

Alien Species of *Lepidium* in the Flora of Romania: Invasion History and Habitat Preference

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Abstract

The history of spread and habitat preferences during invasion of four alien species of *Lepidium* in Romania, namely *L. densiflorum*, *L. oblongum*, *L. sativum*, and *L. virginicum* are presented in this paper. The floristic records of these species, collected between 1816 and 2013, were used in the study. *L. sativum* was sporadically mentioned by earlier botanic references, as a casual alien plant in ruderal places. *L. oblongum* was reported from a single locality, but it may be considered a potential invader of ruderal habitats from southern regions. For *L. densiflorum* and *L. virginicum*, distribution maps were made in the Universal Transverse Mercator system, and exponential regression models were fitted to the cumulative number of records against time. Both *L. densiflorum* and *L. virginicum* are invasive in Romania, and their spread was initiated at the middle of last century. The slope of invasion curves, which was used as a measure of the invasion rate, did not differ significantly between the two invasive species. Although both *L. densiflorum* and *L. virginicum* were first reported in the North-West of the country, they followed different paths of migration in Romania. Ruderal habitats associated with railways played an important role in the invasion process of both species, but invaded habitats became more diversified over the time. Among the four species, only *L. densiflorum* tends to invade agricultural crops.

Keywords: distribution map, herbarium specimen, non-native weeds, transportation routes

Introduction

The genus *Lepidium* L. is one of the largest genera in the *Brassicaceae* family, being distributed on all continents, except Antarctica (Al-Shehbaz and Gaskin, 2010). In the alien flora of Europe, the genus *Lepidium* is currently represented by 20 species, of which 11 are from outside of Europe, and nine are native in certain regions of the continent, but alien outside of their native range (Drake, 2009). Among these, three species were recorded in Romania (Ciocârlan, 2009), namely: *L. virginicum* L., *L. densiflorum* Schrader (including *L. neglectum* Thell.), and *L. sativum* L. All these three species are listed among the most widespread alien plant species in Europe (Lambdon *et al.*, 2008). A fourth alien species, *L. oblongum* Small, was newly reported from Romania by Sîrbu and Oprea (2011).

In order to understand causes of invasions, and develop successful management strategies for invasive alien species, a useful tool is the reconstructing of the spread history of invasive plants, using data from herbaria (Chauvel *et al.*, 2006; Crawford and Hoagland, 2009; Csontos *et al.*, 2010;

Delisle *et al.*, 2003; Lavoie *et al.*, 2007), monographs (Mihulka and Pyšek, 2001), or from multiple floristic sources in a given region (*i.e.* herbaria, literature and unpublished records) (Essl *et al.*, 2009; Pyšek and Prach, 1993; Williamson *et al.*, 2005). Maps based on historical floristic records can indicate points of introduction, invasion pathways, rates of spread and other data on the spreading of alien plants in the invaded areas (Csontos *et al.*, 2010; Lavoie *et al.*, 2007).

In this study, we aimed to reconstruct the history of spread and habitat preferences of alien species of *Lepidium* in Romania, using all the available data from herbaria and literature, as well as our own recent unpublished records.

Materials and methods

In order to reconstruct the history of invasion and habitat preferences of alien species of *Lepidium* in Romania, all occurrence data up to 2013 were registered. The information was gathered from literature (see Sîrbu and Oprea (2011) for primary sources of data), public herbaria, and recent records of the authors (2012-2013).

Herbarium data were collected from the following main herbaria of Romania (abbreviations according to Holmgren *et al.*, 1990): BUAG, BUC, BUCA, BUCM, CL, CLA, CRAI, I, IAGB, and IASI. In addition, some smaller collections were investigated, from Bacău, Oradea, and Tg. Mureș cities.

Each herbarium specimen was checked out for correct identification, sampling location, date of sampling, and habitat characteristics. The date of collection on the specimen label (for herbarium data), or the publication year (for the data from literature) unless other specific information from the fieldwork was given, were accepted as data of presence of a certain species in a given area. Repeated reports on the occurrence of a species from the same locality and the same year were treated as a single record. The nomenclature of *Lepidium* taxa follows Al-Shehbaz and Gaskin (2010).

The status of populations (naturalized or non-naturalized) was assessed for each record according to the terminology and definitions recommended by Richardson *et al.* (2000), and the pattern used by Essl *et al.* (2009). Populations were considered naturalized, if (i) this status has resulted unambiguously in the original data source, (ii) populations consisted of a large number of reproductive individuals (more than 100), (iii) populations smaller than 100 individuals were reported in the same location at least two consecutive years, or several small populations were recorded in the same locality, the same year. In all other cases, populations were considered non-naturalized.

The distribution maps of *L. densiflorum* and *L. virginicum* in Romania were made using the Universal Transverse Mercator (UTM) grid system (Lehrer and Lehrer, 1990). All records of these two species were marked on the map based on the locality code from UTM grid with cells of 10×10 km.

In order to obtain a global estimation of the invasion rate for *L. densiflorum* and *L. virginicum*, exponential regression models ($y = e^{a+bx}$) were fitted to the cumulative number of records against time and the slope b was used as a measure of the invasion rate (Delisle *et al.*, 2003; Mihulka and Pyšek, 2001; Pyšek and Prach, 1993). The significance of difference between the slopes was tested using the t -test of parallelism (Zar, 2010). We also tested, for these two species, whether the length of the railway network (km), as well as the rail traffic intensity of freight (tons per year) and people (thousand passengers per year), between 1950 and 2010, was positively related to the number of records by calculating the Spearman's correlation coefficients (r_s), with right-tail tests of significance (Zar, 2010). To assess habitat preferences of *L. densiflorum* and *L. virginicum*, a G^2 -test of independence (McDonald, 2008) was performed on the observed frequencies of species in various habitat types. The program XLSTAT (version 2011) was used for statistical analyses.

Results

General result

A total number of 174 records of four alien species of *Lepidium* (*L. sativum* L., *L. densiflorum* Schrad., *L. virginicum* L., and *L. oblongum* Small) have been reported in

Romania in a period of 197 years (between 1816 and 2013). Of these, 62 records were obtained from 92 herbarium sheets, 94 from literature sources, and 18 from field investigations (2012-2013). Herbarium data were recorded in 13 public herbaria, of which the most important was IASI (38 specimens). Four herbaria contained no specimens of alien species of *Lepidium*.

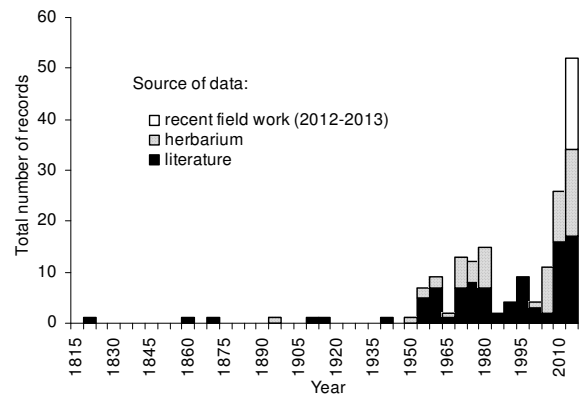


Fig. 1. Distribution of the total number of records of the alien species of *Lepidium* in Romania, between 1816 and 2013

Four periods of intensive recording of alien species of *Lepidium* can be distinguished (Fig. 1), of which the most important was between 2004 and 2013. Herbarium specimens were collected especially between 1966 and 1980 and between 2004 and 2013.

History of invasion and distribution

Lepidium sativum was the first alien species of *Lepidium* reported in Romania, in 1816. Until 1955, this species was reported only in 6 localities, and there are no reliable data on its naturalization in Romania. Since 1955 the species was no longer reported. All specimens of *L. sativum* from various herbaria were collected from vegetable gardens.

Historical data on the distribution of *L. densiflorum* and *L. virginicum* in Romania are represented on the maps in Fig. 2 and Fig. 3, respectively.

Lepidium densiflorum was first observed in Romania in the province of Crișana (1893), and later on in Transylvania (1958), Moldavia (1967), Muntenia (1968), Oltenia (1976), and Dobruđja (2011). Overall, *L. densiflorum* has been reported so far from 110 UTM cells of 100 km^2 (*i.e.*, 4.6% of the country area), corresponding to 89 localities, of which 1.1% before 1950, 41.6% between 1951 and 2000, and 57.3% after the year 2000. This species is widespread in the eastern half of Romania, mainly in Moldavia (60 localities) and Muntenia (11 localities), and it is less widespread in the western half of the country. In Maramureș and Banat it has not been reported so far. The first reliable data on naturalized populations of this species in Romania dates back to 1967, in Moldavia. Until 2013, *L. densiflorum* has been reported in Romania, as a

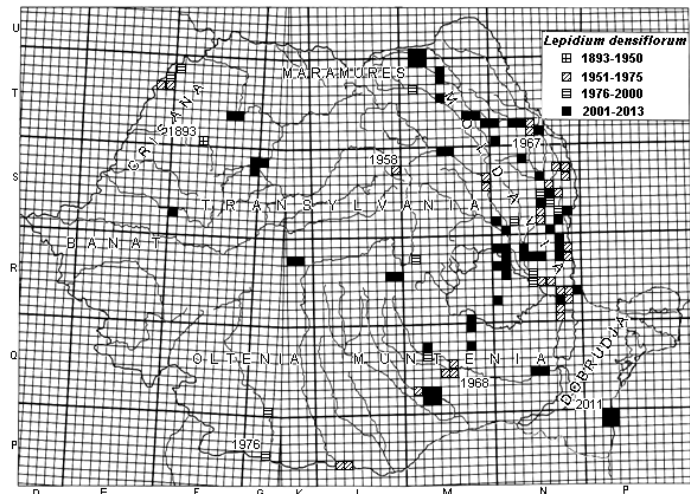


Fig. 2. Distribution of *Lepidium densiflorum* in Romania, between 1893 and 2013, by species occurrence within UTM cells of 10 x 10 km. The years of the oldest records for each historical region were indicated

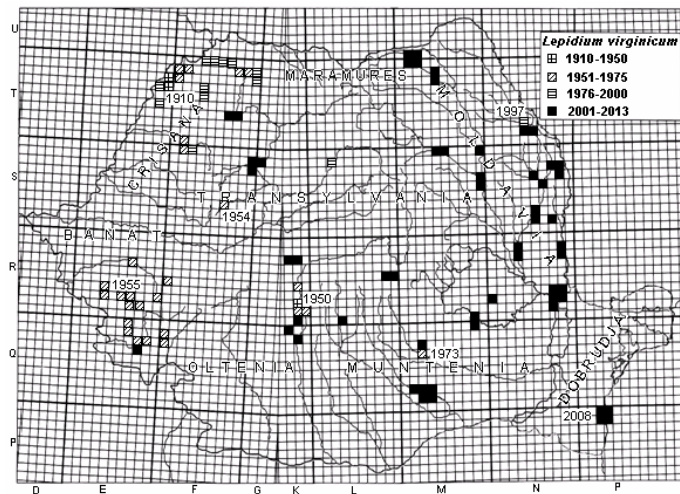


Fig. 3. Distribution of *Lepidium virginicum* in Romania, between 1910 and 2013, by species occurrence within UTM cells of 10 x 10 km. Meaning of numbers displayed as in Fig. 2

naturalized species, from 59 localities (which is 66.3% of all records), of which 51 localities (86.4%) after the year 2000.

Lepidium virginicum was first documented in 1910, in Crișana, and subsequently in Oltenia (1950), Banat (1955), Transylvania (1962), Muntenia (1973), Maramureș (1974), Moldavia (1997), and Dobrudja (2009). The occurrence of *L. virginicum* has been reported so far from 101 UTM cells of 100 km² (i.e. 4.2% of the country area), corresponding to 76 localities, of which 2.6% between 1910 and 1950, 48.7% between 1950 and 1999, and 48.7% after the year 2000. Nowadays, this species has spread to all historical provinces of Romania, being more frequent in Moldavia (22 localities), Crișana (16 localities), and Banat (12 localities). In Oltenia, Muntenia, and Transylvania it is sporadic, while in Dobrudja and Maramureș, it is rare. The first record of a naturalized population was in 1955, in Banat. Until 2013, this species has been reported as naturalized in 32 localities (which is 42.1% of all records), of which 27 localities (84.4%) after the year 2000.

The slopes of invasion curves of *L. densiflorum* and *L. virginicum* (Fig. 4) do not differ significantly from each

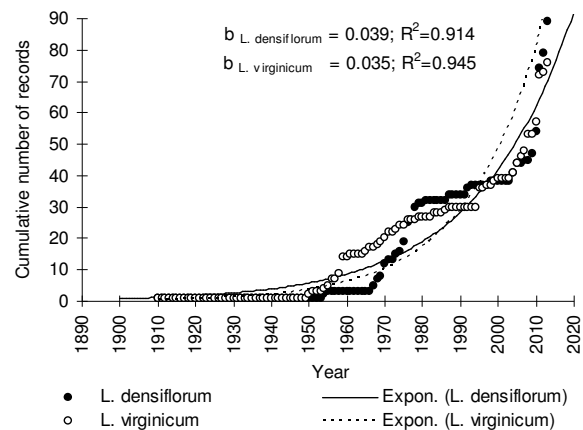


Fig. 4. Exponential regression curves of the cumulative number of records of *Lepidium densiflorum* and *L. virginicum* in Romania. The estimated invasion rates (slopes b) are both statistically different from zero at 5% probability level

other (test of parallelism: $t = 0.207$, $P = 0.836$). Two periods of invasiveness (*i.e.* sharp increase of the lines of distribution) can be distinguished for both *L. densiflorum* (*i.e.* between 1967-1979, and 2004-2013, respectively) and *L. virginicum* (*i.e.* 1950-1976, and 1995-2013, respectively).

No significant positive relationships were found between the length of railway network (km) and the number of records of *L. densiflorum* and *L. virginicum* ($r_s = -0.003$, $p = 0.491$; $r_s = -0.438$, $p = 0.001$, respectively). In addition, no significant positive relationships were found between the rail traffic of goods (thousand tonnes per year) or passengers (thousand passengers per year) for the period 1950-2010 and number of records of species *L. densiflorum* ($r_s = 0.118$, $p = 0.183$; $r_s = -0.068$, $p = 0.301$, respectively) and *L. virginicum* ($r_s = -0.387$, $p = 0.001$; $r_s = -0.382$, $p = 0.001$, respectively).

The most recent alien species of *Lepidium* recorded in Romania's flora is *L. oblongum* (Fig. 5). It was found in 2011, only in a single locality, in the railway station of Râmnicu Sărat, Buzău County, between the platform of the station and the rail lines.

Habitat preferences over time.

Two of the species considered in this paper were observed each in a single type of habitat, namely, ruderal habitats near gardens (*L. sativum*) or associated with railways (*L. oblongum*). The proportion of each habitat types invaded over time by the other two species (*L.*

ruderal habitats, as well as on sandy lands. However, in recent decades, a significant diversification of invaded habitats has not been further registered. The main habitats,

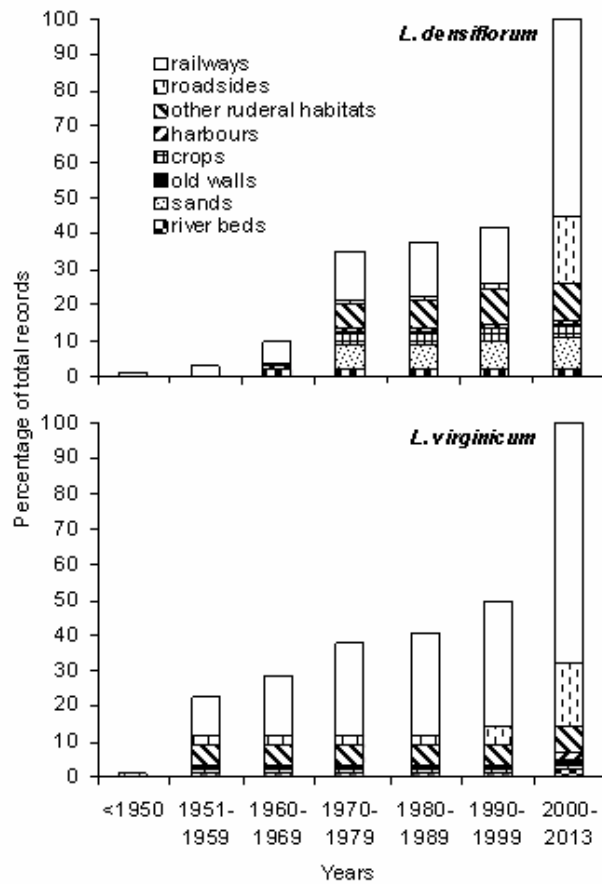


Fig. 6. Relative frequency of habitat types invaded over time in Romania by *Lepidium densiflorum* and *L. virginicum*

in which *L. densiflorum* has been observed since 1980 are represented by railways and, to a lesser extent, roadsides and other ruderal sites.

Lepidium virginicum has been mainly recorded along railways. To a lesser extent, this species invaded roadsides and other ruderal habitats. It was also observed on ruderalized sands, on old walls, on sandy gravels of river beds, as well as in harbours. It has not been recorded until now as a weed in crops.

Discussion

General distribution and invasion history

Lepidium sativum originated in North-East Africa and South-West Asia, being cultivated since ancient times as a vegetable or as a herb (Jansen, 2004; Markgraf, 1963; Thellung, 1906). According to Akeroyd and Rich (2010), it is frequent as a casual weed and locally naturalized in Europe, but it is impossible from the available data to distinguish between naturalized and casual distribution. However, Lambdon *et al.* (2008) listed this species among the most widespread 20 alien plant species in Europe. *L. sativum* was also reported as naturalized in North America, South America (Argentina), Australia (Al-Shehbaz, 2010), and Eastern Asia (Taiyan *et al.*, 2001).



Fig. 5. *Lepidium oblongum*: a) herbarium specimen, b) basal leaf, c) upper cauline leaves; d) fruits, e) seed. Scale bar: a = 20 mm, b = 10 mm, c = 5 mm, d, e = 1 mm

densiflorum and *L. virginicum*) is shown in Fig. 6. The difference in invaded habitat types between *L. densiflorum* and *L. virginicum* was significant (Wilks' $G^2 = 14.07$, d.f.=7; $p=0.041$).

Since 1883 *L. densiflorum* has been mainly recorded in ruderal places associated with railways. Diversification of habitats invaded by this species began in the late 1960s, when it was collected from floodplains of some rivers. Since 1970s, it has been also observed in harbours, cereal crops or vineyards on sandy soils, along roadsides and in other

We suppose *L. sativum* was introduced in Romania as a vegetable, before the nineteenth century, when it was first reported from Transylvania (Baumgarten, 1816). Up to the middle of the last century, this species was mentioned sporadically in the literature, as a subsponaneous plant, escaped from gardens (Nyárády, 1955), in Transylvania (Baumgarten, 1816; Schur, 1866), Banat (Heuffel, 1858), Muntenia (Panțu, 1912) and Bukovina (Prodan, 1939). However, according to Simonkai (1886), *L. sativum* was found in Transylvania only as a cultivated plant. After 1955, this species has not been reported from other localities in Romania, and nowadays it is rarely cultivated as a vegetable. All the examined specimens of *L. sativum*, from herbaria, were collected from gardens. Therefore *L. sativum* can be considered as a casual alien plant in Romania, based only on old data from the literature.

Lepidium densiflorum is a species native to North America, recorded as a casual alien after 1870 in Central Europe (Markgraf, 1963). Nowadays, it is naturalized in most of Europe, except in Great Britain, the Iberian Peninsula and the Balkan Peninsula (Akeroyd and Rich, 2010), being listed among the 100 most widespread alien plant species in the continent (Lambdon et al., 2008). It is also naturalized in South America (Al-Shehbaz, 2010) and Asia (Taiyan et al., 2001). In the neighbouring countries of Romania, *L. densiflorum* has been known since 1895 in Ukraine (Protopopova et al., 2006), and since 1935, in Hungary (Pénzes, 1941).

The presence of *L. densiflorum* in Romania was first reported by Negrean (1980), based on herbarium specimens collected by the author in several localities, as well as on the revision of some earlier herbarium collections that had been erroneously identified as *L. virginicum*. The first record of this species in Romania is a specimen collected by Richter, in 1893, in the northwestern part of the country (Crișana), at Ciucea village. According to Negrean (1980), this specimen was first assigned to *L. virginicum*, and subsequently revised by Thellung (1906), as *L. neglectum* (today included in *L. densiflorum*). However, it seems that the plants that arrived here accidentally from the West, via rail transport, were not able to naturalize in that initial point of introduction, which thus remained isolated on the distribution map. Although in the 1950s new introductions appeared independently of the initial introduction both in Crișana, and in eastern Transylvania, a significant wave of migration of this species cannot be recognized yet in these two provinces.

In the eastern Romania (Moldavia), *L. densiflorum* was collected in 1967, in Iași and Socola railway stations (Iași county), but confused with *L. virginicum* and distributed under that name in *Flora Romaniae Exsiccata* (FRE), no. 3060, and *Flora Moldaviae et Dobrogeae Exsiccata* (FMDE), no. 40 (Negrean, 1980), a clear evidence that it was abundant in these localities at the time. After that year, an important increase in records of this species occurred in Moldavia, especially along railways. Populations of *L. densiflorum* from Moldavia could have originated from Ukraine, where this species is quite widespread and was first registered in 1895 (Protopopova et al., 2006). The fact that the first information about the occurrence of this species in

Moldavia come from two cities situated near the eastern border of Romania, along the railways linking Ukraine and Romania, can support this hypothesis.

In the southern regions of Romania *L. densiflorum* was first collected in Muntenia (1968), then in Oltenia (1976) (Negrean, 1980) and much later in Dobruđa (2011). We suppose that populations from southern regions are linked with those of Moldavia from where they could migrate along railways. The expansion from Transylvania, through mountain passes, toward eastern and southern regions of the country, cannot be excluded, but it is less likely, given that *L. densiflorum* is even nowadays a quite rare species in Transylvania. Probably it could not arrive in these regions either from the South, because it has not been registered yet in the southern neighbouring countries (Bulgaria, Serbia) (Akeroyd and Rich, 2010).

Lepidium virginicum is another North American species, widely naturalized in Europe (Akeroyd and Rich, 2010), as well as in Asia (Taiyan et al., 2001), South America, Africa, and Australia (Al-Shehbaz and Gaskin, 2010). According to Markgraf (1963), *L. virginicum* was introduced in the Botanic Garden of Montpellier, in 1697, and has been recorded in Central Europe as a subsponaneous plant, beginning with the eighteenth century (in 1786). Subsequently, it has gradually spread throughout the continent (Akeroyd and Rich, 2010; Markgraf, 1963; Thellung, 1906), mainly along railways. According to Lambdon et al. (2008), *L. virginicum* is currently one of the most widespread alien plant species in Europe, occurring in more than 80% of European regions.

In neighbouring countries of Romania, *L. virginicum* was reported in Hungary, in the beginning of the last century (Thellung, 1906), Serbia, in the 1970s (Ivković, 1978), the Caucasus region (Fedorov, 1979; Vinogradova et al. 2010), Ukraine (Protopopova et al., 1994), and in Turkey (Terzioğlu and Anşin, 2001).

In Romania, *L. virginicum* has arrived most probably from Central Europe, along railways, being recorded in 1910, in the North-West of the country (Crișana), near the actual border with Hungary (the Pișcolt village) (Karácsonyi, 1995). The previous indication from Crișana (at Ciucea village, leg. 1901) made by Degen (1902), is not a certain one, since subsequently in the monograph of the genus *Lepidium*, Thellung (1906) mentioned only "*L. neglectum*" from that locality: "1893, L. Richter – Herb. Degen".

After these first indications, the occurrence of this species was reported, almost simultaneously, at the middle of the last century, both in Crișana (Vadu Crișului railway station, Bihor County, leg. Soran, 03.VI.1951, herbarium CL-216713), and in three other provinces in the western half of the country, namely: Oltenia (herbarium CLA-06400, Lotru railway station, leg. Nyárády, 19.VI.1950), Transylvania, in the Mușca railway canton, Alba county (leg. Soran, 1954) (Soran, 1962), and Banat, in the railway station of Călnic, Caraș-Severin County (leg. Goga, 1955) (Goga, 1960). Reports on the presence of this species during such a short period of time (1950-1955) in localities so distant from one another (100-250 km), from four different provinces, suggests that in the first half of last century, an active spread of this species took place, along railways,

starting from Crişana, the initial centre of introduction, southward, in Transylvania, Banat and Oltenia. However, we cannot exclude the hypothesis that new introductions occurred in all that time independently of the initial introduction. The introduction of this species in the southwestern Romania (Banat) from the neighbouring country (Serbia) is unlikely because there, *L. virginicum* was reported much later, in the 1970s (Ivković, 1978). In the subsequent decades, the spread of this species has continued along the railway network, especially in Banat, Crişana, and, to a lesser extent, in Oltenia (along the Olt River) and Transylvania. Also, *L. virginicum* migrated from Crişana to Maramureş, where it was first observed in 1974 (at railway station Ilba) (Negrean, 1980).

In Muntenia, *L. virginicum* was first collected in 1973, in the railway station Prahova, situated on the railway line Braşov-Bucharest. It was introduced there, probably, by rail transports, from Transylvania. The absence of this species in Bulgaria (Akeroyd and Rich, 2010) excludes its arrival in southern Romania from the Balkans.

In Moldavia, *L. virginicum* was recorded by error between 1967 and 1997, based on specimens of *L. densiflorum*, as mentioned above. Because of these wrong identifications, Negrean (1980, 1987) considered the presence of this species in Moldavia as uncertain. Indeed, upon examination of the herbarium specimens (I, IAGB, IASI) collected prior to 1997, we found that all of them were wrongly determined, and that they belong actually to *L. densiflorum* (Sirbu, 2006). *L. virginicum* has been found with certainty in Moldavia since 1997, being collected in the railway station of Socola-Iaşi (herbarium IASI - 17957, leg. Sirbu and Oprea, 21.VII.1997) (Oprea et al., 1997). However, the current data indicate that it is quite widespread in Moldavia, mainly in railway stations. Since *L. virginicum* is missing in Republic of Moldova (Negru, 2007), and it was discovered only recently in Ukraine (Protopopova et al., 1994), we suppose this species arrived in eastern Romania either from the West (Transylvania), through mountain passes, or, more likely, from the South, along the railway lines linking Bucharest with the major cities of Moldavia.

In Dobrudja, *L. virginicum* was recently reported in a single locality (in Constanţa harbour), by Anastasiu et al. (2009).

Lepidium oblongum originates in North America (Southern and Central USA) and Central America (Mexico, El Salvador, and Guatemala) (Al-Shehbaz and Gaskin, 2010; DiTomaso and Healy, 2007). There is a single record of this species in Romania (Sirbu and Oprea, 2011), and according to Akeroyd and Rich (2010), and Drake (2009), it is so far unknown in other regions of Europe. In the railway station of Râmnicu Sărat, the population of *L. oblongum* consists of several dozens of individuals (Sirbu and Oprea, 2011). Because their seeds have a high capacity of germination (over 80%, in light conditions) (Sirbu, 2011, unpublished), and the population persisted for three consecutive years in the same place, we can assume that this species is naturalized in Romania, even if it was reported only from a single location, so far. We suppose that it arrived in Râmnicu Sărat railway station with goods or passenger trains, but we do not know

currently the ways of its migration from North America to Romania. As it was shown by many authors (e.g., Guo et al., 2012; Mihulka and Pyšek, 2001), there are often positive relationships between the latitudinal distributions occupied by species in their native and exotic ranges. As the primary area of *L. oblongum* extends up to Oregon (on the West coast of the United States) (DiTomaso and Healy, 2007), ca. 44°N, we can suppose that it may have a potential to invade southern regions of Europe, but further studies are required in this regard.

Lag time and invasion curves

The spread of *L. densiflorum* and *L. virginicum* in Romania was initiated, as stated above, at the middle of the last century, about 60, respectively 40 years after registration of the first specimen of these species in the country. This is not surprising since a lag time of over 40-50 years between initial colonization and the onset of rapid population growth and geographic expansion is a common feature of alien plant invasions (Binggeli, 2001; Essl et al., 2009; Pyšek and Prach, 1993). The increase of the invasion slope after 1950 for both species could be related to the intensive railway transport of troops and military equipment, during the Second World War, as well as the environmental disturbances caused by that war.

According to our results, the slopes of invasion curves, which give global estimations of the invasion rates (Delisle et al., 2003) do not differ significantly for *L. densiflorum* and *L. virginicum* in Romania. However, periods of invasibility (i.e. sharp increase in slope of the invasion curve) differ between the two species in the second half of the last century. The active spread of *L. virginicum* has been recorded since 1950, with an important advance against *L. densiflorum* (1967). Moreover, evidence of naturalized populations occurred earlier in *L. virginicum* (45 years after first registration in Romania) as against *L. densiflorum* (84 years after first registration in Romania).

Since the invasion curve has an evident increasing trend in the last decade, for both *L. densiflorum* and *L. virginicum*, we can assume that the two species are still far from reaching the saturation phase of invasion in Romania – i.e. when the rate of invasion slows down (Essl et al., 2009), and that they will continue to spread in the future.

Habitat preferences and the role of traffic lines in plant spreading

Within their natural range, *L. densiflorum*, *L. virginicum* and *L. oblongum* grow in various disturbed natural and anthropogenic habitats, such as: prairies, pastures, waste grounds, fields, roadsides, railways (all three species) (Al-Shehbaz and Gaskin, 2010; DiTomaso and Healy, 2007), flood plains (*L. densiflorum* and *L. oblongum*), sagebrush flats, gravelly hillsides, rock crevices, seashores, sandy places, open mesa (*L. densiflorum*), llanos, calcareous sand, alluvial terraces (*L. oblongum*) (Al-Shehbaz and Gaskin, 2010) etc. As for the species *L. sativum*, in its native area, it prefers not too warm sites, with rich, open soils, well supplied with water, although it is fairly drought tolerant (Bush 1939; Jansen 2004).

In Central Europe, according to Markgraf (1963), *L.*

densiflorum and *L. virginicum* are usually found on nutrient-rich soils, in railway stations, between the tracks, along roads, on ruderal places, on sands and gravels in harbours, rarely as weeds in crops, entering in composition of the ruderal communities from the orders *Sisymbrietalia* and *Onopordetalia*. In Central Europe, *L. sativum* occasionally escapes from cultivation, in weed communities on newly disturbed fields, rich in nutrients (*Sisymbrium*) (Markgraf, 1963). In Romania, the *Lepidium* species taken into account invade a more limited range of habitats than in their natural areas, but (except *L. oblongum*) comparable with other regions in Europe.

It is well known that the repeated transport of propagules by trains or cars can facilitate the spread and naturalization of alien species along traffic lines (Hulme, 2009; Kowarik, 2003; Von der Lippe and Kowarik 2007). It is probably the case of species studied by us, except *L. sativum*. In more than 86%, and respectively 74% of the total number of records in Romania, *L. virginicum* and respectively *L. densiflorum* grow in ruderal habitats associated with traffic infrastructure, and railway stations have the largest share in the total number of records. The predominance of these species in habitats associated to railways suggests that they immigrated to and spread throughout Romania mainly via the railway transport.

Consequently, it was expected that the spread of both species be influenced by extension of railway network, by intensity of goods and passenger traffic, as well as by disturbance status of habitats associated with railways. But the length of railway network in operation did not change significantly in Romania, in the last 60 years. Between 1950 and 1995, it increased only by 4.8% (from 10853 to 11376 km), and between 1995 and 2010 it even decreased by 5.2%, reaching today below the level of the year 1950 (INSR, 1950-2011). In addition, surprisingly, for the period 1950-2010, we did not find significant positive relationships between the number of records of the species *L. virginicum* and *L. densiflorum* and the rail traffic of goods or passengers. Therefore, we can assume that the spread of both species was determined rather by the favourability of disturbed habitats associated with railways (especially ruderal habitats from train stations). This made possible the germination of seeds accidentally arrived with trains from long distances, and, subsequently, the growth of plants and seed production for several generations. Naturalized plants in new locations have further spread, via anemochorous, epizoochorous (over short distances) or anthropochorous seed dispersal (over variables distances), in ruderal habitats closely associated with railways and roads, as well as in other anthropogenic or natural habitats, on lands situated near transport routes. This agrees with the pattern of stratified dispersal, consisting of long-distance movements, and neighbourhood diffusion (Essl et al., 2009; Kowarik, 2003; Ming and Albrecht, 2004).

Overall, according to our data, it seems that *L. densiflorum* has a more pronounced tendency of diversifying the invaded habitats than *L. virginicum*. Only *L. densiflorum* has been reported so far in Romania as a segetal weed in cereal crops (*Flora Olteniae Exsiccata*, 951, leg. Păun, 21.VI.1976; Vițalariu et al., 1977), or in vineyards, on sandy soils (Negrean, 1980). According to Vițalariu et al.

(1977), in wheat crops, this species can achieve a significant level of weed infestation (300-400 individuals per m²). After 1980, however, further cases of crop infestation by this species have not been registered. In natural habitats, only *L. densiflorum* and *L. virginicum* (especially the first one) were found, on sandy lands and river beds, probably in conditions of ruderalization, but reports in this respect were only occasional.

The reliability of the data set

According to the data from literature (Chauvel et al., 2006; Crawford and Hoagland, 2009; Delisle et al., 2003; Pyšek and Prach, 1993; Pyšek and Hulme, 2005), to successfully reconstitute the introduction and invasion of a species on a large geographical scale through floristic data, a sufficient and constant intensity of floristic investigations within that area is necessary. This condition is broadly achieved in Romania, because of the strong and long tradition of floristic research in this country, dating back to the second decade of the 19th century. However, the reconstitution of plant invasions could be affected by the fluctuation in time of the interest shown by botanists to collect herbarium specimens, which may sharply decrease at one time, because a certain degree of saturation can be attained (Chauvel et al., 2006). Our data proved, for instance, that between 1950 and 1980, there was an increasing trend to collect herbarium specimens of *L. densiflorum* and *L. virginicum*, but no other specimen was collected over the next 15 years even though new records continued to appear in the published literature, all that time. Therefore, by using data from multiple sources (herbaria, published literature, field studies), we tried to reduce bias in assessing the patterns of invasion. On the other hand, we have no reasons to believe that botanists have tended to collect or record *L. densiflorum* more than *L. virginicum*, or vice versa. In fact they are very similar morphologically, as already shown, and usually grow in similar habitats. So, the recording effort could be considered similar for the two species over the time. However, such reconstitution remains unavoidably influenced by the magnitude of floristic investigations. Therefore, we suppose that *L. densiflorum* and *L. virginicum* are still under-recorded in Romania, and their genuine distribution could be larger than it is suggested by the currently available data used in this paper.

Conclusions

Four alien species of *Lepidium* were registered till now in the flora of Romania, of which one is casual (*L. sativum*), one naturalized (*L. oblongum*), and two are invasive (*L. densiflorum* and *L. virginicum*). The invasion of the last two species started after a lag time of about 60, respectively 40 years. Although both species were first reported in the northwestern Romania, they subsequently followed different paths of migration in the country. However, the slopes of the invasion curves do not differ significantly between the two species. The predominance of these invasive species in habitats associated to railways suggests that they immigrated to and spread throughout Romania mainly via the railway transport. Naturalized populations along railways have further dispersed to neighbouring

suitable habitats, especially ruderal ones, following the pattern of the stratified dispersal. Although invasive, neither *L. densiflorum* nor *L. virginicum* proved to be harmful to crops or natural habitats, so far.

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