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Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and its role in the Czech forests

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Abstract: The presented study summarizes the results concerning the effects of cultivation of Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) in the Czech Republic. It focuses on more recent results, published especially in the last decades, it includes also older relevant data. It describes the intensity of production as well as non-production forest functions in the conditions of the Czech Republic. It analyses the research results concerning the volume and value production in comparison with native tree species, also documents effects on soil and herb vegetation diversity in forest ecosystems, and from point of view of stability and cultivation in the last period. Main target is defined by the comparison with the Norway spruce, which can be with advantages substituted partly by this species, with favourable impact on amount and value of the timber production, on the forest soil and ground vegetation biodiversity status. Also the stability of forest stands can be supported considerably. This species represents important alternative to the Norway spruce in lower and middle altitudes and it can contribute considerably to the competitiveness of the Czech forestry.

Keywords: literature review; introduction; production; environment

In the territory of former Czechoslovakia, Douglas-fir has attracted attention, especially of private forest owners. On the other hand, the state administration and environmental organizations show an attitude of restraint and rejection of non-native tree species in recent decades (Ťavoda, Lengyelová 1996; Ťavoda 2007; Podrázský et al. 2009a, 2013b). At present, new plantation's area of Douglas-fir has been decreasing annually; on the other hand, the stands got older together with the increasing growing stock (Kouba, Zahradník 2011; Podrázský et al. 2013c). The stand area of Douglas-fir has totalled approximately 5,800 ha in the Czech Republic (Podrázský et al. 2013a, c; Vašíček 2014), and 1,200 ha in Slovakia (Kubeček et al. 2014), and, in some measure, Douglas-fir is still being planted every year. Private forest owners have shown eminent interest in Douglas-fir, especially in relation to current issues of Norway spruce decline.

In both the Czech and Slovak Republics, Douglas-fir has long been considered one of the most promising tree species (Hofman 1964; Ťavoda 2007; Petráš, Mecko 2008; Podrázský et al. 2009a). In the second half of the 20th century, several provenance experiments were established to study variability of the species. The experiments proved the importance of the place of origin and a substantial

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endogenous variability of Douglas-fir. The studies confirmed that particular original regions produce seed with the highest probability of successful planting (Hofman 1964; Šika, Heger 1972; Šika 1975, 1985; Šika, Páv 1990; Beran 1993, 1995; Ťavoda, Krajňáková 1993; Ťavoda, Lengyelová 1996; Cafourek 2006; Kšír et al. 2015). These native ranges are located especially in the northern parts of the U.S. Pacific Coast and south part of neighbouring Canadian province British Columbia, and can be used as propagation material resource also in the future (Martiník, Palátová 2012).

Approximately since the beginning of the 2000s, the interest in Douglas-fir has been on the increase again, especially for its valuable timber and capability for stabilization of forest stands. Foresters are more concerned about forest economics and about issues of vitality and stability of Norway spruce stands, particularly at lower altitudes (Podrázský et al. 2013d). Norway spruce silviculture is thought to pose a threat to both stability of forest stands and biodiversity of forests in large parts of Europe (Augusto et al. 2003; Máliš et al. 2010). It has been proved, that Norway spruce's influence increases with the time it has been growing on a non-original site, i.e. since the stand composition has been converted (Hadač, Sofron 1980). This was documented in many studies in the territory of the Czech and Slovak Republics (Ambros 1990; Poleno 2001; Šomšák, Balkovič 2002; Šomšák 2003), following – to some extent – differences between natural beech and Norway spruce stands (Vacek, Matějka 2010). Natural tree species composition disrupted by Norway spruce is also considered to have caused vast acidification of forest soils (Oulehle, Hruška 2005). However, another native tree silver fir has been also documented as a species with lower soil improving potential (Třeštík, Podrázský 2017). In the Czech sources, the newest information on Douglas-fir are summarized in comprehensive publications by Kubeček et al. (2014), Slodičák et al. (2014) and Novák et al. (2018).

Aim of the presented study is the consideration of the potential of Douglas-fir, as the production supporting tree species on one side as well as the newly introduced environmental factor in the Czech forests. At present, the production potential is possible to evaluate basing on more sources, there is also possible to summarize the presently available data on the soil and ground vegetation effects of this species.

Douglas-fir production

It is Douglas-fir production that has always attracted the most attention. Both the quality and production efficiency of Douglas-fir were confirmed in many studies (Hofman 1964; Beran, Šindelář 1996; Pagan 1999; Šindelář 2003), analysing Douglas-fir performance in forest stand mixtures. For example, Kantor et al. (2001a, b) found the superior production of Douglas-fir in mixtures of 6 other tree species such as pine, larch, oak, beech, hornbeam and linden in middle-aged (68 years) forest stands. At the given age, the timber volume of individual trees amounted to 2.9 m^3, at 100 years, the volume can increase up to 6 m^3. Douglas-fir is recommended to share 10–30% in the stands of other tree species.

During a growth analysis of 29 adult mixed stands aged 85–136 years on nutrient-rich sites. Kantor (2008) studied parameters of 10 largest Norway-spruce and Douglas-fir individuals in Douglas-fir dominated stands. The volume of Douglas-fir trees exceeded almost three times the values of accompanying species as the mean volume of 10 largest Douglas-fir trees was 9.12 m^3, compared to 3.17 m^3 of spruce and 3.70 m^3 of larch. An analysis of annual rings allowed researchers to assess an annual volume increment of one trunk ranging 0.12–0.16 m^3, which might amount to 1.5 m^3 in an individual within a 10-year period (Kantor 2008).

The same approach to the production role of Douglas-fir was also studied on acidic sites (Kantor, Mareš 2009). Seventeen mixed forest stands with a high share of Douglas-fir aged 88 to 121 years were analysed. A comparison of 10 largest trees of Douglas-fir, Norway spruce, Scots pine and European larch in the stand confirmed the highest production potential of Douglas-fir. For example, one of the surveyed stands showed the mean volume of 10 largest trees was 6.30 m^3 for Douglas-firs, 1.93 m^3 for Norway spruce and 2.25 m^3 for European larch. A volume increment of Douglas-fir individuals based on annual-ring analyses ranged 0.06 to 0.10 $m^3 \cdot yr^{-1}$.

Martiník and Kantor (2007, 2009) analysed above-ground biomass of Douglas-fir in two stands aged 69 and 75 on nutrient-rich sites [*Querceto-Fagetum mesotrophicum* – Viewegh (2005)], focusing on its volume and nutrient contents. They supplied evidence of the crucial role of the tree position in the stand structure for growth parameters, assimilatory apparatus formation and nutri-

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ents binding by above-ground elements of biomass. They pointed out a substantial risk of Douglas-fir capability for acquiring a high amount of nutrients from the soil, which – in the case of whole-tree extraction – might lead to the site nutrient deficiencies. They recommend to mix Douglas-fir with autochthonous tree species and to leave as much non-utilizable biomass as possible on the site (Martiník, Kantor 2007, 2009).

Tauchman et al. (2010) found 47-year-old Douglas-fir stock per ha at the mesic site was 18% higher than 16 years older Norway spruce, and 136% higher in comparison with mixed broad-leaved forest stand of the same age as spruce.

The oldest from the surveyed stands is characterized by an altitude of 410 m a.s.l., average annual precipitation of 650 mm and average annual temperature of 8°C. The stock was calculated at the age of 97 years. In accordance with the representation of Norway spruce and Douglas-fir, the stock of stands on permanent research areas varied between 830 and 1,030 $m^3 \cdot ha^{-1}$, while Douglas-fir represented 14–30% of the number of individuals, 32.4–42.4% of the stand basal area and 36.6–58.3% of the stock. After chemical preparation, the number of individuals was 16–31 thousand of individuals per hectare; in the closed stand with significant admixture of Norway spruce, however, the regeneration quickly disappears (Remeš et al. 2006, 2010).

Another locality represents the change from the natural-tree-species stand (oak, hornbeam, linden) at the age of 69 years to Norway spruce monocultures (61 years) and Douglas-fir (45 years) at a site characterized by the *Querceto-Fagetum acidophilum* (Viewegh 2005) group of forest habitat types (420 m a.s.l., 8.5°C, 550–650 mm, albic luvisols). The stock in this case was 266 $m^3 \cdot ha^{-1}$ for broad-leaved, 507 $m^3 \cdot ha^{-1}$ for Norway spruce and 579 $m^3 \cdot ha^{-1}$ for the youngest Douglas-fir. An average annual increment was 4.43 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for broad-leaved, 8.45 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for Norway spruce and 12.87 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for the last tree species (Podrázský et al. 2009a; Podrázský, Remeš 2010).

The latest published study documents the production (and soil-forming) function of mixed stands on afforested agricultural land. The research compared the stock of Norway spruce, Scots pine, European white birch and Douglas-fir at the age of 39 on a site characterized by an altitude of 430 m a.s.l., average annual temperature of 7.5°C, annual precipitation of 600 mm, from gleyed albic luvisols to stagnosols. Under these conditions, the values of mean stems in Scots pine were 20.6 m in height and 19.5 cm DBH, 20.1 m and 19.5 cm in Norway spruce, 24 m and 21.4 cm in European white birch and 21.6 m and 23.8 cm in Douglas-fir, which, considering 1,408, 1,157, 440 and 928 stems per hectare, was 352.1, 349.4, 157.1 and 438.6 $m^3 \cdot ha^{-1}$ in Douglas-fir, making it clearly the most productive tree species (Podrázský et al. 2009a, b, 2010).

Afforestation of agricultural land must always respect suitability of habitat for particular tree species, as demonstrated, for example by Bartoš and Kacálek (2011). Depending on the humidity and general soil conditions, the European larch can outgrow Douglas-fir on some plots. Their results also showed that Douglas-fir is at least equivalent to Norway spruce in growth shortly after plantation in various localities of submontane areas of the Orlické Mountains. For the time being, research of Douglas-fir value production has been rather scarce. In the Czech Republic, only one substantial study was published so far (Podrázský et al. 2013a). The authors evaluated volume and value production based on data provided by forest management plans of the Training Forest District Hůrky of the Bedřich Schwarzenberg's Forestry College and Secondary Forestry School in Písek. All forest-stand groups with Douglas-fir share exceeding 20% and older than 30 years were analysed. For the purposes of this comparison, stands were selected on a site characterized by the 3K forest habitat group (acidic *Querceto–Fagetum*). In total, 372 stand groups were surveyed: 92 groups containing Douglas-fir, aged 30–124 years, European beech (130 groups, 30–160 years), oak (various subspecies, 164 groups, 34–160 years) and European larch (120 groups, 32–160 years). The standing volume in $m^3 \cdot ha^{-1}$ by particular tree species and age was taken from forest management plans (valid for 2010–2019). The standing volume of analysed tree species was adjusted to full stand density and one hectare. To study the course of production parameters, Korf function was used (Korf 1939). At the time of culmination, the common value increment was 26,622 $CZK \cdot ha^{-1} \cdot yr^{-1}$ in Douglas-fir, 19,926 $CZK \cdot ha^{-1} \cdot yr^{-1}$ in oak, 19,494 $CZK \cdot ha^{-1} \cdot yr^{-1}$ in Norway spruce, 14,427 $CZK \cdot ha^{-1} \cdot yr^{-1}$ in European larch and 9,360 $CZK.ha^{-1}.year^{-1}$ in European beech. An average value increment for particular tree species was calculated as follows: 13,098 $CZK \cdot ha^{-1} \cdot yr^{-1}$ (Douglas-fir), 10,698 $CZK \cdot ha^{-1} \cdot yr^{-1}$ (Norway spruce),

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7,831 CZK·ha^{-1}·yr^{-1} (European larch), 7,751 CZK·ha^{-1} per year (oak) and 5,293 CZK·ha^{-1}·yr^{-1} (European beech). Although the production of Douglas-fir was undervalued due to a lack of real data (for example, Norway spruce assortment prices were used to calculate the prices of the assortments of Douglas-fir), not only the volume production but also the value production of Douglas-fir were significantly higher compared to other studied tree species. Significant potential value production was documented even in the case of stands that reached harvest maturity (Remeš et al. 2010), Norway spruce reached about 70% of value production of Douglas-fir.

Also in middle-aged stands, value production of Douglas-fir was considerably higher than that of compared tree species. In the above-mentioned stand (Podrázský et al. 2009a; Podrázský, Remeš 2010), Remeš et al. (2010) documented an average annual increment in relative values of 100% in Douglas-fir, 66% in Norway spruce and 34% in mixed broadleaves.

Studies comparing the production of Douglas-fir with the main native tree species demonstrate a significant increase in the production function of forest stands when Douglas-fir is introduced into the stand composition. This is a significant increase not only in volume but also in value production, even when compared to Norway spruce as the most important domestic tree species. Schelhaas (2008) states, that the use of the mixture of Douglas-fir and European beech changed the competitive pressure on Douglas-fir, and hence the relation of height to diameter (slenderness quotient) and the risk of wind damage. The results of this study suggest that the current close-to-nature management trend could lead not only to the reduction of wind calamities but also to an increase in total production.

When evaluating the production function of Douglas-fir, we should keep in mind that the differences between particular species can vary quite considerably if we evaluate individual trees, e.g. the largest ones, and entire stands (Koudela 2013).

The significance of a suitable mixture for optimal silviculture of Douglas-fir is documented in Petráš and Mecko (2008). Based on evaluation of yield table models for pure stands of particular tree species with comparable site indicators, they supplied evidence of 26–35% lower production of Douglas-fir (both volume and value) in comparison with Norway spruce and silver fir, and as much as 22% lower production in comparison with European beech. The reason of the poor results lies in the lower density of Douglas-fir stands compared with other tree species, and lower standing volume on the site with the same site index.

However, the above-mentioned analysis clearly shows a significantly higher production potential (volume and value) of Douglas-fir when compared with trees of the same age, growing on the same site. That can still be accentuated by growing a suitable mixture. It is therefore documented that, in terms of both volume and value production, Douglas-fir silviculture brings considerable benefits.

Douglas-fir effect on soil

Even the earliest studies, demonstrating the influence of the Douglas-fir on the soil environment, showed higher demands on soil nutrients and, on the other hand, a more favourable decomposition and transformation of Douglas-fir litter fall into humus, especially compared to Norway spruce (Podrázský et al. 2001a, b, 2002). In the habitats of the beech with oaks forest sites *Querceto-Fagetum acidophilum* to *Querceto-Fagetum oligo-mesotrophicum* (Viewegh 2005), it has been shown that, compared to the natural species composition (oak, hornbeam, linden), there is a significant accumulation of humus with higher soil acidity characteristics under Douglas-fir; on the other hand, soil properties are considerably more favourable compared to spruce stands on the same site. Douglas-fir has thus shown less adverse impact on the state of forest soils, namely humus forms, compared to Norway spruce.

Martiník (2003) studied mixed stand at the age of 73 years at nutrient-rich habitats [(*Querceto-Fagetum mesotrophicum* – Viewegh (2005)] with similar results. Pedochemical properties and mineral nutrition were studied, in relation to the share of Douglas-fir in the stand mixture. The results showed a deterioration of soil properties with an increasing share of Douglas-fir in the tree species composition such as low base cations (Ca, Mg) in the A horizon. It is an evidence of nutrient-binding in the intensely growing biomass. Foliar content of nutrients was approaching the optimum according to European standards. Accordingly, the author recommends to admix only individuals or groups of Douglas-fir in the stand.

Menšík et al. (2009) compared the soil conditions in mixed Norway spruce and European beech, in Norway spruce and Douglas-fir on acidic [(*Querceto-Fagetum acidophilum* – Viewegh (2005)] and

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nutrient-medium (*Fagetum illimerosum mesotrophicum*) sites. Douglas-fir stands accumulated 25.0 $t \cdot ha^{-1}$ of surface humus compared to 79.4 $t \cdot ha^{-1}$ in spruce stands. In Douglas-fir stands, the soil reaction values were higher in both holorganic and organomineral horizons, and the C/N values were also favourably influenced (i.e. lowered) by Douglas-fir compared to other tree species on the same sites.

In the above-mentioned stand (Podrázský et al. 2010), the beneficial effects of Douglas-fir in comparison with Norway spruce were also documented (Podrázský, Remeš 2008). Pedochemical characteristics were significantly more favourable in the profile of humus forms: soil reactions, characteristics of soil sorption complex, dynamics of soil organic matter and nitrogen. The influence of Douglas-fir was more similar to the effects of grand fir, and was less favourable compared to broad-leaved stands, but significantly more favourable compared to Norway spruce. But it seems that effects of grand fir are more favourable comparing to Douglas-fir, which was documented also at other sites (Podrázský et al. 2016a).

The same issues associated with Douglas-fir silviculture in mixtures are also addressed by Cremer and Prietzel (2017) who argue that, compared to pure coniferous stands, mixed stands could maintain fertility, reduce soil acidification, nutrient leaching, and at the same time reduce the depletion of soil base cations.

A pronounced effect of the Douglas-fir on the state of humus forms in terms of soil chemistry was also documented on the afforested agricultural land (Podrázský et al. 2009a, b, 2010). Humus forms in the 39-year-old stands of Douglas-fir, Norway spruce, Scots pine, and European white birch on former agricultural land were compared also with the corresponding soil component of the neighbouring mature forest ecosystem (pine, spruce) on the permanent forest land as well as on a neighbouring oil rape field. In the topsoil humus, the most favourable indicators of soil chemistry (pH, S – bases content, H – hydrolytical acidity, T – cation exchange capacity, V – base saturation) were proved in the Douglas-fir stand (in the birch stands, humus had not developed yet). A fast growing Douglas-fir stand manifested a decrease in the soil content of available phosphorus. In all stands on afforested agricultural land, the situation was significantly more favourable compared to the older coniferous stand; the European white birch stand differed the least from the soil environment of the neighbouring field. The effect of Douglas-fir can be evaluated as less acidifying in comparison with other coniferous species.

Podrázský and Kupka (2011) evaluated the pedophysical characteristics of horizon A in the same stands. The results documented some changes in the state of hydrophysical characteristics of forest soils, depending on the tree species structure, felling or afforestation of agricultural land. According to preliminary results, afforestation of agricultural land leads to a significant decrease in the soil's bulk as well as volume density, specific weight of soil and, on the contrary, to a significant increase in porosity and aeration, probably due to the activity of root systems, edaphone and mixing of organic and mineral soils. Felling activities have quite the opposite impact. Of the forest tree species studied, Douglas-fir's impact was relatively the lowest, given its intense growth associated with water and nutrient demands and the rate of decomposition of its fall. Forestry measures on the other hand do not seem to pose any significant threat to the retention properties of forest soils; on the contrary, afforestation leads to better retention and water management conditions in the landscape. Douglas-fir silviculture in suitable admixtures will not significantly affect the water regime of forest soils if we do not consider its higher demands on water in terms of transpiration.

Foreign sources, e.g. Augusto et al. (2003), confirmed that on a larger landscape scale, the soil and ground vegetation conditions are more affected by geographical and geological conditions and by forestry measures rather than by the actual tree species structure of forest stands (pine, Douglas-fir, fir, beech, oak); only Norway spruce influences the site more profoundly. However, studies focusing on particular localities and highlighting the influence of individual tree species have clearly confirmed – in our conditions – such effect of Douglas-fir on soil properties that entitles us to evaluate it very favourably in comparison with the dominantly regenerated conifers, namely Norway spruce. When grown in mixed stands, it is possible to assume the potential of maintaining rather favourable soil properties, taking into account the conditions of individual localities.

Other aspects of Douglas-fir cultivation

The data on the influence of Douglas-fir on other components of the environment and the biodiversity of forest ecosystems are still rather scarce in

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the Czech Republic. For example, Podrázský et al. (2011) studied the composition of ground vegetation in stands with various species composition, including Douglas-fir, on a set of 44 plots in different habitats of the Czech Republic. In the stands of this tree species, an insignificant but noticeable increase in the number of species was proved, compared to other species, especially Norway spruce, and at the same time shift of phytocoenoses towards nutrient-richer habitat indicators, especially with respect to nitrogen, which corresponded to the results documented abroad (Augusto et al. 2003). Other published research results, on a substantially larger set of plots (over 100), show similar findings (Podrázský et al. 2014; Viewegh et al. 2014; Matějka et al. 2015).

The survey results in all studies demonstrate the influence of Douglas-fir, which is much less pronounced and deviating phytocoenoses from their natural state than that of Norway spruce. From the point of view of the influence on biodiversity of ground vegetation, Douglas-fir is far more environmentally friendly.

An important function of the studied species is its support of static stability of forest stands. Mauer and Palátová (2012) studied the development of root systems at nutrient-rich sites at the age of 10, 20, 30, 60 and 80 years. Development of a compact root system ensuring considerable stability of individuals was confirmed since the young age. Mauer and Vaněk (2014) analysed the architecture and health status of the root system of Douglas-fir and suggested that Douglas-fir may draw water from the deep soil horizons, therefore will not compete with neighbouring trees. They recommend the use of Douglas-fir as soil-improving from the 2nd (oak with beech) to 7th (spruce with beech) altitudinal vegetation zones. They also show that there are no differences between the root systems of Douglas-fir of natural and artificial regeneration origins. Douglas-fir can thus be a significant stabilizing element of forest stands, as confirmed also by foreign sources (Sergent et al. 2010). More extensive introduction of Douglas-fir might pose a risk of increased nitrification and potential nitrogen loss, especially in pure stands (Zeller et al. 2010), which corresponds to the natural dynamics of Douglas-fir stands and their phytocoenoses, with frequent disturbances and with a pronounced representation of alders on natural sites with frequent incidents of fire (Binkley 1986).

The potential of Douglas-fir in terms of natural regeneration is also significant. On acidic sites, Douglas-fir is documented to regenerate massively, which can easily be used for stand regeneration (Bušina 2007; Kantor et al. 2010); on nutrient-richer sites, forest weeds competition might be an issue (Hart et al. 2010). Douglas-fir is able to regenerate even on open rocks with shallow soil and on the edges of forest paths (Knoerzer 1999). Furthermore, Kramer et al. (2006) generally concludes that the effects of forest management on regeneration of Douglas-fir are much greater than the damage caused by deer on the regeneration. Moreover, regardless of the numbers of deer, the effects of game damage are approximately the same.

In all, it is possible to incorporate Douglas-fir in the shelterwood system and natural regeneration without major difficulties. Even in the European context, flexibility of Douglas-fir is sometimes referred to as a feature of invasiveness, and we often witness efforts to include Douglas-fir into invasive non-autochthonous species. However, it should be emphasized that this feature of Douglas-fir is not much of an issue in most habitats. Douglas-fir might pose a problem in forests with minimum silviculture care, e.g. in protected areas. Douglas-fir is unacceptable there and must be eliminated by foresters. In commercial forests, however, Douglas-fir is not a problem, it needs to be repeatedly emphasized.

Martiník and Palátová (2012) studied and verified suitability of various methods of pre-sowing preparation of Douglas-fir seeds. They compared 7 provenances of the green variant (of which one seed lot of unknown origin is from the Czech Republic) and 7 provenances of the grey variant. They demonstrated the suitability of the various pre-sowing preparation methods and their suitability and necessity for the proper use of seed resources. Differences between provenances have also been proven, which must be respected in the further introduction from the original areas of the Douglas-fir.

In the future, it will be necessary to re-evaluate the acquisition of reproductive material of Douglas-fir. The seed can be imported from the area of the original range, or from European areas with intensive Douglas-fir silviculture. To verify the first mentioned option we need to evaluate our existing provenance areas, mostly under the management of Forestry and Game Management Research In-

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stitute. The results of both older (Hofman 1964; Šika 1975) and recent studies (Kšír et al. 2015) prove the Pacific coast, Vancouver region and British Columbia territory as the most suitable, esp. lower altitudes with moderate climate. Import from this area is certainly possible under the approved principles.

The import of material from Western Europe is more problematic, as we risk to bring along diseases and pests, especially the so-called needle cast. These are a major problem in this area, and there is no need to threaten domestic populations of this tree species. The state of health and vitality of young stands in recent years have been aggravated by an increased incidence of Scottish (*Rhabdocline pseudotsugae* Sydow) and Swiss (*Pheaocryptopus gaeumannii* (T. Rohde) Petrak) needle cast, mainly in mixtures with Norway spruce (Půbalová, Holkup 2015). Jankovský et al. (2014) warned that before any use of planting material, testing for sensitivity to Swiss needle cast must be carried out. It is definitely worth considering to use the domestic population, growing for a century in our conditions as it has already undergone some pressure of our environment and show exceptionally good condition and growth. Although the quality of the directly obtained material is sometimes disputed, it is sufficient for successful natural regeneration, and it would be worth the efforts to develop programs to obtain reproductive material of both generative and vegetative origin.

The silviculture of Douglas-fir will not demand more additional skills. The regeneration can be natural at proper sites, otherwise the planting of the reproductive material of proper origin can be used. Douglas-fir can be regenerated both as the main crop species, but also as site improving and stabilizing tree. In both case, it is more recommendable to introduce Douglas-fir as group admixture (10 to 40%), at higher age as individual admixture too. This species should always dominate the stand to use maximum of its production potential. The silvicultural aspects are summarized in the complex monographies and available for Czech practice foresters (Slodičák et al. 2014; Novák et al. 2018).

CONCLUSIONS

An analysis of studies of mainly the Czech origin proves that the attention paid to Douglas-fir is fully justified; as in other European (and other) countries, it appears to be a tree species with a great potential for forestry use. Particularly significant is its comparison with Norway spruce, which is on the decline in the Czech forestry at present, whether for its effects on the environment of the forest ecosystem or in terms of the state of health. Share of the Norway spruce in the Czech forests and especially in the volume felled is expected to show a decreasing trend in the coming decades (Podrázský et al. 2013b, 2016b). Douglas-fir is then considered to be its possible and more than adequate substitute for a number of reasons:

(*i*) The production potential of Douglas-fir at lower and middle altitudes is significantly higher than other domestic trees, including Norway spruce;

(*ii*) Its effect on soil condition is less pronounced, the acidification effect significantly lower and in coniferous stands, Douglas-fir has the character of soil improving tree species;

(*iii*) Its effect on the biodiversity of ground vegetation is less pronounced, it is comparable or higher in Douglas-fir stands, compared to natural phytocoenoses, and there is a less pronounced shift in their habitat-indicative character;

(*iv*) Douglas-fir has a considerable stabilizing effect in forest stands;

(*v*) Its silviculture requirements will not be diametrically different from those of spruce or other conifers, including nurseries and natural regeneration;

(*vi*) The role Douglas-fit as a substitute for Norway spruce can be even more important as one of forestry reactions to climate change, Douglas-fir seems to be more resistant to coming conditions.

The majority of the potentially negative consequences of its introduction, especially the high nutrient demand, can be largely eliminated by its dominant cultivation in mixtures with other tree species. The optimal admixture ranges from 20 to 40% of individuals in the stand, preferably high-quality ones, evenly spread over the area.

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