THE HISTORY OF RAGWEED IN THE WORLD

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Abstract. The aim of the study is to provide a survey on the history of ragweed worldwide. Its climate dependence, impacts in agriculture, health effects and social costs are also presented. In Europe common ragweed *(Ambrosia artemisiifolia)* is predominant of all *Ambrosia* species that is supported by population genetic data. The most important habitat areas of ragweed and the highest pollen concentrations occur, in decreasing order of the pollen levels (1) in the south-western part of the European Russia, (2) in the southern and eastern parts of Ukraine, (3) in the Pannonian Plain in Central Europe, (4) in the Rhône-Alpes region in France, furthermore (5) in the Po River valley in Italy. Besides Europe, ragweed occurs in China, India, Japan and in other Asian countries, furthermore in Australia and the Unites States of America. However, beyond the USA few information are available. Warming trends due to the climate change favours the expansion of ragweed, producing higher pollen levels worldwide. In association with the warming, increasing ambient CO_2 levels generate greater biomass and increased pollen production. Hence, ragweed pollen production can be expected to increase significantly under predicted future climate conditions, bringing severe impacts to areas that have yet been suffering slightly.
Keywords: *origin of ragweed, social costs of ragweed, distribution of ragweed, climate change, respiratory allergy*

Introduction

Origin of ragweed

Common ragweed *(Ambrosia artemisiifolia)* (Asteraceae family) is an annual species, native to North America, which has been introduced and subsequently naturalized in many countries including a large part of Europe (Jäger, 1998; Juhász, 1998; Rybníček and Jäger, 2001; Bullock et al., 2010), Asia and Australia (Lawalrée, 1953; Priszter, 1960) following its introduction to many places in the world. The name *Ambrosia* is the same as that of the delicious food eaten by the mythical Greek gods that conferred them immortality (Makra et al., 2004). The term might refer to the tenacity of the plants, which makes it hard to rid an area of them if they occur as invasive weeds.

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The genus is best known for the severe and widespread allergies caused by its pollen (Béres, 2003).

Ambrosia artemisiifolia belongs to the phylum of angiosperms (Angiospermatophyta), to the class of Dicotyledonouses (Dicotyledonopsida), to the ordo of Composites (Asterales), to the family of Daisies (Asteraceae), to the subfamily of disc-florets (Tubuliflorae) and to the genus of ragweeds (*Ambrosia spp.*). This genus comprises 42 species. The most species occur in the Unites States, some of them in Central- and South America, while *Ambrosia senegalensis Dc.* is native in Africa (Béres et al., 2005).

The Sonora desert in Arizona (USA), north and west of the Bay of California, is considered the gene centre of *Ambrosia* species (Bohár, 1996), where about 10 species occur (Bohár, 1996). *Ambrosia artemisiifolia* was discovered in the USA before 1838 (Wagner and Beals, 1958), while in Canada in 1860 (Bassett and Crompton, 1975). There are 41 species worldwide. In Europe, introductions of *A. artemisiifolia* stems from two different regions of their native area. Namely, populations established in Central Europe appear to have originated from eastern North America and Eastern European populations from more western North America. This may result from differential commercial exchanges between these geographic regions (Gaudeul et al., 2011).

Ambrosia pollen has been found in deposits of over sixty thousand years in Canada. Nevertheless, its amount in peat deposits, except for the last 250 years, is small. However, due to deforestation and land use changes associated with the incursion of the western civiliziation, this amount increased over 100-fold. Recently, ragweed has extended areas in North-America unitl the southern part of Canada (Szigetvári and Benkő, 2004).

Climatic and environmental associations

Ambrosia species are adapted to the arid climates of the desert. Ragweed favours temperate climate and prefers dry, sunny and grassy plains, sandy soils, river banks, roadsides, and ruderal sites (disturbed soils) such as vacant lots and abandoned fields (Ziska et al., 2006; Kazinczi et al., 2008a; 2008b). Fields along roads are especially suitable for facilitating its spreading. In Quebec Province, Canada in strips of land along the roads 4-16 plants occur per square meter (Simard and Benoit, 2010).

Ragweed can take hold up and prosper if the temperature sum exceeds the threshold of 1400°C, necessary for its floral and seed development (Cunze et al., 2013). Below this threshold, under maritime climate (north-eastern Spain, Netherlands), ragweed populations seem only survive. At the same time, if the temperature sum is too high, for example in the Mediterranean, summers are hot and dry that involves a substantial decline of pollen release. However, the species is widely distributed in countries that are largely unsuitable for ragweed but import lots of seed, such as Netherlands or Belgium. In these countries, the distribution overstates the very low impact of the casual introductions (Bullock et al., 2010).

Contrary to regular mowing, ragweed grows rapidly, producing rather large amounts of biomass and even they can bloom as well (Patracchini et al., 2011). Their shadow tolerance is also very good, they satisfy with less light. They grow better in shadow compared to native plants (Qin et al., 2012). Their water-use efficiency in the growing period, and their nitrogen-use efficiency and the ratio of photosynthesis/respiration in the blooming period are very high (Pajević et al., 2010). *Ambrosia,* according to a study performed in Hungary (Pinke et al., 2011), like acidic and sandy soil, however it grows

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rarely in soils containing high Na, K and Mn concentrations. In those years, when rainfall amount in April exceeds 39 mm, or mean temperature in May exceeds 15.5°C, ragweed coverage increases. Namely, these meteorological components may have of predictive value (Pinke et al., 2011).

Based on stuyding 22 American and 12 European populations, plants in Europe grow faster and reproduce better than the American plants. However, during drought, plants die faster in Europe compared to the plants of the American native populations. This can be explained by the fact that due to the fast growing, European plants are less toleratant to drought (Hodgins and Rieseberg, 2011).

The northern and high-elevation range margin of ragweed is regulated by thermal and photoperiod constraints. Beyond their habitat areas, ragweed occurs casually and is unable to set seeds (Dahl et al., 1999; Saar et al., 2000). In the northern range of its habitat area, even though the populations can produce seed, low temperatures or the cold climate promotes extinction. In general, over these areas ragweed grows to adulthood but fails to reproduce properly because it is too cold. At the same time, in the southern edge of its habitat, drought is considered a major factor limiting the invasion. This is the main aspect explaining a lack of ragweed pollen records from Spain and Portugal, where seed import rates should cause many introductions to occur (Bullock et al., 2010).

For the American populations, blooming period of ragweed has been extending. Accordingly, allergic patients are longer exposed to the effect of the highly allergenic ragweed pollen. Longer blooming period is due to the global warming, since in association with the climate change first frost in fall occurs later (Ziska et al., 2011). Due to the climate change, the climate of Europe will be warmer and *Ambrosia* will spread towards north and north-east. For this reason it may proliferate over the northern part of France, Germany, the Benelux states, Czech Republic, Poland, the Baltic states, Belarus and Russia, as well (Cunze és mtsai., 2013).

Long-range transport of ragweed pollen (traveling more than 100 km distance between the source area and the arrival point) can deliver pollen over less polluted areas, e.g. from the Pannonian Plain in Central Europe over the Basin of Vienna, northern Slovakia, Poland, Balkans or northern Greece and in the same way, from Ukraine over Poland (Šikoparija et al., 2009; Makra et al., 2010; Kasprzyk et al., 2011; Šikoparija et al., 2013). Ragweed pollen coming from the Pannonian Plain can reach even the area of Niš and Skopje in the Balkans taking over 400 km (Šikoparija et al., 2009).

Impacts on agricultural activity

The extensive spread of *A. artemisiifolia* can be associated to the political transitions in 1990s that led to the formation of young democracies in Eastern Europe. During these processes, the structure and the size of the cultivated areas, as well as land use changed. Namely, co-operatives were cut into smaller parcels due to privatization. Thus large, formerly well-kept agricultural fields were abandoned and quickly colonised by *A. artemisiifolia* (Kiss and Béres, 2006).

Ambrosia is a noxious agricultural weed. It grows frequently on roadsides, railway embankments, waste places and in cultivated lands. It can overgrow alfalfa and purple clover entirely, cause severe damages in potato fields and occurs often in sunflower and corn fields, as well. Substantial crop failure due to ragweed can be explained by its strong allelopathic effect influencing even life processes of algae in the soil. In corn plantations 1 plant/m^2 ragweed occurrence may cause a yield loss of even 0.2-0.3 tonne / hectare (Varga, 2002). According to a test of inhibition of germination, three

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extractions (water, alcohol and acetone) were prepared and it was found that for each treatment *A. artemisiifolia* decreased germination of soy and corn (Béres et al., 2002).

Ambrosia appears in large quantities in stubbles, effectively utilize large amounts of fertilizer, have high productivity, and regenerate well in dry and infertile soils. Their ability to block sunlight causes reduced crop productivity (Xie et al., 2001). Furthermore, it does not have any natural competitors. *Ambrosia* has less sensitivity to herbicides than other weeds (Voevodin, 1982; Ballard et al., 1995; Patzoldt et al., 2001; Makra et al., 2014).

Ragweed tolerates leaf loss very well against herbivorous. This time, on the expense of the root system, the plant allocates more nutrients into the stem in order to fast replacement of leaves. According to observations plants in the Euroepan populations produce more seeds, substantially raising the tolerance against grazing (Gard et al., 2013). Invasive species, such as ragweed, indicate a very good model for studying ecological and evolutionary processes having a great role in colonization of new areas (Prentis and Pavasovic, 2013).

Health effects

Climate change in association with an extended urbanization, with high levels of vehicle emissions in urban areas, living in artificial environment with little movement may contribute to increasing frequency of respiratory allergy and asthma (D'Amato, 2011). Pollen is an important trigger of respiratory diseases. Greater concentrations of carbon dioxide and, consequently, higher temperatures may increase pollen quantity and induce longer pollen seasons (Ziska et al., 2003; Clot, 2008). Pollen allergenicity can also increase as a result of these changes in climate. Furthermore, there is evidence that high levels of traffic-derived air pollutants may interact with pollen and bring about more intense respiratory allergy symptoms (Hjelmroos et al., 1999; Andersen et al., 2007; Díaz et al., 2007; Alves et al., 2010). Accordingly, global warming may induce a wide pollen-related public health problem, for which the societies should be prepared in time.

Pollen of ragweed is extremely allergenic and this is why ragweed is the most dangereous allergy-related plant and its pollen is one of the most frequent cause of hay-fever. Ragweed pollen causes severe human ecological and health problems. A plant, depending on its size, may produce 100 million – 3 billion pollen grains, even one million pollen grains per day (Fumanal et al., 2007). One hectare ragweed releases 66 kg pollen in a mere season (Šikoparija et al., 2009).

Two major allergens of ragweed pollen are Amb a I and Amb a II. Furthermore, it comprises several smalle and middle-sized protein allergens (Amb a III, IV, V, VI, VII and cystatin), as well. Getting into the airways, mucous membrane is irritated and the eyes are inflamed for sensitive people. Amb I allergen, belonging to the pectate lyase family and being a pectinolytic enzyme, is the dominant with a 90% IgE activity. The protein is acidic, non-glycosylated, with a mass of 38 kDa that contains two chains of 26 kDa and 12 kDa, respectively (Wopfner et al., 2005).

Symptoms due to common ragweed include a runny nose, sneezing, puffy or irritated eyes, and a stuffy or itchy nose and throat, as well as hay-fever allergies (Matyasovszky et al., 2011). Furthermore, *A. artemisiifolia* has a wide ecological tolerance and can colonize a large range of disturbed habitats (Kazinczi et al., 2008a; Pinke et al., 2011; Makra et al., 2014). Its invasion is also facilitated by its resistance to certain herbicides (Kazinczi et al., 2008b), the lack of natural enemies (MacKay and Kotanen, 2008) and the high genetic variability of invasive populations (Genton et al., 2005; Chun et al.,

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2010). These harmful effects, with its potential for rapid spread has made ragweed one of the most dangerous invasive non-native species in Europe. The European Commission has identified the species as a significant problem for many Member States of the EU and a very serious threat for others.

Sensitivity thresholds

In Hungary, Kadocsa et al. (1991) detected sensitization against ragweed pollen even above 10 pollen grains / m^3 of air / day. Zink et al. (2012) found that allergic reaction may occur at a pollen concentration of 12 pollen grains / m^3 of air / day. For pollen sensitive patients, threshold value of clinical symptoms is generally 20 pollen grains / m^3 of air / day (Jäger, 1998). At the State Public Health Office, Hungary the threshold value is 30 pollen grains / m^3 of air / day (Mányoki et al., 2011). At the same time, Juhász (1995) suggests 50 pollen grains / m^3 of air / day at which threshold around 60-80% of patients suffering from hay fever are sensitive to ragweed pollen.

Contrarily, besides the Carpathian Basin in those regions where ragweed pollen counts are substantially smaller, even a very low pollen load (1-2 pollen grains / m^3 of air / day) may produce slight allergic symptoms (Déchamp et al., 1997). Taking this into account a so called “subpathological risk period” has been introduced, when ragweed pollen concentration is a mere 0.1 pollen grains / m^3 of air / week, under the condition that the next week a higher pollen concentration occurs. The next level is the first week, when pollen load reaches 5 pollen grains / m^3 of air / week. This is the so called “pathological risk period” (Déchamp et al., 1997).

Benefits, positive effects

Feeding

Sheep and goats feed ragweed with pleasure in every phenophase. For sheep, feeding value of the whole plant, the seeds and the seed meal were studied, respectively. It was concluded that both the whole plant and the seed meal were very well utilizable feed containing protein, they were easily digestible and were characterised by balanced amino acid composition. However, undamaged seeds get through the body of the sheep undigested (Husvéth et al., 1999).

Phytoremediation

Ragweed can be used well for phytoremediation purposes, namely for extracting heavy metal content, especially lead content of the soil, because ragweed effcetively pick up and accumulate them. It was observed that spreading of *Ambrosia* is much more extended over agricultural areas, since the soil comprises more nutrients. Ragweed exploits higher nutrient spots and their growing and spreading occur at a higher rate there than over nutrient-poor areas. Their above-mentioned feature can be used since heavy metals can be accumulated with a higher rate facilitating bioremediation (Kazinczi et al., 2008b).

According to Patterson (1995), at higher CO_2 level ragweed produces more biomass with higher quality.

Heavy metals are strongly adsorbed in the soil and, as a result, they appear in water systems and, in this way, in groundwater and even in the drinking water network, as well. Quickly spreading plants can prevent this process. *A. artemisiifolia* can bind

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especially large volume of heavy metals; namely, 500mg/kg from cobalt, 2000mg/kg from lead and 500mg/kg from zinc. Ragweed leaf adsorbs significantly more lead and zinc than the control plant (Taylor, 2005).

Their seed is an important nutrient for birds due to its high oil content, especially in winter (Húsvéth et al., 1999).

Ecological and biological control options against ragweed

In addition to traditional procedures, biological control would also be important against ragweed. A certain bug seems to be successfully applied against *Ambrosia*. Ragweed was introduced also into China and they spread there fast, too. According to experiments, the bug Ophraella communa (Coleoptera: Chrysomelidae) effcetively decreased the height of the plant, the number of its branches and the surrface of its leaves, as well. Even if only one bug is allowed to a plant, the young plant is damaged substantially. For an adult plant, before blooming 12 bugs per a plant caused similarly big damage as an herbicide (Guo et al., 2011).

According to experiments in Hungary, Aphis fabae, Brachycaudus helichrysi and Myzus persicae can substantially decrease the size and mass of the plant, as well as the number of flowers. Brachycaudus helichrysi preferred better ragweed than sunflower. However, Aphis fabae preferred better sunflower. At the same time, Myzus persicae did not show any specific preference. Nevertheless, during free conditions neither of the species could decrease the size of ragweed and the number of plants effectively, as ragweed grow too fast (Basky and Magyar 2009).

Social costs

Common ragweed and its pollen cause serious losses in the economy and several fields of the everyday life.

Common ragweed and its pollen cause serious losses in the economy and several fields of the everyday life. The current costs of *A. artemisiifolia* in terms of human health and agriculture were estimated by Bullock et al. (2010) for 40 European countries. All the costs are given in Euros at 2011 prices. The human health impacts were estimated to affect around 4 million people with total estimated medical costs of €2,136 million per year. Furthermore, total estimated workforce productivity losses and agricultural costs due to *A. artemisiifolia* as high estimates were €529 million and €3,559 million, respectively. The estimated total costs are valued at €6.224 billion per year. Over 80% of these impacts are lost crop yields. Estimated agricultural, human health, workforce and total costs are the highest in Ukraine, Romania and Hungary with €995, €770 and €605 million, respectively (Bullock et al., 2010). At the same time, in the USA, allergic disorders represent an important group of chronic diseases with estimated costs at approximately $21 billion per year. Among twenty-five of the most harmful invasive species of China, economic losses due to ragweed, found in most of the provinces, amount to 397.9 million USD, taking ragweed the 2nd most harmful species in the country (Ding et al., 2004; Li et al., 2014).

Realizing the danger, those countries polluted with ragweed, have introduced anti-*Ambrosia* campaigns under the control of the National Ministries of either Health Affairs or Agriculture.

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Distribution of ragweed in Europe

A limitation of ragweed pollen observations is that the pollen of *A. artemisiifolia* cannot be distinguished from other species of the *Ambrosia* genus. In Western Europe, the first temporary colonization of *Ambrosia* was reported from Brandenburg and Pfaffendorf (Germany) in 1863 (Hegi, 1906; Priszter, 1960; Hodişan and Morar, 2007). In Western Europe, four American species have established: *A. artemisiifolia, A. psilostachya, A. tenuifolia* and *A. trifida* (Járai-Komlódi and Juhász, 1993; Makra et al., 2004). However, in Europe, common ragweed *(A. artemisiifolia)* is predominant of all *Ambrosia* species (Makra et al., 2005; Bullock et al., 2010; Vinogradova et al., 2010; Páldy et al., 2006) that is supported by the population genetic data of Mátyás and Vignesh (2012).

The only two native species of ragweed in Europe can only be found in some maritime locations around the Mediterranean coastal area. The earliest described colonization of seaside *Ambrosia* (*Ambrosia maritima*) occurred in Dalmatia (Croatia) in 1842 near Dubrovnik (Croatia) and Budva (Montenegro) areas and on the neighbouring islands (de Visiani, 1842). While, in the western basin of the Mediterranean, *A. maritima* (Balearic Islands) and *A. tenuifolia* (Minorca Island) are autochton species (Fraga and García, 2004). According to some botanists they are native, while others consider them as an annual variant of *A. psilostachya* or a variant of *A. artemisiifolia*. *A. psilostachya* occurs only sporadically in Europe (Szigetvári and Benkő, 2004). However, according to the genetic analysis of both 100-year old items coming from herbaria and recently collected plants, the current population has of much higher genetic and allelic diversity than 100 years ago. Based on a study using eight microsatellite loci, among recent populations in Europe the genetic distance is smaller and the populations are less structured then ever (Chun et al., 2010). Using NimbleGen microarray, Hodgins et al. (2013) looked for genes that could contribute to the successful spreading of ragweed in Europe. They compared several European and American populations, as well as populations living in different enviroments (control, light stress and nutritional stress). They found around 180 genes that were modified in popuations settled in Europe. These genes have a role in producing secondary metabolites and stress tolerance, as well as in degradation of xenobiotics (Hodgins et al., 2013).

The distribution of *A. artemisiifolia* in Europe started after the First World War (Makra et al., 2014). Seeds of different *Ambrosia* species were transported to Europe from America by purple clover seed shipments, and grain imports. Major nodes of its distribution pathways are European ports, namely Rijeka (Croatia) towards Croatia and the western part of Hungary (Járai-Komlódi and Juhász, 1993; Makra et al., 2005), Trieste and Genoa (Italy) towards Northern Italy (Járai-Komlódi and Juhász, 1993; Makra et al., 2005), Marseille (France) towards the Rhône valley in France (Járai-Komlódi and Juhász, 1993; Comtois, 1998; Makra et al., 2005) and Odessa (Ukraine) towards southern and eastern Ukraine (Rodinkova et al., 2012). After having been settled in Europe, ragweed spread quickly, since herbivorous and granivorous species harrmful for *A. artemisiifolia* in its homeland were missing from Europe (Mackay and Kotanen, 2008).

The most important habitat areas of ragweed and the highest pollen concentrations occur, in decreasing order of the pollen levels, (1) in the southern, eastern and the northern-eastern parts of Ukraine (Rodinkova et al., 2012), (2) in the Pannonian Plain in Central Europe including Hungary and some parts of Serbia, Croatia, Slovenia,

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Slovakia and Romania (Makra et al., 2005; 2014), (3) in the Rhône valley in France (Déchamp and Cour, 1987, Laaidi and Laaidi, 1999; Chauvel et al., 2006; Gladieux et al., 2011), (4) in the south-western part of the European Russia (Reznik, 2009), furthermore (5) in north-western Milan and south Varese (Lombardy, Po River valley) in Italy (Carosso and Gallesio, 2000; Bonini et al., 2012). Less extended habitat areas with smaller pollen levels occur in the Balkan Peninsula (Yankova et al., 2000; Dimitrov and Tzonev, 2002; Šikoparija et al., 2009), in the remaining part of the European Russia (Reznik, 2009), Switzerland (Clot et al., 2002), Germany (Zink et al., 2012), Czech Republic (Rybníček et al., 2000), Poland (Kasprzyk et al., 2011), Bulgaria (Yankova et al., 2000), the Baltic States (Saar et al., 2000), Spain (Fernandez-Llamazares et al., 2012) and they even occur casually in Sweden (Dahl et al., 1999). At the same time, the northern border of its permanent occurrence is the 55°N latitude in Europe, namely the southern parts of Poland and Germany (Szigetvári and Benkő, 2004). Historic spread of *A. artemisiifolia* for the European countries is reported by Buttenschøn et al. (2009) and Bullock et al. (2010) in detail.

Bullock et al. (2010) synthesised and reviewed (1) the information on the current extent of ragweed infestation in Europe; (2) the measures controlling ragweed spread and (3) the economic, social and environmental aspects of harmful effects in all economic sectors.

Ragweed in individual countries, worldwide

Ragweed in Hungary may have originated in Canada, rather than the United States (Cseh et al., 2008). Here, *A. artemisiifolia* was firstly described in Budapest in 1888 (Thaisz, 1910) then in Orsova and Herkulesfürdő (Lower-Danube region, in the historical Hungary) in 1907 and 1908 (Jávorka, 1910; Csontos et al., 2010). As an arable weed, its first appearance in the South-Transdanubian part of Hungary (i.e. on the south-western part of the Pannonian Plain) was proved near Somogyvár (Somogy county) in 1922 in the south-western part of Hungary (Lengyel, 1923). Since then, they have been spread rapidly towards the north-east parts of the country. Between the Danube and Tisza rivers *A. artemisiifolia* was spread from Szeged city, in the middle of the Pannonian Plain, towards North-Hungary (Tímár, 1955). Recently the annual ragweed pollen level is 36-45% of the total annual pollen release in Szeged (Juhász, 1998). East from the Danube, the northern part of Pannonian Plain was infected from Szeged city (Kazinczi et al., 2008a). By the end of the last century, Hungary was fully occupied by ragweed excluding the mountainous areas. In the 1950s, based on the Hungarian National Weed Survey, the species was ranked 21st in the weed list and has since risen to: 8th in the 1970s and to 4th by the 1980s (Járai-Komlódi, 1998; Novák et al., 2009; Bullock et al., 2010). The phases of their distribution in Hungary have been mapped by Priszter (1957; 1960) and Béres and Hunyadi (1991). Song and Prots (1998) reconstructed the invasion of *Ambrosia artemisiifolia* in the Pannonian Plain in Central Europe and the Ukrainian Carpathians Mountains on the basis of floristic records. They found that the spreading speed of the species was around 70 km/year (on the average) since the middle of the 20th century.

The species was first recorded in Serbia around 1935 in the village of Osojci, near Derventa (Maly, 1940). The species was then recorded in 1953 around Sremski Karlovci, Petrovaradin and Novi Sad. It is believed that the species arrived from Romania on ships that sailed on the Danube (Slavnić, 1953). From the 1970s to the

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present, *A. artemisiifolia* has spread across a wide area of Serbia and recently it is considered to be a widespread ruderal weed species in Vojvodina often forming large, compact communities in sandy and ruderal habitats (Konstantinović et al., 2004; Bullock et al., 2010).

In Croatia, the first records of *A. artemisiifolia* were collected in the 1940s around Pitomaca in Central Croatia. Inland parts of the country are highly infested with *A. artemisiifolia*, while in the coastal areas it is mainly concentrated in some districts (Peternel et al., 2006; Galzina et al., 2010). *A. artemisiifolia* is expanding towards west, at a rate of between 6 and 20 km per/year (Galzina et al., 2010).

In Slovenia, *A. artemisiifolia* was introduced at the end of the Second World War. It is now well established and spreads widely and fast in the lowlands of the country (Kofol Seliger, 1998). Spreading of *A. artemisiifolia* towards both Serbia (Šikoparija et al., 2009) and Bosnia and Herzegovina (Soljan and Muratović, 2004) occurred from north, i.e. from the Pannonian Plain.

Until 1995, no data were available on the distribution of *Ambrosia* species in Bulgaria. Yankova et al. (1996; 1998) published the first results on *Ambrosia* pollen measurements in the air of Sofia, Bulgaria, that started in 1981. Here, ragweed colonization is extended in the Danubian Plain and Sofia region only (Dimitrov and Tzonev, 2002) and peak annual pollen concentrations here are very high, exceeding 10,000 pollen grains·m^{-3} of air in several years (Yankova et al., 1996).

The source region of *A. artemisiifolia* in Slovakia is Csallóköz and eastern Slovakia. The first description of its presence (Komarno, Southwest Slovakia) dated back to 1949. *A. artemisiifolia* is partly native and partly transported either by southerly winds from Hungary or arrived via cereals transports from the former Soviet Union (Makovcová et al., 1998).

The first record for Austria is a herbarium specimen collected in 1883, while the first naturalized population was recorded in in Lower Austria, Burgenland and Linz in 1952 (Essl et al., 2009). Furthermore, fields have been colonized by the 1970s (Essl et al., 2009). *Ambrosia* pollen can be transported from the Pannonian Plain to eastern Austria and Vienna during August and September, when south-eastern winds are predominant in the region (Essl et al., 2009; Karrer, 2010). Jäger and Litschauer (1998) detected pollen of *Ambrosia* coming from western Hungary in the air of Vienna. Native *Ambrosia* is also found in the Austrian countryside (Jäger and Berger, 2000). The migration velocity of new plant occurrences from east to west is 6-20 km/year (Jäger and Litschauer, 1998).

In the Czech Republic, the species was first recorded in 1883 in clover fields near Třeboň and a field near Doudlevice u Plzně (Slavík and Štěpánková, 2004). Over the past 30 years *A. artemisiifolia* has spread from harbours, grain houses, silos, mills and transport links to lowland areas of south and north east Moravia, as well as along the Elbe valley (Slavík and Štěpánková, 2004).

Ambrosia pollen came to Switzerland by the southerly winds from Northern Italy and the Rhône valley (Peeters, 1998). However, it was recently shown that there is native *Ambrosia* in Geneva, Switzerland, as well (Clot et al., 2002). In the country, *Ambrosia* pollen was firstly observed in Basel in 1970 by Leuschner (1974).

In France, *A. artemisiifolia* occurred in at least three botanical gardens in the 18th century (Lyon, 1763; Paris, 1775; and Poitier, 1791) and during the first half of the 19th century in at least five gardens, namely in: Alençon, Angers, Avignon, Montpellier and Strasbourg. The earliest herbarium record in Europe also comes from France in 1863

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1302_489512

(Chauvel et al., 2006; Bullock et al., 2010). The species showed a gradual but continuous spread in this region, demonstrating their continuous presence in the area of Lyon, which seems to be the focus of its current French distribution (Thibaudon, 1998; Chauvel et al., 2006; Gladieux et al., 2011). The agricultural trade between America and Europe in the 19th century and the First World War facilitated the introduction and spread of *A. artemisiifolia* in France. The plant is spreading from north to south in the mid-Rhone valley area and it is more dominant in rural than in urban areas (Déchamp and Penel, 2002). The temporal and spatial spread of the species in France has speeded up in the last 30 years with a number of sub-regions being free of *A. artemisiifolia* declining dramatically from 54 in 1982; to 38 in 2004; and 9 in 2011 (Chauvel et al., 2006; Bullock et al., 2010; Petermann, 2011).

In Italy, the species was first recorded in 1901-1902 from Piedmont. *A. artemisiifolia* has been naturalized in the province of Milan (Lombardy) since the 1940s (Stucchi, 1942; Zanon et al., 1998); however, it has been spreading rapidly since the 1980s. Currently, the north-western Milan and south Varese (Lombardy, Po River valley) are the most polluted areas with ragweed pollen in Italy (Bonini et al., 2012).

In Spain, *Ambrosia* species occur only over some areas, namely northern Spain (Laínz and Loriente, 1983), the Basque Country, the Cantabric coasts and Galice (Fernández-Llamazares et al., 2012), as well as central Spain (Amor et al., 2006). The first record of the genus *Ambrosia* here dates back to the 19th century and corresponds to *A. maritima*, the only native species in the Peninsula (Pérez, 1887). The major ragweed colonies in Spain and Portugal are closely associated with some of the most important harbours, such as Barcelona, Bilbao, Lisbon, Porto, Santander or Valencia (Fernández-Llamazares et al., 2012).

In the United Kingdom, the species was first recorded as a casual species in 1836. It is considered to be increasing in range and abundance, but most records are still classed as casual (Casarini, 2002; Bullock et al., 2010).

In Germany, *A. artemisiifolia* was first recorded in 1860, in Hamburg. It is believed that *A. artemisiifolia* was introduced with grain and seed shipments from the USA. Up until the 1970s, *A. artemisiifolia* was found in only a few areas but since the 1990s it has spread eastward. The species is mostly found in the south and east of the country (Alberternst et al., 2006) in areas where anthropogenic activity is the highest (Bullock et al., 2010). Zink et al. (2012) found that in north-eastern Germany the majority of the pollen originated in local areas; however, up to 20% of the total pollen load came via long-range transport from Hungary. Furthermore, according to Boehme et al. (2009) a substantial ratio of children was sensitized by ragweed pollen in Baden Wurttemberg.

In Belgium the species was first recorded in 1883 and has since become widely spread with most records from the north of the Samber-Meuse river corridor. The majority of the records are found in the more urbanised regions (Martin and Lambinon, 2008; Bullock et al., 2010).

For Denmark, the earliest record of *A. artemisiifolia* dates from 1865 but today it has only a limited distribution in the country. However, the species has been noted as spreading from the established areas (Bullock et al., 2010).

In Poland, *A. artemisiifolia* was first introduced into Szczepanowice (Silesian Lowland - south-western Poland) in 1873. It is also possible that the species may have been introduced as early as 1613 (Tokarska-Guzik, 2005). The species has since spread to southern and central-eastern Poland (Chlopek et al., 2011). The spreading rate is poorly understood since both the species and incidence of biological recording in the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1302_489512

country are increasing. However, in southern Poland *A. artemisiifolia* is supposed to have spread 30 km in the period 2007-2010 (Bullock et al., 2010; Chlopek et al., 2011). Ragweed pollen arrives in Poland from Slovakia, the Czech Republic and Austria (Kasprzyk et al., 2011). However, its most important source areas are the Pannonian Plain (Makra et al., 2010; Šikoparija et al., 2009; 2013) and the Ukraine (Rodinkova et al., 2012) not only for Poland but for all Central European countries. Their distribution here is limited to ruderal places, waste lands, lawns, sea ports, places near roads and railway tracks (Kasprzyk et al., 2011).

Concerning the Baltic area, ragweed is considered a casual species and the spreading rate is considered to be very low. *A. artemisiifolia* was first found in Lithuania in 1884, in Latvia in 1936 and in Estonia in 1954 (Tabaka et al., 1988; Gudžinskas, 1993; Saar et al., 2000). *A. artemisiifolia* is mostly recorded along railways and close to major cities (Herbarium of Institute of Biology of the University of Latvia) (Bullock et al., 2010; Šaulienė and Veriankaitė, 2012).

On the territory of Romania the species was first recorded in 1908 in Orsova (south-western Romania), the area belonged to the Austro-Hungarian Empire at the time (Jávorka, 1910). Recently common ragweed has extended its range across the entire country with the exception of the mountainous regions (Hodişan and Morar, 2008; Bullock et al., 2010). The agricultural areas have been greatly infested. *Ambrosia* has extended from the west and north-west towards the central and southern part of Romania and continues to extend to the east and north-east (Ianovici and Sirbu, 2007; Skjøth et al., 2010; Ianovici et al., 2013).

In Moldova, *A. artemisiifolia* was first reported at Ungheni (Borza and Arvat, 1935), downstream of the Nistru River (Marza, 2010). Since its introduction, the species has spread in the south-eastern part of the country (Bullock et al., 2010; Marza, 2010).

Ambrosia was introduced to Ukraine through a few trade routes in different years. A German pharmacist Krikker grew ragweed in the Dnipropetrovsk region as a medicinal plant (substitute for quinine and as an anthelmintic remedy) in 1914 (Mar'yushkina, 1986). Ragweed was first described in the Kyiv region in 1925. The army of General Denikin brought *Ambrosia* with seeds of alfalfa to Eastern Ukraine, so this weed was spread in Zaporozhye, Donetsk and Lugansk regions (Rodinkova et al., 2012). The next ragweed intervention to Ukraine was registered in 1946 when the first wheat consignment was shipped to USSR from USA.

This allergenic weed is currently found in all over the country. Ragweed is usually spread from southern and eastern parts of Ukraine toward north-west by transportation, with sunflower seeds contaminated by seeds of ragweed while they are transported from steppe to forest-steppe zone of Ukraine. Sensitivity of compromised children to *Ambrosia* pollen in 2000 was 3%, and in 2009 it was already 10% in the western part of Ukraine (Besh et al., 2011), which is consistent with a significant increase in *Ambrosia* pollen abundance (Palamarchuk et al., 2012).

In Russia, *Ambrosia artemisiifolia* was first recorded in the southern European part of the country in 1918 (Kovalev, 1989). The first occasional introductions were possibly connected with the increasing international trade via the Black Sea ports (Kovalev, 1989) and rail roads (Mar'yushkina, 1986). However, until the mid-sixties, there was no information on allergic properties of ragweed pollen in USSR (Ostroumov, 1964). Recently, almost 80% of the total square infested by common ragweed in Russia falls in Krasnodar territory (Moskalenko, 2002). Also Stavropol' territory, Rostov province and the Russian North Caucasus are highly infested extending southwards to Georgia.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1302_489512

Furthermore, Primorsk and Khabarovsk territories (Russian Far East) are another, relatively small, isolated areas of common ragweed invasion (Reznik, 2009).

Israel is also infected with *Ambrosia*. The invasion of new species of *Ambrosia* into Israel is still in progress, mainly in the eastern Galilee and in the Sharon plain (Waisel et al., 2008).

A. artemisiifolia is extensively distributed in Asia, North and South America and Australia (Lawalrée, 1953; Priszter, 1960). The dynamic spread of *A. artemisiifolia* in Turkey is a serious environmental issue (Kaplan et al., 2003; Zemmer et al., 2012). *Ambrosia* species extensively occur in large areas of India (Singh et al., 2004; Saha and Mishra, 2009), while Ballard et al. (1995) reported that *A. artemisiifolia* and *A. trifida* are important weeds of soybean plantations here. Ragweed invaded South Korea from Europe and North America (Kil et al., 2004), while Japan from North America (Fukano and Yahara, 2012). In Japan, pollen allergy due to *A. artemisiifolia* is the 2nd most important following Cryptomeria (Kazinczi and Novák, 2012). Populations growing in Japan produce less secondary metabolites than local plants but grow faster (Fukano and Yahara, 2012). In China, common ragweed was first documented in 1935 both in the north-eastern part of the country (Chen et al., 2007a; 2007b) and in Eastern China (Hangzhou, Jiangsu Province). Since that time on, ragweed has rapidly spread to northern, central and eastern China including over 15 provinces. Giant ragweed reportedly invaded Northeast China in the 1950s. By 1989, ragweed had expanded from centres in Shenyang, Nanjing, Nanchang and Wuhan to include 12 provinces (Wan et al., 1993; Li, 1997; Xie et al., 2001). Ragweed reated papers were published concerning the Jiangsu area (Zhan et al., 1993), the Shanghai area (Duan and Chen, 2000) and the Liaoning area (EPPO, 2013). The suitable areas for ragweed include almost exclusively the eastern, most populated part of the country with the Sichuan basin, supplemented with parts of Xinjiang Uygur Autonomous Region. This suggests that ragweed may be able to invade these areas in the future (Chen et al., 2007b). *A. artemisiifolia* is in abundance in the reaches of the Changjiang (Yangtze) River and along roadsides, while *A. trifida* along village paths and riverbanks in northeastern China (Wang et al., 1985). The species continue their southward spread into the subtropical regions of the country (Qin et al., 2012). The reason of the large-scale invasion of *A. artemisiifolia* in China is its great germination success over the highly variable climatic conditions (Sang et al., 2011). Li et al. (2012) found that high levels of genetic variation in China indicate that there has been no erosion of genetic variance due to a bottleneck during the introduction process. They also suggest that the successful invasion of *A. artemisiifolia* into Asia was facilitated by repeated introductions from multiple source populations in the native range creating a diverse gene pool within Chinese populations.

In the United States, the suitable region for ragweed involves almost exactly the eastern half of the country, including the Pacific coastal areas (Chen et al., 2007b). Here, in the home of *Ambrosia spp.*, duration of the ragweed pollen season has been increasing in recent decades as a function of latitude, in association with an enhanced warming (Ziska et al., 2011). In southern Québec (Canada), *A. artemisiifolia* has been present since at least 200 years but the species was probably restricted to the Montréal area during the 19th century (Lavoie et al., 2007). It is unclear whether common ragweed is native here or has been introduced from the Canadian Prairies (Rousseau, 1974; Bassett and Crompton, 1975). However, this species is clearly more widespread here today than at the beginning of the 20th century (Rousseau, 1974).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1302_489512

In South America, *Ambrosia* species are widely prevalent weeds (Sulsen et al., 2011; Masciadri et al., 2013).

In Australia, ragweed pollen is in the air in abundance for a sufficient length of time and its concentration to sensitize and provoke fall hay fever and asthma exacerbations (Bass et al., 2000).

Perspectives

At high CO_2 levels, *A. artemisiifolia* showed substantially greater biomass, as well as increased pollen production compared to those in ambient CO_2. Hence, ragweed pollen production can be expected to increase significantly under predicted future climate conditions (Wayne et al., 2002; Rogers et al., 2006).

Warming trends in long-term climate change involve greater exposure times to seasonal allergens that lead to higher risk potential of public health incidences (D'Amato and Cecchi, 2008; Shea et al., 2008).

In North America, duration of the ragweed pollen season has been increasing in recent decades as a function of latitude (Ziska et al., 2011). For Europe, future spread of ragweed will depend on the climate and land use change. Based on different models, ragweed will spread north (e.g. Germany, Poland, northern part of the European Russia) with a warmer climate compared to its current range, bringing severe impacts to areas that have yet been suffering slightly (Bullock et al., 2010; Cunze et al., 2013).

Nevertheless, there is some evidence to suppose that very high temperatures are harmful for ragweed. The highest increase in the mean temperature, especially in summer time (August), represents a limit for pollen production of *Ambrosia*. In this period, the loss of water makes a difficulty for phyto-physiological processes, so in order to save water the plant reduces its pollen production. This effect will limit the climate change related expansion of ragweed (Makra et al., 2011).

Concerning future economic expenses of *A. artemisiifolia* for Europe, without controls the influence of climate change will increase the medical and work productivity costs, but the agricultural costs will reduce. This suggests that, due to the climate change, agricultural areas will reduce and pollen sensitivity will increase in the population (Bullock et al., 2010).

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