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ORIGINAL RESEARCH PAPER

Seasonal changes in plant pollen concentrations over recent years in Vinnytsya, Central Ukraine

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Abstract

The control of plant pollen season patterns is especially important in the expectation of climate change, as the timing of potential varying pollen seasons affects the human population. An ever-increasing number of people suffer from hay fever symptoms with varying severity during the pollen season. This paper presents data on the seasonal variations of pollen concentration and the factors which are the likely causes of these variations in Vinnytsya, a city in Central Ukraine, in order to establish the apparent pattern of this variation and so improve the efficiency of hay fever control in Ukraine.

Pollen counts were obtained by gravimetric and volumetric methods employing a Hirst-type volumetric spore trap.

Alder (*Alnus*) and birch (*Betula*) peaks of pollen release occurred approximately 1 month earlier than was observed at the end of the twentieth century. This was due to the seasonal heat accumulation related to the appropriate temperature regimen registered in January and February prior to the growing season. Other trees – including poplar (*Populus*), maple (*Acer*), walnut (*Juglans*), common hazel (*Corylus*) – did not show distinct changes in pollen season pattern over the past decades.

Mean daily temperature seems to be the leading factor promoting early season onset and a seasonal pollen peak shift of the grass and herb flora such as ragweed (*Ambrosia*). The shift of the ragweed seasonal pollen maximum towards later in the season correlated with higher temperatures during September. Our study has shown that droughts may also significantly decrease the ragweed pollen concentration.

Keywords

airborne pollen; pollen season change; temperature increase; heat accumulation

Introduction

The main plant groups of airborne allergenic pollen producers in Ukraine include both woody and herbaceous species. Airborne tree pollen allergens include birch (*Betula*), alder (*Alnus*), hazelnut (*Corylus*), hornbeam (*Carpinus*), oak (*Quercus*) together with other pollen grain types. Tree pollen is an important allergy causal agent that affects human health as its impact occurs at the beginning of the period of the year when the pollen season starts after the gap caused by winter months in the temperate zone [1].

Grass (Poaceae) pollen is considered to be one of the most important airborne allergens in Europe [2,3], including Ukraine [1], where 334 species of 98 genera of this family are recognized [4,5]. Long-term studies have shown the prevalence of grass pollen allergy in both Ukrainian children and adult patient groups [1,6].

Ragweed (*Ambrosia artemisiifolia* L.) is the weed pollen type causing one of the greatest impacts on human health in Europe and North America [7]. Ukraine is no exception; the presence of this allergenic weed is currently registered in each of the 25 regions of Ukraine. The total area contaminated by ragweed was 31.5 times larger in 2013 than in 1973 (3,523,138 ha versus 107,600 ha, respectively). The east of Ukraine is more contaminated with this weed than the center and the west of the country. The government reports that the largest areas of *A. artemisiifolia* are located in the regions of Donetsk (1,016,796 ha), Zaporizhzya (838,835 ha), Mykolayv (813,406 ha), Kherson (288,764 ha), Kropivnytskiy (276,335 ha), and Dnipropetrovsk (193,722 ha). Ragweed is usually spread from the southern and eastern parts of Ukraine towards the northwest. Seed distribution is facilitated by cars, railway networks, and in sunflower seed contaminated by ragweed when it is transported from the steppe to the forest-steppe zone of Ukraine for planting [8]. Abundant ragweed pollen inventories show Ukraine as one of the most important *Ambrosia* pollen producers on the European subcontinent [9]. It is known that long-distance transport of ragweed pollen can cause patient symptoms [10,11] and this distant transport from the Ukrainian territory to various European countries has recently been reported [12,13]. Therefore, in addition to manage the pollen inventories (which is not always possible to perform), it is also important to control the timing and intensity of the pollen season of local flora in order to reduce the effects on sensitive individuals.

Recent studies have shown that the pollen season of *Ambrosia* in Ukraine has changed [8]. However, a comprehensive analysis of the observed trends has not been previously performed. Tree and grass pollen season patterns may also be modified over time and so there is also a need for their analysis in order to establish the full character and direction of these changes.

The fact that Ukraine is affected by global warming processes is confirmed by data from NASA [14]. It reports that Ukraine is among the territories where the temperatures rose most relative to 1951–1980 averages. The average air temperature over Europe from 2006 to 2015 was ca. 1.5°C warmer than the preindustrial level, which makes it the warmest decade on record [15]. A decrease in average annual precipitation is also recorded in Europe [16]. December 2015, January and February 2016 were noted as the most abnormally warm months in recorded history. The Earth's average temperature is expected to rise in future years [14] and are expected to cause environmental, ecological, and social problems, including the increase threats to human health [17–21].

Global warming influences plant systems, promoting their adaptation to the new weather patterns. Specifically, plants can change their natural distribution patterns and show shifts in the timing of their flowering season to an earlier or later time, or express both of these tendencies [22–25]. Furthermore, it is apparent that during the pollen season an ever-increasing number of people suffer from hay fever symptoms of varying severity [26,27]. A knowledge of the exact timing of the pollen season may help alleviate or even prevent the development of allergic symptoms. It poses a particular challenge to a researcher to accurately predict the onset, peak, and the end of the pollen season under changing environmental conditions [28]. Expectations of weather conditions could help predict likely periods of high pollen production and so give a warning to allergy sufferers and be prompt with preventive treatments.

The aim of our study was therefore to determine the seasonal changes of pollen concentration and the causal factors of these changes over the last 17 years in Vinnytsya, a city in Central Ukraine, in order to establish the direction of these changes and improve the efficiency of hay fever control in Ukraine.

Material and methods

Pollen counts from 1999 to 2000 were obtained by gravimetric sampling using a Durham trap at three monitoring stations in different districts of Vinnytsya City, located

Fig. 1 Image of the Durham trap which was exposed at the monitoring Site 1 (Tab. 1). It is kept now set-up in the Aerobiological Laboratory of VNMU, Ukraine.

in the center of Ukraine in the forest-steppe zone. Durham traps were made in accordance with Erdtman's method [29] from two plexiglass discs 5 mm in width and 22.5 cm in diameter, with 10.5 cm separation between them. A microscope slide was held in place with duralumin holders (Fig. 1).

A section of steel water pipe 1.5-m long was used as the trap stand. Samples were collected from March 1 until October 31 on a daily basis. The slide surface was completely covered with Vaseline as an adhesive, as recommended by Rapiejko [30].

The pollen count for 1999–2000 was performed after the acetolysis following the methodology of Gamal [31]. Pollen samples were treated with a mixture of acetic anhydride and concentrated sulfuric acid in a ratio of 9:1, $(CH_3CO)_2O : H_2SO_4$ (conc). After acetolysis of air samples for 7 min in this mixture, the material obtained was transferred to test-tubes, which were then placed in a water bath at 70°C for 15 min. Following this, the mixture was centrifuged for 5 min at 1,500 rpm. The supernatant was decanted, the residue washed twice with 5 mL of distilled water and then transferred on to microscopic slides.

The total area of the coverslip (3.24 cm^2) was recorded for pollen under a magnification of ×400. The acetolysis was performed at a time when the best reference database for acetolyzed pollen grains and their full morphological description was available in Ukraine [32,33].

Pollen collections from 2009 to 2015 were conducted using volumetric methods employing a Hirst-type volumetric spore trap [34], placed at a height of 25 m above the ground on the roof of a Vinnytsya Medical University building. The maximum distance between the volumetric and gravimetric monitoring sites was 3.9 km, the minimum was 2.37 km (Tab. 1).

Tab. 1 Pollen trap locations, counting and sampling methods used in different years of investigation, Vinnytsya, Central Ukraine.

No.	Location name	Location (lat. °N)	Location (long. °E)	Location altitude above the ground, m	Distance to the Location 4, km	Sampling method	Sampling period	Counting method
1	118 Kelets'ka Str., multistoreyed building	49.23	28.40	27.00	3.32	Gravimetric	1999–2000	Count on 3.24-cm^2 area after pollen acetolysis
2	VSPU*, 32 Ostroz'ky Str.	49.24	28.50	27.00	3.90	Gravimetric	1999–2000	Count on 3.24-cm^2 area after pollen acetolysis
3	Vinnytsya Municipal Hospital No. 3, 138 Maiakovsky Str.	49.21	28.47	18.00	2.37	Gravimetric	1999–2000	Count on 3.24-cm^2 area after pollen acetolysis
4	VNMU*, 56 Pirogov Str.	49.23	28.44	25.00	0.00	Volumetric	2009–2015	2009–2011 – longitudinal, 2012–2015 – vertical transects

* VSPU – Vinnytsya State Pedagogical University; VNMU – Vinnytsya National Medical University.

Samples were collected with the Hirst-type volumetric spore trap from March 1 until October 31 on daily basis. Melinex tape with a gelatin-based adhesive was used as a sampling surface. Specimens were stained with basic fuchsin after exposure. Pollen counts were performed by the three horizontal transects method from 2009–2011, and by the 12 vertical transects method from 2012 to 2015. Appropriate correction factors were applied [35] to determine the mean daily pollen concentrations. Two hundred and fifty-two specimens (corresponding to the number of sampling days) were prepared from the Melinex tape exposed each year of the volumetric sampling. These samples were analyzed with a light microscope at magnifications of ×400 (×1,000 in some cases) to improve pollen recognition.

Data for the genera *Alnus*, *Alnus*, *Acer*, *Ambrosia*, *Betula*, *Corylus*, *Carpinus*, *Juglans*, *Populus*, *Pinus*, *Quercus*, *Ulmus*, and for Poaceae were used for the further analysis. The mean daily pollen concentration data were used for analyses of the airborne pollen spectrum from 2009–2015. Average pollen quantity/cm^2 for the three sites was used for 1999–2000.

In order to establish the relationships between the timing of the pollen seasons and weather parameters which might be associated with pollen production patterns, descriptive data analysis was made using Excel and Matlab software. The standard seasonal threshold method was employed to establish the onset, peak, and end of the pollen season, defined as 2.5% (onset) and 97.2% (end) of the total sum of pollen collected for individual species [36]. Meteorological data for daily mean temperature and precipitation were obtained from the TuTiempo resource at http://en.tutiempo.net/climate.

Results

The *Alnus* pollen maximum in the ambient air of Vinnytsya, Ukraine, in 1999–2000 was recorded in the second 2 weeks of April. However, pollen monitoring was re-established in Vinnytsya in 2009 and revealed that *Alnus* peaks now occur mostly at the end of March (2010–2012 and 2014), or in the middle of it (2015). Years 2009 and 2013 were characterized by the poorest alder pollen season and the peaks recorded at the time were "natural" for *Alnus*, i.e., the middle of April. However, sunny and warm weather in 2015 promoted an unusually early alder peak; the season started at the beginning of March as usual but ended on March 23 with the peak recorded on March 13. This was a month earlier than in 1999–2000, 2009, and 2013 (Fig. 2).

It was established that *Alnus* pollen season patterns are determined by the temperatures in January and February and heat accumulation before the onset of the season. The average sum of daily temperature accumulated from January 1 and/or from February 1, 2015 was the highest in all the years of observation (Tab. S1). This factor may affect an early flowering and peaking of the *Alnus* pollen.

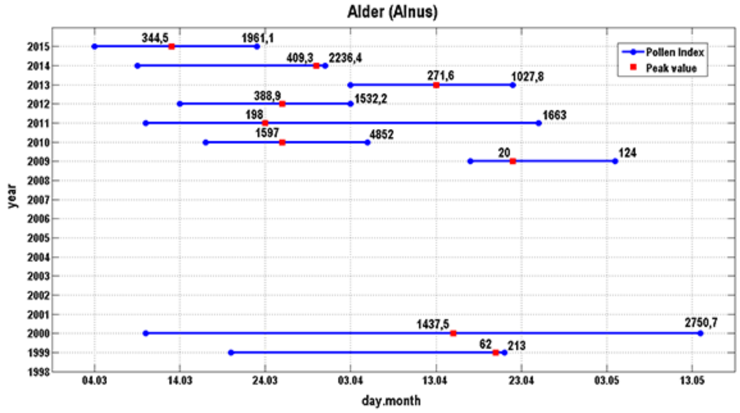

Fig. 2 *Alnus* pollen season characteristics, Vinnytsya, Ukraine, 1999–2000 and 2009–2015 (pollen grains/cm^2 of the slide surface for the years 1999–2000; pollen grains/m^3 for the years 2009–2015).

The analysis revealed a distinct biennial rhythm for the intensity of *Betula* pollen production. Thus, in 2000 we collected 25 times more *Betula* pollen than in 1999. Volumetric methods also showed increased amounts of pollen for every even year, whereas 2009, 2011, 2013, and 2015 were characterized by low pollen production by *Betula*. The amount of this pollen type collected in 2010 was 19.2 times higher than in 2009, and in 2012 it was 7.3 times higher than in 2011. The two subsequent years followed the pattern with a higher abundance of pollen recorded in 2014 than in 2013. Pollen peaks recorded for the even years included 1,450 and 1,681 pollen grains/m^3 for 2010 and 2012, respectively (Fig. 3).

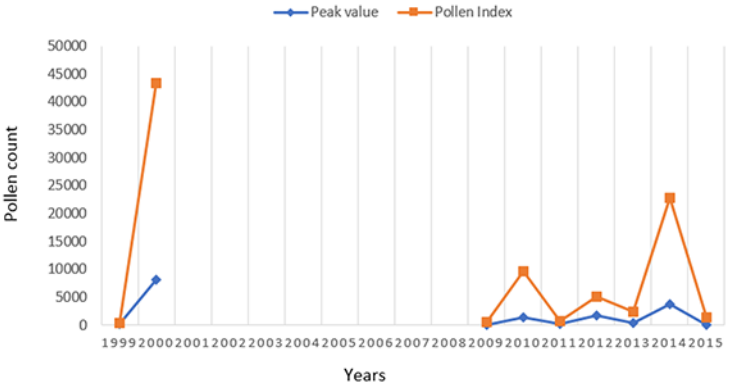

Fig. 3 *Betula* pollen index and peak value fluctuations in 1999–2000 and 2009–2015, Vinnytsya, Ukraine.

The *Betula* pollen season onset, peak, and end occurred within the same periods for the years 2009–2015 with 2014 being a marked exception (Fig. 4). Thus, in 2009–2012 the *Betula* peaks occurred on the same date, namely April 21. The peak days for the years 2015 and 2013 were similarly recorded on April 20 and April 18, respectively. However, an unusually early *Betula* peak was seen in 2014. It occurred on April 2.

The temperature conditions at the beginning of the pollen season were analyzed to establish the weather impact on the pollen season patterns. The analysis of the changes in seasonal temperature patterns showed a twofold average daily temperature sum increase seen for the years 2009–2015 in comparison with 1999 and 2000.

The average daily temperature summed from March 1 to October 31 during 1999 and 2000 was 1494.5°C and 1378.0°C, respectively, whereas in the successive sampling period, this varied between 3151.0°C in the "warmest" year (2012) to 3607.4°C in the "coldest" year (2010). The mean temperature in February did not correspond with flowering intensity; both relatively high and low temperatures were recorded in years with intense pollen production (Tab. S1).

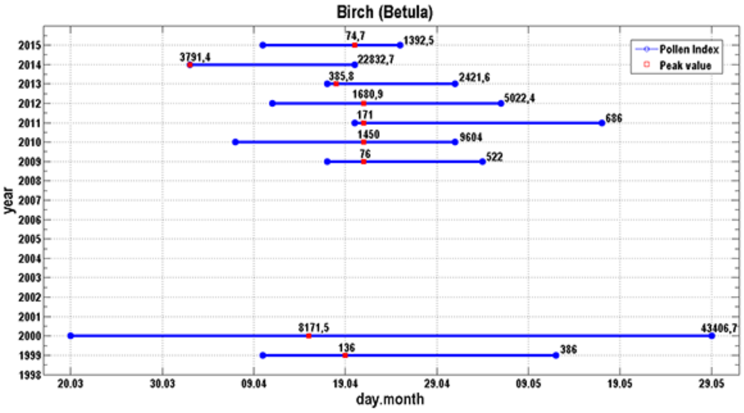

Fig. 4 *Betula* pollen season characteristics, Vinnytsya, Ukraine, 1999–2000, 2009–2015.

No clear correlation was seen between the average daily temperatures in June, when the buds of *Betula* develop, and pollen season intensity in the following year. June of 1999 was characterized by the highest mean temperature seen in the whole dataset and the pollen season of 2000 was very abundant. However, the season of 2010 characterized by abundant pollen production, was preceded in 2009 by a June with one of the lowest mean temperatures recorded for this month. In addition, the second highest mean temperature of June 2012 did not promote the high *Betula* pollen index in 2013, which was the third lowest in the dataset.

June rainfall, in combination with the temperature, did not show a clear correlation with the *Betula* pollen season intensity; the active pollen production of 2000 was preceded by the driest, albeit warm, June in the dataset (Tab. S1). However, both warm and relatively wet weather in 2010 did not promote an active *Betula* pollen season in 2011 (Fig. 4).

An unusually high degree-days factor above a 3.5°C threshold was recorded in March 2014. It fluctuated from 14.8°C to 45.1°C in every season of the observations except in 2014 when the summed degree days of March gave a value of only 87.7°C.

A similar pollen season pattern with an early peaking was also seen for *Carpinus*, *Corylus*, *Fraxinus*, and *Ulmus* in 2014.

Late flowering trees such as *Pinus*, *Quercus*, and *Juglans* did not show any clear evidence of an impact of the temperature increase on the onset, peak and end of their pollen seasons (Fig. S1–Fig. S7).

Changes in the season of grass pollen release were more clearly defined. The Poaceae demonstrated a tendency in the most recent years for an early start and end of the season, in comparison with 1999 and 2000. Poaceae pollen concentration for August was very low in the last years of the observation. Conversely, this pollen concentration was recorded at its peak in August of 1999 and 2000. An intense grass pollen season started at the beginning of June, and its first wave finished at the end of this month in the years 1999 and 2000 (Fig. 5). This was 2 weeks later and 2 weeks earlier, respectively, than that seen at present. August was the second period of an intense grass pollen production in 1999–2000. In 2009–2015, the most active grass pollen season started in mid-May and ended in mid-July. Furthermore, the period of Poaceae pollen production is now more intense and shorter in current years, although not in August. On the other hand, the onset of the Poaceae season is now recorded at the beginning of May, whereas it was seen in mid-May in the years 1999 and 2000.

The intensity of the *Ambrosia* pollen season showed some variations from 1999 to 2009 but has a similar timing. The greatest ragweed pollen concentration is seen from the beginning of August until the beginning or middle of September (Fig. 6).

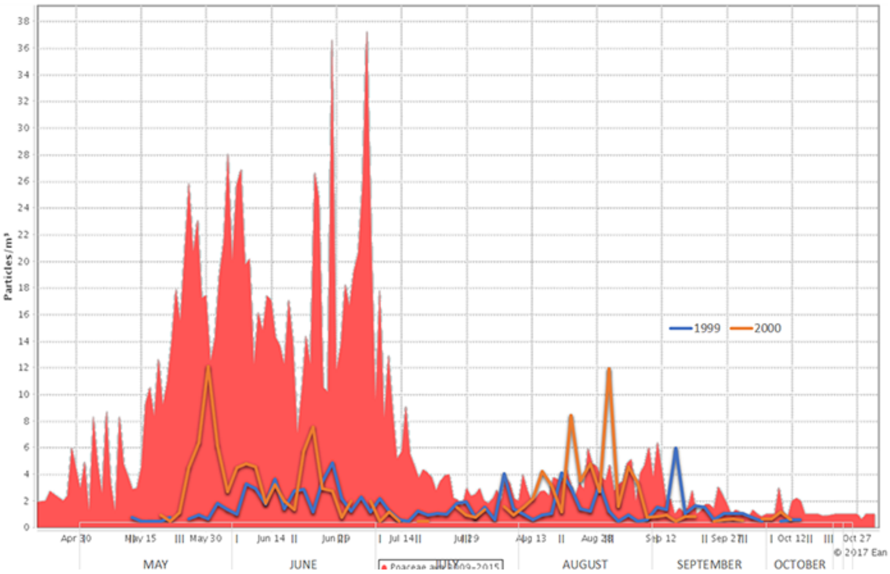

Fig. 5 The progress of the grass pollen season in the years 2009–2015 (shadowed area) in comparison to the years 1999–2000 (curves).

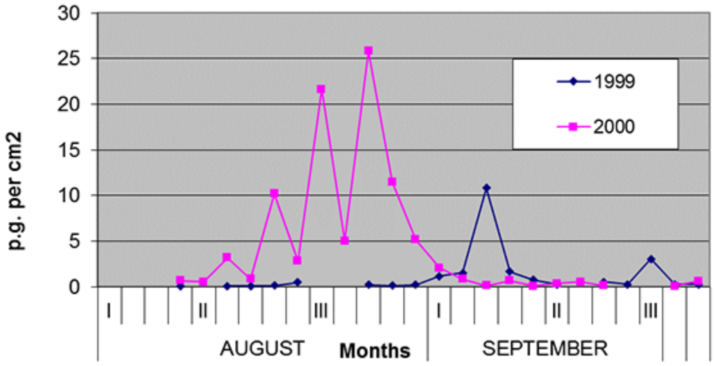

Fig. 6 *Ambrosia* pollen seasons in Vinnytsya, years 1999–2000.

The most intense period of *Ambrosia* pollen was registered at the end of August and a week or two later in early or mid-September in the years 1999, 2000, 2009, 2011, 2012 and in 2014 (Fig. 7).

The first increase in pollen concentration usually occurred at the end of August, corresponding to the seasonal peak. The highest ragweed activity was seen from August 22 until August 29 for different years. The earliest increase of pollen concentration in fall was registered on September 5, 1999 (Fig. 6); the latest on September 18, 2012. However, the years 2010 and 2013–2015 were characterized by unusual patterns of peak timing. A rapid rise in the ragweed pollen concentration was seen at the beginning or in the middle of August, 2 or more weeks earlier than usual. For example, the value of this unusual peak on August 13, 2010 exceeded the other high pollen concentration values recorded the ragweed period on August 27, 2010 (102 pollen grains/m^3 cf. 76 pollen grains/m^3), but was lower than that seen on September 15, 2010 (83 pollen grains/m^3). The year 2013 was characterized by a significant rise in the pollen concentration on August 11, but the annual pollen peak was observed on August 27, 2013. Conversely, ragweed pollen concentrations were not significant in September of 2013.

The earliest registered increase in the pollen concentration occurred on August 6 2014. However, it was much lower than the seasonal peak recorded on August 29. The next notable increase in pollen concentration occurred on September 11.

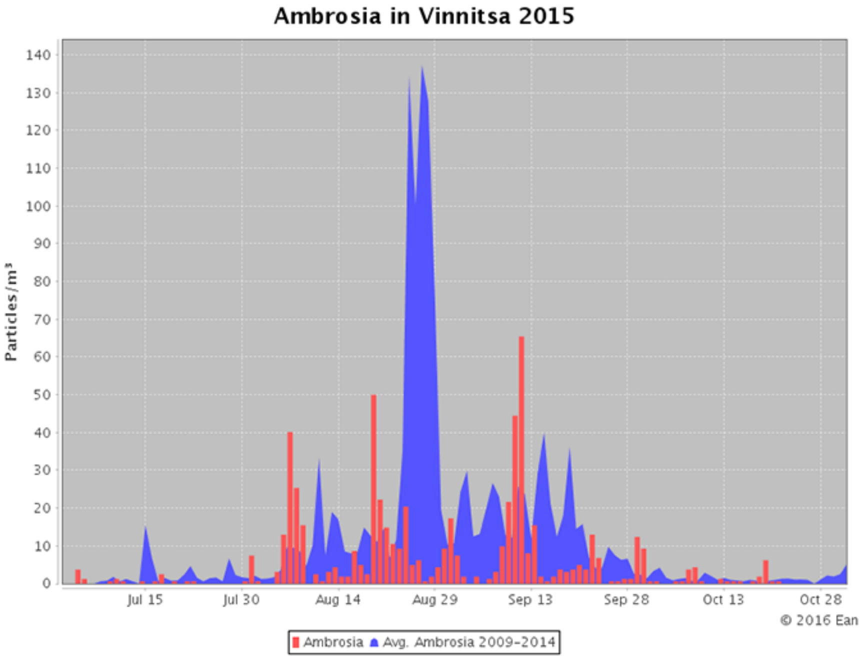

Fig. 7 *Ambrosia* pollen season, Vinnytsya in 2015 in comparison to the years 2009–2014.

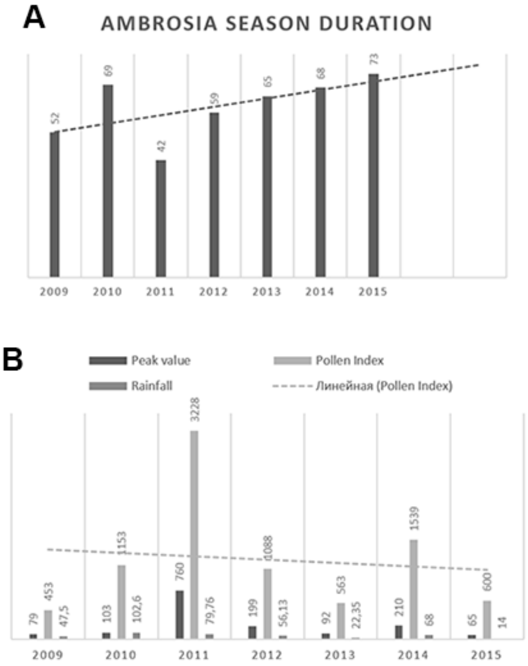

Fig. 8 *Ambrosia* season duration and its linear trend (**A**) and other season parameters with the linear trend for pollen index (**B**).

All three periods of pollen concentration increase were especially obvious in the year 2015, when *Ambrosia* pollen concentration raised 3 times during the season on August 6, August 19, and September 11, being low or very low between these dates. Droughts in June 2015 (Tab. S1) and some decline in the trend of the annual pollen index were seen during 2009–2015 for ragweed (Fig. 8B).

Rainfall also controls the intensity of the pollen season; the pollen concentration was highly dependent on rainfall in July when the active ragweed vegetation is seen. The total pollen concentration was lower in the years when the total rainfall was <50 mm per month (Fig. 8B).

Discussion

Several studies have been reported in recent years stating that the pollen season onset and peak occur earlier for different species due to an increase in global temperatures [17,26,37–40]. The general tendency to increase the pollen index, peak value, and season duration for different taxa has been shown by numerous studies [17,41,42]. These tendencies are apparent in different combinations for birch, alder, grass, and ragweed pollen seasons in Vinnytsya. However, no clear correlation was seen between the temperatures in June, when birch buds develop, and birch pollen season intensity during the season in the following year, as was reported by Grewling et al. [43]. No or little influence of the mean temperature in the preceding year on the annual *Betula* pollen sum was also found by Nowosad [44]. This author reported that a certain temperature accumulative threshold is needed for an increase in tree pollen concentration. This suggestion on the impact of heat accumulation on the pollen season [44,45] is supported by our present research. For example, the birch season onset is considered to coincide with an accumulation of about 70°C degree-days above a 3.5°C threshold [45]. Our findings do not support this hypothesis. There were no exact values of accumulated heat sum corresponding to either the birch season onset or peak. The speed of heat accumulation was the most important factor promoting the season onset and peak. Specifically, the rapid active heat accumulation may explain the early flowering and peaking of *Betula* in 2014 (Tab. S1). This effect is very similar to that described in Denmark where growing degree hours were determined as a factor, which can explain the earlier start of the birch season [46], and in Spain where growing degree days were used to predict the onset of the *Quercus* pollen season [47]. A thermal model has also been used to predict the *Olea* season in Spain [48]. An early *Betula* peak occurring on April 2, 2014 correlated well with data about patient symptoms recorded around that date [1].

Our findings presented here might be associated with a twofold increase in the average daily temperature sum seen in Vinnytsya for the most recent period in comparison to the years 1999 and 2000. In contrast, our results correspond to the findings of Polish scientists showing birch has a biennial biological rhythm, with the more abundant pollen season every second year [43]. The same tendency for a biennial rhythm was not found for *Alnus* in Ukrainian or in Polish and British studies [49].

Our results are similar to the findings of other authors discussed for *Alnus* [50,51]. They indicate that the temperatures in January and February can regulate the timing of the alder season onset, and its flowering can be taken as a useful marker of plant responses to weather conditions [25]. A temperature decrease in February followed by an increase in March has been shown by other workers to be an indicator of an early pollen season onset of *Alnus*, *Corylus*, and *Betula* [52,53]. Our findings suggest that these trees are more sensitive to changes in weather patterns than later-blooming genera.

The mean daily temperature increase seems to be the primary factor promoting early season onset and seasonal pollen peak shift for the herbaceous flora such as grasses, which agrees with the findings of García-Mozo et al. [47]. Intensive eradication of *Ambrosia* in the Vinnytsya region in the summer of 2012 led to a significant decrease

(4–5-fold, in comparison to 2011) of pollen concentration of this type in the ambient air of the city. The eradication measures to prevent seasonal allergy symptoms included cutting *Ambrosia* plants before the flowering season. Furthermore, in Ukraine a fine is imposed on households and farms for ragweed plants found on their property. Control of the ragweed area also includes the checking of sunflower seeds for contamination with those of ragweed before planting [54]. However, as we indicate, not only preventive measures affect the intensity of ragweed flowering. An increase in the intensity of the *Ambrosia* pollen season has been shown in Spain [55], but in Ukraine a tendency was found for a decrease in the annual ragweed pollen index. This effect is unlikely to be caused by certain preventive measures, which are rather limited at present due to the difficult current economic situation in Ukraine. Thus, both the ragweed low seasonal peak and low pollen index can be explained in 2015 by droughts in June 2015, which preceded the ragweed pollen season (Tab. S1). In contrast, the duration of the *Ambrosia* pollen season is tending to increase, which agrees with the findings of other authors (e.g., [41]). Its expansion to northern areas, as it is seen in Ukraine, is peculiar for Europe [56] and North America. The increased length of the *Ambrosia* pollen season due to warming by latitude is also seen in these subcontinents [41].

The changing pattern of the timing of the ragweed pollen season has been observed in Vinnytsya over the last 4 years. The photoperiodic requirement of this plant is considered to be the main factor for ragweed pollen formation [57,58]. *Ambrosia* is a short-day plant and its flowering starts when the day length decreases to 14.5 hours [9]. Natural peaking based upon photoperiodic requirements occurred in Vinnytsya at the end of August, and it was clearly predictable in our city until the year 2010 when the increased temperatures caused the peak timing to move forward by 2 weeks. The *Ambrosia* seasonal patterns have been found likely to be weather-independent in Croatia [42]. Here, the seasonal peak was recorded on August 27, at the same time as in Ukraine, where it was probably caused by the photoperiodism of ragweed plants. In contrast, 2012 and 2015 were years with the *Ambrosia* seasonal maximum recorded in September in Vinnytsya, which might relate to global warming processes. Year 2010 was the first year of observation when an extreme heat wave was recorded in Europe. The next were seen in 2014 and in 2015 [15], promoting the appearance of the temperature-dependent ragweed season pattern in Ukraine; it can be described as a “three-maximum” season. Spikes in pollen concentration at the beginning and then at the end of August and in September characterize this. The shift of the last pollen maximum towards the later period may be attributed to increased temperatures. The data presented in this paper are important for accurate tree and grass pollen allergy forecasting and control of the ragweed season. This suggestion is in agreement with recent studies which support the possibility of using past pollen count data from monitoring sites for predicting particular days with high pollen concentrations [44].

Further studies on the factors and their combinations which impact on the pollen season are clearly needed in order to accurately predict the direction of the seasonal changes and to help reduce exposure for hay fever sufferers.

Conclusions

A general tendency of the *Alnus* pollen season to shift to an earlier period has been observed in Vinnytsya in recent years. Currently, the seasonal peak values for *Alnus* can be recorded 1 month earlier than in the years 1999–2000, which can impact sensitive individuals and promote an early development of hay fever symptoms. An early observed *Betula* peak might relate to the rapid degree-day sum accumulation during March preceding the pollen season. The *Betula* seasonal maximum was observed around 20 days earlier in comparison to the regular peak timing for trees of this genus. A clear biennial pattern was observed for *Betula* with intense pollen production in every even year, whereas odd years were characterized by a relatively weak season demonstrating no discernible correlation with the weather conditions. The period of the most active grass pollen season has shifted to approximately 1 month earlier and is seen in May in June in contrast to August in the years 1999–2000. Appearance of the temperature-dependent ragweed season pattern was also found in Ukraine. It can be described as a “three-maximum” season. Spikes in pollen concentration at the beginning and end of August and in September characterize it, corresponding to the established trend of the lengthening of the *Ambrosia* season. An increase in pollen season intensity for September was also noted. It was demonstrated that droughts can cause a decrease in *Ambrosia* pollen concentration as opposed to the lengthening of the season in the recent years. The change in average air temperature was found to be a major factor promoting the alteration of tree and grass pollen seasons. A combination of both increasing temperature and decreasing humidity was found to be important for *Ambrosia*. Further studies of the changes in plant seasonal patterns are required to provide the data necessary to adequately control the severity of hay fever symptoms in the population.

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Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/aa/rt/suppFiles/aa.1731/0:

Fig. S1	Pollen season for *Corylus*.
Fig. S2	Pollen season for *Ulmus*.
Fig. S3	Pollen season for *Juglans*.
Fig. S4	Pollen season for *Quercus*.
Fig. S5	Pollen season of *Acer*.
Fig. S6	Pollen season of *Pinus*.
Fig. S7	Pollen season for *Populus*.
Tab. S1	Weather parameters that may affect the tree pollen season in Vinnytsya, Ukraine.

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Sezonowe zmiany zawartości pyłku roślin w areoplanktonie Winnicy (Ukraina Centralna). Badania wieloletnie

Streszczenie

Monitoring sezonów pyłkowych jest szczególnie ważny w związku ze zmianami klimatu, ponieważ czas występowania tych sezonów ma wpływ na kondycję zdrowotną ludzi. W sezonie pylenia coraz większa część populacji na objawy kataru siennego o różnym nasileniu. W artykule przedstawiono dane na temat sezonowych zmian stężenia pyłku i czynników, które są prawdopodobnymi przyczynami tych zmian w Winnicy (Centralna Ukraina), w celu opracowania wzorca, który poprawiłby skuteczność kontroli występowania sezonów pyłkowych i zapadalności na katar sienny u osób wrażliwych.

Monitoring pyłkowy był prowadzony metodą grawimetryczną i wolumetryczną (pułapka typu Hirst).

Najwyższe stężenia pyłku olchy (*Alnus*) i brzozy (*Betula*) zaobserwowano około miesiąca wcześniej niż było to notowane pod koniec XX wieku. Wynikało to z sezonowej akumulacji ciepła związanej ze wzrostem temperatury powietrza rejestrowanym w styczniu i lutym przed sezonem wegetacyjnym. Inne drzewa – w tym topola (*Populus*), klon (*Acer*), orzech (*Juglans*), leszczyna (*Corylus*) – nie wykazały wyraźnych zmian w przebiegu sezonu pyłkowego w ciągu ostatnich dziesięcioleci.

Średnia temperatura powietrza wydaje się być wiodącym czynnikiem promującym początek wczesnej pory roku i sezonowe przesunięcie intensywnego pylenia traw i roślin zielnych, takich jak ambrozja (*Ambrosia*). Opóźnienie okresu maksymalnego stężenia pyłku ambrozji korelowało z wyższymi temperaturami powietrza we wrześniu. Badania wykazały, że deficyt opadów może znacznie zmniejszyć stężenie pyłku ambrozji.