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Analysis of high allergenicity airborne pollen dispersion: common ragweed study case in Lithuania

Ingrida Šaulienė, Laura Veriankaitė

Department of Environmental Research, Šiauliai University, Šiauliai, Lithuania

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Abstract

The appearance of ragweed pollen in the air became more frequent in northerly countries. Attention of allergologists and aerobiologists in these countries is focused on the phenomenon that *Ambrosia* plants found relatively sporadic but the amount of pollen is high in particular days. Over the latter decade, a matter of particular concern has been *Ambrosia* pollen, whose appearance in the air is determined by the plants dispersing it and meteorological processes that alter pollen release, dissemination, transport or deposition on surfaces. Pollen data used in this study were collected in three pollen-trapping sites in Lithuania. The data corresponding to 2006-2011 years of pollen monitoring were documented graphically and evaluated statistically. Analysis of the pollen data suggests that although the number of ragweed plants identified has not increased over the latter decade, the total pollen count has been on the increase during the recent period. The highest atmospheric pollen load is established on the last days of August and first days of September. The estimated effect of meteorological parameters on pollen dispersal in the air showed that in Lithuania ragweed pollen is recorded when the relative air humidity is about 70%, and the minimal air temperature is not less than 12°C. Analysis of wind change effect on pollen count indicates that pollen is most often recorded in the air when the changes in wind speed are low (1-2 m/s). We have established a regularity exhibiting an increase in ragweed pollen count conditioned by south-eastern winds in Lithuania.

Key words

pollen, allergy risk, *Ambrosia*, meteorological variables

INTRODUCTION

Allergies caused by pollen of anemophylous plants have become the centre of attention of clinicians and environmentalists. Over the last decade, allergenic ragweed pollen has been a major concern. One ragweed plant produces more than 108 pollen grains [1], and a few pollen grains is enough to sensitize people [2]. It has been reported that 1-3 pollen grains/m^3 of air can cause allergic symptoms in people who have been sensitised before [3], while 10-20 pollen grains/m^3 nearly always cause allergic symptoms in sensitised patients [4]. For instance, in Switzerland more than 10 ragweed pollen/m^3 of air is considered a high pollen load [5]. The pollen is recorded even in the countries with very few or no ragweed plants at all [6, 7, 8].

The society in urbanized territories is more sensitive to pollen impact due to pollution particles stick to pollen [9]. Thus, chemical and biological air pollution acting together pose new challenges for environment quality strategy shaping and control. The contemporary air pollution modelling, forecasting and prevention is becoming a worldwide issue not confined to a single country [10]. In rural areas, ragweed is a weed of cultivated crops, which is intensively spreading from Southern to Northern Europe. The universal sustainable development idea prompts expansion of organic farms; however, reduced herbicide use in agriculture results in the naturalization of new weed species, which in turn deteriorates yield quality [11, 12].

Appearance of pollen in the air is determined by the plants releasing it and by the meteorological processes, which influence pollen release, dispersal, transport or deposition on surfaces [13, 14]. Assessment of pollen distribution often considers a whole complex of meteorological indicators or the key ones determining the variation of pollen count in the air. Air temperature is often distinguished as a major factor affecting pollen concentration in the air and pollen season. However, meteorological factors such as wind speed, relative air humidity, rainfall are also of relevance. The effect of meteorological elements on pollen dispersal is also dependent on the geographical position of the location [14].

The current study was designed to ascertain the impact of meteorological parameters for common ragweed pollen dispersal in Lithuania. The research findings might be of great benefit in modelling, forecasting and prevention of allergy in the territory under study as well as in other countries.

MATERIALS AND METHODS

Lithuania is a country situated on the eastern coast of the Baltic Sea. Its population is 3.3 million, of which 0.5 million reside in the capital Vilnius. The country's territory is 65.300 km^2, of which plains account for 75%. Lithuania's territory is situated at the junction of boreal coniferous and broad-leaved forest zones.

Lithuania is in the northern part of temperate climate zone, the warmest month is July and the coldest month is January.

Address for correspondence: Ingrida Sauliene, Department of Environmental Research, Siauliai University, Visinskis street 19, Siauliai, 77156, Lithuania.
E-mail: oikos@fm.su.lt

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According to the climate norm, the mean air temperature is 16.7 °C and -5.1°C [15]. Lithuania is a country of weak and moderate winds (average annual wind speed 3-6 m/s). Transport of western air masses is prevalent all year round. Wind roses prevailing in Lithuania during ragweed flowering period (August, September) are presented in Fig. 1.

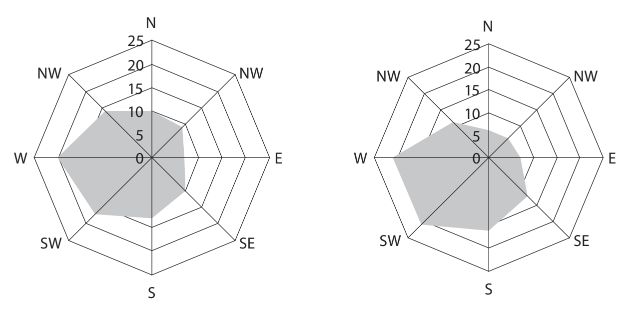

Figure 1. Wind rose of August (on the left) and September (on the right) in Lithuania during the 1961-1990 period [15]

The annual course of relative air humidity in Lithuania is inversely proportional to the course of air temperature. Humidity minimum occurs in May, and its territorial distribution within a year practically does not change: it is higher in the western part and lower in the eastern part. According to the amount of precipitation, Lithuania's territory lies in the excess irrigation zone, i.e. more precipitation falls than can be evaporated. The average annual precipitation rate is 675 mm [15]. In Lithuania's territory, moving from the west towards the east climate's continentality increases: annual and daily temperature amplitudes increase, winters become more severe, snow layer persists longer, and air humidity goes down.

Pollen counts were monitored during the period from 2006 to 2011. Aerobiological stations of Lithuania are located in Vilnius (south- eastern part of the country), Siauliai (northern part of Lithuania) and Klaipeda (in the west, the coastal zone). The pollen traps are mounted at the height of 18-20 m above the ground and equipped with a Hirst-type continuous volumetric pollen sampler, a 7-day recording version. The trapping area consists of various herbaceous plants with *Tilia* trees predominating in Vilnius and Siauliai. The station in Klaipeda is near a large forested region with *Pinus* as dominant trees. Air throughput of samplers is 10 litres per min. Equipment wind vane is always pointed to the wind direction. Particles are impacted on adhesive-coated transparent plastic tape supported on a clockwork-driven drum. Every week the tape was removed and cut into segments corresponding to seven days of the week. The average daily pollen concentration was assessed by scanning the slide area under the microscope. Results are presented as the number of pollen per 1 m^3 of sampled air averaged over 24 hours (pollen grains/m^3). The diurnal variation of pollen count is presented using the UTC time.

To estimate the effects of meteorological parameters, the pollen was grouped according to the lowest allergenicity level. Considering the fact that the lowest threshold level causing sensitization is 1-3 ragweed pollen grains in the air [3], we chose 4 pollen grains as a starting point. The cases were divided into two groups: ≥1 pollen and ≥4 pollen. Correlation coefficient among airborne pollen count and air temperature and relative air humidity was calculated for each group of the cases. The relationship between pollen dispersal and meteorological conditions was studied using meteorological data (mean, minimum and maximum air temperature, relative air humidity, wind speed and direction) for the period 2006–2011, provided by the Lithuanian Hydrometeorological Service.

The data corresponding to 6 years (2006-2011) of pollen monitoring were documented graphically and evaluated statistically. Correlation coefficients of meteorological parameters and pollen concentrations were calculated using the Spearman rank correlation method.

RESULTS AND DISCUSSION

Ragweed, which is native to North America, is accidentally introduced in new territories or is transported with various agricultural produce [1, 16]. Control of ragweed distribution in Europe is a major challenge in seeking to ensure environmental quality both in rural and urban territories. Ragweed ousts native plant species and the allergens present in its pollen get into respiratory tract with inhaled air [17-19]. In Lithuania, ragweed is still very rare [8], however, its pollen in the air is recorded annually. During the test period, the highest ragweed counts were recorded in 2008, 2010 and 2011 (Fig. 2).

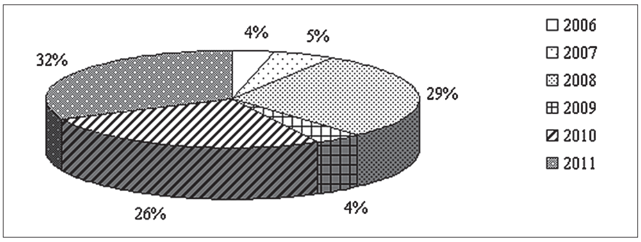

Figure 2. Ragweed pollen concentration in Lithuania in separate years

Given the fact that ragweed is not abundant in Lithuania, it can be assumed that pollen detected in the atmospheric bioareosol is transported with air masses [7, 20, 21] from the territories where the concentration of this plant (as well as pollen) is high. Management and control of pollinosis requires comprehensive analysis of meteorological elements which determine dispersion of ragweed pollen in the atmosphere.

It is seen from Fig. 3 that the main ragweed pollen load occurred in August, irrespective of the aerobiological station. The Vilnius case in the year 2008 was exceptional because of the highest pollen load recorded in September. Annual ragweed pollen counts are usually highest in Vilnius, while the lowest counts are recorded in Klaipeda. The latter situation results from the fact that Klaipeda is situated near the Baltic Sea and pollen is not carried there by the prevailing winds from the sea (Fig.1). Notwithstanding this, ragweed pollen counts recorded in Lithuania's atmosphere as well as in the aerobiological monitoring station based in the littoral region are annually increasing.

In 2009, there were recorded only a few pollen grains on separate days, while in 2010 and 2011 ragweed pollen counts were significantly higher. The total ragweed pollen count during August-September period in separate observation sites exceeded 100 pollen grains and in 2011 in Vilnius 250 pollen grains. Of special interest were the cases of the end of August (26th-28th) 2011 when more than 25 ragweed pollen

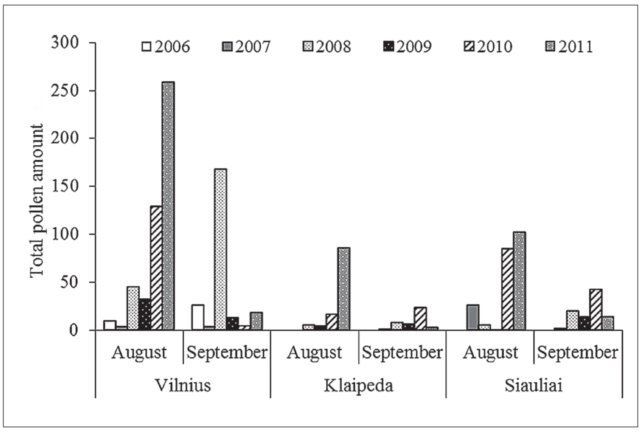

Figure 3. Distribution of *Ambrosia* pollen count in different towns

grains were recorded for several successive days. It has been documented that much lower ragweed pollen counts can cause allergy [2, 4, 5], therefore health authorities and services should pay attention to the factors responsible for such high pollen counts.

Ragweed pollen counts are started to be recorded all over Lithuania on around 225th day of the year. Sporadic pollen grains are recorded already at the end of July. Because of the frequent intervals from one case to another, it is very complicated to treat ragweed pollen appearance as pollen season and establish factors determining it [22]. Based on the available data set, it was established that the shortest ragweed pollen period was in Klaipeda, the longest season was in Vilnius (on average 25 days), while in Siauliai sporadic pollen grains were recorded on September 25, 2010.

The fact that ragweed pollen is not recorded continuously as is the case with indigenous plants during their flowering season, leads to the assumption that ragweed pollen appears in Lithuania more as a result of long distance transport [21] rather than due to pollination of local plants. Biological plant peculiarities determine specific periods when plants release pollen into the atmosphere. It is known that ragweed pollen emission begins at around 6.30 a.m. and lasts to midday [23], however, it still has not been established how fast pollen gets into traps used for aerobiological monitoring. It has been reported that pollen emission in Burgundy is at its peak from 9 a.m. to 1 p.m. [24]. In Croatia, the diurnal periodicity showed a peak from 1 a.m to 12 p.m [25], while in Poland there were recorded two peaks: one early in the morning and the other in the afternoon [17]. Analysis of Lithuania's case revealed that the major counts of ragweed pollen (not less than 35%) are recorded during the period from 5 a.m to 1 p.m. (Fig. 4). Thus the time when members of the public are active (travel to work, manage their affairs, kindergarten children are taken out for walks) is unfavourable for outdoor activities due to the likely but hard to forecast occurrence of ragweed pollen in the air. Since sensitization caused by ragweed pollen allergens has a specific lag phase lasting for a year or several years [19], even a low load of pollen can exert an adverse effect on human health, especially children's, if they have had contact with ragweed pollen before.

The time that the pollen is recorded can vary depending on the transport time (a product of distance and wind speed) from the source to the trap. The daily variations in ragweed pollen concentrations are most affected by unstable atmospheric conditions [18].

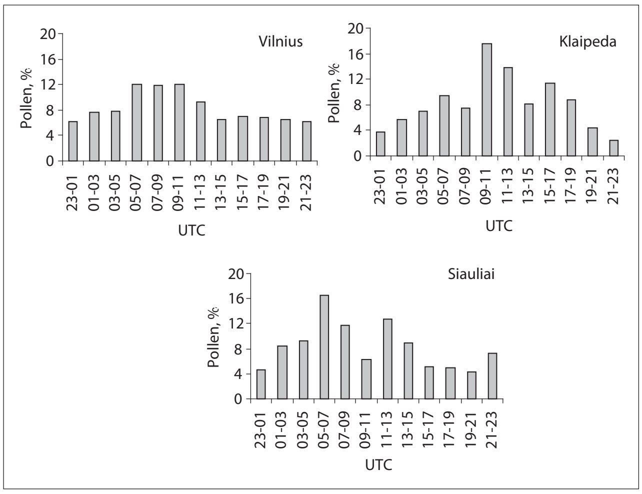

Figure 4. Diurnal variation of *Ambrosia* pollen load

Assessment of the effects of meteorological factors such as relative air humidity and temperature on pollen counts in the air, based on systemized results, is presented in Table 1. Statistical analysis revealed that at higher air temperatures higher counts of ragweed pollen are recorded (r_s (mean) =0.28, p<0.01, r_s (max) =0.39, p<0.01). Lithuanian climatologists [26] have established that with higher temperatures in the autumn, air humidity declines. Especially marked negative changes are forecasted for the second half of summer and beginning of autumn. Since this is the period when ragweed is flowering, there is stronger likelihood that the number of flowering plants as well as pollen emission will increase. This assumption is validated by the statistical data obtained from airborne ragweed pollen analysis. The research evidenced that higher pollen concentration was recorded at lower air humidity (rs=-0.40, p<0.01).

Table 1. Correlation coefficient between pollen count and main meteorological parameters based on the Spearman correlation (r_s) test

Meteorological element	Pollen	r_s	t (N-2)	p-level
	Air temperature			
Mean (2 hours)	≥1	0.28	4.88	0.00
	≥4	0.21	1.77	0.08
Min	≥1	0.25	2.67	0.01
	≥4	0.30	1.49	0.15
Max	≥1	0.39	4.29	0.00
	≥4	0.20	0.99	0.33
	Air humidity			
Mean (2 hours)	≥1	-0.13	-2.10	0.04
	≥4	-0.32	-2.74	0.01
Mean	≥1	-0.40	-4.38	0.00
	≥4	-0.16	-0.78	0.45

This enables us to assume that the currently warming and drying autumns in Lithuania can determine more abundant and longer-lasting ragweed pollen emission both form local and transported sources. Such type of origin of airborne biological particles is not specific to the territory therefore it is likely that the number of sensitized people will rise.

Analysis of ragweed pollen distribution provided in Fig. 5 shows that annual pollen loads is shaped by the different number and intensity of episodes. For example, in 2008 there were recorded 6 cases when ragweed pollen count exceeded 5%. While in 2011, the annual pollen load was shaped by the two cases that stood out by particularly high pollen abundance for the tested territory. Assessment of the effects of meteorological factors on these cases revealed that the highest pollen concentration is recorded when relative air humidity is falling and maximal air temperature is rising. Lithuania's data indicate that ragweed pollen concentration in the air generally increases at a relative air humidity of around 70%, and minimal air temperature not less than 12°C. The fact that the number of ragweed plants found in Lithuania is small (only a few flowering plants annually), and ragweed pollen concentrations at the time of recording on separate days are high (Fig. 5), points to the long distance pollen transport.

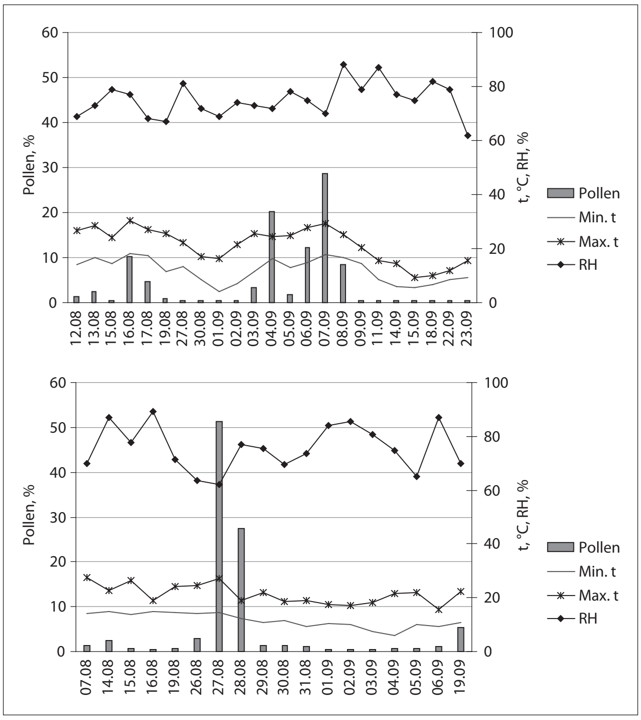

Figure 5. Mean pollen distribution, expressed in percentage and minimum, maximum air temperature (Min. t, Max. t), relative humidity (RH) in Vilnius during 2008 (upper graph) and 2011 (bottom graph)

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It has been earlier found that deep layer of atmospheric periphery in Slovakia and Hungary can determine ragweed pollen long distance transport to the neighbouring countries – Poland, Germany, Denmark, and the Baltic countries [20]. In Lithuania, the autumns becoming consistently warmer and drier can result in more prolific and longer-lasting emission of locally growing ragweed as well as in higher transport from other European regions.

In the localities with a large number of ragweed plants, pollen concentration in the air depends not only on the air temperature (pollen emission intensity depends on it) but also on wind speed, which determines pollen transport [13]. The effects of increasing wind velocity on the pollen counts in the morning have been documented by French researchers [16].

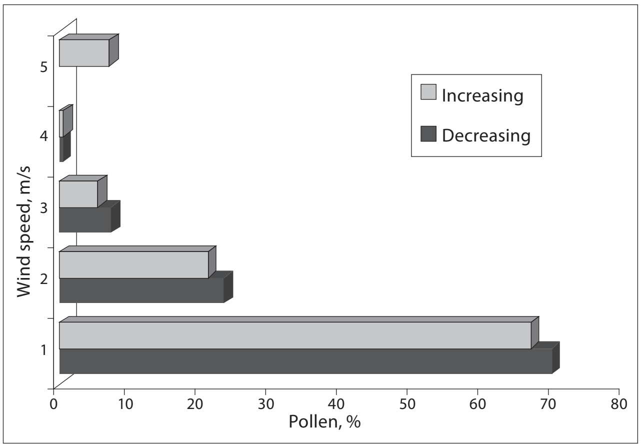

Figure 6. The effect of wind speed variation on pollen counts in the air in Vilnius

In Lithuania, wind speed normally varies from weak to moderately strong. Analysis of wind speed impact on the abundance of ragweed pollen in the air indicated that the highest counts of ragweed pollen (over 70% of the cases) were recorded with the wind getting weaker (Fig. 6). It was found that different wind speed variations have a diverse effect on pollen concentration in the air. The highest pollen concentrations in the air is recorded when wind speed variations are small (1-2 m/s), irrespective of the fact whether wind speed increases or declines.

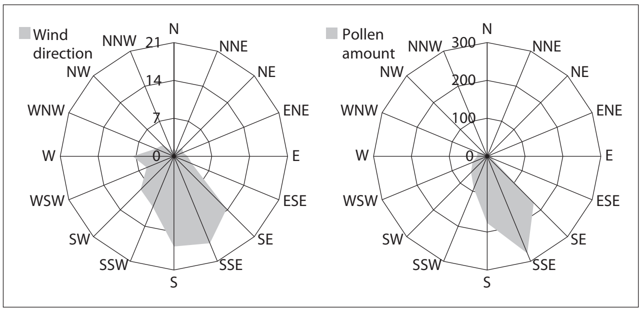

Figure 7. Wind rose during the pollen recording period (on the left) and the ratio (on the right) of pollen count in the air to wind direction

Analysis of the data of wind direction frequency and ragweed pollen count in the air suggests that the highest pollen counts occur in Vilnius when southern and south-eastern winds prevail (Fig. 7). Despite the fact that according to the climate norm, the prevailing winds in Lithuania during the August–September months are those from the westerly direction (Fig. 1), 83% of ragweed pollen is recorded in Vilnius aerobiological station when southern winds blow. Similar findings have been reported by I. Kasprzyk [22] suggesting that the highest ragweed pollen concentrations are recorded when south-eastern winds prevail.

Conditions that leads expansion of allergenic pollen in the air is important information for clinicians and aerobiologists [4, 5, 18, 27] in case to decrease the cost of medical treatment. The rising ragweed pollen recording in the atmospheric samples in central or more northerly European regions is becoming an increasingly more common phenomenon and underlies international health problems.

CONCLUSIONS

Analysis of the data indicated that ragweed pollen concentrations in Lithuania vary from year to year. Although the number of ragweed plants found in Lithuania does not increase, the total pollen counts have been consistently increasing over the recent period. The highest atmospheric pollen load is recorded on the last days of August and first days of September. In separate cases the pollen load is as high as 30 pollen grains/m^3 air during this period. Since pollen emission is recorded episodically and pollination season is irregular, public health is threatened when up to 50% of season's pollen count is recorded in the atmosphere. Assessment of the effects of meteorological parameters on pollen detection in the atmosphere showed that rising air temperature and declining air humidity are one of the major factors that determine ragweed pollen counts. In Lithuania, ragweed pollen is recorded when relative air humidity is around 70% and minimal air temperature is not below 12°C. Analysis of the aerobiological monitoring data covering the 2006-2011 period suggests that ragweed pollen is recorded when south-eastern winds prevail. Having estimated wind change effects on pollen counts, it was found that the pollen is most often recorded in the air when there are small (1-2 m/s) changes in wind speed, irrespective of the fact whether the wind speed increases or decreases. The findings obtained during the study period lead to the assumption that under changing climate conditions, increasing air temperature and changes in other meteorological factors can result in growth of common ragweed allergens.

Acknowledgements

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REFERENCES

1. Simard MJ, Benoit DL. Effect of repetitive mowing on common ragweed (*Ambrosia artemisiifolia* L.) pollen and seed production. Ann Agric Environ Med. 2011; 18: 55-62.
2. Heinzerling L, Frew AJ, Bindslev-Jensen C, Bonini S, Bousquet J, Bresciani M, Carlsen KH, Cauwenberge P van, Darsow U, Fokkens WJ, Haahtela T, Hoecke H van, Jessberger B, Kowalski ML, Kopp T, Lahoz CN, Lodrup Carlsen KC, Papadopoulos NG, Ring J, Schmid-Grendelmeier P, Vignola AM, Wöhrl S, Zuberbier T. Standard skin prick testing and sensitization to inhalant allergens across Europe – a survey from the GA2LEN network. Allergy 2005; 60: 1287-1300.
3. Comtois P, Gagnon L. Concentration polliniques et fréquence des symptômes de pollinose: une méthode pour déterminer les seuils cliniques. Rev fr Allergol. 1988; 28: 279-286.
4. Bergmann KC, Werchan D, Zuberbier MM. The threshold value of *Ambrosia* pollen inducing acute nasal reactions is very low. Allergo J. 2008; 17: 375-376.
5. Gehrig R, Pietragalla-Köhler B, Clot B, Herren T, Graber MJ, Hauser M. Luftpollengehalt in der Schweiz 2010. Zürich, 2011.
6. Dahl A, Strandhede SO, Wihl JA. Ragweed – An allergy risk in Sweden? Alergologia 1999; 15: 293-297.
7. Kasprzyk I, Myszkowska D, Grewling Ł, Stach A, Šikoparija B, Skjøth CA, Smith M. The occurrence of *Ambrosia* pollen in Rzeszów, Kraków and Poznań, Poland: investigation of trends and possible transport of *Ambrosia* pollen from Ukraine. Int J of Biomet. 2011; 55: 633-644.
8. Šaulienė I, Gudžinskas Z, Veriankaitė L, Malciūtė A, Leščiauskienė, V. Distribution of *Ambrosia* plants and airborne pollen in Lithuania. J Food Agr Environ. 2011; 9: 547-550.
9. Behrendt H, Becker WM. Localization, release and bioavailability of pollen allergens: the influence of environmental factors. Curr Opin Immunol. 2001; 13: 709-715.
10. Pushnov A, Berengarten M. Ecological aspects of industrial cooling towers exploitation and it's influence to environment. J Environ Eng Landsc Manag. 2011; 19: 158-166.
11. Maikštėnienė S, Arlauskienė A, Velykis A, Satkus A. Enhancement of competitive ability of cereals towards weeds by means of crop rotations. Zemdirbyste-Agriculture 2009; 96: 23-34.
12. Feiza V, Feizienė D, Auškalnis A, Kadžienė G. Sustainable tillage: results from long-term field experiments on Cambisol. Zemdirbyste-Agriculture 2010; 97: 3-14.
13. Makra L, Juhász M, Borsos E, Béczi R. Meteorological variables connected with airborne ragweed pollen in Southern Hungary. Int J of Biomet. 2004; 49: 37-47.
14. Veriankaitė L, Siljamo P, Sofiev M, Šaulienė I, Kukkonen J. Modelling analysis of source regions of long-range transported birch pollen that influences allergenic seasons in Lithuania. Aerobiologia 2010; 26: 47-62.
15. Galvonaitė A, Misiūnienė M, Valiukas D, Buitkuvienė MS. Lietuvos klimatas. Vilnius, 2007.
16. Laaidi M, Laaidi K, Besancenot JP, Thibaudon M. Ragweed in France: an invasive plant and its allergenic pollen. Ann Allergy Asthma and Immun. 2003; 91: 195-201.
17. Stach A, Smith M, Skjoth CA, Brandt J. Examining *Ambrosia* pollen episodes at Poznan (Poland) using back-trajectory analysis. Int J of Biomet. 2007; 51: 275-286.
18. Taramaracaz P, Lambelet C, Clot B, Keimer C, Hauser C. Ragweed (*Ambrosia*) progression and its health risks: will Switzerland resist this invasion? Swiss Med Wkly. 2005; 135: 538-548.
19. Tosi A, Wüthrich B, Bonini M, Pietragalla-Köhler B. Time lag between *Ambrosia* sensitisation and *Ambrosia* allergy. Swiss Med Wkly. 2011; 141: 132-153.
20. Smith M, Skjøth CA, Myszkowska DUA, Puc M, Stach A, Balwierz Z, Chlopek K, Piotrowska K, Kasprzyk I, Brandt J. Long-range transport of *Ambrosia* pollen to Poland. Agr For Met. 2008; 148: 1402-1411.
21. Šaulienė I, Veriankaitė L. The distribution of airborne *Ambrosia* pollen in Lithuania. Acta Biologica Universitatis Daugavpiliensis 2009; 9: 255-262.
22. Kasprzyk I. Non-native *Ambrosia* pollen in the atmosphere of Rzeszow (SE Poland): Evaluation of the effect of weather conditions on daily concentrations and starting dates of the pollen season. Int J of Biomet. 2008; 52: 341-351.
23. Ogden EC, Hayes JV, Raynor GS. Diurnal patterns of pollen emission in *Ambrosia*, Phleum, Zea and Ricinus. Am J Bot. 1969; 56: 16-21.
24. Laaidi K, Laaidi M. Airborne pollen of *Ambrosia* in Burgundy (France) 1996–1997. Aerobiologia 1999; 15: 65-69.
25. Peternel R, Culig J, Hrga I, Hercog P. Airborne ragweed (*Ambrosia artemisiifolia* L.) pollen concentrations in Croatia, 2002–2004. Aerobiologia 2006; 22: 161-168.
26. Rimkus E, Kažys J, Junevičiūtė J, Stonevičius E. Lietuvos klimato pokyčių XXI a. prognozė. Geografija 2007; 43: 37-47.
27. Reinhardt F, Herle M, Bastiansen F, Streit B. Economic impact of the spread of alien species in Germany. Report No. UBA-FB 000441e. Federal Environmental Agency. Berlin, Germany, 2003.