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Expansion of the range of the introduced moth *Acontia candefacta* in southeastern Europe

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Abstract

The nearctic moth *Acontia candefacta* (Lepidoptera Noctuidae) is expanding its range in Europe. The species is considered a successful agent for biological control of *Ambrosia artemisiifolia* (Asterales Asteraceae), a weed whose pollen causes allergies in humans. A few additional findings of the moth have been recorded at several new sites in southeastern Europe (Serbia) using light trapping. We here present and discuss the current distribution of the moth in Europe and the paths of its spreading on the basis of GIS data. GIS technology was used to map the distribution and quantify values of environmental variables within the range of the analysed moth species. Additionally, the potential colonization of the moth across Europe is modelled on the basis of its current distribution, environmental variables and the host plant's distribution.

Key words: *Acontia candefacta*, olive-shaded bird-dropping moth, *Ambrosia artemisiifolia*, distribution, Europe, invasive alien species, Noctuidae.

Introduction

Ambrosia artemisiifolia L. (Asterales Asteraceae) (the common ragweed), native to North America, was introduced to Europe in the second half of the 19th century, where it rapidly enlarged the area of its distribution across the continent. It is linked to human-disturbed habitats and cultivated areas, where it causes significant losses to agriculture. A major weed in European agriculture, it causes serious damage worth millions of Euro to spring-sown crops such as sunflower, maize, sugar beet and soybean (Kőmives *et al.*, 2006). In addition to crop losses, cattle may eat *A. artemisiifolia* after grasses have been exhausted, which changes the flavour of the milk, thereby producing an undesirable product (Spencer, 1957). It is considered a serious health problem as well, since the pollen is highly allergenic to humans (Rybncek and Jäger, 2001). The presence of *A. artemisiifolia* can degrade the biological diversity of species in the region and may be destructive to its flora (Siniscalco and Barni, 1994; Moskalenko, 2001).

A. artemisiifolia has a very wide distribution across a significant part of Europe, stretching from the United Kingdom in the west, across Central Europe and into the Carpathian basin in the east (Bullock *et al.*, 2010). The southern and coastal regions of Scandinavia and Finland also show relatively significant populations at this time. In Mediterranean countries, abundant occurrences of *A. artemisiifolia* have been recorded in southern France, northern Italy and the northwestern and western parts of the Balkan Peninsula (Cunze *et al.*, 2013) (figure 1A). The southern limit of the species' range currently lies in the Mediterranean region, where records in southern Italy and on the Iberian and Balkan Peninsulas become sparse. In Poland and to the east and north of the Carpathian basin, the records also become more sporadic as the species appears to find its eastern and northern limits (Bullock *et al.*, 2010).

The highest number of records of *A. artemisiifolia* occur in the Rhône Valley (France), Hungary, Serbia (Vrbničanin *et al.*, 2008; Petanović *et al.*, 2014) and the Netherlands, while the records of its presence are somewhat more sporadic and less extensive in the United Kingdom, Germany, Scandinavia and Finland (Bullock *et al.*, 2010). The populations in other European regions are neither as dense nor as extensive as the ones in the aforementioned key regions (Bullock *et al.*, 2010).

Biological control of *A. artemisiifolia* has been performed with success in China and Australia (Palmer *et al.*, 2010; Zhou *et al.*, 2010a; 2010b), but it has not been successful in Europe. As for the possibility of biological control in Europe, seven phytophagous insects and one rust pathogen from the native North American range of the plant are considered the most promising candidate species for biological control of *A. artemisiifolia* in Europe (Kiss *et al.*, 2008; Gerber *et al.*, 2011; Müller-Schärer *et al.*, 2014). They are as follows: the pollen feeder *Trigonorhinus tomentosus* (Say) (Coleoptera Anthribidae); two seed feeders - *Smicronyx perpusillus* Casey (Coleoptera Curculionidae) and *Euaresta bella* (Loew) (Diptera Tephritidae); four defoliators - *Zygogramma disrupta* (Rogers) (Coleoptera Chrysomelidae), *Ophraella slobodkini* Futuyma (Coleoptera Chrysomelidae), *Ophraella communa* LeSage (Coleoptera Chrysomelidae) and *Acontia candefacta* (Hubner) (Lepidoptera Noctuidae) (olive-shaded bird-dropping moth); and the leaf pathogen *Puccinia xanthii* Schwein. (Basidiomycota Pucciniaceae) (Conner *et al.*, 2000; Charudattan, 2001; Gerber *et al.*, 2011; Müller-Schärer *et al.*, 2014).

The phytophagous insect fauna associated with *A. artemisiifolia* was widely investigated in southern California during the 1970s (Goeden and Ricker, 1976). Historically, *A. candefacta* is the first insect species that was intentionally introduced into Europe for biological

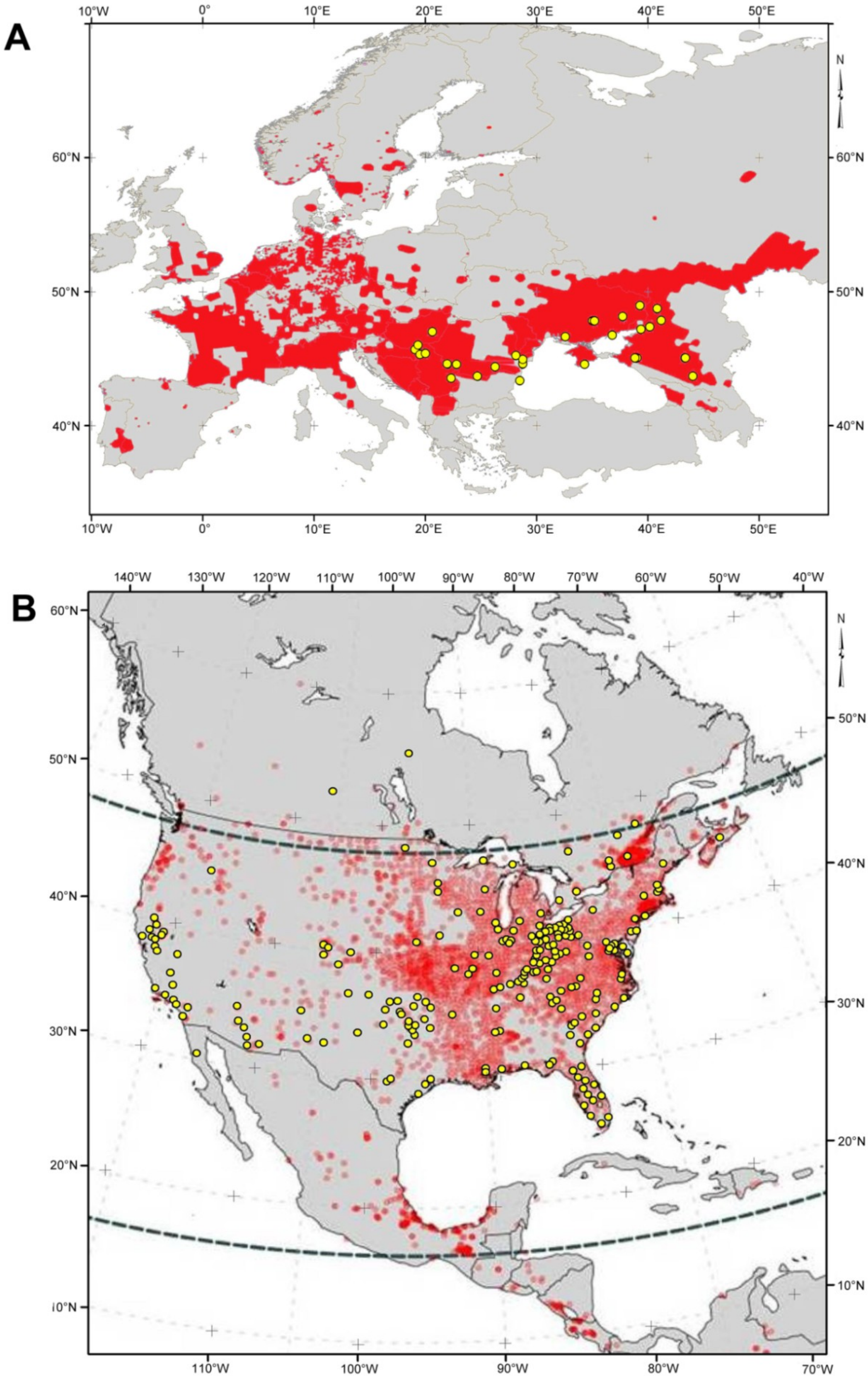

Figure 1. Area of distribution of *A. artemisiifolia* (red zones) and *A. candefacta* (yellow dots). **A:** The range in Europe. The weed's distribution is based on the information of more than 40 national distribution maps and international databases combined with the European GBIF records (modified after Cunze *et al*., 2013) (GBIF.org). Projection: WGS-84; **B:** The range in North America. The weed's distribution is based on GBIF occurrence data in North America. The grey dashed line indicates the 95% north-south extent of GBIF occurrences (modified after Leiblein-Wild *et al*., 2016) (GBIF.org). Projection: Lambert.
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control of an invasive weed species (Goeden and Ricker, 1976; Kljuchko *et al*., 2004; Poltavsky and Artokhin, 2006). The species was introduced into territory of the Krasnodar and Stavropol regions in the former USSR (now southern Russia) in 1969 (figure 2A), but it recently expanded its range (Poltavsky and Artokhin, 2006; Poltavsky *et al*., 2009). The population density in 2005 in the Rostov province was up to three eggs per plant and one caterpillar per 1 m^2 (Poltavsky and Artokhin, 2006). The increased abundance was attributed by Poltavsky and Artokhin (2006) to the influence of global warming (the winters were unusually mild and moist).

The life cycle of *A. candefacta* is dynamic, involving 2-4 generations from May to September (Kovalev and Runeva, 1970; Covell, 1984). Each female moth produces 300-500 eggs and lives for 15-30 days. The minimum temperature for flight is 15 °C. The caterpillars feed on leaves of the host plant and require 13-25 days for development (Gilstrap and Goeden, 1974). The host range includes several Asteraceae species, mostly *Ambrosia* spp. (Robinson *et al*., 2010). In the Nearctic, the hosts are *A. artemisiifolia*, *A. psilostachya* DC., *Arctium lappa* L. and *Symphyotrichum dumosum* (L.) G. L. Nesom, while in the Holarctic (Europe), the only host recorded so far is *A. artemisiifolia* (Robinson *et al*., 2010). Since it might attack plants other than *A. artemisiifolia* (non-target ones, of which *A. psilostachya* and *A. lappa* are also distributed in Europe), it is important to follow its further spread. The caterpillars pupate in the soil and the pupae overwinter (Kovalev and Runeva, 1970).

An additional three insect species (*E. bella*, *T. tomentosus* and *Z. disrupta*) were first proven to be sufficiently specific in host specificity tests performed in Russia and were afterwards released, but did not become established there (Julien and Griffiths, 1998; Gerber *et al*., 2011). In 1978, *Zygogramma suturalis* (F.) (Coleoptera Chrysomelidae) was released in the northern Caucasus, Kazakhstan, Georgia and Ukraine, and then became established in the former two areas (Julien and Griffiths, 1998). After this, the species was released in 1985 and 1990 in Croatia. The first results with the beetle were very promising, but it was later shown that it is not able to control *A. artemisiifolia* efficiently (Reznik, 1991; Dhileepan *et al*., 2000; Reznik *et al*., 2007; Hasan and Ansari, 2016). Regarding the fungal pathogens, epidemics of *Phyllachora ambrosiae* (Berk. et M. A. Curtis) Sacc. and *Plasmopara halstedii* (Farl.) Berl. et De Toni at first affected *A. artemisiifolia* in Hungary (Vajna *et al*., 2000; Vajna, 2002), but several years later did not (Kiss, 2007). Thus, a complex of several biological agents could be used to influence *A. artemisiifolia*, but the control agents should be successful and safe.

A. candefacta was recently recorded in the Lugansk and Donetsk regions and in the Crimea in Ukraine (Kljuchko *et al*., 2004; Rennwald, 2011; 2012) and in the northern part of the Rostov-on-Don region in Russia (Poltavsky *et al*., 2005). The species subsequently migrated both east (to the Kabardino-Balkar Republic, northern Caucasus Mts., Russia) (Poltavsky, 2007) and west (to Zaporozhye and Cjurupinsk near Cherson, southeastern Ukraine) (Lehmann, 2007), with further westward expansion of its range through the steppes north of the Black Sea. The first finding on the Balkan Peninsula was reported on 18 May 2009 in Bulgaria (at Karaboaz near Gulyantzi) (Beshkov, 2010). It was later found from May to August 2008-2010 in Romania (in northern Dobrogea and the environs of Bucharest) (Rákosy and Mihai, 2011; Székely *et al*., 2011), from where its original range expanded into the southern part of the country (Oltenia) (Rennwald, 2013). After entering the Balkans, the moth continued to spread westward following the course of the Danube river, but also southward along the coast of the Black Sea (Balgarevo, Kaliakra, Bulgaria; Székely *et al*., 2011). According to the newest data (Stojanović *et al*., 2011; Szeőke, 2012), the range of the mentioned species now reaches Central Europe, having expanded along the course of the Danube through Serbia. It was reported for the first time in Serbia on 10 August 2009 (Stojanović *et al*., 2011). The northernmost finding was registered in Mezőtúr (Hungary) on 17 September 2012 (Szeőke, 2012). Until now it was not possible to determine the paths of its migration, dynamics of its spreading or abundance of its populations.

The finding of *A. candefacta* in the Đerdap National Park (eastern Serbia) on 10 August 2009 (at the Kurmatura - Šomrda site) (Stojanović *et al*., 2011) at a distance of about 1,200 km northwest of the site of its introduction into Europe more than 40 years ago suggests that recent climate changes might be mostly responsible for further spreading of the species in Europe in certain habitat types, since expansion of the range of the host plant, *A. artemisiifolia*, in Europe is promoted by climate change (Mazzi and Dorn, 2012; Cunze *et al*., 2013). If this be the case, it might be expected that the area of distribution of *A. candefacta* in Europe could expand similarly, due to climate changes, following the host plant's spread. If climate change in Europe continues, further radiation of both the host plant and the moth might be expected in the future. This is supported by Poltavsky and Artokhin (2006) and Essl *et al*. (2015), who stated that the moth initially suffered from the harsh continental climate in the region where it was introduced, but that a series of mild winters between 2002 and 2005 has since promoted the build-up of large populations. Other factors might have partially played a role in the moth's recent expansion since temperatures started to increase in the late 1970s (Dai *et al*., 2011).

For most ecological studies, we need more spatially explicit and quantified information about the factors that might actually explain the observed environmental variables, distributions and patterns of landscape features (Radović *et al*., 2005; 2014; Ćirović *et al*., 2008; Denoël *et al*., 2009; Stevanovic *et al*., 2013; Simeunović *et al*., 2014).

The aim of the present study is to report the newest findings of *A. candefacta* in Europe and analyse the paths of its spreading on the continent using available GIS data. In this study GIS technology was used to map the distribution and quantify values of environmental variables within the range of the moth *A. candefacta*.

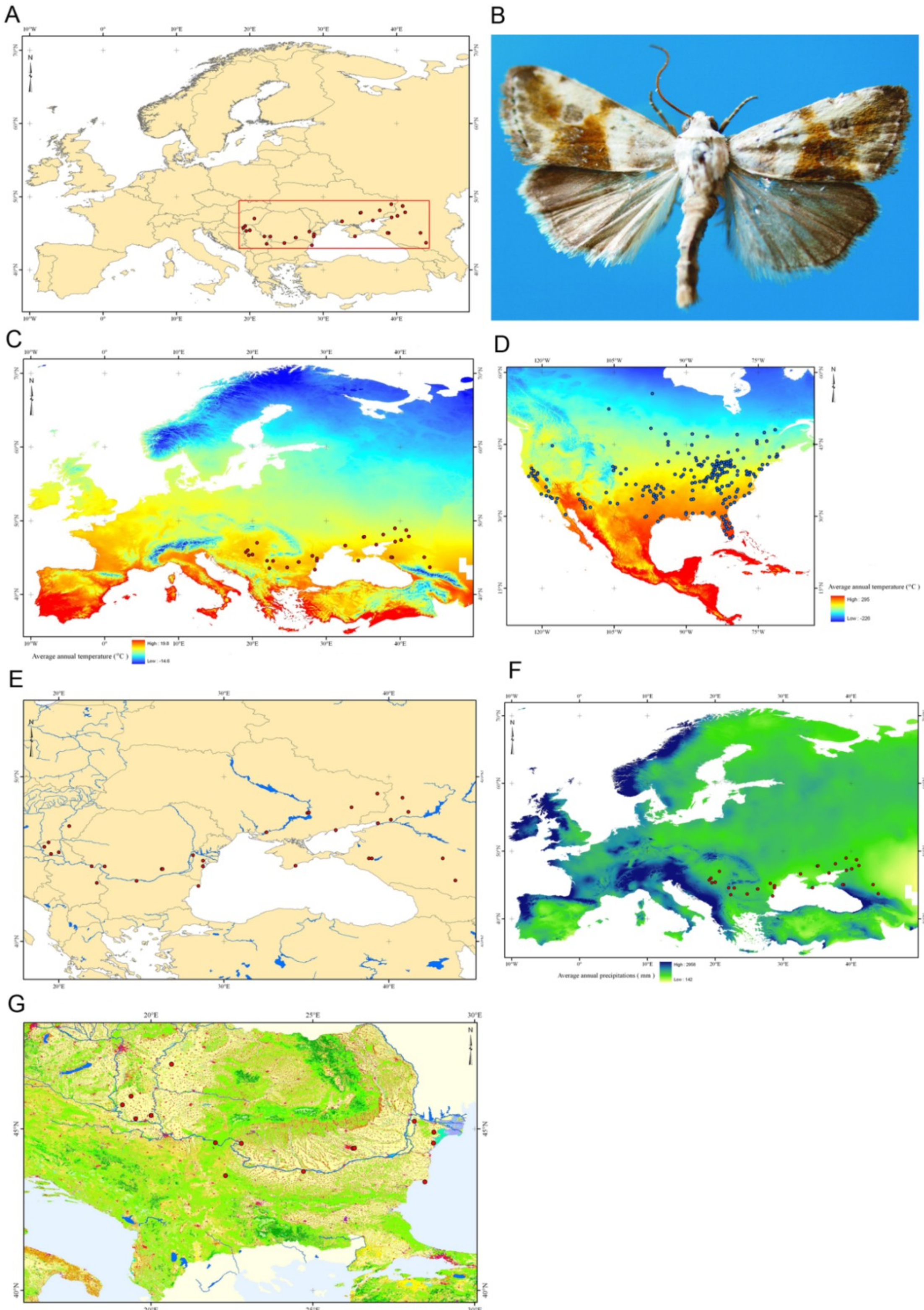

Figure 2. The olive-shaded bird-dropping moth *A. candefacta*. **A:** Range in Europe (within the red rectangle). The red dots represent locations of findings of the moth, while the grey lines are country borders; **B:** *A. candefacta* male (wingspan of about 19-23 mm); **C:** Range in Europe on digital model of average annual temperature. The red dots represent locations of findings of the moth; **D:** Range in North America on digital model of average annual temperature (after Bugh *et al*., 2006). The blue dots represent locations of findings of the moth; **E:** Range in Europe in relation to vicinity of major rivers and lakes (blue surfaces). The red dots represent locations of findings of the moth; **F:** Range in Europe on digital model of average annual precipitation. The red dots represent locations of findings of the moth; **G:** Corine Land Cover 2006 data and range in Bulgaria, Romania, Serbia and Hungary. The blue surfaces are major rivers and lakes, while the red dots represent locations of findings of the moth.
(In colour at www.bulletinofinsectology.org)

Materials and methods

Adult specimens of *A. candefacta* were caught by light traps of two types: a TEŽ WTF trap, consisting of a 400-W light bulb with a piece of cotton canvas behind it (used in eastern and southeastern Serbia); and an RO Agrobečej trap, containing a 250-W mercury bulb as the light source (used in northern Serbia). Sampling was performed from 2009 to 2015 over a huge area in Serbia (at more than 100 sites throughout the whole of the Vojvodina province and in nearly all regions of Serbia proper) at different altitudes and in several types of terrestrial habitats (forests, grassland). Moths were collected during 2009-2015 at the following six sites in Serbia: Kurmatura - Šomrda, near Donji Milanovac, Đerdap National Park; Baranica, near Knjaževac, Stara Planina Mts.; Sombor (the southern suburban part of the city); environs of Čelarevo, near Bačka Palanka (a few km north of the village); environs of Bajmok, near Subotica (north of the village); and Gospođinci, near Žabalj (supplemental material table S1). Light trapping at the sites in northern Serbia lasted from 10 April to 10 October every night each year (184 nights per year) (in Sombor - from 1994, in the environs of Čelarevo - from 2008, in the environs of Bajmok - from 2014), while at the sites in eastern and southeastern Serbia it lasted from February to November each year (2010-2014). The moth specimens were gathered with an entomological net in the vicinity of the light source, as well as directly at the lamp. Moth collecting in eastern and southeastern Serbia was done at night and lasted about seven hours per night, from 20:00 to 3:00, while in northern Serbia it was done at night, from sunset to sunrise. Specimens were killed by putting them in modified killing jars with diethyl ether, which was used for narcosis and neutralization. Morphological characteristics of the wings (figure 2B) and chitinous armatures of the male genital apparatus were used for both taxonomic analysis and determination of the specimens. *A. candefacta* can be reliably identified on the basis of morphology of the wings (figure 2B) and the male and female genitalia (Lehmann, 2007). It can be readily distinguished from related taxa due to its smaller size (19-23 mm wingspan) and different wing pattern, one of the most obvious features of which being the lack of a well defined black submarginal band on the hindwings (Székely *et al*., 2011). Analysis of genital structure was performed according to the standard method (Hardwick, 1950; Fibiger *et al*., 2009). The posterior part of the abdomen was carefully removed with a forceps from fresh or dry specimens, then macerated and stored in a vial filled with 10% KOH. The material was subsequently immersed in a bath of boiling water, after which permanent microscope slides were made. Prepared adult moths of both genders are deposited in the private collections of the first and second authors of the present paper, along with durable preparations of the chitinous genital armatures. The most important morphological features of the specimens were photographed with a special digital photo accessory on a Carl Zeiss Stemi 2000 stereomicroscope. Photographs were processed using Motic® image stacking software. Classification and nomenclature follow Fibiger *et al*. (2009).

The vector (point) data refer to locations of data sampling, state borders and hydrological features (rivers and lakes), in addition to which Corine Land Cover (CLC) seamless vector data (European Environment Agency, 2006) are also presented. Corine Land Cover data are available for Serbia, Hungary, Bulgaria and Romania. We used the WorldClim - Global Climate Data (Hijmans *et al*., 2005) digital model of average annual temperature and digital model of average annual precipitation. The vector data and the database were integrated, analysed and printed with GIS software (ArcGIS 9).

We mapped 30 locations of moth sample collection in different parts of Europe, six of which are in Serbia (other sampling data came from Russia, Ukraine, Romania, Bulgaria and Hungary). This enabled us to create a table (supplemental material table S2) with site names, average annual temperature (°C), average annual precipitation (mm), CLC type and altitude (m a.s.l.) at points of sampling of the moth *A. candefacta* in Europe.

For mapping purposes, we used data on the occurrence of *A. artemisiifolia* in Europe and North America provided by the Global Biodiversity Information Facility (GBIF) (GBIF.org). Additionally, we also gathered data on the distribution of *A. artemisiifolia* in Europe available in cells with grids measuring 50 km × 50 km based on the information of more than 40 national distribution maps and international databases (Cunze *et al*., 2013; Leiblein-Wild *et al*., 2016).

The possible spreading of *A. candefacta* in Europe is modelled by combining several things, viz., the distributions of *A. artemisiifolia* and *A. candefacta* in Europe and environmental variables obtained from data on the present distribution of *A. candefacta* on the continent (average annual temperature, average annual precipitation and altitude).

The area where the moth could further spread in Europe is calculated as the intersection where the three tested environmental variables were within the defined values for the moth species and where *A. artemisiifolia* is present, assuming the extracted area in Europe to be favourable for the further expansion of *A. candefacta*.

Results

New findings of adults of *A. candefacta* in Europe were recorded from a total of five locations in Serbia (supplemental material table S1). Although a number of other sites representing different habitat types were visited throughout the country, no additional finding of the moth was reported. The collected specimens were active at night (the specimens from southeastern Serbia were caught in the vicinity of the employed light trap around midnight), but we observed and photographed one specimen in daylight during the morning hours on the stem of a carrot growing on a carrot plantation (Gospođinci, near Žabalj, 8th September 2015). Unlike the other specimens, which were collected in places with the presence of *A. artemisiifolia*, the moth specimen recorded in daylight was collected at a site with no any evidence of *A. artemisiifolia* in the surroundings over a distance of approximately 500 m.

The moth has been reported for the following European countries: Russia, Ukraine, Romania, Bulgaria, Serbia and Hungary (figure 2A). Its range is spreading westward in Europe (toward North America). The appearance of adults (including those of the population in Serbia) is recorded during the period from May to September. The list of sampling dates in Serbia (supplemental material table S2) indicates that the moth was collected in eastern and southeastern Serbia from the end of July to the beginning of August (2009 and 2012), while in northern Serbia it was found more frequently and in longer annual periods (from the beginning of May to the beginning of September 2012-2015), as was previously reported in the literature (Covell, 1984). The species was recorded the greatest number of times (22) in August, considerably less frequently in July (six times) and only once in each of the following months: May, June and September (supplemental material table S2).

The moth prefers lower altitudes, from sea level (0 m a.s.l.; the Sea of Azov coast in Ukraine) up to altitudes of several hundred metres (468 m a.s.l.; Kurmatura - Šomrda site in Serbia) (supplemental material table S2). It primarily inhabits plains, but recent findings in Serbia from Mt. Miroč (468 m a.s.l.) and in the Stara Planina Mountains (375 m a.s.l.) indicate the possibility of inhabiting the slopes of mountains and lower mountains as well.

The range of average annual temperature at the analysed sites is from 8 °C (Lugansk region, Ukraine) to 12.2 °C (Balgarevo, Kaliakra, Bulgaria), the mean value being 10.4 °C (supplemental material table S2). It can be asserted that the moth inhabits European areas where the average annual temperature is relatively high or moderate (figure 2C), as is the case in North America as well (figure 2D).

In Serbia, if not present directly by rivers (the Danube and tributaries), the moth can be found by artificial channels filled with water (the findings in northern Serbia).

The sites in Europe where the moth has been recorded are characterized by average annual precipitation in the range of 409 mm (Histria, northern Dobrogea, Romania) to 735 mm (Elizavetinskaya, Russia), the mean value being 547.2 mm (supplemental material table S2). The moth prefers relatively dry or moderately humid areas (figure 2F).

By consulting available Corine Land Cover data, we obtained information concerning the types of areas, vegetation and habitats in Europe where *A. candefacta* lives (supplemental material table S3 and figure 2G). The CLC codes at the locations were as follows: 211, 231, 243, 321 and 511 (supplemental material table S3). On plains (Vojvodina province in Serbia, Dobrogea in Bulgaria, the Danubian plain in Bulgaria), the species is chiefly associated with arable land in agricultural areas (211) and somewhat less often with pastures in agricultural areas (the case of the site on the Danubian plain) (231). At somewhat higher altitudes in Romania (Oltenia) and Serbia (Mt. Miroč and the Stara Planina Mountains), the moth inhabits land principally given over to agriculture, with significant areas of natural vegetation. In the case of the finding on the coast of the Black Sea in Bulgaria, it lives there in a natural grassland consisting of associations of scrub/herbaceous vegetation (321). The occurrence of ruderal plants is observed at the analysed sites, such plants including the moth's host plant (*A. artemisiifolia*). The finding in Mezőtúr (Pannonian plain of Hungary) confirms the fact that it follows inland watercourses (511).

The available data indicate that *A. candefacta* is found in Europe between 43 and 49°N (from the site on the coast of the Black Sea in Bulgaria to places in the vicinity of the Don river in Russia) and between 19 and 44°E (from northern Serbia to the northern Caucasus in Russia) (figure 2A).

Figure 1A shows the distribution of *A. artemisiifolia* in Europe and the locations where samples of *A. candefacta* were collected on the continent, while figure 1B shows distribution of the weed and that of the moth in North America. These maps are useful for suggesting that the moth is simply spreading to areas where the weed is present, and can help to predict where it may spread in the future. Figure 1A is particularly informative for areas in which the moth has been present for decades (e.g., the Krasnodar and Stavropol regions in Russia), where the moth occupies only a narrow range of habitats with the weed, suggesting that factors other than host availability can determine its geographic range. From analysis of figures 1A and 1B, it is obvious that the distributions of the weed and the moth for the most part overlap, indicating that spreading of the moth, apart from other factors, is under strong influence of the host plant's distribution.

A model of the possible paths of further spreading of the moth in Europe is presented on the basis of intersection of environmental parameters obtained from the sampling locations (average annual temperature, average annual precipitation, altitude) and current distribution of the host plant (*A. artemisiifolia*) on the continent (Cunze *et al*., 2013; Leiblein-Wild *et al*., 2016) (figure 3). The populations of *A. candefacta* from the Bačka region (northern part of the Vojvodina province in Serbia) might migrate inland both to the west and north toward the Western Carpathians and Eastern Alps (following the course of the Danube and smaller rivers), which represent natural barriers preventing its further spreading northward. The population from eastern Serbia could follow the Danube river westward to reach the Banat region in both Serbia and Romania, and also migrate toward the north, where suitable environmental conditions for the moth and the host plant occur. Moreover, the moth could expand its range following major tributaries of the Danube, migrating westward to inhabit lowland areas by the Sava and Drava rivers, northward along the Tisza river on the Pannonian Plain and southward through the valley of the Morava river (figure 3).

Discussion

The newest data obtained in monitoring the spread of *A. candefacta* in the Republic of Serbia suggest that the area of distribution of the moth in Europe might be expanding parallel with the radiation of *A. artemisiifolia* due to climate changes (Poltavsky and Artokhin, 2006;

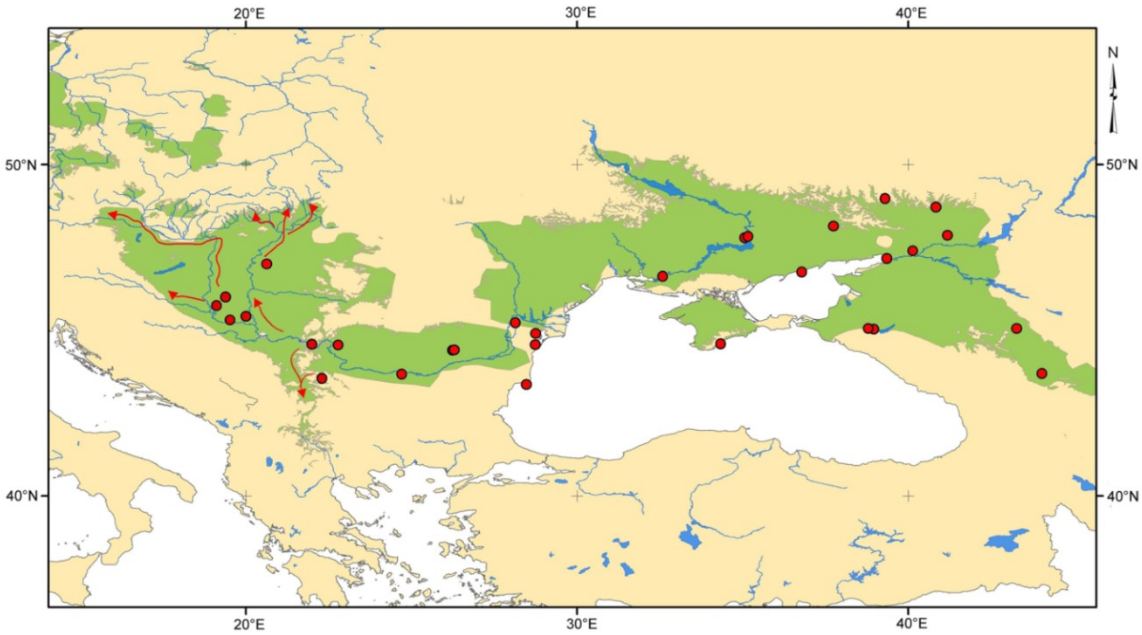

Figure 3. Area of distribution of *A. candefacta* in Europe (red dots) and possible directions of its further spreading on the continent. The blue surfaces are major rivers and lakes, the red arrows indicate possible directions of the moth's further expansion, while the green areas represent a calculated clip combining values of three environmental variables (altitude, average annual temperature, average annual precipitation) favourable for occurrence of *A. candefacta* and distribution of *A. artemisiifolia*.
(In colour at www.bulletinofinsectology.org)

Stojanović *et al*., 2011; Essl *et al*., 2015; current study) (figures 1A, 2A, and 2E). The second finding in the country, at the Baranica site, confirmed expansion of the range of the species along a right-hand southern tributary of the Beli Timok river (which merges with the Crni Timok to form the Timok, a tributary of the Danube) on the eastern border of the foothills of the Stara Planina Mountains at a distance of about 115 km south of the first finding place in Serbia (Kurmatura - Šomrda) (Stojanović *et al*., 2011), around 120 km away from the latest finding in Romania (2 km northeast of Hinova, Mehedinţi, Oltenia) (Rennwald, 2013) and about 200 km southwest of the site of the first Bulgarian finding (Karaboaz near Gulyantzi) (Beshkov, 2010). The most recent findings of *A. candefacta* recorded in the Vojvodina province (the northernmost findings in Serbia), in places located more than 250 km north of the first finding site in Serbia (Kurmatura - Šomrda) (Stojanović *et al*., 2011) and about 170 km south of the only finding site in Hungary (Mezőtúr) (Szeőke, 2012), confirm expansion of the moth's range up the Danube towards Central Europe.

The moth's presence and spreading are associated with the proximity of water, either stagnant or flowing, where the host plant exists (Székely *et al*., 2011). Up to now the moth has been reported in the drainage basin of the Black Sea, including sites located on the coast and along the great rivers (the Danube, Don and Dnieper) and smaller ones (e.g., the Tisza and the Timok, tributaries of the Danube) as well (figure 2E).

The moth has followed a restricted path of dispersion in Europe from the place of its introduction westward between 43 and 49°N (figure 2A). A clear trend of migration towards the place of origin in the west (North America) is observed. Comparison with the distribution in North America (in both Canada and the USA) (figure 2D) shows that the moth lives in the same range of geographic latitudes there, but has a distribution that is somewhat wider in the south. The temperature affinities of the moth are similar in both the European and North American populations.

To date, *A. candefacta* has not been recorded in western, central or southern Serbia. Systematic investigations need to be performed over the course of several seasons on the whole territory of Serbia in order to clarify the precise time of the moth's appearance. The spread of the moth seems to depend primarily on the presence of its host plant. Specimens from Serbia have been collected in both steppe and ruderal habitats on agricultural land (either arable or with significant areas of natural vegetation) inhabited by *A. artemisiifolia* where the soil was predominantly chernozem (the case of the findings in northern Serbia) (supplemental material table S3). The host plant in Serbia is chiefly distributed in the northern and central parts of the country (on plains and by river courses) (Vrbničanin *et al*., 2008; Petanović *et al*., 2014), where populations of *A. candefacta* have been recorded as well. On the coast of the Black Sea, the moth prefers habitats with sandy and salty soil (Beshkov, 2010). Its occurrence there is associated with rather low altitudes and the presence of rivers/channels in the vicinity. *A. artemisiifolia* develops in open, disturbed areas such as fields, wastelands, roadsides and riverbanks (Fumanal *et al*., 2006). It is rather indifferent to soil type and will thrive in soil containing large amounts of clay, gravel or sand (Landolt, 1977).

A. candefacta is capable of following *A. artemisiifolia* into new areas probably because the habitats of the moth and the host plant and soil types preferred by them overlap. Cases of its attacking plants other than *A. artemisiifolia* in Europe have not been recorded, either by previous researchers or by us. However, this might be possible since the moth in North America can feed on other Asteraceae (among which *A. psilostachya* and *A. lappa* are distributed in Europe as well), so eventually it might affect non-target plants belonging to the family Asteraceae in the new areas it has invaded. Currently, the moth has a rather narrow potential for controlling *A. artemisiifolia* in the new areas it has invaded and no natural outbreaks in abundance of the species have been recorded so far (Kljuchko *et al*., 2004; Poltavsky *et al*., 2005; Poltavsky, 2007; Lehmann, 2007). Moreover, the number of adult specimens collected by light traps in the Vojvodina province of Serbia was relatively low in spite of the fact that the traps were positioned in habitats covered with dense populations of *A. artemisiifolia*. Additionally, no caterpillars were found there on the host plant. It seems that current populations of the moth in Europe are not capable of controlling *A. artemisiifolia*, but the moth can be artificially bred in the laboratory and then introduced in great numbers into natural settings inhabited by the host plant.

The abundance of moth specimens collected in Serbia is relatively low (1-5 specimens per each site) (supplemental material table S1). Comparison of the abundance of specimens recorded at the collecting sites in northern Serbia in 2015 and prior to that year (2012-2014) shows that a somewhat higher number of them was recorded in 2015 (26 vs. 10). The number of collected specimens per site was also higher in 2015 compared with previous years (1-5 vs. 1-2) (supplemental material table S1).

Since we used the method of moth collecting by light traps, we were unable to detect evidence of leaf damage on *A. artemisiifolia* at the sampling sites. The collected moth specimens were active at night, and the one specimen recorded during the daytime was not active. Proximity of the host plant (*A. artemisiifolia*) was observed in all cases except for the moth specimen noticed in daylight on a carrot plantation.

With respect to the state of the population of *A. artemisiifolia* in Europe (Smith *et al*., 2013), the greatest density of the weed and highest average values of its pollen index have to date been recorded in areas north of the Black Sea, in the northern and central Balkans and in Central Europe, which corresponds to the current European range of *A. candefacta.* A somewhat lower plant population density is observed both in the north and in the south. Due to climate changes, *A. artemisiifolia* in Europe is predicted to further expand westward, southward and eastward in the future (Cunze *et al*., 2013; Hamaoui-Laguel *et al*., 2015).

On the basis of the current distribution of *A. artemisiifolia* in Europe and available GIS data on environmental variables obtained from locations of *A. candefacta* sampling in Europe, we have mapped a model of possible paths of the moth's further spreading in Europe over a short-term period ahead (figure 3). Any long-term prediction of its migration in Europe (including a similar prediction for *A. artemisiifolia*) depends mostly on global climate changes (presumably warming) (Cunze *et al*., 2013) and cannot be performed at the moment with the data we currently possess.

Conclusions

New findings of *A. candefacta* in Europe are indicated in the present paper. The presence of the species in Serbia is confirmed (Stojanović *et al*., 2011). The living world is under the influence of climate fluctuations and represents the most reliable indicator of the climate type of a given landscape. We assume that the further spreading of *A. candefacta* in Europe is probably closely linked with ongoing climate changes and further expansion of the host plant (Chen and Chen, 2013; Cunze *et al*., 2013). New findings of the moth in Europe will help us to predict future paths of expansion. The range of *A. candefacta* in Europe will probably expand in the time to come due to suitable climate conditions for its development there. It is therefore necessary to follow the expansion and appearance of the moth at other localities in the future. The moth's typical habitats need to be elucidated, as well as its ecology under the climate conditions prevailing in the Balkans and other areas in Europe where the species is present. Future studies should be devoted to gaining an understanding of the precise role of the moth as an agent for biocontrol of *A. artemisiifolia*.

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