

REVIEW PAPER

Silvicultural potential of the main introduced tree species in the Czech Republic – review

Stanislav Novotný, Josef Gallo*, Martin Baláš, Ivan Kuneš,
Zdeněk Fuchs, Pavel Brabec

Czech University of Life Sciences, Faculty of Forestry and Wood Sciences, Department of Silviculture, Kamýcká 129,
CZ-16520 Praha 6-Suchbát, Czech Republic

Abstract

Only 1.82% of the Czech forests are covered by the introduced (exotic, non-native) tree species, they represent only a very minor part of the forest area in the Czech Republic. Despite this fact under certain circumstances and locally, they can play an important role in the forest restoration of declined forests. The main non-native tree species used in the Czech Republic are: black locust (*Robinia pseudoacacia* L.), Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco), grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), black walnut (*Juglans nigra* L.), northern red oak (*Quercus rubra* L.), and blue spruce (*Picea pungens* Engelm.). Other tree species are cultivated on very small areas, despite their much larger potential. The aim of the presented review paper is to summarize information on the introduced tree species, available especially from national sources, and give comprehensive information concerning the potential and risk of their use in the conditions of the Czech Republic. The authors mention also other tree species eligible for silviculture under current as well as future climatic circumstances. The current area and silvicultural potential in the climate changing conditions are analysed and summarized.

Key words: climatic change; forest restoration; assisted migration; forest productivity; stability and vitality

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1. Introduction

Contrasting with situation in agriculture, the non-native trees (NNTs, syn. introduced, exotic, alien trees) cover relatively small area in the European forests, including the Czech Republic. In Europe, it represents some 8.54 million ha, being about 4% of the forest area (Wohlge-muth et al. 2022), and 1.82% in the Czech forests respectively (Beran 2018). There was a general tendency of testing particular tree species in forest stands since second half of the 19th century and specifically many tree species were tested in the air-polluted areas at the end of the 20th century in the Czech lands (Borůvka et al. 2005; Baláš et al. 2019). Úradníček et al. (2012) describe several stages of introduction with differentiated prevailing aims: agro-fruit introduction (until Middle-Age time), general botanical introduction (15th–17th centuries), parc/horticultural introduction (17th–18th centuries), forestry introduction (since 19th century) and finally so called scientifically controlled introduction of the last

period, taking into account not only production, but also biodiversity and environmental aspects.

Nowadays, importance of NNTs can grow significantly in the current situation of ongoing climate change and the turbulent environment in forestry (Furst et al. 2007; Baláš et al. 2019). Across all Central Europe, forest stands, especially Norway spruce (*Picea abies* [L.] Karts.), are being large-scale disturbed and salvage logged as a result long-term drought, climate extreme events, non-natural Norway spruce propagation in the past centuries and resulting in secondary bark beetle calamity (Šimůnek et al. 2021; Vacek et al. 2021a; D'Andrea et al. 2022). Therefore, NNTs can thus play an important role as alternative substitutes of native tree species in forestry management for adaptation to climate change (Vacek et al. 2023). Although it is still necessary to bear in mind the dominant position of indigenous species, as well as the potential of optimisation of age and spatial structures, albeit under different conditions and in other forms, the introduced tree species may repre-

*Corresponding author. Josef Gallo, e-mail: gallo@fd.czu.cz

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sent at least a partial solution to the current unfavourable situation (e.g. *Pseudotsuga menziesii* [Mirbel] Franco). Situation was very similar in many European countries (Brundu & Richardson 2016; Castro-Díez et al. 2019, 2021; Brundu et al. 2020, Pötzelsberger et al. 2020).

In some countries, the NNTs represent on the contrary major tree and timber species, like blue gum (*Eucalyptus globulus* Labill.) in Portugal, black locust (*Robinia pseudoacacia* L.) in Hungary and Sitka spruce (*Picea sitchensis* [Bong.] Carr.) in the UK, while in most other countries including Central Europe these species have a minor importance in comparison with native ones (Hasenauer et al. 2016; Brus et al. 2019). Many of them show very good adaptation, consisting in the acclimatization to local conditions and even naturalization, i.e. joining as an integral part of forest ecosystems. In some cases, specific species can be considered as invasive, over-competing natural species (Dodet & Collet 2012; Úradníček et al. 2012; Baláš et al. 2019).

Aim of the presented study is to summarize the knowledge sources relevant for the Czech conditions and present the review in a form, applicable for the forestry practice on one side and prepare level for the further research in the second line.

2. General approach

The issue of introduction was specifically addressed by the Forestry and Game Management Research Institute (FGMRI) in the Czech Republic, which emphasized the precautions and formulated the following requirements for introduced tree species (Beran 2018, see also commentaries Baláš et al. 2019 *in italics*):

- sufficient wood mass production *which should be higher than the production of native tree species supplemented or replaced by introduced wood species, both in terms of quality and volume production (Douglas-fir, Grand fir, black walnut etc.)*,
- higher quality of wood *which should be comparable to native species or substantially higher (e.g. black walnut, Turkish hazel)*,
- tolerance to extreme conditions; *the tree species in question are able to create functional forest stands even in conditions where native tree species are no longer able to do so. This is gaining in importance in the current climate extremes and leads to reflection on the introduction of, for example, the Balkan or Mediterranean species. We can mention northern red oak, black locust, or black pine, among the currently used tree species. However, there is also a risk of colonization of non-forest protected sites, significant for nature conservation (by black locust – *Robinia pseudoacacia* L., Austrian black pine (*Pinus nigra* Arn.) and tree of heaven – *Ailanthus altissima* [Mill.] Swingle*,
- resistance to domestic diseases, pests, anthropic

influences, *bearing in mind the risk of introducing new harmful factors; it is better to use reproduction sources of the safe (domestic) origin. This may include, for example, northern red oak – the introduction of infected material may endanger Douglas-fir*,

- other production, such as fruits; *this may be of importance for the carrying capacity of habitats in terms of hunting (horse-chestnut, hickories, rowans)*,
- positive or insignificant effect on soils, *compared to native species, such as Douglas-fir compared to domestic conifers, Grand fir, black walnut*,
- suitability for stands formed together with native tree species; *this aspect is largely unresearched so far, as in practice rather unmixed stands have been established, with the exception of Douglas-fir*,
- the elimination of invasive behaviour, the negative impact on native vegetation; *this aspect still requires extensive research, only sparse data is available in our conditions*,
- the ability of natural regeneration; *this aspect can become the matter in dispute because successful natural regeneration, emphasized by the forestry view, can also be evaluated as invasive behaviour. This is clear in the case of protected areas where the introduced tree species should not be applied.*

3. Use of introduced tree species in the Czech Republic

The proportion of particular introduced tree species or their groups is shown in Table 1. It is based on the most recent data published (Beran 2018). The work summarizes the current data on the stand area of these species and their representation in Czech forests. Based on the available analysis, the table presents plain data to make us seriously think of focusing on silvicultural research, growth and production, environmental impacts and possibilities of using individual introduced tree species. It will allow us to point out unresearched areas and concentrate further research on them, if there is enough interest, resources and demand. It is necessary to emphasize that the results must be submitted not only to the academic community in the form of publications in professional journals as it would not bring any practical impact. The same applies for formal final reports addressed to the state administration. This would be as good as throwing the results down the drain. Research results must be made commonly available through infotainments and campaigns for practical foresters, forest owners and managers, and also, no less importantly, for the state.

Other introduced tree species occur on negligible areas, not registered by the national forestry inventories, or at non forest lands – urbanized area, road lines, agricultural lands. This can be also case of some invasions, not perceived by forestry, but very dangerous in many cases.

Table 1. Area and stand volume of the main introduced tree species in the Czech Republic (Beran 2018).

Species	Stand area		Standing volume		Mean age
	[ha]	[%]	[thous. m ³ u. b.]	[%]	
Conifers					
Exotic spruces	9,194	0.49	277	0.05	24
<i>Pseudotsuga menziesii</i>	6,081	0.32	1,599	0.28	
<i>Pinus nigra</i>	3,564	0.19	801	0.14	91
<i>Pinus strobus</i>	2,700	0.15	799	0.14	71
<i>Pinus banksiana</i>	132	0.00	28	0.00	
<i>Pinus contorta</i>	127	0.00	5	0.00	21
<i>Abies grandis</i>	1,284	0.07	228	0.04	26
Exotic firs	9	0.00	1	0.00	23
Conifers total	23,091	1.23	3,738	0.66	
Broad-leaves					
<i>Robinia pseudoacacia</i>	13,993	2.01	1,746	1.37	65
<i>Quercus rubra</i>	6,101	0.88	1,138	0.90	47
Exotic poplars	2,304	0.33	583	0.46	41
<i>Juglans nigra</i>	836	0.12	189	0.15	43
<i>Acer negundo</i>	339	0.05	33	0.03	45
<i>Castanea sativa</i>	27	0.00	5	0.00	53
<i>Ailanthus altissima</i>	16	0.00	1	0.00	42
Broad-leaves total	23,616	3.40	3,695	2.92	

4. State of the research and potential priorities for individual introduced tree species

The following part presents the individual introduced tree species and briefly describes the research focused on them, its results, importance of these tree species and other monitoring priorities. The results of the original research of the authors' team are used, primarily. The species of interest are especially exotic spruces, Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco), grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), northern red oak (*Quercus rubra* L.) and black walnut (*Juglans nigra* L.). Special attention is paid to black locust (*Robinia pseudoacacia* L.), as it is our most widely spread introduced tree species. Other species can be also perspective, but the sources available are very limited.

Exotic spruces

The introduced spruce species are, overall, among the most important species of geographically non-native conifers (we exclude European larch – *Larix decidua* Mill. from the set of introduced trees, larch is considered as non-native species at majority of the Czech area by the nature conservation authorities). In our conditions, blue spruce (*Picea pungens* Engelm.) is the most common. It was used at higher altitudes, especially in the Ore Mountains (Krušné hory); further in the Jizera Mountains (Jizerské hory) and the Giant Mountains (Krkonoše), and elsewhere, to a lesser extent (Podrázský 2008; Baláš et al. 2019). In this mentioned mountain ranges, air pollution calamity (especially high SO₂ concentrations) caused disturbance and large-scale dieback of native Norway spruce stands in the 80s and 90s of the last century (Král et al. 2015; Putalová et al. 2019; Vacek et al. 2021) and this introduced tree species was used for afforestation. In the

juvenile stage, blue spruce showed immunity to air pollution and especially to game-induced stress, therefore its stands survived also at the sites prepared by bulldozers (approx. 5,000 ha) in the Ore Mountains (Podrázský et al. 2006). But the effects on the soil characteristics are relatively adverse (Podrázský et al. 2005). However, its habitat requirements are different from the conditions of air-polluted clearings, water-logged sites and anthropotechnically degraded areas. As a result, blue spruces face reduced vitality, fungal pathogen attacks and subsequent decline (Šefl et al. 2020; Samek et al. 2022). In mixtures with native spruce, blue spruce is naturally displaced and eliminated from the stands. It can be expected to gradually disappear from the stand structures, even without active intervention. Priority must be given to the restoration of its stands by other tree species, depending on the specific local conditions and circumstances (Moravčík 1994; Balcar & Kacálek 2008; Špulák & Dušek 2009; Novák et al. 2011; Špulák 2012).

Other spruce species have been tested in air-polluted areas as well, especially black spruce (*Picea mariana* [Mill.] Britton, Sterns & Poggenburg), Serbian spruce (*Picea omorica* [Pančić] Purk.), and, very rarely, other spruce species. In terms of production, however, these tree species lag behind in production when compared to native Norway spruce (Vacek et al. 2021b). The spruce exotics were almost destroyed by game in the air-polluted areas, with exception of the blue spruce. It might be of interest to observe these species, but apparently no significant results can be expected from them. Sitka spruce may seem promising, but its high moisture requirements must be taken into account with respect to climatic extremes. It is a widely used tree species in Western Europe, but under incomparable climatic and soil conditions (Mason 2015). In areas threatened by drought, Serbian spruce should deserve more attention (Ivetić & Aleksić 2019).

Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco)

If the spruce exotics are the most important in terms of area coverage, Douglas-fir is the most important introduced tree species in terms of production and potential for use. It was also given considerable attention in forestry research, and it is an object of enormous interest in forestry practice (Kubeček et al. 2014; Slodičák et al. 2014; Novák et al. 2018; Mondek & Baláš 2019; Nicolescu et al. 2023). It is indeed a tree species that has no competition in terms of quantity and quality of coniferous wood among the species of the temperate zone; the wood can be used similarly as spruce wood (Remeš & Zeidler 2014; Podrázský et al. 2016a; Zeidler & Borůvka 2018; Zeidler et al. 2022a).

Production of Douglas-fir was widely studied at the individual tree level (Kantor 2008; Kantor & Mareš 2009; Kantor et al. 2010) as well as based on inventory data (Podrázský et al. 2013a, 2013b; Pulkrab et al. 2014; Remeš et al. 2020). Much more evident production dominance was documented analysing standing volume in particular stands at the stand level (Podrázský et al. 2009; Tauchnam et al. 2010). It is always important to test, select and use proper provenances, having major effect on the plantation growth and prosperity (Kšir et al. 2015; Beran et al. 2019), in all European countries (Petkova et al. 2014; Popov et al. 2014). It was documented very important stabilizing function of Douglas-fir in the forest stands due to its very intense root system (Mauer & Palátová 2012; Kacálek et al. 2017; Novák et al. 2018), the less negative effects on forest soils comparing to native needle trees was also documented in many cases. Douglas-fir can be considered as soil improving species in the conifer stands (Podrázský & Remeš 2008; Menšík et al. 2009; Podrázský et al. 2009; Ulbrichová et al. 2014; Podrázský et al. 2016b). The positive effect on pedophysical characteristics were not documented (Kupka & Podrázský 2010). The impact on vegetation environment is also less unfavourable compared to native conifers, some tendencies to more ruderal and nitrophilous communities can be documented, in mixed stands these changes are less visible and dangerous (Podrázský et al. 2014; Viewegh et al. 2014; Matějka et al. 2015).

At present, however, its implementation and use are accompanied by a number of cardinal issues. Its demand on water resources is one of them. Although it has greater resistance in comparison to spruce (and other tree species), on the other hand, even at a small transpiration coefficient, it has high water consumption requirements due to its high production. This can be seen as risky in the increasing aridity of the environment (Slodičák et al. 2014; Novák et al. 2018). Furthermore, it is necessary to check its potential for efficient use of nitrogen – we have only insufficient results so far confirming its very favourable effect on the acceleration of the dynamics of this nutrient in forest soils (Podrázský et al. 2020a). Nitrogen fertilization is thus a common part of Douglas-fir management in areas of its intensive silviculture,

which strictly limited by legal and administrative issues under the Czech conditions. With the increasing share of this tree species in our forests, it is definitely necessary to increase the attention paid to phytosanitary issues and to provide reproductive material from non-hazardous, preferably domestic and quality sources (Kubeček et al. 2014; Novák et al. 2018; Mondek & Baláš 2019).

There are some objections of nature conservation authorities against Douglas-fir as a potentially invasive species, this can be prevented by proper management. On the other side, successful natural regeneration can be expected using corresponding silvicultural practices (Bušina 2007; Hart et al. 2010).

Grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.) and other exotic firs

Grand fir is the mostly widespread introduced species of fir in the Czech Republic, and the only one planted in the forest stands at a detectable level. Its production on convenient sites (fresh nutrient rich soils) surpasses even that of Douglas-fir (Fulín 2015; Fulín & Remeš 2015). So far, it has also shown a significant soil improving effect, unlike native silver fir (Podrázský et al. 2016b; Fulín et al. 2017a, 2018). On the other hand, its wood is supposed to be less usable, suitable habitats are rather sparse and, at present periods of drought, it also shows health problems (honey fungus, insect pests – bark beetle species). Despite this, research results show that the timber of grand fir has its commercial importance too (Zeidler et al. 2015; Zeidler et al. 2022b). Provenance trials and comparison among *Abies* genus show superiority of grand fir and importance of proper provenance selection (Frydl et al. 2018). From other species besides *A. grandis* [Douglas ex D. Don] Lindl., the *A. concolor* [Gordon] Lindl. ex Hildebr. and *A. procera* Rehder did show positive growth, on the contrary *A. balsamea* [L.] Mill., *A. pinsapo* Boiss., *A. cilicica* [Antoine & Kotschy] Carrière, *A. magnifica* A. Murray bis, *A. bornmuelleriana* Mattf. and *A. lasiocarpa* [Hook.] Nutt. failed (Čáp et al. 2012).

Exotic pines

Among introduced pine species, there are registered black pine (*Pinus nigra* Arn.), eastern white pine (*Pinus strobus* L.), Banksian (*Pinus banksiana* Lamb.) and lodgepole pines (*Pinus contorta* Dougl. et Loudon). Black pine was often used for afforestation of extreme, dry, warm and degraded sites for centuries, not only in the Czech Republic, but also in other countries (Vacek et al. 2018; Podrázský et al. 2020b; Ayan et al. 2021; Deligöz et al. 2021; Ulsan 2022). There, it showed acceptable growth even in circumstances where domestic tree species were already withering (similarly to black locust). This results in the occurrence of black pine in potentially non-forest localities or sites with a sparse woody component and thus very interesting for nature conservation (steppes, rocky steppes). In black pine, we face the issue of uncer-

tain usability of production, although some works have shown that it is comparable, albeit with reservations, to native Scots pine (Zeidler & Borůvka 2018). Furthermore, black pine is threatened by phytopathological factors. On the other hand, it is interesting to consider its potential in view of its natural range being so close to our countries, and in view of the climate change. It might be a species of potentially natural species composition and we should consider an appropriately assisted transfer/assisted migration.

Another used pine species is represented by Eastern white pine. This tree species significantly prefers poorer and lighter soils (Andrews et al. 1998). It is characterized by relatively high-volume production, but it faces challenges on the Czech (and surrounding) market. It is in demand for specific purposes (pencils, matches), but as the importance of these articles decreases, so does demand. A significant problem is posed by its invasive behaviour at suitable sites, which very often come under the nature protection measures, at the same time. The use of its significant and specific volume production is possible together with establishing an appropriate trade situation and in conditions where its invasive behaviour does not threaten protected localities. It is also possible to consider research on the optimization of its silviculture and on the effects of this species on the soil and on the state of phytocoenoses. This pine is shows also significant healthy problems and negative impact on forest soils, consisting in strong acidification (Podrázský & Kupka 2011). There is a lack of information concerning Banksian pine, despite this species was planted in some regions. It occurs only sporadically and we are yet to update our knowledge on this species, no potential production and environmental effects were documented.

On the contrary, logdepole pine looks more promising. It is a tree species with a distinct pioneering character, tolerating even extreme habitats (Vacek et al. 2021b, 2022). In Northern Europe, it has been rather widely introduced. In our conditions there is a possibility of planting and growing in locations where native Scots pines are expected to face problems. The results so far have shown that there are provenances available that can fulfil this role (Fulín et al. 2017b; Novotný et al. 2017; Beran 2018; Čáp et al. 2018). However, it is necessary to check its influence on the stand environment (Podrázský 2006), its real resistance, and also to quantify the production potential of a selected provenances.

Among **other introduced coniferous** tree species, the testing and evaluation should be in relation to climate change and forest stability should be oriented at the genera *Cedrus*, *Sequoiadendron*, *Metasequoia*, the information available is insufficient (e.g. Podrázský & Kupka 2011), eventually the research is in very initial state (Gallo et al. 2022).

Black locust (*Robinia pseudoacacia* L.)

Black locust is the most abundant introduced tree in Czech forests, and it is one of the oldest tree introductions realised in the country (Nožička 1957; Vítková et al. 2017). It was widely planted in gardens and parks, later also in forests, groves and windbreaks. It is a very resistant and strongly competitive tree species (Kuneš et al. 2019a) often tending to invasive behaviour (Vítková et al. 2015). Given the invasiveness of black locust (Vilà et al. 2009) and the ability to convert its habitat (Bartha et al. 2008), extreme caution regarding its use in the open landscape is certainly important (Kuneš et al. 2019b). However, the site-specific management of the species seems to be the relevant approach (Vítková et al. 2016; Sádlo et al. 2017), because black locust can provide also important services and benefits (Keresztesi 1988; Kowarik et al. 2013; Bayer et al. 2018). From the viewpoint of forestry research in the Czech Republic, there is a lack of relevant data for the balanced evaluation of black locust in terms of production, growth, quality and use of timber. An overview regarding principal silvicultural and management approaches was provided by Kuneš & Baláš (2020). In the context of the changing climate in Europe, also the experiences from some rather warmer or more arid European countries such as Hungary (Redei et al. 2018; Ábri et al. 2021; Ábri & Rédei 2022), Ukraine (Lovynska et al. 2018; Lovynska et al. 2019) or Romania (Nicolescu et al. 2018; Nicolescu et al. 2020a) could be useful. Still, further forestry research focused on the positive and negative aspects of black locust is needed directly in the Czech Republic.

Black walnut (*Juglans nigra* L.)

Black walnut (*Juglans nigra* L.) was introduced in the Europe from North America at the beginning of the 17th century and became a species of high interest in the forestry and gardening. He is characterized by specific site demands – for good growth and excellent production requires nutrient rich soil and convenient water supply; in Czech conditions was cultivated almost entirely only at the sites corresponding to flood-plain forests (Prudič 1991; Hrib 2005). The ground water is adequate substitution for missing precipitation sources there. In the forest plantation it was introduced in SE Moravia since the end of the 18th century with big success. Cultivation in these conditions is causing many conflicts with nature conservation – all these sites are of site protection interest – NATURA 2000 (Mráček 1925; Nicolescu 1998; Nicolescu et al. 2020b).

Black walnut represents a very suitable supplement to the woody species composition of rich lowland habitats well supplied with water. On the other hand, no other floodplain deciduous tree species can compete its quality and value production (Podrázský & Šálek 2018; Nicolescu et al. 2020b). Its impact on the soil condition and biocoenoses composition has not been analysed in detail yet, but no significant issues have not been indi-

cated so far. Herb communities in the stands of this species show a higher proportion of grasses, which is explained by biochemical changes in the soil (Hrib et al. 2017). In any case, further research, also focused on mixed stands, is highly desirable.

The silvicultural treatments should be aimed at production of high quality stems both in monocultures, both in mixed stands, black walnut need to be grown in the main tree layer with full access to light. So, at the young age, it should be applied negative tending from above, this approach should be changed into positive tending from above later. The admixture of shade tolerant species in lower stands layers is desirable to improve growth and prevent biodiversity problems. The higher rotation is to be recommended to achieve bigger proportion of valuable assortments, at least 140 years comparing to prescribed 80. The prices of black walnut timber were always much higher comparing to other hardwoods. Not only the value, but also the volume production is superior. This species can be assumed as highly valuable substitution for some tropical timber. To this moment, there are not manifested dangerous pathogens of black walnut in the Central Europe, unlike to natural range, eventually W and S European countries (Baláš et al. 2019). For black walnut, the negative effects in the root zone are assumed due to exudation of juglone having alelopathic effects. These should inhibit some species, on the contrary e.g., grasses can be supported, this was registered in foreign as well as local studies to some extent (Willis 2000; Tokár & Krekulová 2002; Csiszár et al. 2013;). The hybridization with *J. regia* is documented in some cases (Hrib et al. 2002). Nevertheless, this species represents considerable potential contribution to high-value forestry.

Northern red oak (*Quercus rubra* L.)

This introduced tree species represents one of the most common broadleaved species in the Central Europe, as well as in other European regions (Kouba & Zahradník 2011; Nagel 2015). It is also very durable and grows well in habitats where native species already face problems (e.g. Kupka & Dimitrovský 2011). It was in the centre of research interest also in neighbouring countries (Štefančík 1992, 2011), especially as a consequence with decline of domestic oak species. In terms of volume production, it outperforms native species of oaks (Miltner & Kupka 2016; Kupka et al. 2018), but the quality of wood is somewhat poorer and the environmental impact is slightly but perceptibly less favourable compared to native species (Miltner et al. 2016, 2017; Zeidler & Borůvka 2016; Špulák 2022). It will be used also in the future at sites with low local oak species production and at reclamation activities.

Other broad-leaved tree species were introduced in much smaller extent, or they are used in very specific conditions. In intensive plantation the Canadian poplar (*Populus × canadensis* Moench) and its hybrids and

clones are planted extensively. Hybrids of European and American poplar species show excellent production. Optimum growth and production are achieved again mainly at floodplain habitats (nutrient and water supply). As with other species, hybrids of poplar and willow clones, the main research issue is the future use of production (including chemical and energetic industries), health status, stability and impact on ecosystem components, but the use in common forestry is very limited (Baláš et al. 2019).

Another group of non-native tree species represents the potentially or actually invasive plants. Species as Box elder (*Acer negundo* L.), tree of heaven (*Ailanthus altissima* [Mill.] Swingle), were originally used in park and garden plantings but showed a clear tendency to behave invasively (along with wild black cherry and, in some localities, with eastern white pine). Forestry use will continue to be limited in the future, but research of its population biology is seen as important, just as the defensive measures against further spread. The prevention of continuing invasiveness is so the main topic.

There is still a set of tree species able to join the list of perspective trees, potentially interesting for Czech conditions, especially in connection with climate change. They are both conifers (*Sequoiadendron giganteum* [Lindl.] J. Buchh., *Cedrus* spp., *Metasequoia glyptostroboides* Hu & W. C. Cheng) and broad-leaves (*Castanea sativa* Mill., *Corylus colurna* L., *Platanus* spp., *Carya* spp. and others, like some spruce species – *Picea sitchensis* [Bong.] Carr., *P. omorika* [Pančić] Purk.). The testing and planting are in the centre of the forestry research in the last period (e.g. Svoboda 1978; Zeidler et al. 2010; Podrázský & Kupka 2011; Melicharová & Kupka 2021; Gallo et al. 2022; Haltofová & Jankovský 2023).

5. Conclusions

Most probably, introduced tree species will not form a significant part of the Czech forests in the near future. However, they have been addressed by forestry research and the attention paid to them has been increasing recently. The issue of afforestation of large calamity areas, together with climate change and weather extremes, makes it necessary to consider the use of less common forest tree species. Despite the uncertainties related to the anticipated development of ecological and economic-political conditions, it is necessary to think of the introduced tree species as an alternative albeit not the dominant and decisive one to increase diversity of our forests. Another important area to use introduced tree species is in further afforestation of agricultural land, and especially degraded and devastated sites and further forest regeneration in climatically more extreme regions,

especially with regard to moisture conditions. The use in agroforestry systems is another big issue.

The knowledge base on the growth, prosperity and environmental impacts of these species is certainly not complete nor sufficient. Further research and gathering of information in this area is of the utmost relevance, and while not being currently a mainstream forestry issue, it is undoubtedly important. The aim of this review is therefore to summarize the available knowledge in the given area and to provide users with an overview to be used in further studies and in forestry practice. The paper presents the results of the original research and the findings from the Czech Republic where their application is expected, in the first place. In brief, our knowledge is summarized in Table 2, where the current opinion on the importance of at least the most important introduced tree species for the forestry of the Czech Republic is presented.

In the main tree species, the evaluation is based on extensive exploration and original research (see the relevant chapters), while in the minor ones, it is based on general literature. Often these are assumptions indicating the directions of future research. As a consequence of climate change, it is quite justified to try other species that have not been tested in Czech forestry, such as plane-tree, Turkish hazel (*Corylus colurna* L.), hickories (*Carya* spp.), the dawn redwood (*Metasequoia glyptostroboides* Hu & W. C. Cheng), giant sequoia (*Sequoiadendron giganteum* [Lindl.] J. Buchh.), cedars (*Cedrus* spp.) and others. A special position can be assumed for black pine, which used to be planted in the past in our country and whose natural area is near our southern borders. In the case of black pine and other similar species, it would be theoretically possible to consider so-called assisted migration, where the species is intentionally spread in an area with potentially corresponding conditions and related to the current area, but is unable to colonise the area spontaneously.

The publication also does not include truly invasive species such as glandular ailanthus, boxelder, wild black

cherry and others, as these will certainly not be the subject of forest management. Presented species and others may play a minor, though certainly a more important role in the forestry of the Czech Republic than at present. It is also necessary to distinguish between the cases where these species can spontaneously spread to the territory under a nature conservation regime and where the forests are regularly and purposefully cared for. There, most of the tree species can be managed very effectively by forest management. In any case, it is necessary to considerably expand research activities in relation to the introduced tree species so that their effects in the Czech landscape are properly documented and their effective use optimized within the sustainable use of forests and the whole landscape.

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References

- Ábri, T., Keserű, Zs., Rásó, J., Rédei, K., 2021: Stand structure and growth of *Robinia pseudoacacia* ‘Jász-kiséri’ – ‘Já-szkiséri’ black locust. *Journal of Forest Science*, 67:489–497.
- Ábri, T., Rédei, K., 2022: Analyses of periodic annual increment by diameter and volume in differently aged black locust (*Robinia pseudoacacia* L.) stands: Case study. *Journal of Forest Science*, 68:213–219.

Table 2. Evaluation of the potential of the most important introduced tree species in the conditions of the Czech Republic.

Species / Criterion	1	2	3	4	5	6	7	8	9	10	11	12
<i>Pseudotsuga menziesii</i>	+++	+	++	+	0	+	++	+	++	0	++	+
<i>Abies grandis</i>	+++	–	0	+	?	–	0	0	+	+	+	+
<i>Picea pungens</i>	--	--	0	--	?	–	+	--	+	+	--	?
<i>Pinus nigra</i>	+	+	+	–	?	+	+	–	+	0	+	?
<i>Pinus strobus</i>	+	?	0	–	–	0	–	–	+	–	+	+
<i>Pinus contorta</i>	0	?	++	–	?	+	+	0	++	+	+	?
<i>Pinus ponderosa</i>	+	+	?	0	0	+	+	+	+	+	+	?
<i>Pinus banksiana</i>	?	?	0	?	?	+	?	0	0	+	+	?
<i>Robinia pseudoacacia</i>	+	+	+	+-	–	+	+	+	+	--	–	+
<i>Quercus rubra</i>	+	0	+	+	0	+	0	0	+	0	+	+
<i>Juglans nigra</i>	+	++	+	0	0	–	+	+	+	+	+	0
<i>Populus</i> spp. hybr.	++	+	0	0	0	–	–	–	–	0	+	0
<i>Castanea sativa</i>	+	++	0	+	0	0	0	0	+	+	+	+

Criteria:

1 – Volume production, 2 – Quality of raw wood material, 3 – Ecological plasticity, 4 – Amelioration effects, effect on soil condition (in relation to comparable species), 5 – Impact on biodiversity, 6 – Drought resistance, 7 – Resistance to other abiotic factors (wind, snow, frost), 8 – Biotic pest hazard, 9 – Crossbreeding with native species, 10 – Invasive behaviour, 11 – Suitability for mixed stands, 12 – Ability of natural regeneration.

Evaluation:

+ positive importance for forestry, – negative importance for forestry, 0 comparable to relevant native species, ? unknown effects and impacts.

- Andrews, J. A., Johnson, J. E., Torbert, J. L., Burger, J. A., Kelting, D. L., 1998: Minesoil and Site Properties Associated with Early Height Growth of Eastern White Pine. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 27:192–199.
- Ayan, S., Yücedağ, C., Simovski, B., 2021: A major tool for afforestation of semi-arid and anthropogenic steppe areas in Turkey: *Pinus nigra* JF Arnold subsp. *pallasiana* [Lamb.] Holmboe. Journal of Forest Science, 67:449–463.
- Baláš, M., Bažant, V., Borůvka, V., Dimitrovský, K., Fulín, M., Kuneš, I. et al., 2019: Silvicultural, Production and Environmental Potential of the Main Introduced Tree Species in the Czech Republic. Kostelec nad Černými lesy, Lesnická práce, 186 p.
- Balcar, V., Kacálek, D., 2008: European beech planted into spruce stands exposed to climatic stresses in mountain areas. Austrian Journal of Forest Science, 125:27–38.
- Csiszár, Á., Korda, M., Schmidt, D., Šporcic, D., Süle, P., Teleki, B. et al., 2013: Allelopathic potential of some invasive plant species occurring in Hungary. Allelopathy Journal, 31:309–318.
- Bartha, D., Csiszár, Á., Zsigmond, V., 2008: Black locust (*Robinia pseudoacacia* L.) In: Botta-Dukát, Z., Balogh, L. (eds): The Most Important Invasive Plants in Hungary. Institute of Ecology and Botany. Hungarian Academy of Sciences, Vácrátót, p. 63–76.
- Bayer, D., Reischl, A., Rötzer, T., Pretzsch, H., 2018: Structural response of black locust (*Robinia pseudoacacia* L.) and small-leaved lime (*Tilia cordata* Mill.) to varying urban environments analyzed by terrestrial laser scanning: Implications for ecological functions and services. Urban Forestry & Urban Greening, 35:129–138.
- Beran, F., 2018: Introdukované dřeviny v lesním hospodářství ČR – Přehled. In: Vacek, Z., Podrázský, V. (eds.): Introdukované dřeviny jako součást českého lesnictví. Kostelec nad Černými lesy, ČLS, p. 7–16. (In Czech).
- Beran, F., Dostál, J., Fulín, M., 2019: Vyhodnocení nejstarších provenienčních ploch s douglaskou tisolistou v České republice. Zprávy lesnického výzkumu, 64:65–76. (In Czech).
- Borůvka, L., Podrázský, V., Mládková, L., Kuneš, I., Drábek, O., 2005: Some approaches to the research of forest soils affected by acidification in the Czech Republic. Soil Science and Plant Nutrition, 51:745–749.
- Brundu, G., Richardson, D. M., 2016: Planted forests and invasive alien trees in Europe: A code for managing existing and future plantings to mitigate the risk of negative impacts from invasions. NeoBiota, 30:5–47.
- Brundu, G., Pauchard, A., Pyšek, P., Pergl, J., Bindewald, A. M., Brunori, A. et al. 2020: Global guidelines for the sustainable use of non-native trees to prevent tree invasions and mitigate their negative impacts. Neo-Biota, 61:65–116.
- Brus, R., Pötzelsberger, E., Lapin, K., Brundu, G., Orazio, C., Straigyte, L. et al., 2019: Extent, distribution and origin of non-native forest tree species in Europe. Scandinavian Journal of Forest Research, 34:533–544.
- Bušina, F., 2007: Natural regeneration of Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) in forest stands of Hůrky Training Forest District, Higher Forestry School and Secondary Forestry School in Písek. Journal of Forest Science, 53:20–34.
- Castro-Díez, P., Vaz, A. S., Silva, J. S., Loo, M., Alonso, Á., Aponte, C. et al. 2019: Global effects of non-native tree species on multiple ecosystem services. Biological Reviews, 94:1477–1501.
- Castro-Díez, P., Alonso, Á., Saldaña-López, A., Granda, E., 2021: Effects of widespread non-native trees on regulating ecosystem services. Science of the Total Environment, 778:146141.
- Čáp, J., Novotný, P., Beran, F., Frýdl, J., Dostál, J., Jírec, J., 2012: Vyhodnocení růstu proveniencí cizokrajných druhů jedlí ve věku 36–41 let. Zprávy lesnického výzkumu, 57:151–159. (In Czech).
- Čáp, J., Novotný, P., Fulín, M., Dostál, J., Beran, F., 2018: Evaluation of lodgepole pine (*Pinus contorta* Dougl. ex Loudon) on a provenance plot situated in a formerly air-polluted area of the Krušné hory Mts. at the age of 34 years. Journal of Forest Science, 64:118–128.
- D’Andrea, G., Šimůnek, V., Castellaneta, M., Vacek, Z., Vacek, S., Pericolo, O. et al. 2022: Mismatch between Annual Tree-Ring Width Growth and NDVI Index in Norway Spruce Stands of Central Europe. Forests, 13:1417.
- Deligöz, A., Bayar, E., Genç, M., Karatepe, Y., 2021: Differences in water relations and total carbohydrate content between precommercially thinned and unthinned *Pinus nigra* subsp. *pallasiana* stands. Journal of Forest Science, 67:125–133.
- Dodet, M., Collet, C., 2012: When should exotic forest plantation tree species be considered as an invasive threat and how should we treat them? Biological Invasions, 14:1765–1778.
- Fulín, M., 2015: Pěstování, produkční potenciál a ekologické důsledky pěstování jedle obrovské (*Abies grandis* [Douglas ex D. Don] Lindl.) v České republice – přehled. Lesnický časopis – Forestry Journal, 61:262–266. (In Czech).
- Fulín, M., Remeš, J., 2015: Produkce jedle obrovské v mladém věku. Zprávy lesnického výzkumu, 60:262–266. (In Czech).
- Fulín, M., Novotný, P., Podrázský, V., Beran, F., Dostál, J., Jehlička, J., 2017a: Evaluation of the provenance plot “Hrubá Skála” (Northern Bohemia) with grand fir at the age of 36 years. Journal of Forest Science, 63:75–87.

- Fulín, M., Novotný, P., Čáp, J., Dostál, J., Frýdl, J., 2017b: Vyhodnocení provenienční plochy s borovicí pokroucenou (*Pinus contorta* Dougl. ex Loudon) na borovém stanovišti na Třeboňsku. Zprávy lesnického výzkumu, 62:262–270. (In Czech).
- Fulín, M., Podrázský, V., Baláš, M., 2018: Vliv jedle obrovské na stav lesních půd: případová studie. Zprávy lesnického výzkumu, 8:129–135. (In Czech).
- Frýdl, J., Dostál, J., Beran, F., Čáp, J., Fulín, M., Framp-ton, J. et al., 2018: Exotic *Abies* species in Czech provenance trials: assessment after four decades. Acta Silvatica et Lignaria after four decades, 14:9–134.
- Furst, C., Vacík, H., Lorz, C., Makeshin, F., Podrázský, V., 2007: Meeting the challenges of process-oriented forest management. Forest Ecology and Management, 248:1–15.
- Gallo J., Záruba J., Baláš M., Podrázský V., 2022: Výzkumná plocha Doubek – introdukované dřeviny na zemědělské půdě. In: Nové poznatky ve výzkumu introdukovaných dřevin. Sborník příspěvků. Kostelec nad Černými lesy, 28. 06. 2022. Česká lesnická společnost, p. 45–52. (In Czech).
- Haltořová, P., Jankovský, L., 2003: Kaštanovník jedlý *Castanea sativa* Mill. jako perspektivní i problémová dřevina. Zprávy lesnického výzkumu, 48:112–115. (In Czech).
- Hart, V., Hartová, M., Tauchman, P., 2010: Analysis of herbicide effects on Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) natural regeneration. Journal of Forest Science, 56:209–217.
- Hasenauer, H., Gazda, A., Konner, M., Mohren, G., Pötzelsberger, E., Spiecker, H., Van Loo, M., 2016: Non-Native Tree Species for European Forests: Experiences, Risks and Opportunities. Vienna, University of Natural Resources and Life Sciences, 427 p.
- Hrib, M., Koblížek, J., Maděra, P., 2002: *Juglans × intermedia* Carr. – an interesting finding in the Židlochovice Forest Enterprise. Journal of Forest Science 48:475–481.
- Hrib, M., 2005: Pěstování ořešáku černého (*Juglans nigra* L.) v lesích jižní Moravy. Sborník prací institucionálního výzkumu, Brno, MZLU, 2:1–78. (In Czech).
- Hrib, M., Podrázský, V., Matějka, K., Viewegh, J., 2017: Effect of black walnut (*Juglans nigra*) on the understorey vegetation – A case study of South Moravian forests (Czech Republic). Journal of Forest Science, 63:136–148.
- Ivetić, V., Aleksić, J. M., 2019: Serbian Spruce and Climate Change: Possible Outcomes and Conservation Strategy. In: Šijačić-Nikolić, M., Milovanović, J., Nonić, M. (eds): Forests of Southeast Europe Under a Changing Climate. Advances in Global Change Research, 65:353–371.
- Kacálek, D., Mauer, O., Podrázský, V., Slodičák, M. et al., 2017: Meliorační a zpevňující funkce lesních dřevin. Kostelec nad Černými lesy, Lesnická práce, 300 p. (In Czech).
- Kantor, P., 2008: Production potential of Douglas fir at mesotrophic sites of Křtiny Training Forest Enterprise. Journal of Forest Science, 54:321–332.
- Kantor, P., Mareš, R., 2009: Production potential of Douglas fir in acid sites of Hůrky Training Forest District, Secondary Forestry School in Písek. Journal of Forest Science, 55:312–322.
- Kantor, P., Bušina, F., Knott, R., 2010: Postavení douglasky tisolisté (*Pseudotsuga menziesii* [Mirb.] Franco) a její přirozená obnova na školním polesí Hůrky středních lesnických škol Písek. Zprávy lesnického výzkumu, 55:251–263. (In Czech).
- Keresztesi, B., 1988: The Black Locust. Budapest, Akadémiai Kiadó, 197 p.
- Kouba, J., Zahradník, D., 2011: Produkce nejdůležitějších introdukovaných dřevin v ČR podle lesnické statistiky. In: Prknová, H. (ed.): Aktuality v pěstování méně častých dřevin v České republice. Sborník příspěvků z konference, Kostelec nad Černými lesy, 25. 11. 2011. Praha, ČZU, p. 52–66. (In Czech).
- Kowarik, I., von der Lippe, M., Cierjacks, A., 2013: Prevalence of alien versus native species of woody plants in Berlin differs between habitats and at different scales. Preslia, 85:113–132.
- Král, J., Vacek, S., Vacek, Z., Putalová, T., Bulusek, D., Štefančík, I., 2015: Structure, development and health status of spruce forests affected by air pollution in the western Krkonoše Mts. in 1979–2014. Lesnícky časopis – Forestry Journal, 61:175–187.
- Kšíř, J., Beran, F., Podrázský, V., Novotný, P., Dostál, J., Kubeček, J., 2015: Výsledky hodnocení mezinárodní provenienční plochy s douglaskou tisolistou (*Pseudotsuga menziesii* [Mirb.] Franco) na lokalitě Hůrky v Jižních Čechách ve věku 44 let. Zprávy lesnického výzkumu, 60:104–114. (In Czech).
- Kubeček, J., Štefančík, I., Podrázský, V., Longauer, R., 2014: Výsledky výzkumu douglasky tisolisté (*Pseudotsuga menziesii* [Mirb.] Franco) v České republice a na Slovensku – přehled. Lesnícky časopis – Forestry Journal, 60:120–129. (In Czech).
- Kuneš, I., Baláš, M., Bažant, V., Borůvka, V., Prknová, H., 2019a: Black locust (*Robinia pseudoacacia* L.). In: Podrázský V., Prknová H. (eds.): Silvicultural, production and environmental Potential of the Main Introduced Species in the Czech Republic. Praha a Kostelec nad Černými lesy, Česká zemědělská univerzita v Praze a Lesnická práce, p. 118–148.
- Kuneš, I., Baláš, M., Gallo, J., Šulitka, M., Suraweera, C., 2019b: Trnovník akát (*Robinia pseudoacacia*) a jeho role ve středoevropském a českém prostoru: review. Zprávy lesnického výzkumu, 64:181–190. (In Czech).
- Kuneš, I., Baláš, M., 2020: Trnovník akát (*Robinia pseudoacacia*) – jeho množení, pěstování a likvidace: review. Zprávy lesnického výzkumu 65:11–19. (In Czech).
- Kupka, I., Podrázský, V., 2010: Vliv druhového složení porostů na zalesněné zemědělské půdě na pedofy-

- zikální vlastnosti a poutání uhlíku v povrchových horizontech. In: Knott, R., Peňáz, J., Vaněk, P. (eds): Pěstování lesů v nižších vegetačních stupních. Křtiny 6.–8. 9. 2010. Brno, Ústav zakládání a pěstění lesů LDF Mendelova univerzita v Brně, p. 71–76. (In Czech).
- Kupka, I., Dimitrovský, K., 2011: Výsledky testování vybraných dřevin pro lesnické rekultivace na Sokolovsku: review. Zprávy lesnického výzkumu, 56:52–56. (In Czech).
- Kupka, I., Baláš, M., Miltner, S., 2018: Quantitative and qualitative evaluation of Northern red oak (*Quercus rubra* L.) in arid areas of North-Western Bohemia. Journal of Forest Science, 64:53–58.
- Lovynska, V., Lakyda, P., Sytnyk, S., Lakyda, I., Grithan, Y., Hetmanchuk, A., 2019: Stem production of Scots pine and black locust stands in Ukraine's Northern Steppe. Journal of Forest Science, 65:461–471.
- Lovynska, V., Sytnyk, S., Gritsan, Y., 2018: Energy potential of main forest-forming species of stands in the Northern Steppe, Ukraine. Journal of Forest Science, 64:25–32.
- Mason, W. L., 2015: Implementing continuous cover forestry in planted forests: Experience with Sitka spruce (*Picea sitchensis*) in the British Isles. Forests, 6:879–902.
- Matějka, K., Podrázský, V., Viewegh, J., Martiník, A., 2015: Srovnání bylinné etáže v porostech douglasky tisolisté (*Pseudotsuga menziesii* [Mirb.] Franco) a v porostech jiných dřevin. Zprávy lesnického výzkumu, 60:201–210. (In Czech).
- Mauer, O., Palátová, E., 2012: Root system development in Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) on fertile sites. Journal of Forest Science, 58:400–409.
- Melicharová, L. V., Kupka, I., 2021: Kaštanovník jedlý (*Castanea sativa* Mill) v měnících se podmínkách Evropy a České republiky. Zprávy lesnického výzkumu, 66:147–154. (In Czech).
- Menšík, L., Kulhavý, J., Kantor, P., Remeš, M., 2009: Humus conditions of stands with the different proportion of Douglas fir in the Hůrky Training Forest District and Křtiny Forest Training Enterprise. Journal of Forest Sciences, 55:345–356.
- Miltner, S., Kupka, I., 2016: Silvicultural potential of northern red oak and its regeneration – Review. Journal of Forest Science, 62:145–152.
- Miltner, S., Kupka, I., Třeštík, M., 2016: Effects of Northern red oak (*Quercus rubra* L.) and sessile oak (*Quercus petraea* [Mattusch]. Liebl.) on the forest soil chemical properties. Forestry Journal, 62:157–160.
- Miltner, S., Podrázský, V., Baláš, M., Kupka, I., 2017: Vliv dubu červeného (*Quercus rubra* L.) na lesní stanoviště. Zprávy lesnického výzkumu, 62:109–115. (In Czech).
- Mondek, J., Baláš, M., 2019: Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and its role in the Czech forests. Journal of Forest Science, 65:41–50.
- Moravčík, P., 1994: Development of new forest stands after a large scale forest decline in the Krušné hory Mountains. Ecological Engineering, 3:57–69.
- Mráček, J., 1925: Ořešák černý (*Juglans nigra* L.). Lesnická práce, 4:209–217. (In Czech).
- Nagel, R.-V., 2015: Roteiche (*Quercus rubra* L.). In: Vor, T., Spellmann, H., Bolte, A., Ammer, Ch.: Potenzi-ale und Risiken eingeführter Baumarten. Göttingen, Göttinger Forstwissenschaften, p. 219–267. (In Germany).
- Nicolescu, N.-V., 1998: Considerations regarding black walnut (*Juglans nigra*) culture in the north-west of Romania. Forestry, 71:349–354.
- Nicolescu, V.-N., Hernea, C., Bakti, B., Keserű, Z., Antal, B., Rédei, K., 2018: Black locust (*Robinia pseudoacacia* L.) as a multi-purpose tree species in Hungary and Romania: a review. Journal of Forestry Research, 29:1449–1463.
- Nicolescu, V.-N., Rédei, K., Mason, W. L., Vor, T., Pöet-zelsberger, E., Bastien, J.-Ch. et al., 2020a: Ecology, growth and management of black locust (*Robinia pseudoacacia* L.), a non-native species integrated into European forests. Journal of Forestry Research, 31:1081–1101.
- Nicolescu, V.-N., Rédei, K., Vor, T., Bastien, J.-Ch., Brus, R., Benčat, T. et al. 2020b: A review of black walnut (*Juglans nigra* L.) ecology and management in Europe. Trees, 34:1087–1112.
- Nicolescu, V.-N., Mason, W., Bastien J. C., Vor, T., Petkova, K., Podrázský, V. et al., 2023: Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in Europe: an overview of management practices. Journal of Forestry Research, 740:1–18.
- Novák, J., Slodičák, M., Dušek, D., Kacálek, D., 2011: Ecological aspects of biomass removal in the localities damaged by air-pollution. In: Atazadeh, I.: Biomass and Remote Sensing of Biomass. Rijeka, InTech, p. 21–34.
- Novák, J., Kacálek, D., Podrázský, V., Šimerda, L., 2018: Uplatnění douglasky tisolisté v lesním hospodářství ČR. Kostelec nad Černými lesy, Lesnická práce, 214 p. (In Czech).
- Novotný, P., Fulín, M., Dostál, J., Čáp, J., Frýdl, J., Liška, J. et al., 2017: Růst proveniencí borovice pokroucené v podmínkách acidofilní doubravy v Západních Čechách ve věku 34 let. Zprávy lesnického výzkumu, 62:197–207. (In Czech).
- Nožička, J., 1957: Přehled vývoje našich lesů. Praha, Státní zemědělské nakladatelství, 462 p. (In Czech).
- Petkova, K., Goergieva, M., Uzunov, M., 2014: Investigation of Douglas-fir provenance test in North-Western Bulgaria at the age of 24 years. Journal of Forest Science, 60:288–296.
- Podrázský, V., Ulbrichová, I., Moser, W. K., 2005: Využití břízy a smrku pichlavého při obnově porostů na plochách s nenarušenou vrstvou nadložního humusu. Zprávy lesnického výzkumu, 50:75–77. (In Czech).

- Podrázský, V., 2006: Lodgepole pine (*Pinus contorta*) as a preparatory tree species in immission area Orlické hory Mts. *Scientia Agriculturae Bohemica*, 37:67–70.
- Podrázský, V., Remeš, J., Ulbrichová, I., 2006: Rychlost regenerace lesních půd v horských oblastech z hlediska kvantity nadložního humusu. *Zprávy lesnického výzkumu*, 51:230–234. (In Czech).
- Podrázský, V., 2008: Tvorba povrchového humusu při zalesňování zemědělských ploch a po buldozerové přípravě v Krušných horách. *Zprávy lesnického výzkumu*, 53:258–263. (In Czech).
- Podrázský, V., Remeš, J., 2008: Půdotvorná role významných introdukovaných jehličnanů – douglasky tisolisté, jedle obrovské a borovice vejmutovky. *Zprávy lesnického výzkumu*, 53:27–34. (In Czech).
- Podrázský, V., Remeš, J., Hart, V., Moser, W. K., 2009: Production and humus form development in forest stands established on agricultural lands – Kostelec nad Černými lesy region. *Journal of Forest Science*, 55:299–305.
- Podrázský, V., Kupka, I., 2011: Vliv borovice vejmutovky a metasekvoje čínské na stav nadložního humusu na stanovišti potočního luhu. *Zprávy lesnického výzkumu*, 56:14–19. (In Czech).
- Podrázský, V., Zahradník, D., Pulkrab, K., Kubeček, J., Peňa, J. F. B., 2013a: Hodnotová produkce douglasky tisolisté (*Pseudotsuga menziesii* [Mirb.] Franco) na kyselých stanovištích Školního polesí Hůrky, Písecko. *Zprávy lesnického výzkumu*, 58:226–232. (In Czech).
- Podrázský, V., Čermák, R., Zahradník, D., Kouba, J., 2013b: Production of Douglas-fir in the Czech Republic based on national forest inventory data. *Journal of Forest Science*, 59:398–404.
- Podrázský, V., Martiník, A., Matějka, K., Viewegh, J., 2014: Effects of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) on understorey layer species diversity in managed forests. *Journal of Forest Science*, 60:263–271.
- Podrázský, V., Remeš, J., Sloup, R., Pulkrab, K., Novotný, S., 2016a: Douglas-fir – partial substitution for declining conifer timber supply – review of Czech data. *Wood Research*, 61:525–530.
- Podrázský, V., Fulín, M., Prknová, H., Beran, F., Třeštík, M., 2016b: Changes of agricultural land characteristics as a result of afforestation using introduced tree species. *Journal of Forest Science*, 62:72–79.
- Podrázský, V., Šálek, L., 2018: Produkční možnosti ořešáku černého (*Juglans nigra* L.) v České republice. *Zprávy lesnického výzkumu*, 63:237–242. (In Czech).
- Podrázský, V., Kupka, I., Prknová, H., 2020a: Substitution of Norway spruce for Douglas-fir: changes of soil microbial activities as climate change induced shift in species composition, a case study. *Central European Forestry Journal*, 66:71–77.
- Podrázský, V., Vacek, Z., Vacek, S., Vítámvás, J., Gallo, J., Prokúpková, A. et al., 2020b: Production potential and structural variability of pine stands in the Czech Republic: Scots pine (*Pinus silvestris* L.) vs. introduced pines – case study and problem review. *Journal of Forest Science*, 66:197–207.
- Popov, E. B., 2014: Results of 20 years old Douglas-fir provenance experiment established on the northern slopes of Rila Mountain in Bulgaria. *Journal of Forest Science*, 60:394–399.
- Pötzelsberger, E., Spiecker, H., Neophytou, C., Mohren, F., Gazda, A., Hasenauer, H., 2020: Growing Non-native Trees in European Forests Brings Benefits and Opportunities but Also Has Its Risks and Limits. *Current Forestry Reports*, 6:339–353.
- Prudič, Z., 1991: Růst ořešáku černého (*Juglans nigra* L.) na LZ Strážnice. *Lesnictví*, 37:359–369. (In Czech).
- Pulkrab, K., Sloup, M., Zeman, M., 2014: Economic impact of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) production in the Czech Republic. *Journal of Forest Science*, 60:297–306.
- Putalová, T., Vacek, Z., Vacek, S., Štefančík, I., Bulušek, D., Král, J., 2019: Tree-ring widths as an indicator of air pollution stress and climate conditions in different Norway spruce forest stands in the Krkonoše Mts. *Central European Forestry Journal*, 65:21–33.
- Rédei, K., Bakti, B., Kiss, T., Takács, M., Keserű, Z., 2018: Yield and crown structure characteristics in a black locust (*Robinia pseudoacacia* L.) stand: A case study – Short Communication. *Journal of Forest Science*, 64:96–100.
- Remeš, J., Zeidler, A., 2014: Production potential and wood quality of Douglas fir from selected sites in the Czech Republic. *Wood Research*, 59:509–520.
- Remeš, J., Pulkrab, K., Bílek, L., Podrázský, V., 2020: Economic and Production Effect of Tree Species Change as a Result of Adaptation to Climate Change. *Forests*, 11:431.
- Sádlo, J., Vítková, M., Pergl, J., Pyšek, P., 2017: Towards site-specific management of invasive alien trees based on the assessment of their impacts: the case of *Robinia pseudoacacia*. *NeoBiota*, 35:1–34.
- Samek, M., Modlinger, R., Bata, D., Lorenc, F., Vachová, J., Tomášková, I. et al., 2022: *Gemmamyces piceae* Bud Blight Damage in Norway Spruce (*Picea abies*) and Colorado Blue Spruce (*Picea pungens*) Forest Stands. *Forests*, 13:164.
- Slodičák, M., Novák, J., Mauer, O., Podrázský, V., Dušek, D., Houšková, K. et al., 2014: Pěstební postupy při zavádění douglasky do porostních směrů v podmínkách ČR. Kostelec nad Černými lesy, Lesnická práce, 272 p. (In Czech).
- Svoboda, A. M., 1978: Pěstování kaštanovníku jedlého (*Castanea sativa* Mill.) v Čechách a na Moravě. *Folia Dendrologica*, 4:23–48. (In Czech).
- Šefl, J., Mottlová, V., Schořálková, I., 2020: Bud blight (*Gemmamyces piceae*) in the eastern part of the Krušné hory Mountains. *Journal of Forest Science*, 66:309–317.

- Špulák, O., Dušek, D., 2009: Comparison of the impact of blue spruce and reed *Calamagrostis villosa* on forest soil chemical properties. *Journal of Forest Science*, 55:208–214.
- Špulák, O. 2012. Aboveground biomass and nutrients in an 18-years-old stand of blue spruce (*Picea pungens* Engelm.) as a substitute tree species. *Journal of Forest Science*, 58:253–264.
- Špulák, O., 2022. Živinové poměry půdy pod dubem červeným na oglejeném stanovišti v porovnání s dalšími dřevinami. In: Belko, M., Štefančík, I., Mačejovský, V.: *Pestovanie lesa v strednej Európe. Zborník vedeckých prác na tému. Zvolen, NLC*, p. 177–184. (In Czech).
- Šimůnek, V., Vacek, Z., Vacek, S., 2020: Solar Cycles in Salvage Logging: National Data from the Czech Republic Confirm Significant Correlation. *Forests*, 11:973.
- Štefančík, I., 2011: Vplyv výchovy na rast a vývoj porastu duba červeného (*Quercus rubra* L.). In: Prknová H. (ed.): *Aktuality v pestovaní méně častých dřevin v České republice. Sborník příspěvků z konference, Kostelec nad Černými lesy, 25. 11. 2011. Praha, ČZU*, p. 106–112. (In Slovak).
- Štefančík, L., 1992: Vplyv výchovného zásahu na porast duba červeného (*Quercus rubra* L.) skúpeľnoliečebnou a produkčnou funkciou. *Lesnícky časopis – Forestry Journal*, 38:253–260. (In Slovak).
- Tauchman, P., Hart, V., Remeš, J., 2010: Srovnání produkce porostu douglasky tisolisté (*Pseudotsuga menziesii* [Mirbel] Franco) s porostem smrku ztepilého (*Picea abies* [L.] Karst.) a stanovištně původním smíšeným porostem středního věku na území ŠLP v Kostelci nad Černými lesy. *Zprávy lesnického výzkumu*, 55:187–194. (In Czech).
- Tokár, F., Krekulová, E., 2005: Influence of phytotechnology on growth, production and leaf area index of black walnut (*Juglans nigra* L.) monocultures in Slovakia. *Journal of Forest Science*, 51:213–224.
- Ulbrichová, I., Kupka, I., Podrázský, V., Kubeček, J., Fulín, M., 2014: Douglaska jako meliorační a zpevňující dřevina. *Zprávy lesnického výzkumu*, 59:72–78. (In Czech).
- Ulusán, M. D., 2022: Responses of the germination and phytochemical content of *Pinus nigra* Arn. subsp. *pallasiana* [Lamb.] Holmboe. (Anatolian black pine) seeds to salt stress. *Journal of Forest Science*, 68:365–375.
- Úradníček, L., Maděra, P., Tichá, S., 2012: Introdukce dřevin. *Lesnická práce*, 91:481–483. (In Czech).
- Vacek, Z., Cukor, J., Vacek S., Podrázský, V., Linda, R., Kovařík, J., 2018: Forest biodiversity and production potential of post-mining landscape: opting for afforestation and leaving it to spontaneous development? *Central European Forestry Journal*, 64:116–126.
- Vacek, Z., Vacek, S., Prokůpková, A., Bulušek, D., Podrázský, V., Hůnová, I. et al. 2020: Long-term effect of climate and air pollution on health status and growth of *Picea abies* [L.] Karst. peaty forests in the Black Triangle region. *Dendrobiology*, 83:1–19.
- Vacek, Z., Prokůpková, A., Vacek, S., Bulušek, D., Šimůnek, V., Hájek, V. et al., 2021a: Mixed vs. monospecific mountain forests in response to climate change: structural and growth perspectives of Norway spruce and European beech. *Forest Ecology and Management*, 488:119019.
- Vacek, Z., Cukor, J., Vacek, S., Linda, R., Prokůpková, A., Podrázský, V. et al. 2021b: Production potential, biodiversity and soil properties of forest reclamations: Opportunities or risk of introduced coniferous tree species under climate change? *European Journal of Forest Research*, 140:1243–1266.
- Vacek, S., Vacek, Z., Cukor, J., Podrázský, V., Gallo, J., 2022: *Pinus contorta* Douglas ex Loudon and climate change: A literature review of opportunities, challenges, and risks in European forests. *Journal of Forest Science*, 68:329–343.
- Vacek, Z., Vacek, S., Cukor, J., 2023: European forests under global climate change: Review of tree growth processes, crises and management strategies. *Journal of Environmental Management*, 332:117353.
- Viewegh, J., Podrázský, V., Matějka, K., 2014: Charakterystyka roslinnosci runa kształtującej się pod drzewostanami daglezjowymi (*Pseudotsuga menziesii* [Mirbel] Franco) w lasach gospodarczych Republiki Czeskiej. *Sylwan*, 158:277–284. (In Polish).
- Vilá, M., Basnou, C., Gollasch, S., Josefsson, M., Pergl, J., Scalera, R., 2009: One Hundred of the Most Invasive Alien Species in Europe. In: *DAISIE: Handbook of Alien Species in Europe*. Dordrecht, Springer, p. 265–268.
- Vítková, M., Tonika, J., Müllerová, J., 2015: Black locust – Successful invader of a wide range of soil conditions. *Science of the Total Environment*, 505:315–328.
- Vítková, M., Pergl, J., Sádlo, J., 2016: Black locust: from global ecology to local management – a case study from the Czech Republic. In: Krumm, F., Vítková, L., (eds): *Introduced tree species in European forests: opportunities and challenges*. European Forest Institute, p. 306–318.
- Vítková, M., Müllerová, J., Sádlo, J., Pergl, J., Pyšek, P., 2017: Black locust (*Robinia pseudoacacia*) beloved and despised: A story of an invasive tree in Central Europe. *Forest Ecology and Management*, 384:287–302.
- Willis, R. J., 2000: *Juglans* spp. Juglone and allelopathy. *Allelopathy Journal*, 7:1–55.
- Wohlgemuth, T., Gossner, M. M., Campagnaro, T., Marchante, H., van Loo, M., Vacchiano, G. et al., 2022: Impact of non-native tree species in Europe on soil properties and biodiversity: a review. *NeoBiota*, 78:45–69.
- Zeidler, A., Gryc, V., Vavřík, H., 2010: Kaštanovník jedlý. *Lesnická práce*, 89:463. (In Czech).

- Zeidler, A., Salem, M. Z. M., Borůvka, V., 2015: Mechanical properties of grand fir wood grown in the Czech Republic in vertical and horizontal positions. *BioResources*, 10:793–808.
- Zeidler, A., Borůvka, V., 2016: Wood density of Northern red oak and pedunculate oak grown in former brown coal mine in the Czech Republic. *BioResources*, 11:9373–9385.
- Zeidler, A., Borůvka, V., 2018: Charakteristika dřeva vybraných druhů introdukovaných dřevin. In: Vacek, Z., Podrázský, V. (eds.): *Introdukované dřeviny jako součást českého lesnictví*. Kostelec nad Černými lesy, Česká lesnická společnost, p. 49–55. (In Czech).
- Zeidler, A., Borůvka, V., Černý, J., Baláš, M., 2022a: Douglas-fir outperforms most commercial European softwoods. *Industrial Crops and Products*, 181:114828.
- Zeidler, A., Borůvka, V., Remeš, J., Pulkrab, K., 2022b: Heat-Treated Wood from Grand Fir Provides the Same Quality Compared to Silver Fir. *Forests*, 13:1542.