation between propagule pressure and the abundances of the vital saplings gave significantly positive results for all combinations used. It can be stated that the propagule pressure can be interpreted as a null model of spread regardless of the environment. However, the indices describing the individual effect of propagule pressure were very low, suggesting that other factors may play a more important role in the formation of the occurrence and abundance patterns. Differences between spatial scales suggested that abundance is primarily determined by the closest environment. Differences between groups also indicated differences between the Tree of heaven − Boxelder and the Common hackberry − Black cherry species pairs.

In the vegetation structure investigations, low shrub cover (< 2 m) was the most important explanatory factor among the structural elements that reduce spread. This was particularly true for low height classes (0–25 cm and 25–50 cm) of all four tree species. Canopy cover and upper shrub layer (< 6 m) were also strong regulators, but were generally less important in the best fitted models. An interesting result was, however, that the abundance of Black cherry in the higher classes (> (50–)100 cm) increased with increasing closure. The presence of nearby gaps was significantly positively correlated with the abundances of mainly the Tree of heaven and the Common hackberry. The herbaceous level, consisting of graminoids, had a negative effect on the Tree of heaven, but a positive effect on the Boxelder. Dense weed cover was negatively related to the abundance of the Common hackberry and the Black cherry. Another interesting result was the positive association between the European privet (*Ligustrum vulgare*) and the Common hackberry (0–25 cm). Finally, seeder trees that may have been missed during the first round of treatments showed a positive correlation with the abundances of the Black cherry and the Tree of heaven.

Perhaps the clearest results of the doctoral thesis came from the assessment of the causal relationship between the spread of the Tree of heaven and silvicultural practices. It can be stated, that cuttings (thinning and clear-cutting) accelerated the spread of the tree species in a deterministic manner. In comparison, the increases measured in control stands were orders of magnitude lower. The establishment of stump deposits in the course of clear-cutting and artificial reforestation of stands previously containing the Tree of heaven also guaranteed rapid revitalization of the species. It can be said, that it takes only a few years for seed production to start from the stump deposits, thus identifying these linear structures as central sources of the (re)spread of the species.

Spreading dynamics of the Tree of heaven and the Common Hackberry in relation to different treatments

The results showed that the two species have sharply different dispersal dynamics, and there are also differences regarding the regulators of their dispersal. The treatments in 2019 led to a seed bank burst of the Tree of heaven, but its natural mortality exceeded 90–95% over the years. The Common hackberry showed a more balanced seed bank expression over time, its mortality was relatively low, and by the end of the experiment, having overcome its initial disadvantage, it caught up with the Tree of heaven in terms of abundance. In the once-treated quadrats, the tree species became (on average) more abundant by the end of the experiment than at baseline. The rate of increase also exceeded that in the control quadrats, but in the latter this was only due to seedlings, whereas in the higher classes there was no significant change. During the years of the experiment, eradication was not achieved in any treated quadrats, but the effect of the treatments in the quadrats with the 25 m buffer zone was detectable. In all cases, the experimental setting had the greatest explanatory power for the abundances of the two tree species. For both tree species, closure ratios proved to be equally important regulators. The relative dominance (control) of the Tree of heaven in the upper canopy had a positive effect on the abundances of the saplings of the tree species, whereas a negative effect on the Common hackberry seedlings and saplings. Propagule pressure was found to be important only in the case of Tree of heaven, and herb layer did have a negative effect only on its seedling abundances. The abundance of the Tree of heaven decreased with the thickness of the leaf litter, but a slight positive effect was observed for the Common hackberry. In contrast, the canopy ratio of the Pedunculate oak (*Quercus robur*) (and the Sycamore maple (*Acer pseudoplanatus*)) had a strong negative effect on the abundances of the Common hackberry.

4. Conclusions and recommendations

One of the first tasks in describing biological invasions is to establish a well-supported spreading history. It is in this context that the invasive species themselves can be discussed, and it is in this context that we can best explain to the general public why these human-driven processes are of such concern. One or two methodological approaches are most often used to explore the spreading history of invasive species on large scales. At local scales, however, this is unlikely to be practical because of the low data density. To overcome this, it is therefore worth using several approaches in combination, and using them in a complementary way will make it easier to identify the first introductions and to characterize the spreading process. The results have shown that, although the six approaches used have yielded a lot of new information on an individual basis, it is the combination of these approaches that has made possible to explore the spreading history of the four tree species. For most invasive species, it is not possible to determine the time and place of first introductions due to lack of documentation. In the Peszér-forest, clear documentation was available only for the Black cherry. For the other three tree species, however, in addition to the literature, the examination of old trees, the archival forestry data, and partly the hotspot analyses, made it possible to draw strong conclusions. The circumstances revealed suggested that the tree species were first planted in the area by the foresters of the time. Nationwide, this was relatively 'late', in the 1930s. One of the most interesting results was the simultaneous population burst of the tree species at the turn of the millennium, which represents a lag time of 60–70 years. Similar phenomena have been documented for many plant species worldwide. Based on local knowledge, three near simultaneous changes in the late 1990s have been identified. Drastic changes in forest and game management at the turn of the millennium, and the effects of climate change, which were already being felt from this time onwards, may have contributed to the simultaneous expansion of the four species. The cause was therefore an environmental lag, which has also been detected in the invasions of many species. In addition to describing current occurrence and abundance patterns, recent field surveys and hotspot analyses could also be used as a retrospective tool. Indeed, their application has been successful in inferring the locations of first introductions of the Tree of heaven and the Boxelder from current patterns, and in identifying later plantings of Common hackberry and Black cherry.

Effective control of invasive tree species most often requires data series that closely approximate reality. These can be used to draw up action plans, which include, among other things, a schedule of work and resource allocation. As long as accurate abundance data for closed vegetation conditions and saplings cannot be obtained using remote sensing and other technologies, planning will require data collected through field surveys. The reliability of these will be determined by the sampling intensity used, regardless of the method. While for some forest indicators (density of the main tree species, yield, etc.) good estimates can be made even with very low sampling intensities, this is hardly conceivable for a group of organisms that are essentially uncontrollable by humans. This has been confirmed by the results of simulations in several respects. The spread of invasive tree species is not strictly speaking random, but determined by systemic processes. However, when capturing a snapshot, i.e. when describing occurrence and abundance patterns, it is certainly closer to random from a methodological perspective due to the significant spatial aggregation and the unpredictability. This can only be captured by using high sampling intensities, preferably full-coverage. The results show that this statement is not species-dependent, as all four tree species showed the same patterns regarding sampling error. However, it does depend somewhat on the abundance and prevalence of the species at a given spatial scale. Also, it is important to stress that with low sampling intensities, the probability of failing to find smaller hotspots is very high. These are precisely the hotspots from which invasion is triggered, and finding and treating them would be what we call prevention. The generally high estimation errors obtained in simulations of low sampling intensities could deviate downwards by up to 100% ('not found' cases), but upwards there were overestimates of up to five orders of magnitude. In the tendering context, this can have very serious consequences for the costing of invasive tree species management plans, but also for feasibility in general.

Based on the causal analysis and the results of the *in situ* experiment, it can be concluded that the invasion of the four tree species is controlled by a combination of propagule pressure, vegetation environment and disturbances. These are central tenets of invasion biology and have been confirmed in the Felső-Kiskunság forest-steppe forests from several points of view. If we take these sets of variables into account in our control efforts (by managing, modifying, or abandoning certain elements), we can significantly reduce the rate of spread of the four tree species. Without seed-bearing individuals, invasions would of course not take place, so eliminating seeder individuals as soon as possible is a priority. At the same time, the targeted search for seeder individuals that may have been missed during treatments is at least as important, because they will be the first to determine the future population density (the closest environment is the most important). If a treatment is started, we must undertake the work that will take several years, otherwise the situation could be much worse than if we had done nothing, due to the disturbance. On the other hand, it might be worth inserting a waiting period between treatments, which could be as long as 5–10 years. In all cases, the most important objective is to ensure that viable seeds on the soil surface or in the topsoil lose their ability to germinate. This takes time, but for the four tree species, even a few years can make a big difference. On the other hand, natural mortality should not be ignored in the case of germinated and growing specimens, because if the mortality rate of the Tree of heaven in the experiment is taken as a basis, then this also means a significant reduction in management costs. The results highlight the fact that oak stands, often ignored in lowland forest management, are in fact much more resistant to the invasion of the non-native tree species than seemingly better conditioned but simpler poplar, Black locust and other plantations. The protection of lowland oak stands is justified not only because of their conservation value, but also because they are certainly more resistant to invasion by tree species in the longer term. For example, in the oak stands in the Peszér-forest, which have not been disturbed since the 1990s, the Tree of heaven and the Boxelder have been practically driven out. Preserving and facilitating the establishment of more natural conditions could certainly reduce these forests' invasibility. This includes the need to stop disturbance after treatments. In particular, it is important to pay more attention to shrub cover in general and to consider planting shrubs alongside the main tree species in artificial reforestations. The results showed that shrub cover is the primary line of defense against the invasion of the four tree species. Its protection would also be justified during cutting, since the invasion of e.g. the Tree of heaven in the forest-steppe forests is primarily due to silvicultural activities. In these forests, it would therefore be advisable to at least exclude the preliminary cuts during raising the stands, but also to carry out further cuts with less vigor and frequency.

5. New scientific results

The new scientific findings of the thesis are summarised as follows:

1. Development and testing of a new combined methodology for exploring the spreading history of invasive tree species at the local scale
2. Using low sampling intensities, the occurrence and abundance of invasive tree species can only be estimated with unacceptably high error at forest compartment and subcompartment spatial scales. Real conditions can only be approximated by full-cover field surveys
3. Propagule pressure estimated at forest subcompartment spatial scale is positively correlated with sapling abundance for all four tree species. Depending on stand age and use background,

it is more decisive for anemochor species (the Tree of heaven and the Boxelder) than for zoochor species (the Common hackberry and the Black cherry)

4. Vegetation structure plays an important regulatory role in the spread of all four tree species. The most dominant vegetation structure element regarding the abundance of seedlings and young (0–25 cm) saplings of the four tree species in the Peszér-forest is the low shrub level (< 2 m) and to a lesser extent the canopy level. It is recommended to reduce the frequency and intensity of felling and, above all, to avoid preliminary cuttings in order to maintain the protective effect of the shrub layer
5. Selective cuttings, clear-cuttings and the creation of stump deposits accelerate the invasion of the Tree of heaven by orders of magnitude compared with its spontaneous spread. The sudden spread of the species occurs deterministically even in the presence of a few seed-bearing individuals
6. Even in the short term, single treatments can lead to much less favourable conditions than if no intervention had been carried out. Therefore, treatments should only be started if follow-up treatments are assured in the following years. Treatments that increase the closure deficit have a positive effect on the Tree of heaven seed bank, but not on the Common hackberry's. However, the mortality rate of the former is many times higher than that of the latter, and within a year or two the abundances of the two species will equalise as they revitalise their stands
7. The propagule pressure and herbaceous level are much more important in the recolonisation of the Tree of heaven from seed (from the environment and the local seed bank combined) than in the case of the Common hackberry. For both species, the co-closure of woody vegetation, the thickness of the leaf litter, the stand-forming tree species, especially pedunculate oak, are important regulators.

New scientific advances:

1. Reconstruction of the spreading history of the Tree of heaven, Common hackberry, Black cherry and Boxelder in the Peszér-forest: a.) identification of the first place and estimated time of introduction of the tree species; b.) identification of the slow spread ('lag time') of the tree species locally for 60–70 years and the simultaneous 'burst' of the populations at the turn of the millennium c.) Identification of the differences between the spread of the Tree of heaven and Boxelder species pairs, and the Common hackberry and Black cherry pairs, and the demonstration of the potential for tracing undocumented plantings using hotspot analyses; d.) the usefulness of local knowledge in distribution-history reconstructions
2. Estimation error decreases with increasing abundance and frequency of invasive tree species and with increasing sample area size
3. As shrub and canopy closure increases, the abundance of the saplings of the Tree of heaven, Common hackberry and Boxelder decreases, but the higher saplings of the Black cherry (> 50–100 cm) are positively affected by a more closed vegetation
4. The presence of gaps has a positive effect on the sapling abundance of the Tree of heaven, Common hackberry and Boxelder, but no effect on the Black cherry
5. The abundances of the four tree species are significantly influenced by the composition of the herbaceous layer, including the occupation of space by graminoids and weeds

6. The European privet plays an important role in the survival of the seedlings of the Common hackberry
7. Seed-bearing individuals of invasive tree species that may have been missed in first-round treatments continue to contribute significantly to the abundances of the vital saplings, therefore their continous search and removal is essential
8. The spatially and temporally sequential cuts lead to the "exponential rotational dynamics" of the Tree of heaven (the conceptual hypothesis, however, requires further investigation)
9. Buffer zone treatment can significantly reduce the rate of spread of the Tree of heaven and Common hackberry, but maintaining a distance of 25 m and 3 years of treatment are certainly not sufficient for eradication

6. Most important publications

English, peer-reviewed WoS/Scopus journals

Erdélyi A., Hartdégen J., Malatinszky Á., Vadász Cs. (2023): Historical reconstruction of the invasions of four non-native tree species at local scale: a detective work on Ailanthus altissima, Celtis occidentalis, Prunus serotina and Acer negundo. *One Ecosystem* 8: e108683. https://doi.org/10.3897/oneeco.8.e108683 (Q1)

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. *Botanikai Közlemények* 110(2): 167-190. https://doi.org/10.17716/BotKozlem.2023.110.2.167 (Q2)

Hungarian, peer-reviewed journals

Vig T., Erdélyi A., Malatinszky Á. (2023): A mirigyes bálványfa (Ailanthus altissima [Mill.] Swingle) elterjedésének jellemzése a Dél-Börzsöny területén. *Erdészeti Lapok* 158(4): 164-169

Molnár, Á. P., Erdélyi, A., Hartdégen J., Biró M., Pánya I., Vadász, Cs. (2022): Természetvédelmi célú történeti elemzés – a Peszéri-erdő elmúlt három évszázada. *Tájökológiai Lapok* 20(1): 73–105. https://doi.org/10.56617/tl.3381

Erdélyi A., Hartdégen J., Malatinszky Á., Lestyán Cs. J., Vadász Cs. (2021): Egyes erdőgazdálkodási tevékenységek hatása a mirigyes bálványfa (Ailanthus altissima (Mill.) Swingle) terjedésére meszes homoki termőhelyeken. *Erdészettudományi Közlemények* 11(1): 1-13. DOI: 10.17164/EK.2021.002

Erdélyi A., Hartdégen J., Malatinszky Á., Lestyán Cs. J., Vadász Cs. (2021): Egyes erdészeti beavatkozások hatása a mirigyes bálványfa terjedésére meszes homoki termőhelyeken. *Erdészeti Lapok* 156(4): 142-147

Erdélyi A., Hartdégen J., Molnár Á. P., Hajagos G., Vadász Cs. (2019): A mirigyes bálványfa (Ailanthus altissima (Mill.) Swingle) finomléptékű elterjedésének vizsgálata archív és recens

adatok alapján a Peszéri-erdőben. *Tájökológiai Lapok* 17(1): 75-84. https://doi.org/10.56617/tl.3466

English, conference proceedings

Erdélyi A., Hartdégen J., Malatinszky Á., Vadász Cs. (2021): Silvicultural Practices as Main Drivers of the Spread of Tree of heaven (Ailanthus altissima (Mill.) Swingle). *Biology and Life Sciences Forum* 2(1):17. https://doi.org/10.3390/BDEE2021-09467

Hungarian, conference proceedings

Andrési D., Bárány G., Erdélyi A., Heilig D., Madácsi S., Vadász Cs. (2023): Megújult a Peszéri-erdő, az OAKEYLIFE projekt eredményei. In: Csiha I. (ed.): Alföldi Erdőkért Egyesület Kutatói Nap: Tudományos eredmények a gyakorlatban. Alföldi Erdőkért Egyesület, Kecskemét. pp 183-188. ISSN 2063-8256

English, presentation and poster abstracts

Erdélyi A., Hugyecz M., Pálfi M., Lerch T., Hartdégen J., Malatinszky Á., Vadász Cs. (2023): Common hackberry (Celtis occidentalis L.): a warning from Hungary. In: Pérez Diz M., González N. N., González L., Rodríguez B. (eds.). Book of Abstracts - III International young researchers Conference on Invasive Species. ISBN 978-84-09-51676-6

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