Two Potentially Invasive Tree Species of Coppice Forests: *Ailanthus altissima* and *Robinia pseudoacacia*

Alexander Fehér and Gheorghe F. Borlea

Introduction

Biological invasions lead to ecosystem degradation and threaten biodiversity and related ecosystem services. The two trees species that are most likely to invade coppice forests are *Ailanthus altissima* and *Robinia pseudoacacia*.

While *Robinia* is at times itself considered a species suitable for coppice management, *Ailanthus* is almost solely considered invasive in Europe. The latter is rarely cultivated, with only a few exceptions of Short Rotation Forestry management in Mediterranean countries (Bianco et al. 2014).

Despite the invasive nature of these two species, both also have certain uses and advantages. Along with providing a description of the general characteristics of *A. altissima* and *R. pseudoacacia*, this article will address some of these negative and positive aspects.

Ailanthus altissima

Species and Range

The *Ailanthus* genus (*Simaroubaceae* family) comprises tree species distributed in the Middle East and the Far East, but its only temperate zone representative is the tree of heaven or sky-tree (*Ailanthus altissima*). One of the other species, *Ailanthus confucii*, was native to Europe in the Tertiary (Eocene-Pliocene). *A. altissima* is native to Northern-Central China (in the Yangtze River regions), Northern Vietnam and North Korea. It was introduced to Europe and the United States in 1784, with its recent secondary range covering almost the whole of Europe, and it has spread to new areas of Asia, Africa, South America and Australia. The common names refer to the species' ability to grow up to 30 m high, as well as its outstanding fertility and competitive ability, especially on poor soils and in polluted air. The species can invade as seedlings or ramets derived from one or more individuals, forming concentric patches (clumps) in open grazing areas, forest gaps and clearcuts, including coppice (Knapp and Canham 2000, Call and Nilsen 2003). In some European countries (e.g. Greece), it is common in hedgerows surrounding arable lands and in adjacent wetlands, but quite rare in shrublands, grasslands and forests (!) (Fotiadis et al. 2011).

Ecology

A single tree can produce more than 2 million seeds, some of which are persistent. It also has a powerful ability to sprout without damage; its suckering and clumping system is impressive, capable of extending to more than 100 m in diameter. *A. altissima* is less successful in heavily canopied forests (high forests), but coppicing, cultivation, browsing or any natural disturbance (e.g. frost, fire, stem or root damage) will stimulate its expansion and colonisation. Any vegetative propagules can set adventitious shoots and roots, and *A. altissima* has many seed dispersal mechanisms: wind (medium dispersal distance 120 m), water, birds, rodents and human agencies (people or machinery).

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The species can tolerate pollution and poor site conditions, being indifferent to soil fertility, and it can adapt to a broad range of natural and artificial soils, including barren rocky layers, sandy or clay loams, dry calcareous and shallow soils, artificial deposits of gravel, sand and other materials, saline soils (roots can be submerged in sea water), as well as acidic and alkaline soils. It can withstand conditions in most urban and industrial areas, but it is sensitive to ozone (Gravano et al. 2003).

It has a large ring-porous wood structure with which water is rapidly transferred from its roots to its leaves and, conversely, it can reduce transpiration on hot days by summer branch drop (Kowarik 1983, Harris 1983, Lepart et al. 1991). It effectively reduces water loss by stomatal closure and lowered root hydraulic conductance (Trifilo et al. 2004). Two-year-old seedlings develop coarse, lateral, unbranched and widely spreading roots up to 2 m long. *A. altissima* is classified as a shade-intolerant, early successional species (Knapp and Canham, 2000). Delayed hard frosts may cause injury to young plants and to the upper shoots of older plants; however, it can survive temperatures as low as -35 °C. The tree has allelopathic properties in bark extracts, leaves, and seeds etc. due to flavonoid substances such as acacetin, apagenin etc. (Udvardy 2008). The direct influence of secondary metabolites of *Ailanthus* on biodiversity in natural ecosystems has been questioned by Mihoc et al. (2015).

Figure 1. Canopied, uncut coppice forest (left), and *A. altissima* growing in a clearing (right), Bábsky Les, Slovakia (Photo: Fehér 2015)

The forest understoreys of *A. altissima* are usually species-poor and rather cosmopolitan in character; its root sucker density negatively correlates with floristic richness (e.g. in France: Motard et al. 2011).

No significant natural enemies are known for *A. altissima*, but mistletoe (*Viscum album*) can cause its death. A rare decline in *Ailanthus altissima* was reported from Styria (Austria), where both older (35 year-old) and young trees were infected with agricultural soil microfungi (*Verticillium* sp., *Phomopsis ailanthi, Nectria coccinea, Fusarium* sp. and *Verticillium* sp.), causing dieback of branches in the upper crown, with bark necroses extending down the stem (Maschek and Halmschlager 2018).

Case Study

Description

In our case study, the invasive behaviour of *A. altissima* was studied after making clearings in an aged oak-hornbeam coppice forest in Bábsky les (Slovakia) in 2015 and 2016. Each of the three sample plots measured 400 m^2:

A : clearing made in 2006,

B : clearing made in 2014, and

C : canopied coppice forest in process of aging at present – the uncut control (Fig. 1).

Observations

The herb layer of the two studied clearings (A and B) was dominated by nitrophilous species, with *Sambucus ebulus* and *Galium aparine* together forming almost 100% cover.

After spontaneously invading, *A. altissima* outcompeted the native apophytic and synanthropic forest species through allelopathy and nitrogen accumulation, dramatically changing the species composition. In **area A**, the phytocoenological relevée had the highest abundance of the following species: *A. altissima, Sambucus ebulus, Galium aparine, Geum urbanum,* *Mercurialis perennis, Pulmonaria officinalis* and *Urtica dioica*. In **area B**, most abundant were *A. altissima, Quercus cerris, Carpinus betulus, Galium odoratum* and *M. perennis*, while in **area C** *Q. cerris* and *Acer campestre* were dominant. The behaviour of different species depended on the nature of the competition. In **area B**, *M. perennis* had a different seasonal optimum than *A. altissima*; *S. ebulus* (when simultaneously cut with *A. altissima*) re-grew more quickly than *A. altissima* but *G. aparine* and *Bromus benekenii* disappeared under dominant *A. altissima*. In **area A**, *Hedera helix* and *Clematis vitalba* spread, but *Melica uniflora* and *G. aparine* disappeared when *A. altissima* dominated (Fehér et al. 2017, unpubl.). Plant communities of clearings in the same forests were also studied by Pilková (2014), who related the species composition to different environmental conditions of water, nutrients, light, continentality, soil reaction and temperature (Fig. 2).

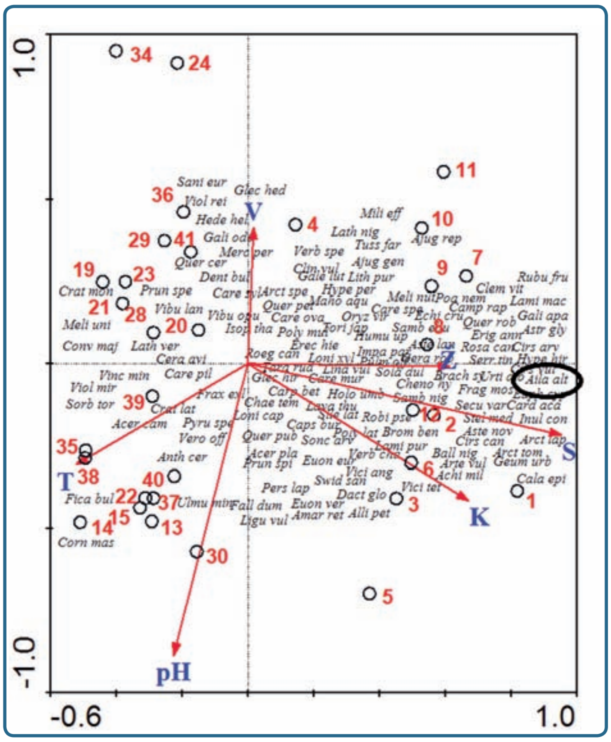

Figure 2. Occurrence of *Ailanthus altissima* is interrelated with nutrients and light (Pilková 2014, modified by Fehér). Ellenberg values: V - water, Ž - nutrients, S - light, K - continentality, pH - soil reaction, T - temperature

Management

To control *A. altissima* is quite problematic: for example, prescribed fire during the dormant season had a limited impact on its distribution (Rebbeck et al. 2017). Short-term mechanical and chemical treatment combinations did not reduce the number of resprouts over a five year period, although resprout biomass was reduced. Nevertheless, the long-term control of *A. altissima* resprouting was efficient, mainly as a result of reduced above-ground and below-ground growth; cutting alone, however, did not reduce it significantly. Some herbicides can be used to treat *A. altissima* but the required effect is poor (http://rvm.cas.psu.edu). The best control strategy is repeated and combined mechanical-chemical treatment.

Conclusion

We can conclude that the presence of *Ailanthus altissima* in forests influences the species composition and structure of ecosystems, as well as the services provided by them. Sladonja et al. (2015) have carried out a detailed assessment of the disadvantages and advantages of the species: In terms of potential biological threat, *A. altissima* has a high invasive potential (fast growth and regeneration, allelopathy, high resistance to pollution and tolerates a wide range of environmental conditions), causes a decrease of biodiversity (i.e. replaces natural flora), is toxic and causes allergic reactions and dermatitis. On the other hand, it can provide certain ecosystem services, such as provisional services (pharmaceutical use, honey production, timber, paper, essential oils etc.), regulating services (erosion control, land reclamation etc.), cultural services (ornamental use, shade etc.) and supporting services (nutrient cycling, soil formation etc.). The extract from *A. altissima* is an antioxidant, antimicrobial and phytotoxic, having anticancer properties and is source of ailanthone (quassinoids), which has potential in treating malaria, HIV etc.

Robinia pseudoacacia

Species and Range

The second invasive plant, black locust (*Robinia pseudoacacia*), belongs to the family *Fabaceae*. Approximately 20 species of *Robinia* are known in North and Central America, the majority being shrubs. The *Robinia* genus was present in geohistorical Europe (Eocene-Miocene) (Keeler 1990). *R. pseudoacacia* is native to the Eastern part of North America where it has a patchy distribution, the most important being in the Appalachian Mountains (Cierjacks et al. 2013). It has become common in many parts of the world, including almost the whole of Europe (mainly Central and South-East), Asia, North and South Africa, South America, Australia and New Zealand. There are more than 3 million ha of plantations worldwide (Hanover et al. 1991). In Europe, other species of the genus are quite rare (e.g. *R. viscosa* and *R. hispida*).

Ecology

R. pseudoacacia is a tree that can reach over 30 m in height and can live for well over 200 years. The root system is strong and produces suckers with root nodules that can fix nitrogen (at c. 30 kg of N year^{-1} ha^{-1}) and it can adapt well to the local soil conditions. The species grows well on sand dunes and alkaline soils and tolerates drought, but cannot survive in anaerobic soils with stagnant water. Although young plants can tolerate shade, older trees require light.

Figure 4. *R. pseudoacacia* coppice a few years after the selection of stems, Romania (Photo: Fehér 2015)

Figure 3. *Robinia pseudoacacia* coppice stand, Slovakia (Photo: Fehér 2015)

Seeds remain on the tree for a long time (even until the following year) and a single individual can produce 15.000-17.000 seeds per year. Seed production increases exponentially with age; a 50-year-old stand can produce 1 billion seeds ha^{-1} year^{-1}. The seeds are dispersed by wind and endozoochory. Germination is limited by a hard episperm, so that only a portion of the current year's seed may germinate annually; seeds in the soil seed bank can remain viable for over 40 years (Bartha et al. 2008). Abiotic factors, such as low temperature, can damage the seed perisperm and may limit seed germination. Young seedlings can grow up to 1 m tall in the first year; flowering occurs after five years. Vegetative propagation is sometimes dominant, arising either from the stem or root suckers. Its "rope-like roots" can be as long as 20 m. Due to this excellent vegetative propensity, coppicing is the most common form of management (Fig. 3 & 4).

Alliances

Stands of *R. pseudoacacia* are usually mono-dominant, but mixed forests are formed when they invade other forests (eg. oak forests, Fig. 5). The ground flora of *Robinia* forest is rich in nitrophilous plants, such as *Chelidonium majus, Ballota nigra* and *G. aparine*. Within the

Figure 5. Mixed aged oak-horbeam coppice forest invaded by *R. pseudoacacia*, Slovakia (Photo: Fehér 2010)

Rhamno-Prunetea class we can distinguish three alliances with *R. pseudoacacia*:

1. *Chelidonio majoris-Robinion pseudoacaciae* monodominant mesic groves with a well developed shrub layer and the associations *Chelidonio majoris-Robinietum pseudoacaciae* and *Poa nemoralis-Robinietum pseudoacaciae*;

2. *Balloto nigrae-Robinion pseudoacaciae* woodlands in dry, sandy habitats with grass-dominated herb layers and the association *Arrhenathero elatioris-Robinietum pseudoacaciae* and

3. *Euphorbio cyparissiae-Robinion pseudoacaciae* stands on dry shallow soils, with the association *Melico transsilvanicae-Robinietum pseudoacaciae* (Chytrý 2013).

Distribution, Management & Use in Europe

In Europe, the best ecological conditions for *R. pseudoacacia* are in the Central-East, due to its continentality. Most production of black locust is in Hungary, where it covers 22-24 % of all forests (two-thirds of which are of coppice origin). About 50 years ago, Hungary had more black locust forests than all other European countries put together (Frank et al. 2017; "Hungary" report in Chapter 6 of this volume).

The new Hungarian forest act (Act 2009 XXXVII) allows for the coppicing of black locust. Different technologies are used, such as afforestation with deep loosening, trenching or deep ploughing, or semi-natural reforestation with root suckers and man-made reforestation using deep loosening or complete soil preparation (Frank et al. 2017). Rarely, the trees are also pollarded (e.g. Slovakia, Fig. 6). In Hungary, the tree is often defined as a national treasure or cultural heritage ("Hungaricum") and the majority of foresters and the local population disagree with the dominant European perception of an "invasive plant to be removed". The Hungarian understanding of the species is exemplified by the following statement: "The economic viability of biomass production by black locust has been debated many times ... but established in a multi-purpose, ecocycle-based agricultural system where its invasive character is carefully controlled and its usefulness is fully utilised (applying even clone selection for site-adaptation and best possible performance), both environmental sustainability and profitability should be guaranteed." (Némethy et al. 2017). In other Central and Eastern European countries (Slovakia, Romania etc.) new plantations are rarely established, but old plantations are maintained. A very productive variety with distinct features was described in Southern Romania. The profitability of black locust as short rotation coppice can be questionable (Stolarski et al. 2017) but it can be ecologically and environmentally attractive in previous mining and agricultural areas (Carl et al. 2017).

Figure 6. Pollarded *Robinia pseudoacacia* trees along a lane, Slovakia (Photo: Fehér 2010)

In the rest of Europe, *Robinia* is not planted, or only rarely, for example to limit soil erosion on sand dunes and hill slopes. The species is one of the most important melliferous trees (half of the Hungarian honey production originates from the black locust) and it produces excellent fuelwood, garden furniture and raw material for pulp. It can be important for soil improvement and N fixation, and for the phytoremediation of heavy metals and polycyclic aromatic hydrocarbons. Forests create shelter for wildlife, and parts of the plant can be eaten. The fresh flowers, for example, were traditionally consumed in Hungary, Slovakia and Romania, and sometimes still are today. The seeds are likely edible as well, although some authors label them as toxic since most parts of the tree contain toxalbumin and other toxins. Black locust also has medicinal properties (e.g. as an antispasmodic, emollient, diuretic and laxative). *R. pseudoacacia* is fast growing when young and resistant to harmful pests and diseases. It tolerates pollution well, but prevents natural succession processes and reduces local biodiversity. When it colonises an area, it changes the habitat radically through allelopathy, N fixation, altered water balance and shading, etc.) and it is almost impossible to control. The prescribed control strategy is a combination of mechanical and chemical treatments (for a minimum of 3 years), but new seedlings will emerge from the soil seed bank for many years afterwards.

Discussion

It is challenging to compare the invasive competition of *A. altissima* with *R. pseudoacacia*. Although *R. pseudoacacia* originally arrived earlier than *A. altissima*, the latter was able to spread at a faster rate over a period of 30 years (Radtke et al. 2013). During the coppice cycle of native species, both *Ailanthus* and *Robinia* can invade synchronously and successfully colonise fresh clear-cuts. Coppice management, consisting of repeated clear cuttings every 20-30 years, favours this spread. In the United States, Call (2002) observed that *A. altissima* and the native *R. pseudoacacia* were frequently found on disturbed sites and presented similar growth and reproductive characteristics, yet each had distinct functional roles, such as allelopathy and nitrogen fixation. *A. altissima* was the better competitor in mixed plantations; it consistently produced larger above- and below-ground relative yields. Locally, increased disturbances could lead to more opportunities for *A. altissima* to invade and negatively interact with *R. pseudoacacia*, besides replacing the native species.

We can conclude that both *A. altissima* and *R. pseudoacacia* are successful invaders that have become naturalised in many temperate regions. They are good competitors in relation to other trees and understory herbs in coppice forests, forest gaps and clear cuts (Tab. 1). They outcompete the local forest vegetation communities protected in NATURA 2000, and have a negative impact on biodiversity. NATURA 2000 habitats that are endangered by invasions of these species include 9170 *Galio-Carpinetum* oak-hornbeam forests, 91G0 Pannonic woods with *Quercus petraea* and *Carpinus betulus* and 91H0 Pannonian woods with *Quercus pubescens* etc. (Viceníková and Polák 2003). In other countries, the occurrence of either *A. altissima* or *R. pseudoacacia* is used as a criterion to assess the state of the NATURA 2000 habitat condition (Polák and Saxa, 2005). Nevertheless, in some European countries black locust is considered important both culturally and economically, and is well accepted and understood to be part of the cultural heritage. Such countries are interested in its future preservation (mainly in Hungary),

Table 1. Attributes of invasive behaviour in *Ailanthus altissima* and *Robinia pseudoacacia*

Attributes of invasive behaviour	*Ailanthus altissima*	*Robinia pseudoaccacia*
early flowering maturity	3-4 y	5 y
flowers are easily pollinated by insects	yes	yes
no danger of late frosts	yes	yes
very prolific annual fruiting and sprouting	yes	yes
easy propagule dispersion by wind, water, animals, hazards	yes	yes
successful natural regeneration	yes	yes
rapid rooting and growth	yes	yes
successful vegetative propagation by adventitious buds	yes	yes
allelopathic substances inhibit growth of other seedlings and herbs	yes	yes
no important pests and parasites or predators	yes	yes
high tolerance of climatic conditions, pollution and infertile soils	yes	yes
seeds preserve their germination ability for a long time	yes	yes
nitrogen accumulation in the soil	yes	yes
expected life span	c. 150 y	c. 250 y

but in others this is debated (eg. Romania, Slovakia). Coppice regimes should take into careful consideration the invasive potential of both species, especially in the continental climates of Central and Eastern Europe. A positive ecological utilisation of both species is also possible, such as the phytoremediation of soils contaminated by heavy metals (e.g. Cudic et al. 2016).

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