

THE CHANGES OF PHENOLOGICAL PHASES ON THE EXAMPLE OF SELECTED INVASIVE SPECIES OF TREES

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'New' species of trees are sought for cities. These species must cope with difficult urban conditions. Unfortunately, it happens that such new plants well-feeling in the city, they begin to grow uncontrollably. These species of plants desired change in invasive plants and displacement of other plant species from urban spaces and substantially affect the rate of biodiversity loss. There is also the possibility of passing such invasive plants from the cities of natural spaces (e.g. *Acer negundo* L. and *Robinia pseudoacacia* L.). *Ailanthus altissima* (Mill.) Swingle is such a new and potentially dangerous species. It is typically a thermophilic species, because in many Polish cities it occurs in more and more areas. *Ailanthus* is one of the dominant trees in urban centres, such as Wrocław. *Ailanthus altissima* (Mill.) Swingle, *Caragana arborescens* Lam., *Syringa vulgaris* L., *Acer negundo* L., *Gleditsia triacanthos* L. and other species may also appear in unusual places for its ecological optimum in the example of Warsaw. *Ailanthus* is a species of thermophiles and therefore urban conditions (a heat island effect) favour the development of trees and increase its population. Nevertheless, several-years locations of *Ailanthus* outside the city are recorded, too. As an example of such a position serve urban forests in the northern border of the city. The observations were carried out from 2000 to 2018. Such a location of plants may be indicative of an adaptation to climatic conditions and a possibility of transition to natural plant formations. The simplified phenological observations are the main research tools. They allow you to conclude that plants growing in the central parts of the city have a long vegetation and stronger growth. However, in the locations situated on the outskirts of the city and in the urban forests, the growing period is shorter and plants often remain in the form of shrubs. These species belong to the thermophilic plants, but in just a few years, in the case of *Ailanthus*, and in a slightly longer time, in the case of other species, plants have managed to adapt to the habitat conditions in the cooler areas outside the municipal buildings. The only modification is that the course of their phenophases sometimes shortens the growing period to a few days.

Keywords: foreign species, invasive species, synantropisation, anthropological changes, urban forests

1 Introduction

Invasive species of plants and animals are a very serious problem today. The entry of invasive species into foreign ecosystems was considered a second direct reason for the reduction of the biodiversity, after the destruction of habitats. It is thought that foreign invasive species could cost the world economy up to 5% of world GDP (Pimental et al., 1999). Statistically, out of 10 species introduced to the crop, one 'escapes' to man. From 10 'escapees', one fruit starts to reproduce. And from 10 such species one becomes invasive. The problem of invasive species is constantly growing due to the expansion of the world trade, transport and tourism that could facilitate the introduction and spread of

alien species in the environment. If for a given species the new environment is good enough, this species could survive and reproduce. Invasive species, without encountering natural enemies or other restrictions, could increase the area of their occurrence and displace the native species. The further climate change is highly dangerous for phytocenoses, air and water pollution, loss of habitats and every other anthropogenic change in the environment.

Home gardens and other fragments of vegetation are the most important sources of the biodiversity risk through a penetration of the introduced alien species. The use of ornamental trees and shrubs with a poorly understood response to new habitat conditions is of a particular importance in this respect, because they



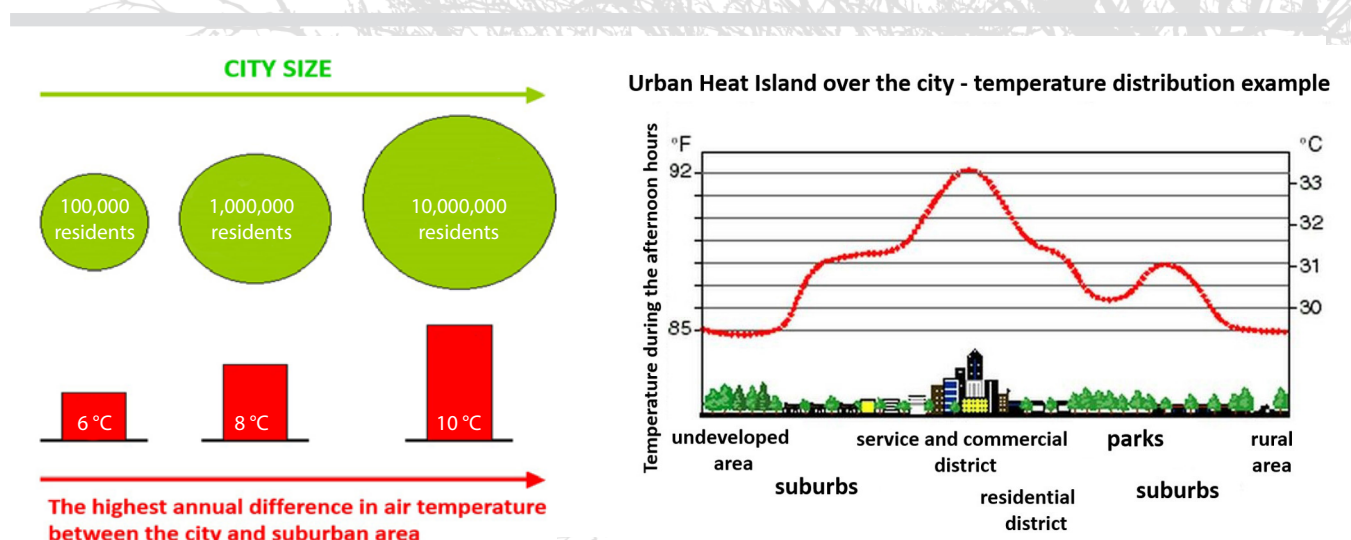
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could lead to a long-term transformation of a floristic composition, forest and shrub structure, phytocenosis, especially if cultivated for a longer time and used in large clusters. The number of species of trees and shrubs of an alien origin used in forestry, horticulture and agriculture deliberately introduced by humans to increase a productivity and competitiveness (e.g. *Quercus rubra* L.) or planted as ornamental plants in gardens and parks (e.g. *Acer negundo* L.) has increased very much in the last 100 years. Very often, these species simply get out of control. Their expansiveness is expressed not only in the appropriation of space, but also in the unprecedented possibilities of adapting to the habitat and climate conditions. The examples of such species are *Ailanthus altissima* (Mill.) Swingle, *Caragana arborescens* Lam., *Syringa vulgaris* L., *Robinia pseudoacacia* L., *Gleditsia triacanthos* L., *Acer negundo* L. Although they are plants that largely prefer a gentler thermal environment, characteristic of the central parts of the city, they are increasingly getting into the open areas, where they create compact clusters that prevent the renewal of the natural plant-specific vegetation. The buffer zone of the Park Młociny, the forest complex on the northern part of the external districts of Warsaw, is an example illustrating such processes.

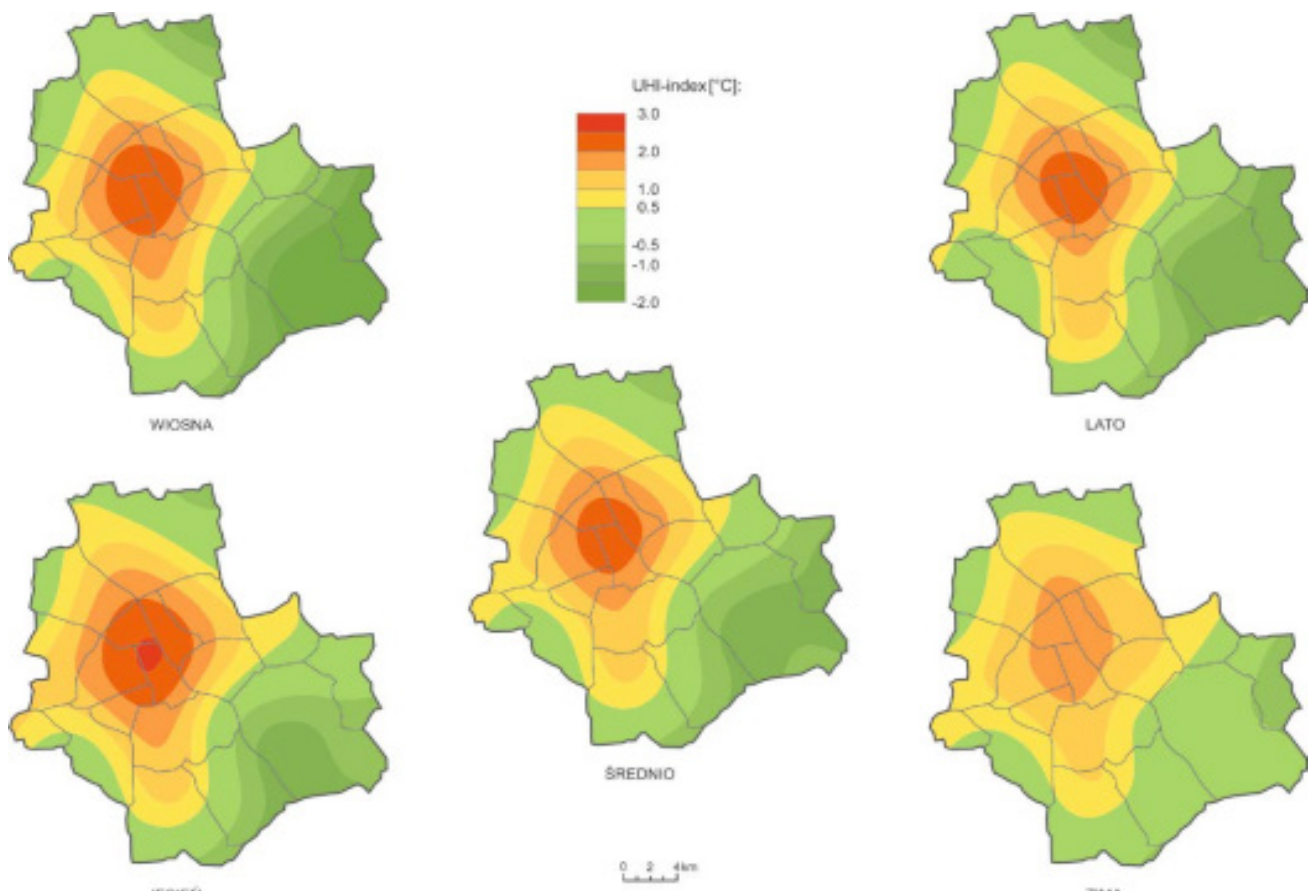
From the biodiversity point of view in the local or regional dimension, the emergence of an alien species is always a serious and a potential threat to native species: it introduces new interactions in ecosystems, habitats, in which it is often difficult to predetermine their degree of aggressiveness and ability of penetration of the alien species in natural or semi-natural ecological systems, often act as a reducing species for the native

species (Olaczek 2000). Such a phenomenon was, for example, observed in a gypsy pine. *Ailanthus altissima* (Mill.) Swingle is a very competitive species for a large number of native and domesticated species of trees and shrubs (it produces up to 350,000 seeds per year, as it is a fast growing plant drowning the other plants that grow nearby and it also produces toxins that prevent their development). Its root system is so strong that it could destroy the foundations of buildings and the underground infrastructures like sewerage. *Ailanthus altissima* (Mill.) Swingle could also appear in its ecological optimum also in the atypical places outside the city. Nevertheless, for several years, the trees of heaven locations outside the city have been registered. The urban forests on the northern city border are an example of such a situation.

The aim of this work is to demonstrate the presence of *Ailanthus altissima* (Mill.) Swingle, *Caragana arborescens* Lam., *Robinia pseudoacacia* L., *Gleditsia triacanthos* L., *Syringa vulgaris* L., *Acer negundo* L. in various parts of Warsaw: in the centre (loc. 1), districts located on the periphery (loc. 2) and suburban areas (loc. 3), and the degree of an adaptation of a plant development to a less favourable habitat and thermal conditions. This adjustment is evident in the course of phenophases. The location of the observed dendrological specimens is conditioned by a temperature distribution of an urban heat island (UHI). Many factors contribute to the creation of the UHI. The number of city residents determines the creation of UHI. When it is 500,000–1 million, the inner city air temperature is usually higher by 1.1–1.2 °C than outside the city. The temperature difference increases



■ **Figure 1:** The dependence of the number of city residents and the heat island over the city on the maximum intensity of the urban heat island – an example of the temperature distribution
Source: Wypych and Bokwa, 2015



■ **Figure 2:** The thermal characteristics of the Warsaw heat island
Source: Błażejczyk, 2014

up to 1.2–1.5 °C, when the number of inhabitants exceeds 1 million. However, the highest observed values are much higher as shown in the Figure 1.

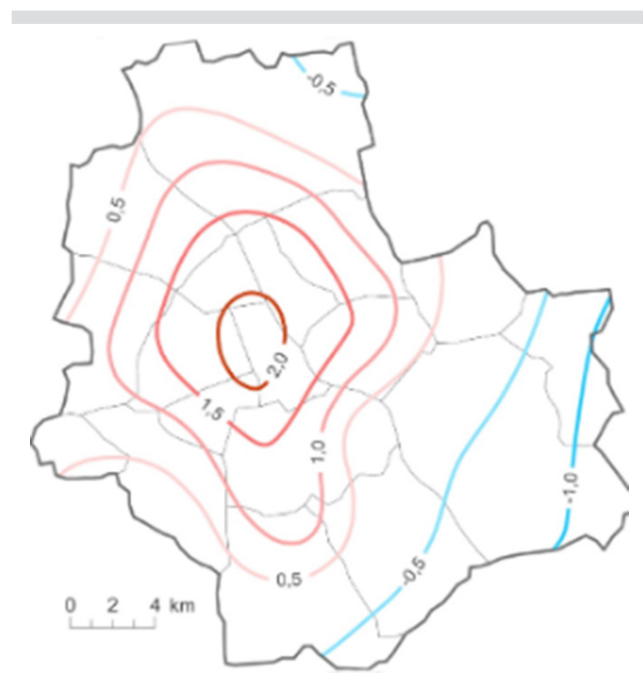
2 Material and methods

10 positions for each species in the zones with the UHI Isolation Index values were selected for an observation:

- 1.5–2.0 [loc. 1],
- 0.5–1.5 [loc. 2],
- -1.0–0.5 [loc. 3].

The observed species were: *Ailantus altissima* (Mill.) Swingle (Simaroubaceae), *Caragana arborescens* Lam., *Robinia pseudoacacia* L., *Gleditsia triacanthos* L. (Fabaceae), *Syringa vulgaris* L. (Oleaceae), *Acer negundo* L. (Aceraceae). 20 specimens from each of the listed species were observed.

The observations covered the period from 2016 to 2017. The phenological observation method was used. The phenological observations were carried out on mature individuals (around 20 years old). The simplified set of



■ **Figure 3:** The intensity of the urban heat island in Warsaw (UHI-index) in the years 2011–2012, the average values
Source: Błażejczyk, 2014

phases was used to observe phenological phenomena (Kozłowski 1998):

1. Vegetative phases:

- V-phase of a cultivation (V1 – swelling and cracking of buds, V2 – a leaf stage, V3 – a fall of the phase leaves).

2. Generative phases:

- Fl – a flowering phase,
- Fr – a fruiting phase (from a fruit harvest to maturity).

For each of the phenophases an average duration was calculated. The presented results show the averages from the observation period. The collected data of the duration of the individual phenophases from all years were analyzed by calculating the arithmetic mean of their duration.

3 Results and discussion

Currently, over 2,500 taxa of trees and shrubs grow in Poland, which is 10 times higher than the number of the indigenous tree species. Many of them may become the plants with an invasive life strategy in the future.

As the observations show, *Ailanthus altissima* (Mill.) Swingle definitely prefers places related to the occurrence of the phenomenon of the 'urban heat island'. The specimens of *Ailanthus altissima* (Mill.) Swingle in Warsaw are developing mainly in the central part of the city. Very often, they appear in the crevices of sidewalks and foundations of buildings, as are the crevices of hardened surfaces (e.g. concrete slabs). The silver birches (*Betula pendula* Roth.) resemble their developmental strategy. They form dense thickets through an intense growth of root systems and a development of rapidly growing root suckers. In the central part of Warsaw, most of the positions of groups, in which some plants were planted deliberately (e.g. parks, squares and adjacent green streets), and groups of plants spontaneously developing from root suckers or seeds could be distinguished.

The situation is slightly different in the case of other species of trees and shrubs. This is mainly due to the fact, that these plants were introduced to Poland much earlier and adapted to the prevailing climatic and habitat conditions. All analyzed species occur individually or in the concentrations with a similar frequency in the city centre to different radii. Concerning the similar frequency, it is possible find them in the suburban area also. In these locations, they constitute the most serious threat to the native plant communities. These

phenomena are particularly well visible in the areas of the urban forest complexes.

The frequency of the occurrence of *Ailanthus altissima* (Mill.) Swingle decreases as we move away from the city centre.

However, the presence of *Ailanthus altissima* (Mill.) Swingle outside the urban area, although found within the urban forests as well, such as the Młociny Park and the northern part of Warsaw, is the most interesting fact. *Ailanthus altissima* (Mill.) Swingle has got a certain limited ability to adapt to a growth under the less favourable thermal conditions.

The average lengths of each phase were used for the comparison. Comparing the average lengths of the individual phenological phases, one could notice that the specimens growing in the central parts of the city are characterized by the longer vegetative and generative phases, compared to other locations. The phase difference V2, between the copies growing in the city centre and the suburban areas, is up to 20 days. Similarly it is seen in the Fr phase, fruits in the city centre mature faster (as well as longer in the trees) than in the suburban areas. On this basis, it could be concluded that the heat island promotes an acceleration of vegetation and extends the duration of the individual phases. Generalizing, it could be said that the UHI promotes the occurrence and development of the thermophilic species.

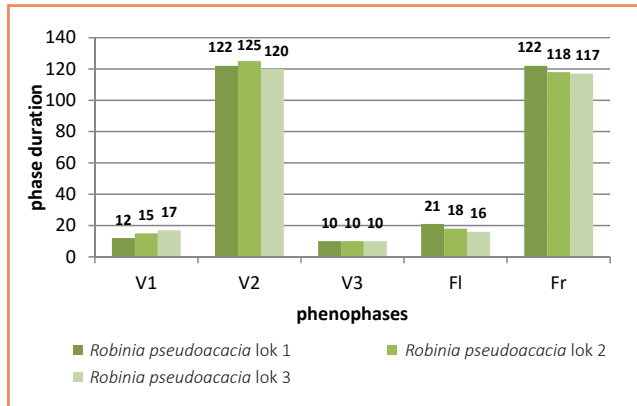
These observations indicate that the conditions in the central part of the city support the processes of synantropisation and confirm the thermal preferences of the species. However, this does not exclude the adaptation of species to less comfortable thermal conditions. In the case of specimens growing in the outer parts of the city, it could be observed that the plants do not form a tree. This happens due to the fact, that *Ailanthus altissima* (Mill.) Swingle is a typically thermophilic species, while in the suburban area the thermal balance is less favourable than in the central part of the city. The early spring and late autumn frosts are particularly destructive for the younger plants of *Ailanthus*. As a result, the plants stop during a bush stage.

However, it should be emphasized, that the unfavourable thermal conditions do not constitute a strong barrier to the development of this species, are not able to eliminate plants and do not prevent their self-renewal and independent spreading in the natural or seminal plant communities. *Ailanthus altissima* (Mill.) Swingle is propagated by seeds, but above all by the root suckers. These are the means by which plants form

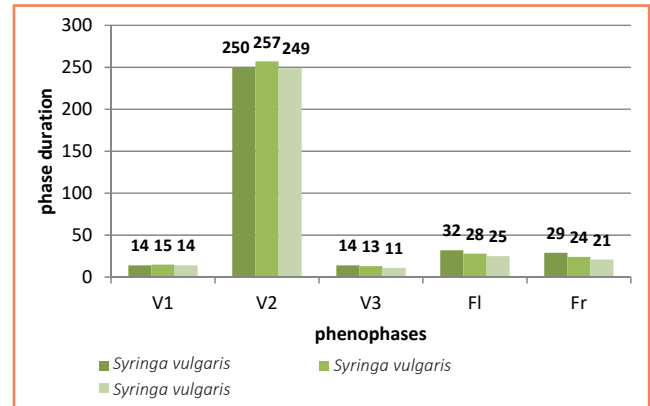
dense clusters hindering the development of other plants in their vicinity.

From the length of the individual phenological phases, very important conclusions could be drawn. The copies growing in the city centre start to grow faster

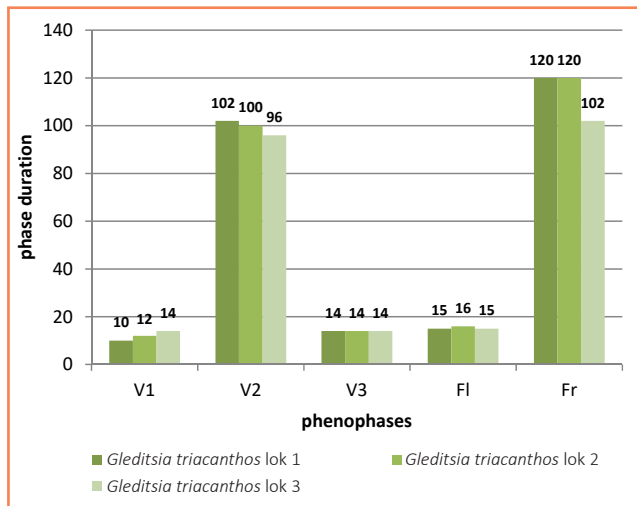
(a difference up to 10 days). This occurs similarly in the end of the growing season. The end of the vegetation happens about 14 days earlier in the case of the specimens growing in the suburban zone in comparison to the specimens growing in the city centre.



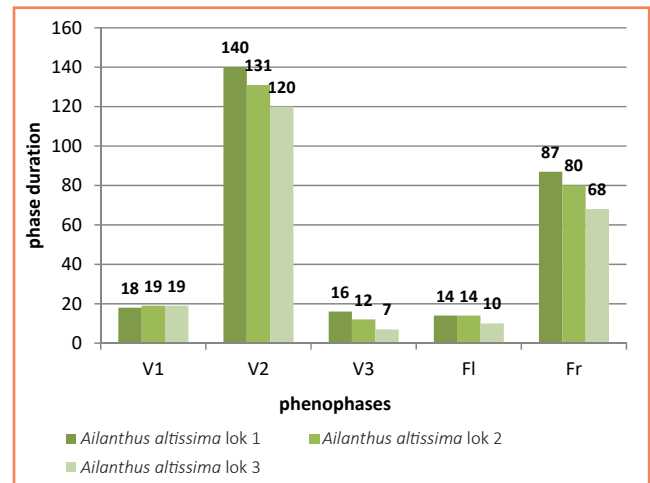
Robinia pseudoacacia



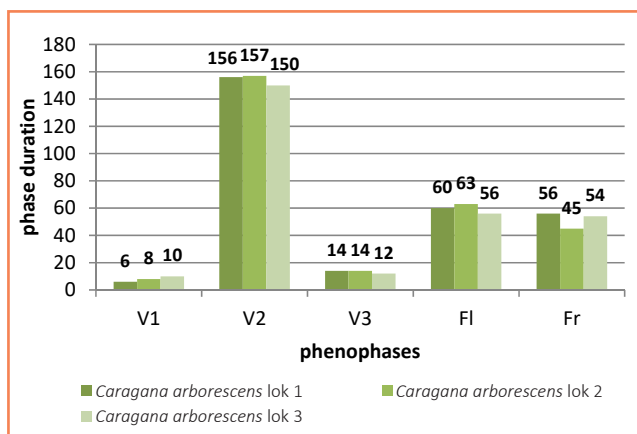
Syringa vulgaris



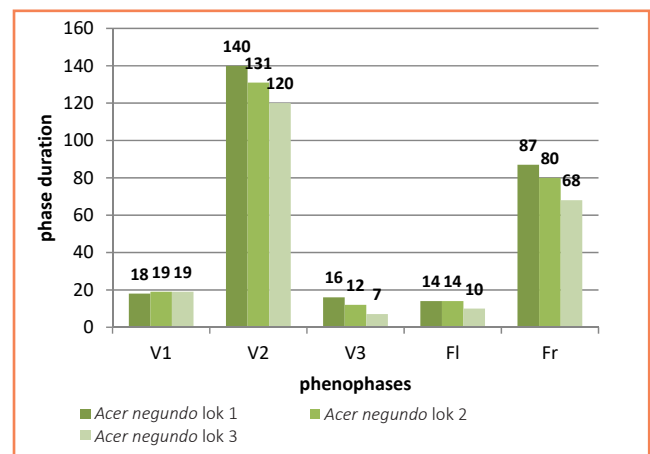
Gleditsia triacanthos



Ailanthus altissima



Caragana arborescens



Acer negundo

Figure 4: The average duration of the selected phenophases

In three locations: lok. 1 – the city centre, lok. 2. – districts on the outer part of the city, lok. 3. – suburban areas

Other species of trees and shrubs show minimal and irrelevant differences in the length of the individual phenophases. This may indicate a very deep adaptation of these species to the climatic conditions prevailing in various habitats.

4 Conclusion

The process of synantropisation is particularly intense in the urban areas due to the specific habitat conditions difficult to accept by the native vegetation and the emergence of species of a foreign origin recruiting from the areas similar to the urban habitats, in particular in the field of heat. The great interest in the flora of the urban areas occurred almost 200 years ago (Jackowiak, 1998; Pyšek, 1989; Sudnik-Wójcikowska, 1998a). In particular, the interest concerns the species composition of the urban vegetation and its functions in the urban ecosystem, as well as the role of man in shaping the urban flora. In Warsaw, just like in Wrocław, the number of *Ailanthus altissima* (Mill.) Swingle increased in various habitats. The largest number of the individuals could be noted in the most transformed part of the city, the central part. Since *Ailanthus altissima* (Mill.) Swingle is characterized by a high resistance to the level of the soil salinity, it is often found in the inner-city areas, in the places associated with the greenery of the street areas. The number of individuals has also increased in the industrial quarters. However, the tree of heaven particularly develops in the vicinity of parks, where such trees have been deliberately planted. *Ailanthus altissima* (Mill.) Swingle produces similar structures in Warsaw, Poznań and Wrocław, similarly also in Berlin, where trees usually appear in the same habitats (Kowarik and Bocker 1984).

The centre of a big city is warmer than the surrounding area due to the phenomenon of the 'urban heat island'. Its creation is controlled by various factors, such as the effect of building the insulation that results from the absorption of heat during the day and its emission in the evening, additional sources of heat emission generated by the industry, and most importantly, home heating. The occurrence of the thermophilic plant species, i.e. species of a foreign origin, as well as those subjected to the analysis is the result of the heat island existence. These species include also *Clematis* (Czekalski and Kidawska 2003) and *Buddleia davidii* Franch. (Kownas 1958). The distribution of *Ailanthus altissima* (Mill.) Swingle and other species in Warsaw (similarly in Wrocław in 1998–2001) is concentrated in the areas where the air temperature is by several degrees higher. Probably, the heat factor had a decisive influence on

such distribution, because the species of synantropic plants, especially those with the invasive life strategies, come from the warmer zones and the thermal index is associated with the warmest areas of the Central European city and highly industrialized regions, e.g. in Duisburg, Berlin, Leipzig, Halle and Zurich, as well as on the French coast of the Mediterranean and the Ruhr area in Germany (1983a, 1983b, Kowarik, Kowarik and Böcker, 1984; Kunick, 1984; Landolt, 1991a, 1991b; Sudnik-Wójcikowska and Moraczewski, 1993; Sudnik-Wójcikowska, 1998a). In Poland, the occurrence of the analyzed species of trees and shrubs, in particular *Ailanthus altissima* (Mill.) Swingle in cities, was presented by Pacyniak (1976) and Sudnik-Wójcikowska (1998b) for Warsaw and Łódź. However, in the last decade, the appearance of *Ailanthus altissima* (Mill.) Swingle and other species outside the 'urban heat island' area may raise concerns about the process of wide changes in the natural plant communities. This may indicate both the climate change, expressed by the increasing thermal equilibrium and the systematic warming of the climate, as well as the adaptation of the species to the less favourable thermal conditions. This phenomenon is very unfavourable, because the species are characterized by a high expansiveness. Thus, they begin to appear in the natural as well as in the semi-natural forest complexes.

The executed phenological observations showed that plants growing in the central parts of the city have got long vegetation and a stronger growth. However, in the places located on the outskirts of the city and in the urban forests, the vegetation period is shorter and the plants often remain in the form of shrubs. The occurrence, and above all the length of the individual phenophases, is an indicator characterizing the urban island of heat. Therefore, the phenological research is a valuable complement to the climate research.

The central part of the city, with the warm island accompanying it, is the most favourable place for the invasive plants, as they could self-reproduce, sow and form thickets by root suckers there. This process is intensified more and more each year.

The vegetation length of *Ailanthus altissima* (Mill.) Swingle in the central part of the city reaches about 180 days and in the case of the suburban, this number is reduced to about 150 days. In the case of other species, the process of shortening of the vegetative phases outside the area of the 'urban heat island' is almost imperceptible.

The same relations of the duration of the individual phenophases and the location of the observed

specimens could be seen in the case of the copies of all the analyzed species. In the case of all vegetative specimens, the prolongation of vegetation has been noticed.

In the last 20 years, the change of *Ailanthus altissima* (Mill.) Swingle occurrence zone from the only centre and outer parts greenery parts to the of the city and the suburban areas has become noticeable.

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