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Collection of Experiences: 25 Years' Work on Seed Propagation of Allochthonous Woody Plants in Skopje and Their Possible Role in the Urban Landscape

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ABSTRACT

In the past decades, numerous landscaping efforts in the urban and suburban areas of Skopje have provided a diversified presence of allochthonous woody species. From the registered 206 allochthonous woody plants, in the past 25 years, 65 species (19 *Gymnospermae* and 46 *Angiospermae*) have been the focus of various research and monitoring efforts, including seed propagation and analysis of the generative propagation potential. Considering the variability in the experimental approach, we have performed an extensive literature revision and combined the results from the two in a summary of species that could be of potential interest in the green infrastructure in Skopje, due to their benefits (ornamental use and air pollution remediation) or risks (invasive and allergenic potential). We have also underlined the potential of using urban species as seed banks and species conservation, along with various services they could provide. To the best of our knowledge, this is the first attempt that summarizes the allochthonous woody species in Skopje along with the experience regarding their generative potential and possible use in urban forestry. As such, it serves as a base for future experimental research that could provide more information about the seed quality and the species' benefits in Skopje and the surrounding areas.

Keywords: generative propagation; urban forestry; dendroflora; air pollution remediation; ornamental use; invasive species; allergenicity

INTRODUCTION

The location and history of what is today the territory of North Macedonia (MKD) has provided suitable conditions for human settlements over two millennia. The high population rates and increased mobility in the region have also contributed towards frequent plants movement, primarily of edible and economically viable plants, e.g., *Ficus carica* L., *Morus*, *Cydonia oblonga* Mill. etc., as well as ornamental species. Some of these allochthonous species have adapted very well to the new ecological conditions, to such an extent that today they are considered as 'native' (Rizovska Atanasovska 1999). During the Ottoman Imperia rule over MKD (14th – 19th century), and especially towards the end of the 19th century, ornamental species were even more intensively introduced, especially in Skopje, the city that is still the capital today. At the beginning of the 20th century, green areas in Skopje, today distinguished as urban green infrastructure, were established mainly as avenues and lawns, and later as city parks. For example, the location of the 'Skopje City Park' has not changed but its area has expanded over the last century. The subsequent expansion of Skopje, especially after the Second World War and the catastrophic earthquake in 1963, provided opportunities for more planned activities regarding the green infrastructure. However, this was followed by a period of more random and localized urban greenings, as smaller parks and similar types of green infrastructure, which accompanied the new residential and commercial zones (Rizovska Atanasovska and Vulgarakis 2014).

From a scientific standpoint, several planting activities have been noted as of particular interest, in the context of enriching the species diversity and planned introduction of allochthonous species. The Botanical Garden, established by and in close proximity of the Faculty of Natural Sciences and Mathematics in the 1950s, provides a collection of curated and selected species cultivated in an open area. With support of the former Faculty of Agriculture and Forestry in the 1950s (today Faculty of Agricultural Sciences and Food, and the Hans Em Faculty of Forest Sciences, Landscape Architecture and Environmental Engineering (HEF), respectively), two live collections of autochthonous and allochthonous woody plants were established, (i) the Dendropark which surrounds the Faculties, and (ii) the arboretum in the Trubarevo village, located on the periphery of Skopje (Em et al. 1968).

Despite the large species diversity, few research efforts have focused on the allochthonous woody plants used in the green infrastructures. In the mid-1990s, the first comprehensive registration of allochthonous species in the urban and suburban areas in Skopje was established, listing 206 species (38 *Gymnospermae*, 168 *Angiospermae*) (Rizovska Atanasovska 1999). An ongoing collaborative project between Skopje and the United Nations aims to create a 'green cadastre' to analyse and monitor the greenery surface area of the city, but currently in Skopje there is little output, while in one of the neighbouring cities, similar attempts using modern geomatic techniques have been done (Mihajlovski et al. 2018). The reproductive potential of the present allochthonous woody plants has never been the primary research focus.

However, during the past 25 years, the period of establishment of some green areas which contain particular diversity, most trees and shrubs from the various green areas in Skopje (e.g., the Dendropark, the arboretum, the Botanical Garden, the City Park, etc.) have gone through their fructification stage. During this period, at the Department of Seed Science and Forest Stands at HEF, the reproductive material of some allochthonous woody plants has been periodically analysed. The aim of this paper is to summarise these experiences and provided insight into the species' characteristics, focusing on those of potential benefits or risks when used in the urban and suburban areas of Skopje. As urban trees can have a significant role as a seed source for both forest species in decline and non-native invasive species (Woodall et al. 2010), the output of this study is meant to serve as a tool for future selection of allochthonous woody plants and planning of relevant research activities for the local nurseries and urban greenery.

MATERIALS AND METHODS

The Skopje Region: Characteristics and the Seed Source Locations

The capital of North Macedonia, Skopje (42°0′N 21°26′E), is located in the Skopje Valley, at an elevation of 245 m asl, bordered by mountains on all four sides (west-Shar Mountains, south-Jakupica range, east-Osogovo range, north-Skopska Crna Gora). The urban area of the city is mostly flat, spread on the north side of the Mount Vodno (1,066 m), the highest point inside the city borders. According to the last green census from 2012, two categories of urban greenery are present in Skopje, urban greenery with an area of 388 ha and peri-urban greenery with an area of 141 ha, in total covering 6% of the city area (EMA 2015). The complex geographical attributes contribute to a particular microclimate of Skopje, a mix of continental and Mediterranean climate, exhibited by very hot and dry summers with short periods of heat waves, average cold and wet winters, with uneven spatial and temporal precipitation distribution (Donevska and Panov 2019). Late spring and early autumn frosts are an additional particularity that has been a major contributor towards the success/failure of plant establishment as part of the urban greenery (Shotaroska et al. 2019). Especially in the past decade, similarly to other highly urbanised cities, the air pollution during winter has had a severe negative impact on the climate and air quality (Martinez et al. 2018, Mirakovski et al. 2020).

Over the past 25 years (1997-2021), sampling was done at different locations in the city (Figure 1). The sampling sites have provided material for different allochthonous woody plants and include: the Dendropark of HEF located around the Faculty; the Arboretum of HEF in Trubarevo village; the Botanical Garden of the Faculty of Natural Sciences and Mathematics; several city parks (Skopje City Park, Park Zhelezara, Park Aerodrom); green areas around Lake Treska; park-forest Vodno and park-forest Gazi Baba; and, when available, residential gardens, and greenery of private and public enterprises.

Seed Handling and Analysis

Although the reproductive material was gathered over 25 years, the principles of the protocol were preserved, with appropriate modification depending on the species. The trees and shrubs that served as seed sources were subjected to regular phenological observations, across all seasons, throughout the years. Once the seeds, fruits, and/or cones had matured and ripened, they were appropriately collected. After an initial cleaning and drying, the collected material was processed, according to the species features and demands for sowing. The cones were dried outdoors or in a heated room until they opened. Based on the dormancy characteristics of the sowing material, a single treatment, or a combination of following pre-sowing treatments was performed:

- Pre-soaking in cold water (duration one-to-several days)
- Hydro-thermal procedure (immersing in boiling water for 10-40 seconds, then leaving in lukewarm water for 24 hours, followed by sowing)
- Pre-soaking in warm water (50-60°C) for several hours
- Maceration in 18-20% hydrogen chloride (HCl) for several hours
- Cold stratification in wet sand, on temperature of 3-8°C in the refrigerator or in outdoor objects (garage or soil tranches) for several weeks or months

The quantity of the collected material and seed/fruit features determined the type of subsequent analysis. When larger quantity was available, a laboratory-based germination rate or seed viability of the seeds was performed, by using a Jacobsen germination table or manual cutting, respectively. When smaller seed quantity, field germination rate was estimated by sowing the seeds in containers or in soil, at the nurseries of HEF (located in Skopje, Trubarevo and Krushevo) and in some nurseries of the PE National forests. As the ecological conditions of these

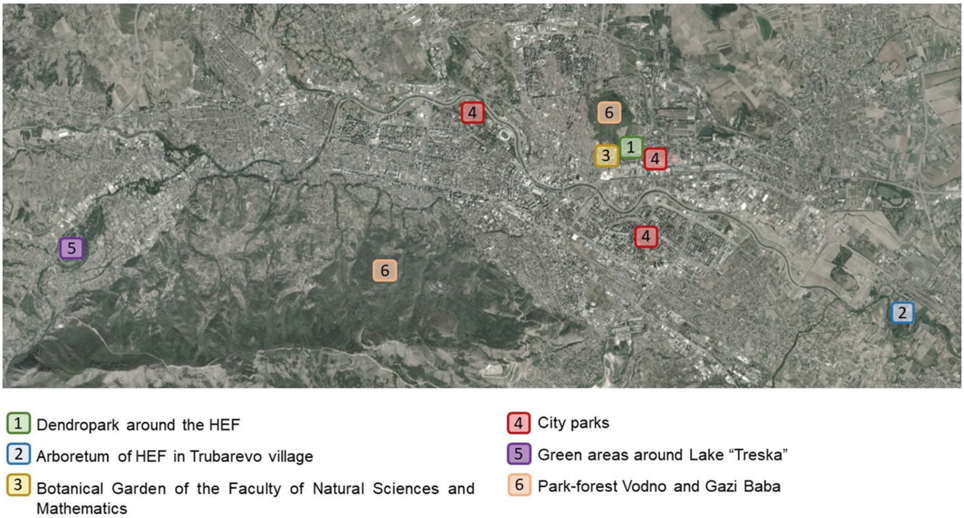

Figure 1. Locations in Skopje and the surrounding area where the samplings took place.

nurseries significantly differ (location altitude between 240 – 1,300 m), the preferred ecological conditions of the species were taken into consideration. For the majority of the seed material, the sowing was done in the spring season, except for several species that require sowing in the autumn season (*Quercus*, *Juglans*, *Ginkgo biloba* L.). For all species, one-year old (1+0) seedlings were measured for shoot height (SH) and root collar diameter (RCD). Based on the list of analysed species, a literature review was done in order to separate them in one of the predetermined categories. In the context of Skopje, four categories were defined, two regarded as negative (potential species of risk) and two regarded as positive (potential species of benefit) (Figure 2).

RESULTS

In the present study, we report the propagation characteristics of seeds from allochthonous woody plants, collected in the Skopje region as part of different sampling efforts between 1997 and 2021. These sampling efforts resulted with 65 species, 19 *Gymnospermae* and 46 *Angiospermae,* that were further categorized based on their level of presence. The germination or viability was also accounted (Table 1). The data shows that of the listed *Gymnospermae* species, all are coniferous except *Ginkgo biloba*, while all of the *Angiospermae* species are broadleaf species. The sampling efforts have been more inclusive towards broadleaf trees and shrubs, as they generally prevail in the green areas in Skopje (Rizovska Atanasovska 1999) and partly because the cone collection for the case of conifers as high trees is extremely difficult. Low germination/viability rate of the seeds was registered in coniferous species which are characterized by such feature (e.g., *Cupressus* (Tadros et al. 2010)*, Pseudotsuga*), but also in solitary broadleaf trees, where probably an inbreeding, i.e. a self-pollination occurs (e.g., *Sterculia platanifolia* L. (Brizicky 1966), *Pterocarya fraxinifolia* Poir.*, Idesia polycarpa* Maxim.*, Acer davidii* Franch.). In *Acer davidii* almost every year abortion was registered, i.e., the rejection of immature fruits, shortly after the insemination in May (Kolevska, personal communication). The selection of suitable pre-sowing treatment is a crucial step for insuring higher germination rates. For some species that are generally more studied, the

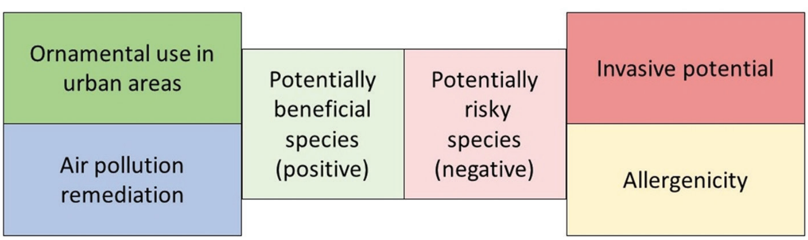

Figure 2. The four categories considered for grouping the species.

applied adequate pre-sowing treatments have contributed to higher laboratory and field germination rates (e.g., *Acer negundo* L., *Fraxinus americana* L., *Gleditsia triacanthos* L., *Robinia pseudoacacia* L.) (Supplementary Material 1). The limited knowledge avaliable and experience regarding some of the studied allochthonous species might also contribute to reduced germination rates, especially during the selection of the pre-sowing treatment. The literature revision allowed us to assign at least one category to 39 species (Table 1) (Figure 3).

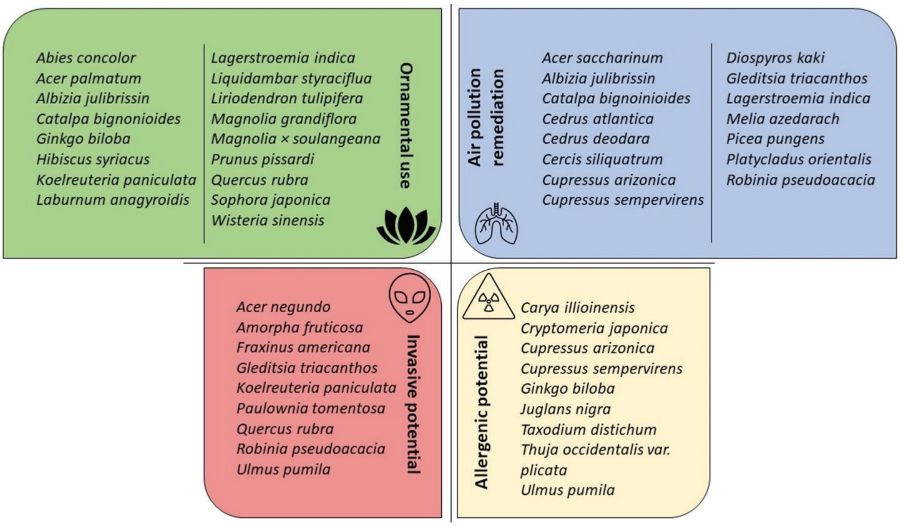

Figure 3. Woody plant species of interest for Skopje from the four categories of species of interest, ornamental use, and air pollution remediation as those of beneficial interest, and invasive potential and allergenic potential as those of risky interest. The included species are the overlaps between the revised literature and the studied species.

Table 1. Characteristics of sampled allochthonous woody plants in Skopje (1997-2021).

	Species	Level of presence[1]	Germination or viability[2]	Risk/benefit categories			
				Invasive potential	Allergenicity	Ornamental use	Air pollution remediation
Gymnospermae	*Cryptomeria japonica* D.	RARE	VL		x		
	Calocedrus decurrens Torr.		L				
	Pinus wallichiana Jacks.		M				
	Taxodium distichum L.		M		x		
	Thuja occidentalis var. *plicata* Donn.		M		x		
	Abies concolor Lindl.	COMMON	L			x	
	Chamaecyparis lawsoniana Murray		L				
	Larix decidua Mill.		L				
	Pseudotsuga menziesii Mirb.		L				
	Cedrus deodara Roxb.		M				x
	Cedrus atlantica Endl.		M				x
	Ginkgo biloba L.		H		x	x	
	Picea pungens Engelm.		H				x
	Picea omorika Pančić		H				
	Pinus strobus Thunb.		H				
	Cupressus arizonica Greene	ABUNDANT	L		x		x
	Cupressus sempervirens L.		L		x		x
	Thuja occidentalis L.		L				
	Platycladus orientalis L.		M				x

Table 1. (continue) - Characteristics of sampled allochthonous woody plants in Skopje (1997-2021).

	Species	Level of presence[1]	Germination or viability[2]	Risk/benefit categories			
				Invasive potential	Allergenicity	Ornamental use	Air pollution remediation
	Acer buergerianum Miq.		VL				
	Sterculia platanifolia L.		VL				
	Acer davidii Franch.		L				
	Exochorda racemosa L.		L				
	Idesia polycarpa Maxim.		L				
	Melia azedarach L.		L				x
	Pterocarya fraxinifolia Poir.		L				
	Alnus cordata Lois.		M				
	Aronia melanocarpa Michx.	RARE	M				
	Chimonanthus praecox L.		M				
	Citrus trifoliata L.		M				
	Maclura tricuspidata Carrière		M				
	Parrotia persica DC.		M				
	Aesculus glabra Willd.		H				
	Carya illinoinensis Wangenh.		H		x		
	Juglans mandshurica Maxim.		H				
	Quercus aegilops L.		H				
	Acer palmatum Thunb.		L			x	
	Diospyros kaki L.		L				x
	Lagerstroemia indica L.		L			x	x
	Liquidambar styraciflua L.		L			x	
	Liriodendron tulipifera L.		L			x	
Angiospermae	*Albizia julibrissin* Durazz.		M			x	x
	Amorpha fruticosa L.		M	x			
	Campsis radicans L.		M				
	Koelreuteria paniculata Laxm.		M	x		x	
	Laburnum anagyroidis Medik.		M			x	
	Maclura pomifera Raf.	COMMON	M				
	Magnolia grandiflora L.		M			x	
	Magnolia × soulangeana hort.		M			x	
	Wisteria sinensis Sims.		M			x	
	Acer saccharinum L.		H				x
	Catalpa bignonioides Walter		H			x	x
	Cercis siliquastrum L.		H				x
	Juglans nigra L.		H		x		
	Paulownia tomentosa Thunb.		H	x			
	Pistacia vera L.		H				
	Quercus rubra L.		H	x		x	
	Ulmus pumila L.		H	x	x		
	Prunus pissardi Carrière		M			x	
	Sophora japonica L.		M			x	
	Acer negundo L.		H	x			
	Fraxinus americana L.	ABUNDANT	H	x			
	Gleditsia triacanthos L.		H	x			x
	Hibiscus syriacus L.		H			x	
	Robinia pseudoacacia L.		H	x			x

[1] Rare - solitaries or only several individuals; Common - present in many green areas; Abundant - very often present in green areas. [2]VL - very low (<0%); L - low (10-40%); M - medium (40-60%); H - high (> 60%).

DISSCUSSION

In urban and suburban areas, vegetation provides a myriad of services, i.e., microclimate regulation, moisture increase, air cooling, oxygen supply, noise reduction, improvement of the radiation regime, suspended particulate matter filtration, wind reduction or redirection, supporting the diversity of arthropod and vertebrate communities, etc. (Attorre et al. 2000, Schmitt-Harsh et al. 2013, Irmak et al. 2018, Frank et al. 2019, Rita Baraldi et al. 2019, Csontos et al. 2020, Ribeiro et al. 2020, Masalova et al. 2021). Furthermore, trees also have a mnemonic and social role, and green infrastructure has the potential to give new life to the city after a catastrophic event, build solidarity and commemorate the past (Magnus and Sander 2019). All these aspects underline the sustainable and multifunctional role of the urban vegetation. During the historical and recent development of Skopje, a variety of woody plant have been introduced. Thus, a particular urban landscape has been established, which has not been thoroughly examined, and often not thoroughly planned. Urban areas that are not characterized by a great species diversity can undergo a great reduction of the green areas, due to unforeseen negative conditions and upcoming climatic challenges (Sjöman et al. 2010). Therefore, species selection needs to be based on their ability to provide various ecosystems services, as well as their tolerance to climatic changes, as diversified urban forests hold higher potential (Sjöman et al. 2021). However, the relationship between urban areas and the urban vegetation is dynamic and reciprocal. Appropriately selected species can satisfy the main requirements of the urban areas, by demonstrating capacity for resistance of the anthropogenic pressures and meeting the aesthetic needs (Masalova et al. 2021). Furthermore, urban areas can serve as easily accessible and managed points of *in situ* conservation of potentially endangered species (Pan et al. 2019) or species of particular interest whose genetic material can be used in local nurseries for the production of better adapted individuals to the particular eco-climatic conditions (Sjöman and Watkins 2020). The lack of knowledge regarding the species performance in urban areas has a negative impact, not only on the potential for suitable further selection of species, but also as a significant financial burden on the public budget, which can be remediated with appropriate species-site selection (Percival et al. 2006). It is therefore of vital importance that future selection is made by experts and that the already established green infrastructure is monitored, appropriately managed, and maximally used.

In the present study, we have provided an overview of 25 years of experience with generative propagation of allochthonous woody plants present in Skopje, as a first attempt to summarize and contribute towards the body of knowledge. In particular, considering the limitations of the study, we have focused on 65 species in terms of their presence and seed germination/viability, as well as their potential benefits and/or risks in Skopje, as part of the green infrastructure. Although some of the examined allochthonous species can be more successfully propagated by vegetative methods, we have focused solely on the potential for generative propagation from various seed sources from green areas of Skopje and its surroundings (Supplementary Material 1).

The Importance of Quality Planting Material

Well-planned, executed and maintained urban greenery can yield numerous ecological, economic and social benefits, thus increasing the life quality in cities and urbanized areas (Allen et al. 2017). However, the highest percentage of plant mortality, up to 90%, takes place during the earliest life stages (Labatore et al. 2017). This is especially the case for urban trees in the first two-three years after transplantation and it can be greatly reduced by accounting for the planting season, site selection and management (Koeser et al. 2014). Prior to that, the nursery stage, i.e., the production steps of trees and shrubs used for urban greenery impacts numerous seedling properties, e.g., root architecture, fine root hydraulic conductance, stem girdling root production, plant establishment and growth response, nutrient uptake and post-transplant irrigation requirements, pathogen susceptibility, which significantly impact the success rate of the post-transplant establishment of urban trees (Allen et al. 2017). Furthermore, it is also important to account for continuous tree recruitment, i.e., gathering, analysing and seed selection, in order to ensure a sustainable urban vegetation structure (Labatore et al. 2017).

In MKD, through decades, the ecological as well as the political and economic changes and challenges (Arsovski et al. 2018) have concurrently impacted the nursery production of seedlings of allochthonous trees and shrubs, used for reforestation and ornamental purposes. Between 1995 and 2000, the average annual production of seedlings in forest nurseries was ca. 6 million, of which 78% coniferous and 22% broadleaf species (Kolevska 2005). Among the coniferous, 4 species were autochthonous and 6 allochthonous. From the allochthonous species, *Cupressus arizonica* Greene (ca. 600,000 seedlings) and *Pseudotsuga taxifolia* Lamb. (390,000 seedlings) were more dominant, and sporadically, depending on seed supplies, seedlings of *Cedrus deodara* Roxb., *Chamaecyparis lawsoniana* Murray, *Platycladus orientalis* L. and *Sequoidendron giganteum* Lindl. were produced in significantly smaller quantities (ca. 1,000 – 14,000 seedlings). Among the broadleaf species, 5 species were autochthonous and 3 allochthonous, with an absolute domination of *Robinia pseudoacacia* (average production of 1 mil. seedlings), while *Fraxinus americana* and *Acer negundo* were produced in much smaller quantities (50,000 and 18,000 seedlings, respectively). In the following decade, a general decrease of the number of produced seedlings and afforestation rates had taken place, with a preference towards allochthonous species. Kolevska et al. (2017) note that in 2016, from a total of 22 nursery-produced species, 11 were allochthonous. Out of those, 63% were coniferous (*Cupressus arizonica* – 276,000 seedlings, *Pseudotsuga taxifolia* – 234,000 seedlings, *Platycladus orientalis* – 1,500 seedlings) and 37% broadleaf (*Robinia pseudoacacia* – 900,000, *Fraxinus americana* – 327,000 seedlings, and other allochthonous species as *Acer negundo, Junglans nigra* L., *Albizzia julibrissin* Durazz., *Cercis siliquastrum* L., *Koelreuteria paniculata* Laxm. and *Sophora japonica* L. in quantities of 1,300-8,000 seedlings), and the majority of these species were produced primarily for ornamental use (Kolevska et al. 2017). The ornamental plant production in nurseries in MKD is particular for other reasons as well. During the 1980s and the 1990s, most ornamental tree species were produced from seed, with a strong preference towards autochthonous species and only certain allochthonous species (e.g., *Abies concolor* Lindl.*, Cupressus arizonica, Picea pungens* Engelm.*, Cedrus deodara, Cedrus atlantica* Endl.*, Pinus ponderosa* Douglas ex Loudon*, Pinus strobus* Thunb.*, Pinus wallichiana* Jacks.) (Kolevska, 1995 – unpublished data). However, due to globalization, the past 20 years have been marked with a rapid production decline of ornamental seedlings in the country and import of mainly big transplants, which has severely affected the domestic ornamental nurseries with long and successful tradition in generative propagation and production of big seedlings (Kolevska, personal communication). This situation marks yet another aspect that needs to be taken into consideration, the inclusion of local nurseries in the process of green infrastructure establishment and the knowledge availability regarding allochthonous seed preference for growing conditions and management.

The nursery-to-landscape transplantation is extremely stressful and critical for the plant establishment and growth resumption (Franco et al. 2006). The container size and type are another delimitating factor in the plant production process and the trend of reducing the size of the container, i.e., reducing the production costs per plant, affects the growth and the development of plants, especially the root characteristics in the case of woody plants (Franco et al. 2006). Indeed, we observed differences in the quality features in 1+0 seedlings, i.e., shoot height and root collar diameter (Supplementary Material 1), which can vary significantly from nursery to nursery as a factor of both ecological characteristics of the nursery and the management practices. This is especially notable when comparing seedlings from the same species grown as bare roots in different nurseries. For example, in *Albizia julibrissin* seedlings grown as bare roots in similar ecological conditions, SH varies between 15 cm and 180 cm; in *Pseudotsuga taxifolia* SH varies between 7 cm and 35 cm; in *Robinia pseudoacacia* SH varies between 23 and 240 cm (Supplementary Material 1). When the seedlings were grown in containers, bigger and thicker seedlings were developed and less differences were observed between plants grown in different nurseries. Considering that living plant collections from botanical gardens and green urban areas can provide experience on the development of allochthonous species as well as reproductive material (seeds) (Sjöman and Watkins 2020), the study was aimed towards woody plants that could be produced in MKD nurseries suitable for further use in urban forestry, especially due to their properties for climate mitigation and the increase of the air quality.

Different Outcome from the Use of Allochthonous Woody Species

The allochthonous trees and shrubs that have been examined in the past 25 years (Table 1, Supplementary Material 1) provided a list of species that we are interested to explore further, due to their benefits and/or risks for the urban greenery in Skopje. As there is very limited research regarding the experience in Skopje, we employed a literature revision analysis to gather external experience and potential references for future selection and management of the species. As described in the previous sections, we predefined two categories, the potentially risky species (negative impact) and the potentially beneficial species (positive impact).

Potentially Risky Species – Negative Impact

Within the group of species with potential negative impact in the context of urban areas, we defined two groups, species with invasive potential and species with allergenic potential, both of relevance in the context of Skopje. The invasive potential of allochthonous species is an active discussion in forestry (Pötzelsberger et al. 2020b, Bindewald et al. 2021, Dimitrova et al. 2022), but it is also important in urban areas. Over the centuries and with the increase of anthropogenic mobility, due to their exotic nature, many allochthonous species were primarily introduced in urban areas from where they could disperse and employ both active and passive invasive mechanisms (Trusty et al. 2007, Deparis et al. 2022). While active invasion is a result of the introduction of species that spread quickly and easily under suitable new conditions, passive invasive mechanisms refer to species that have been present for a long time and/or are present in considerable numbers, and thus become more dominant (Trusty et al. 2007). Regardless of the mechanism, the risks of these allochthonous species is a potential escape from the borders of their cultivation in (semi) natural areas and the establishment of self-sustaining stands where they might exhibit invasive behaviour (Csontos et al. 2020). Which species exhibit invasive behaviour depends not only on their biological characteristics, but also on the environmental conditions. For several of the studied species, the invasive behaviour and invasive potential have been noted, both in MKD and across Europe (e.g., *Amorpha fruticosa* L.*, Koelreuteria paniculata, Maclura aurantiaca* Nutt*, Quercus rubra* L.*, Fraxinus americana* and *Gleditsia triacanthos* (Kolevska and Acevski 2005, Krumm and Vitková 2016, Dimitrova et al. 2022)). Considering that these species have been characterized either as 'common' or 'abundant', and with medium or high germination rate (Table 1), they impose a need for close monitoring in urban green areas. As the literature notes, *Gleditsia triacanthos* and *Koelreuteria paniculata* have been characterized as being able to establish high-density soil seed banks underneath the canopy with viable, hard-coated seeds which can be further dispersed by birds and mammals to great distances (Csontos et al. 2020, Ljubojević et al. 2021). *Paulownia tomentosa* Thunb. Has already been recognized as a colonizer, mainly of disturbed urban areas in Central Europe, but its future expansion due to the climatic changes is probable (Essl 2007). *Amorpha fruticosa* is a registered invasive alien species in Europe, with high tolerance to various habitat conditions and strong colonization potential, especially in riparian areas (Kozuharova et al. 2017, Boscutti et al. 2020). In Skopje, invasive species that successfully colonize riparian areas are a significant threat to the riverbanks of the Vardar River. While in the more urbanized zones (the central and adjacent regions) riverbanks are regularly managed, in the peripheral city areas and the left bank, there are considerably less organized activities to maintain and select the flora. From the species noted as present in Skopje, potentially risky is *Acer negundo,* with demonstrated preference for these types of habitats in Central and South Europe and a threat for the *Salix* and *Fraxinus* species (Saccone et al. 2010, Erfmeier et al. 2011, Porté et al. 2011, Sikorska et al. 2019, Deparis et al. 2022). Furthermore, rivers can easily transport vegetative parts and seeds of invasive species and contribute to active invasion of different ecosystems, something which has indeed been detected for *Amorpha fruticosa* and *Acer negundo* in the north, in neighbouring Serbia (Radovanović et al. 2017). The near-natural habitat colonization has been seen in the case of the severely invasive *Aillanthus altissima* Mill. (Essl 2007) as well as *Ulmus pumila* L. (Lykholat et al. 2018). *Robinia pseudoacacia* is another species which has emerged as a serious threat in Europe (Vítková et al. 2020) and while some areas such as railways could be a suitable habitat where the black locust can provide ecological and aesthetic services, its interaction potential with other urban and ecological patterns needs to be further examined (Deparis et al. 2022). In the context of MKD, the contrasting information between the species produced in nurseries and the legal restrictions is also interesting. Pötzelsberger et al. (2020a) report that for species such as *Acer negundo* and *Robinia pseudoacacia* soft ban laws exist, yet the on-field situation in nurseries is different. This raises concerns, since both species exhibit high germination rates and viability (Table 1). The impact of invasive allochthonous species on recreational ecosystem services that are urbanized on various levels is an emerging field of interest as these species also affect the use of the recreational areas, thus influencing how people see them and how they value them (Sikorska et al. 2019). Prevention by regular and planned management, raising awareness and biological investigations of the seeds are crucial steps to reduce the potential risk of increased presence of invasive species in both urban and suburban environments (Csontos et al. 2020, Deparis et al. 2022). Alternative scenarios for using invasive species have also been considered, e.g., using various parts of *Amorpha fruticosa* as a resource for remedial purposes (Kozuharova et al. 2017) and *Koelreuteria paniculata* seeds as a novel feedstock for biodiesel production (Ljubojević et al. 2021).

The allergenic potential of species used in urban areas is relevant since increased pollen concentrations negatively impact the air quality and human health. The increase of allergies and pollen distribution has also been noted in Skopje, and it is expected to rise along with the predicted temperature increase (Kendrovski et al. 2014). Trying to fulfil aesthetic and recreation needs along with rushed species selection has led to use of both autochthonous and allochthonous woody plants with high allergenic potential in the urban areas (Velasco-Jiménez et al. 2020). Velasco-Jiménez et al. (2020) list paper mulberry, Australian pine, cypress, olive, plane tree, poplar and elm as most allergenic species, but Cariñanos and Marinangeli (2021) have comprised an extensive overview in this regard for 150 species in the Mediterranean region. Considering the climatic similarities with Skopje and the surroundings, we extracted the overlap between their list and our sampled species, concluding that attention in this aspect needs to be brought to the following species: *Cryptomeria japonica* D., *Cupressus arizonica, Cupressus sempervirens* L., *Ginkgo biloba, Taxodium distichum* L., *Thuja occidentalis* var. *plicata* Donn., *Carya illinoinensis* Wangenh., *Juglans nigra,* and *Ulmus pumila.* While the majority of these species are coniferous, and only three of them are broadleaf species (*Carya illinoinensis, Juglans nigra,* and *Ulmus pumila)*, there is large variability in terms of the germination rate and occurrence in the city (Table 1). Indicatively, species that showed to be more common and had higher germination rate are to be more closely monitored, e.g., *Ginkgo biloba, Juglans nigra, and Ulmus pumila* (Lorenzoni-Chiesura et al. 2000). *Cryptomeria japonica* is known to be a species with high allergenic potential in Japan (Nakamura and Xiu 2012), but we found no relevant literature regarding the other species. We can therefore recommend further research into the pollen production of the allochthonous species present in Skopje, and predictive models that use the trunk size, canopy area and height, as well as the number of flowers per tree, the number of anthers per flower and the number of pollen grains per anther (Katz et al. 2020).

Potentially Beneficial Species – Positive Impact

Within the group of species with potentially positive impact in the context of urban areas, we defined two groups, species of particular ornamental value for urban areas and species that can be used for air pollution remediation. All woody species, depending on their specific characteristics, have their own role in the landscape design of urban spaces. The ornamental value of many trees is often based on their special colour, shape and structures and many of them possess ornamental value because of their particular colour of leaves, flowers and/or other organs at certain developmental stages (Wang et al. 2014). In our study, we underline some species whose ornamental value is more emphasized due to their flowers (*Albizia julibrissin* Durazz., *Catalpa bignonioides* Walter, *Hibiscus syriacus* L., *Koelreuteria paniculata, Laburnum anagyroides* Medik., *Lagerstroemia indica* L., *Liriodendron tulipifera* L., *Magnolia grandiflora* L., *Magnolia × soulangeana* hort., *Sophora japonica* or *Wisteria sinensis* Sims.) and fruits (*Catalpa bignonioides*), their crown shape (*Abies concolor, Albizzia julibrissin and Catalpa bignonioides*), and the shape and/or colour of leaves (*Acer palmatum* Thunb., *Albizzia julibrissin, Catalpa bignonioides, Ginkgo biloba, Liquidambar styraciflua* L., *Liriodendron tulipifera, Prunus pissardii* Carrière and *Quercus rubra*). For example, autumn leaf colour makes sweet gum (*Liquidambar styraciflua*) a favourable ornamental tree species for landscape beautification and urban greening (Wang et al. 2014), red leaves in autumn increase ornamental value of *Quercus rubra* (Dyderski et al. 2020) and golden leaves in autumn make *Ginkgo biloba* more attractive. *Acer palmatum* is a small woody tree widely ornamentally used for leaf shapes and colour (Li et al. 2015). *Catalpa bignonioides* is a tree with an attractive ornamental value and compact shape (Poșta et al. 2021) and its decorativeness is also increased due to the unusual shape of the leaf. The use of *Prunus pissardii* is often considered in the context of contrast in landscape design, specifically, the contrast combinations of leafage colours in red-garnet (*Prunus pissardii*) with the silver colour of *Elaeagnus argentea* Pursh. (Anca 2012). Indeed, contrast is one of the most used criteria in landscape designing as contrasts of forms, and especially of colours, assure spectacular effects to the entire vegetal composition (Anca 2012). Another plant that is decorative not only for its leaves but also for its flowers is *Albizzia julibrisssin,* a small deciduous tree growing up to 5–16 m (16–52 ft) tall which is widely planted as an ornamental plant in parks and gardens, grown for its leaf texture and flowers (Roy et al. 2016). The decorativeness of the leaves is not based only on the non-specific form (the leaves are bipinnate), but also on their ability to slowly close during the night and during periods of rain, and the leaflets bowing downward, hence its modern Persian name *shabkhosb* which means "night sleeper" (Roy et al. 2016). *Liriodendron tulipifera* is also an ornamental tree thanks to the extraordinary tulip-shaped flowers and goose web-like leaves (Wei et al. 2022). During previous urban greening activities in Skopje, these attributes have indeed been taken into consideration for the species selection (Figure 4). Furthermore, we can observe that when species of higher ornamental value have been selected, the management has been more focused and consistent, providing for higher greenery quality and longer lifespan.

One of the ecosystem services of woody plants is also air pollution remediation, by a dual strategy. Trees, both through their above- and below ground organs, are able to (1) significantly contribute to the reduction of air pollution by accumulation of metals and pollutants (Li et al. 2019, Simon et al. 2021) and (2) serve as long-term indicators of air pollution due to the direct and indirect uptake of atmospheric pollutants (Cui et al. 2022). Different woody species have different capacities, usually determined by their morphological characteristics (e.g., leaves with big surface area such as *Catalpa bignoinioides* or compound leaves such as *Albizia jullibrissin*) (Vordoglou et al. 2019). Furthermore, species tolerant to air pollutants are those that can serve as sinks or traps for atmospheric particulate matter (PM), while species sensitive to air pollutants can serve as indicators (Ogunkunle et al. 2019, Simon et al. 2021). The rise of air pollution in cities has also raised interest in the suitable species selection for these purposes. However, it is also worth noting that one species cannot do everything, which further emphasises the need for using different species which are able to be more efficient in the accumulation of different pollutants. For example, in a case-study in Hungary, Simon et al. (2021) found *Robinia pseudoacacia, Tilia europaea* L.*, Acer platanoides* L.*, Fraxinus excelsior* L.*, Betula pendula* Roth.*,* and *Celtis occidentalis* L. to be a suitable sensitive indicator species of air pollution, while *Acer saccharinum* L.*, Betula pendula* and *Platanus* x *acerifolia* Willd. were recommended as pollutant-accumulator species. Several other studies provide details regarding the accumulator species. Yang et al. (2015) provide a comprehensive list of the most frequently occurring species in urban areas and their PM removal efficiency as well as negative impact and suitability for urban environments, concluding that from the most frequent species, *Platanus* x *acerifolia, Acer saccharinum* and *Gleditsia triacanthos* exhibit above-average efficiency. In more detail, *Albizia jullibrissin* has exhibited higher capacity for capturing manganese and zinc, while *Cupressus arizonica* captured copper, lead, cadmium, chromium and nickel (Samara and

Figure 4. Examples from the use of oriental tree species due to their particular characteristics in urban areas in Skopje. **(a)** and **(b)** *Ginkgo biloba* leaves, leaf colour in autumn as an ornamental point of interest; **(c)** *Prunus pissardii* in bloom, flowers as an ornamental point of interest; **(d)** *Magnolia* × *soulangeana* in bloom, flowers as an ornamental point of interest; **(e)** *Prunus pissardii*, leaf color throughout the year, as an ornamental point of interest. Photo credit: Viktorija Brndevska Stipanović, Skopje 2022.

Tsitsoni 2014). *Platycladus orientalis* L. could also aid in cadmium mitigation (Cui et al. 2022). Some species have also been determined as more resistant to air pollution and as such are recommended for heavily polluted (semi) urban areas, e.g. *Robinia pseudoacacia, Cupressus arizonica* and *Platanus orientalis* L. at industrial sites (Isinkaralar 2022b), *Magnolia denudate* Desr., *Diospyros kaki* L., *Ailanthus althisima, Fraxinus chinensis* Roxb. and *Rosa chinensis* Jacq. along heavy traffic roadsides (Zhang et al. 2016). The sensitivity of other species makes them more suitable to be used for biomonitoring and a combined list could include *Ailanthus altissima, Platanus orientalis, Cedrus deodara, Cupressus semprevirens, Pinus pinea* L., *Nerium oleander* L., *Ligustrum ovalifolium* Hassk., *Pittosporum tobira* Aiton., *Lagerstroemia indica, Melia azedarach, Acer pseudoplatanus,* and *Quercus ilex* L. (Pignata et al. 1999, Rucandio and Petit-domínguez 2011, Bozdogan 2016, Liang et al. 2017, Shrestha et al. 2021, Emel and Hakan 2022). From the viewpoint of species-heavy metal pollutant preference, in the case of *Cedrus atlantica* gradual concentration increase of lead and cadmium has been noted due to the increase of the number of vehicles (Savas et al. 2021, Isinkaralar 2022a). The annual rings of *Cupressus arizonica* are suitable biomonitors for iron, but not for lithium and chromium (Cesur and Zeren 2022). *Sabina chinensis* Antoine. has also exhibited pollution sensitivity (Cui et al. 2022), along with *Betula pendula* which is suitable regarding cadmium, while *Aescullum hippocastanum* L. could be efficiently used for monitoring lead pollution (Gh et al. 2012). *Picea pungens* has been noted for chromium and zinc (Sulhan et al. 2022), while *Cercis siliquatrum* is suitable for lead and cadmium but not for iron (Yaşar et al. 2010, Hatamian et al. 2019). Liang et al. (2017) also found *Cedrus deodara* to be suitable for lead and cadmium, while they determined *Nerium indicum* Mill. and *Platanus acerifolia* as most suitable for copper and *Pittosporum tobira* Aiton. for zinc and cadmium. In the context of urban greenery, an important consideration is how air pollution can negatively impact seed germination/viability (Tadros et al. 2010) as seen in *Pinus nigra* Aiton. and *Cupressus arizonica* (Babapour et al. 2020).

The overlaps between the studied woody plants and the literature indicate that regarding air pollution mitigation for Skopje, species of special interest could be *Cedrus deodara, Cercis siliquatrum, Cupressus arizonica* and *C. sempervirens, Lagerstroemia indica, Melia azedarach, Picea pungens,* and *Robinia pseudoacacia* for biomonitoring different pollutants, and species such as *Acer saccharinum, Albizia julibrissin, Cupressus arizonica, Diospyros kaki, Gleditsia triacanthos,* and *Platycladus orientalis* as sinks for certain pollutants. The air pollution patterns in Skopje follow both a diurnal and seasonal cycles, with pollution peaks in the autumn and winter, in the morning and the late evening, and being a particularly big issue in the winter months, mainly due to the heating (Mirakovski et al. 2020). This needs to be considered for future species selection for air pollution mitigation, as mainly *Gymnospermae* species would be able to fulfil the function during the pollution's peaks.

Urban Seed Sources: Impacts of Climatic Changes, Urbanization, and Species Selection in Skopje

The climatic changes and increased levels of urbanisation have contributed to the early spring phenomenon in cities in comparison with the surrounding countryside, which impacts the trees phenology and furthermore the arthropod communities, birds migrations and breeding, and the overall vegetation composition (Shustack et al. 2009, Stanciu et al. 2021). Over the 25 years during which the presented data was gathered, the natural process of aging, diseases, pests, pollution, climate changes, insufficient care and maintaining, has negatively impacted some of trees and shrubs used as seed sources in our investigation. This loss of potential seed sources is particularly adverse in the case of rare specimens from our investigation, such as *Ideasia polycarpa* Maxim. and *Cudrania tricuspidata* Buraeu which are now unavailable for further propagation. During the on-field observations, we have registered dying of some other specimens (*Alnus cordata* Loisel., *Paulownia tomentosa, Libocedrus decurrens* Torr.), but in these cases the seed sources are generally not jeopardized yet. The forementioned factors have also impacted numerous other species, especially in residential green areas, but the reconstruction and emergence of new green areas have also introduced numerous other species. For example, since 2012, in the reconstructed Macedonia Park, *Ginkgo biloba, Larix decidua* Mill., *Metasequoia glyptostroboides* Hu&Cheng, *Picea pungens, Koelreuteria paniculata, Lagestroemia indica, Liquidambar styraciflua, Liriodendron tulipifera, Platanus occidentalis* etc. are now present (Shotaroska et al. 2019), enlarging the existing seed sources from other parts of the city. Notably, these newly planted trees are mostly very young and therefore their fructification is still expected or insufficient, but they are to be considered as valuable seed sources, and regularly observed for their development progress. Thus, the urban areas of Skopje and the surroundings are promising as a seed source, but continuous management and observations are crucial for their maintenance. For example, the transformation of Skopje into a 'Green City' and the inclusion of a more varied type of green areas, e.g., green corridors and management of riparian areas (Penchikj and Hadzi Pecova 2018), might be a unique opportunity for on-field trials. From the investigated species that are of particular interest for ornamental use, those classified as 'rare' need to be treated as "endangered" and preserved by propagation. These seed sources cannot provide sufficient reproductive material for mass production, however, even the smallest quantity of seeds needs to be sown and seedlings distributed on various locations, to create new groups of trees and shrubs, which will fructify in the future. This is the case for species such as *Aesculus glabra* Willd. and *Melia azedarach,* which seem to be interesting for their potential for air pollution remediation, but are rare in Skopje and have exhibited low germination rates. On the contrary, species such as *Acer negundo, Fraxinus americana* and *Robinia pseudoacacia* have emerged as abundant and with medium to high germination rates (Table 1), and they need to be more closely monitored in Skopje due to their potentially negative impact.

Not all urbanized areas are used in the same manner and undergo same maintenance so the risk of spontaneous emergence of invasive species differs, which needs to be taken into consideration (Deparis et al. 2022). This is also the case in Skopje, where we have observed a variety of the urban landscapes (riverbanks, parks, residential areas of different range, industrial and semi-industrial zones etc.), whose impact further complicates species selection and requires interdisciplinary expertise. The location where the species is planted has an impact on its functionality and can further enhance or diminish its services, since plants employ different trade-off and adaptation strategies in adverse conditions (Zhu et al. 2020). For example, *Liquidambar styraciflua* has shown to be efficient in rainfall and stormwater mitigation on vacant and underutilized urban land (Kirnbauer et al. 2013). In a study in Germany, Gillner et al. (2017) concluded that while species employ different strategies to deal with the heat and drought in urban areas, *Corylus* and *Tilia* were efficient even at stressful sites, while *Liriodendron tulipifera* and *Ginkgo biloba* were limited to the less demanding urban areas. *Prunus majestica* Koehne. was very efficient in PM accumulation in the industrial area, but *Osmanthus fragrans* Lour., *Loropetalum chinese* Oliv. and *Cinnamomum japonicum* Siebold. have shown to be more efficient in PM accumulation in high traffic and university campus area, indicating that the species efficiency varies depending on the level and type of air pollution (Li et al. 2019). With this in mind, we have identified some of the pressing requirements of the urban greenery and we have provided further details of the potential specie suitability in Skopje based on reported experience in literature. One is the formation of the so-called urban heat island, the phenomenon of increased air temperatures in urban areas in comparison to their rural surroundings. The mitigation of the urban heat island does not depend only on the vegetation, but appropriate species selection has a positive impact (Ballinas and Barradas 2016). Generally, some species such as *Gleditsia triacanthos, Pyrus calleryana* 'Chanticleer' Decne., *Platanus* × *hispanica* 'Acerifolia' Mill. and *Acer campestre* L. have been noted as more tolerant to urban environmental stress, while, by comparison, *Tilia × europaea* 'Pallida', *Tilia cordata* 'Greenspire' Mill. and *Ginkgo biloba* have shown the lowest tolerance (Swoczyna et al. 2010). Urban water availability and management needs also to be taken into consideration for the species selection, since it can result in sustainable water costs and/or increased species mortality and low establishment success (Pataki et al. 2011). Furthermore, the water use efficiency can be a useful metric and one of the criteria for suitable selection of urban tree species, since species with low water use are not always characterized with reduced growth and the balance between the services the vegetation it provides, and the costs for its establishment could be optimized (McCarthy et al. 2011). The Fraxinus genus has been characterized with a wide genotypic variation in the drought response, with species such as *F. excelsior, F. nigra* Marshall., *F. ornus* L., and *F. angustifolia* Vahl. exhibiting higher and species such as *F. americana and F. velutina* Torr. exhibiting lower sensitivity to drought (Percival et al. 2006). One way to do a selection is by comparing the leaf gas exchange parameters as an indicator of drought tolerance, which in the Magnolia genus has pointed towards *Magnolia grandiflora* L. as a better alternative to *Magnolia* × *soulangeana* (Vastag et al. 2020). *Liquidambar styraciflua* is another species with noted ability to persevere seasonal drought and increased soil salinity (Baraldi et al. 2019b), as well as *Maclura pomifera* Schneid., which could more easily recover from the common drought cycles (Khaleghi et al. 2019). Trees could additionally reduce the water run off during heavy rains in urban areas, and their efficiency in this again depends on the morphological characteristics, i.e., the leaf area, shape and size, in which smaller leaves are shown to be more efficient (e.g., *Ginkgo biloba)* (Yang et al. 2019). Species with smaller leaves are also able to stay cooler at higher air temperatures, e.g. *Gleditsia triacanthos* (Leuzinger et al. 2010). Another issue that has to be considered is the species susceptibility to pathogens, which some of the listed species have exhibited in other environments. For example, weakened *Pinus omorika* Pančić trees by drought and tree-pathogenic fungi have been threatened by the double spined bark beetle (*Ips duplicatus)* (Vakula et al. 2021). The great spruce bark beetle (*Dendroctonus micans*) has been determined as a new threat for *Picea punges,* but it has also been shown to infect other species from the *Picea*, *Abies*, *Larix*, *Pinus* and *Pseudotsuga* genera (Lukášová et al. 2014). *Ginkgo biloba* has shown to have a high resistance to pathogens, as well as air pollution (Dmuchowski et al. 2019). An emerging area of interest is the carbon sequestration capacity of urban trees. Some species indeed have exhibited higher potential for it, such as *Prunus cerasifera* Ehrh., *Quercus cerris* Blanco., *Celtis australis, Acer campestris* and *Acer platanoides* (Baraldi et al. 2019a), while for some the urban residual biomass from maintenance coul be used for biofuel production, e.g., *S. japonica* (Sajdak and Velazquez-Marti 2012). The literature revision has also revealed some specific issues (and potential research topics) regarding the vegetation in the urban and semi urban areas in Skopje that need to be addressed, i.e., better understanding of the tree stability in urban areas (Kontogianni et al. 2010, Göcke et al. 2018), the role of the urban fungi communities and associations (Karpati et al. 2011), the carbon sequestration potential in urban soils (Schmitt-Harsh et al. 2013), the plants' phyllosphere bacteria interaction for the reduction of air pollution (Franzetti et al. 2020), landfill revegetation and regeneration (Kim and Lee 2005), urban plant biomass use for compost and biofuel production (Ljubojević et al. 2021) etc. Considering the numerous factors that impact tree development in urban areas, as well as the services they are expected to provide, species assessment process through multi-criteria decision-making methods (Ghafari et al. 2020), dendroecological studies with Climate-Species Matrix (Roloff et al. 2009) or the use species selection models (Li et al. 2011) could be of interest for future interdisciplinary research.

Beyond urban forestry, the use of allochthonous woody plants for forestry purposes (afforestation and reforestation) is not a novelty, and it is a well-known strategy especially in the context of climate adaptive forestry (Bolte et al. 2009, Brus et al. 2019). Urban areas can be used for case studies of the climatic change effects on forests, as part of urban forests which are already exposed to conditions expected to occur in (semi) natural forests in the coming future, e.g., increased soil content of nitrogen, elevated CO_2 level, increased temperature on the urban heat islands etc. (O'Brien et al. 2012). Previous reforestation efforts in MKD have included some of the analysed species, e.g. *Cupressus arizonica, Acer negundo, Fraxinus americana, Robinia pseudoacacia.* These species are also abundant in the green areas of Skopje, require less demanding pre-sowing treatment and exhibit high germination rate and good seedling establishment

(Supplementary Material 1), but as previously mentioned, they have been known for their invasive potential. This reduction of species diversification in afforestation urgently needs to be addressed as erosion rates in the rural and mountainous areas are rising under the climatic pressure and natural field conditions (Kolevska et al. 2017). Thus, urban allochthonous species can serve as a seed source (Zhu and Lou 2013) and living experiments to better understand the stages of plant establishment and optimization of the sowing and growing protocols. Considering the climatic and ecological conditions, as promising species we underline *Cryptomeria japonica, Alnus cordata, Carya pecan, Juglans mandshurica* Maxim.*, Quercus aegylops* L. *Cedrus deodara, Cedrus atlantica, Ginkgo biloba, Larix decidua, Ulmus pumila, Juglans nigra,* and *Sophora japonica*, some of which have been previously used in small-scale reforestation efforts (Kolevska, personal communication), but further studies and trials are needed.

CONCLUSIONS

Urban areas continue to be under significant pressure due to rural-urban migrations and land availability leading to various types of (urban) pollution, e.g., air, noise, water etc. This, in combination with extreme temperatures and climatic changes severely threatens the life quality in urban regions. Urban forestry and green infrastructures, primarily increasing the green public spaces, is a promising solution (Arsovski et al. 2018), yet species selection, appropriate planning and maintenance are crucial factors for success. In the city of Skopje and its surroundings, green areas are comprised of both autochthonous and allochthonous species, the later ones being of particular interest in the past century. In attempts to contribute to the limited body of knowledge, the present study summarises 25 years of experience with allochthonous woody plants from the Skopje region, focusing on their presence and generative propagation potential. This information, combined with literature revision, has allowed us to pinpoint the allochthonous woody species of potential benefit and risk for Skopje. Furthermore, it has allowed us to conclude that indeed tracking the allochthonous species from urban areas is essential for insuring seeds and seedlings of higher quality and establishment success (Babapour et al. 2020). An accompanying factor are the nursery production systems (Allen et al. 2017) which, as emphasised in previous studies, need to be improved, modernized and better-adapted (Kolevska et al. 2017). Future, long-term studies and interdisciplinary approaches that consider the biological characteristics of the species under the changing climatic conditions, would allow for better overview and more solid recommendations for practical use.

Author Contributions

AD and DDK conceived and designed the research. DDK collected the plant material, performed the laboratory analysis, provided the tables data, supervised the research and provided valuable feedback to the manuscript. AD and VBS wrote the manuscript and jointly contributed to the figures. AD dealt with the revision process.

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Conflicts of Interest

The authors declare no conflict of interest.

Supplementary Materials

Supplementary File 1 - Additional information regarding the presence and generative properties of the examined species. Data for the examined woody plants (total of 65) including: Species Latin name, level of presence in Skopje, Germination or viability, type of pre-sowing treatment applied, 1+0 old Seedlings features (height and root collar diameter).

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