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DISTRIBUTION OF TREE-OF-HEAVEN, *Ailanthus altissima* (Mill.) Swingle, IN WROCŁAW, LOWER SILESIA, POLAND

Przemysław Bąbelewski, Mieczysław Czekalski*
Agricultural University in Wrocław
*August Cieszkowski Agricultural University in Poznań

Abstract. In 1998–2001, 2025 trees-of-heaven were recorded in 647 locations in Wrocław, Lower Silesia, Poland. They grew in a variety of habitats. Most were found in low- or high-density residential areas, commercial areas, and in city's parks. These habitats were moderately to highly transformed and classified as euhemerobic, mainly β-euhemerobic. The mean level of their hemeroby was 61. This is probably an optimum level of hemeroby for tree-of-heaven growing in the urban environment. Because the highest concentration of the locations, where tree-of-heaven grows, was found in densely developed areas of the urban thermal island, it is considered a thermophilic species adapted to urban conditions. Tree-of-heaven spreads largely spontaneously. It is a pioneer species colonising habitats unsuitable for other trees. Therefore, it is recommended for planting in urban areas, especially those situated in western Poland.

Key words: tree-of-heaven, *Ailanthus altissima*, Wrocław, Lower Silesia, Poland

INTRODUCTION

Tree-of-heaven, *Ailanthus altissima* (Mill.) Swingle, is endemic to central China, where it grows in six provinces. It was brought to Europe in the early 17th century. In Poland, the first trees were planted in 1808 in the Cracow Botanical Garden [Seneta 1991]. The Wrocław population of the tree-of-heaven, the largest in the country, is probably associated with its introduction to Berlin in 1797 [Kowarik and Böcker 1984]. The first trees planted in Wrocław have long been gone, but they have left their off-springs which still persist owing to their great ability to adapt and self-regenerate. The Wrocław population of tree-of-heaven makes an excellent subject for comprehensive studies on the biology, ecology and possible applications of tree-of-heaven in urban areas. Tree-of-heaven grows to 20–25 m tall, usually with a low trunk and a broad

Corresponding author – Adres do korespondencji: Przemysław Bąbelewski, Department of Horticultural, Agricultural University in Wrocław, Rozbrat 7, 50-334 Wrocław, Poland, e-mail: przemo@ozi.ar.wroc.pl; Mieczysław Czekalski, Department of Ornamental Plants, Agricultural University in Poznań, Dąbrowskiego 159, 60-594 Poznań, Poland, e-mail: elen.czek@op.pl

crown. Its decorative qualities include very large, odd-pinnate leaves, flowers and yellow- or red-colored fruits borne in panicles. It is a valuable ornamental tree for cultivation in urban areas. In Poland, it is recommended for planting along broad avenues and streets, and in squares and parks of western, central and southern Poland [Bugała et al. 1984]. Its soil requirements are modest; it can grow in dry, low fertility, and transformed antropogenic soils with a high admixture of rubble. It often sows itself and regenerates in places where other plants are unable to grow. It displays an excellent ability to adapt, also to the difficult urban and industrial conditions continually changing under the human impact. Research carried out in the cities of Central and Southern Europe, especially Germany, has shown tree-of-heaven to be a kenophyte whose time of introduction is easy to establish, and whose expansion occurred over the last 50 years [Kowarik 1983a, 1983b]. In Central European cities the distribution of tree-of-heaven was determined with reference to the level of area development. An assessment was made of the ability of the tree to grow in habitats showing a specified degree of human impact, or its hemeroby. Sukopp [1972] and Sudnik-Wójcikowska [1998a, 1998b] classified tree-of-heaven as a thermophilic species, i.e., growing the warmest areas in many Central European cities.

There is a limited data on distribution of tree-of-heaven in Polish cities [Pacyniak 1976]. This is why a comprehensive study of this species was undertaken in the urban areas of Wrocław. It included an inventory of the locations with tree-of-heaven in zones of varying land use. The species ability to grow in habitats displaying various degrees of human impact, or its hemeroby, was determined. An analysis was made of the response of the trees to the existence of a thermal island. The structure and abundance of the population was also studied. To identify individual variation of trees, the photosynthetic area of leaves was measured in individual specimens growing in 30 locations. Observations were also made of the seasonal growth pattern of tree-of-heaven in 1999–2001. Studies conducted in 12 locations included inventories of companion plants and an analysis of the N_{NO3}, P, K, Mg and Ca content in the soil as well as that of N, K, Ca, Mg and Na in leaves. The levels of cadmium and lead in the soil and leaves were also determined. As a result, a body of information was collected offering an insight into the conditions in which tree-of-heaven grows and spreads in Wrocław, i.e., far outside its natural range, and into its status as an urban tree. This article presents only data related to the distribution of tree-of-heaven in Wrocław.

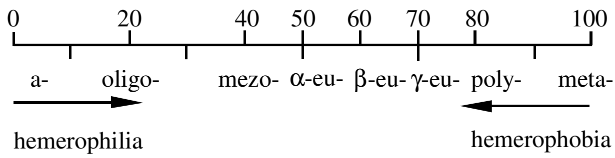
METHODS

The research was carried out in 1998–2001. The first stage involved taking an inventory of all the locations with tree-of-heaven within the administrative limits of Wrocław. For each location the number of trees, their diameter at breast height (130 cm above ground level), sex, health, and color of fruits were recorded. The mapping was done using the raster technique, that is, a grid of 1 km^2 quadrants was established and the number of trees-of-heaven growing in each quadrant was determined. The description of each location included its land use, type of buildings, and degree of hemeroby of the habitat. The distribution of land-use zones in Wrocław was generalised in a grid of 1 km^2 quadrants [Szymanowski 2002].

Phot. 1. Fruits of *Ailanthus altissima* `Erythrocarpa' (photo M. Czekalski)
Fot. 1. Owoce bożodrzewu gruczołkowatego odmiany czerwonoowocowej (fot. M. Czekalski)

Hemeroby is a comprehensive measure of the impact that anthropogenic factors, both past and present, have on the world of living organisms. It is possible to give a range of hemeroby for each species, i.e., to assess its ability to live in habitats with a specified level of anthropogenic impact and at specified time [Sudnik-Wójcikowska 1998a, Jackowiak 1998]. Sukopp's [1969, 1972, 1978] system of classification, which defines the ability of a species to survive and develop in habitats with a specified level of anthropogenic impact, was adopted. Sukopp's categories are: ahemerobic, oligohemerobic, mesohemerobic, euhemerobic, polyhemerobic, and metahemerobic. The system is based on three elementary criteria: habitat, phytosociological and floristic. It takes into consideration changes in a habitat involving the physico-chemical properties of the soil and water. The phytosociological criterion shows the degree of deviation of the actual plant communities from potential natural vegetation. For lack of space, the categories are not defined here [cf. Sukopp 1969, 1972, 1978]. Within the euhemerobic category, including ruderal and segetal vegetation, three sub-categories were distinguished [Chmiel 1993]: α-euhemerobic sub-category are grass and shrub communities of roadsides, scarps, road and railway embankments, field boundary strips, and drainage ditches; β-euhemerobic sub-category includes relatively stable plant communities around buildings and along fences; and γ-euhemerobic sub-category are the segetal communities of arable fields and gardens. For each location studied, the type and level of anthropogenic factors present, the state and degree of transformation of the soil, and the composition of the flora, were determined. On this basis, for each recorded localition the category of hemeroby was defined using the key developed by Chmiel [1993].

The particular ranges of hemeroby were transformed into a system of numerical coefficients using a 100-point scale:



The presented hemeroby scale reflects a continuous variation of anthropogenic transformations of the environment, where the assignment of the categories is a matter of convention. The higher the values of the hemeroby scale, the more intense is the anthropogenic influence (hemerophilia). The low values are characteristic of hemerophobic habitats, i.e., those responding adversely to anthropogenic factors. Using the hemeroby coefficients, a mean level of hemeroby (a 'center of gravity') for tree-of-heaven was calculated, using the following formula:

$$H_{śr} = [h_o(n) + h_m(n) + h_{\alpha\text{-}e}(n) + h_{\beta\text{-}e}(n) + h_{\gamma\text{-}e}(n) + h_p(n)] / N,$$

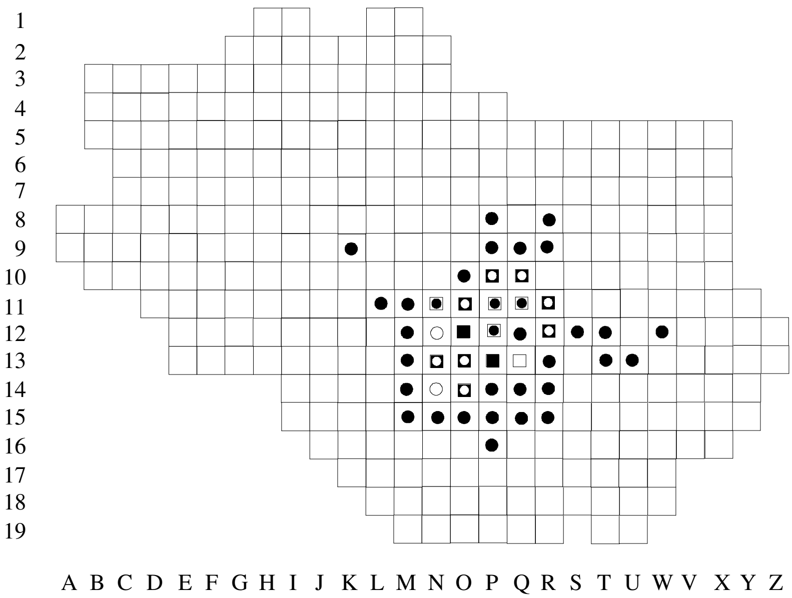
where: $H_{śr}$ – mean level of hemeroby,
h_o to h_p – values of hemeroby coefficients,
n – number of specimens within the given hemerobic range,
N – total number of locations with tree-of-heaven.

An attempt was also made to determine if tree-of-heaven responded to the climatic phenomenon called the urban thermal island. Studies conducted in Zurich, Warsaw, Cologne, Leipzig and Halle have shown that tree-of-heaven was a thermophilic species responding to the urban thermal islands [Kowarik and Böcker 1984, Sudnik-Wójcikowska and Guzik 1998]. In Wrocław the phenomenon of the urban thermal island occurs frequently and it affects the city's climate, which varies with the size, infrastructure and industrialisation of a given area. Diurnal variations in temperature are smaller in highly urbanised areas. They are invariably warmer than in the city's suburbs, with the differences being the smallest during the day and the most pronounced in the evening and at night. Lack of wind and clear sky is conducive to the development of the urban thermal island over the city. Its size varies with the size of the most intensely urbanised area. The distribution of the urban thermal island in Wrocław is generalised in a grid of 1 km^2 quadrants which has been prepared on the basis of meteorological materials gathered by the Department of Meteorology and Climatology of Wrocław University [Szymanowski 2002].

The trees were divided into 7 classes based of their diameter at breast height (130 cm above ground level). Class 1 included trees with a diameter of 1–50 cm; class 2, with a diameter of 50.1–100 cm; class 3, 100.1–150 cm; class 4, 150.1–200 cm; class 5, 200.1–250 cm; class 6, 250.1–300 cm; and class 7, over 300.1 cm.

RESULTS

In 1998–2001, 647 locations with the tree-of-heaven were found in Wrocław. The trees occupied various habitats. A majority of the locations – 255, or 39% of the total – were in low-rise (up to 5-storey high), high-density residential zone. The next, with 188 locations, or 29% of the total, was the commercial zone. Then, 117 locations, or 8% of the total, were in the high-rise (over 5-storey high) residential zone. In low-rise, low-density residential area there were 57 locations, or 9% of the total, while in the city's parks there were 31 locations, or 5% of the total (fig. 1 and 2).



Number of locations in a square: ● from 1 to 10, ○ from 11 to 20, ◘ from 21 to 30, ▣ from 31 to 40, ■ from 41 to 50, □ from 51 to 55

Liczba stanowisk w kwadracie: ● od 1 do 10, ○ od 11 do 20, ◘ od 21 do 30, ▣ od 31 do 40, ■ od 41 do 50, □ od 51 do 55

Fig. 1. Distribution of tree-of-heaven in Wrocław generalized in a grid of squares 1 km^2 in area
Ryc. 1. Rozmieszczenie bożodrzewu gruczołkowatego we Wrocławiu, uogólnione w sieci kwadratów o powierzchni 1 km^2

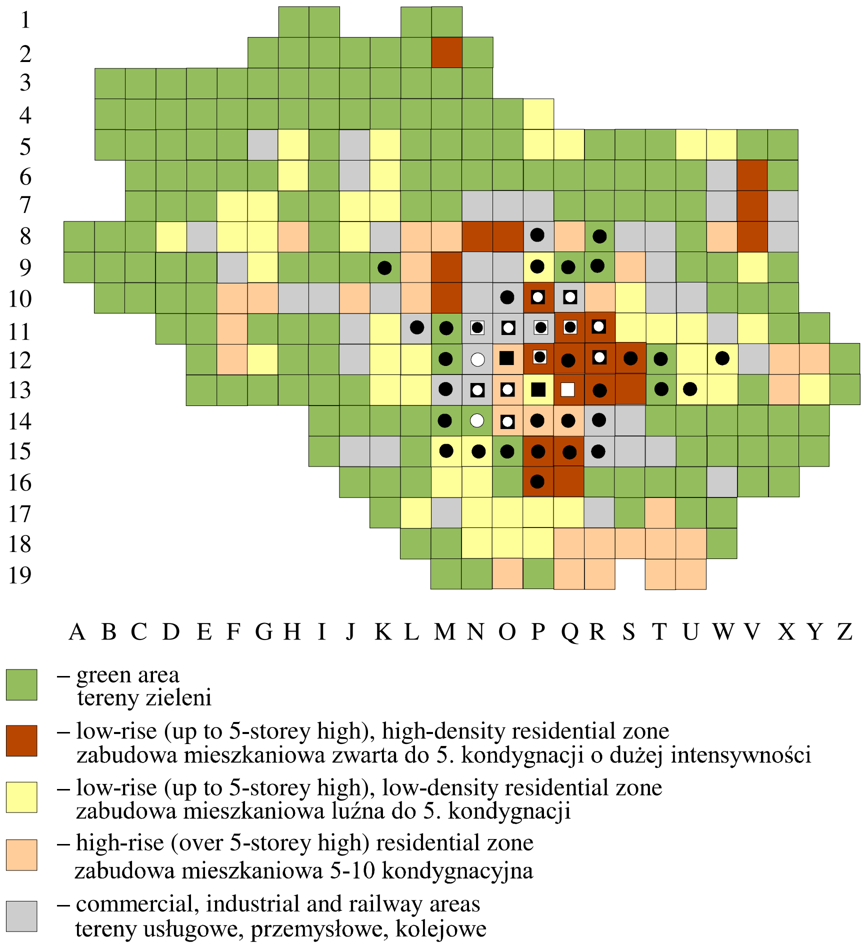


Fig. 2. Distribution of tree-of-heaven in Wrocław by land use zones and type of building (number of locations the same as the figure 1)
Ryc. 2. Rozmieszczenie bożodrzewu gruczołkowatego we Wrocławiu według stref użytkowania terenu i typu zabudowy (liczba stanowisk taka sama jak na rycinie 1)

There were 2025 trees-of-heaven recorded in all of the locations, of which 699, or 34.5%, were female and 805, or 39.8%, were male. Hermaphrodite individuals were the least numerous, with 25, or 1.2% of the trees listed. The rest, 496 trees, or 24.5% of the total, were non-flowering young trees.

Out of the total population of 2,025 trees-of-heaven, 1536, or 76%, were self-sown. The self-sown trees grew in atypical places, e.g., in gardens close to a fence or wall, dump sites, construction sites, or drainage ditches. Planted trees made up 24% of the total and grew in city's parks and along streets, e.g., Powstańców Śląskich Street. Fruit--bearing female trees constituted 34.5%, i.e., there were 699 of them. Out of that number, there were 421, or 60.2%, with yellow-red fruits (an intermediate color); this color predominated. There were 192 trees, or 27.5%, with yellow fruits, and 86 (12.3%) with fruits bright-red fruits maturing. The latter could be classified as the red-fruited cultivar *A. altissima* (Mill.) Swingle 'Erythrocarpa' (see color inset).

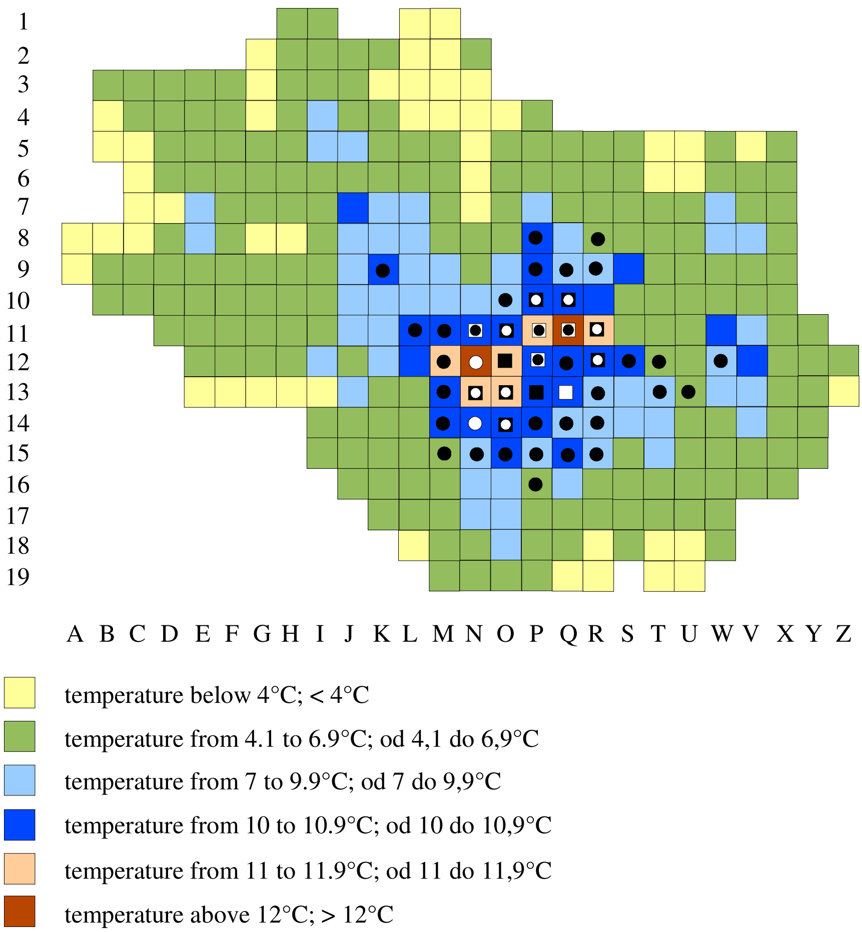


Fig. 3. Distribution of tree-of-heaven in Wrocław and the urban thermal island (number of locations the same as the figure 1)

Ryc. 3. Rozmieszczenie bożodrzewu gruczołkowatego we Wrocławiu na tle miejskiej wyspy ciepła (liczba stanowisk taka sama jak na rycinie 1)

As to the diameters of the trees, most of them, i.e., 762, or 38%, belonged to class 2; followed by class 1 with 582, or 29%, trees; class 3 with 436, or 21.8%, trees; class 4 with 160, or 8%, trees; class 5 with 53, or 2.6%, trees; class 6 with 8, or 0.4%, trees; and the smallest class 7 with 4, or 0.2%, trees. Trees-of-heaven with widest trunks were found along the streets: Krakowska, on the premises of the Municipal Transport Depot – 323 cm, female; 31 Komuny Paryskiej – 327 cm, female; Lelewela – 317 cm, male; and Powstańców Śląskich by the State Higher Theatrical School – 300 cm, male.

The locations with trees-of-heaven were also divided according to the number of individuals growing there. Most of them, 259 locations, had a single tree, there were 131 places with 2 trees, 74 with 3 trees, 51 with 4 trees, and 33 with 5 trees. Those with the largest number of trees were situated along the streets: Grobla – 47 trees, Powstańców Śląskich – 45, Długa – 35, Sikorskiego – 29, Sikorskiego-Drukarska – 23, Swobodna – 23, Kościuszki – 25, and Rybacka – 21. There were 137 trees branching at a height lower than 130 cm. They had more than one trunk and constituted 6.8% of those listed. Trees with a single trunk predominated. They made up 93.2% of the total.

In 1998–2001 the distribution of tree-of-heaven in Wrocław was related to the intensity and type of land use. Most of the basic quadrants, 24, were in the commercial zone, while 12 were in the low-rise, high-density residential zone. There were only 6 and 5 quadrants, respectively, in low-rise, low-density residential zone and high-rise residential zone (fig. 1 and 2).

Distribution of tree-of-heaven in Wrocław was plotted on a thermal map showing the extent of the urban thermal island and also presented in the form of quadrants (fig. 3). Trees are clustered largely in the city center, which includes the Old Town, downtown areas, and industrial quarters. The trees were located in 45 quadrants on the thermal map. The largest number of locations, 346, were in 22 quadrants with a temperature ranging from 10°C to 10.9°C, 48 locations were in 11 quadrants with 7°C to 9.9°C, 201 locations were in 6 quadrants with 11°C to 11.9°C, 4 quadrants with 4°C to 6.9°C had 4 locations, and in 2 quadrants where the temperature exceeded 12°C there were 48 locations (fig. 3).

Table 1. Hemeroby of the habitats of tree-of-heaven in Wrocław in 1998–2001
Tabela 1. Hemerobia siedlisk bożodrzewu gruczołkowatego na terenie Wrocławia w latach 1998–2001

Degree of habitat hemeroby Stopień hemerobii siedliska	Number of locations Liczba stanowisk	Share in total number of locations Udział w ogólnej liczbie stanowisk (%)
Mesohemerobic Mezohemerobowy	10	1,5
α-Euhemerobic α-Euhemerobowy	97	15,0
β-Euhemerobic β-Euhemerobowy	448	69,2
γ-Euhemerobic γ-Euhemerobowy	17	2,7
Polyhemerobic Polyhemerobowy	75	11,6
Total Ogółem	647	100,0

Tree-of-heaven hemeroby range in Wrocław grows in moderately or strongly transformed habitats. Out of the total of 647 locations, 86.9% were euhemerobic with a strong and continuous impact of anthropogenic factors. They were usually β-euhemerobic – 69.2%, and α-euhemerobic – 15%; only 2.7% belonged to the γ-euhemerobic sub-range. 11.6% locations were in polyhemerobic habitats, i.e., ones with a high concentration of anthropogenic factors, like cemeteries, roadsides, dump sites, and communication routes. The least numerous locations, only 1.5% of the total, were those classified as mesohemerobic (tab. 1). In Wrocław, tree-of-heaven did not occur in oligohemerobic habitats. It can be regarded as a euhemerobic species, or one found in all the zones of the city. The mean level of hemeroby of habitats with tree-of-heaven in Wrocław was 61 and coincided with the occurrence of β-euhemerobic habitats. It is an optimum level of hemeroby for this species in Wrocław.

DISCUSSION

The process of synantropisation is especially intensive in urban areas. Its essence is transformation of the qualitative and quantitative composition of plant communities over a specified length of time. Interest in the flora of urban areas has been shown for almost 200 years, but the research has intensified in Europe, mainly Central Europe, since the early 1950s [Jackowiak 1990, 1998, Pyšek 1989, Sudnik-Wójcikowska 1998a]. The species composition of urban vegetation and its function in the urban ecosystem as well as the role of man are significant because these factors affect ecological conditions in urban areas. To date, inventories have been taken of the flora of a few dozen large cities and several hundred smaller towns. They include Poznań [Jackowiak 1993a, 1993b], Warsaw [Sudnik-Wójcikowska and Moraczewski 1998], Zurich [Landolt 1991a, 1991b] and Berlin [Sukopp 1978]. In Poland synantropic vegetation has been a subject of study since the 1970s. Highly important among them has been the work by Krawiecowa and Rostański [1976] describing factors controlling the synantropic flora in selected Polish towns. The publications dealt predominantly with herbaceous species, less often with trees and shrubs. In Wrocław, for instance, studies have been made of the occurrence of common ivy [Świerkosz 1994], flora and plant communities of the city walls [Świerkosz 1993], and distribution of traveller's-joy [Czekalski and Kidawska 2003].

Tree-of-heaven in Wrocław grew in a variety of habitats. The greatest number of its locations were found in quarters with high-rise and high-density residential areas. In the Old Town and downtown areas they often grew in places associated with transportation infrastructure. Tree-of-heaven grew also in industrial quarters, e.g. Gądów. The vegetation of the city keeps undergoing transformation over time as a result of the changing ecological conditions.

The hemeroby structure of habitats where tree-of-heaven grows in Wrocław agrees with data from Berlin, where the tree was also usually found in the same habitats [Kowarik and Böcker 1984]. In Wrocław, tree-of-heaven was found the least frequently in mesohemerobic locations. Research on the herbaceous flora of urban areas has shown that mesohemerobic locations have the most diverse flora [Sudnik-Wójcikowska

1998b]. The α-euhemerobic locations, however, are increasingly found to match them [Chmiel 1993]. Jackowiak [1998] reports that the majority of species growing in Vienna occur in α-euhemerobic locations. 80% of locations of common ivy in Wrocław are also euhemerobic [Świerkosz 1994], and so are 54.9% of locations of traveller's-joy in that city [Czekalski and Kidawska 2003]. The mean level of hemeroby for tree-of-heaven in Wrocław was 61 and coincided with the distribution of β-euhemerobic habitats. This can be considered an optimum level of hemeroby for this species in the urban environment; it occurs in all zones of the city. Similarly, a typical euhemerobic species in Berlin is black locust [Kowarik 1990]. In contrast to euhemerobic species, stenohemerobic ones are usually associated with a specified urbanisation zone.

The center of a big city warmer than the surrounding areas. There occurs the so-called urban thermal island. Its formation is controlled by a variety of factors, like the warming effect of buildings resulting from heat absorption during the day and its emission in the evening, additional heat emission sources generated by industry, and most importantly, the heating of houses. A consequence of the thermal island existence is the appearance of thermophilic plant species, i.e., with higher temperature requirements, and locally even an expansion of some of them. Those species include tree-of-heaven, traveller's-joy [Czekalski and Kidawska 2003] and buddleia [Kownas 1958]. The distribution of tree-of-heaven in Wrocław in 1998–2001 concentrated in areas where air temperature was a few degrees higher. Presumably the heat factor had a decisive influence on such a distribution, because tree-of-heaven has been shown to be a typical thermal indicator associated the warmest areas of Central European cities and highly industrialised regions, e.g., in Cologne, Duisburg, Berlin, Leipzig, Halle and Zurich, as well as on the French coast of the Mediterranean and the Ruhr Basin in Germany [Kowarik 1983a, 1983b, Kowarik and Böcker 1984, Kunick 1984, Landolt 1991a, 1991b, Sudnik-Wójcikowska and Moraczewski 1993, Sudnik-Wójcikowska 1998a]. In Poland data on distribution tree-of-heaven in urban areas were presented by Pacyniak [1976] and Sudnik-Wójcikowska [1998b] for Warsaw and Łódź. The latter author noted differences in the frequency of occurrence of tree-of-heaven in Central European cities: towards the north-east, the number of locations of this species declined. This probably resulted from a lower heat total of the vegetation period [Kowarik and Böcker 1984]. Gutte et al. [1987] reported that the spontaneous spreading of tree-of-heaven was observed in areas where the mean annual temperature of 8.5°C or higher. This matches the thermal conditions of Wrocław, which has a mean annual temperature of 8.5°C [Dubicka 1994]. This corroborates the status of tree-of-heaven as a thermophilic species. Such species are confined to the central, warmest parts of the city and grow there in spite of such unfavourable conditions as dry and poluted air and soil. Only rarely they are found in the peripheries of the cities.

CONCLUSIONS

1. In 1998–2001, 647 locations with tree-of-heaven were identified in Wrocław. They grew in a variety of habitats. Most were found in the high- and low-density residential zones, commercial zone, and city’s parks. These habitats were moderately to

highly transformed and classified as euhemerobic, mainly β-euhemerobic. The mean level of their hemeroby was 61. This is probably an optimum level of hemeroby for tree-of-heaven in urban areas.

2. The greatest concentration of tree-of-heaven in the high-density residential zone suggests that this species is adapted to urban environment and tolerates high levels of soil salinity and dry, polluted air.

3. The distribution of tree-of-heaven in Wrocław concentrated in the urban thermal island, or the area where air temperature was a few degrees higher, confirming it status as a thermophilic species.

4. In Wrocław, tree-of-heaven proved to be highly tolerant of conditions in the urban environment. It is a valuable ornamental tree thanks to its rapid and vigorous growth, large leaves, showy inflorescences and colorful fruits, adaptability, self-regeneration, ease of propagation from seed, resistance to pest and pathogens , and sufficient hardiness. In Wrocław it spreads largely spontaneously, without human interference, and can be considered a pioneer species. Therefore, it is recommended for planting in other Polish cities, especially those situated in the western part of the country.

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WYSTĘPOWANIE BOŻODRZEWU GRUCZOŁKOWATEGO *Ailanthus altissima* (Mill.) Swingle WE WROCŁAWIU, DOLNY ŚLĄSK, POLSKA

Streszczenie. W latach 1998–2001 na terenie Wrocłwia zlokalizowano 647 stanowisk z 2025 drzewami bożodrzewu gruczołkowatego. Znajdowały się one na różnych siedliskach. Najwięcej było ich w strefach zwartej i luźnej zabudowy mieszkaniowej, na terenach usługowych, przemysłowych, związanych z kompleksem transportowym oraz zieleni miejskiej. Siedliska te były od średnio do silnie przekształconych i zaliczono je do euhemerobowych z przewagą β-euhemerobowych. Średni poziom ich hemerobii wynosił 61. Jest to najprawdopodobniej optymalny poziom hemerobii dla tego gatunku w miastach. Największe zagęszczenie stanowisk na obszarze zwartej zabudowy miejskiej wyspy cieplnej pozwala uznać bożodrzew gruczołkowaty za gatunek urbanofilny i ciepłolubny. Drzewo to we Wrocławiu częściej rozprzestrzenia się spontanicznie i jest pionierskie w zajmowaniu siedlisk nieodpowiednich dla innych gatunków drzew. Bożodrzew gruczołkowaty warto zalecać do uprawy w miastach, zwłaszcza położonych w zachodniej części kraju.

Słowa kluczowe: bożodrzew gruczołkowaty *Ailanthus altissima*, Wrocław, Dolny Śląsk, Polska

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