

## CHAPTER 15

# NON-INDIGENOUS PLANT SPECIES IN CENTRAL EUROPEAN FOREST ECOSYSTEMS

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**Abstract.** In the study presented here, the occurrence of non-indigenous vascular plant species in Central European forest ecosystems is outlined with regard to the current state and future perspectives. A focus is laid on Germany. This analysis is based on numerous ecological investigations on the species and ecosystem level. In total, 29 non-indigenous woody and 25 non-indigenous herb species are recorded within forest stands. Generally, there are much less exotic species, which grow on forest sites compared to habitats more or less strongly altered by human impact like, for example, agricultural and urban-industrial ecosystems. Most of the exotic species found in forests belong to the plant families Rosaceae, Pinaceae, and Asteraceae and have their origin in North America. A wide range of different natural and anthropogenic forest communities are invaded by non-indigenous plants, such as floodplain forests, mixed broad-leaved and conifer forests on nutrient-poor to nutrient-rich sites, and dry oak forests. The establishment of non-indigenous species in forests can affect the ecosystem considerably. This is shown, for instance, for the tree species *Robinia pseudoacacia* (alteration of the soil conditions) and *Prunus serotina* (influence on forest regeneration) and the herbs of the genus *Fallopia* (decrease of species richness on a local scale). Few non-indigenous species in forests, like for example *Prunus serotina*, can cause problems with regard to land use on a supra-regional scale. In conclusion, the management of non-indigenous species in forests on a local scale, in accordance with regional nature conservation objectives and considering socio-economic aspects might be useful. However, an assessment of a positive or negative impact of non-indigenous species on forest ecosystems has to be based on properly defined values.

### 1. INTRODUCTION

The anthropogenic alterations of flora, ecosystems, and landscapes throughout the world are considered a part of the global change. Many research efforts focus on invasions by non-indigenous organisms because the subsequent biodiversity loss is

recognized as one of the biggest global environmental problems of our time (Vitousek et al., 1997; Sandlund et al., 1999). Additionally, the costs related to biological invasions, for example for the management of established and invasive non-indigenous species, can be considerably high for society (e.g., U.S. Congress, 1993).

In Central Europe, invasions by non-indigenous plants are recorded and investigated along the whole range from anthropogenically strongly altered towards natural ecosystems (Kowarik, 2003). Thus, for example, settlements (Pyšek, 1993; Zerbe et al., 2003) and agricultural ecosystems like grassland and fields (Pyšek et al., 2002) have been studied with regard to plant invasions, both concentrating on invasive species as well as invaded habitats. Anthropogenic disturbances of sites and vegetation are considered, additionally to others like dispersal abilities and vectors, one of the driving forces of spread and establishment of non-indigenous plant species (Trepl, 1983; Falinski, 1986; Kowarik, 1995; Rejmánek et al., 2005).

Compared to non-forest habitats, there are much less comprehensive studies on plant invasions in Central European forest ecosystems (e.g., surveys from Lohmeyer and Sukopp, 1992 and Kowarik, 2003). Against the background that Central Europe is naturally a woodland area and that the percentage of forest cover is relatively high in many present-day landscapes, plant invasions in forest ecosystems have to be considered an important issue for science as well as for practice, such as forestry and nature conservation. Most studies on plant invasions in forests focus on certain species. Thus, for example, the annual herb *Impatiens parviflora* (Trepl, 1984) and the tree species *Prunus serotina* (Starfinger et al., 2003) and *Pseudotsuga menziesii* (Knoerzer, 1999) have been investigated in detail. Although there are comprehensive surveys on Central European forest vegetation (e.g., Oberdorfer, 1992; Ellenberg, 1996), studies with regard to plant invasions in forest ecosystems based on large vegetation data sets rarely exist. Accordingly, Zerbe and Wirth (2006) analyse a large database of vegetation samples taken in Central European pine forests in order to identify plant invasions and the ecological range of non-indigenous plant species in those forests.

This paper will focus on the following questions: (1) Which non-indigenous vascular plant species invade Central European forests? (2) Which forest ecosystems are invaded? (3) How do these plant invasions affect the forest ecosystems and what problems can be identified with regard to land use and nature conservation, respectively? The study presented here, is based on a broad range of ecological investigations and findings on non-indigenous species in Central Europe, and in particular in Germany (e.g., Lohmeyer and Sukopp, 1992; Böcker et al., 1995; Hartmann et al., 1995; Pyšek et al., 1995, 2002; Starfinger et al., 1998; Kowarik, 2003). Here, only those species are considered, which have been introduced to Central Europe after 1,500 A.D. (neophytes according to Schroeder, 1969).

## 2. WHICH SPECIES INVADE CENTRAL EUROPEAN FORESTS?

Compared to heavily disturbed ecosystems like those in urban-industrial areas with a high percentage of non-indigenous plant species (according to investigations

from Pyšek, 1998a up to about 60 % exotic species in Central European urban floras), relatively few plant invasions have been recorded in forest ecosystems up to now (Table 1). A considerable number of woody species has been introduced for forestry purposes. Thus, the N American tree species *Abies grandis*, *Picea pungens*, *P. sitchensis*, *Pinus strobus*, *Prunus serotina*, *Pseudotsuga menziesii*, *Quercus rubra*, and the hybrids of the native *Populus nigra* L. and N American poplars (= *P. x euramericana*) have been afforested to a more or less large extent on Central European forest sites (Knoerzer and Reif, 2002). Additionally, tree species with E European and Asian origin, respectively, like *Abies nordmanniana* and *Larix kaempferi* are found in managed forests. For many of the mentioned tree species, such as for *Pinus strobus* (e.g., Zerbe, 1999), *Prunus serotina* (e.g., Starfinger, 1997), *Pseudotsuga menziesii* (Knoerzer, 1999), and *Quercus rubra* (e.g., Zerbe, 1999) spontaneous regeneration in forests has been recorded.

Furthermore, a considerable number of exotic tree species occur in Central European urban or landscape parks, where they have often been introduced as ornamental plants (Lohmeyer and Sukopp, 2001). Thus, for example, Ahrens and Zerbe (2001) list some specimens of the N American *Thuja plicata* D. Don among other non-indigenous tree and shrub species in a park forest south of the city of Berlin, a forest which is built up by *Acer platanoides* L. and *Tilia platyphyllos* L.

Most of the non-indigenous shrub species, which occur in Central European forests, escaped from cultivations in gardens or on green spaces in and around settlements. The N American *Mahonia aquifolium* and *Symphoricarpos albus*, for example, are dispersed by birds mostly into forests adjacent to cities (Kowarik, 1992; Adolphi, 1995; Auge, 1997). This holds also true for *Amelanchier lamarckii* (Schroeder, 1972). North American blueberries (hybrids of *Vaccinium corymbosum* and *V. angustifolium*) spread in NW Germany, where cultivars have been grown commercially (Schepker and Kowarik, 1998). Much less commonly, *Spiraea alba* (Lohmeyer and Sukopp, 1992; Kowarik, 2003) grows on forest sites.

Among all non-indigenous species, the Central Asian annual herb *Impatiens parviflora* is considered the most successful with regard to plant invasions in Central European forest ecosystems. First records of its spontaneous spread from botanical gardens in Central Europe date back to the 1830ies (Trepl, 1984). Nowadays, this species is found in forests throughout Central Europe (cp. distribution map for Germany from Bundesamt für Naturschutz, 2005). Additionally, also the occurrence of the non-indigenous annual and perennial herbs *Conyza canadensis*, *Fallopia* div. spec., *Helianthus tuberosus*, *Heracleum mantegazzianum*, *Impatiens glandulifera*, *Lysichiton americanus*, and *Solidago canadensis* has been recorded in forests.

Lohmeyer and Sukopp (1992, 2001) list several additional species as so-called agriophytes, which are non-indigenous species not only found on anthropogenic sites but are also considered a part of the natural vegetation in Central Europe. Thus, *Allium paradoxum*, *Aster novi-belgii*, *Claytonia sibirica*, *Eranthis hyemalis*, *Iris versicolor*, *Ornithogalum nutans*, *Scilla sibirica*, *Scutellaria altissima*, *S. columnae*, and *Tulipa sylvestris* contribute to the non-indigenous annual and perennial herbs and *Alnus rugosa* to the exotic trees found in Central European forests.

Table 1. Survey of non-indigenous vascular plant species (woody and herb species) which have been recorded in Central European forests on a local or regional (○) and supra-regional (●) scale with information on the plant family, origin, and forest communities in which they occur; x = most frequent non-indigenous species in Germany as stated by Kowarik (2003), including all habitats; information mostly based on the comprehensive surveys from A,B: Lohmeyer and Sukopp (1992, 2001), C: Knoerzer and Reif (2002), D: Kowarik (2003), and E: Zerbe and Wirth (2006).

Non-indigenous species	Plant family	Origin	Occurrence in forests	Frequency in forests	Selected references
<b>Trees and shrubs</b>					
<i>Abies grandis</i> (Dougl.) Lindl.	Pinaceae	N America	mixed forests on moist sites under a broad range of soil nutrient conditions	○	C
<i>Abies nordmanniana</i> (Stev.) Spach	Pinaceae	SE Europe	mixed forests on dry to moist sites	○	C
<i>Acer negundo</i> L.	Aceraceae	N America	floodplain forests, pine forests	●	A, D
<i>Aesculus hippocastanum</i> L.	Hippocastanaceae	SE Europe	floodplain forests, broad-leaved slope forests	● <sup>x</sup>	A
<i>Ailanthus altissima</i> (Mill.) Swingle	Simaroubaceae	E Asia	dry oak forests, floodplain forests	○	A, D
<i>Alnus rugosa</i> (Du Roi) Sprengl.	Betulaceae	N America	mire forests	○	B
<i>Amelanchier alnifolia</i> (Nutt.) Nutt.	Rosaceae	N America	pine forests	○	B, D, E

Table 1 (cont.)

Non-indigenous species	Plant family	Origin	Occurrence in forests	Frequency in forests <sup>3</sup>	Selected references
Trees and shrubs (cont.)					
<i>Amelanchier lamarkii</i> Schroeder	Rosaceae	N America	oak forests on acid sites, mire forests	●	A, D
<i>Amelanchier spicata</i> (Lamk.) C. Koch	Rosaceae	N America	acid oak forests	○	A
<i>Cornus stolonifera</i> Michx.	Cornaceae	N America	mire forests	○	A
<i>Cotoneaster horizontalis</i> Deene.	Rosaceae	E Asia	pine forests	○	A
<i>Laburnum anagyroides</i> Med.	Fabaceae	S Europe	dry oak forests	○	A, D
<i>Larix kaempferi</i> (Lamb.) Carr.	Pinaceae	E Asia	open mixed forests on moist and oligotrophic sites	●	C
<i>Ligustrum vulgare</i> L.	Oleaceae	S Europe, Asia	pine forests	○	A, D, E
<i>Mahonia aquifolium</i> (Pursh) Nutt.	Berberidaceae	N America	pine forests, dry oak and beech forests	●	A, D, E
<i>Parthenocissus inserta</i> (Kerner) Fritsch	Vitaceae	N America	floodplain forests	○	A
<i>Physocarpus opulifolius</i> (L.) Maxim.	Rosaceae	N America	floodplain forests	○	A
<i>Picea pungens</i> Engelm.	Pinaceae	N America	open mixed forests under various site conditions	○	C

Table 1 (cont.)

Non-indigenous species	Plant family	Origin	Occurrence in forests	Frequency in forests <sup>3</sup>	Selected references
Trees and shrubs (cont.)					
<i>Picea sitchensis</i> (Bong.) Carr.	Pinaceae	N America	mixed forests on moist and oligotrophic sites	○	C
<i>Pteris floribunda</i> Benth. et Hook.	Ericaceae	N America	mire forests	○	A
<i>Pinus strobus</i> L.	Pinaceae	N America	mixed coniferous forests on acid sites	●	B, C, D, E
<i>Populus x euramericana</i> (Dode) Guinier	Salicaceae	N America <sup>1</sup>	floodplain forests	●	A, D
<i>Prunus serotina</i> Ehrh.	Rosaceae	N America	pine and oak forests on acid sites	● <sup>x</sup>	A, D, E
<i>Pseudotsuga menziesii</i> (Mirb.) Franco	Pinaceae	N America	mixed broad-leaved and conifer forests on acid sites	●	B, C, D
<i>Quercus rubra</i> L.	Fagaceae	N America	pine forests	● <sup>x</sup>	B, C, D, E
<i>Robinia pseudoacacia</i> L.	Fabaceae	N America	pine forests, dry forests, floodplain forests	● <sup>x</sup>	A, D, E
<i>Spiraea alba</i> Du Roi	Rosaceae	N America	floodplain forests	○	A, D
<i>Symphoricarpos albus</i> (L.) Blake	Caprifoliaceae	N America	pine forests, floodplain forests	○ <sup>x</sup>	A, D, E
Hybrids of <i>Vaccinium corymbosum</i> L. and <i>Vaccinium angustifolium</i> Ait.	Ericaceae	N America <sup>1</sup>	oligotrophic pine forests and mire forests	○	B, D

Table 1 (cont.)

Non-indigenous species	Plant family	Origin	Occurrence in forests	Frequency in forests <sup>3</sup>	Selected references
Herbs					
<i>Allium paradoxum</i> (M.B.) G. Don	Liliaceae	W Asia	floodplain forests	○	A
<i>Aster novi-belgii</i> L.	Asteraceae	N America	floodplain forests	○	A
<i>Bidens frondosa</i> L.	Asteraceae	N America	floodplain forests	○ <sup>x</sup>	D
<i>Claytonia sibirica</i> L.	Caryophyllaceae	N America	oak forests on acid sites	○	A
<i>Coryza canadensis</i> (L.) Cronquist	Asteraceae	N America	pine forests	○ <sup>x</sup>	A, D, E
<i>Eranthis hyemalis</i> (L.) Salisb.	Ranunculaceae	SE Europe	floodplain forests	○	A
<i>Fallopia x bohemica</i> (Chrtek et Chrteková) J.P. Bailey	Polygonaceae	E Asia <sup>2</sup>	floodplain forests	○	B, D
<i>Fallopia japonica</i> (Houtt.) Ronse Decr.	Polygonaceae	E Asia	floodplain forests	● <sup>x</sup>	A, D
<i>Fallopia sachalinensis</i> (F. Schmidt) Ronse Decr.	Polygonaceae	E Asia	floodplain forests	● <sup>x</sup>	A, D
<i>Helianthus tuberosus</i> L.	Asteraceae	N America	floodplain forests	○ <sup>x</sup>	A, D
<i>Heracleum mantegazzianum</i> Somm. et Lev.	Apiaceae	W Asia	floodplain forests	● <sup>x</sup>	A, D
<i>Impatiens capensis</i> Meerb.	Balsaminaceae	N America	swampy forests	○	B
<i>Impatiens glandulifera</i> Royle	Balsaminaceae	S Asia	floodplain forests	● <sup>x</sup>	A, D

Table 1 (cont.)

Non-indigenous species	Plant family	Origin	Occurrence in forests	Frequency in forests <sup>3</sup>	Selected references
Herbs (cont.)					
<i>Impatiens parviflora</i> DC.	Balsaminaceae	Central Asia	beech forests, floodplain forests, pine forests, swampy forests	● <sup>x</sup>	A, D
<i>Iris versicolor</i> L.	Iridaceae	N America	mire forests	○	A
<i>Lupinus polyphyllus</i> Lindl.	Papilionaceae	N America	dry oak forests	○	D
<i>Lysichiton americanus</i> Hultén and St. John	Araceae	N America	swampy forests	○	B, D
<i>Ornithogalum nutans</i> L.	Liliaceae	SE Europe	floodplain forests	○	A, D
<i>Rudbeckia laciniata</i> L.	Asteraceae	N America	floodplain forests	○	A
<i>Scilla siberica</i> Andr.	Liliaceae	E Europe	floodplain forests	○	A
<i>Scutellaria altissima</i> L.	Lamiaceae	SE Europe	dry broad-leaved forests	○	A
<i>Scutellaria columnae</i> All.	Lamiaceae	SE Europe	oak forests on acid sites	○	A
<i>Solidago canadensis</i> L.	Asteraceae	N America	floodplain forests, pine forests	○ <sup>x</sup>	A, D, E
<i>Solidago gigantea</i> Ait.	Asteraceae	N America	floodplain forests	○ <sup>x</sup>	A, D
<i>Tulipa sylvestris</i> L.	Liliaceae	SE Europe	floodplain forests	○	A

<sup>1</sup> hybrids with parents from N America; <sup>2</sup> hybrid with parents from E Asia; <sup>3</sup> assessment on the basis of published studies in Central Europe with a focus on Germany



Most of the non-indigenous woody species in Central European forests (Table 1) belong to the plant families Rosaceae and Pinaceae, each with 24 %. About 30 % of the non-indigenous herbs are part of the Asteraceae. This is in accordance with results from Pyšek (1997) who found that this plant family is over-represented among aliens compared to other plant families in a global perspective (also see Pyšek, 1998b). Accordingly, Pyšek (1997) states that the plant species of this family are remarkably successful as invaders in terms of dispersal and establishment. About 60 % of all recorded non-indigenous vascular plant species in forests have their origin in N America (Table 1). This does not reflect the general trend in the Central European flora with a higher percentage of non-indigenous species from other parts of Europe (e.g., S Europe) and from Asia (Kowarik, 2003: Figure 1).

The survey given in Table 1 for non-indigenous woody (29) and herb species (25), which have been found in Central European forests on a local, regional, and supra-regional scale, is thought as a minimum list. Here, only those species are presented which have been found within forest stands. If all sites or vegetation structures within wooded landscapes were taken into account, such as forest paths, clear-cuts, and small forest mires for example, other species might add to the number of non-indigenous species in forests. Thus, Lohmeyer and Sukopp (1992) point out that clear-cuts in woodland areas can also be habitats for non-indigenous plant species. Examples are given with *Conyza canadensis* (see Table 1 for forests), *Epilobium ciliatum* Raf. (origin: N America), and *Erechtites hieracifolia* (L.) Raf. (origin N and S America). Furthermore, Dostálek (1997) mapped non-indigenous plants, like the North American *Rudbeckia laciniata* along roads through a woodland area of the Orlické mountains in the Czech Republic. Similar observations of non-indigenous plants along forest roads and paths made Schepker (1998) in NW Germany (e.g., *Heracleum mantegazzianum*).

These occurrences along forest roads and paths might reflect one possible way of (mostly anthropogenic) dispersal and invasions into forest ecosystems. Additionally, many of the non-indigenous herbs are found in floodplain forests (see Lohmeyer and Sukopp, 1992 and Table 1), a phenomenon which also indicates a way of dispersal and introduction into natural vegetation along rivers and streams (Pyšek and Prach, 1994).

### 3. WHICH FOREST ECOSYSTEMS ARE INVADED?

There is comprehensive knowledge on the forest types, which are invaded by *Impatiens parviflora*. This species is found in various beech forest communities on meso- to eutrophic sites throughout Central Europe (Trepl, 1984; Zerbe, 1999; Oberdorfer, 2001). According to the large vegetation data set compiled by Oberdorfer (1992) for S Germany, *Impatiens parviflora* also commonly occurs in floodplain forests. However, there are only few records of this species on sites with stagnating wetness on which *Alnus glutinosa* forests grow (Zerbe and Vater, 2000), thus indicating an ecological limitation of occurrence on wet sites. Derived from the ecological indicator values given by Ellenberg et al. (1991) for *Impatiens parviflora*, this species preferably grows on sites with intermediate light supply and soil moisture conditions, respectively, and relatively high nitrogen availability.

As shown in Table 1, the forest types which are invaded by vascular plant species range from broad-leaved to conifer, from dry to wet, from oligotrophic to nutrient-rich, and from natural to anthropogenic (e.g., plantations) forests. The broad range of invaded forest ecosystems has also been revealed by Kowarik (1995) on a regional scale (city of Berlin) and by Pyšek et al. (2002) on a supra-regional scale (Czech Republic). Both studies show the relatively high percentage of non-indigenous plant species in floodplain forests compared to other forest types.

With a focus on natural and anthropogenic pine forests, we analysed a data set of about 2,300 vegetation samples from NE Germany with regard to the occurrence of non-indigenous plant species (Zerbe and Wirth, 2006). Out of a total of 362 taxa recorded in these pine forests along a broad range of soil and climate conditions, only 12 non-indigenous species, including trees, shrubs, annual and perennial herbs, and one bryophyte were found. These exotic species in pine forests commonly grow on sites with relatively high nitrogen availability and soil pH (Figure 1). In general, species-rich forests on nutrient-rich sites seem to be invaded more often by non-indigenous plant species than forests on nutrient-poor acid sites. This is in accordance with the findings of Huennecke et al. (1990), Hobbs and Huennecke (1992), McIntyre and Lavorel (1994), Stohlgren et al. (1999), Deutschewitz et al. (2003), and Cassidy et al. (2004), who point out a positive effect of habitat disturbance and nutrient availability on plant invasions. In particular, atmospheric nutrient depositions, a widespread phenomenon in Central Europe (Hüttl, 1998), can affect the upper soils of forests, thus enhancing the establishment of non-indigenous plant species (Zerbe and Wirth, 2006). However, there are some non-indigenous species with a relatively broad ecological range, such as *Prunus serotina* and *Quercus rubra*. Both species quite commonly occur in various pine forest communities with the exception of pine forests on very acid, nutrient-poor, and wet sites (Figure 1).

It is evident that some forest types are rarely or even not invaded by non-indigenous species. Thus, our analysis (Zerbe and Wirth, 2006) revealed no plant invasions on nutrient-poor, acid forest mires with species like *Eriophorum vaginatum* L., *Ledum palustre* L., *Sphagnum* L. div. spec., and *Vaccinium oxycoccus* L. (Fig. 1: community # 19). Similar findings were made by Chmura et al. (2005) in S Poland. Reasons for this observation could be that (1) near-natural forests (e.g., forest mires) are less susceptible for plant invasions than anthropogenic ones, (2) there are limitations in the ecological range of the non-indigenous plant species which have been introduced to Central Europe up to now (present-day exotic species pool), which excludes a possible invasion of certain forest types (e.g., mires), and (3) there are limitations in dispersal into these forests.

Although anthropogenic disturbances might enhance the establishment of non-indigenous species like it has been shown, for example, for the city of Berlin by Kowarik (1995) by taking all plant communities into account, there is no evidence that near-natural forests are resistant against plant invasions. *Impatiens parviflora*, for example, is established on a broad range of near-natural broad-leaved forests throughout Europe.

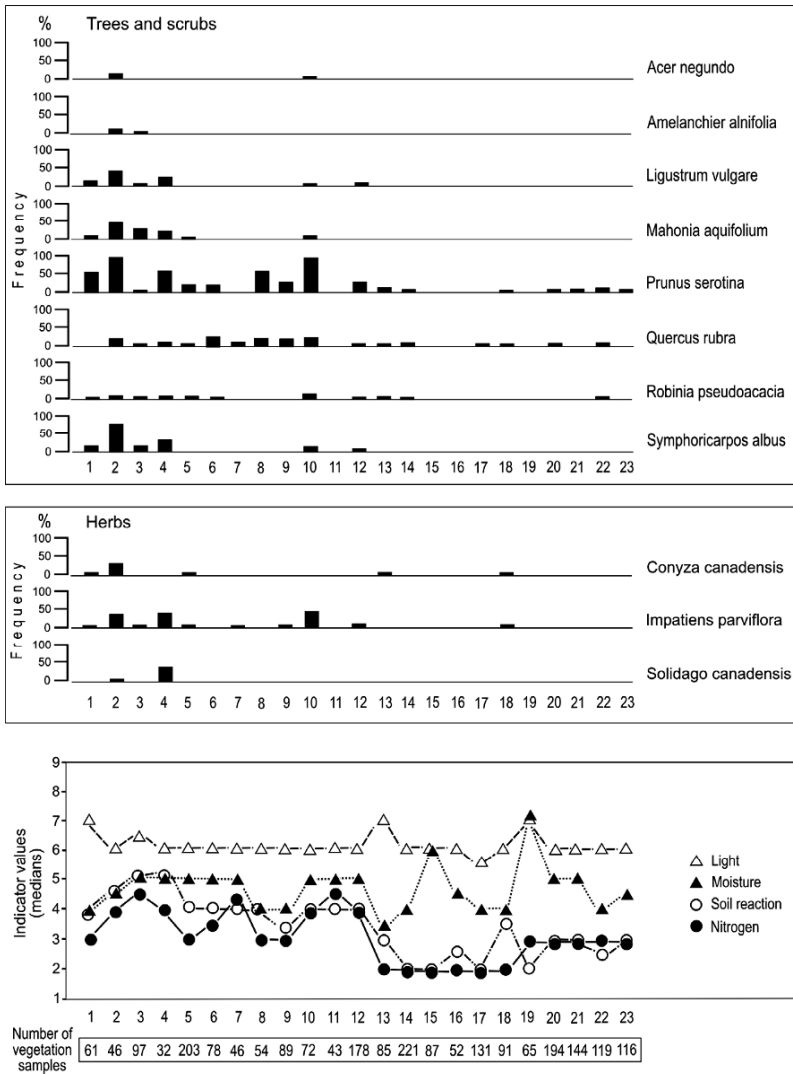


Figure 1. Occurrence of non-indigenous vascular plant species in pine forest ecosystems of NE Germany on a broad range of sites. The environmental conditions of the different pine forest communities (clusters # 1 to 23) were assessed by means of ecological indicator values of the species present according to Ellenberg et al. (1991) for vascular plants and Benkert et al. (1995) for bryophytes (for the methodological approach see Ellenberg et al., 1991 and Dupré and Diekmann, 1998). Medians of the indicator values for light, moisture, soil reaction, and nitrogen were computed; the values are expressed on a 1 to 9 scale, i.e. the higher the value, the higher the species' demand for the particular factor (from Zerbe and Wirth, 2006).

Among the non-indigenous herb species recorded in Central European forests (Table 1) there are mostly species, which have a relatively high light demand. Thus, those species are not able to grow in forest communities or forest succession stages with a dense canopy cover (e.g., old-growth beech forests) and are limited to relatively open forests. However, few studies focus on ecological limitations of non-indigenous plant species in forests like it was done for pine forests in NE Germany by Zerbe and Wirth (2006).

Kowarik (2003) comes to the conclusion that the relatively low number of non-indigenous plant species in Central European forests compared to non-forest ecosystems is mostly due to limited dispersal into woodland.

#### 4. ECOLOGICAL EFFECTS AND PROBLEMS OF PLANT INVASIONS IN FOREST ECOSYSTEMS

It has been well investigated for *Robinia pseudoacacia* that the introduction and establishment of a non-indigenous plant can have strong influence on ecosystems. Due to the enrichment of the soil with nitrogen by its litter, this tree can completely alter the site conditions and the vegetation on formerly nutrient-poor sites towards nutrient-rich conditions with an accumulation of organic matter (Hoffmann, 1961). This was shown, for example, by Kowarik (1992) who compared acid, nutrient-poor grassland without *Robinia pseudoacacia* with stands dominated by *R. pseudoacacia* under formerly similar site conditions in the city of Berlin. Within the *Robinia* stands, nitrophytic species increased in frequency and abundance and species richness decreased. Forest succession was also influenced by enhancing the establishment and growth of broad-leaved trees with a relatively high nutrient demand, such as species of the genus *Acer*. Consequently, *Robinia pseudoacacia* can be a problem in nature conservation with regard to the protection of nutrient-poor vegetation and land-use types, respectively (e.g., Paar et al., 1994).

*Prunus serotina* is considered to inhibit forest regeneration, in particular the rejuvenation of native trees (Spaeth et al., 1994; Schepker, 1998). Additionally, it has been revealed that species richness decreases as a consequence of a dense cover of *Prunus serotina* under an open pine canopy (Schepker, 1998; Starfinger et al., 2003). As these findings have mainly been recorded for anthropogenic pine forests (conifer plantations) in the Central European lowlands, it may be concluded that *Prunus serotina* is just a stage within the succession towards more natural broad-leaved forests like it is known for indigenous short-lived tree species (for *Sorbus aucuparia* L. and *Betula pendula* Roth; see Zerbe, 2001 and Kreyer and Zerbe, 2006). Starfinger et al. (2003) document the invasion history and perception or use of this non-indigenous tree species in Central Europe and come to the conclusion that 'the mere presence of *P. serotina* in forests in Central European lowlands does not justify an eradication campaign on the basis of its adverse effects on species conservation goals' and '*P. serotina* as an 'aggressive invader' of forest ecosystems is mostly a symptom of preceding silvicultural practice'.

Knoerzer (1999) considers the N American *Pseudotsuga menziesii* a problem with regard to habitat protection in SW Germany. This non-indigenous tree successfully regenerates on dry rocky mountain sites with a unique vegetation

structure. On oligotrophic wooded slopes, the height growth exceeds that of the native trees (e.g., *Abies alba* Mill., *Picea abies* (L.) Karst., *Pinus sylvestris* L., *Quercus petraea* Liebl.), which build up these mixed oak forests. Additionally, due to the alterations of the organic layer by the litter of Douglas fir, a change of the original vegetation can be observed (Zerbe, 1999; Zerbe et al., 2000).

The decrease of species richness on a local scale has been revealed in dominant stands of non-indigenous plant species, in particular with large leaves as a consequence of light competition. This is documented, for instance in stands with *Heracleum mantegazzianum* (Pyšek and Pyšek, 1995) and non-indigenous *Fallopia* species (Kowarik, 2003). However, these dominant stands rarely occur within forests, but are more commonly found on anthropogenically disturbed sites in urban-industrial areas or the agricultural landscape.

In Białowieża Forest (E Poland), Falinski (1986) recorded an increase in biomass of the herb layer due to the presence of *Lupinus polyphyllus* compared to plots without this non-indigenous species.

It can be concluded that non-indigenous plant species in forests can affect the ecosystem by

- Changing the abiotic site conditions such as the nitrogen availability (e.g., *Robinia pseudoacacia*) or light conditions on the forest floor (e.g., *Lysichiton americanus*, *Prunus serotina*),
- Increasing the biomass of the herb layer due to nitrogen enrichment (e.g., *Lupinus polyphyllus*),
- Altering the state of biodiversity such as the decrease of species richness, e.g. by the development of dense stands (e.g., *Prunus serotina*) or the establishment of the legume *Robinia pseudoacacia* as well as the increase of species richness by contributing positively to the forest species pool (e.g., *Impatiens parviflora*),
- Influencing forest succession by, e.g. decelerating forest regeneration with native species (e.g. *Prunus serotina*), and
- Changing the composition of the native vegetation to a large extent (e.g., *Pseudotsuga menziesii*, *Robinia pseudoacacia*).

According to an investigation by Kowarik and Schepker (1998) on the attitude and perception of non-indigenous species by public authorities (e.g., nature conservation, forestry, and water management) in NW Germany, vegetation changes as a consequence of plant invasions are perceived as most important conflict.

## 5. EMERGING FOREST ECOSYSTEMS WITH NON-INDIGENOUS SPECIES?

If the abiotic site factors have been changed irreversibly and/or species and populations have been lost (e.g., after peat mining, deposition of man-made substrates, and as a consequence of excavations) or introduced (e.g., by planting non-indigenous trees), new nature can develop which is described by Hobbs et al. (2005) as “emerging ecosystems”. This holds in particular true for strongly degraded landscapes like mining areas, military training areas, quarries, or urban-industrial areas, where neither natural conditions nor any state of the historical cultural landscape can be regenerated.

So what about emerging forest ecosystems in Central Europe as a consequence of biological invasions in forests? Up to now, there is no evidence that the Central European woodland vegetation will profoundly change to a large extent due to the introduction and establishment of non-indigenous species. *Impatiens parviflora*, for example, now has its niche in the herb layer of broad-leaved forests, thus enhancing species diversity but not changing the native forest vegetation on the community level. The widespread establishment of this species is hardly considered a problem with regard to socio-economics or nature conservation (Kowarik and Schepker, 1998).

Nevertheless, new forests with non-indigenous plants have developed on the local and regional scale on urban-industrial sites (Kowarik and Körner, 2005). In particular, on those sites where buildings were destroyed during World War II (e.g. Kohler and Sukopp, 1964; Kowarik, 1995) or where industrial areas have been abandoned (e.g., Rebele and Dettmar, 1996; Keil, 2005) non-indigenous trees have been established and form new forest communities, e.g. *Robinia pseudoacacia* forests. According to Kowarik and Körner (2005), a 'new wilderness' develops, which opens new perspectives for urban forestry.

On a regional or local scale, new forest ecosystems can also evolve outside settlements, in particular if keystone species (according to Mills et al., 1993 and Jordán et al., 1999) such as *Robinia pseudoacacia* are introduced. This N American tree species has been established within Central European settlements (e.g., Kohler and Sukopp, 1964; Kowarik, 1992) as well as in woodland areas (e.g., Jurko and Kontris, 1982; Kowarik, 1990; Wilmanns and Bogenrieder, 1995). At sites where native, shade tolerant species like *Acer spec.*, *Fagus sylvatica* L., or *Picea abies* are not able to grow and probably would out-compete *Robinia pseudoacacia* (e.g., warm and dry slopes in the Rhine valley; Wilmanns and Bogenrieder, 1995; see also Klauck, 1986), this tree can build up forests with a relatively open canopy. Due to its ability to live in symbiosis with nitrogen-fixing bacteria and thus accumulate organic matter on formerly nutrient-poor sites, it can profoundly change the soil conditions. Consequently, the whole forest vegetation is influenced by this species, forming new forest communities like the *Chelidonio-Robinetum* (Jurko, 1963) or the *Sambucus nigra-Robinia pseudoacacia* community, respectively (Klauck, 1986). Based on the broad ecological knowledge, which has been gathered on *Robinia pseudoacacia* in Central Europe (Böhmer et al., 2001; Kowarik, 2003), Kowarik (2003: p161) concludes that the forest succession of *Robinia* stands towards other possible communities is still an open question.

With the ongoing transformation of anthropogenic forests (in particular conifer monocultures with *Pinus sylvestris* and *Picea abies*) towards natural broad-leaved forests with native beech (*Fagus sylvatica*) and oak (*Quercus petraea* and *Q. robur* L.) in Central Europe (Olsthoorn et al., 1999; Klimo et al., 2000; Zerbe, 2002), most of the non-indigenous species most probably might not be able to compete successfully in the natural forest vegetation. This is due to the shady site conditions, e.g. in beech forest, where light demanding species like *Coryza canadensis*, *Robinia pseudoacacia*, *Solidago canadensis* (Table 1) cannot grow. The occurrence of these species is mostly restricted to anthropogenic forests with an open canopy (e.g., pine and oak forests).

On a local scale, non-indigenous species can alter forest vegetation and biodiversity in a considerable way as it was shown above for, e.g. non-indigenous *Fallopia* species and *Pseudotsuga menziesii*. If this is considered a problem in terms of changing the native vegetation a necessity for human response might be derived. However, as the example of *Prunus serotina* shows, the management success in order to control the biological invasion is limited. According to an investigation from Schepker (1998) in NW Germany, the management success (control by mechanical and chemical means) is given with only about 30 %.

The discussion on positive or negative impact of an invading non-indigenous species is often controversial due to divergent underlying values with regard to nature conservation and environmental protection, socio-economics, or recreation. Additionally, an assessment of this impact depends on values that are often not properly defined (Starfinger et al., 2003). In conclusion, the management of non-indigenous species in forests on a local scale, in accordance with regional nature conservation objectives and considering socio-economic aspects might be useful. Then, however, a continuous monitoring of the control success is necessary.

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