Robinia pseudoacacia in urban forests

Management implications based on a literature survey and a case study in Warsaw

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Abstract

Robinia pseudoacacia L. (Black locust) is a widespread and widely used alien species in Europe, locally considered to be invasive. Among others, it is cultivated in plantations, planted for decorative purposes, used in the reclamation of degraded areas, but it is also spreading uncontrolled in forests and woodlands.

The aim of this study was to consider how *R. pseudoacacia* fits into the needs of urban forestry and what environmental risks are associated with its presence. For this purpose, 80 scientific publications were reviewed. Based on this literature review, *R. pseudoacacia* stands in urban forests were characterised in three dimensions: social, economic and environmental. This analysis distinguished the trend of changes in the sites of occurrence of this species in Europe like homogenization, dominance in the stand and change in biodiversity and species composition.

To assess the impact of *R. pseudoacacia* on forest composition and structure in Warsaw, 24 sample plots in *R. pseudoacacia*-dominated, 14 plots in mixed and 24 plots in *Pinus sylvestris*-dominated forest patches were examined from two study areas, forest Na kole and forest Lindego. The results show that *R. pseudoacacia*, compared to *Pinus sylvestris* L., does not negatively affect the species richness of the undergrowth and ground vegetation as well as does not favour occurrence of other alien species. Studies indicate that the light-demanding *R. pseudoacacia* regenerates poorly in urban stands, which is probably due to high shading of the forest floor. On the other hand, species such as *Quercus rubra* L., *Acer platanoides* L. and *Acer pseudoplatanus* L. regenerate extensively under its canopy, creating a future potential change in species composition.

Relating the situation of Warsaw's forests to generally observed trends in Europe indicates a need to observe the *R. pseudoacacia* in the future, especially considering climatic changes such as droughts and rising temperatures, which favour the invasiveness of this species.

Keywords: Robinia pseudoacacia L., urban forestry, biodiversity, invasive alien species, environmental impact, socioeconomic benefits, management recommendations.

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1. Introduction

1.1 Climate change

Climate changes are probably the biggest challenge for new generations of foresters. In the case of Europe many native species of trees like *Fraxinus excelsior* (Pautasso et al. 2013), *Pinus sylvestris* (Dyderski et al. 2018), *Picea abies*, (Dyderski et al. 2018) and *Ulmus* sp. (Napierala-Filipiak et al. 2016) are now under a threat. The threat is caused by changing conditions, such as access to water, temperature, new diseases and pathogens (La Porta et al. 2008, Dyderski et al. 2018). In the context of climate change, the topic about utilization of alien species is increasingly coming up in scientific discussions (Sjöman et al. 2016, Nicolescu et al. 2020, Vítková et al. 2020). On the one hand, researchers are concerned about potential invasiveness in local environments (Marozas et al. 2015, Slabejová et al. 2019, Nicolescu et al. 2020), on the other hand, they consider alien species as alternative for suffering or lacking native species with possible benefits for people (Sjöman et al. 2016, Nicolescu et al. 2018, Kowarik et al. 2019, Nicolescu et al. 2020).

By the time of introduction we can divide alien species into two groups, archaeophytes, species introduced before the era of geographical discovery, and neophytes, later introduced species. *Robinia pseudoacacia* L. (Black locust) is an example of neophytes for Europe, introduced around 400 years ago in the 17th century (Pyšek et al. 2009, Vítková et al. 2017). Many studies indicate that *R. pseudoacacia* can be a serious threat to the ecosystem, leading to changes in ecosystem functions (Pyšek et al. 2009, Maroz et al. 2015, Ivajnšič et al. 2012, Campagnaro et al. 2022). *R. pseudoacacia* is a species able to colonise a new area very quickly if it is given sufficient access to light (Nicolescu et al. 2020). In Poland, *R. pseudoacacia* is the second ranked species right after *Impatiens parviflora* in terms of the number of colonised habitats (Tokarska-guzik et al. 2012), at the same time it is also one of the trees most frequently introduced into the forests. *R. pseudoacacia* appears in many European countries. According to the analysis of the 100 most invasive species in Europe, *R. pseudoacacia* occurs currently in 41 countries, and in 32 of them it is naturalized (Pyšek et al. 2009). In terms of naturalization, only one species, *Conyza canadensis*, achieved a higher result (Pyšek et al. 2009). On the European list of worst alien species, it reaches 13th place among all organisms, and 5th place if we consider only plants (Nentwig et al. 2018).

For traditional forest managment *R. pseudoacacia* also could be a serious problem. This alien species is able to spread rapidly in gaps and clearings, causing damage, sometimes even making regeneration impossible (Tokarska-Guzik 2012). For this reason, it is not recommended to use *R. pseudoacacia* for afforestation or regeneration. Under Polish conditions, it is rather treated as a species of small woodland and shrubland (Szwagrzyk 2000, Feliksik et al. 2007). Also, in literature from other European countries, it is not recommended to replace native stands with *R. pseudoacacia*, protecting against invasiveness (Tokarska-Guzik 2012, Sádlo et al. 2017, Vítková et al. 2017, Klisz et al. 2021). Moreover, today's research based on models and observations predicts that consequences of climate changes like drying and warming will favor further expansion of the *R. pseudoacacia* in the close future (Kleinbauer et al. 2010, Dyderski et al. 2018, Vítková et al. 2020, Puchałka et al. 2021, Visztra et al. 2023). However, other studies indicate that climate warming may also harm populations of *R. pseudoacacia* (Wilkaniec et al. 2021). Climate change not only creates favorable conditions for the invasion of the *R. pseudoacacia* but also for the expansion of its pathogens from America to Europe, which is already observed in Poland (Wilkaniec et al. 2021). Diseases caused by viruses are also an observed threat to this species in Poland; trees infected with them also become a potential epidemiological risk for other species (Zarzyńska-Nowak et al. 2015). Therefore, studies of *R. pseudoacacia* are important for the planning and management of European forests and woodlands.

1.2 History and purpose of introduction

Robinia pseudoacacia is a North American tree that was brought to Europe as an ornamental species and quickly gained popularity in botanical gardens (Vítková et al. 2017). It is considered to have been first imported to France in the early 17th century, from where it was distributed to other European countries. However, it is most likely that there were a few independent introductions of this species at this time (Vítková et al. 2017). In the second half of the 17th century *R. pseudoacacia* was recorded among others in Germany, in the early 18th century in the Czech Republic, Hungary and Slovakia (Vítková et al. 2017). It is considered to have been brought to the territory of today's Poland in 1806, and half a decade later in 1860 it was used for afforestation (Vítková et al. 2017). *R. pseudoacacia* is utilized today for ornamental properties, afforestation, soil reclamation, timber and non-timber products as well as for recreation in many European countries.

The primary purpose of introducing *R. pseudoacacia* was its ornamental qualities. The *R. pseudoacacia* trunks, although irregular, are characteristic due to their shape and texture. An element of *R. pseudoacacia* that is particularly attractive are the long clusters of white flowers. *R. pseudoacacia* starts blooming between May and June, earlier than several native tree species in central Europe. The flower clusters are 10-20 cm long (Tomanek, 1987) so they are visible from a far distance. The flowers diffuse a specific sweet smell, which is also characteristic of *R. pseudoacacia* woodlands during spring time. For visual purposes it is common to plant garden varieties of *R. pseudoacacia*, such as '*Bessoniana*', '*Frisa*' '*Umbraculifera*', '*Microphylla*' or '*Pyramidalis*' (Tomanek 1987, Seneta et al. 2012). To this day, this species and its varieties are a popular avenue tree.

Later, when the characteristics of the species were known better, it began to be used for afforestation, reclamation and plantation purposes. Thanks to its ability to grow relatively quickly in difficult conditions on poor soils and its capability to fix nitrogen, *R. pseudoacacia* very quickly became a species for problematic sites for afforestation (Vítková et al. 2017). This species was used for afforestation and reclamation, among others, in Hungary, Austria and Poland (Vítková et al. 2017, Nicolescu et al. 2020) and, until World War II, also in the Czech Republic (Vítková et al. 2017). As a plantation species in Europe, it was used among others in Hungary, Romania, Ukraine, France and Italy (Nicolescu et al. 2018).

1.3 Urban forestry

The usefulness of an alien species depends significantly on our goals. Depending on our needs and interests, a particular species could be harmful in one situation and beneficial in another (García-Llorente et al. 2008). Therefore, when assessing *R. pseudoacacia* in urban forestry, it is necessary to establish what are the purposes of that kid of forest. Urban forestry and city tree management is a specific branch of forestry. Usually in Europe there are no top-down rules or clearly defined legal regulations on how these forests should be managed (Jaszczak 2022). Even within a single country, each city may have different management strategies, like for example in Poland (Jaszczak 2022).

The concept of urban forestry began to take shape in the USA in the 1960s, although the history of urban forests is almost as old as the history of cities themselves (Miller et al. 2015, Jaszczak et al. 2017). One of the first definition of urban forestry was formulated by Jorgensen (1970). According to him Urban forestry is:

> “...a specialized branch of forestry and has as its objective the cultivation and management of trees for their present and potential contributions to the physiological, sociological, and economic well-being of urban society. These contributions include the over-all ameliorating effect of trees on their environment, as well as their recreational and general amenity value…”. (Miller et al. 2015)

Another definition of urban forestry used by Konijnendijk et al. 2006:

> “…art, science and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide society…”. (Konijnendijk et al. 2006)

Based on these two definitions we can conclude that the most important goal for urban forestry is to serve citizens, and this service can be divided into three categories of values: social, economic and environmental.

In Poland the economical value of urban forest is not very important compared to recreational and other social values (Gołos 2013, Chudy 2017, Jaszczak et al. 2017, Jaszczak 2022). This is a different approach from traditional forestry, where the economic objectives usually are dominant (Jaszczak et al. 2017). Nature conservation and environmental values of urban forests are mentioned in the literature, but they are not specified. In practice, each local unit defines them at its own convenience (Jaszczak et al. 2017). There are some recommendations to make these forests as close to natural as possible (Szwagrzyk 2000), but many factors like touristic pressure, small size of forest areas, the history of the site, legal regulations and different forms of ownership can make this difficult.

2. Problem description and aim of the study

Robinia pseudoacacia is one of the most popular alien plant species in Europe (Vítková et al. 2017, Vítková et al. 2020). We know now, that it is undesirable for traditional commercial forestry (Danielewicz et al. 2020), but there are still not many studies on how *R. pseudoacacia* suits to urban forestry, whose objectives focus more on social, recreational and environmental functions than the timber production. Research has shown that very frequently *R. pseudoacacia* has a negative impact on biodiversity, but this effect can vary in different places. Studies indicate that in Europe *R. pseudoacacia* has a predisposition to invasiveness especially in Central European countries (Vítková et al. 2017, 2020). Therefore, Poland as one of them was chosen as the study area. The studies are located in the city of Warsaw, with several large forest complexes where *R. pseudoacacia* is occurring. In the past, the Warsaw City Office started a *R. pseudoacacia* control programme (Miścicki et al. 2012), but this species is still present in many sites. However, a sustainable long-term management approach for these species in urban forestry continues to be unclear. Past experience has shown that combating *R. pseudoacacia* can involve technical, financial and social problems (Obidziński et al. 2016, Miścicki et al. 2021).

By combining a literature review with a case study of two urban forests, this paper aims to increase our understanding of the role of *R. pseudoacacia* in Warsaw urban forestry considering social, economical and environmental values. Is *R. pseudoacacia* a threat to Warsaw's urban forests or should it be part of them also in the future? The aim of the study is also to expand the knowledge on how *R. pseudoacacia* affects the biodiversity and species composition of other plants compared to native trees stands, under urban condition.

3. Hypotheses

- Areas with *R. pseudoacacia* differ in the species composition of the ground vegetation compared to stands with a tree layer of native species like *P. sylvestris*.
- *R. pseudoacacia* favors the appearance of other alien species in the undergrowth and understory.
- *R. pseudoacacia* is an undesirable species for urban forests, in the interest of protecting urban forest habitats, programmes to eliminate *R. pseudoacacia* should be initiated.

4. Case study site characteristics

The forest area of Warsaw is around 8000 ha which is 15% of the total city area. These are both state and private forests, under the supervision of state institutions, in this case the Urban Forests of Warsaw (lasymiejskie.waw 2023). This study included forests managed by Urban Forest of Warsaw. Two sites were selected considering their location inside the city, and a high share of *R. pseudoacacia*.

The first study area, Na kole forest, is located in the Wola district, surrounded by a residential area, directly bordering the Prince Janusz Park and the railway tracks (figure 2). The whole forest covers 43.2 hectares, but only 23.0 hectares on the south side of the tracks are under the management of the Urban Forest. Only this part was included in this study. The Na kole forest was created in an action of afforestation of non-utilised land before World War II, so the age of the stand is ca 100 years (lasymiejskie.waw 2023). In the middle of the forest there are recreational facilities (figure 1A), but also some remains of older architecture such as foundations or cement fence pillars (figure 1C). The urban forest website informs that the forest does not have a high economic value and therefore its main purpose is recreation (lasymiejskie.waw 2023). The low economic values are related to the young age of the stand, the high pressure from the visiting people, and the degradation which is visible in the species composition. Inside the forest there are playgrounds, pathways, gyms and a place in memory of murdered people during World War II. The forest is often visited by the local community, by families with children, dogs and for practising sports such as running or cycling. The forest stand is composed mainly of *Pinus sylvestris*, *R. pseudoacacia* and *Quercus rubra*, (another introduced species), but in smaller admixtures also by many other species such as *Carpinus betulus*, *Acer platanoides, A. pseudoplatanus*, or *Larix* sp. (table 1, figure 1B).

The second study area is located in the Bielany district. Its boundaries are defined by Lindego, Kasprowicza and Marymondzka streets, and from the south-east side it neighbours the hospital building (figure 3). The area of this forest is 20.3 ha, all under the administration of the Urban Forests of Warsaw. The Lidego Forest is a remnant of the old range of the Kampinos Forest (lasymiejskie.waw 2023). Its establishment date as a park is similar to the first site during the inter-war period. Today, Lindego Forest is part of the buffer zone to the nearby Bielański forest nature reserve (lasymiejskie.waw 2023). The forest zone in and around the Lindego forest is consequently older in origin than the forest Na kole. Like the first research area, the main purpose of the forest is recreation (eko.um.warszawa 2023). The forest is densely crossed by paths, with playground areas and benches placed inside. It is also a popular recreational area for the local community, and is open to families with children, sporting activities and feeding the large population of red squirrels. Main species in the stand are also *P. sylvestris*, *R. pseudoacacia* and *Q. rubra* (table 2).

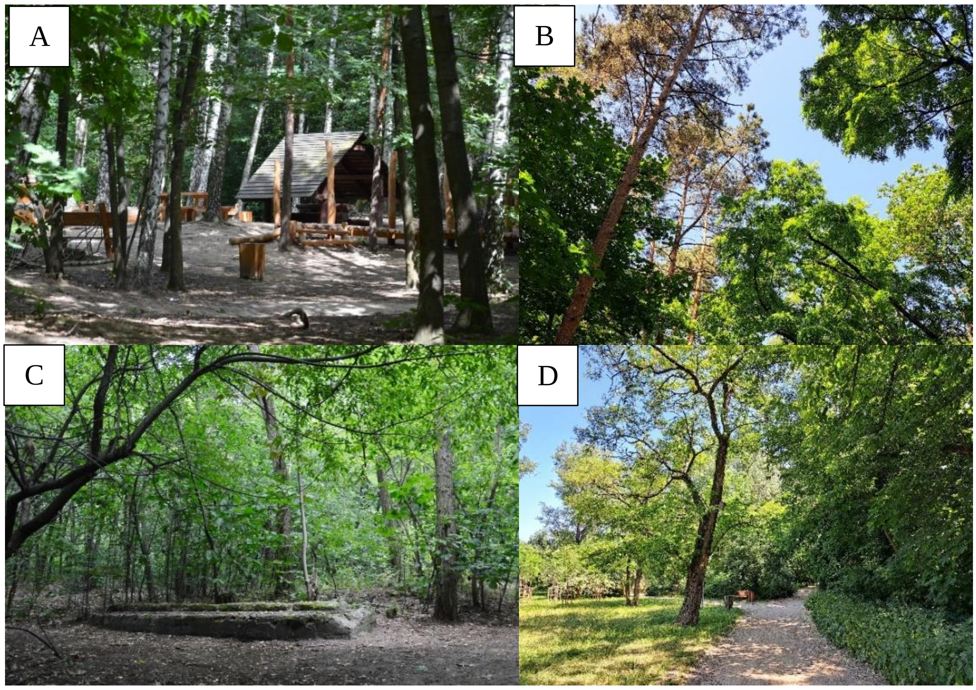

Figure 1. Forest Na kole. A: recreational facilities, B: trees canopy Acer , Pinus, Robinia; C: old foundation, D: border between park and forest

Those two inner city forests have a lot in common. From the administrative side, both are managed by Warsaw Urban Forest. The total area is similar. Both are established during the inter-war period so age of the trees is also comparable. After damage during World War II, both required work to restore their serviceability. In both cases, the stand is not compatible with the natural habitat, there are signs of degradation such as the presence of alien species like *R. pseudoacacia*. The path of introduction of alien species into the forest is unknown. Their economic value is low in both cases and the main value is recreation. As part of making the forests accessible to people, benches, playgrounds and other recreational facilities have been installed, also the path network has been densified. The woodland area around Lindego forest is much older than that of the forest Na kole and its forest character is more noticeable. The terrain in Lindego forest is much more varied, there is a stream and an earth embankment which differentiates, for example, the moisture conditions while the forest Na kole is isolated from the larger forest complexes and its terrain is much less varied (figure 2, figure 3).

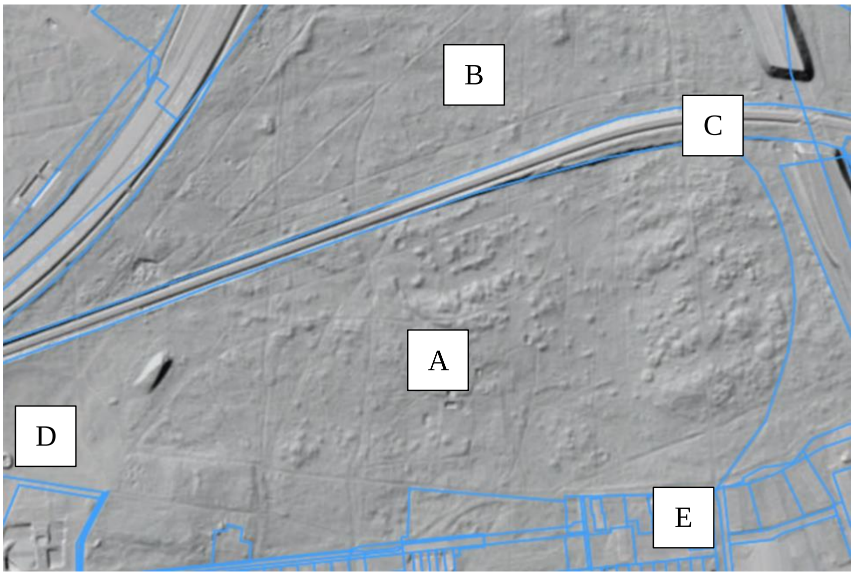

Figure 2. Forest Na Kole. A: research forest area, B: other part of the forest, C: train tracks, D: park, E: builidings. Map 1992 (EPSG 2180) 1:5000, https://mapy.geoportal.gov.pl/

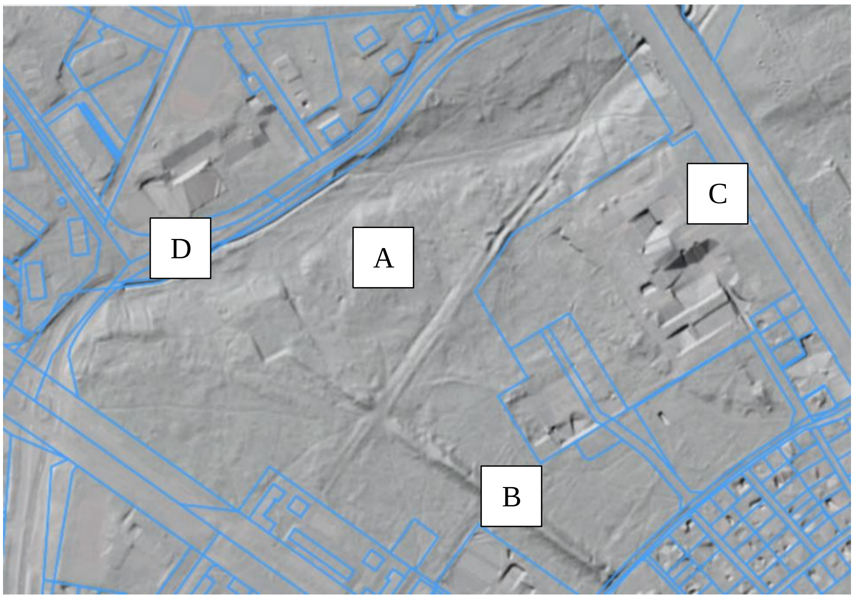

Figure 3. Forest Lindego. A: research forest area, B: embankment, C: Hospital, D: stream. Map 1992 (EPSG 2180) 1:5000, https://mapy.geoportal.gov.pl/

5. Methods

5.1 Literature review

The publications were searched using terms like "*Robinia pseudoacacia* in urban forestry", "Alien species urban forestry", "invasive *Robinia pseudoacacia*" in Google Scholar.The literature analysis included 80 publications, 79 of which were from the period 2000-2023 and one from 1987 from which information on the morphology of *R. pseudoacacia* was taken. The analysed publications were divided into five thematic groups (appendix 1), 14 of which were classified into two of the created groups. The largest group "Environment impact and invasiveness" included 33 publications, "Urban forestry" 25 publications, "Production and management" 23 publications, and "Public attitudes and social aspect" nine publications. The last group "Overwiew of *R. pseudoacacia*" included five publications that presented general information about the species or described it in a broad multi-dimensional way.

5.2 Case study field work

The field work included 62 square plots, each of 100 m^2, located in two different study sites. A total of 42 plots were sampled in the Na kole forest, distributed among three groups with 14 plots each (figure 4). The first group contained sample plots with *R. pseudoacacia* dominating in the tree layer, the second included plots where *R. pseudoacacia* occurred but did not attain more than 20% of species cover in the tree layer, and the third group contained control plots, where *R. pseudoacacia* did not occur in the tree layer. A total of 20 plots were sampled in Lindego forest (figure 5). Of these, 10 were sample plots in which *R. pseudoacacia* was present in the tree layer, a further 10 plots were control plots in which *R. pseudoacacia* was not present in the layer of trees.

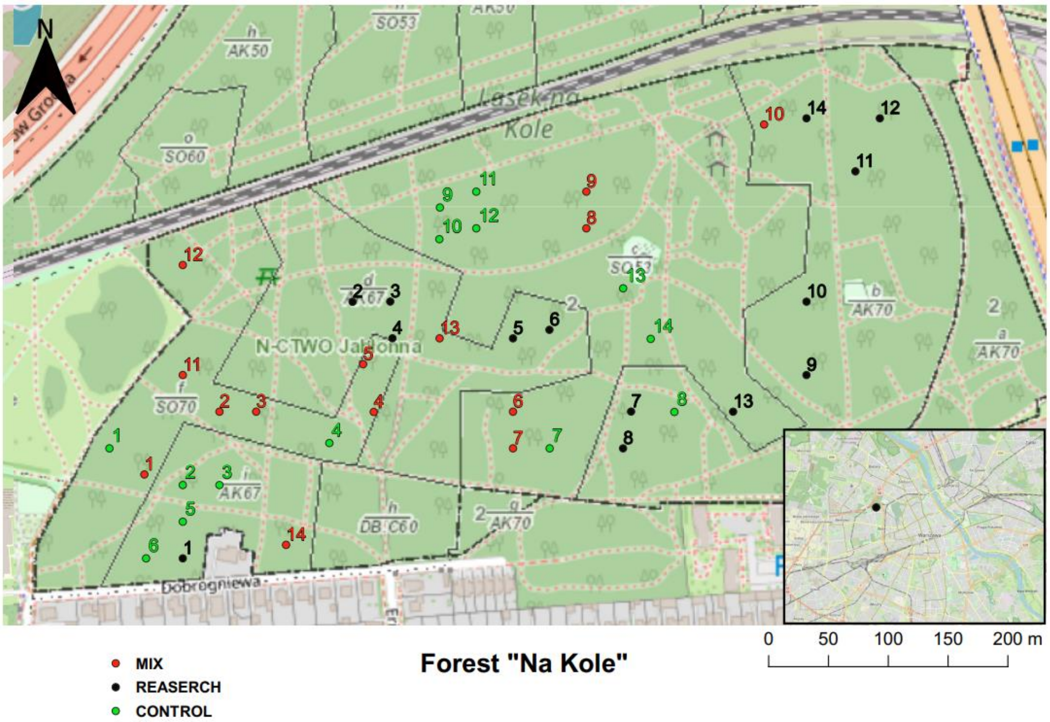

Figure 4. Map of plot distribution in Na kole forest

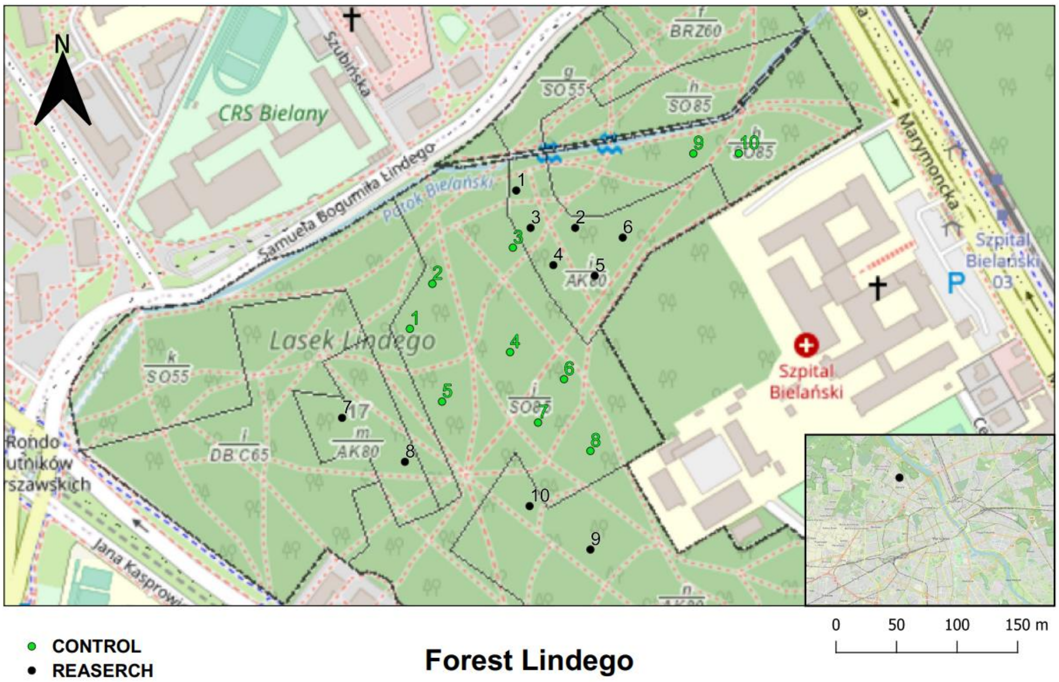

Figure 5. Map of plot distribution in Lindego forest

The locations and arrangement of the study plots were first determined in a systematic way by superimposing a 30 x 30 m grid of points on the forest map in QGIS service (figure 6). Subsequently, plots were excluded from the field with boundaries less than 5 m from a road or other object, as well as those with objects such as concrete structures, rubbish dumps, etc. A distance of at least 30 m was kept between each plot. In some cases, the center of the survey plot was moved a few metres away from the grid in order to meet those conditions. In the field, a paper map with a grid of points created in QGIS was used for orientation (figure 4, figure 5).

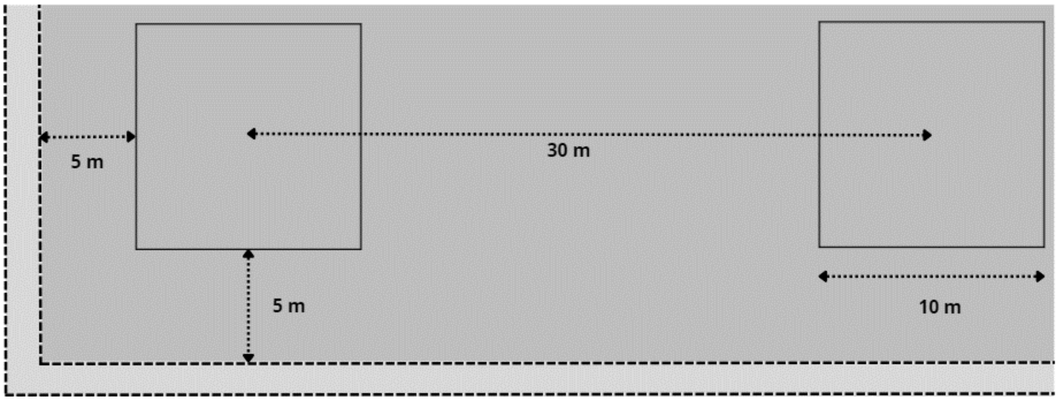

Figure 6. Minimum distance maintained during the designation of plots

Each plot had a size of 100 m^2 (10 x 10 m) (Figure 6). The percentage cover of four different vegetation layers was visually estimated, including an upper tree layer (A1), a lower tree layer (A2), the shrub layer (B), and the ground layer (C). The abundance of each species in the layers was estimated using the Braun-Blanquet cover class scale, using "+" for layer coverage below 1%, ”1” for cover between 1% and 5%, “2” for 6-25%, “3” for 26-50%, “4” for 51-75% and “5” for 76-100% of cover (figure 7). The data were noted in a survey form, shown in figure 7. All plots were surveyed between the 2nd half of June and the 1st half of August 2023. Only the summer vegetation was thus considered in this inventory.

Herbaceous species occurring in urban degraded stands with Robinia pseudoacacia, Antonina Dubińska, SLU Euroforester program. Mail: aara0008@stud.slu.se		Number		Date
N:	S:	Place:		
Layers [%] A1 A2 B C		Research plot	x	Control plot
Exposition: - Slope - high above sea				

	Species	[%] <1 (+), 1-5(1), 6-25 (2) 26-50 (3), 52-75 (4), 76-100 (5)		Species	[%] <1 (+), 1-5(1), 6-25 (2) 26-50 (3), 52-75 (4), 76-100 (5)
A 1			A2		
B					
	Species	[%] <1 (+), 1-5(1), 6-25 (2) 26-50 (3), 52-75 (4), 76-100 (5)		Species	[%] <1 (+), 1-5(1), 6-25 (2) 26-50 (3), 52-75 (4), 76-100 (5)
C					
Other information					

Figure 7. Form used in data collection

5.3 Data analysis

The data collected in the forms were compiled in tables with the distribution by vegetation layer and study area in Microsoft Excel files. The two study sites Na kole and Lindego were treated separately in all data analyses.

To compare the numbers of non-native and native species, all vascular plant species were divided into two groups, species native to Poland and non-native species according to Rutkowski (2022).

5.3.1 Species richness and cover

Kolmogorov-Smirnov tests were applied in Minitab version 21.4.2 to test for normal data distribution. As the results showed that the data were not normally distributed, non-parametric tests were applied to compare differences in species richness and vegetation cover between plot groups and in the four vegetation layers. Differences in the layers of different plot groups were tested using the Kruskal-Wallis test. For Na kole forest, pairwise Mann-Whitney tests were calculated to compare all pairs of the three plot groups.

5.3.2 Species composition

Differences in species composition between sample plots of the two study sites were analysed with Principal Components Analysis (PCA), and with cluster analysis using Ward´s method (and Euclidean distances).

For each of the two sites, the tree layers A1 and A2, and the understory layers B and C were merged prior to multivariate analyses. Species richness data included all species present in a plot in these merged layers. Abundance data used are sums of the two abundance class values in each pair of layers.

All multivariate analyses were computed in the program package Past 4.16 (Hammer et al. 2001).

6. Results - Literature review

6.1 Societal aspects

6.1.1 Value of urban forests for citizens

From city residents' point of view, urban forests are foremost recreational areas (Jaszczak 2022). Forests are used by them as a meeting place, a destination for walks with the family, pets and also as a space for sports activities. For this purpose, it is very common to install facilities like benches, shelters, playgrounds, outdoor gyms or fire places. From survey-based research we knew that city residents value green areas for their peaceful atmosphere, beauty and variety of landscape (Mierzejewska 2011). A survey from the Polish city Poznań showed that greenery is an important issue for 83% of respondents (Mierzejewska 2011). Urban citizens use green spaces very often. A survey of Warsaw citizens from 2007-2008 points out that over 40% of respondents are visiting forests at least once a month (Gołos 2013). Especially high numbers of people are accessing forests during weekends (Gołos 2013). The respondents most often used the Kampinoski National Park and the Kabaty Forest. But the authors of the study pointed out that also the area around the Bielański Forest and Na kole Forest require special care due to the high number of visitors (Gołos 2013).

6.1.2 People´s attitude to alien species

Strong human pressure, pollution, and poor soil conditions imply that not every native species can handle urban conditions. This is why a common practice is to complement forest compositions with non-native species that are more resistant to stresses (Kaliszewski 2006, Sjöman et al. 2016) or for aesthetic purpose (Lenard 2007, Czerniewska-Andryszczyk et al. 2021). So far, in several cities around the world, the attitude of citizens towards non-native species in urban forests has been studied, among others in Berlin (Lippert et al. 2022) and Warsaw (Dmochowska et al. 2003). A study from Germany showed positive public attitudes towards designed urban forests dominated by the non-native *R. pseudoacacia* (Lippert et al. 2022). Similarly, positive public attitudes were observed in Warsaw, where around half of the respondents were against felling of *R. pseudoacacia* in the urban forest (Miścicki et al. 2021, Miścicki et al. 2021 about Dmochowska et al., 2003). However, slightly differently structured studies from Scotland (Bremner et al. 2007) and Switzerland (Junge et al. 2019), showed that the majority of respondents support the management and eradication of invasive alien species. Public attitudes towards alien species can vary widely across different social groups, so it is urged to include a possible diverse group of respondents with different perceptions and interests in public consultations (García-Llorente et al. 2008).

6.1.3 Importance of public opinion

The public can have a decisive voice in alien species policy (García-Llorente et al. 2008). The public's opinions can influence whether or not active control is initiated against a given alien species (Pietras-Couffignal 2021). This is illustrated well by the history of the elimination programme of *R. pseudoacacia* from Warsaw's Bielański forest, started in 1992 (Miścicki et al. 2012). The elimination of *R. pseudoacacia* was initially planned for a 40-year period, in cutting rotations every 8-10 years (Miścicki et al. 2012). After the first few years, the conservation programme was slowed down by people's protests (Miścicki et al. 2012, Miścicki et al. 2021). The example from Warsaw shows that even control methods towards an alien species can be limited according to public sensitivity. In 2003, based on responses to a survey of 200 visitors to the Bielanski Forest, less than half agreed with the felling of alien tree species (Miścicki et al. 2021 about Dmochowska et al., 2003). This demonstrates the kind of public sympathy towards this species and strongly divided opinions.

Opinions arising from the interests that can be gained from an alien species can influence not only on local but also on international policy. The different approaches of the European Union Member States to *R. pseudoacacia* result in a lack of top-down control of the management of this species (Vítková et al. 2017). The EU has not listed *R. pseudoacacia* as an invasive species for the entire territory of the Member Countries, but some of them are introducing their own regulations, and consider *R. pseudoacacia* as invasive (Vítková et al. 2017).

6.2 Forest management and economy

6.2.1 Potential of *Robinia pseudoacacia* wood

The literature indicates a high potential for the utilization of *R. pseudoacacia* wood (Kamperidou et al. 2016, Bijak et al. 2021). *R. pseudoacacia* wood is commonly used in furniture making, as ornamental elements, structural wood and for energy purposes (Ciuvat et al. 2022, Nicolescu et al. 2018, Vasiliki et al. 2017). Such versatility of use is explained by its properties. *R. pseudoacacia* wood is relatively hard, heavy, mechanically robust, is possible to modulate during processing and has a high biological resistance (Kamperidou et al. 2016). Thanks to its resistance to outdoor conditions, even unprotected structural elements can serve for many years. For example, wood from German plantations is used for the construction of playgrounds (Pietras-Couffignal et al. 2021). Wood of this species is also valued for aesthetic reasons mainly due to its colour. The colour varies from yellow, reddish to dark brown, and the contrast between very light sapwood and darker heartwood is a typical feature that is considered as ornamental (Kamperidou et al. 2016). It is also possible to modify the colour of timber later during processing by steaming (Kamperidou et al. 2016). Poor quality wood, however, is used as firewood, which is also the most common form of its utilisation (Ciuvăț et al. 2022). Looking at economic considerations, the potential use of *R. pseudoacacia* timber is promising, but this prediction mainly applies to wood from plantations and not from urban forest stands.

6.2.2 Where to find good quality timber?

In Europe, *R. pseudoacacia* is commercially grown in plantations, usually as short rotations, which can be found among others in Bulgaria, Slovenia and Hungary (Gil 2018). Breeding of *R. pseudoacacia* may be focused on fast harvesting for energy purposes or to grow specially selected trees with straight stems (Nicolescu et al. 2018, Zajączkowski 2012). Breeding programmes for the production of high-quality timber are conducted, for example, in Romania and Hungary (Nicolescu et al. 2018). Under Polish conditions, straight-stemmed *R. pseudoacacia* are known from the Krosno Forest District, in the west of the country (Feliksik et al. 2007, Zajączkowski 2012). The best growth results for *R. pseudoacacia* are obtained on fertile soils, which are the most recommended for cultivation (Zajączkowski 2012). However, an advantage of *R. pseudoacacia* over many other species is the possibility of quite good growth even on poor degraded soils (Kraszkiewicz 2021). The studies from Poland, which have considered stands in different soil and climatic conditions in the country, showed that soil richness has minor role in *R. pseudoacacia* growth, but confirm that sun and water access influence on the volume (Kraszkiewicz 2021).

6.2.3 Non-timber products

Today, *R. pseudoacacia* is one of the most important species planted for honeymaking. As a species for honey production, it is compared to rape *(Brassica*) and lime (*Tilia sp.*) (Wojda et al. 2014, Ciuvăț et al. 2022), and it is particularly valued for its high yield (Wojda et al. 2014, Ciuvăț et al. 2022). In countries like Romania, Hungary and Bulgaria honey is an important non-timber product

(Zajączkowski et al. 2012, Ciuvăț et al. 2022). The honey itself is characteristic due to its high sucrose content and relatively slow crystallization time, which are considered as desirable qualities (Wojda et al. 2014). *R. pseudoacacia* flowers, at a smaller scale than for honey are also used for other purpose in cuisine (Sitzia et al. 2016). The *R. pseudoacacia* flowers are eatable and they can be used for dishes decoration and as ingredient in cooking recipes.

6.2.4 Costs and control methods

One of the experiments on control the spread of *R. pseudoacacia* took place in the Kampinoski Forest, next to Warsaw. Studies were done using various mechanical, chemical, and combined control methods, but also biological methods were considered in the discussion. Although all methods showed some effects, all were assessed as insufficient. Each method was relatively expensive and time-consuming and did not give satisfying chance for success (Obidziński et al. 2016). Of the mechanical methods, multiple harvests during the vegetation period repeated in following years, girdling and clearing are reported (Pietras-Couffignal et al. 2021, Obidziński et al. 2016). Sabo (2000) mentions that bulldozing the surface is one of the more effective methods, however, it has a destructive effect not only on *R. pseudoacacia* but also on all the vegetation, moreover, it is increasing the risk of soil erosion (Sabo 2000). Another mechanical method proposed by Sabo is burning but this is unlikely to be successful in urban conditions (Sabo 2000). Measures developed on the basis of natural compounds appear to be interesting for the future. Research involving plantations in Slovakia and Hungary in 2014 indicated that *Celtis occidentalis* L. has an antagonistic effect on the *R. pseudoacacia* and compounds from its leachates could be used to control it (Ferus et al. 2019). In conclusion, its eradication is very problematic, being labour-intensive, time-consuming and thus expensive (Obidziński et al. 2016).

It is possible to manage mixed forests with *R. pseudoacacia* by limiting clear-cutting (Sádlo et al. 2017, Radtke et al. 2013). Considering cost and effectiveness, probably the best control option is to maintain a high degree of shading in the stand to limit the spread of *R. pseudoacacia.* A more costly option, but with good results is to combine mechanical, chemical or biological methods together (Sabo 2000, Obidziński et al. 2016). It is more easily achievable to reduce the occurrence of *R. pseudoacacia* in a stand, but its complete eradication is much more difficult and costly (Sádlo et al. 2017). The possibility of eradicating this species in urban areas may be additionally limited by the protests from urban residents.

6.2.5 Benefits in the management of *Robinia pseudoacacia* in urban areas

R. pseudoacacia can grow well in urban conditions and also brings benefits such as cleansing the soil of heavy metals or improving the microclimate by cooling (Băbău et al. 2021, Środek 2022, Moser et al. 2015, 2016 , Franceschi et al. 2023, Rahman et al. 2019, Rötzer et al. 2021). Since the 20th century, *R. pseudoacacia* has been used for afforestation and reclamation of industrial degraded soils (Vítková et al. 2017, Nicolescu et al. 2020, Băbău et al. 2021, Środek et al. 2022). Modern research also indicates a positive impact of this species on the phytomediation of contaminated places (Băbău et al. 2021, Środek 2022). *R. pseudoacacia* can accumulate metals like Cu and Pb from soil into their tissues (Băbău et al. 2021, Środek 2022). A high level of contaminants is found in their leaves. Therefore, when using *R. pseudoacacia* removing leaf litter or another remedial method should be considered so that the filtered contaminants do not return back to the soil (Băbău et al. 2021). *R. pseudoacacia* is considered as a species resistant to drought and water stress (Moser et al. 2016, Franceschi et al. 2023). According to research from Germany, *R. pseudoacacia* slows down its growth during water stress, but it regenerates faster than the comparable *Tilia cordata* (Moser et al. 2016). Other studies from Germany also indicated a positive impact of this species on carbon accumulation, which can also be considered a beneficial impact (Rötzer et al. 2021). Research on the influence of species in creating the microclimate in cities, indicates that *R. pseudoacacia* has a positive impact on heat mitigation (Rahman 2019, Rötzer et al. 2021, Moser et al. 2015). However, depending on the situation and the analyzed factor, other species such as *T. cordata* may demonstrate an even more favourable impact, e.g. due to higher transpiration activity (Rötzer et al. 2021).

6.2.6 Economical possibilities in urban forestry

Robinia pseudoacacia in urban areas tends to be feral, the trunks are deformed and often have many branches that are not desirable for mechanical processing (Wojda et al. 2015). Therefore, under urban conditions, it is difficult to find *R. pseudoacacia* trees whose wood could be used for higher purposes. Poor quality wood could be used as a raw material for energy. However, firewood production involves frequent cutting, and this is problematic in an urban condition, due to, for example, the safety of the occupants, public misunderstanding which can lead to conflicts, the risk of invasion by *R. pseudoacacia*, or the issue of cost-effectiveness of machinery operating in often very small forest sites. For this reason, despite the potential of the species itself, the economic value for urban forests means little.

6.3 Environmental aspects

6.3.1 Risk for the ecosystem

From different studies in Europe about *R. pseudoacacia* environmental impact, we can distinguish similar findings. The most frequently mentioned are **change in biodiversity** and **species composition** (Rahmonov 2009, Sádlo et al. 2017, Gentili et al. 2019), trends to **dominance in the stand** (Akatov et al. 2012, Ivajnšič et al. 2012) and **homogenisation**[1] of the habitat (Šibíková et al. 2019, Obidzinski et al. 2016). A repeated result of research on biodiversity in *R. pseudoacacia* forests is their poorer abundance of typical forest species relative to native stands. Such results were given by studies in Poland (Rahmonov 2009), Italy (Gentili et al. 2019) and the Carpathian-Pannonian region (Slabejová et al. 2019). The forests are colonised by nitrophilous, shade-tolerant and generalist species at the same time with declines in characteristic species (Gentili et al. 2019, Obidziński et al. 2016). More generalist species in *R. pseudoacacia* stands are observed also with other organisms than plants. A study from the Czech Republic has shown that *R. pseudoacacia* decreases the proportion of specialist bird species to generalists (Reif et al. 2016). Another study indicates that the presence of *R. pseudoacacia* may favor the settlement of herbivores from North America (Mally et al. 2021). The character of the *R. pseudoacacia* forest habitat itself is becoming more synanthropic and ruderal (Rahmonov 2009, Slabejová et al. 2019).

However, the pattern indicating the negative impact of *R. pseudoacacia* in forests, is not a rule without exceptions. For example, studies from Italy (Sitzia et al. 2012), Western Caucasus (Akatov et al. 2012) and Northeastern USA (Von Holle et al. 2005) found no significant change in biodiversity compared to native stands.

Whether the occurrence of *R. pseudoacacia* in a stand has a negative, neutral or positive effect on the environment, depends on a variety of different factors. An example of a negative impact is the situation in the Goričko Landscape Park, where *R. pseudoacacia* is spreading rapidly in sensitive areas along watercourses, which supports the spread of seeds (Ivajnšič et al. 2012). Also in the case of the Northern Apennines where studies have shown a decline in biodiversity in pure *R. pseudoacacia* forests compared to native forest (Benesperi et al. 2012). A neutral character of environmental impact can be considered when there is no decrease in biodiversity or loss of certain forest functions. Research indicates that the environmental impact of *R. pseudoacacia* is significantly reduced when this species is kept as an admixture species rather than the dominant (Sádlo et al. 2017,

[1] Definition of homogenization: „Biological homogenization is a process of biodiversity loss driven by the introduction and invasion of widespread species and the extinction of specialized, endemic species" (Šibíková et al. 2019).

Vitkowa et al. 2020). A lack of significant impact on the biodiversity of the forest understorey has been observed for example in the Eastern Alps (Sitzia et al. 2012). Furthermore, analyses covering central and southern Europe indicate that a small admixture of *R. pseudoacacia* can be beneficial for local fauna in human-made habitats and regularly managed stand with mix structure (Sádlo et al. 2017). *R. pseudoacacia* can be used to help restore the soil by enriching with plant-available nitrogen and by producing a rapidly decomposing organic matter (Rahmonov 2009). This feature made this species popular in Europe for afforestation and reclamation, in countries like: Poland, Czech Republic or Germany (Sádlo et al. 2017). According to that, positive impacts have been reported usually in heavily degraded areas, where *R. pseudoacacia* is utilized for land restoration (Papaioannou et al. 2016, Ciuvăț et al. 2022).

6.3.2 Mechanisms of changing the ecosystem

Shading and changing soil chemistry are two of the major mechanisms by which *R. pseudoacacia* influences habitat species composition (Rahmonov 2009, Šibíková et al. 2019, Nicolescu et al. 2020). *R. pseudoacacia*, due to its rapid ability to grow and colonise new area, very quickly shades the forest under its canopy. This limits the regeneration of more light-demanding species, which are often the typical vegetation in poor and sandy areas (Rahmonov 2009). Above this, it modifies soil chemistry by enriching the soil with nitrogen and releasing allelopathic compounds. However, the increased availability of nitrogen in the soil is less important in fertile areas than in poor areas with nutrient deficiency. Increased nitrogen can open the way for nitrophilous species to colonise, including *Acer negundo, Sambucus nigra, Chelidonium majus, Galium aparine, Hedera helix* or *Urtica dioica* (Rahmonov 2009, Sádlo et al. 2017, Vítková et al. 2017). It is still debatable how much influence allelopathic compounds have on vegetation modification, and therefore on *R. pseudoacacia* colonising success. A growing number of promising lab studies are available on this topic (Nasir 2005, Medina-Vilar 2017, Ferus 2019), but laboratory results may misrepresent the scale of how important this mechanism is in the field (Medina-Villar 2017). Through laboratory studies, we know that *R. pseudoacacia* leaf litter contains phytocins that inhibit root developed and can cause losses in plant biomass (Nasir 2005, Ferus 2019). Some species are more resistant to these toxins, others less, so this may lead to selective suppression (Nasir 2005). Unfortunately, so far, larger field studies are lacking due to the difficulty of conducting them.

6.3.3 Intensity of changes in the ecosystem

Effects of *R. pseudoacacia* on the stand vary between studies from different countries (Sjöman 2018). Sometimes even studies from the same country uncover local differences. Furthermore, the intensity of effects can also vary in different locations. These differences, especially in biodiversity between different *R. pseudoacacia* forests, are explained by factors like: **level of urbanisation** (Dyderski et al. 2015, Marozas et al. 2015), **history of introduction** (Marozas et al. 2015), **geological/topographical differences** (Ivajnšič et al. 2012, Marozas et al. 2015), as well as **local ecosystem sensitivity** (Vítková et al. 2017, 2020).

Urbanization is a process associated with expansion of urban lands and bigger concentration of human population. The level of urbanization was mentioned as one of the factors explaining differences in the Polish city Poznań in *Chelidonio-Robinietum* community (Dyderski et al. 2015), and in research comparing *R. pseudoacacia* and *Acer negundo* stands from Lithuania and Latvia (Marozaz et al. 2015). The history of introduction also plays a relevant role. *R. pseudoacacia* in Europe has been introduced in many countries and in many locations which helped to facilitate its expansion (Vítková et al. 2017). The length of time that *R. pseudoacacia* has been present in an area also influences its potential for invasiveness. Two of the first countries to introduce *R. pseudoacacia* to Europe were France and Germany, while Slovakia decided to introduce *R. pseudoacacia* relatively late, in the 19th century. Most often, *R. pseudoacacia* spread where people planted it and in neighbouring areas (Vítková et al. 2017). The history of management treatments is also important, where patches are often exposed during thinning, expansion may occur faster and be more severe for the habitat. Studies indicate that in central Europe, *R. pseudoacacia* more frequently invades warm and dry areas, where *R. pseudoacacia* can win in competition with other species due to its high tolerance to stress factors and disturbances (Sádlo et al. 2017, Vítková et al. 2017). Taking into account topographical considerations, steep slopes, valleys or watercourses may facilitate seed dispersal (Ivajnšič et al. 2012, Vítková et al. 2020). On the other hand, low temperatures and sea level height are limiting factors for its occurrence (Kleinbauer et al. 2010, Vítková et al. 2017). In Europe *R. pseudoacacia* is favoured by a sub-Mediterranean climate (Vítková et al. 2017). The success of colonisation of new areas also depends on how vulnerable and susceptible the area is to invasion (Crosti et al. 2016).

7. Results - Case study

7.1 Frequency of species occurrence

Tables 1, 2 and 3 show the frequency of species in the stands divided into layers A1, A2, B and C in two stands in Warsaw. In total, 40 vascular plant species were recorded. In the tree layers (A1+A2) 16 of them, of which 15 occurred in the Na kole forest and nine occurred in the Linde forest (table 1). Species like *P. sylvestris*, *R. pseudoacacia*, *A. platanoides*, *Q. rubra* and *A. pseudoplatanus* were frequently found in these layers (table 1).

Table 1. Frequency of species occurrence in A1+A2 layers in Na kole *forest (n=14 in each group) and Lindego forest (n=10)*

A1+A2 [%]	Na kole control	Na kole mix	Na kole Robinia	Lindego control	Lindego Robinia
Acer platanoides	43	43	71	100	80
Acer pseudoplatanus	7	21	0	30	40
Aesculus hippocastanum	7	0	0	0	0
Betula pendula	36	36	0	0	0
Carpinus betulus	21	0	0	0	30
Larix sp.	7	0	0	0	0
Pinus sylvestris	100	100	7	100	30
Populus tremula	0	0	0	0	10
Prunus avium	0	0	14	0	0
Prunus serotina	7	21	14	0	0
Prunus spinosa	7	0	0	0	0
Quercus robur	7	0	0	0	10
Quercus rubra	79	29	64	0	40
Robinia pseudoacacia	0	100	100	0	100
Tilia cordata	7	0	0	0	0
Ulmus sp.	7	0	7	0	10

In the shrub layer (B) 21 species were recorded of which 20 occurred in the Na kole forest and 13 in the Lindego forest (table 2). Species such as *A. platanoides*, *Q. rubra* and *C. betulus* were the most common in this layer (table 2).

Table 2. Frequency of species occurrence in the B layer in Na kole *forest (n=14 in each group) and Lindego forest (n=10)*

B [%]	Na kole control	Na kole mix	Na kole Robinia	Lindego control	Lindego Robinia
Acer campestre	0	7	0	0	0
Acer negundo	29	14	14	20	0
Acer platanoides	86	79	79	90	100
Acer pseudoplatanus	29	36	21	40	10
Aesculus hippocastanum	29	7	0	0	10
Carpinus betulus	43	14	21	10	40
Corylus avellana	7	14	7	10	10
Euonymus verrucosus	0	0	0	0	30
Prunus avium	0	14	7	0	0
Prunus domestica	7	7	0	10	0
Prunus padus	0	7	0	0	0
Prunus serotina	36	43	14	0	0
Prunus spinosa	0	21	0	0	0
Quercus robur	0	7	0	0	10
Quercus rubra	79	93	86	50	40
Robinia pseudoacacia	21	21	21	0	0
Sambucus nigra	14	21	0	20	10
Sorbus aucuparia	14	0	0	0	0
Taxus baccata	0	7	0	0	0
Tilia cordata	7	14	0	10	20
Ulmus sp.	0	14	7	10	0

In the ground layer (C), 34 species were found, all of which occurred in the Na kole forest, and 16 also were found in the Lindego forest (Table 3). The most common species in the ground layer were *A. platanoides*, *Q. rubra*, *Impatiens parviflora*, *Hedera helix* and *Sambucus nigra* (Table 3). Species like *Corylus avellana*, *Prunus serotina* or *Urtica dioica* were only found in Na kole forest.

Table 3. Frequency of species occurrence in the C layer in Na kole *forest (n=14 in each group) and Lindego forest (n=10)*

C [%]	Na kole control	Na kole mix	Na kole Robinia	Lindego control	Lindego Robinia
Acer campestre	0	7	7	0	0
Acer negundo	14	14	14	0	0
Acer platanoides	100	71	86	100	100
Acer pseudoplatanus	29	50	29	20	30
Aesculus hippocastanum	0	7	0	0	10
Alliaria petiolata	0	7	14	0	0
Berberis vulgaris	0	7	0	0	0
Carpinus betulus	29	7	7	10	20
Chelidonium majus	14	29	14	0	10
Convallaria majalis	7	7	0	0	30
Corylus avellana	7	14	0	0	0
Euonymus verrucosus	7	0	7	0	0
Geranium robertianum	7	0	0	0	0
Geum urbanum	0	0	7	0	0
Hedera helix	21	29	14	40	70
Impatiens parviflora	43	29	57	30	30
Parthenocissus sp.	21	7	0	0	0
Poaceae	0	14	0	0	0
Prunus avium	0	0	7	0	0
Prunus domestica	7	0	0	0	0
Prunus padus	0	0	7	0	0
Prunus serotina	50	50	57	0	0
Quercus robur	0	21	0	10	20
Quercus rubra	71	93	100	70	60
Ribes sp.	7	7	0	20	0
Robinia pseudoacacia	21	29	29	40	20
Rubus sp.	0	0	7	0	0
Sambucus nigra	29	21	29	40	60
Sorbus aucuparia	7	7	0	20	0
Symphoricarpos albus	7	0	0	10	10
Tilia cordata	14	0	0	10	50
Ulmus sp.	7	7	7	0	0
Urtica dioica	0	0	7	0	0
Vinca minor	0	0	7	0	0

7.2 Species richness

7.2.1 Na kole forest

The Kruskal-Wallis test of the data collected in Na kole forest showed significant differences only in layer B in terms of the number of species (table 4). That is, the number of species in the plots with *R. pseudoacacia* was found to be significantly lower compared to the mixed and control plots.

Table 4. Median number of species in four vegetation layers in Na kole *forest. P-values according to Kruskal-Wallis test of three groups of sample plots (n=14 in each group)*

Layer	Control	Mix	Robinia	P-value
A1	2	1	1	0.206
A2	2	2	2	0.384
B	4	4.5	3	0.005
C	5.5	5	5	0.864

7.2.2 Lindego forest

The Kruskal-Wallis test of the data collected in Lindego showed significant differences only in the C layer in terms of the number of species (table 5). The number of species in the undergrowth layer in the *R. pseudoacacia* plots was found to be significantly higher compared to the control plots. In addition, there was a trend ($p<0.1$) for higher species richness in both tree layers of the *R. pseudoacacia* plots.

Table 5. Median number of species in four vegetation layers in Lindego forest. P-values according to Kruskal-Wallis test of two groups of sample plots (n=10 in each group)

Layer	Control	Robinia	P-value
A1	1	2	0.079
A2	1	2	0.054
B	3	2	0.431
C	4	5.5	0.029

7.3 Layer cover

7.3.1 Na kole forest

The Kruskal-Wallis tests of the data collected in the Na kole forest showed no significant differences for cover of the different vegetation layers, although there was a trend ($p<0.1$) for higher cover of the upper tree layer (A1) in the *R. pseudoacacia* plots (table 6).

Table 6. Median cover % of four vegetation layers in Na kole *forest. P-values according to Kruskal-Wallis test of three groups of sample plots (n=14 in each group)*

Layer	Control	Mix	Robinia	P-value
A1	30	30	50	0.069
A2	45	45	45	0.712
B	50	55	45	0.377
C	25	30	40	0.718

7.3.2 Lindego forest

The Kruskal-Wallis test of the data collected in Lindego forest showed no significant differences in terms of layer cover between the plot groups (table 7). Comparing the two forests, tree layer cover was higher than in Na kole forest and undergrowth cover was lower (table 6, table 7).

Table 7. Median cover % of four vegetation layers in Lindego forest. P-values according to Kruskal-Wallis test of two groups of sample plots (n=10 in each group)

Layer	Control	Robinia	P-value
A1	70	70	0.603
A2	80	80	0.968
B	30	20	0.666
C	10	10	1.000

7.4 Species composition

7.4.1 Na kole forest

Hierarchical cluster analysis performed using Ward's method did not show clear general differences between control, mixed and Robinia plots in Na kole forest for the tree layers A1+A2 (figure 8).

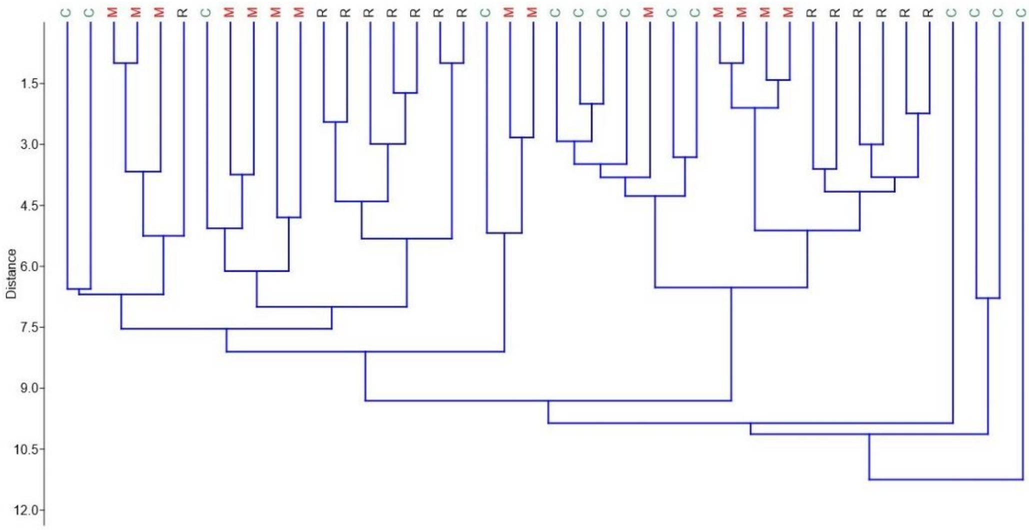

Figure 8. Hierarchical cluster analysis for A1+A2 layers in Na kole forest. C-control, M-mix, R-Robinia

Similarly to the results for the tree layer, Ward's hierarchical cluster analysis did not show clear general differences between control, mixed and Robinia plots in Na kole forest for undergrowth layers B+C (figure 9).

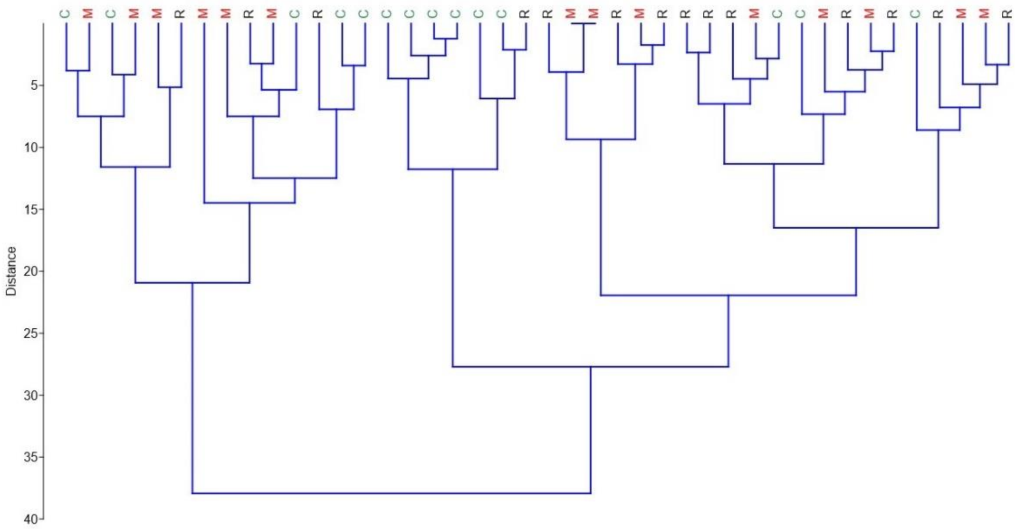

Figure 9. Hierarchical cluster analysis for B+C layers in Na kole forest. C-control, M-mix, R-Robinia

The Principal Component Analysis (PCA) of the data collected from undergrowth layers (B+C) in Na kole forest showed no clear tendency to grouping into the plot groups (figure 10).

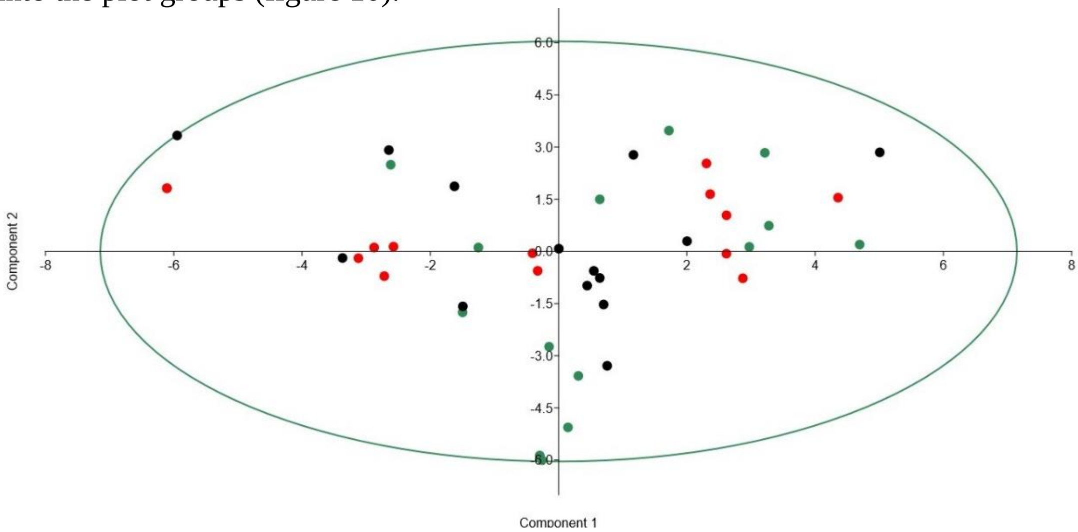

Figure 10. PCA analysis for B+C layers in Na kole forest with the 95% confidence limit marked. Green-Control plots, Red-Mix plots, Black-Robinia plots

7.4.2 Lindego forest

Ward's hierarchical cluster analysis indicated a general difference between control and Robinia plots, except for two of the Robinia plots being more similar to control plots (figure 11).

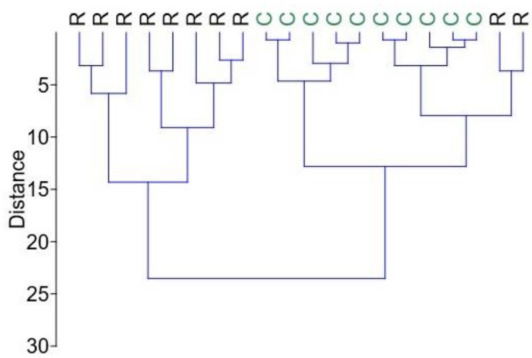

Figure 11. Hierarchical cluster analysis for A1+A2 layers in Lindego forest. C-control, R-Robinia

Ward's hierarchical cluster analysis did not show clear differences between control and Robinia plots in layers B+C. Only five out of ten of the control plots form a distinct group (figure 12).

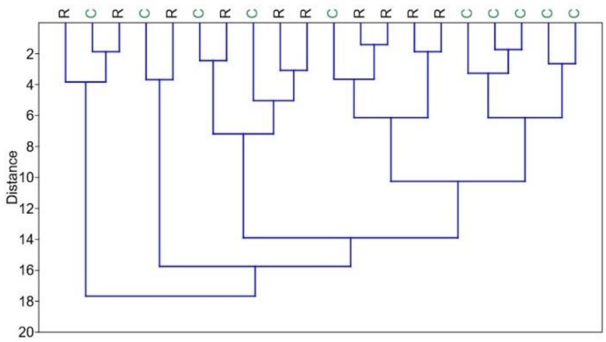

Figure 12. Hierarchical cluster analysis for B+C layers in Lindego forest. C-control, R-Robinia

Principal Component Analysis (PCA) for undergrowth layers (B+C) in Lindego forest showed no significant tendency to grouping (figure 13).

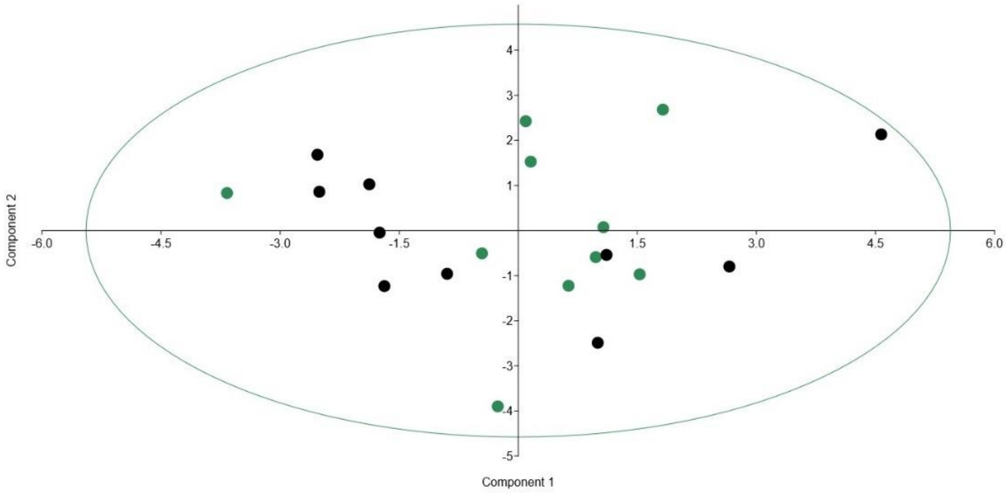

Figure 13. PCA analysis for B+C layers in Lindega forest with the 95% confidence limit marked. Green-Control plots, Black-Robinia plots

7.5 Number of alien and native species

On the basis of Rutkowski (2022), among the observed species, 29 native and 11 alien species were distinguished (Appendix 1). Further analysis was carried out on the basis of this division.

7.5.1 Number of native species

Na kole forest

The number of native species in the upper tree layer (A1) was lower in the *R. pseudoacacia* plots than in the other two plot groups, but there were no differences in the other vegetation layers (table 8).

Table 8. Median number of native species in four vegetation layers in Na kole forest. P-values according to Kruskal-Wallis test of three groups of sample plots (n=14 in each group)

Layer	Control	Mix	Robinia	P-value
A1	1	1	0	0.000
A2	1	1	1	0.832
B	2	3	1	0.119
C	3	3	2	0.584

Lindego forest

The Kruskal-Wallis test of the data collected in Lindego forest showed a significantly higher number of native species in the ground vegetation (C) of the *R. pseudoacacia* plots, but no differences in the other layers (table 9).

Table 9. Median number of native species in four vegetation layers in Lindego forest. P-values according to Kruskal-Wallis test of two groups of sample plots (n=10 in each group)

Layer	Control	Robinia	P-value
A1	1	1	0.463
A2	1	1	0.577
B	2	2	0.530
C	2.5	4	0.006

7.5.2 Number of alien species

Na kole forest

The Kruskal-Wallis test of the data collected in the Na kole forest showed a significantly higher number of alien species in the upper tree layer (A1), but a lower number in the lower tree layer (A2) in the *R. pseudoacacia* plots. There were no differences between the plot groups in the understory layers (table 10).

Table 10. Median cover % of alien species in four vegetation layers in Na kole forest. P-values according to Kruskal-Wallis test of three groups of sample plots (n=14 in each group)

Layer	Control	Mix	Robinia	P-value
A1	0	0	1	0.000
A2	1	1	0.5	0.018
B	2	2	1	0.120
C	3	3	2	0.647

Lindego forest

The Kruskal-Wallis test of the data collected in the Lindego forest showed a higher number of alien species in the Robinia plots in both tree layers (A1 and A2), but there were no significant differences in the understory layers (table 11).

Table 11. Median cover % of alien species in four vegetation layers in Lindego forest. P-values according to Kruskal-Wallis test of two groups of sample plots (n=10 in each group)

Layer	Control	Robinia	P-value
A1	0	1	0.000
A2	0	0	0.029
B	0	1	0.362
C	2	1	0.277

8. Discussion

8.1 Study design

Many studies covering wider forest areas in Europe point to detrimental effects of *R. pseudoacacia* in habitats. However, not all studies indicate this trend, some of them noting no major impact (Von Holle et al. 2005, Akatov et al. 2012, Sitizia et al. 2012), in some situations the impact can be even positive (Papaioannou et al. 2016, Sádlo et al. 2017, Ciuvăț et al. 2022). Therefore, the study presented here not only analyzed general trends in the impact of *R. pseudoacacia* on the environment, but also conducted field studies that give a perspective on the current situation at a specific site.

The research presented here shows how *R. pseudoacacia* influences the formation of lower layers in the urban conditions in Warsaw. The study compared biodiversity inside patches with *R. pseudoacacia* with *Pinus sylvestris* patches in the tree layer. The edges of the stands and vegetation close to paths and roads whose species composition may differ significantly from the species inside, were excluded. Despite the fact that oak-hornbeam forest is considered to be an appropriate plant community for these urban forests (Fogel et al. 2018), fragments of such forest are practically not found. Therefore, fragments with *P. sylvestris* were treated as controls, since they are the actual vegetation of Warsaw's inner-city forests, and also *P. sylvestris* being a species native to Poland.

The results of the field studies allow to conclude on the current condition of the discussed stands in Warsaw and only to estimate further development in the near future. Warming and drying climate may lead to the promotion and stronger invasiveness of *R. pseudoacacia* as is predicted by model studies (Kleinbauer et al. 2010, Dyderski et al. 2018, Vítková et al. 2020, Puchałka et al. 2021, Visztra et al. 2023). However, it should be remembered that ongoing climatic changes may as well reduce it by encouraging the development and colonization of its pathogens (Zarzyńska-Nowak et al. 2015, Wilkaniec et al. 2021).

8.2 How does *Robinia pseudoacacia* fit into urban forestry?

Among the various functions provided by urban forests, three groups were identified for the analysis: social, economical and environmental (figure 14). The discussion of these topics is intended to help analyse the pros and cons of the presence of an alien species in an urban environment.

8.2.1 Social aspects

Considering the social aspects, the *R. pseudoacacia* has many potential advantages, but so far, there is a lack of broader studies on public approach to alien species in the cities. Green areas inside cities are important for their citizens, mainly for recreation purposes (Gołos 2013, Mierzejewska 2011, Jaszczak 2022). Public opinion can have a significant impact on forest policy and management decisions (Miścicki et al. 2012). This is why it is worth to fill this knowledge gap in future research, before starting new control programs for alien species. Over the years, *R. pseudoacacia* trees have been appreciated for their ornamental reasons, which was one of the main reasons for their import to Europe (Vítková et al. 2017). The visual attractiveness of *R. pseudoacacia* is also evidenced by its numerous varieties that are being used in urban greenery design (Tomanek 1987, Seneta et al. 2012).

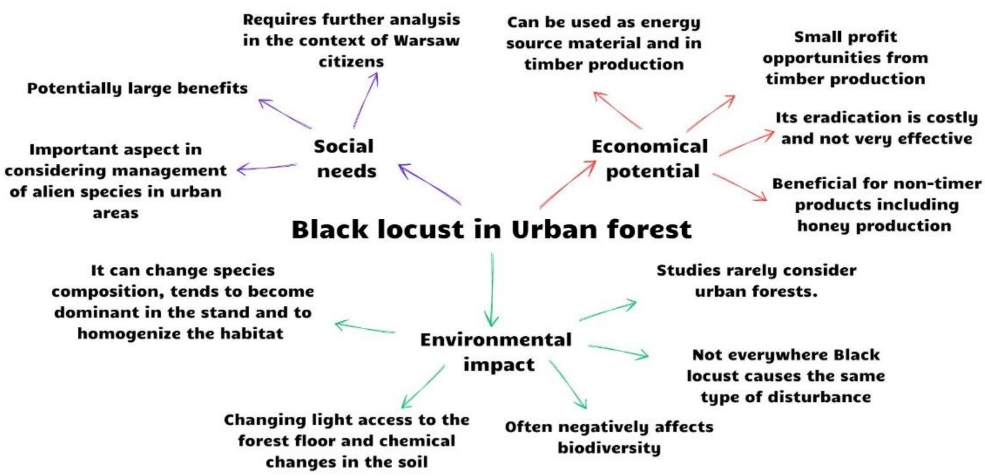

Figure 14. Impact of R. pseudoacacia (Black locust) *on three groups of urban forest values, based on literature*

8.2.2 Economic aspects

Regarding economic aspects, forestry in cities is usually not carried out for production purposes. The reason for this is mainly due to the relatively small area of forest stands and the difficulty of conducting active timber management inside a densely populated city. *R. pseudoacacia* itself is effectively used in plantations in other countries, but outside urban agglomerations. *R. pseudoacacia* wood has a great potential, it is used in the energy industry, furniture production and construction timber. Above that, *R. pseudoacacia* is also valued for its non-timber products like honey. Cultivation of this species in cities, however, can be used successfully to remove heavy metal pollution from soils, improve microclimates by mitigating Urban Heat Island (UHI) effects and create greenery in heavily degraded areas where conditions do not allow for successful cultivation of native species.

R. pseudoacacia can also cause damage in the management budget. Poorly managed or uncontrolled *R. pseudoacacia* may need to be reduced or eliminated, which is a very difficult and costly task. Methods developed so far, such as repetitive cutting, ringing, or chemical methods, do not give satisfying results (Obidziński et al. 2016). *R. pseudoacacia* can provide benefits when grown in plantations, but in urban areas its presence comes at the risk of high costs for control treatments, but can nonetheless bring non-production benefits.

8.2.3 Environmental aspects

In studies analyzing the impact of the *R. pseudoacacia* on forests habitats, problems were noted with a trend to dominance of this species (Akatov et al. 2012, Ivajnšič et al. 2012), homogenization of the habitat (Šibíková et al. 2019, Obidzinski et al. 2016) and changes in species composition (Rahmonov 2009, Sádlo et al. 2017, Gentili et al. 2019, Šibíková et al. 2019). However, the present case study of two urban forests in Warsaw did not show significant differences in species composition. A reason for this may be a generally high level of forests degradation, including both fragments with *R. pseudoacacia* and with *P. sylvestris*. Degradation, strong pressure from the surrounding city and visitors could be a factor shaping the richness of species. Therefore, the difference between the Robinia and control samples was blurred. In the literature it is noted that the presence of *R. pseudoacacia* also can cause changes in light access to the forest floor (Rahmonov 2009, Slabejová et al. 2019). In the context of the analyzed stands, this effect was small, visible only in the A1 and A2 layer in Na kole Forest, where plots with *R. pseudoacacia* were denser than with *P. sylvestris* (table 6). Forests with *R. pseudoacacia* thus have common features. Among the species reported in the study from Na kole forest and Lindego forest, species on the plots such as *Acer negundo*, *Sambucus nigra*, *Chelidonium majus*, *Hedera helix* and *Urtica dioica* have also appeared in other studies from Europe (Rahmonov 2009, Sádlo et al. 2017, Vítková et al. 2017). The results from Warsaw in relation to the main conclusions from the literature (figure 14) are presented in figure 15.

Sometimes the regional dendroflora is too limited to be able to use only native species in urban spaces, in such situations, according to Sjöman, planting an alien species should be considered (Sjöman 2016). He argues that too fast, non-native species are excluded from utilisation. A native-only approach, according to the author, can lead in some situations to weakened resilience of urban stands (Sjöman 2016).

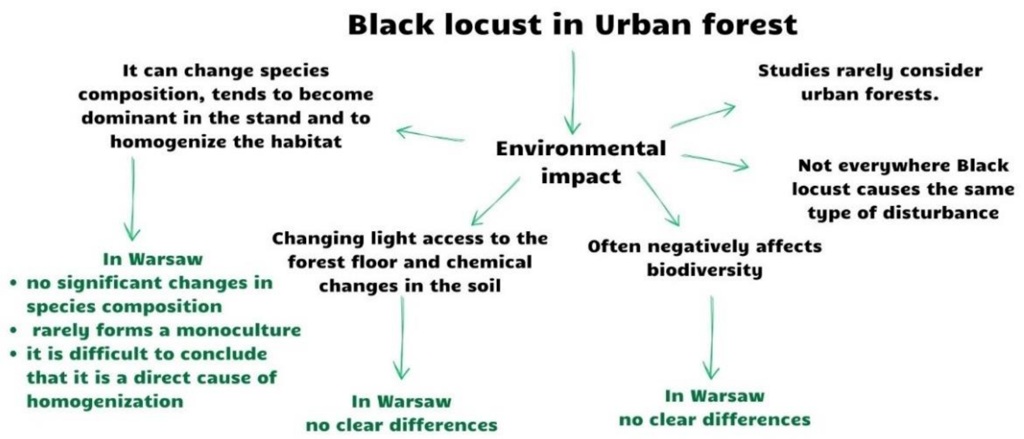

Figure 15. Environmental impact of R. pseudoacacia (Black locust) *in the case study in Warsaw*

When talking about the impact of *R. pseudoacacia* on biodiversity, it is worth looking beyond the plants to the populations of other taxonomical groups. As an insect-pollinated plant, *R. pseudoacacia* can also be used in cities to protect wild bee populations. According to research from Berlin, 20 wild bee species, including red-listed species, were found on selected *R. pseudoacacia* trees (Hausmann et al. 2016). Despite that the share of bee species was observed to be greater on *Acer platanoides* (34 species) and *Tilia cordata* (25 species) than on *R. pseudoacacia* (20 species), it is worth considering using the *R. pseudoacacia* as a support species for urban bees (Hausmann et al. 2016). In another study from the Czech Republic bird biodiversity was studied in native trees and non-native (*R. pseudoacacia*) stands (Reif et al. 2016). It was shown that in alien stands the number of specialized species was lower, which, according to the authors, is a reason not to support this type of stands, considering the biodiversity of bird species (Reif et al. 2016).

8.3 Situation in the case study forests

8.3.1 Biodiversity

In the studies presented here, there is no indication that *R. pseudoacacia* has a more negative impact on biodiversity or the proportion of non-native species in urban stands than patches of forest composed of native tree species. As these studies indicate, reducing or eliminating patches with *R. pseudoacacia* by replacing them with species such as *P. sylvestris* will probably not improve the biodiversity or naturalness of the lower layers of the stands. The analysis of the two forest sites Na kole forest and Lindego forest suggests that the biodiversity of the undergrowth is more influenced by the density of the upper layers than by the presence of *R. pseudoacacia*, potentially enriching the soil with nitrogen.

8.3.2 Regeneration

On the analysed plots, *Acer pseudoplatanus* and *A. platanoides* regeneration, species inherent to the native oak-hornbeam forests, appeared in most of the analyzed areas. These species were successfully used as sub-canopy species in the *R. pseudoacacia* reduction programme in the Bielański Forest, being adjacent to Lindego forest (Miścicki et al. 2012, 2020). Both *Acer* species grew well in both *P. sylvestris* and *R. pseudoacacia* patches (table 3) maintaining strong shading on the forest floor. The density of the upper layers of the stands is high enough to effectively inhibit the regeneration of *R. pseudoacacia* under the canopy. *R. pseudoacacia* seedlings have only been observed in open areas, such as gaps left by fallen or removed trees. Apart from the *R. pseudoacacia, Quercus rubra* proved to be the most frequently occurring alien tree species (table 3). Unlike *R. pseudoacacia*, *Q. rubra* frequently regenerated under the canopy of stands, both in control and study plots (table 3). The omnipresence of this species in all analysed strata and sites indicates that it may be a greater threat to local stands than *R. pseudoacacia*.

8.4 Management recommendations

Based on the literature review and the results from the case study, the following recommendation can be given for future forest management plans in Warsaw:

- **Maintain a mixed forest structure**

  Much more serious changes in ecosystem functioning are expected in stands where *R. pseudoacacia* fully dominates the stand, while in mixed forests with native species the changes could be softer (Vitkowa et al. 2020). Therefore, it seems to be an important issue to take care of preserving the mixed form of urban forests with *R. pseudoacacia* in the Warsaw area in the future. Small admixtures of *R. pseudoacacia* in urban forests can bring benefits through their cultural value, diversifying the tree-stand structure and adding new functions (Vítková et al. 2020).

- **For the next generation of trees, plant *maple*s (*Acer spp.*)**

  Pinus sylvestris does not regenerate naturally on the study plots, the main reason being too much shade. However, its regeneration by the clear cut method is risky due to its close neighbourhood with *R. pseudoacacia*. It is therefore recommended to promote *Acer spp.* regeneration during future forest succession. *Quercus rubra* is very likely to be a greater threat to native tree species.

- **Observe the changes**

Monitor how the proportion of *R. pseudoacacia* develops in stands to early detect places where it becomes invasive. It is also worth to monitor *Q. rubra* due to its frequent regeneration in the lower layers of the forest.

- **Reduce cuttings inside the stand to minimum**

Reducing access to light can effectively control a light-demanding species such as *R. pseudoacacia* (Radtke et al. 2013).

- ***R. pseudoacacia* shouldn't be introduced on new sites** (Crosti et al. 2016)

R. pseudoacacia is an alien species with invasive characteristics that is relatively difficult to eradicate. Therefore, its introduction should be avoided in places where it did not occur previously.

9. Conclusions

- In the case of both analysed urban forest stands in Warsaw, *R. pseudoacacia* does not appear to cause a significant environmental problem at present.
- In the urban forests of Warsaw, there are no significant differences in the species composition of ground vegetation in stands with *R. pseudoacacia* compared to surrounding forest fragments with *P. sylvestris*.
- *R. pseudoacacia* in Warsaw's urban forests seems not to promote other alien species more than *P. sylvestris*.
- For improving biodiversity and naturalness of the studied sites, it is not sufficient to remove *R. pseudoacacia*.
- *R. pseudoacacia* does not require elimination. However, its impact in future years should be monitored.
- Maintaining continuous shading of the forest floor in patches of the *R. pseudoacacia* effectively limits its regeneration, promoting native species like *Acer platanoides* and *A. pseudoplatanus*.
- Keeping the forest floor well-shaded can be a long-term minimum-cost method of controlling the expansion of *R. pseudoacacia*.
- *R. pseudoacacia*, thanks to its adaptation to harsh conditions, is easier to grow in urban conditions than some of the native tree species
- *R. pseudoacacia* fragments in Warsaw's forests may be beneficial considering the diversity of forest structure, species diversity of upper forest layers, pollination services, ornamental aspects, phytoremediation and mitigation of urban heat island effects.

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Popular science summary

Robinia pseudoacacia (Black locust) is an alien species to Europe, introduced in the 17th century from North America. It can be found in plantations, woodlands, green areas and avenues, practically in all European countries. Contributing to its popularity is its remarkable tolerance to harsh environmental conditions. This feature has some benefits as well as risks. On the one hand, we can use *R. pseudoacacia* to reforest difficult sites, even landfills or post-industrial areas. On the other hand, *R. pseudoacacia* is considered as an invasive species.

Robinia pseudoacacia can quickly colonize new areas as long as it has sufficient access to light. However, this creates a problem for traditional forestry. You can imagine a situation in which you are tasked to regenerate *Pinus sylvestris* forest, so it is necessary to remove several hectares of forest to create the proper conditions. However, we can imagine the scale of the damage if all this space will be overgrown by *R. pseudoacacia*, leaving no space or light for the planned seedlings. It is also worth mentioning at this point that the removal of the *R. pseudoacacia* by cutting or using other mechanical or chemical methods, is very expensive and usually does not give a satisfactory result.

However, the situation of urban forests seems to be slightly different. In contrast to traditional forests, economic goals do not play such an important role. Instead, social and environmental benefits are much more important. Urban forests tend to cover small areas, they are frequently visited by people and often struggle with soil or air pollution. Difficult living conditions for trees in cities can limit the choice from native species, this is also a reason why a discussion about alien species is an important issue. Therefore, the starting point for this research was the question: how serious a threat is *R. pseudoacacia* to urban forests, and what is its function? To answer for these questions, an analysis of 80 scientific publications was conducted, searching information about potential pros and cons taking into account social, economic and environmental considerations (figure 14).

From the society's point of view, *R. pseudoacacia* can be considered to be attractive for visitors, especially in early spring during flowering. How the community perceives *R. pseudoacacia* can have a direct impact on the species' management policies, both nationally and internationally.

In terms of economic aspects, the species is successfully used in plantations as firewood or construction timber. Moreover, from its flowers honey is produced, which locally can be an important non-timber product. *R. pseudoacacia* has a good economic potential, but unfortunately rather in plantations than in cities. However, in cities, *R. pseudoacacia* can help mitigate urban heat island effects, as well as clean contaminated soil. Nevertheless, there is always a risk that it will affect the biodiversity of local habitats negatively.

From an environmental point of view, many studies from European countries highlight the riskiness of introducing *R. pseudoacacia*. In forests, after its appearance, a decline in the number of plant species may be observed, some of them being replaced by other, often less valuable species, and the habitats themselves becoming less diversified. *R. pseudoacacia* also has the ability to enrich the soil with nitrogen through symbiosis with bacteria. Most of the studies about environmental impact are not directly related to urban forests, so this analysis was completed by surveying 62 sample plots from two Warsaw urban forests, Na kole and Lindego forest.

The aim of the study was to check how the parts of forests with *R. pseudoacacia* differed from the parts with *P. sylvestris* in terms of the present species. The results showed that there were no significant differences in the number of plant species, and moreover, the presence of *R. pseudoacacia* did not favor the colonization of other alien species. This is an interesting result because published studies much more often observe a negative effect of this species than a neutral or positive. Above that, maintaining forest shading at the present level may be an effective method in reducing *R. pseudoacacia* regeneration. These results mean that the *R. pseudoacacia* in Warsaw is no greater threat to the environment than the *P. sylvestris*, and its elimination itself will not improve the biodiversity of the forests.

In conclusion, studies from different parts of Europe indicate that *R. pseudoacacia* has a variety of effects on the environment. In the urban area, *R. pseudoacacia* can bring benefits, as long as it is properly managed. However, it is necessary to systematically monitor the forests, especially in the context of climate change. It is also worth conducting further research to better understand the role of this species in urban ecosystems and its impact on biodiversity.

Streszczenie popularnonaukowe

Robinia akacjowa (*Robinia pseudoacacia*) jest gatunkiem obcym dla Europy, przywiezionym w XVII wieku z Ameryki Północnej (Vítková et al. 2017). Można ją spotkać na plantacjach, w zadrzewieniach oraz przydrożnych alejach, praktycznie we wszystkich krajach europejskich (Pyšek et al. 2009). Do jej popularności przyczyniła się jej niezwykła tolerancja na trudne warunki środowiska. Jednakże, ta cecha ma zarówno pozytywne, jak i negatywne aspekty. Z jednej strony możemy wykorzystywać ją do zalesiania trudnych terenów takich jak obszary miejskie, a nawet wysypiska śmieci czy tereny po przemysłowe (Băbău et al. 2021). Z drugiej strony jednak w wielu miejscach rozważana jest jako gatunek inwazyjny (Vitkova et al. 2017).

Robinia akacjowa może szybko zasiedlać nowe tereny, jeśli tylko ma wystarczający dostęp do światła. Stwarza to jednak problem dla tradycyjnego leśnictwa. Wyobraźmy sobie sytuacje w której mamy za zadanie odnowić fragment sosnowego lasu. Konieczne jest usunięcie kilku hektarów lasu, aby stworzyć odpowiednie warunki dla nowych drzew. Można sobie jednak wyobrazić skalę szkód, jeśli cała ta przestrzeń zostanie zarośnięta przez robinie akacjową, nie pozostawiając tym samym miejsca ani wystarczającego dostępu do światła dla planowanych sadzonek. Warto również w tym momencie wspomnieć, że usuwanie robinii akacjowej poprzez wycinkę lub przy zastosowaniu innych metod mechanicznych czy chemicznych, jest bardzo kosztowne i zazwyczaj nie daje satysfakcjonującego efektu (Obidziński et al. 2016).

Jednak sytuacja lasów miejskich wydaje się być nieco inna. W przeciwieństwie do tradycyjnych lasów, cele ekonomiczne nie odgrywają tu tak istotnej roli. Znacznie ważniejsze są za to korzyści społeczne oraz środowiskowe (Jaszczak et al. 2017, Jaszczak 2022). Lasy miejskie mają zwykle niewielkie powierzchnie, są często odwiedzane przez ludzi i nie rzadko zmagają się z zanieczyszczeniami. Trudne warunki życia dla drzew mogą ograniczać ich wybór z pośród rodzimych gatunków (Sjöman et al. 2016). Dlatego też punktem wyjścia dla tych badań było pytanie: **jak poważnym zagrożeniem dla lasów miejskich jest robinia akacjowa i jaką pełni ona funkcję w lasach miejskich?** Aby odpowiedzieć na te pytania, przeprowadzono analizę 80 artykułów poszukując informacji o potencjalnych zaletach i wadach biorąc pod uwagę względy społeczne, ekonomiczne i środowiskowe (figure 14).

Z punktu widzenia społeczeństwa robinia akacjowa może być uznawana jako atrakcyjna dla odwiedzających osób, zwłaszcza wczesną wiosną podczas kwitnienia. To jak społeczność postrzega robinię akacjową ma bezpośredni wpływ na politykę zarządzania tym gatunkiem, zarówno krajową jak i międzynarodową (García-Llorente et al. 2008, Vítková et al. 2017, Pietras-Couffignal 2021).

Pod względem ekonomicznym, gatunek ten z powodzeniem jest wykorzystywany na plantacjach jako drewno opałowe czy konstrukcyjne. Z jej kwiatów natomiast wytwarza się miód, który lokalnie bywa ważnym nie-drzewnym produktem. W miastach natomiast robinia akacjowa może pomóc w walce z wyspami ciepła (Rahman et al. 2019), a także w oczyszczaniu gleby (Băbău et al. 2021). Niemniej jednak zawsze istnieje ryzyko, że zacznie ona zagrażać lokalnym siedliską.

Z punktu widzenia środowiska wiele badań z krajów Europejskich podkreśla ryzykowność występowania robinii akacjowej (Tokarska-Guzik 2012, Vítková et al. 2017, Klisz et al. 2021). W lasach po jej pojawieniu, obserwuje się spadek w liczebności gatunków roślin, jedne gatunki ustępują miejsca innym, często dużo mniej pożądanym i cennym, a same siedliska stają się mniej zróżnicowane (Rahmonov 2009, Obidzinski et al. 2016, Gentili et al. 2019). Ma ona również zdolność do wzbogacania gleby w azot dzięki współpracy z bakteriami azotowymi w korzeniach (Nasir 2005, Ferus 2019). Jednak większość spośród analizowanych badań nie dotyczy bezpośrednio lasów miejskich, dlatego też powyższą analizę uzupełniono o badania 62 powierzchni badawczych z dwóch Warszawskich lasów miejskich, lasku Na kole oraz lasku Lindego.

Celem badania było sprawdzenie jak różnią się pod względem występujących gatunków części z robinią akacjową od części lasów z sosną zwyczajną. Wyniki pokazały że fragmenty te nie różnią się istotnie liczebnością gatunków roślin, a ponad to obecność robinii akacjowej nie sprzyjała kolonizacji innych gatunków obcych (table 10, table 11). Jest to niezwykle ciekawe ponieważ w publikowanych badaniach dużo częściej obserwuję się negatywny wpływ tego gatunku niż neutralny czy pozytywny. Ponad to utrzymanie zacienienia lasów na poziomie jakim jest teraz może być skuteczną metodą w ograniczaniu jej występowania. Wyniki te oznaczają że robinia akacjowa w Warszawie nie stanowi zagrożenia dla środowiska bardziej niż sosna, a sama jej eliminacja nie przyniesie poprawy bioróżnorodności lasu.

Podsumowując, badania z różnych części Europy wskazują na różnorodny wpływ robinii akacjowej na środowisko. W mieście Robinia akacjowa może przynosić korzyści, pod warunkiem jej odpowiedniego zarządzania. Jednakże, konieczne jest systematyczne monitorowanie lasów, zwłaszcza w kontekście zmian klimatycznych. Warto również prowadzić dalsze badania, aby lepiej zrozumieć rolę tego gatunku w ekosystemach miejskich oraz jego wpływ na bioróżnorodność.

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Appendix 1 Thematic division into groups of analyzed publications

Group 1
Public attitudes and social aspects

1. Bremner et al. 2007
2. Dmochowska et al. 2003
3. García-Llorente et al. 2008
4. Gentili et al. 2019 *
5. Junge et al. 2019
6. Kraszkiewicz 2021 *
7. Mierzejewska 2011
8. Reif et al. 2016 *
9. Šibíková et al. 2019 *

Group 2 Production and management

1. Bijak et al. 2021
2. Băbău et al. 2021
3. Ciuvăț et al. 2022
4. Crosti et al. 2016
5. Dmochowska et al. 2003 *
6. Dyderski et al. 2015 *
7. Feliksik et al. 2007
8. Gil 2018
9. Kamperidou et al. 2016
10. Kraszkiewicz 2021
11. Lippert et al. 2022 *
12. Miścicki et al. 2012
13. Miścicki et al. 2021
14. Nicolescu et al. 2018
15. Nicolescu et al. 2020
16. Obidziński et al. 2016
17. Papaioannou et al. 2016
18. Sádlo et al. 2017
19. Środek et al. 2022

20. Vasiliki et al. 2017
21. Wojda et al. 2014
22. Zajączkowski et al. 2012
23. Radtke et al. 2013

Group 3 Environment impact and invasiveness

1. Akatov et al. 2012
2. Benesperi et al. 2012
3. Campagnaro et al. 2022
4. Danielewicz et al. 2020
5. Dyderski et al. 2018
6. Ferus et al. 2019
7. García-Llorente et al. 2008 *
8. Gentili et al. 2019
9. Ivajnšič et al. 2012
10. Kleinbauer et al. 2010
11. Klisz et al. 2021
12. La Porta et al. 2008
13. Mally et al. 2021
14. Marozas et al. 2015
15. Medina-Villar et al. 2017
16. Nasir et al. 2005
17. Nentwig et al. 2018
18. Nicolescu et al. 2020 *
19. Puchałka et al. 2021
20. Pyšek et al. 2009
21. Rahmonov 2009
22. Reif et al. 2016
23. Sabo 2000
24. Šibíková et al. 2019
25. Sitzia et al. 2012
26. Sitzia et al. 2016
27. Slabejová et al. 2019
28. Szwagrzyk 2000
29. Tokarska-Guzik et al. 2012
30. Visztra et al. 2023
31. Von Holle et al. 2006
32. Wilkaniec et al. 2021
33. Zarzyńska-Nowak et al. 2015

Group 4 Urban forestry

1. Chudy 2017
2. Ciuvăț et al. 2022 *
3. Czerniewska-Andryszczyk et al. 2021
4. Dyderski et al. 2015
5. Feliksik et al. 2007 *
6. Fogel et al. 2018
7. Gołos 2013
8. Jaszczak et al. 2017
9. Jaszczak2022
10. Kaliszewski 2006
11. Kamperidou et al. 2016 *
12. Konijnendijk et al. 2006
13. Kowarik et al. 2019
14. Lenard 2007
15. Lippert et al. 2022
16. Miller et al. 2015
17. Pietras et al. 2021
18. Wilkaniec et al. 2021
19. Zarzyńska-Nowak et al. 2015
20. Środek et al. 2022
21. Moser et al. 2015
22. Moser et al. 2016
23. Rötzer et al. 2021
24. Rahman et al. 2019
25. Franceschi et al. 2023

Group 5 Overview about *R. pseudoacacia*

1. Seneta et al. 2012
2. Sjöman et al. 2016
3. Tomanek 1987
4. Vítková et al. 2017
5. Vítková et al. 2020

*publications classified in two group

Appendix 2 Lists of native and alien species

List 1. Native species

1. *Acer campestre* L.
2. *Acer platanoides* L.
3. *Acer pseudoplatanus* L.
4. *Alliaria petiolata* (M. Bieb)
5. *Berberis vulgaris* L.
6. *Betula pendula* Roth
7. *Carpinus betulus* L.
8. *Chelidonium majus* L.
9. *Convallaria majalis* L.
10. *Corylus avellana* L.
11. *Euonymus verrucosus* Scop.
12. *Geranium robertianum* L.
13. *Geum urbanum* L.
14. *Hedera helix* L.
15. *Pinus sylvestris* L.
16. *Poaceae*
17. *Populus tremula* L.
18. *Prunus avium* L.
19. *Prunus padus* L.
20. *Prunus spinosa* L.
21. *Quercus robur* L.
22. *Rubus* sp.
23. *Sambucus nigra* L.
24. *Sorbus aucuparia* L.
25. *Taxus baccata* L.
26. *Tilia cordata* Mill.
27. *Ulmus* sp.
28. *Urtica diorica* L.
29. *Vinca minor* L.

List 2. Alien species

1. *Acer negundo* L.
2. *Aesculus hippocastanum* L.
3. *Impatiens parviflora* DC.
4. *Larix* sp.
5. *Parthenocissus* sp.
6. *Prunus domestica* L.
7. *Prunus serotina* Ehrh.
8. *Quercus rubra* L.
9. *Ribes* sp.
10. *Robinia pseudoacacia* L.
11. *Symphoricarpos albus* (L.) S.F. Blake

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