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Faculty of Biology, University of
Szczecin, Poland**Authors' contributions**

NK led the study, formulated the main objectives of the study and research design, conducted material collection, meteorological data processing as well as data analysis and interpretation, prepared the figures and tables, and wrote the manuscript; KV conducted the microscope pollen analysis, pollen data analysis, statistical analyses, diagram plotting, and meteorological data processing; NV conducted material collection and reviewed the final text

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Competing interests

No competing interests have been declared.

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INVITED ORIGINAL RESEARCH PAPER

Corylus and *Alnus* pollen concentration in air of Lviv (Western Ukraine)

Nataliya Kalinovych^{1*}, Kateryna Voloshchuk¹, Nataliya Vorobets²

¹ Department of Botany, Biological Faculty, Ivan Franko National University of Lviv, Hrushevskogo 4, Lviv 79005, Ukraine

² Department of Pharmacognosy and Botany, Faculty of Pharmacy, Danylo Halytsky Lviv National Medical University, Pekarska 69, Lviv 79010, Ukraine

* Corresponding author. Email: kalinovychnataliya@gmail.com

Abstract

Corylus and *Alnus* trees are common throughout Western Ukraine. They are important producers of allergenic airborne pollen in the environment of Lviv city. The objective of this study was to examine the dynamics of the *Corylus* and *Alnus* air pollen concentration in Lviv with reference to changes in weather conditions. Pollen data (2011–2015) were obtained by the gravimetric method for a site located at the center of Lviv city. The total annual *Corylus* pollen sums varied from 281 to 724, while the *Alnus* sums were several times more abundant and varied from 656 to 2505. There were 43 days of difference in start dates of the *Corylus* pollen season. The start dates for the *Alnus* pollen season showed a 30-day difference over the 5 years. The season duration differed by 17 days for *Corylus* and 31 days for *Alnus*. There is some evidence of synchronous patterns for *Corylus* and *Alnus* pollen seasons in Lviv. A trend was observed towards earlier starts of seasons that corresponded to a gradual increase in the average February temperature over 2011–2015.

Keywords

climate change; winter pollination; airborne pollen; hazel; alder

Introduction

According to assessment reports of the Intergovernmental Panel on Climate Change, there is a great deal of evidence that global air temperature has changed during the last decades. Climate change leads to various changes in ecosystems, including the functioning of vegetation [1,2]. Among others, an alteration in the timing of plant phenological processes has become clear, in particular in the time of the presence of airborne pollen of anemophilous plant species in the atmosphere. Climate changes may affect the quality and amount of airborne pollen grains. The direct assessment of such an effect requires long observation periods [3]. During a few last decades, aeropalinologists have paid special attention to research on the impact of climate change on pollination features of many plant species which flower at different seasons of the year. The changes recorded involve, above all, the time of pollination, start and end dates of pollen season, the pollen season duration, the peak date of pollen concentration, the total year pollen sum, and pollen productivity. Plant response to temperature change is noticeable in temperate climate zones in which the seasons of the year are clearly differentiated. Temperature changes are especially evident in the cold seasons and plants that flower in winter and early spring are more affected by warming than species flowering later in the year [4]. The features of pollination have been studied in connection with winter and spring warming in recent years [5]. There is strong evidence from various studies that the observed higher temperatures due to climate change are associated with an earlier start of plant flowering in winter and spring [4,6–8].

The beginning of the pollen season has been significantly sensitive to climate change. In some regions, however, a slight trend in the delay in the onset of pollen seasons of some species (for instance *Alnus*) has been recorded, contrary to the general trend found for spring flowering species [7]. A trend towards an earlier start of the pollen season results in earlier peak days in some species [4].

Apart from a shift in the start of flowering, there is also a trend towards higher annual pollen quantities in some species and an increase of the highest daily pollen concentrations [9]. However, there is no evidence of any distinct changes in the end of pollen seasons.

There is evidence that the length of the pollen season shows significant variations. In the warmer years, pollination is shorter than in the years with lower temperature. In general, the trend for the pollen season duration shows a significant decrease [4,6]. Usually, shorter seasons are more intense [8]. But the pollen seasons of some species have become longer and more severe [10]. In some cases, the seasons are also extended to autumn flowering [4].

In most European countries aeropalynological monitoring has been carried out over a long time and allows long airborne pollen data sets to be used to examine the influence of the temperature increase on the time of flowering [3,6,8,11,12]. In Lviv, continuous year-round observation began a few years ago, actually from 2011. Although this timeframe is not quite sufficient to identify significant correlations between climate changes and the features of plant pollination, we yet decided to conduct this comparison for some winter and spring flowering species: *Corylus* spp. and *Alnus* spp.

Hazel (*Corylus avellana* L.) and alder [*Alnus glutinosa* (L.) Gaertn.] trees are common throughout Western Ukraine. It is possible to suggest that they are important producers of airborne pollen in the environment of Lviv city. There are no published papers regarding *Corylus* and *Alnus* pollination for the region of Western Ukraine. This paper aims to examine whether any changes occurred in the pollen seasons of the early flowering trees *Corylus* and *Alnus* in Lviv over 2011–2015 in the context of weather changes.

Material and methods

Lviv is situated in the southwestern part of the East European Plain, approximately 100 km north from the East Carpathian Mountains, Western Ukraine. The average altitude in Lviv is 296 m above the sea level. The climate is mild continental. The potential natural vegetation of the Lviv region can be defined as the deciduous forest community type. There are several large park zones with the remnants of natural vegetation within the city. The environs of Lviv are formed by a mosaic of forests and farmlands.

The pollen-monitoring site was located in the central part of Lviv city (49°50'8" N; 24°1'58" E; Fig. 1). The gravimetric method was used for pollen collection. A special factor was used for calculations to make the data obtained with the gravimetric method comparable to those obtained with the volumetric method [13]. Pollen concentration was expressed as the daily average number of pollen grains in 1 m³ of air (p.g./m³) per 24 h. The beginning and end of the pollen season were determined using the 95% method [14]. To calculate the number of days when the pollen concentrations exceeds the clinically important level, 35 p.g./m³ were considered as the threshold [15].

Meteorological data on daily mean temperature and humidity, average monthly temperature and humidity, monthly sum of precipitation were obtained from the weather archives at the website of the Lviv airport meteorological station [16].



Fig. 1 Location of the pollen monitoring site – Lviv (*).

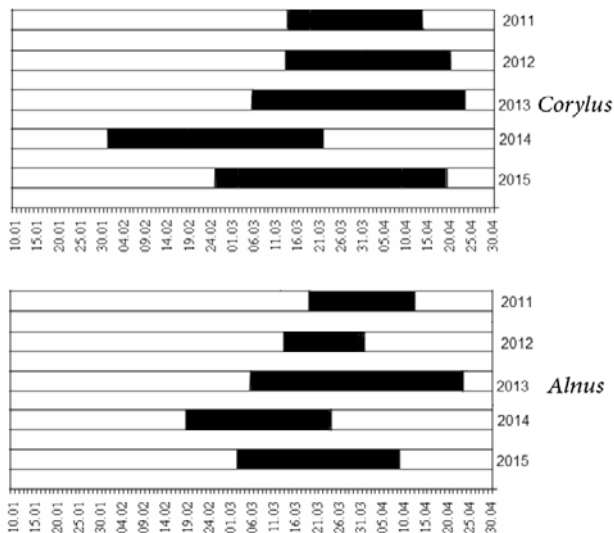


Fig. 2 Duration of *Corylus* and *Alnus* pollen seasons during the years 2011–2015.

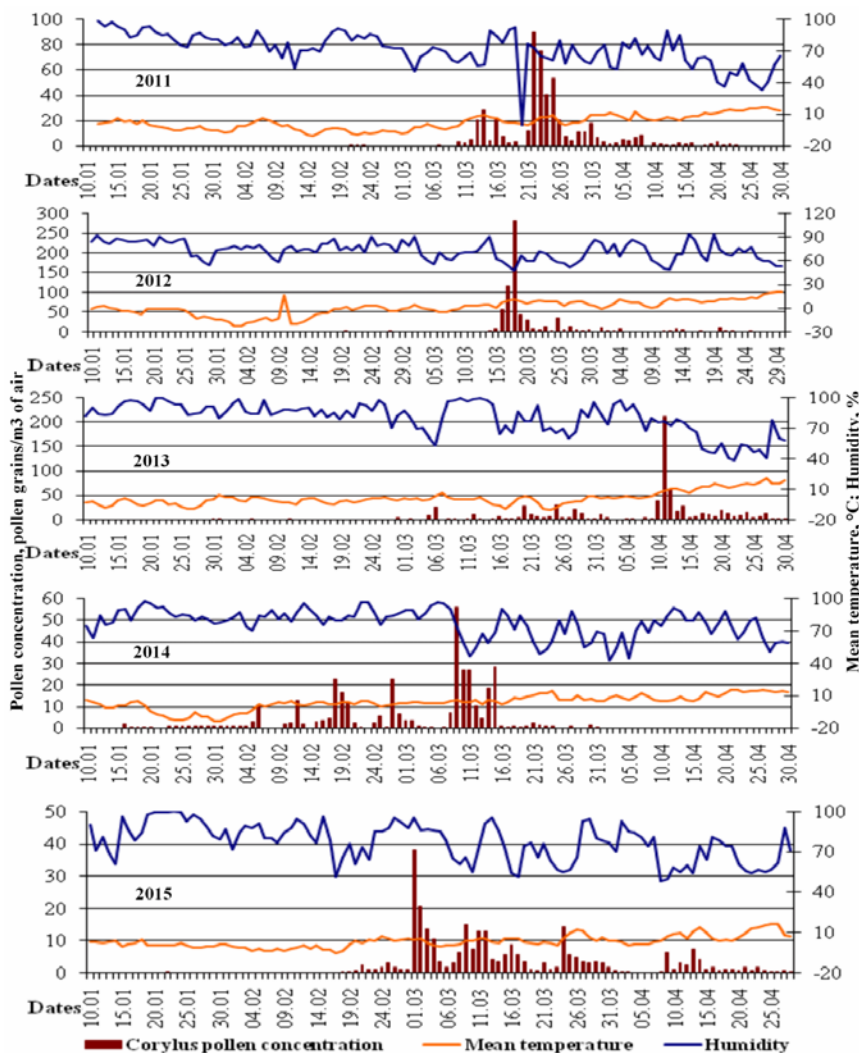


Fig. 3 Dynamics of *Corylus* pollen concentration in relation to temperature and humidity in Lviv in the years 2011–2015.

Results

The first *Corylus* pollen grains appeared in the atmosphere in the Lviv area in the period between the middle of January and the third decade of February. During 2011–2014, these dates were the following: February 21, February 5, January 30, and January 16, respectively. In 2015 the first pollen grains of *Corylus* were recorded on January 22, which was a week later than in 2014, but earlier than in the previous 3 years. *Corylus* pollen seasons, calculated with the 95% method, have demonstrated a similar tendency over the 5-year study period (Fig. 2). The start dates of the pollen seasons in 2011 and 2012 were March 13 and March 15, respectively. In 2013 the *Corylus* pollen season started a week earlier, on March 6. In 2014 the *Corylus* pollen season started more than a month earlier, on February 1. In 2015 it was recorded on February 26, which was 25 days later than in 2014, but earlier than in the previous 3 years. A comparison of these dates with the weather conditions in

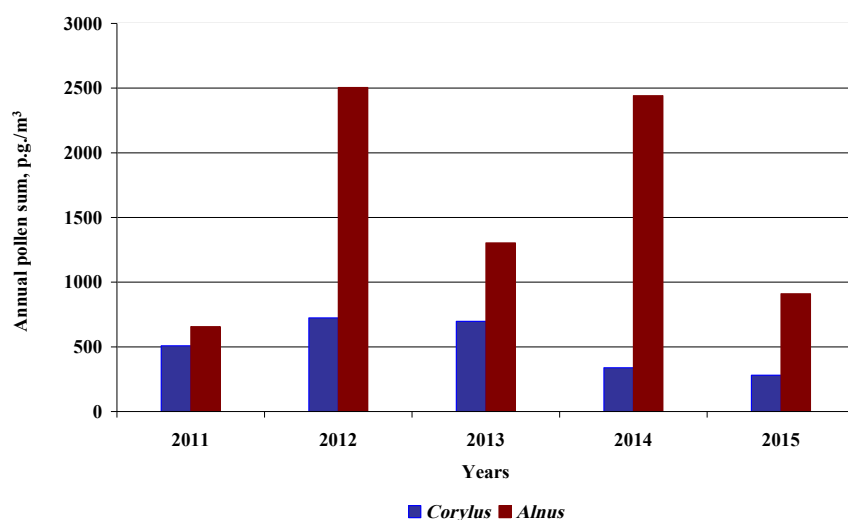
the corresponding years revealed an unexpected phenomenon: the earliest pollen season (2014) started at low temperatures (between -14°C and -7°C ; Fig. 3). There is a visible relationship between the average February temperatures over the 5-year period and the start dates of the hazel pollen (Fig. 2, Tab. 1). Over the period 2012–2015, an increase in average February temperature was observed.

The end dates of the *Corylus* pollen season differed greatly. The earlier start of the season was not always accompanied by an early end. The shortest *Corylus* pollen season was in 2012 and it lasted 36 days. On the other hand, the longest ones were in 2013 and 2015 when they lasted 53 days.

Over 2011–2015, the annual hazel pollen sums varied from 281 in 2015 to 724 in 2012 (Fig. 4). The highest daily hazel pollen concentration was recorded in 2012 and it reached 280 p.g./m^3 (Fig. 3). In 2014 the highest concentration did not exceed 60 p.g./m^3 , while in 2015 it did not exceed 40 p.g./m^3 , which corresponded to a small annual sum. There were 40 days of difference in the time when the maximum *Corylus* pollen concentration occurred over the studied years. The peaks of hazel pollen concentration were observed from March

Tab. 1 Characteristics of weather conditions in Lviv during January–April over 2011–2015.

Weather parameter	Month			
	January	February	March	April
2011				
Average monthly temperature (°C)	−1.6	−4.0	1.8	10.0
Average monthly humidity (%)	86	77	68	60
Monthly sum of precipitation (mm)	82	69	30	73
2012				
Average monthly temperature (°C)	−2.6	−8.8	4.0	9.7
Average monthly humidity (%)	81	77	68	70
Monthly sum of precipitation (mm)	96	87	48	76
2013				
Average monthly temperature (°C)	−3.2	−0.9	−1.5	9.4
Average monthly humidity (%)	86	85	79	67
Monthly sum of precipitation (mm)	112	75	205	66
2014				
Average monthly temperature (°C)	−2.4	0.7	6.3	9.9
Average monthly humidity (%)	86	84	73	71
Monthly sum of precipitation (mm)	86	50	67	77
2015				
Average monthly temperature (°C)	−0.1	0.2	4.2	7.7
Average monthly humidity (%)	86	82	75	67
Monthly sum of precipitation (mm)	63	29	79	57

**Fig. 4** *Corylus* and *Alnus* annual pollen sums over 2011–2015.

1 to April 11. Mostly they were in March, with the exception of 2013 when the maximum *Corylus* pollen concentration was recorded in April.

The number of days with the hazel pollen concentration above the threshold value for inducing allergy symptoms ranged from 1 to 6. Such days were observed mainly in March.

The start dates of *Alnus* pollen seasons changed similarly to the trend found for *Corylus* over the 5-year period of investigation (Fig. 2). Over 2011–2014, the start dates gradually came earlier. In 2015 it was recorded in March, which was 2 weeks later than in 2014, but earlier than in the previous 3 years. Thus, a common trend is observed that the start of the pollen season is shifting closer to the beginning of the year. Over the 5 years, the earliest start (February 19) of the alder pollen season against the highest average February temperature occurred in 2014 (Tab. 1).

The end dates of the *Alnus* pollen season varied greatly. An earlier start of the season was not always accompanied by an early end. The shortest *Alnus* pollen season was recorded in 2012 and it lasted 18 days. The longest one was in 2013 and lasted 49 days.

The annual *Alnus* pollen sums over 2011–2015 varied greatly: from 656 in 2011 to 2505 in 2012 (Fig. 4). In 2011 and 2015 the alder pollen sums were considerably lower than in 2012, but the pollen seasons were longer.

The highest alder pollen concentrations were recorded in 2014 when it reached about 900 p.g./m³ (Fig. 5). In 2012 and 2013 the maximum concentrations were 430 and 260 p.g./m³, respectively, while in 2011 and 2015 they did not exceed 120 p.g./m³. There was a more than 1-month difference in the time when the maximum *Alnus* pollen concentration occurred during the study period. The peaks of the alder pollen concentration were observed from March 9 to April 13. They mainly

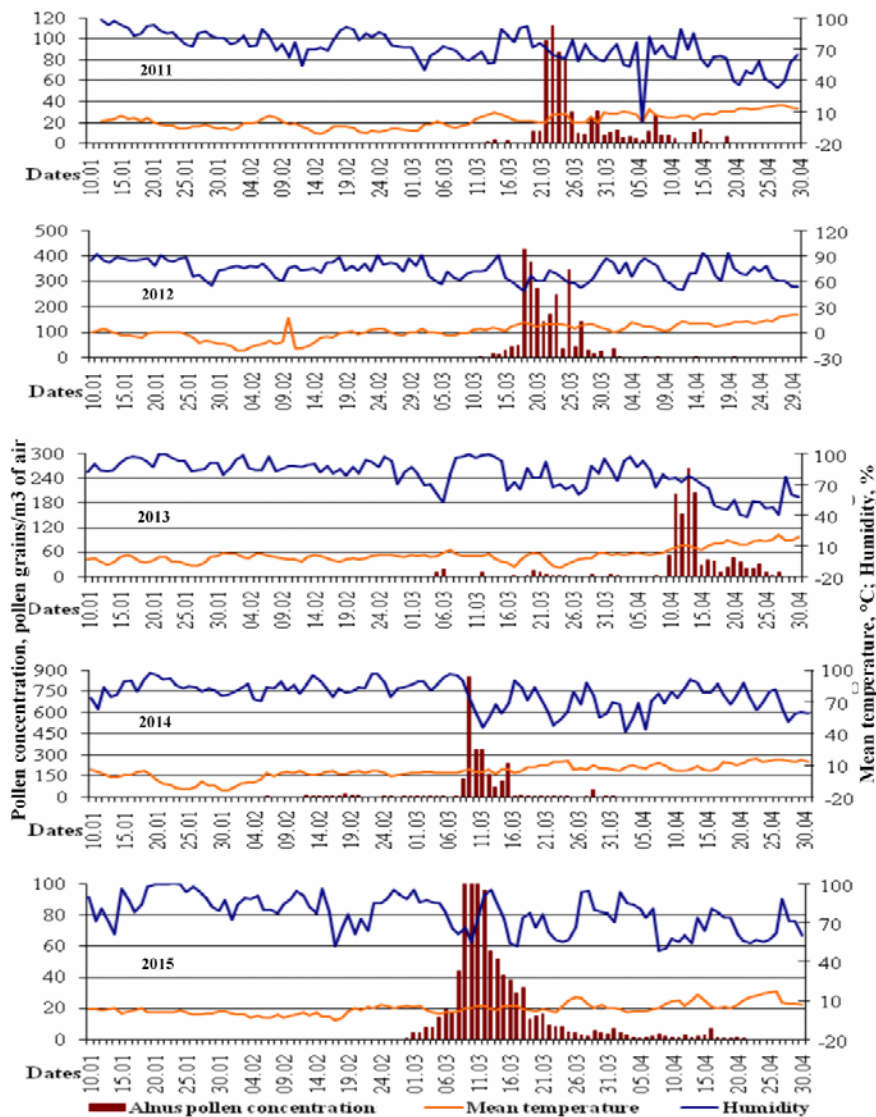


Fig. 5 Dynamics of *Alnus* pollen concentration versus temperature and humidity conditions in the Lviv atmosphere over 2011–2015.

occurred in March, but in 2013, when the maximum *Alnus* pollen concentration was recorded, the peak was in April.

The number of days when the presence of *Alnus* pollen in the atmosphere of Lviv had the clinically important value ranged from 4 to 9. Such days were observed mainly in March.

Because the *Corylus* and *Alnus* pollen seasons overlapped, we estimated the total pollen concentration of these taxa. Thus, within the period of *Corylus* and *Alnus* pollination there were from 8 to 15 days when the total pollen concentration exceeded 35 p.g./m³.

Discussion

In different regions of Europe *Corylus* and *Alnus* start flowering at different times. There is a clearly defined trend of a later start of pollen season in eastward-situated regions [17,18]. The pollen seasons of these two taxa last from late December or early January to late March in Great Britain [8,19] while in Moscow they usually last from March to April [18].

The presence of hazel and alder pollen in the atmosphere of Lviv over 2011–2015 lasted from January to April and occurred almost simultaneously with a slight delay for alder.

The first pollen tend to appear in the Lviv atmosphere closer to the beginning of the year. Although the 5-year period of monitoring is not sufficient for a final conclusion, the additional observation made at the end of 2015 and the beginning of 2016 adds more evidence in support of this opinion. Last winter, *Corylus* flowering and pollination began at the end of December 2015 (own unpublished data).

The *Corylus* and *Alnus* pollen seasons in Lviv lasted from February to April with a trend to come earlier. During the time of our observation, pollen seasons never started in January as it was recorded in Lublin (Poland) [20], which is situated only 1 meridional degree to the west of Lviv.

In 2014 the *Corylus* pollen season started on February 1 at low negative temperature. The review of the wind direction data during the previous 10 days revealed that the winds from the southeast and south had predominated. These winds could have brought pollen from the regions in which hazel pollination had started earlier and could have caused an increased pollen concentration in Lviv. Such a phenomenon is well known in Europe [21–24].

The duration of the *Corylus* pollen season in Lviv varied from 36 to 53 days. In some years, the longer pollen season can be explained by the highest level of the total annual pollen sum, as observed for example in 2013 compared to 2011. But the earlier beginning of the *Corylus* pollen season and its later end in 2013 in comparison with

2012 cannot be explained by the total annual pollen sums because they are similar. Instead, this phenomenon can be explained by the different mean daily temperatures during the *Corylus* pollen seasons: 7°C in 2012 compared to 3.5°C in 2013.

The hazel pollen seasons in 2013 and 2015 were identical in terms of duration and lasted 53 days, despite that the total annual pollen sum in 2015 was twice smaller. The review of the data on mean daily temperature and humidity during the pollen seasons in 2013 and 2015 revealed their close similarity: 3.5°C and 4.7°C, 74% and 73%, respectively. But some differences were recorded in wind speed and direction. During the *Corylus* pollen season in 2013, the number of days when the wind blew from the south was 1.5 times higher than in 2015. It may be concluded that a part of the annual hazel pollen sum recorded in Lviv can originate from long-distance transport from the areas where the vegetation grows earlier. On the other hand, during the *Corylus* pollen season in 2015 the number of calm days was 1.5 times higher than in 2013 and this could have slowed down the pollen release and extended the pollen season.

Usually, the maximum hazel pollen concentration in Lviv was observed in March. 2013 was an exceptional year when the peak concentration of both *Corylus* and *Alnus* pollen was recorded in April. Similar patterns of the *Corylus* and *Alnus* pollen seasons in 2013 were recorded in closely located Ivano-Frankivsk [25]. The negative average monthly temperature (−1.5°C), unusual for March, might have caused this phenomenon. The duration of the *Alnus* pollen season varied from 18 to 49 days. The longest one was in 2013.

Unexpectedly, it was found that the annual alder pollen sum in 2013 was considerably smaller than in 2012 (1300 in relation to 2500) when the pollen season lasted 18 days. The review of the weather conditions at the time of alder pollination revealed that the level of precipitation in 2013 was 10 times higher than in 2012 (242 mm against 23 mm). Such wet conditions could have slowed down the pollen release and made the pollen season longer. The negative average February temperature in 2013 (relative to positive temperatures in the other years) additionally affected this phenomenon.

In 2011 and 2015 the alder pollen sums were considerably lower than in 2012, but the duration of the pollen season was longer. In this case, the higher amount of precipitation (63 mm in 2011 and 100 mm in 2015) could also have extended the *Alnus* pollen season.

In all the years of observation, the duration of *Corylus* pollen seasons was longer than in the case of *Alnus* and in some years it was more than twice longer, despite the fact that the total annual *Alnus* pollen sum was usually much higher than the annual sum of *Corylus*. It was shown that the pollen productivity of *Alnus glutinosa* is twice higher than the pollen productivity of *Corylus avellana* [26]. In our observations, this corresponds with the higher alder pollen maximum which, in some years, exceeded 20 times the hazel pollen maximum.

The weather conditions at the time of *Corylus* and *Alnus* pollination does not affect their pollen productivity because in their case the time of pollen formation is the end of August – beginning of September in the geographical zone of Central Europe [26]. The review of the total annual pollen sums of *Corylus* and *Alnus* versus the weather parameters in Lviv during the months July–August of the year preceding pollination did not reveal any correlation, despite that *Alnus* pollen concentration was assumed to be influenced by meteorological conditions in late summer – early autumn of the previous year [27].

Conclusions

Over 5 years of study, *Corylus* and *Alnus* pollen was present in the air of Lviv city from January to April. But the pollen season, calculated by the 95% method, lasted from February to March or April. In January and February the average monthly temperatures are usually negative. However, over the last 2 years slightly positive temperatures were recorded in February: 0.7°C in 2014 and 0.2°C in 2015. Such weather conditions resulted in the earliest start of the *Corylus* and *Alnus* pollen seasons in 2014 and 2015 during the 5-year study period. Usually, the maximum concentrations of *Corylus*

and *Alnus* pollen in Lviv occur in March when the average monthly temperatures are positive. In case of negative ones, as it was in 2013, the peak of the airborne pollen concentration shifted to April. Within the period of *Corylus* and *Alnus* pollination, 8–15 days were recorded in Lviv when the total pollen concentration exceeded the clinically important level.

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Stężenie pyłku *Corylus* i *Alnus* w powietrzu Lwowa (zachodnia Ukraina)

Streszczenie

Gatunki z rodzaju *Corylus* i *Alnus* występują powszechnie na terenie całej zachodniej Ukrainy. Są one istotnymi producentami alergennego pyłku w powietrzu Lwowa. Celem niniejszej pracy było zbadanie dynamiki stężenia pyłku *Corylus* i *Alnus* w powietrzu Lwowa w odniesieniu do zmian w warunkach pogodowych. Dane dotyczące pyłku (2011–2015) uzyskano za pomocą metody grawimetrycznej z punktu pomiarowego usytuowanego w centrum Lwowa. Ogólna roczna suma pyłku leszczyny wahała się od 281 do 724 ziaren pyłku, podczas gdy sumy pyłku olszy były kilkakrotnie wyższe i wahały się od 656 do 2505 ziaren pyłku. W okresie badawczym stwierdzono różnicę terminu początku sezonu pyłkowego *Corylus* wynoszącą 43 dni. Terminy początku sezonu pyłkowego *Alnus* wykazywały różnicę 30 dni. Różnica w długości sezonu pyłkowego wynosiła 17 dni dla *Corylus* oraz 31 dni w przypadku *Alnus*. Obserwowano synchroniczny przebieg sezonów pyłkowych *Corylus* i *Alnus* we Lwowie. Zaobserwowano tendencję do wcześniejszego początku sezonu pyłkowego, która była zbieżna ze stopniowym wzrostem średniej temperatury lutego w okresie 2011–2015.