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Black locust (*Robinia pseudoacacia*) beloved and despised: a story of an invasive tree in Central Europe

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Abstract

Robinia pseudoacacia, invaded many countries a long time ago and is now a common part of the Central European landscape. Positive economic but negative environmental impacts of *Robinia* result in conflicts of interest between nature conservation, forestry, urban landscaping, beekeepers and the public when defining management priorities. Because current legislation will determine the future distribution of *Robinia* in the landscape, a comprehensive view of this species is necessary. Although this species is well studied, most of the scientific papers deal with the economic aspects. Other information is published in local journals or reports. Therefore we reviewed the ecological and socio-economic impact of *Robinia* placing particular emphasis on the species' history, vegetation ecology, invasiveness and management. In Central Europe, *Robinia* is limited climatically by late spring frost combined with a short vegetation period, soil hypoxia, shade and frequent major disturbances. The long historical tradition of using *Robinia* for afforestation has resulted in its popularity as a widespread forest tree and it being an important part of the economy in some countries. The main reasons are its fast growth, valuable and resistant wood, suitability for amelioration, reclamation of disturbed sites and erosion control, honey-making and recently dendromass production. On the other hand, a side-effect of planting this nitrogen-fixing pioneer tree, very tolerant of the nature of the substrate, is its propagation and spread, which pose a problem for nature conservation. *Robinia* is considered invasive, threatening especially dry and semi-dry grasslands, some of the most species-rich and endangered types of habitat in the region, causing extinction of many endangered light-demanding plants and invertebrates due to changes in light regime, microclimate and soil conditions. Other often invaded habitats include open dry forests and shrubland, alluvial habitats, agrarian landscapes, urban and industrial environments and disturbed sites, e.g. post-fire sites, forest clearings or degraded forestry plantations. Without forestry, black locust abundance would decrease during succession in forests with highly competitive and shade tolerant trees and in mature forests it occurs only as admixture of climax trees. The limited pool of native woody species, lack of serious natural enemies and a dense cover of grasses and sedges can suppress forest succession and favour the development of *Robinia* monodominant stands over 70 years old. A stratified approach, which combines both tolerance in some areas and strict eradication at valuable sites, provides the best option for achieving a sustainable coexistence of *Robinia* with people and nature.

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Keywords

Robinia pseudoacacia; Central Europe; history; invasiveness; threatened habitat; management

1 Introduction

Robinia pseudoacacia L. (black locust) was one of the first North American trees to be introduced into Europe at the beginning of the 17th century (e.g. Ernyey, 1927; Kolbek et al., 2004; Vadas, 1914). It is one of the most widely planted woody species in the world (Keresztesi, 1988), but also very invasive. It is listed amongst the 40 most invasive woody angiosperms globally (Richardson and Rejmánek, 2011) and is reported as naturalized in 154 regions out of a total of 843 in the world (GloNAF; Pyšek et al., unpublished data; van Kleunen et al., 2015). In several European databases *Robinia* is classified as highly invasive (CABI, 2015; DAISIE, 2006; EPPO, 2002) and is included in national Black Lists and checklists of alien species across Europe (e.g. Norway – Gederaas et al., 2012; Czech Republic – Pergl et al., 2016b; Pyšek et al., 2012b; Germany – Seitz and Nehring, 2013; Switzerland – FOEN, 2010; info Flora, 2014; Italy – Celesti-Grapow et al., 2009; Central Russia – Vinogradova et al., 2010). Due to unavailability of a comprehensive risk assessment as well as the pressure from some EU Member States it is not included in the list of invasive alien species (IAS) of Union concern (Commission Implementing Regulation (EU) 2016/1141 of 13 July 2016 adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council). Despite *Robinia pseudoacacia* meeting the criteria listed in Article 4 of the Regulation for being included among the IAS of Union concern, its general ban for silvicultural use across the entire EU would be problematic (Sitzia, 2014; Sitzia et al., 2016a). According to Article 12, black locust can be included in the national lists of IAS in the Member State concern category and appropriate measures (mentioned in Articles 7, 8, 13 to 17, 19 and 20) can be taken. Among Central European countries, black locust is not a subject to legislation for example in Slovakia and Poland (Table 1).

In Central Europe, *Robinia* has been studied for a long time (e.g. Cierjacks et al., 2013; Göhre, 1952; Keresztesi, 1988; Kowarik, 1992; Vadas, 1914), but mainly in terms of its economic value (Lukasiewicz et al., 2015; Mantovani et al., 2014; Quinkenstein and Jochheim, 2016; Yang et al., 2004) rather than its ecology. There is currently no summary of the ecological and socio-economic impact of *Robinia* with respect to the species' history, vegetation ecology, invasiveness and management. Such information is rather rare and scattered, and often published in local journals or reports. The only existing review by Cierjacks et al. (2013) for the British Isles focuses mainly on ecophysiology, reproductive biology, mycorrhiza, parasites and diseases, here we review the Central European literature and our unpublished results of a long-term study on the above mentioned aspects of the black locust invasion in this region.

The objectives of this paper are to (1) summarize and evaluate existing knowledge on *Robinia* in Central Europe, (2) explain its regional distribution in a historical context; (3) assess the causes and consequences of its invasion, including those in threatened habitats;

(4) categorize black locust plantations growing under various environmental conditions, and (5) outline management strategies for the region. For a definition of Central Europe we follow the common concept (e.g. Encyclopædia Britannica) and include Austria, Czech Republic, Germany, Hungary, Lichtenstein, Poland, Slovakia, Slovenia and Switzerland (Fig. 1).

2 History of introduction, planting and invasion

Invasion history of *Robinia pseudoacacia* follows that typical of cultivated aliens; following introduction, date of which is rather unclear, there was a long lag phase and then rapid invasion supported by frequent planting in the wild. Although it was first described in honour of Jean Robin by Cornutus in 1635 as *Acacia Americana Robini*, Ernyey (1927) explains that both Robins (Jean and his son Vespasian) did not introduce this plant to Paris and therefore dismisses the often cited first year of introduction to Paris as of 1601. There were probably several independent introductions from North and South America (Ernyey, 1927), which has resulted nowadays in widespread plantations. Following introduction, it was quickly distributed as a rare ornamental exotic to botanical gardens all over Europe, with Paris the most important distribution centre (Wein, 1930). In Central Europe, it was first introduced into Germany (1672 in Berlin; Wein, 1930) where it soon became fashionable, to plant it (Böhmer et al., 2001) and according to Flora Norimbergensis (Volckameri, 1700) it was already very common in southern Germany at the beginning of the 18th century. It also quickly spread to Hungary and the Czech Republic with the first record of introduction into both countries in 1710 (Nožička, 1957; Vadas, 1914). The very latest introduction in Central Europe was in Slovenia at the beginning of the 19th century, probably from northern Italy (Friuli plain; Rudolf and Brus, 2006). For a summary of the history of introduction across Central Europe see Table 2.

The invasion of black locust in Central Europe was encouraged by extensive planting. *Robinia* was first recommended for large-scale afforestation by Johann Georg Kramer for Hungarian lowlands in 1735 but these plans were never put into practice due to the death of Prince Eugen von Savoyen, who was to provide financial support (Ernyey, 1927). The first large afforestation was 290 ha to protect the Fortification of Komárom-Herkály (Hungary) in 1750. Because it proved successful, *Robinia* was planted on various soils – from wind-blown nutrient poor sands to the most fertile soils (Vadas, 1914), and its planting was recommended in forestry literature, for example in Bohemia (Czech Republic) as early as 1767 (Nožička, 1957). Between 1796 and 1803, Friedrich Casimir Medicus established a special journal to promote the planting of black locust (named "Unechter Akazienbaum, zur Ermunterung des allgemeinen Anbaues dieser in ihrer Art einzigen Holzart"). Together with reports about the advatages of *Robinia* from foresters returning as volunteers from the American War of Independence, this literature encouraged the planting of *Robinia* in Germany, Hungary and the Czech Republic (Bartha et al., 2008; Böhmer et al., 2001; Hegi, 1924; Nožička, 1957). Despite warnings against the excessive expectations that *Robinia* plantations would solve the lack of fuel wood (e.g. from Georg Ludwig Hartig; Vadas, 1914), *Robinia* became a fashionable and highly recommended tree. Increasing demands for wood production at the beginning of industrialization, need to control erosion after forest degradation and success of large-scale plantations in the Hungarian puszta landscape to

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stabilize the sandy soils and mitigate the climate extremes in the early 19th century generated the so called „black locust mania“ (Göhre, 1952; Hegi, 1924; Vadas, 1914). In other Central European countries, *Robinia* also became a popular forest tree due to the long-lasting quality of its timber, resistance to insects and fungi, rapid growth, easy propagation and ability to stabilize soils (e.g. Göhre, 1952; Vadas, 1914). Only in Slovenia, where the introduction happened late, this species was not promoted for afforestation, therefore it was planted only in certain areas to provide farmers with timber often for vineyard poles and wine barrels (as early as 1858; Anonymous, 1858; Brus, pers.com.). In other Central European countries, large-scale afforestation campaigns were organized at the state level in the late 19th and early 20th centuries. In some countries, such as Hungary, Poland and Austria, black locust was planted mostly on sandy soils on flat plains, in others, such as the Czech Republic and Switzerland, it was used to protect steep eroded hillsides along rivers that were threatened by soil erosion (former pastures deforested at the beginning of the 17th century; Kolbek et al., 2004) and transport corridors (Bettosini, 2014; Kolbek et al., 2004).

In the early 20th century *Robinia* forest stands were usually coppiced at 6 to 25 year intervals (mostly 6–8 years) depending on what the wood was to be used for (Svatoš, 1941). However, after two to three rotations, timber production began to decline because the soil was exhausted and the herb layer in the forest became impoverished and completely dried out during summer (Fehér, 1935; Kolbek et al., 2004). In addition to these drawbacks, Austrian fruit growers identified *Robinia* as a secondary host of an insect pest *Parthenolecanium corni* in the 1930's. This is why *Robinia* forests were felled throughout Europe in the 1930's (Ondra, 1936). However, after a few years of felling, the interest in *Robinia* increased again because of its high nectar yield for producing honey (Kolbek et al., 2004). At the end of WWI, Hungary lost 84% of its forests as a result of the Treaty of Trianon. Such a large reduction in the area of forest resulted in a national afforestation programme, in which black locust was one of the most important species (Tobisch and Kottek, 2013). By contrast, in the Czech Republic, *Robinia* was virtually not planted after WWII, except for a short period in 1970's when it was used for soil stabilization in mining areas (FMI, 2014).

The beginning of *Robinia* invasion is poorly documented and reasons for its late start are rather unclear. This process was probably inhibited by a cool climate of early modern times and accelerated only later due to the emergence of urban and industrial landcapes (Sukopp and Wurzel, 2003). However, the key factor behind a the rapid increase in *Robinia* abundance was its planting outside parks and gardens. Before its deliberate cultivation in the landscape, *Robinia* most likely spread clonally from sites of cultivation, but such escapes were only occasional and thus not paid attention. The first escape of *Robinia* from cultivation is mentioned in 1824 in Brandenburg, Germany (Buek, 1824 in Krausch, 1988) and followed the use of *Robinia* for afforestation (Table 2). Therefore, it took 200 years between its first introduction to Europe and the first published record of escape. The first record of *Robinia* escape in a Central European country always followed its first utilization in forestry, although the date and lenght of the interval between such events differ substantially (Table 2). Although the sites suitable for the black locust invasion occured even before World War II (Kohler and Sukopp, 1964), the species was then perceived as a commonly naturalized tree without any negative impact on native communities (Hegi, 1924).

After 1945, *Robinia* specifically invaded the rubble left after bombing of urban sites where it occurred as a spontaneous pioneering tree in areas with relatively continental climate and warm summers (Kohler and Sukopp, 1964). The trend of steady increase of *Robinia* stands has been recorded since 1950s (e.g. Berg et al., 2016).

The naturalization and invasive spread of *Robinia* was favoured by the tree's acceptance as part of the cultural identity of individual countries. Across Europe, *Robinia* is not perceived as being an alien component of the landscape by the public (Fischer et al., 2011a). In Hungary, it is even considered as an unofficial national tree (Keresztesi, 1988). In most Central European countries (Chrtková, 1995; Hegi, 1924; Kowarik, 2010), the tree is traditionally grown in gardens, city avenues or at memorable sites such as by chapels, wayside crosses or in cemeteries. Some of *Robinia* trees of exceptional historical, cultural or biological value are declared protected monument trees according to the national legislation (e.g. drusop.nature.cz; baumkunde.de; stromy.enviroportal.sk). Public perception of which species are natural part of Central European landscape is rarely studied in the scientific literature (but see Fischer et al., 2011a, b; Kowarik and Schepker, 1998). *Robinia* was adopted by the general public, as illustrated by hundreds of toponyms of streets, forests and hills (e.g. Bába and Nemes, 2014; Olivová-Nezbedová and Matúšová, 1991), songs, poems and proses, herbal products and culinary recipes. In conclusion, it should be noted that planting of *Robinia* and its integration into broader cultural awareness have worked reciprocally, i.e. its popularity among the public has triggered its spread.

3 Current distribution and extent of planting

Robinia is native to two separate areas in the south-eastern USA with the distribution centre in the Appalachian Mountains, where it commonly occurs in species rich forests at 150 to 1500 m a.s.l. (Fowells, 1965; Huntley, 1990). It is currently planted in the whole of Europe, except in the north and on some Mediterranean islands (Weber, 2003). The estimated area of *Robinia* plantations outside its native distribution is over 30,000 km^2 (Schneck, 2010) in 35 countries in Europe, temperate Asia, temperate South America, northern and southern Africa, Australia and New Zealand (Cierjacks et al., 2013; Li et al., 2014), and is still increasing (Schneck, 2010). *Robinia* is the most problematic invasive forest tree in Europe covering half of the total forest area designated as dominated by an invasive tree species (MCPFE, 2007). The figures given below (Fig. 1 and 2) refer only to forest land in individual countries (both planted and spontaneous), but the area of black locust stands on non-forest land (mostly spontaneous), such as urban areas, parks and agricultural land including recent energy plantations established on arable land (in Hungary, Germany, Poland and Slovakia), is also significant. Estimates of the extent of the populations growing on non-forest land, and those of spontaneous origin are not available, although their area can be considerable. For example in the Czech Republic, only area of 36 plantations of *Robinia* is known (Table 3), but Křivánek et al. (2006) report 615 other localities, mostly of spontaneous origin.

The distribution of *Robinia* in Central Europe (Fig. 1) is constrained by: (i) soil properties, namely the lack of oxygen in soil, as it does not occur in wetlands or such parts of alluvial forests that are subject to frequent and long-term waterlogging and the soils are compact; (ii) climate: frost, mainly in late spring, combined with a short vegetation period and generally cold climate in the sub-mountain to alpine belt; (iii) competition with other species: tree shade in closed forests and shrubland, and (iv) permanent heavy disturbance by trampling, or in mown lawns, meadows and arable fields.

In Central Europe, the invasion of *Robinia* is more successful in areas with a subcontinental or sub-Mediterranean climate than in areas under oceanic influence (Sukopp and Wurzel, 2003). It is usually planted up to 700 m a.s.l. (Fig. 2), but in the southern parts it can be planted (naturalized) at higher altitudes, such as over 1000 m a.s.l. in the Alps. For expample Hegi (1924) reported black locust stands at 1200 m a.s.l. (Ticino and Südtirol regions) and naturalized individuals at 1300 m a.s.l. (Valais), and Sitzia et al. (2016b) reported individuals up to 1640 m a.s.l. (Southern Alps). In Central Europe, rainfall is not a limiting factor, it commonly occurs in areas with 480–800 mm per year (Fig. 2). It grows in climatically warm areas with the mean annual temperature usually between 6–11°C (the most common minimum mean May and June temperatures are 7.6 and 11°C, respectively). The northern limit of this species coincides with zone of frost days continuing up to the middle of May, because late frosts damage the leaves and young shoots (Bartha et al., 2008). In the semi-continental climate of Central Europe, late-spring frosts are typical even in warmer areas. Repeated frosts can result in distorted trunks, still *Robinia* is able to resprout to some extent. In northern Europe, a combination of spring frosts, short vegetation period and generally cold climate limits the species survival.

In Central Europe, it is most widespread in Hungary (ca 24% of forests; Tobisch and Kottek, 2013; Table 3), where the percentage of *Robinia* forests is greater than in all the other European countries combined (Walkovszky, 1998). In Hungary, black locust is grown mainly in the south and southwest Transdanubia (hill-ridges in Vas-Zala and Somogy counties), the plain between the Rivers Danube and Tisza (Central Hungary) and in north-east Hungary (Nyírség region; Rédei et al., 2012), and the area planted with this species is still increasing (Tobisch and Kottek, 2013). As in other Central European countries, the majority of stands are mixed, with only up to 10% *Robinia*. Pure and almost pure stands with over 75% *Robinia* cover only 0.1% of the area (State Forest Service Mapping Department, 2006). Slovenia is one of the most forested countries in Europe, and *Robinia* occurs scattered at low altitudes (up to 600m a.s.l.) covering 4.7% of the total forested area, mostly in the southwest and east of the country. The majority of these stands have up to 10% *Robinia* and stands dominated by this species only comprise 0.3% (Slovenian Forest Service 2007 – Matijašić, pers.com.). In Poland, this species occurs almost across the entire country with the highest concentration in the west. *Robinia* forms 3.4% of Poland state forests (of the 430 Forest Districts it is present in 419), and dominates in 0.1% (the most dominated are districts in Zielona Góra, Poznań, Łódź, Szczecin and Wrocław; Wojda et al., 2015). In Slovakia, it is common in the southern and southeastern Pannonian lowlands with the center in the Danube lowlands (Benčať, 1995; Petrášová et al., 2013) and makes up 1.7% of the Slovakian state forests. One third of these forests are pure or almost pure *Robinia* stands, which is the largest percentage of pure stands recorded for all the countries considered (SFP, 2014). In the Czech Republic, *Robinia* covers around 0.5% of the forested area and new *Robinia* plantations are not currently being planted (FMI, 2014; MZE, 2014). Over the last decade its area has hardly changed (FMI, 2014; Křivánek et al., 2006; Vítková et al., 2004).

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It is scattered at low altitudes all over the country, preferring south oriented 30–40° slopes at 210–350 m a.s.l. (Vítková et al., 2004, 2015). In Germany it is widespread, covering 0.3% of the total forested area and is only absent in high mountain areas. It is most common in the drier regions in the East (over 60% of stands are located in Brandenburg and Saxony-Anhalt) and sandy areas in the Upper Rhine (Grünewald et al., 2009; Kanzler et al., 2015; Schneck, 2010). In Austria, *Robinia* is only rarely planted in forests where it makes up 0.2% of the cover (Berg et al., 2016; Kirchmeir et al., 2001) but is widely established in warm and dry regions in Burgenland (4.0% of the total number of trees in that county), Lower Austria (2.6%) and the eastern part of Styria (0.2%), including the National parks Thayatal and Donau-Auen and adjacent forests in the foothills of the Alps (Berg et al., 2016; Büchsenmeister, pers.com., Kleinbauer et al., 2010; Wallner, 2005). Small isolated populations occur in other lowland regions, such as low valley bottoms in the Alps (Kleinbauer et al., 2010). In Switzerland, *Robinia* makes up only a small part of the forests (approximately 0.2%, mostly in mixed stands; Bachofen et al., 1988). It is scattered in most of the lowlands up to 600 m a.s.l., rarely in the lower mountain belt (Wittenberg et al., 2006). Half of the *Robinia* stands occur on the southern slopes of the Alps, mainly in the southernmost canton of Ticino (surroundings of Mendrisio and Lugano, Swiss National Forest Inventory; Conedera pers.com.). In Liechtenstein, there are no stands of *Robinia*, only isolated trees growing in the Rhine Valley between 430 and 700 m a.s.l. (Schmuck, pers. com.).

4 Ecological risks

In terms of invasion and spread outside plantations, *Robinia* is a light-demanding pioneer species, which is able to disperse quickly and colonize a broad range of xeric to mesic habitats, including steep rocks or toxic man-made substrata (e.g. Bartha et al., 2008; Cierjacks et al., 2013; Vítková and Kolbek, 2010). Large-scale disturbances followed by abandonment and spontaneous succession over several years to decades, which is typical of modern landscapes, are especially suitable for *Robinia*. In the warmer parts of Europe it is a crucial dominant of woody stands in broad range of habitats. Usually, populations in the landscape are interconnected, moreover *Robinia* is able to effectively migrates at the local scale and persist on the site in the first decades of secondary succession. It dominates early stages of forest regeneration (Radtke et al., 2013) and rapidly colonizes open sites in suburban wasteland, mining areas, abandoned fields and pastures, forest gaps or sites damaged by fire (Cierjacks et al., 2013; Maringer et al., 2012). As a relatively weak competitor, *Robinia* occurs in mixed stands of fast-growing early succesional species, both native and alien: trees such as *Betula pendula*, *Populus tremula*, *Pinus sylvestris*, *Acer negundo* and *Ailanthus altissima*, and shrubs such as *Prunus spinosa* or *Lycium barbarum* (e.g. Kowarik, 1990; Kowarik et al., 2013; Pietrzykowski and Krzaklewski, 2006). Interestingly, saplings of slow growing native trees, such as oaks lose in competition with *Robinia*.

4.1 Dispersal and establishment of new populations

Over short distances, except in shady, wet or continuously disturbed sites, *Robinia* is reported to spread locally up to 1 m per year (Kowarik, 1996) by horizontal root elongation and ramets forming a connected root system (Cierjacks et al., 2013). Compared to other species of trees, *Robinia* is extremely resistant to disturbance. Under unfavourable light conditions, it creates a persistent bud bank including buds on roots, stems and branches, allowing rapid reaction to canopy opening following disturbance (Kowarik, 1996). The tree produces numerous root suckers, even trees over 70 years old. Compared to the seedlings of other species of the same age, they are taller, grow faster (annually up to 4 m) and reach reproductive maturity earlier (e.g. Kowarik, 1996; Vítková and Kolbek, 2010). Mechanical damage of roots or trunks used as a regeneration method in forestry (coppicing, i.e. short rotation management; Rédei et al., 2012) leads to an increase in stem density and rejuvenation of *Robinia* stands, which in turn results in an extension of compact clonal colonies covering areas of several hundred square meters (Kowarik, 1996; Krízsik and Körmöczi, 2000).

Although *Robinia* can quickly spread over short distances, new populations are not easily established. For long-distance dispersal it depends mostly on human-related vectors, such as deliberate planting and/or transport of soil containing seeds and roots (Pyšek et al., 2012a). Natural seed dispersal is constrained by its rather heavy seed, which is mainly dispersed by gravity and wind in the vicinity of the mother tree. Long-distance spread by natural means is not very common, although examples exist, including dispersal by water (ca 20% of pods carried by rivers reach distances of over 1200 m; Säumel and Kowarik, 2013), wind (in Japan on the surface of snow the seeds can be carried up to 67 m from the mother plant; Morimoto et al., 2010), animals (endozoochory by pigs and birds; Cierjacks et al., 2013) and motor vehicles (von der Lippe and Kowarik, 2008). Although an individual tree produces up to 12,000 seeds/m^2 in monodominant stands (Marjai, 1995), their germination under natural conditions depends on environmental conditions, where the seeds with physical dormancy ripen (Baskin et al., 2000). In native range, the percentage germination is low with values ranging from 3.5% to 16.3% (Roberts and Carpenter, 1983). Seedlings are sensitive to shading and their mortality is high in closed herbaceous vegetation and forests, whereas they establish and survive well at disturbed sites with more light and bare soil (especially in burnt areas; Kowarik, 1996; Maringer et al., 2012; Vítková and Kolbek, 2010). Relatively slow dispersal by seed, low percentage germination and weak long-term ability to compete with climax tree species such as *Tilia*, *Acer* or *Ulmus*, which form closed canopy forests are the main factors limiting the establishment of new *Robinia* populations. In this respect *Robinia* differs from other successful invaders colonizing disturbed area even at great distances from the source plant thanks to their high percentage germination and high dispersal ability via water, wind or birds (e.g. *Heracleum mantegazzianum* and *Impatiens glandulifera*; Moravcová et al., 2006; Perglová et al., 2009).

4.2 Invaded habitats: the role of stress, disturbance and competition

Robinia is one of the 10 neophytes with the broadest habitat range in Central Europe (Chytrý et al., 2005) and is recorded in 48% of EUNIS habitats in the Czech Republic (Chytrý et al., 2008). It does not occur at sites that are subject to continuous disturbance and stress due to a high groundwater table and periods of flooding because nitrogen fixation is inhibited in such situations (Vítková et al., 2015). On the other hand, it is able to tolerate both toxic and extremely dry soils (Fig. 3), occurring on shallow genetically young soils, such as cambisols, leptosols and arenosols (Vítková et al., 2015), where this species is planted to augment soil productivity. Both climate change (Chmielewski et al., 2005; Kleinbauer et al., 2010; Sukopp and Wurzel, 2003) and planting for forestry and landscaping (Kowarik, 2003) might even increase the range of habitats colonized by *Robinia* in the future. Central European habitats most often invaded by *Robinia* include (Table 3): (1) dry and semi-dry grasslands including those growing on open sandy steppes and rocky outcrops (Fig. 3 and 4B); (2) dry forests and shrubland; (3) alluvial habitats; (4) agrarian landscapes with abandoned fields, orchards, vineyards, hedgerows, gullies, windbreaks and roadsides (Fig. 4); (5) urban and industrial environments including polluted or salty soils and (5) disturbed sites in most habitats, e.g. post-fire sites, windthrows, previously flooded area, forest clearings or degraded forestry plantations (e.g. Chmura, 2004; Csontos, 2010; Maringer et al., 2012). Although *Robinia* often colonizes different types of deciduous broad-leaved forests (oak forests, oak-hornbeam forests, beech forests and ravine forests; e.g. Botta-Dukát, 2008; Essl and Hauser, 2003; Kleinbauer et al., 2010; Tokarska-Guzik et al., 2012; Wojda et al., 2015), as a light-demanding species it does not occur in forests or shrubland with closed canopies. In such stands, it can only occur as individual trees or groups of trees after disturbance results in a gap in the canopy (e.g. after trees die, fire, windthrow or forest management). On the other hand, it is very common at the margins of forest/shrubland, often near settlements and gardens (Essl et al., 2011). Coppicing in 20–30 year cycle favours the spread of *Robinia* (Radtke et al., 2013).

Open thermophilous shrubland and forest-steppe woodland (such as pine forests and thermophilous oak forests growing on sandy plains or rocky slopes) are likely to be colonized by *Robinia* spreading by means of root suckers from adjacent stands (e.g. Cseresnyés and Csontos, 2012; Vítková and Kolbek, 2010). Of particular concern for nature protection is its spread into dry and semi-dry grassland (Fig. 4), which are among the most species-rich and endangered types of habitat in Central and Western Europe (Fischer and Stocklin, 1997). *Robinia* is a great threat to xeric and calcareous sandy grassland in Poland and Hungary (MÉTA, 2016; Tokarska-Guzik et al., 2012). According to the MÉTA (2016), it has damaged 33,000 ha of open sandy grassland and poplar-juniper thickets and is a threat to another 200,000 ha of natural and semi-natural habitats in Hungary. It is reported to have colonized 40% of the dry and semi-dry grassland in Austria (Kleinbauer et al., 2010). In the Czech Republic, *Robinia* occurs in 24.8% of the protected areas (Pyšek et al., 2004), with the most threatened the species-rich thermophilous grasslands on steep sunny south facing rocky slopes of any bedrock (Vítková and Kolbek, 2010).

Although *Robinia* often invades alluvial forests (Kleinbauer et al., 2010; MÉTA, 2016; Petrášová et al., 2013; Rudolf and Brus, 2006; Skowronek et al., 2014; Staska et al., 2014; Zelnik, 2012), it can spread only on well-drained sites such as sandy, gravel-sandy and gravel banks or flood barriers far from rivers, which experience only occasional short-term flooding (e.g. Höfle et al., 2014; Terwei et al., 2013, 2016). Without forestry interventions, black locust abundance would decrease during natural succession, probably due to its relative short life span and low tolerance of shade. If spontaneously occuring in mature forests, it will prefer sites that are more open or present remnants of earlier disturbances such as fire or windthrow (Höfle et al., 2014; Motta et al., 2009; Somodi et al., 2012; Terwei et al., 2013). Similar mature forests with occasional occurrence of black locust may be formed during natural succession of old *Robinia* monocultures (over 50 years) in mesic to dry habitats, if highly competitive and shade tolerant tree species occur in the neighbourhood (e.g. *Fraxinus excelsior*, *Acer pseudoplatanus*, *A. platanoides*, *A. campestre*, *Euonymus europaeus*, *Rhamnus cathartica* and *Prunus spinosa*). Also in its native distribution, when available soil nitrogen is no longer limiting (after 20–30 years), *Robinia* is replaced by more shade-tolerant and competitive trees (Boring and Swank, 1984; Shure et al., 2006), and becomes a component of highly productive and species-rich forests consisting of *Carya, Quercus, Juglans, Pinus, Tilia* or *Fraxinus* (Boring and Swank, 1984; Fowells, 1965; Shure et al., 2006). Single *Robinia* trees or small groups may persist, grow to a large size and form a small part of the ultimate canopy layer (Huntley, 1990). Larger stands can survive only where the conditions are more unfavourable such as dry rocky slopes or waste places (Thorne and Cooperrider, 1960).

Longevity of *Robinia* monodominant stands in Central Europe, where they can persist for more than 70 years, is explained in terms of a limited pool of native species of trees in most invaded areas and lack of serious natural enemies (Kowarik et al., 2013; Vítková, 2014; Vítková and Kolbek, 2010). Also, a dense cover of grasses and sedges such as *Calamagrostis epigejos*, *Bromus sterilis* or *Carex brizoides* may slow down forest succession (Terwei et al., 2016; Vítková and Kolbek, 2010). In the southeastern part of Central Europe and the whole of Southern Europe, old *Robinia* stands are characterized by a balance between rejuvenating black locust and other trees and shrubs, such as *Juglans regia*, *Castanea sativa*, *Prunus mahaleb*, *Rubus fruticosus* agg. and *Ligustrum vulgare.* Species-rich herb layer is dominated by grasses (*Bromus sterilis*, *Arrhenatherum elatius*, or *Poa angustifolia*), with frequent nutrient demanding herbaceous plants (*Geum urbanum*, *Physalis alkekengi* or *Ballota nigra*) and surviving forest herbaceous plants, most significantly vernal ephemerals and geophytes (such as *Ficaria verna*, *Fumaria schleicheri*, *Holosteum umbellatum*, *Muscari comosum*, *Ornithogalum boucheanum*, *Secale sylvestre*, *Senecio vernalis* (Fekete, 1965; Majer, 1968; Pócs, 1954).

4.3 Impact on plant communities, wild animals and soil

Despite the general statement that *Robinia* reduces biodiversity, its impact on biodiversity of invaded communities is ambiguous. Sitzia et al. (2012) does not record a significant difference in the richness and diversity of the understory plant species in 10 to 36-year-old black locust and native pioneer stands in the hilly piedmont landscape in the Eastern Alps. Homogenisation of tree layer and a tendency towards forming pure *Robinia* stands in spontaneously growing forests across habitats in northern Italy (Sitzia et al., 2012) is not reported in riverine forests in the Western Caucasus (Akatov et al., 2016). Despite the significant increase in understory nonnative species richness and abundance in *Robinia* stands compared with paired native pine–oak and pine stands, this tree does not appear to directly or indirectly affect native species richness or cover (Von Holle et al., 2006). On the other hand, Trentanovi et al. (2013) records significantly lower alpha diversity in *Robinia* stands compared to those of the native *Betula pendula* in urban habitats in Berlin. Black locust significantly reduces the natural diversity of herbaceous plants in *Quercus velutina* savannas and woodland dune communities in northern Indiana (Peloquin and Hiebert, 1999). It also causes homogenization of the plant forest communities in Northern Apennines

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(Benesperi et al., 2012). Nascimbene and Marini (2010) consider the *Robinia* invasion as the most influential factor affecting the composition of lichen communities, preferring species adapted to well-lit, dry conditions, and tolerating air pollution and eutrophication.

Many authors (e.g. Montagnini et al., 1991; Peloquin and Hiebert, 1999; Taniguchi et al., 2007; Vítková and Kolbek, 2010; Von Holle et al., 2006; Wendelberger, 1954, 1955) report that *Robinia* forms specific plant communities, whose herb layer is markedly different from that in forest dominated by native trees. In Central Europe, it changes the conditions under the canopy, which become more favourable for shade-tolerant and nitrophilous species, such as *Alliaria petiolata*, *Anthriscus sylvestris*, *Chelidonium majus*, *Galium aparine*, *Sambucus nigra* and *Urtica dioica* (e.g. Dzwonko and Loster, 1997; Hruška, 1991; Vítková and Kolbek, 2010). There are two different phenological aspects of the herb layer in the first half of the growing season: (1) early spring before the *Robinia* leaves appear (March to April) is characterized by geophytes and ephemeral annuals (e.g. *Ficaria verna*, *Gagea* spp., *Holosteum umbellatum*, and *Valerianella locusta*); (2) late spring (May to June) shadow-tolerant annual herbaceous plants appear (e.g. *Impatiens parviflora, Galeopsis tetrahit*), vines (e.g. *Galium aparine*), perrenial herbacous plants (e.g. *Ballota nigra*, *Geum urbanum*) and grasses (e.g. *Poa nemoralis*). Later in the season, annuals and geophytes disappear and the herb layer often dries out. Such vegetation structure is typical for the most common syntaxonomical unit of *Robinia* stands in Central Europe (Chytrý et al., 2013; Vítková and Kolbek, 2010), namely *Chelidonio majoris-Robinietum pseudoacaciae* Jurko 1963. Other units are characterized by rare nitrophytes and domination of grasses (e.g. *Arrhenathero elatioris-Robinietum pseudoacaciae* Šimonovič et al. ex Vítková et Kolbek 2010) or native thermophilous herbs and shrubs (*Melico transsilvanicae- Robinietum pseudoacaciae* Kolbek et Vítková in Kolbek et al. 2003).

It seems that rather than by allelopathy, which is only recorded in laboratory experiments (e.g. Nasir et al., 2005), the changes in species composition are more likely caused by changes in availability of soil nutrients and light conditions (Vítková and Kolbek, 2010). Because of the slow decomposition of a thin leaf layer due to its high lignin content (e.g. Castro-Díez et al., 2012), nitrogen fixation by symbiotic *Rhizobium* bacteria (Batzli et al., 1992) is the main source of nitrogen in *Robinia* stands (e.g. Liu and Deng, 1991), with the highest nitrogenase activity recorded between June and September (Noh et al., 2010). In a favourable moisture regime, soil nitrogen pool increases, nitrification and N-mineralization rates are enhanced, and more available mineral forms of soil nitrogen acumulate in the A-horizon (e.g. Malcolm et al., 2008; Montagnini et al., 1991; Van Miegroet and Cole, 1984). High soil nitrification may decrease the pH of the litter and upper soil horizons, and potentially lead to higher leaching of ions (Ca, Mg, K, Na and PO_4-P; Van Miegroet and Cole, 1984; Vítková et al., 2015).

In Central Europe, *Robinia* stands are more open over the whole growing season compared to native forests, and both the shrub and herb layers are therefore denser. For example, the canopy cover in *Robinia* stands is 57% compared to 72% in native oak forest, shrub cover 57% compared to 11%, and herb layer 53% compared to 5% (Hanzelka and Reif, 2015a). The period when *Robinia* is in leaf is relatively short. The leaves appear late in spring (May) and begin to fall early, usually during summer droughts (August). The high light supply

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enables light demanding species, spring annual weeds, geophytes, or a dense shrub layer to survive, however at the same time it results in conditions that are unfavourable for the establishment of shade-tolerant native tree seedlings. In grasslands, dense clones of *Robinia* create shaded islands unfavourable for heliophilous plants. After canopy closure, light regime, microclimate and soil conditions of former grassland change, threatening endangered light-demanding plants and invertebrates (Dembicka and Rozwalka, 2007; Greimler and Tremetsberger, 2001; Kowarik, 1996, 2003, 2010; Matus et al., 2003; Vítková and Kolbek, 2010), of which only a few are able to survive or even increase in abundance (e.g. *Anthericum liliago, Aurinia saxatilis*, *Carex humilis*, *Centaurea triumfetti* and *Stipa pennata*; Pyšek et al., 2012a; Vítková and Kolbek, 2010).

The impacts of the structural differences in stands of *Robinia* and native trees on native consumers are rarely studied. In urban wasteland, a rapid shift from dry-grassland to forest-ground beetles and spiders is reported (Platen and Kowarik, 1995). Associated with the *Robinia* spread into urban woodlands are changes in the species composition of ground-dwelling arthropods but surprisingly no decrease in the number of endangered species or in alpha and beta diversity of carabids and spiders (i.e. animals very sensitive to environmental modifications even at small scales; Buchholz et al., 2015). Moreover, old *Robinia* trees can provide a refuge for saprophagous beetles including rare species, for example *Anommatus reitteri* (Stejskal and Vávra, 2013). The spread of *Robinia* is associated with the replacement of birds that are habitat specialists by habitat generalists, although the total number of birds is higher in the invaded stands (Hanzelka and Reif, 2015b; Hanzelka and Reif, 2016; Reif et al., 2016). While the total invertebrate biomass is not lower in invaded habitats (Hanzelka and Reif, 2015a, b), some arthropod species dependent on plants that are suppressed by black locust are missing and therefore bird specialists are limited by a less diverse of food supply, significantly by lower moth diversity. On the other hand, habitat generalists are more flexible to find new breeding opportunities in dense shrub layer in *Robinia* stands (Reif et al., 2016). The availability of nest sites or accessibility remain unchanged, moreover no differences in the level of nest predation and nest positions are reported in native oak and invasive black locust stands (Hanzelka and Reif, 2015a). No wintering or foraging birds prefer *Robinia* stands (Laiolo et al., 2003). In intensively used agricultural landscapes *Robinia* “islands” increase biodiversity and provide food supply and shelter for many plants, macrofungi, invertebrates and vertebrates including rare species (e.g. Heroldová, 1994; Kowarik, 1994; Ślusarczyk, 2012; Stanko et al., 1996; Vítková and Kolbek, 2010).

5 Robinia in the vegetation of cultural landscapes

Robinia stands growing in Central Europe differ markedly in their origin (spontaneous vs planting), structure (dense forests vs semi-open stands and forest vs shrubland), composition (share of native and alien species), age (early successional stands vs decaying stands) and current management (ranging from unmanaged stands to intensive planting). Based on these traits, the following types of vegetation can be distinguished (Table 4): (1) intensive planting of urban or agrarian greenery, (2) *Robinia* dominated forests, (3) mixed forests and (4) open dwarf growth.

(1) In urban and agriculture areas, this species is traditionally planted as a solitary tree, in groups or as a linear feature along roads and streets, in windbreaks, along rivers, in field and vineyard boundaries, gullies, hedgerows etc. In addition to the ornamental nature of such sites, they serve as a protection against soil erosion, a natural barrier (e.g. a noise wall or windbreak), a corridor for wildlife movement (Stanko et al., 1996; Vítková, 2014) and food supply for animals (Hanzelka and Reif, 2015b; Heroldová, 1994). *Robinia* trees often occur at religious sites, e.g. around chapels and wayside crosses or in cemeteries.

(2) *Robinia* dominated forests frequently occur in the lowlands and on hills across Central Europe, mostly as a result of planting, although some are likely to have been established spontaneously. Their plant composition is dependent on the terrain and bedrock, which affect both soil chemistry and water availability (Chytrý et al., 2013; Vítková and Kolbek, 2010). Most common are species-rich nitrophilous *Robinia* forests with vigorous trees of up to 30 m in height growing in mesic habitats on both slopes and flat terrain throughout Central Europe. Species-poor grassy stands rather than nitrophilous *Robinia* forests occur at nutrient-poor and drier sites.

(3) *Robinia* stands with an admixture of other trees can be planted or spontaneous. Reason for planting mixed forests is mainly to improve soil quality, yield and biological diversity in inter-cropping plantations (e.g. Mosquera-Losada et al., 2012); in parks and urban forests where it is planted mainly as an ornamental tree. Spontaneous mixed stands are typical for habitats occuring in urban areas (built-up areas, green spaces, wasteland such as abandoned railway areas, landfills, demolished areas, unmaintained greenery and industrial zones, forests and wetlands) and mining areas across Central Europe (e.g. Keil and Loos, 2005; Kowarik, 1986, 1990, 1992; Kowarik et al., 2013; Kunick, 1987; Pietrzykowski and Krzaklewski, 2006; Prach, 1994; Zerbe et al., 2003). In highly modified urban environment with limited native species pool, such mixed forests composed of allien *Robinia*, native pioneers (e.g. *Betula pendula* and *Populus tremula*) and nitrophilous trees (*Acer platanoides* and *Fraxinus excelsior*) enhance the level of biodiversity, help secure sustainable urban development and create a part of novel ecosystems (Kowarik and Langer, 2005; Sjöman et al., 2016; Zerbe et al., 2003). For example in Berlin, such urban forests are protected in urban nature conservation area Natur Park Südgelände (Kowarik and Langer, 2005).

(4) Low to shrubby *Robinia* growths occur in dry habitats, such as dry grasslands and shrubland or thermophilous oak forests, which originated via root suckers from adjacent planted stands on deeper soils. On sunny slopes, *Robinia* survives mainly due to its highly branched root system and tolerance of drought (Benčať, 1988), but it is at the limit of its physiological abilities and as a consequence tends to have an unshaped crown, deformed trunk and a height of between 3 to 5 m (Fig. 3).

6 Economic benefits

Robinia is an economically important species as a fast growing tree producing valuable water- and rot-resistant timber, firewood, leaf forage for animals and nectar for making honey. It is also used for erosion control, amelioration and reclamation of disturbed sites, and as a shade or nurse tree (e.g. Göhre, 1952; Kasper-Szel et al., 2003; Keresztezi, 1988;

Papanastasis et al., 1998; Rahmonov, 2009; Rédei et al., 2008; Yüksek, 2012). Historically, it served as a source of timber e.g. for vineyard poles, wine barrels, boats, water constructions, roof shingles, and fence posts. Currently, its wood is widely used for making furniture, garden and playground equipment. Black locust is also attractive for landscape gardeners; many interesting horticultural varieties have been bred, especially in France in the first half of the 20th century (Bartha et al., 2008; Hillier and Lancaster, 2014). Due to its ability to tolerate high levels of air pollution, salinity, drought, light intensity, and low soil quality, it is popular in urban areas, such as parks and street avenues (e.g. Hanover, 1990; Hillier and Lancaster, 2014). Utilization of this tree for biomass (dendromass) production in short-rotation energy plantations has become a worldwide trend over the last few decades thanks to its high yields (fast rate of growth, very high density) and nitrogen fixation ability (e.g. Böhm et al., 2011; Medinski et al., 2014; Rédei et al., 2011; Stolarski et al., 2013).

6.1 Productive forests

Robinia is the second most common broadleaved tree (after *Quercus rubra*) introduced for wood production in Europe (MCPFE, 2007). It is very important in Hungary providing 25% of the annual timber production (Tobisch and Kottek, 2013), while in Austria, the Czech Republic, Slovenia and Switzerland it is only used in small scale plantations for honey, firewood or wood for special purposes, such as playgrounds, vineyards or wine barrels. One third of Hungarian plantations are tall forests (planted from seedlings), the rest is coppiced (Rédei et al., 2012). In Slovakia, 95% of *Robinia* forests are of very low quality, the most productive plantations in the southern Slovakia are mostly regenerated by coppicing (Benčať, 1995). In the Czech Republic and Switzerland, new plantations have not been recently established, still existing stands are regenerated by coppicing (MZE, 2014; Brus, Büchsenmeister, Conedera and Essl, pers. com.). In Poland, short-rotation plantations are prefered and long-rotation plantations are not established at present, because the duration of the rotation period needed for optimal harvest (30–40 years) is unacceptably long for farmers (Wojda et al., 2015).

Robinia monocultures have been established on a variety of sites, from good and medium to poor quality ones. The differences in soil composition and water regime cause the tree growths to vary from 10 m (used for example for firewood, poles, props, honey production) to the 35 m in height (providing quality timber; e.g. Benčať, 1995; Keresztesi, 1988; Rédei et al., 2008). During the research programmes in the 1950's and 1960's, new clones and cultivars were bred in Germany and Hungary to provide a high volume of good quality industrial wood (Keresztesi, 1988; Schneck, 2010).

Growing trees from seedlings is a relatively simple and low cost, but germination must be facilitated by mechanical scarification (Rédei et al., 2012), soaking the seeds into concentrated sulfuric acid or boiling water (Huntley, 1990). The highest seed production is carried in the plain between Danube and Tisza rivers and in the Nyírség region (Hungary; Rédei et al., 2012), and Sachsen-Anhalt (Germany; Schneck, 2010). Propagation from root cuttings is suitable for reproduction of superior individuals preserved in the clones or special cultivars. Soil preparation improves both aeration and watering, and includes tilling of inter-row spaces (Rédei et al., 2012).

As a fast-growing tree, *Robinia* is able to quickly close canopy openings. In the Nyírség region (Hungary), one of the most suitable black locust growing regions in Central Europe, the current annual increment reached the maximum at the age of 10 years in case of yield class I–IV (17.5 m^3/ha/yr, 14.2, 11.1, 8.5, respectively) and 15 years in class V–VI (6.2 and 4.2 m^3/ha/yr). Mean annual increment culminates at the age of 20 years consistently in all classes (Rédei et al., 2014). Black locust forests need a regular silvicultural treatments otherwise the quality of wood deteriorates. At 3–6 years of age, a cleaning operation of stands with coppice origin reduces stocking to less than 5,000 trees per ha (Rédei et al., 2008). Further thinning should reduce the density to 500–600 trees per ha at the harvest cut (Wojda et al., 2015). In yield class I, *Robinia* reaches height 28.1 m and breast-height diameter 32.8 cm at the age of 45 years, in comparison to 13.3 m and 15.6 cm for the least valuable yield class VI (Rédei et al., 2014). In the average rotation age of 30 years (20 to 40 years according to the yield class; Rédei et al., 2008), the yield varies between 104 and 409 m^3/ha (Nyírség region, Hungary). On good and medium quality sites at the harvest age of 35–37 years, regeneration from root suckers produces higher yield compared to regeneration from seedlings (Rédei et al., 2012).

6.2 Energy plantations

Because of excellent energy properties (Rédei et al., 2008), the interest in *Robinia* use for dendromass production both in forests and on arable land has increased in Hungary, Germany, Poland, Slovakia and Austria in the last few decades (e.g. Grünewald et al., 2009; Kohán, 2010; Rédei and Veperdi, 2009; Rédei et al., 2008; Schneck, 2010; Wojda et al., 2015). High drought tolerance, ability to grow on extremely diverse soils in terms of physical-chemical conditions, and to fix nitrogen makes *Robinia* suitable for dendromass production on waste soils in post-mining landscapes (Böhm et al., 2011; Grünewald et al., 2009). The cheapest option for such plantations is to transform existing traditional *Robinia* forests, mostly of low quality. A big advantage is large dendromass yield within a short time period, between the 3 to 5 years. Disadvantage of such forests is that the distribution of trees in coppice stands is not as regular as in plantations optimized for energy production (Rédei and Veperdi, 2009; Wojda et al., 2015). The yield varies greatly, depending on climate, site quality, type of cultivar and tree density. The highest annual production was achieved by *Robinia* cultivar 'Üllöi' (8.0 t/ha/yr of dry mass in 7 years; Rédei and Veperdi, 2009). In southern Europe, relatively low production of litter and periodic removal of organic matter in energy plantations causes a long-term depletion of topsoil and leads to decline in productivity after two rotation periods (Vasilopoulos et al., 2007).

6.3 Protective forests and honey production

This species was used to stabilize deforested steep slopes along railways and deep river valleys, mostly in the Czech Republic and Switzerland (Kolbek et al., 2004; Conedera, pers.com.). Today, such protective forests are not as vigorous as was the case with the first generation following planting (also because they are often unmanaged and very old, some over 50 years) and pose problems in terms of their stability, which is debated among foresters. As early as in the 1970's, the potential of *Robinia* for biological reclamation in the post-mining landscapes and landfills was recognised (e.g. Bellon et al., 1977) and the species is still used for such purposes especially in Poland and Germany (Grünewald et al., 2009; Kanzler et al., 2015; Wojda et al., 2015).

Protective *Robinia* forests provide excellent honey. Pale yellow to greenish yellow *Robinia* honey is fruity and fragrant and remains uncrystallised for 3–4 years due to high fructose content (Farkas and Zajácz, 2007; Keresztesi, 1977). Its chemical composition is described by Kasper-Szel et al. (2003) and Lukasiewicz et al. (2015). The capacity to generate honey changes with the tree age, with maximum in 15 years with 418 kg ha/year in Hungary, in Poland with 100 kg ha/year (Csiha, 2013; Keresztesi, 1988; Wojda et al., 2015). The highest amount of *Robinia* honey in Central Europe is produced by Hungary, around 25,000 t/year (Csiha, 2013), representing about 40–50% of European production (Farkas and Zajácz, 2007). Other bigger honey producers are Germany, Slovakia and Poland.

7 Management practices

As many invasive species, *Robinia* generates controversial views because of its positive economic but negative environmental impacts and causes conflicts of interest over its value between different groups (nature conservation, forestry, urban landscaping, beekeepers, public etc.). Priorities for *Robinia* management therefore differ among Central European countries (Table 5). This is quite common for many alien trees used by forestry or in landscaping (Sladonja et al., 2015). If it is included in the list of invasive alien species of Member State concern (Article 12, Regulation (EU) 2016/1141), management measures including prevention, early detection and fast eradication will be implemented according to Articles 7, 8, 13 to 17, 19 and 20 (the same Regulation). Moreover, the Council of Europe promoted the preparation of the Code of Conduct on Planted Forest and Invasive Alien Trees, comprising fourteen principles to prevent new introductions and reduce, control and mitigate negative impacts related to use of invasive alien trees in plantations (Brundu and Richardson, 2016). The Code is a voluntary tool and does not replace any statutory requirements under international or national legislation.

Because forestry is the most important introduction pathway for invasive alien trees (Richardson and Rejmánek, 2011; Richardson et al., 2014), appeals to the European forestry sector have been made to implement a new European regulation and incorporate appropriate measures to help successfully reduce the problem of invasive alien species in forests and adjacent habitats (Sitzia, 2014; Sitzia et al., 2016a). In case of *Robinia*, the coppice management currently applied in forestry, consisting of repeated clear cut, favours its spread into deciduous forests (Radtke et al., 2013). *Robinia* should be used carefully for biomass production, as it can easily escape from cultivation causing frontal invasion with recorded maximum of ~50 m in 20 years after the plantation establishment (Crosti et al., 2016).

Economic benefits complicate the perception of *Robinia* as an invasive species posing serious threats to nature conservation, therefore its spread into nature reserves and endangered habitats is viewed differently in different Central European countries. Since 1992, the EU LIFE scheme has supported 33 projects aimed at removing *Robinia* from mainly threatened thermophilous habitats (Silva et al., 2014). As there is currently no efficient and generally applicable method for eradicating this species (e.g. Böcker and Dirk,

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2007; Pergl et al., 2016a; Schmiedel et al., 2015), action plans for integrated management are needed, based on a site-specific approach resulting in tolerance at selected areas and eradication at valuable sites (Pergl et al., 2016a; Vítková et al., in press.).

8 Conclusions: ecology vs culture and economy

As a result of cultivation and invasion, *Robinia* has become a part of the Central European landscape, nature, culture and economics, including cultural and historical heritage, as it is mentioned in songs, poems, literature and culinary recipes. In several countries it is an economically important tree used for the production of timber, biomass, honey, firewood and for erosion control etc. On the other hand, it is a serious threat to nature conservation, together with other invasive plants with a high negative environmental impact comparable to that of knotweeds (*Fallopia* sp.) or hogweed (*Heracleum mantegazzianum*; Kumschick et al., 2015).

The attempts to list *Robinia* among the invasive alien species of EU concern (Regulations (EU) 1143/2014 and 1141/2016) initiated a public debate among various interest groups, which resulted in the exclusion of *Robinia* from the first Union List. However, individual Member States depending on the context of invasion may take emergency measures against black locust or include it among the list of invasive alien species of Member State concern. It is clear, that the attitude to *Robinia* in the different EU member states still differs markedly. In several countries its economic use is even promoted (e.g. Hungary, Poland and Germany). However, economic benefits should never outweigh its negative environmental impact on conservation in suppressing endangered plants and invertebrates by shading and its uptake of nutrients. Its removal from such stands is very difficult, costly and time-consuming due to its high vitality, exceptional sprouting ability, rapid growth, abundant production of seed and nitrogen fixation, which result in irreversible changes in ecosystems. Stumps of harvested trees rapidly resprout making restoration of the original plant communities very difficult without intensive management. On the other hand, despite the general statement that *Robinia* reduces biodiversity, it can have an opposite effect in some special cases, such as in intensively used agricultural landscape where *Robinia* “islands” increase biodiversity, provide shelter for many plants, invertebrates and vertebrates, and serve as corridors for wildlife movement. Optimal management, therefore, has to be based on a stratified, i.e. site-specific approach leading to tolerance in selected areas and strict eradication at valuable sites (Pergl et al., 2016a).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Areas with the highest occurrence of *Robinia pseudoacacia* in Central European countries. Definition of Central Europe follows the common concept (e.g. Encyclopædia Britannica) and includes Austria, Czech Republic, Germany, Hungary, Lichtenstein, Poland, Slovakia, Slovenia and Switzerland. References: Austria – Walter et al. (2005), Czech Republic – Forest Management Institute (unpublished data), Germany – Bundesamt für Naturschutz (2013), Hungary – State Forest Service Mapping Department (2006), Poland – Wojda et al. (2015), Slovakia – Slovakian Forest Portal (unpublished data), Slovenia – Slovenian Forest Service (unpublished data), Switzerland – National Forest Inventory (1983–1985).

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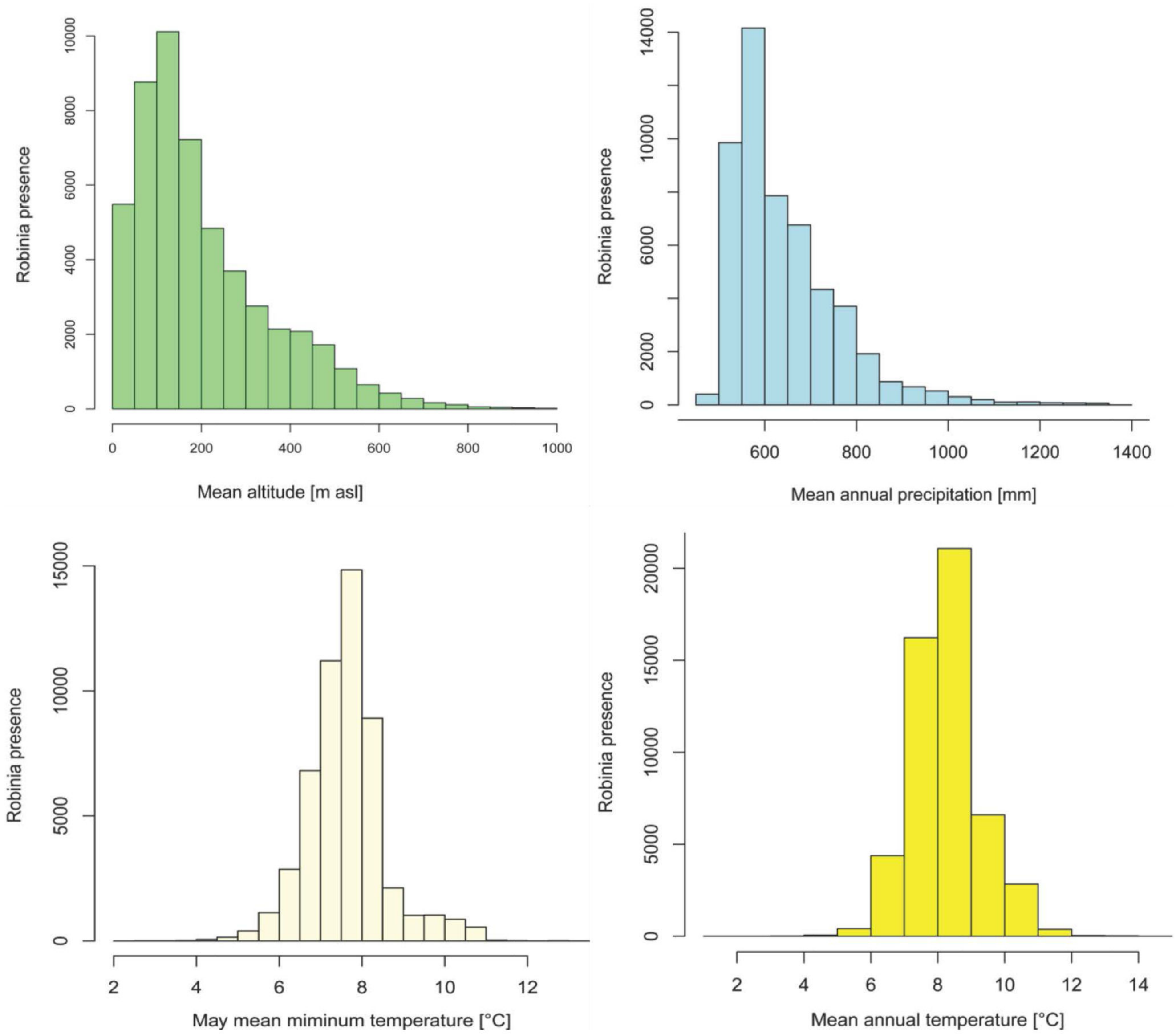

Figure 2.

Frequency distribution of *Robinia* along altitudinal, rainfall and temperature gradients. Environmental variables were derived from WorldClim (http://www.worldclim.org). Sources of the data on the distribution of *Robinia* are cited in Chapter 3 (Current distribution). Austria and Switzerland were excluded from the analysis due to the low precision of the occurrence data for these countries.

Figure 3.
Robinia tolerates extremely dry sites, and is able to grow even on rocky outcrops. In such habitats it threatens endangered heliophilous plants and invertebrates and poses stability problems.

Figure 4.

Robinia is a common part of the Central European agrarian landscape (A, C). Non-invaded cultivations (e.g. orchards, vineyards or fields) surrounding *Robinia* stands act as a biological barrier since periodic farming practices such as ploughing and harrowing suppress both vegetative and generative reproduction of this species (A, yellow polygons; C). Biggest concern for nature protection is its spread into thermophilous grasslands (A, red polygons; B; C in foreground) from which it should be eradicated.

Table 1

Invasiveness of *Robinia pseudoacacia* according to national legislation.

	Invasiveness	References
Austria	**YES**	Essl and Rabitsch (2002); http://www.umweltbundesamt.at/
Czech Republic	**YES**	Pergl et al.(2016b)
Germany	**YES**	Seitz and Nehring (2013)
Hungary	**YES**	Botta-Dukát and Balogh (2008)
Poland	**NO**	Dz.U. 2011 nr 210 poz. 1260
Slovakia	**NO**	Act No. 543/2002 Coll. on Nature and Landscape Protection and Decree no. 158/2014 Coll.
Slovenia	**YES**	Jogan et al. (2012)
Switzerland	**YES**	FOEN (2010), info Flora (2014)

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Table 2

History of the introduction of *Robinia* across Central Europe.

	First record	First afforestation	First published escape	References
Austria	2nd half of the 17th cent.	no information	1850	Hegi (1924); Aliens Austria database; Büchsenmeister, pers.com.
Czech Republic	1710	1760	1874	Nožička (1957); Kolbek et al. (2004); Pyšek et al. (2012a, b)
Germany	1672	1787	1824	Burgsdorf 1787; Buek 1824 in Krausch 1988; Wein 1930
Hungary	1710	1750	no information	Ernyey (1927); Vadas (1914); Czirák, pers.com.
Poland	1806	1860	no information	Pacyniak (1981); Tokarska-Guzik et al. (2012)
Slovakia	1720	1769	1830	David (2006); Kohán (2010); Medvecká et al. (2012)
Slovenia	early 19th cent.	1858	no information	Anonymous (1858); Rudolf and Brus (2006); Ribeiro, pers.com.
Switzerland	1800	around 1850	1900	Bettelini (1904); Hegi (1924); Conedera, pers.com.

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Table 3

Most invaded habitats in Central Europe.

Intensity level: occurrence (+), dominance (+++).

Habitats	Austria	Czech Republic	Germany	Hungary	Poland	Slovakia	Slovenia	Switzerland
Dry grasslands	+++	+++	+++	+++	+++	+++	+	+
Dry forests and shrub stands	+++	+	+++	+++	+	+++	+	
Mesic nutrient-poor forests		+	+	+	+++			+++
Mesic nutrient-rich forests	+	+		+	+	+	+++	
Alluvial habitats	+++	+	+	+++	+	+	+++	+++
Salty habitats	+			+				
Dry heathlands		+			+			
Agrarian landscape	+++	+	+	+++	+	+++	+++	+
Urban-industrial landscape	+	+++	+++	+	+++	+	+	+
Robinia presence	no information	14,087 ha (0.5%)	34,000 ha (0.3%)	446,832 ha (24%)	273,000 ha (3.4%)	33,448 ha (1.7%)	55,189 ha (4.7%)	2,480 ha (0.2%)
Stands dominated by Robinia	7,774 ha (0.2%)	3,170 ha (0.1%)	no information	113,570 ha (6.1%)	8,190 ha (0.1%)	9,794 ha (0.5%)	3,946 ha (0.3%)	no information

Main references: Austria - Kirchmeir et al. (2001), Kleinbauer et al. (2010); Czech Republic - Křivánek et al. (2006), Pyšek et al. (2012a), FMI, authors research; Germany - Schneck (2010), Starfinger and Kowarik (2003); Hungary - Tobisch and Kottek (2013), MÉTA; Poland - Tokarska-Guzik et al. (2012), Wojda et al. (2015); Slovakia - Medvecká et al. (2012), Jarolímek and Kanka, pers.com.; Slovenia - Ivajnšič et al. (2012), Zelnik (2012), SFS; Switzerland - Abegg et al. (2014), Conedera, pers.com.

Abbreviations: FMI - Forest Management Institute (Czech Republic), MÉTA: Magyarország Élőhelyeinek Térképi Adatbázisa (Hungary), SFP - Slovakian Forest Portal (Slovakia), SFS - Slovenia Forest Service (Slovenia).

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Table 4

Types of *Robinia* stands spontaneously invading different habitats in Central Europe.

Columns represent habitats and rows stands. Intensity level: occurrence (+), dominance (+++).

	Dry grasslands	Dry forests and shrubs	Alluvial habitats	Agrarian landscape	Urban-industrial landscape
Species-rich nitrophilous			+++	+	+++
Species-poor grassy	+	+++		+	+
Open dwarfed	+++	+			
Mixed spontaneous	+	+++	+++	+	+++
References	Török et al., 2003 (H)	Vítková and Kolbek, 2010 (CZ)	Rudolf and Brus, 2006 (SLO)	Csecserits and Rédei, 2001 (H)	Kowarik, 1992 (D)
	MÉTA (H)	Kleinbauer et al., 2010 (A)	Zelnik, 2012 (SLO)	Hegedüšová and Senko, 2011(SK)	Keil and Loos, 2005 (G)
	Walter et al., 2005 (A)	MÉTA (HU)	Kleinbauer et al., 2010 (A)	Štefunková et al., 2011 (SK)	Kanzler et al., 2015 (G)
	Vítková and Kolbek, 2010 (CZ)	Kanka pers. com. (SK)	Staska et al., 2014 (A)	Dlapa et al., 2012 (SK)	Dzwonko and Loster, 1997 (PL)
	Tokarska-Guzik et al., 2012 (PL)		Petrášová et al., 2013 (SK)	Ivanjšič et al., 2012 (SLO)	
			MÉTA (H)		

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Table 5
Priorities for utilizing *Robinia* in Central European countries.

Intensity level: occurrence (+), dominance (+++).

Data were obtained from many sources and in most cases discussed with native foresters.

Utilization	Austria	Czech Republic	Germany	Hungary	Poland	Slovakia	Slovenia	Switzerland
Forestry	+++	+	+	+++	+	+	+	
Energy plantation	+		+++	+	+++	+		
Apiculture	+	+	+	+	+	+++	+	+++
Landscaping and soil reclamation	+	+	+	+	+	+	+	+
Poles in vineyards and/or wine barrels	+			+		+	+++	+
Ornamental	+	+++	+	+	+	+	+	