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Silvicultural Practices as Main Drivers of the Spread of Tree of Heaven (*Ailanthus altissima* (Mill.) Swingle) †

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Abstract: The impacts of anthropogenic disturbances on the spread of invasive species is one of the central issues of invasion biology. In our study, we aimed to investigate the relationship between certain silvicultural activities and the spread of Tree of Heaven (*Ailanthus altissima*) in calcareous sand forests (Peszéri-erdő, Central Hungary). We applied full-cover mapping (25 × 25 m grid) and BACI design to monitor the effects of clear-cuttings and selective thinnings on the prevalence and abundance of *A. altissima* in several stands (in total 26 ha). We also investigated young and middle-aged artificial reforestations (4 to 26 yrs.), where stump deposits were made (in total 30 ha). Our results indicate that silvicultural practices may significantly contribute to the spread of *A. altissima*. One or two years after the accomplishment of selective thinning or clear-cutting, the increase in both the small-scale prevalence and the total abundance of *A. altissima* was significantly higher compared to control stands. Stump deposits proved to be deterministic in the spread of *A. altissima*. A decrease in the abundance of *A. altissima* was observable only in one forest stand where verticillium wilt infection was detected, indicating a biological opportunity to control the spread of *A. altissima*.

Keywords: Tree of Heaven (*Ailanthus altissima*); invasive tree species; anthropogenic forest disturbances; logging; selective thinning; clear-cutting; stump deposit; verticillium wilt

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1. Introduction

Ailanthus altissima (Mill.) Swingle (Simaroubaceae) is considered among the worst invasive tree species on the globe. Numerous studies have been conducted to understand its characteristics, social behaviour and various impacts on different community types. *A. altissima* is native to China and North Vietnam, where it is a frequent component of broadleaf forests [1]. During the last three centuries, it has successfully colonized several types of habitats within the temperate to meridional zones in all continents (except Antarctica) [1]. After its first introduction to Paris in 1751 [2], it had become soon a popular exotic tree for several purposes in Europe [1]. In Hungary, *A. altissima* is certainly present at least since 1802 and had been widely used in e.g., forestry, gardening, urban development and agriculture in the last two centuries [3]. By now, it is present all over the country and considered highly undesirable in almost every sector (except occasionally honey making), so nature conservation and economic goals usually meet in this issue.

A. altissima reproduces from wind-dispersed seeds (samaras) and root suckers as well. Seed production can start at the age of 4–5 years [4], but precocious flowering has been observed in 6-week old seedlings as well [5]. Germination rate and seed viability have been investigated under different circumstances in several studies and proved to be extremely high, as sometimes both exceeded 50% averages [4,6,7]. The root suckers usually grow faster than the seed individuals and mechanical impacts can significantly increase their density [3,8]. *Ailanthus altissima* is often mentioned as an early successional, forest edge or gap species as it is usually more successful in habitat patches with higher light availability [1,9,10]. However, it can also be persistent under low light conditions as seeds can germinate and seed or sprout individuals can survive for several years [9,11].

Human-mediated disturbances have been already identified as crucial factors in the invasion of *A. altissima* on both site [12] and regional scale [13]. Although the ecology of *A. altissima* in the urban-industrial environment is relatively well known, only a few studies have investigated how forestry interventions influence its invasion in forests [14]. In general, logging inevitably leads to an expansion of habitat patches in earlier successional stages with a dramatic increase in light availability and soil disturbance. *A. altissima* is capable to utilize these new gaps or opened areas more efficiently and reach the canopy level much faster, than the native tree species [9]. Rebbeck et al. identified timber harvest as the primary predictor of the distribution of *A. altissima* regarding both its presence and density [15]. Carter & Fredericksen documented a significant increase in logged sites of non-industrial private forestlands [16]. Radtke et al. showed that coppice management also favours the invasion of *A. altissima*, and the spread synchronizes with the coppice cycle [14].

Stump removal with heavy machinery is a common silvicultural practice applied worldwide in mainly intensively managed forests and tree plantations. During artificial reforestations after clear-cutting, the stumps are twisted out from the ground, then usually burned or ground. In the case of grinding, the wood chips can be used in many industries including biofuel, paper and mulch production [17]. In Hungary, stump removal is a widely used silvicultural practice especially in the case of lowland forests. However, it is also common that the tree stumps are stacked together in linears and just left at the clear-cut area—due to financial reasons. After stump stacking and waste wood managing the clear-cut area is ploughed. Deep ploughing with other accessory operations usually result in the destruction of any living plants, and also the majority of the viable seeds are buried in deeper soil layers. It is observed in Hungary that *A. altissima* is able to revitalize from stump deposits, but no published information is available on this topic. As linear stump deposits are frequently made in the Hungarian lowland forests for at least 60 years, they might have played a significant role in the invasion of *A. altissima*.

We have revealed the history of the spread of *A. altissima* in the Peszéri-erdő on the stand level in our previous work—based on archive and recent forest inventory data (National Forestry Database), our own field surveys and interviews with the locals [18]. The first occurrence could have been identified at the forest's experimental stand around the 1930s [19]. However, the population explosion of *A. altissima* eventuated much later, at around the millennium [18]. Our goals in this study were: (i) to investigate the changes in the prevalence and the abundance of *A. altissima* following BACI design in forest stands, where selective-thinning or clear-cutting was implemented or was no intervention, (ii) to compare the scale of the invasion of *A. altissima* in artificial reforestations of different ages, where stump deposits were made, (iii) to evaluate the role of stump deposits in the spread of *A. altissima* via abundance-distance measurements.

2. Materials and Methods

2.1. Study Area

The field surveys were carried out in the Peszéri-erdő, Central Hungary. The 1628 ha forest steppe habitat complex is a part of the European Natura 2000 network (ID: HUKN20002). The Peszéri-erdő situates in the westernmost segment of the Eurasian forest steppe zone. It is located at the Danube-Tisza interfluve region, at the north-western border of the Sandhills of Kiskunság. The landscape is characterized by sandhills and depressions, the altitude ranges between 97–106 m above sea level. The main soil type is calcareous sand with various humus content. Temperature maximum can reach 35 °C in summer, and can fall to −16 °C in winter, the average annual precipitation is 550–570 mm. The intensification of forest management in the area had started in the middle of the 19th century, but the high-scale conversion of the—presumably in great extent semi-natural—forest stands took place during the 20th century. In the present time, the forest stands of the Peszéri-erdő can be considered highly mosaic on a multilevel scale regarding to species composition, structure and naturalness. Dominant tree species are firstly poplars (*Populus* spp.), secondary black locust (*Robinia pseudoacacia*) and pedunculate oak (*Quercus robur*). It is important to mention, that the shrub layer is usually very dense, dominated by hawthorn (*Crataegus monogyna*). Besides *A. altissima*, the Peszéri-erdő is threatened by other highly invasive tree species, such as common hackberry (*Celtis occidentalis*), black cherry (*Padus serotina*) and boxelder (*Acer negundo*).

2.2. Study Design

Field data collection of the baseline conditions for the (i) and (ii) surveys and the re-mappings in the case of the (i) survey were implemented according to the invasive tree monitoring protocol developed by the authors in the OAKEYLIFE project. For the (iii) survey a different methodology was set up.

We applied full-cover mapping to collect prevalence and abundance data of *A. altissima* and other invasive species in the forest stands of Peszéri-erdő. This means that instead of sampling an area, it is mapped in its full scale. To prepare the spatial units of data collecting the Peszéri-erdő was covered by a 25 × 25 m grid, then an attribute table containing the necessary variables was attached to each 25 × 25 m assessment units. We collected data on the field using ArcPad run on a field tablet. The data are documented directly in GIS, so can be managed easier later. Stem numbers (ramets) of *A. altissima* was recorded in every assessment units according to a diameter limit of 5 cm dbh. The abundance of those individuals that survived the seedling phenophase (in our case the first or second vegetation period) with dbh < 5 cm were estimated on an ordinal scale from 0 to 5000. Stems with dbh ≥ 5 cm were counted in every assessment units. In this study the protocol was applied for the (i) and (ii) surveys. To assess the extent of the invasion and the (potential) propagule pressure separately, 5 cm dbh is locally the best approximate value regarding the maturation of *A. altissima*. In this study we focus on the dbh < 5 cm fraction—as it expresses the spatial distribution of invasion better—and only describe the relationship between the two categories in some particular cases.

For the (i) survey we collected data in the Peszéri-erdő following the interventions (selective-thinning or clear-cutting) of the local systematic silvicultural management. The baseline conditions for *A. altissima* were mapped in the 2017–2018 and the 2018–2019 dormant periods, and the re-mappings were implemented in the 2019–2020 dormant period. Re-mappings took place after the first or the second vegetation period following the selective-thinning or clear-cutting. In this way, only those saplings of *A. altissima* were recorded, which survived at least their first vegetation period after the intervention. In the case of clear-cuttings, the stands were reforested naturally via root suckering and stump sprouting. All of the investigated forest stands were dominated mainly by grey poplar (*Populus* × *canescens*), secondly by *R. pseudoacacia*. Canopy cover and environmental conditions were similar according to the forest inventory data and our field experiences. The forest stands all had a dense shrub layer, and the tree canopy- and shrub cover together always exceeded 90–95%. For selective thinnings 67 assessment units in 3 forest stands, for clear-cuttings 238 assessment units in 4 forest stands were investigated in a total area of 17.7 ha. Altogether 132 assessment units in 5 similar forest stands, in total 8.4 ha were selected randomly as control. Our main goal in this survey was to determine if there is any significant difference in the spread of *A. altissima* due to the forestry interventions. Therefore we performed Kruskal-Wallis test on the assessment unit level on the differences between the before–after values of stem numbers in the case of clear-cutting, selective thinning and control. We applied Wilcoxon signed-rank test on the assessment unit level to identify the significances among the three cases. Data analyses were implemented on the dbh < 5 cm fraction.

For the (ii) survey we sorted out all of the artificial reforestations with stump deposits in the Peszéri-erdő. Then we selected all the stands, in which (a) the dominant tree species was *P.* × *canescens*, occasionally accompanied with poplar clones and *R. pseudoacacia*, (b) *A. altissima* was indicated in the data archive in the former stand. According to the forest inventory data, the main stand attributes were similar. The shrub layer—as usually in artificial reforestations—was absent or presented by scattered, small patches. Altogether we investigated 540 assessment units in 13 stands between the ages of 4–26 years in a total area of 30.1 ha. The aim of this survey was to identify if there is any relation between the age and the scale of the invasion of *A. altissima*, therefore a linear regression model was used on the level of the assessment units. Data analyses were implemented on the dbh < 5 cm fraction.

In the case of the (iii) stump deposit survey, data collecting was based on sampling and executed in two neighbouring, a 7 years old and a 26 years old *P.* × *canescens* artificial reforestations—which were also included in the (ii) survey. The stump deposits and the directly adjoining stand parts were divided into three, 5 m wide and 100 m long parallel transects. The 1. transect was the stump deposit with an average width of 5 m, the 2. transect started from the foot of the stump deposit and ended at 5 m distance, the 3. transect situated in the 5–10 m distance from the foot of the stump deposit. Every transect was divided into ten sampling units (5 × 10 m), in which the stem numbers of *A. altissima* was recorded in the same way described earlier, except individuals with dbh ≥ 10 cm were counted separately. Three transect triplets were investigated in the 26 years old stand and two transect triplets were investigated in the 7 years old stand (due to spatial limits), so altogether 150 sampling units were assessed, in total 0.55 ha. Our aim in this survey was to identify how the stem numbers of different dbh fractions of *A. altissima* change with the distance from the stump deposit. Therefore we compared the stem numbers of the transects on the sampling unit level using Wilcoxon signed-rank tests in every dbh fractions and then evaluated the significances. With the results of the (ii) survey our main goal was to highlight if the stump deposits do play a determining role in the spread of *A. altissima*.

3. Results

3.1. The Impacts of Selective Cuttings and Clear-Cuttings on the Spread of A. altissima (i)

The prevalence and abundance of the dbh < 5cm fraction of *A. altissima* has increased in almost all the investigated stands within 1–2 vegetation periods (Table 1). However, the Kruskal-Wallis test indicated (H = 114, $p \ll 0.05$) that there is a difference in the growth of abundances between selective cuttings, clear-cuttings and controls concerning every assessment unit ($n = 437$) of all the stands ($n = 12$). Therefore the growth values were individually tested in the three cases with the Wilcoxon tests. The results showed that the abundance of *A. altissima* significantly increased in the stands in which selective thinning (W = 25, z = −6.05, $p \ll 0.05$) or clear-cutting (W = 1234, z = −11.69, $p \ll 0.05$) was implemented. On the other hand, there was no significant growth in the the control stands (W = 3610, z= 0.02, $p = 0.51$). The differences in the main values are shown in logarithmic scale in Figure 1. The total of stem numbers was multiplied on average by 74 in selective cuttings, by 8 in clear-cuttings and only by 1.3 in control stands. Based on the recorded stem numbers in the dbh > 5 cm fraction and the dbh < 5 cm fraction, they are clearly not in any relation regarding stem number growth in the dbh < 5 cm fraction. There was only one control stand, where the stem numbers decreased, in Kunpeszér 6B stand we observed that *A. altissima* individuals were suffering from verticillium wilt infection.

Table 1. The main results of the impacts of forestry interventions on the prevalences and abundances (stem numbers) of *A. altissima* on stand level. Stem numbers are expressed to 1 ha.

Stand ID (National Forestry Database)	Assessed area (ha) / stand area (ha)	Forestry intervention	Stem numbers / 1 ha (dbh > 5 cm)	Prevalence (%) before	Prevalence (%) after	Stem numbers before / 1 ha (dbh < 5 cm)	Stem numbers after / 1 ha (dbh < 5 cm)	Stem number growth (dbh < 5cm)
Kunpeszér 3 E	4.1 / 8	Clear-cutting	50	59	97	175	12 000	x 68.5
Kunpeszér 4 G	5.9 / 5.9	Clear-cutting	110	77	99	1600	4 000	x 2.5
Kunpeszér 8 C	2.3 / 2.3	Clear-cutting	250	100	100	5000	42 000	x 8.4
Kunpeszér 14 A	1 / 2,9	Clear-cutting	3	17	98	15	4 000	x 266.6
Kunpeszér 26 I	2.4 / 2.4	Selective cutting	9	59	69	80	265	x 3.3
Kunpeszér 27 B	1.2 / 2.2	Selective cutting	3	54	82	60	235	x 3.9
Kunpeszér 27 E	2.7 / 3.6	Selective cutting	64	30	100	200	38 500	x 192.5
Kunpeszér 6 B	1.9 / 1.9	Control	127	98	100	1700	1 200	x 0.7
Kunpeszér 11 B	0.6 / 0.6	Control	157	87	100	2800	6 000	x 2.1
Kunpeszér 10 C	1.7 / 1.7	Control	40	44	65	320	330	x 1
Kunpeszér 23 D	1.7 / 1.7	Control	7	62	50	510	1 100	x 2.1
Kunpeszér 23 E	0.6 / 7.2	Control	28	84	92	1500	5 000	x 3.3

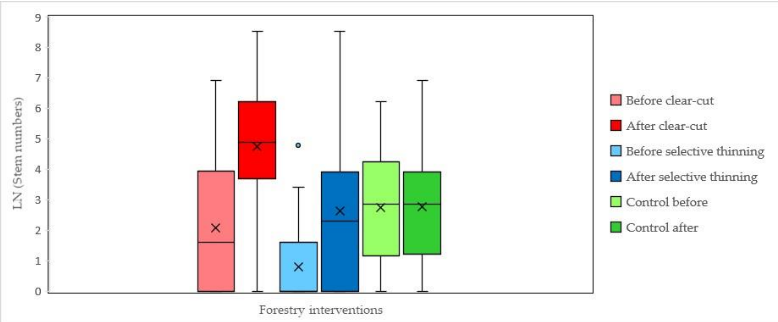

Figure 1. The main changes in the abundances of the dbh < 5 cm fraction of *A. altissima* due to forestry interventions in logarithmic scale.

3.2. The Impacts of Stump Deposits on the Spread of A. altissima (ii, iii)

The abundance of the dbh < 5 cm fraction of *A. altissima* in artificial reforestations proved to be slightly variable between the stands (Table 2.). However, the linear regression ($R^2 = 0.2$, $F = 133.9$ $p << 0.05$) showed that the average abundances of every assessment units ($n = 540$) significantly grow with the age of the stands ($n = 13$). The prevalence of *A. altisssima* was high even in the 4 years old stands and a slightly higher on average in all the stands older than 10 years. The difference was clear at the dbh > 5 cm fraction as the stem numbers in all the stands over 10 years were extremely high. This means on the field that *A. altissima* is dominating at least one layer in a forest stand. In the investigated artificial reforestations it was usually the second canopy layer under the poplar canopy, additionally on stump deposits *A. altissima* was frequently monodominant.

Table 2. The prevalences and abundances of *A. altissima* according to the age of the artificial reforestations.

Stand ID (National Forestry Database)	Assessed area (ha) / stand area (ha)	Stand age (years)	Prevalence (%)	Stem numbers / 1 ha (dbh > 5 cm)	Stem numbers / 1 ha (dbh < 5 cm)
Kunpeszér 9 B	2.4 / 2.4	4	90	7	2300
Kunpeszér 25 C	0.8 / 0.8	4	63	0	100
Kunpeszér 26 B	1.8 / 1.8	4	67	0	228
Kunpeszér 5 D	0.8 / 0.8	5	87	28	700
Kunpeszér 7 K	2.2 / 2.2	5	100	53	2000
Kunpeszér 19 B	1.3 / 1.3	7	66	3	270
Kunpeszér 20 J	1.9 / 1.9	7	88	168	4250
Kunpeszér 11 J	6.7 / 6.7	14	94	250	2000
Kunpeszér 11 F	4.5 / 4.5	16	90	530	11700
Kunpeszér 11 L	1.6 / 1.6	17	90	523	6500
Kunpeszér 27 F	1.9 / 2.7	22	87	93	2700
Kunpeszér 14 B	3.2 / 12	26	73	155	2000
Kunpeszér 20 D	1 / 1	26	100	331	8100

The survey of the stump deposits based on the abundance-distance assessments showed that *A. altissima* definitely spread from the stump deposits to the neighbouring areas and colonize the artificial reforestations early. The abundances of *A. alttisima* in all the diameter fractions were clearly higher on the stump deposits than at 0–5 m or 5–10 m distances. Figure 2 shows the dbh < 5 cm fraction, which can be considered the most balanced case in comparison to the 5 cm ≤ dbh < 10 cm and the dbh ≥ 10 cm fractions. The dbh < 5 cm fraction clearly differs more in the 7 years old stand than in the 26 years old stand, which means that the majority of the stems of *A. altissima* can be found still on the stump deposits. However, in the 26 years old stand the values are more balanced, which means that *A. altissima* is already well-spread in the surroundings. The Wilcoxon tests supported these differences with high significances (Table 3.). However, they also showed that (1) in the case of the older stand in the 0–5 m and 5–10 m distances the abundances were not significant regarding the two higher diameter fractions, (2) the abundances of the dbh < 5 cm fraction on the stump deposits and in the 5–10 m distances, furthermore between the 0–5 m and 5–10 m distances were less significant.

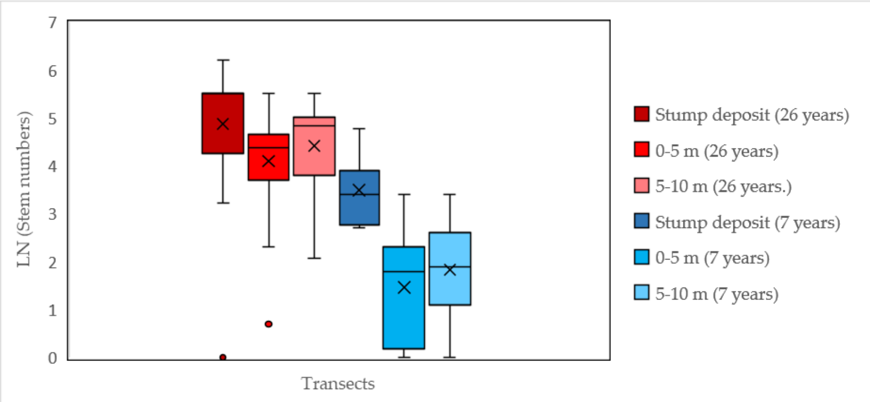

Figure 2. The abundances of the dbh < 5 cm fraction of *A. altissima* on stump deposits, in 0–5 m distances and 5–10 m distances in the 7 years old and the 26 years old artificial reforestation in logaritmic scale.

Table 3. The results of Wilcoxon signed-rank tests on the abundances of the three distance-pairs according to the three diameter fractions of *A. altissima*. Blue: minor significance, red: no significance, sd: stump deposit.

Stands	**Distance pairs**	**dbh > 10 cm**			**10 cm > dbh > 5 cm**			**dbh < 5 cm**		
		W	*z*	*p*	*W*	*z*	*p*	*W*	*z*	*p*
26 years old stand	sd/0-5m	15.5	3.48	<< 0.05	2.5	4.65	<< 0.05	40	3.58	<< 0.05
	sd/5-10m	6	3.8	<< 0.05	8	4.53	<< 0.05	55	3.37	< 0.05
	0-5m/5-10m	17	1.72	0.09	79.5	0.91	0.26	52	-2.98	< 0.05
7 years old stand	sd/0-5m	-	-	-	0	3.92	<< 0.05	0	3.92	<< 0.05
	sd/5-10m	-	-	-	0	3.92	<< 0.05	0	3.92	<< 0.05
	0-5m/5-10m	-	-	-	-	-	-	66	-1.45	0.14

4. Discussion

4.1. Selective Cuttings and Clear-Cuttings as Main Drivers of the Spread of A. altissima (i)

The spread of *A. altissima* was significantly affected by the forestry interventions. In many stands, the growth of the abundances exceeded two orders of magnitude due to selective cuttings and clear-cuttings. After chopping it down, *A. altissima* easily regenerates from the stump and also the density of root suckers increase, which was shown by previous studies [1]. During our field investigations in the Peszéri-erdő we pulled out several thousands of individuals by hand randomly to check their origin. According to our observations, the great majority of the stems were always seed individuals in the logged areas. *A. altissima* exploded in some stands, where it was only present with very low stem numbers before the forestry interventions. That can occur mainly due to (1) a strong propagulum source, which is present in the surroundings and the seeds could disperse from there, (2) the logging and transporting vehicles, which disperse the seeds accidentally all around the area (e.g., in the mud in the wheel, among the waste wood). In other cases, the explosion of *A. altissima* failed even if the propagule pressure was very high in the area. The reason is presumably complex, but according to our observations, it only appears in those natural reforestations, where the sprouting of the other trees and shrubs results in a fully closed, dense stand already in the first vegetation period. In general, our findings agree with the main conclusions of the other studies dealing with the impacts of forestry interventions on *A. altissima* [9,15,16].

Rebbeck & Joliff proposed that the propagule sources (matured individuals) should be removed from the area minimum 6 years before the intervention to avoid the massive germination from the seed bank [7]. However, every management effort needs financial support if voluntary work is not available, furthermore, the laws can already restrict the possibilities. In projects, where the financial and administrative background is provided, *A. altissima* can be controlled in relatively large areas—but that highly depends on the scale of invasion. In Hungary, *A. altissima* is a common tree species and can be found in a high proportion of forests. Therefore, its eradication on country level is highly unlike due to the lack of labour and financial sources. However, an emerging number of studies in North-America and Europe have confirmed that native *Verticillium* species might work as effective tools against *A. altissima* [20]. In the Peszéri-erdő we have recorded in 30 different localities that *A. altissima* stands are collapsing without any human intervention. In some cases all the matured individuals were desiccated, root suckering and even seed germination was apparently suppressed. In this study, a decrease in stem numbers was recorded only in one forest stand (see control stands in Table 1.), where *A. altissima* showed the symptoms of verticillium wilt. Our results also highlight the importance of further research regarding biological control.

4.2. Stump Deposits as Main Drivers of the Spread of A. altissima (i, ii)

We demonstrated in both surveys that the stump deposits play a crucial role in the spread of *A. altissima* in artificial reforestations. Even in some stands younger than 5 years the abundances could reach thousands of stems per 1 ha (see Table 2.). During the first few years *A. altissima* regenerates quickly from the stump deposits, but the majority of the stems can be found on these linear objects (see Figure 2.). It would be highly impossible to declare a certain age when the seeding starts in the stands as it depends on several variables. We observed stems with dense seed clusters sprouted from just 5 years old stump deposits. The lateral roots of *A. altissima* can reach several meters, but penetrating the first lines of poplars in the artificial reforestations would be quite challenging as the poplars also grow a dense lateral root system. In the (iii) survey the stem numbers of the dbh < 5 cm fraction were higher in average in the 5–10 m distance than in the 0–5 m distance from the stump deposits in the 26 years old stand. This finding with the general results of (ii) survey leads to the assumption that from very early the spread of *A. altissima* from the stump deposits is determined mainly by seeding instead of root suckering.

According to our knowledge, no information on this topic has been published before, although sporadic information might exist in the grey literature. In a few Hungarian management plans of Natura 2000 sites stump deposits appear as "cannot be made", but that is for other reasons as well. We investigated the spread of *A. altissima* from the stump deposits, but it is important to mention that other woody species can also regenerate from them. In the Peszéri-erdő besides the native species, the highly invasive *C. occidentalis*, *P. serotina* and *A. negundo* can also sprout from their stacked stumps. However, this is much rarer as they do not develop root suckering as *A. altissima*. The strong stump sprouting and root suckering ability of *A. altissima* ensures its future in artificial reforestations. Besides, making stump deposits determine an early appearing of massive propagule sources for the surroundings including the forest stands with high conservation value.

5. Conclusions

In our surveys, silvicultural practices significantly accelerated the spread of *A. altissima* in the Peszéri-erdő. The selective thinnings and clear-cuttings clearly resulted in population explosions. We also pointed out that the stump deposits function as deterministic sources for the regeneration of *A. altissima*, and leaving stumps deposits in the artificial reforestations leads to a rapid invasion within years. As the local history of the invasion of *A. altissima* was revealed in our previous study [18], now some main drivers of the exponential growth in its spatial distribution and density have been identified.

Forestry interventions can be considered dramatic anthropogenic disturbances. In the forested areas, a proportion of the stands is managed every year. This inevitably leads to the acceleration of the spread of *A. altissima* and also other invasive species, which react to the disturbances almost immediately. As the demand for wood presumably won't decrease in the future, the anthropogenic disturbances in the forests won't get moderated either. *A. altissima* has clearly become unwanted from conservational and many economical aspects, but its eradication in Hungary would lead to unreasoning financial measures. As effective chemical treatments or complete stand conversions are expensive procedures, an easier way must be found. As several native tree species are threatened by invasive pathogens around the world, maybe some native (or non-native) pathogens could also play a role in weakening the populations of the invasive tree species. To control *A. altissima* more effectively the native *Verticillium* strains should be taken into account as strong and cost-efficient support.

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Data Availability Statement:

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