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ORIGINAL RESEARCH PAPER

Changes in the pollen seasons of *Acer* spp. in Lublin, central-eastern Poland, in 2001–2015

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Abstract

Many plant species respond to the climate change reported in the recent decades, which is confirmed by the results of phenological and aerobiological investigations. This paper presents characteristics of the pollen seasons of *Acer* spp. revealed by aerobiological analyses performed with the volumetric method in Lublin, Poland in 2001–2015. Additionally, phenological observations of flowering of four *Acer* species, i.e., *A. negundo*, *A. platanoides*, *A. campestre*, and *A. pseudoplatanus*, were carried out in 2011–2012.

The results indicate a slight upward trend in the annual totals of *Acer* pollen grains. Over the last 10 years, the annual totals of *Acer* pollen grains have increased in comparison to the previous 5-year period. Acceleration of the onset of pollen seasons and the dates of peak days was noted. The comparison of the pollen seasons and flowering phenology of four *Acer* species indicates that *A. negundo* and *A. platanoides* produce the highest concentrations of pollen grains, whereas the pollen of *A. campestre* and *A. pseudoplatanus* accounts for a significantly lower proportion of the pollen content in the air of Lublin.

Keywords

Acer; pollen concentrations; annual totals; phenology of flowering

Introduction

The genus *Acer* (Sapindaceae) is represented by approximately 150 species growing mainly in the Northern Hemisphere, primarily in China and Japan. In Poland, three native species of this genus, i.e., *A. platanoides*, *A. pseudoplatanus*, and *A. campestre* grow in forests and scrubs [1]. One species, *A. negundo*, is regarded as an invasive species in Poland [2]. Furthermore, many species are planted as trees and ornamental shrubs, e.g., *A. tataricum*, *A. rubrum*, *A. saccharinum*, and *A. palmatum* [3,4]. Some species form the genus *Acer* are anemophilous and dioecious, e.g., *A. negundo* and *A. saccharinum*, with flowers developing before leaf formation, which in Poland occurs in March and April. The next species to bloom are *A. platanoides* and *A. campestre* (April–May) followed by *A. pseudoplatanus* and *A. tataricum* (May–June) [5].

In many European countries, *A. platanoides* is monitored for the dates of the onset of different phenological stages, including the beginning of flowering (Czech

Republic, Germany, Latvia, Lithuania, Poland, Romania). Similarly, *A. pseudoplatanus* is an object of phenological investigations (Czech Republic, Switzerland, United Kingdom) as well as *A. campestre* (Romania, United Kingdom) [6]. In Poland, the beginning of leaf development in *A. platanoides* indicates the phenological season of early spring [7].

Kolařova et al. [8] demonstrated a significant increase in the length of the growing season of *A. platanoides* (by 20 days) and *A. pseudoplatanus* (by 25 days) recorded over 35 years (1976–2010) in Central Europe. Similarly, an extended of the growing season, on average by 23.8 days, was noted in the case of other tree species.

Long-term phenological observations reveal that earlier dates of first bloom are recorded in many plant species. Fitter and Fitter [9] showed that the dates of the first flowering in 1991–2000 were on average 4.5 days earlier for 385 species than those from 1954 to 1990. An acceleration rate of at least 15 days was noted in 60 species of this group. It was also found that entomophilous plants were characterized by greater acceleration of the flowering stage than anemophilous species. Menzel et al. [10] carried out phenological investigations of some species of trees, including anemophilous species such as *Betula*, *Populus*, *Quercus*, and *Salix*, growing in various European countries. They showed a trend towards earlier flowering, which was on average 6.3 days, in 16 taxa in 1959–1996. Similarly, based on long-term phenological observations conducted in Boston, Primack et al. [11] reported that many plant species bloomed 8 days earlier in 1980–2002 than in 1900–1920.

Plant responses to climate change are revealed not only through phenological observations but also based on aerobiological data. Rasmussen [12] in Denmark (1979–1998) and Emberlin et al. [13] in different sites in Europe (London, Brussels, Zurich, Vienna) reported clear trends towards an earlier start of *Betula* pollen seasons in 1982–1999. In the Netherlands, van Vliet et al. [14] showed a 10-day earlier onset of the *Betula* pollen season in 1969–2000. The authors noted a similarly accelerated onset of pollen seasons in other plant species (*Juniperus*, *Ulmus*, *Populus*, *Salix*, *Quercus*) in the Netherlands. Frei and Gassner [15] reported an approximately 15-day acceleration of the onset of birch flowering over 38 years (1969–2006) in Switzerland (Basel) as well as increased amounts of released pollen.

Smith et al. [16] demonstrated a significantly earlier start of the Betulaceae pollen season in Reykjavik, Derby, and Sofia. In many plant species, a significant increase in annual pollen totals was noted over the last decades. Levetin [17] reported an increase in the annual totals of *Juniperus*, *Quercus*, *Carya*, and *Betula* pollen in the USA in 1987–2000. In Europe, increased cumulative pollen season totals for *Urtica* spp. (Brussels, Dalmenhorst, Helmond, Leiden, Derby) and *Quercus* spp. (Brussels, Derby, Leiden) were noted [18]. Investigations conducted by Zhang et al. [19] in the USA demonstrated an earlier onset (on average by 3 days) of pollen seasons of different anemophilous species and an increase, on average by 46%, in the annual totals of daily counted airborne pollen.

In Poland, Malkiewicz [20] reported ca. a 30-day acceleration of the *Corylus* pollen season beginning in Wrocław within 10 years (2003–2013). In turn, Myszkowska et al. [21] noted a significant upward trend in the annual total and maximum pollen count for this taxon in Cracow in 2001–2013. Investigations conducted in Szczecin in 2001–2013 showed a 12-day earlier onset of the *Betula* pollen season [22]. The effect of climate change also involves changes in plant distribution, e.g., expansion of *Juniperus* spp. across the different parts of the United States [23,24].

The aim of this study was to compare the course of pollen seasons of *Acer* spp. in Lublin in 2001–2015 and to analyze changes that might have been caused by the increase in temperature. Additionally, phenological observations of the flowering dates in four *Acer* species were carried out in 2011–2012 in order to compare the data with the dynamics of the pollen seasons in this taxon.

Material and methods

The concentration of maple (*Acer* L.) pollen in the air of Lublin was monitored from 2001 to 2015 with the volumetric method. Daily pollen counts were measured using the Hirst trap (Lanzoni VPPS 2000) placed on the roof of the University of Life Sciences building at an altitude of 197 m a.s.l. and a height of 18 m above the ground. The measurement site was located near the city center.

The analysis of the airborne pollen concentration was carried out with standard methods recommended by the International Association for Aerobiology [25]. The beginning and the end of the pollen season were determined using the 98% and 90% method [26,27]. Daily average *Acer* pollen counts were expressed as pollen grains/m^3 (P/m^3). The following features of the pollen seasons were analyzed: the onset, end, and length of the pollen season, the seasonal maximum (the value and the date of occurrence of the maximum concentration), and the annual total of pollen grains. Standard deviation (*SD*) and coefficients of variation (*V*%) were calculated for the individual characteristics and trend lines were determined.

The climate of the Lublin region (Poland) is characterized by the impact of continental air masses. The average annual temperature in Lublin in 2001–2014 was 9.1°C, and the average annual precipitation sum was 546.8 mm. In an earlier period (1951–2000), the average annual air temperature in Lublin was 7.4°C, and the average annual precipitation sum was 550 mm [28].

Observations of the phenology of flowering in three native maple species, i.e., *Acer campestre* L., *A. platanoides* L., *A. pseudoplatanus* L., and in *Acer negundo* L. were carried out in four districts of Lublin: Śródmieście, Sławin, Czuby, and Kalinowszyzna in April and May of 2011 and 2012. Phenological occurrences were recorded at 2–3-day intervals on the same specimens in both years. The phenology of flowering was investigated with the method proposed by Łukasiewicz [29]. Two phases of generative development, i.e., the appearance of the first flowers and the end of flowering were observed.

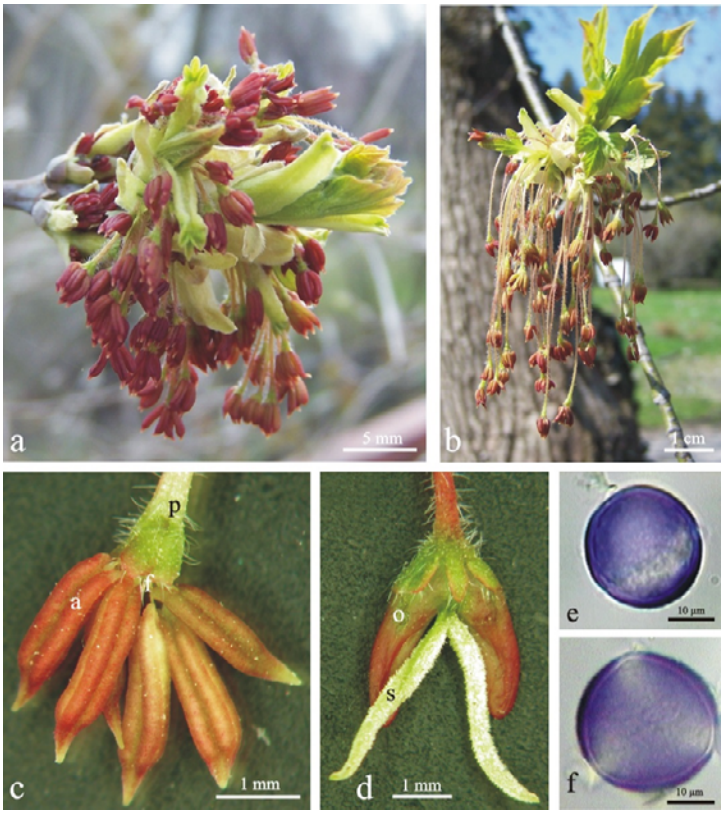

Fig. 1 *Acer negundo*. **a** Inflorescences appearing in bursting buds. **b** Male inflorescences before pollen release with strongly elongated pedicels. **c** Male flower (f – filament; a – anthers; p – pedicel). **d** Female flower (o – ovary; s – stigma). **e** Pollen grain in equatorial view. **f** Pollen grain in polar view.

Results

Characteristics of the flowers of the analyzed *Acer* species

The flowers of *Acer negundo* are dioecious; they are distributed separately on male and female trees and appear before leaf formation. Male inflorescences are arranged in loose panicles composed of several or several dozen flowers (Fig. 1a,b). The perianth is reduced. Each staminate flower comprises 4–6 stamens with red anthers (Fig. 1c). The pistillate flower contains a bipartite pistil with long stigmata (Fig. 1d).

The yellow-green flowers of *Acer platanoides* (Fig. 2a,b) developing before appearance of leaves are gathered in dense, erect corymbs. The end of the blooming occurs after the leaves development (Fig. 2c). The same inflorescence bears three categories of flowers: male, female, and bisexual. They are composed of five sepals, five corolla petals, eight stamens located in the center of the nectary disc, and a pistil with a bipartite stigma. In male flowers, the stamens have longer, outwardly directed filaments (Fig. 2d), and the short stamens in bisexual flowers are located close to the pistil (Fig. 2e).

Acer campestre has few-flowered, umbel-like, erect inflorescences, which develop simultaneously with leaves (Fig. 2h). The flower structure is similar to that in *Acer platanoides*.

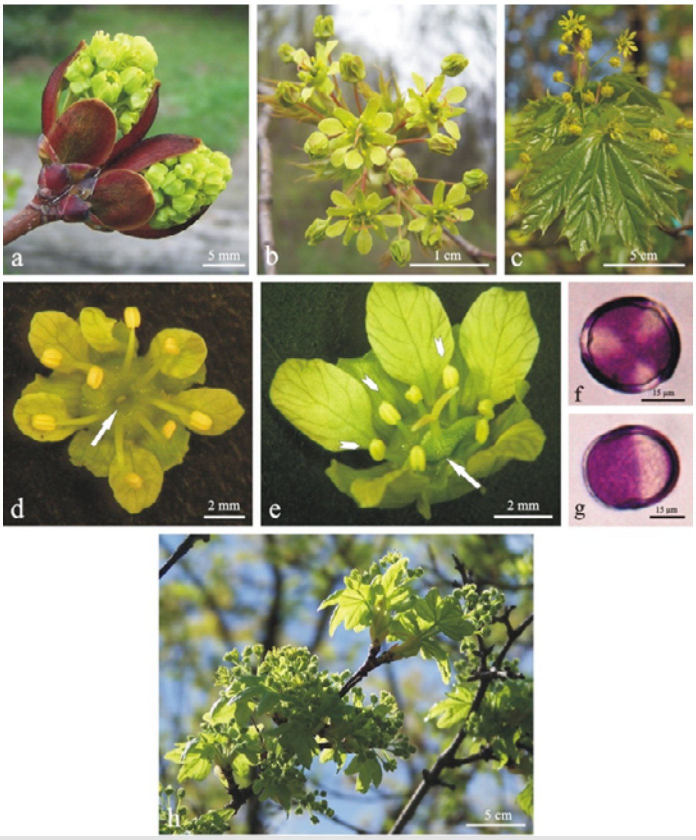

Fig. 2 *Acer platanoides* (**a–g**) and *Acer campestre* (**h**). **a** Young inflorescences with scales covering inflorescence buds visible at the base. **b** Corymb in full bloom. **c** Phase of full leaf development. **d** Functionally male flower; the arrow shows a degenerated pistil. **e** Bisexual flower. The arrow shows the pistil; the arrowheads show stamens. **f** Pollen grain in polar view. **g** Pollen grain in equatorial view. **h** Fragments of *A. campestre* blooming branches.

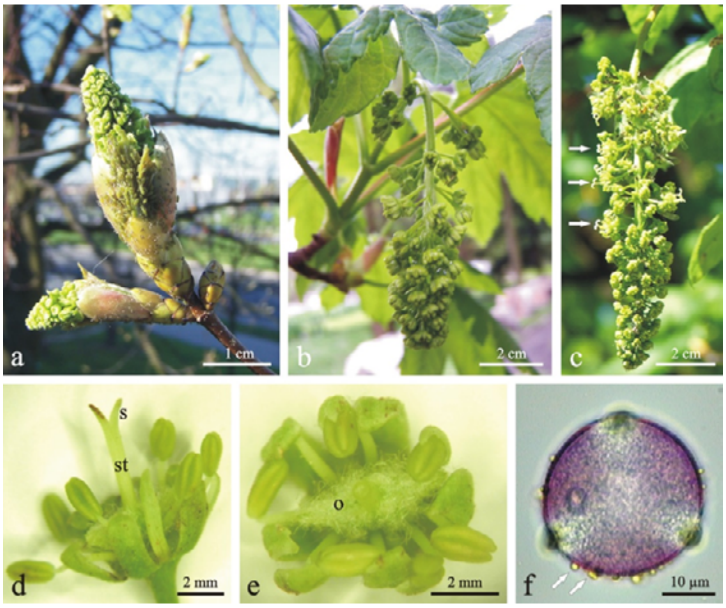

Fig. 3 *Acer pseudoplatanus*. **a** Early phase of inflorescence development. **b,c** Inflorescences at the beginning of flowering. The arrows show stigmas. **d** Bisexual flower – side view (st – style; s – stigma). **e** Bisexual flower without the upper part of the style and stigma – top view (o – ovary). **f** Pollen grain in polar view with visible droplets of pollenkitt (arrows).

Acer pseudoplatanus has long, pendulous inflorescences, which open 2–3 weeks after the development of leaves (Fig. 3a–c). The flowers are small and have five pale yellow petals, which are slightly longer than the five greenish-yellow sepals. The petal apices are folded inwardly. The pistil has two stigmata and a bi-locular, strongly hairy ovary with a ring-shaped, yellow-light green nectary located at its base. There are eight stamens (Fig. 3d,e). Both bisexual and male flowers are present in one inflorescence.

The pollen grains of different *Acer* species are spheroidal or oblate-spheroidal and tricolpate. In entomophilous species, they are covered by pollenkitt droplets (Fig. 1e,f, Fig. 2f,g, Fig. 3f).

Start and duration of the pollen season

The dates of the onset of the *Acer* pollen season in the study years (the 98% method) ranged from February 19 (2002) to April 13 (2013). A striking exception in the timing was 2002, as in a majority of cases the pollen season of this taxon began in the first half of April. The coefficient of variation for this parameter was 15.8%. Substantially higher variability ($V = 33.9\%$) was noted for the length of the pollen season in the range of 17–61 days with an average of 35 days (Tab. 1).

The analysis of all the data concerning the onset of the *Acer* pollen seasons over 15 years did not reveal acceleration of the beginning of pollen release in the last years of the study. However, after exclusion of the extreme thermal results from 2002 and 2013, there was an evident trend ($R^2 = 0.34$) towards an accelerated onset of pollen release (by 12 days; Fig. 4).

Dynamics of pollen seasons

During the 15 years, the curve showing the course of the *Acer* pollen seasons was usually characterized by several peaks (over 10 years). Single-peak curves were obtained in 2003, 2005, 2006, 2008, and 2013 (Fig. 5, Fig. 6). The length of the pollen seasons in these years exhibited relatively low values (17–35 days). In these pollen seasons, abundant quantities of pollen may have been released simultaneously by several *Acer* species. The first peaks of the pollen seasons noted most frequently in the first half of April were undoubtedly associated with the *A. negundo* pollen release, which was confirmed by our phenological observations. The next peaks were related to release of *A. platanoides* and *A. campestre* pollen (Fig. 5, Fig. 6).

Tab. 1 Characteristics of *Acer* pollen seasons 2001–2015 (the 98% method).

Years	Pollen season			Peak day		Pollen sum
	Start	End	Duration (days)	P/m³	Date	
2001	15.03	29.04	46	62	20.04	332
2002	19.02	20.04	61	84	11.04	557
2003	28.03	1.05	35	142	24.04	655
2004	20.03	3.05	45	278	19.04	1082
2005	5.04	3.05	29	369	18.04	810
2006	8.04	2.05	25	311	25.04	1114
2007	2.04	28.04	27	200	11.04	1133
2008	7.04	23.04	17	176	11.04	500
2009	12.04	3.05	22	105	17.04	648
2010	26.03	7.05	43	243	9.04	787
2011	8.04	14.05	37	178	18.04	972
2012	21.03	6.05	47	148	17.04	771
2013	13.04	17.05	35	149	26.04	509
2014	22.03	24.04	34	187	8.04	1301
2015	8.04	29.04	22	373	12.04	1324
Mean	31.03	2.05	35.0	200.3	16.04	833.0
Min	19.02	20.04	17.0	62.0	8.04	332.0
Max	13.04	17.05	61.0	373.2	26.04	1324.4
SD	13.9	7.3	11.9	96.5	5.9	307.7
V (%)	15.8	6.0	33.9	48.2	5.5	36.9

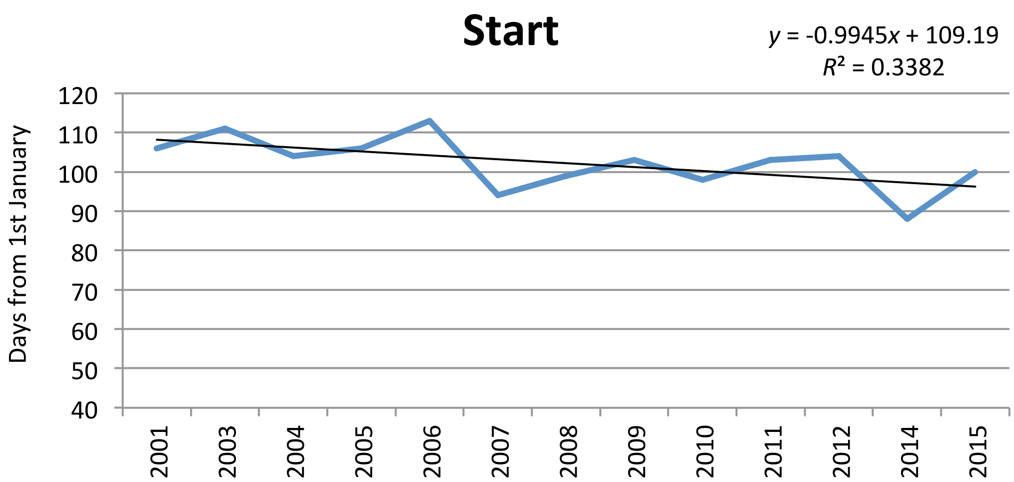

Fig. 4 Onset dates of *Acer* pollen seasons in Lublin (2001–2015) with exclusion of the extreme years 2002 and 2013 (the 90% method).

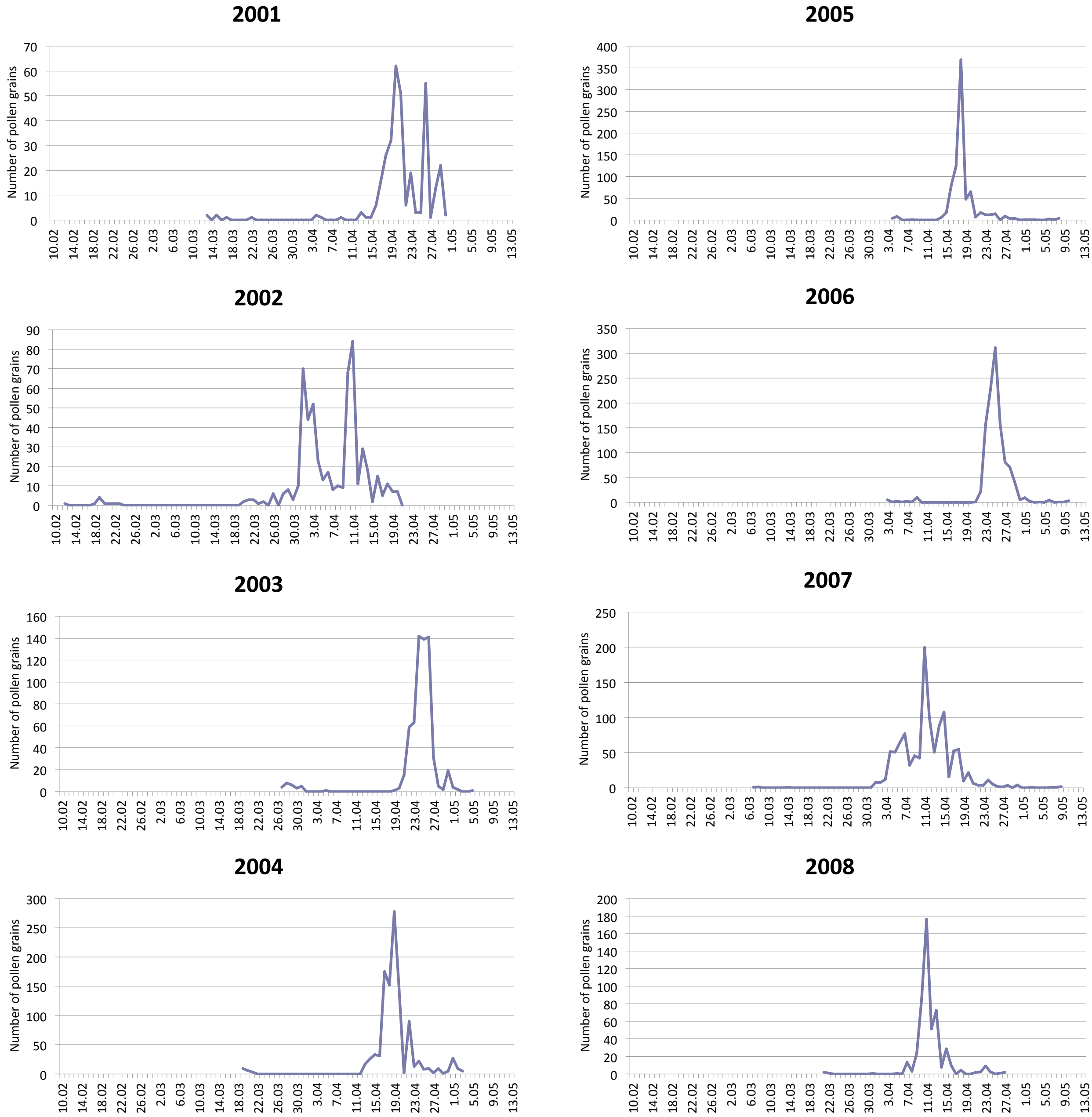

Fig. 5 Dynamics of *Acer* pollen seasons in Lublin, 2001–2008.

Annual totals and peak days

The average value of the annual totals of the *Acer* pollen count from 2001–2015 in Lublin was 833 grains. The lowest value (332 grains) was noted in 2001, whereas the two highest values (1301 and 1324 grains) were reported in 2014 and 2015 (Tab. 1).

The trend line determined for the annual totals exhibits an upward trend (Fig. 7).

During the 15-year study period, the maximum concentration of *Acer* pollen grains was in the range of 62–373 P/m^3. The average value of the highest pollen concentration was 200 P/m^3. The dates of peak days oscillated between April 8 and 26, with April 16 as an average date for the study years (Tab. 1). In 2001–2015, excluding the extreme years of 2002 and 2013, the trend line indicated an 8-day earlier occurrence of the peak day with $R^2 = 0.4$. Earlier dates of the peak days, in particular from 2007, are also visible in Fig. 8.

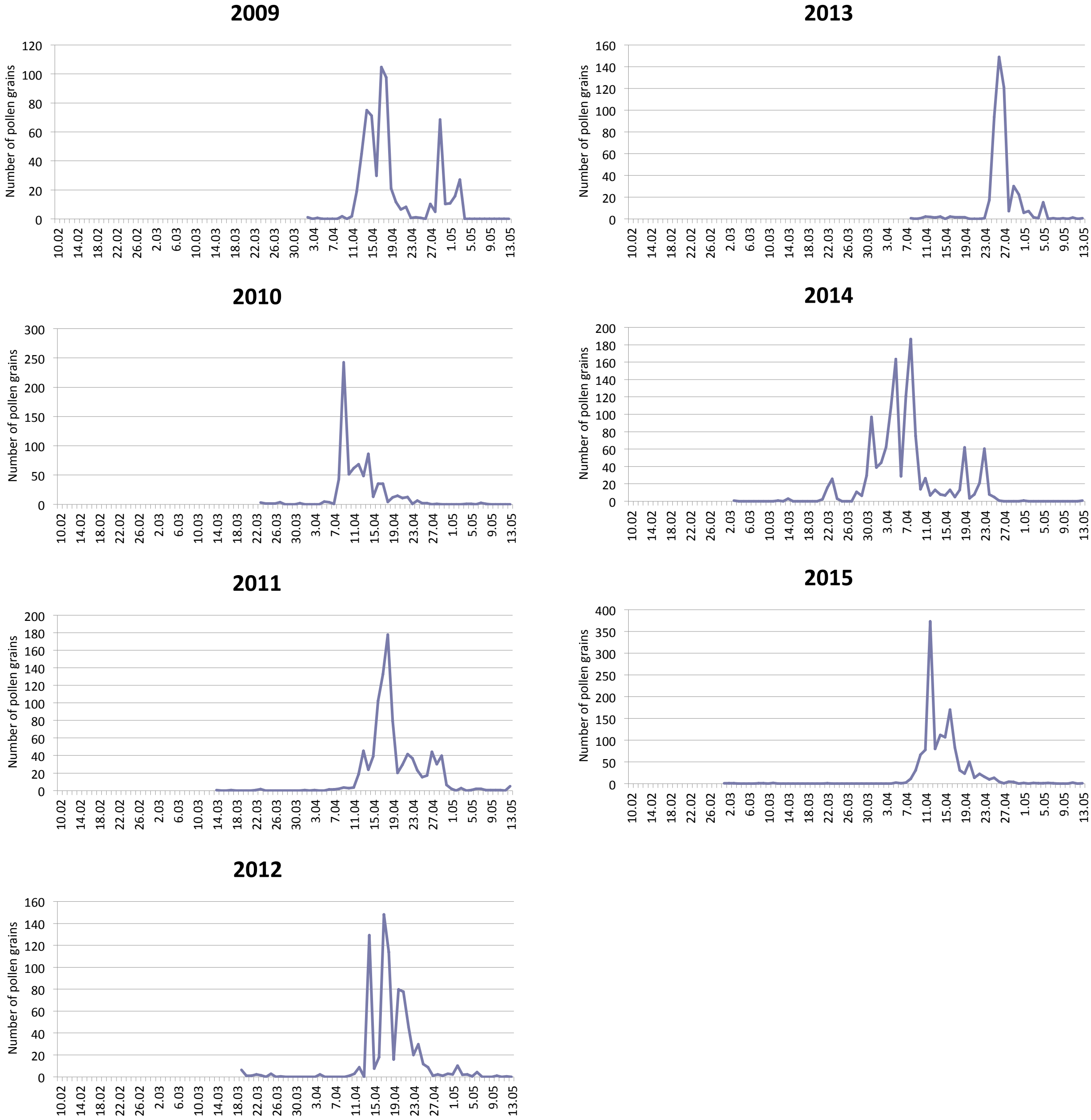

Fig. 6 Dynamics of *Acer* pollen seasons in Lublin, 2009–2015.

Phenological observations of the flowering phase

The phenological investigations conducted in 2011 indicated the following sequence of flowering among the analyzed maple species: *A. negundo* – April 5–26, *A. platanoides* – April 8–29, *A. campestre* – April 21 – May 12, and *A. pseudoplatanus* – April 26–27. The longest flowering period was noted for *A. pseudoplatanus* (32 days), and a similar length was noted in the other three species (21 days, 21 days, 22 days). The results of the observations carried out in 2012 were as follows: *A. negundo* – March 27 – April 28 (33 days), *A. platanoides* – April 16 – April 30 (14 days), *A. campestre* – April 26 – May 9 (14 days), and *A. pseudoplatanus* – April 26 – May 24 (29 days).

The average length of the flowering period in these *Acer* species from 2 years (2011 and 2012) compared with the course of the average pollen seasons in this taxon in the analyzed years is presented in the Fig. 9. It indicates that the highest pollen concentrations in the *Acer* pollen season coincide with the flowering period of *A. negundo* and *A. platanoides*. The other two species (*A. campestre* and *A. pseudoplatanus*) have inconsiderable contribution in the concentration of *Acer* pollen during the pollen season.

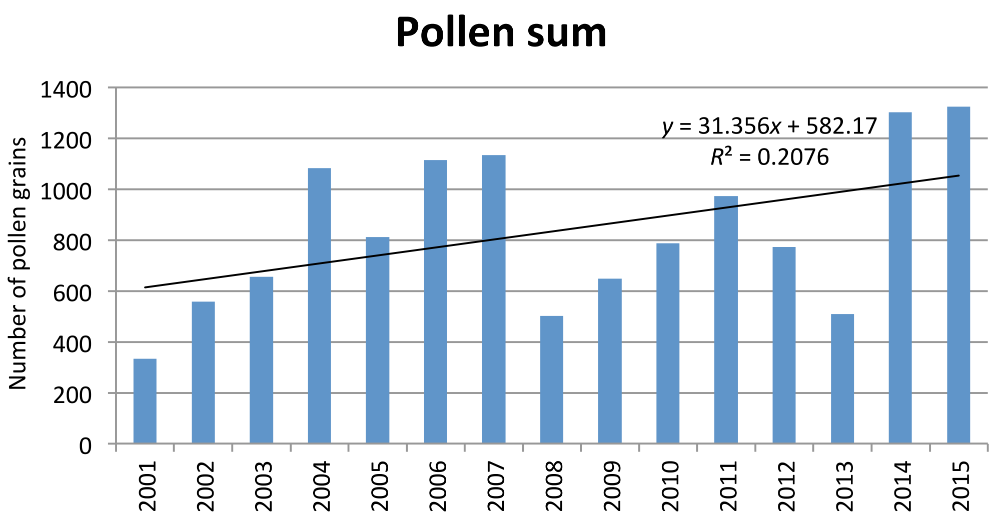

Fig. 7 Comparison of annual totals of *Acer* pollen grains in Lublin, 2001–2015.

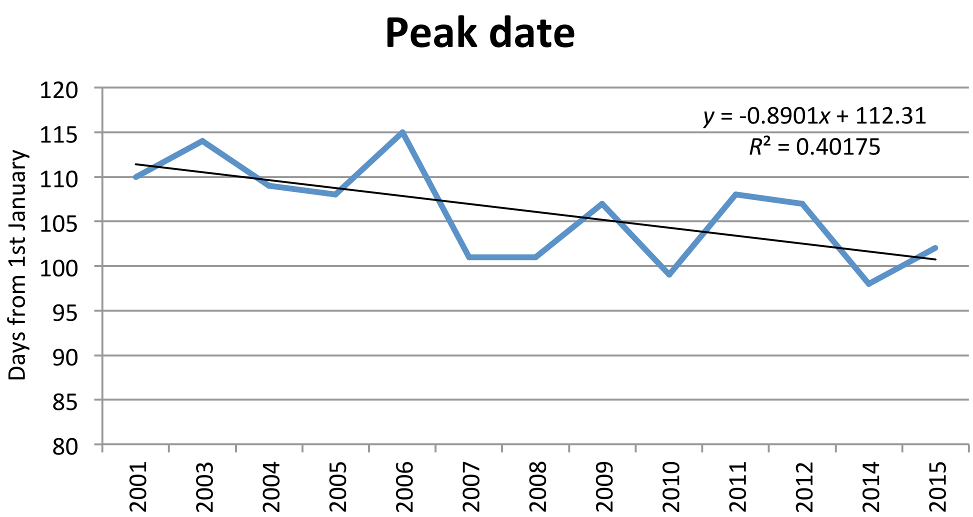

Fig. 8 Dates of maximum concentrations of *Acer* pollen seasons in Lublin, 2001–2015 with exclusion of the extreme years 2002 and 2013.

Discussion

The species from the genus *Acer* growing in Poland represent anemophilous and entomophilous plants. The flowering and pollen release period of the anemophilous trees (*A. saccharinum*, *A. negundo*) is noted in March and April; therefore, the pollen of these species may be the main contributor to the initial period of the *Acer* pollen seasons. Pollen of the entomophilous species flowering early (*A. platanoides*) may also be present in the air during the periods of the highest concentrations in *Acer* pollen seasons, usually persisting until the third decade of April, which was shown in our study. *Acer platanoides* flowers release nectar abundantly, which has great importance for development of bees in early spring [30,31].

In turn, maple species flowering between the third decade of April and the third decade of May (*A. pseudoplatanus*, *A. campestre*) are highly valued in apiculture as they are a valuable source of nectar and pollen reward for insects. Pollen of these species is usually not recorded in the air, as it is primarily transferred by insects. The full bloom of these taxa coincides with the end of the *Acer* pollen season, when there are only a few pollen grains of the taxon in the air. *Acer pseudoplatanus* present in

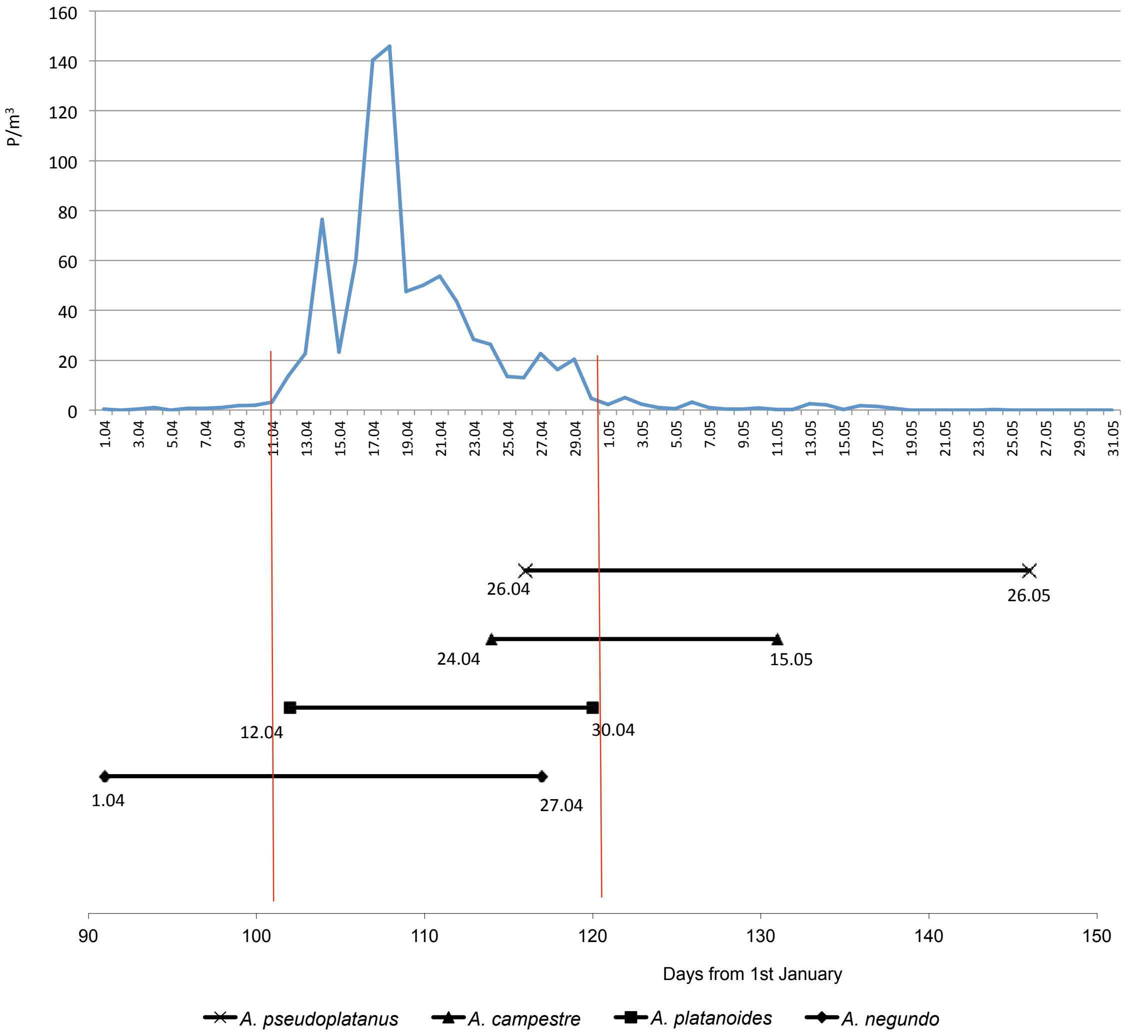

Fig. 9 Comparison of the flowering phenology of four *Acer* species with pollen seasons (average from 2011–2012).

numerous tree arrangements provides bee families, which are better developed in May, substantial amounts of nectar that can yield commercial honey with a light yellow color and characteristic aroma [30,32].

Investigations conducted in previous years showed a clear diversity of the dates of the onset of *Acer* pollen seasons not only in Lublin but also in other cities of Poland. In 2001–2005, dates of the beginning of the pollen season of this taxon that were the most similar to those from Lublin were reported from Sosnowiec, where the average date from 5-year analyses differed only by 9 days. Considerably greater differences between the average values of this parameter in Lublin were found for Szczecin (25 days), Rzeszów (19 days), Poznań (16 days), and Cracow (14 days) [33–38].

Similarly, the length of *Acer* pollen seasons differed significantly between these cities in 2001–2005. Comparison of the average length of the pollen seasons during the 5 years showed the highest value for Sosnowiec (74 days), Poznań (61 days), Rzeszów (54 days), Lublin (43 days), Cracow (35 days), and Szczecin (31 days) [39].

Investigations carried out in different cities of Poland in 2001–2005 showed that the highest annual totals of *Acer* pollen were recorded in Lublin. The average annual total in this period for Lublin was 687 P/m^3, for Szczecin and Sosnowiec 273 and 252 P/m^3, respectively, for Poznań 194 P/m^3, and for Cracow and Rzeszów 117 and 115 P/m^3, respectively [33–38]. This may be a result of the great number of planted maples and favorable conditions for their spread in the area of Lublin. It can also serve as an indicator of faster spread of the invasive *A. negundo* species in the Lublin region facilitated by global warming. The annual average of daily *Acer* pollen count (907 P/m^3) from 10 years (2006–2015) increased significantly (by 32%) in comparison with the period of 2001–2005. The upward trend in the annual *Acer* pollen totals in Lublin is also indicated by the trend line.

However, we did not find a tendency towards extension of the *Acer* pollen seasons, whereas Kolařova et al. [8] observed a significant increase in the length of the growing season of *A. platanoides* and *A. pseudoplatanus* in the Czech Republic.

In the present paper, we have shown for the first time an evident increase in the annual *Acer* pollen totals in central-eastern Poland in 2001–2015. Piotrowska and Kaszewski [40] reported that the mean rise of annual air temperature reached 1°C in Lublin in 2001–2010. It is comparable to the average global air temperature rise by 0.85°C in 1880–2012 indicated by the data of the Intergovernmental Panel on Climate Change (IPCC 2013). In such conditions, changes in the plant flowering phase are highly possible, as evidenced by the analysis of the *Acer* pollen seasons. Over the last 15 years (2001–2015), the annual totals of airborne pollen grains recorded in Lublin have increased significantly, which indicates increased abundance of pollen or an increase in the number of flowering individuals. Furthermore, the beginning of the pollen seasons and the dates of maximum concentrations have been accelerated as well. The present results are comparable with aerobiological data reported by other authors in their investigations in Poland and other countries.

In the USA, a significant increase in the annual totals of *Juniperus*, *Quercus*, *Carya*, and *Betula* pollen was reported [17]. Increased annual *Quercus* pollen totals were noted in several European countries [18,41]. In Switzerland, an increase in the annual *Betula* pollen totals was recorded [15,42]. Myszkowska et al. [21] showed an upward trend in the annual totals and maximum *Corylus* pollen concentration in Cracow. Damialis et al. [43] demonstrated greater changes in pollen production (increase) than changes in flowering phenology.

Dahl et al. [44] suggest that the results of phenological investigations are the most important bioindicators to study the direct impact of global warming on plants. These authors also found that historical pollen databases were highly relevant for global warming adaptation studies. Predictive modeling based on climate projections allows an assumption that pollen seasons for the investigated species will start from 1 week to 1 month earlier at the end of the twenty-first century.

Conclusions

- The results of the investigations conducted in Lublin indicate an upward trend in the annual total pollen count in *Acer*. Over the last 2 years, we have recorded the highest annual total pollen counts in 15 years.
- Comparing the long-term averages, earlier onsets of the pollen season and dates of maximum *Acer* pollen concentrations were noted in 2001–2015.
- The end of the pollen season and dates of maximum *Acer* pollen concentrations were the most stable parameters of the pollen season, whereas the value of the maximum pollen concentrations exhibited the greatest variability.
- The comparison of aerobiological and phenological data indicates that *Acer negundo* and *Acer platanoides* pollen represented the greatest proportion in the airborne pollen content in Lublin during the *Acer* pollen season.

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Zmiany w sezonach pyłkowych *Acer* spp. w Lublinie, Polska środkowo-wschodnia, w latach 2001–2015

Streszczenie

Wiele gatunków roślin wykazuje reakcje na zmiany klimatyczne, które rejestrowane są w ostatnich dziesięcioleciach. Potwierdzają to wyniki badań fenologicznych i aerobiologicznych. W pracy przedstawiliśmy charakterystykę sezonów pyłkowych *Acer* ssp. na podstawie badań aerobiologicznych, przeprowadzonych metodą wolumetryczną w Lublinie w latach 2001–2015. Ponadto wykonaliśmy obserwacje fenologiczne, dotyczące kwitnienia w latach 2011–2012 czterech gatunków *Acer*: *A. negundo*, *A. platanoides*, *A. campestre* i *A. pseudoplatanus*.
Wyniki badań wskazują na występowanie niewielkiego trendu wzrostowego, dotyczącego sum rocznych ziaren pyłku *Acer*. Sumy te w ciągu ostatnich 10 lat badań wzrosły o 32% w porównaniu z wcześniejszym pięcioleciem. Zaznaczyło się również przyśpieszenie początku sezonów pyłkowych oraz dat występowania maksymalnych koncentracji ziaren pyłku. Z porównania sezonów pyłkowych i danych dotyczących fenologii kwitnienia 4 gatunków *Acer* wynika, że najwyższe koncentracje ziaren pyłku przypadają na okres kwitnienia *A. negundo* i *A. platanoides*, zaś pyłek *A. campestre* i *A. pseudoplatanus* mają znaczenie mniejszy udział w zawartości pyłku rodzaju *Acer* w powietrzu Lublina.