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SELECTED PROBLEMS OF *AILANTHUS ALTISSIMA* (MILL.) SWINGLE PRESENCE IN URBAN SPACES: THE CASE OF THE CITY CENTRE OF KRAKÓW

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The objective of the study was to record features of the oldest and largest specimens of tree of heaven in the centre of Krakow and to determine the factors affecting their condition, reproduction, condition, and aesthetical values, as well as the importance of this tree species in an urban space. The methodology of research included inventorying the individual trees and studying their surroundings, as well as performing correlation and regression analyses of selected variables. The analyses and observations made provided the basis for our conclusions. The evaluation of selected parameters of locations permits the conclusion that the studied factors affect tree of heaven specimens only to a limited extent. Their condition is also associated with direct actions by humans e.g. nursing measures, as well as with purely climatic factors. The presence of very large specimens with a circumference of the trunk exceeding 200 cm were found, which may testify to the beneficial effect of the urban climate on the extended longevity of individual trees of this species. At the same time, their condition deteriorates with age.

Keywords: *Ailanthus altissima* (Mill.) Swingle, Krakow, urban trees, invasive species

Introduction

Ailanthus altissima (Mill.) Swingle is an endemic tree species occurring in China and northern Vietnam. It was brought to Europe around the mid-18th century, by a French monk, Pierre Nicolas d'Incarville. The species was initially introduced into France and England (Kowarik et al., 2007). The first records concerning the introduction of the tree of heaven in Poland date back to 1808, when it was planted in the Botanical Garden in Krakow. Soon after that it was introduced into more localities. In the second half of the 19th century, the species was offered in the catalogues of tree nurseries, and its popularity is confirmed by the fact that it appeared in these offers for many years without interruption (Seneta, 1991). In one of the well-known books on gardening it stated that *Ailanthus altissima* in Poland often succumbs to frost, but sprouts easily from its roots, which implies that it has more been often seen as a shrub than as a tree form. At that time, the decorative value of the plant was emphasised, above all for its large feathery leaves (Jankowski, 1888). Freezing shoots during winter had an additional effect of enlarging the leaves which gave the plant a more exotic appearance. In order to achieve this effect it was even recommended that the plants be cut at ground level every year (Seneta, 1991). In the 20th century it was found that the species has low environmental requirements and great resistance to air pollution, therefore making it highly suitable as an urban tree, particularly in industrial regions, although in Poland it was not used in great numbers. According to Pacyniak (1976) who reports the locations of this species, it was planted in a scattered manner almost across the whole country, except for in the eastern and northeastern regions. The mature trees were also valued for their decorative flowers and fruits. However, less recommended were individuals with male flowers because of their unpleasant castor oil smell (Seneta, 1991). Towards the end of 20th century interest in this tree species in Poland waned owing to an increase in publicised information concerning the invasive nature of the species, its uncontrolled spread, and its emergence in the forests of a number of European countries (Eliáš, 2011; Kowarik et al., 2007).

The data on the occurrence of *Ailanthus altissima* in Polish towns and the issues associated with its migration and settlement, are sparse. A small amount of data are available for Warsaw (Sudnik-Wójcikowska, 1998), and Wrocław (Bąbelewski et al., 2005). Detailed data on the location of these tree plants in Krakow, although only within the narrow city centre, was provided by Bogdanowski (1997).

The objective of the study was to record the features of the oldest and largest specimens within the centre of Krakow and to determine the factors affecting their condition, aesthetical values, as well as the importance of trees of heaven within the urban space.

Study area

The study was conducted in the oldest part of the city of Krakow i.e. its narrow centre limited by the second ring road. The area selected is historically the earliest within

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the city, which has started to expand its boundaries intensively since 1910. The second half of the 19th and the beginning of the 20th century coincides with the period of greatest interest in this species in Poland. The area is characterised by dense, compact, and medium-height buildings, with the presence of parks, fragments of urban greenery, and numerous gardens within the perimeters of buildings and yards. Certainly, it was not possible to find all localities of the studied species, meaning that the data has to be augmented by more detailed work directed to this particular objective.

The elevation of the study area ranges between 206 to 212 m a. s. l. From the viewpoint of a geological structure it is situated within the so-called ice marginal valley of the Vistula river (Tyczyńska, 1967b), on an accumulation terrace which emerged in the Pleistocene or Holcene, divided by the edge of numerous river terraces, which are covered by Miocene sediments (Tyczyńska, 1967a).

Krakow is situated on the border between the moderately warm vertical climatic zone of the Carpathians, in the basin-type of climatic variety (Hess, 1969). Autumns have higher temperatures than springs. The vegetation period with above-zero temperatures lasts 222 days per year. The frost-free period lasts 155 days. In terms of mean monthly temperatures, the lowest (-3.1 °C) is that of January, whereas the highest (18.5 °C) – of June. The minimum temperature recorded is -33.1 °C, and the maximum is 37.4°C. In a year, there is an average number of 22 days with freezing cold (below -10 °C) with 37 days recording below-zero temperatures, whereas there are 38 hot days (temperatures above 25 °C). Thermal inversions can occur in more than hundred days in a given year. Such days cause increased concentrations of air pollutants especially in places at lower elevations, including some in the study area. Presently, in line with the global tendencies, the increase in mean temperatures has been also observed in Krakow. Additionally, the increasing urbanisation results in higher amplitudes of temperatures, both in winter and summer (Obrębska-Starklowa et al., 1994; Trepińska, 1997).

The mean precipitation in Krakow is 665 mm. The highest levels occur in June, and the lowest – in January and February. Snow cover occurred on an average of 66 days per year. The frequent thaws are typical of the climate of Krakow which result in periods without snow cover in winter (Hess, 1967).

Soils of the study area are derived in great measure from fertile alluvial-type soils with various levels of transformation (Komarnicki, 1967). A significant portion of the urban area is occupied by buildings. There is a significant degree of heavy metal contamination and salinity in soils which is not a rare phenomenon in urban areas (Bach and Pawłowska, 2007).

Methods

Larger specimens with a circumference of 1 m or greater were inventoried. Younger trees, and sometimes numerous root sprouts of various age were omitted but their presence was recorded. This choice of the sample aimed at the analysis of selected factors affecting adult individuals of the species. Locations of individual trees were noted, and such features as: height, width of crown, trunk circumference, and height of trunk to the crown, were recorded. Also determined were the condition of the trunk and crown, amount of deadwood, visible symptoms of diseases, damage, and the size of cuts made. The occurrence of seedlings and root sprouts, as well as of fruits were recorded.

In order to determine the reproductiveness and condition of trees, the two following variables were created on the basis of data obtained:

- the variable describing reproductiveness was given according to the following scale: 0 – lack of fruits and root sprouts; 1 – root sprouts and fruits present or in small numbers; 2 – numerous sprouts and fruits present; 3 – highly numerous fruits or sprouts;
- the variable describing the condition of trees was given according to the following scale: 1 – cracks present in trunk, depletion of part of the crown, trunks partly rotten; 2 – significant amount of deadwood, evident fungal diseases or significant depletion in the crown; 3 – deadwood present, depletion associated with nursing measures; 4 – very good condition.

Additionally, the features of the surroundings were determined such as: functional characteristics of space, surrounding of the tree from each direction, light conditions (pertaining to the crown) based on the scale given by Zarzycki (1998), and light exposure – as the direction from where the light directly reaches the tree. The granulometric composition and compactness of the surface layer of soil were also determined. Apart from these, the presence of herbs occurring below the tree or immediately near it, or the degree of development of herbal vegetation and its species richness, were recorded, where present. The following variables for the analysis showing a significant degree of diversity were developed:

- presence of herbs or development of herbal layer acc. to the following scale: 0 – lack of herbs or only traces – trampled, compact soil, or surfaced; 1 – thinned out green, small groups of plants of herbal layer; 2 – compact green, ground cover plants, significant coverage of substrate by plants of herbal layer; 3 – abundant herbal layer with numerous species of native herbs;
- covering of the locality (degree of sheltering): 0 – open area; 1 – open, with wall of a building on one side, or near half of the side sheltered by trees; 2 – surrounded by a tree stand, or partly open but with a building wall

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sheltering it on at least one side; 3 – sheltered by a tree stand, and additionally by a building and walls; 4 – closed with buildings of various heights from all sides;

- availability of sunlight: 0 – individuals shaded from all sides by buildings, direct sunlight not reaching them for certain parts of the year; 1 – individuals shaded from the south, or surrounded by a dense tree stand much higher than they are; 2 – individuals shaded from the south but on one side, except the north, open or surrounded by a well-spaced tree stand; 3 – individuals only partly shaded from the south, with good exposure to east or west; 4 – individuals directly exposed to

Table 1 Parameters of inventoried individuals of tree of heaven, and the selected factors of tree surroundings

Lp.	Position GPS in °	Height in m	Trunk circumference in m	Width of crown in m	Height of trunk to the crown in m	Presence of herbs or development of herbal layer (acc. to scale in text)	Availability of sunlight (acc. to scale in text)	Covering of the locality (degree of sheltering) (acc. to scale in text)
1	50.07171 19.94107	17	2.07	12.5	3.5	0	4	3
2	50.07140 19.94152	15	1.26	12	1.8	0	4	2
3	50.06466 19.93902	23	3.4	17	7	2	4	4
4	50.06163 19.94347	13	1.05	10	3	2	3	2
5	50.05884 19.94014	19	2.86	19	5	2	3	2
6	50.05448 19.93883	14	1.77	16.5	1.8	2	1	3
7	50.06382 19.95474	17	2.33	16	6.5	2	0	2
8	50.06290 19.95089	12	1.56	13.5	2	1	1	1
9	50.06235 19.95040	14	1.43	13.5	1	1	2	3
10	50.06211 19.95775	18	1.86	13	7.5	3	1	2
11	50.06293 19.95838	14	1,14	10.5	7.5	1	3	2
12	50.06324 19.95785	18	1.15	16.4	7.5	1	1	1
13	50.06991 19.94186	21	1.53	11.9	6	3	3	2
14	50.06991 19.94186	22	1.63	9.4	4,5	3	3	2
15	50.07000 19.94197	19	1.03	8.6	7	3	3	2
16	50.07005 19.94192	16	1.24	9.4	4	2	3	3
17	50.07005 19.94200	11	1.08	8	5	1	4	3
18	50.06996 19.94224	13.5	1.35	20.3	2.5	2	1	3
19	50.06994 19.94245	14	0.97	11	2.5	1	3	3
20	50.06998 19.94262	21	1.53	11.2	5.5	3	4	2
21	50.06998 19.94266	21	1.06	6.8	4	3	4	1
22	50.07001 19.94255	21	1.63	13	4.5	3	4	1
23	50.07011 19.94243	15.5	2.07	12.5	5	1	2	2
24	50.06978 19.94085	15	2.1	13	3	0	3	2
25	50.07018 19.94126	13	1.5	10	5	3	3	2
26	50.07022 19.94126	13	1.5	8	5	3	2	2
27	50.06444 19.92457	14	1	11	6	1	2	3
28	50.06444 19.92457	16	0.98	14	4	1	2	3
29	50.06506 19.92517	16.5	1.9	13	7	0	3	4

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sunlight from the south and additionally from the east or west.

Statistical analyses were performed in order to determine the relationships between the parameters of individual trees and the factors affecting these parameters. For the variables describing the features of trees such as: height, circumference of trunk, width of crown, condition and reproductiveness, as well as for the variables describing the parameters of the surroundings, the Pearson coefficients of correlation were calculated. For the correlation coefficients, the degrees of statistical significance (alpha) were determined.

In order to find the relationships between the parameters of individuals and the selected factors of the immediate surroundings, the analysis of linear regression was performed. Because of the selection of samples, some variables showed a high degree of skewness. The variables were logarithmically transformed which resulted in a satisfactory symmetrisation of variables for the regression analysis. The statistical significance (alpha) was checked and provided for partial coefficients of regression. The statistical significance of the R^2 coefficient was also tested.

A number of factors which are very similar in the studied locations were omitted, such as: presence of green plants or development of herb layer, sheltering of the location, and availability of sunlight were included as descriptive variables.

Results and discussion

During the inventory made in the study area, 29 trees were found which had trunks with circumferences equal or higher than ca. 100 cm. The most important inventory data are compiled in Table 1.

The correlations obtained among the studied individuals show obvious relationships, such as a positive correlation between the circumference of trunk and the height of an individual (Table 2). They additionally show that the height of an individual correlates with its higher reproductiveness and better condition. The damaged trees most often had a part of the crown destroyed as well as poorer viability, which resulted in a decreased number of sprouts as well as fruits. This was also confirmed by a positive correlation between condition and reproductiveness. The circumference of the trunk shows a strong correlation with the width of the crown, which can be explained by the superior development shown by older individuals.

The independent variables were derived from the parameters of tree surroundings which showed a significant level of diversity. They were chosen in a way that prevented correlations appearing among them. The statistically significant exception was the relationship between shielding the location with the development of a herbal layer and the presence of herbs, where the coefficient of correlation amounted to -0.35401 for the level of significance alpha of 0.02. Perhaps such a situation supported the occurrence of better conditions for vegetation e.g. higher humidity or lower level of soil drying by the wind.

On the basis of the results of regression analysis it can be stated that in the studied sites, the location of individual trees of heaven had only a limited effect on their parameters. The factors defined in the analysis

Table 2 Correlation coefficients of dependent variables

	Height of trees	Trunk circumference	Width of crown	Reproductiveness	Condition of trees
Height of trees	x				
Trunk circumference	0.40046**	x			
Width of crown	–	0.54546***	x		
Reproductiveness	0.16438*	–	–	x	
Condition of trees	0.29767*	–	–	0.25676**	x

*: $0.5 > P > 0.05$; **: $0.05 \geq P > 0.001$; ***: $P \leq 0.001$

Table 3 Partial coefficients of linear regression.

	Covering of the locality (degree of sheltering)	Availability of sunlight	Presence of herbs or development of herbal layer	R^2
Height of trees	0.05265*	-0.00765+	0.07746*	0.27
Trunk circumference	0.0762+			0.04
Width of crown	0.0586+	-0.1105**	-0.0491+	0.31
Reproductiveness			0.5646**	0.15
Condition of trees			0.2484**	0.13

+: $0.1 > P > 0.05$; *: $0.05 \geq P > 0.01$; **: $0.01 \geq P > 0.001$

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explain a small percentage of variability i.e. 15–31%, and – in the case of trunk circumference or condition of the tree i.e. 4–13% regression equitation produce a statistically significant low value. The beneficial effects can be provided by conditions advantageous for the vegetation of plants, less disturbed by humans, where herbs also develop better. These conditions are advantageous to reproductiveness, and they affect the condition of an individual tree and also – to a very little extent – its growth. In the studied locations, there is minor effect resulting from access to light which can slow down growth, whereas shielded locations can support greater heights of individuals. The remaining factors affecting the conditions on the studied locations were not diversified enough to be subjected to analysis.

During the study, several larger, older specimens were found in the area of the city centre. The majority of them were in a poor condition. It was noted that the condition of trees deteriorates with age and injuries appear. Some individual trees were severely trimmed, often had the main boughs cut out, or had trunks that were cracked and internally rotten. Because the species was planted in large numbers at the end of the 19th and the beginning of the 20th century, the reason for their present condition can be their short longevity in the climatic conditions prevailing in Krakow. Severe winters occurring once in a while can cause older specimens to die out or incur major injuries. Perhaps, as a result of the tendency towards climate warming (Obrębska-Starklowa et al., 1994; Obrębska-Starklowa and Trepińska, 1992; Sukopp and Wurzel, 2003) more favourable climatic conditions will emerge for the development of this species in Poland. At present, a high percentage of thermophilic plant species can be observed in town centres (Gutte, 1972; Sudnik-Wojcikowska, 1998).

The specimens recorded in the inventory occur at shielded sites or these exposed to sunlight. In most cases these individuals are shielded by walls on at least one side, or by other trees. The individuals growing in places which are not shielded may be more often exposed to the effects of various adverse factors, including low temperatures, and it is probable that injuries occur then which can also lead to the death of trees. One example could be the park in Kórnik near Poznań where four of the largest specimens were froze to death in the 1928/1929 winter (Seneta, 1991). In Krakow, the oldest and most impressive tree of heaven is located in the very centre of the Old Town on St. John street. It is one of the largest specimens in Poland and was placed under protection as a natural monument under the Nature Conservation Act of 2004 (Ustawa..., 2004). The tree is shielded on all sides and additionally it is well-exposed on the south side, particularly the crown of it. It was found to be in a very good condition. The surrounding of the yard by a wall of tenement houses and high solid fences engenders higher temperatures on the site, resulting from a heating up of the walls and reducing the possibility of heat loss. *Ailanthus altissima* is classified as a thermophilic species, growing in the warmest locations of European cities (Kunick, 1982; Kowarik, 1984; Kowarik, 1992; Kowarik and Böcker, 1984; Modranský and Benčať, 2003; Sukopp and Wurzel, 2003; Sudnik-Wójcikowska, 1998). It is also confirmed by the data from Wrocław where a concentrations of locations of this species was reported in an area of densely arranged buildings characterised by the highest temperatures (Bąbelewski et al., 2005).

Pacyniak (1976) reports, that the sprouts from the last growth increment can be frozen during severe winters. In our studies, the occurrence of deadwood in the tree crowns was found in a number of individuals (90%) and pertained to both young increments and entire branches. This has an obvious deteriorating effect on the decorative value of the trees. It also worsened their value particularly as a component of urban areas because of the possible danger of dry branches falling down (Senata and Dolatowski, 2011). In the climatic conditions prevailing in Krakow, this state of affairs forces the tree keepers to carry out permanent annual nursing measures involving the removal of any dead branches.

The emergence of root sprouts around most of the trees (77%) was found, even when the sprouts were systematically destroyed. The trees in poor condition grow fewer sprouts. However, because the new trees are not recorded proportionally to the number of sprouts, one can infer that the mortality of young individuals is very high, which can be associated with their intolerance to light deficit e.g. under the canopy of trees (Knapp and Canham, 2000; Kowarik, 2007; Pennington et al., 2010), as well as with the susceptibility to frost among young individuals (Kowarik et al., 2007; Seneta, 1991).

It was found that frequent removal of descendant individuals from around the parental tree, means that the possibility of uncontrolled spread of the species is much reduced. The area of the Botanic Garden of the Jagiellonian University is an example. Annual nursing measures are carried out there around the trees every year.[1] Only few new small individuals growing from the roots were found there. On the contrary, in the cases where leaving the surroundings without any intervention this results in the emergence of a high number of descendant plants of various ages. A similar phenomenon was observed around the oldest specimen where the nursing measures were not carried out for

1 The authors wish to thank Mr. Krzysztof Kapała, employee of the Botanic Garden, for information.

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several years in a row. The rapid growth of the young tree of heaven individuals may facilitate the winning of the competition for access to light with other seedlings (Knapp and Canham, 2000; Kowarik et al., 2007; Radtke et al., 2013).

It was also found that the tree of heaven releases allelopathic compounds (Csiszár, 2009; Heisey, 1996; Kowarik et al., 2007) which can again result in eliminating plants susceptible to them, and augment the prospect of spreading the species. Immediately under the specimens of tree of heaven in the Jalu Kurek Park an abundant spring herbal layer occurred, whereas in the Botanic Garden of the Jagiellonian University, under one of the specimens, various summer herbs were growing. In these places no allelopathy phenomenon was observed.

The evaluation of selected parameters of locations warrants a statement that the studied parameters have only a limited effect on the trees of heaven individuals. Their condition is directly associated with human action e.g nursing measures, and also by typical climatic factors. Recently, there has been no purposeful introduction of this species into Krakow's urban space. Because of the small number of older specimens of this species within the city centre, it seems justified to protect these trees and to keep them in good condition, through nursing them and monitoring their surroundings in order to curb uncontrolled dissemination of the species.

Conclusions

This study can be summarised as follows:

- the analyses performed indicate that good availability of sunlight can slow down growth. The sheltered locations can favour taller individuals. The specimens found in the inventory exercise always occurred in zones somewhat sheltered to a certain degree;
- a correlation was found which indicated that the viability and reproductiveness of individuals and their condition are better in individuals surrounded by herb vegetation, and in those that are taller;
- in the climatic conditions prevailing in Krakow, injuries to crowns were found in many individuals, probably associated with the great susceptibility of this species to low temperatures which adversely affecting their decorative value and necessitates the frequent application of nursing measures;
- in the studied sample, a considerable proportion of individuals had in their surroundings, higher or lower number of young individuals. These were mostly ramets derived from the roots growing immediately beneath the soil surface. It was observed that nursing measures can significantly reduce their numbers;
- the presence in the city centre of very large specimens with a trunk circumference exceeding 200 cm, can also testify to the beneficial effect of the urban climate on the longevity of individuals of this species. At the same time, the condition of trees deteriorates with age, and injuries appear, although this was not found in the oldest specimen.

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