Production of Douglas-Fir in the Czech Republic based on national forest inventory data

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ABSTRACT: This article summarizes basic estimates of productivity and trend analysis of one of the principal introduced forest tree species in the Czech Republic, i.e. Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco). As a comparison, we also examine grand fir (*Abies grandis* [D. Don] Lindl), northern red oak (*Quercus rubra* L. syn. *Quercus borealis* Michx.) and black locust (*Robinia pseudoacacia* L). This paper presents estimates of forest land area, standing volume, annual and total increments, distribution of age classes, average ages and site indexes for the period 1979–2010. All data were obtained from the national forest inventory of the Czech Republic. Korf's growth function was used for the assessment of current and mean annual increments (CAI, MAI) of Douglas-fir compared to other tree species. Our results suggest a decline in the annual area afforested by Douglas-fir, as influenced by the State administration management choices, a low rate of an increase in the forest land area, increasing average age of the forests. On the other hand, we observed a dramatic increase in the standing volume as well as high annual increments in volume. Douglas-fir is the most productive major tree species in the Czech Republic and there is a great potential to expand its use throughout the country.

Keywords: Douglas-fir; introduced species; time series; age structure; production

Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) represents one of the most successful introductions in European forestry history, with major economic benefit and commercial potential. The species is native to broad swaths of western North America and is used in plantations in many countries throughout the world, including France, Germany, Great Britain, Ireland, Argentina, Chile, New Zealand, and Iran. It thrives in many different site conditions and forms stable and productive forest stands and plantations (Larson 2010). Douglas-fir has become the most important species used in plantations in the second half of the 20th century; it now covers more than 400,000 ha and approximately 5 million seedlings are planted in France only each year (Ferron, Douglas 2010).

In contrast with the large forest land area of Douglas-fir in other European countries, the Czech Republic has Douglas-fir stands only on 5,600 ha, although it has the potential to thrive on a considerably larger area (Beran, Šindelář 1996; Podrázský, Remeš 2010; Remeš et al. 2010). Despite the small established area, this species has frequently been evaluated in Czech conditions (Kantor et al. 2001a, b; Martiník 2003; Martiník, Kantor 2007; Kantor 2008; Kantor, Mareš 2009; Podrázský et al. 2009; Remeš et al. 2010).

The presence of Douglas-fir in Czech forest stands frequently results in more favourable effects on the soil structure and composition than that of other native conifer species that are established out of their natural range in both Czech and other Eu-

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ropean conditions (Podrázský et al. 2002, 2009; Augusto et al. 2003; Sverdrup et al. 2006; Podrázský, Remeš 2008; Menšík et al. 2009). No evidence has been found that the establishment of Douglas-fir results in soil degradation. In fact, the species was found to be more resistant to drought (Eilmann, Rigling 2010; Urban et al. 2010). Douglas-fir displayed has a lower impact on the ground flora biodiversity compared to planted native conifers (Podrázský et al. 2011). In the past, trees were planted in Czech forests without regard to site requirements. For example Norway spruce was planted on locations not corresponding to its site and environmental demands, especially at lower altitudes. Such sites represent potential opportunities to replace Norway spruce with Douglas-fir. Before considering the establishment of Douglas-fir on such locations, managers should take into account three factors: potential for coexistence with native forest tree species, neutral or positive effects on forest floor biodiversity and minimization of environmental risks.

In order to better evaluate the potential of individual stand growth as well as production and environmental effects, we summarized the data from the Czech national forest inventory for Douglas-fir and other significant introduced species. This summary will help the reader understand the trends of Douglas-fir and provide a basis for our optimism about the potential for Douglas-fir in Czech forestry.

MATERIAL AND METHODS

Three sources of national-level data were used: the National Forest Inventory (2007-NIL), summarized Forest Management Plans (FMP), and Information on the State Forestry Sector (IFS); all data were obtained from and summarized by the Forest Management Institute (ÚHÚL www.uhul.cz). These data are called "Forestry Statistics" (FS) in most European countries, so we will adopt this term in our article. In previous decades, the Summarized Forest Management Plans were available for all forests in the Czech Republic, because of ownership and legislation changes they have to be calculated from existing ones on a part of the territory today.

Data availability at the level of introduced tree species varies by category. The total area of Douglas-fir is available (determined) beginning in 1979, and the area by age classes beginning in 1980. Standing volume data have been summarized regularly since 1998. The data from summarized Forest Management Plans and National Forest Inventory (2007) are not fully compatible methodologically, so they are documented separately. The third source of data is the Statistical Yearbooks of the Czech Statistical Office, the first data appeared in 2011 for the previous year.

The data input was represented by:

– total area of Douglas-fir, as well as compared tree species in individual age classes,
– total volume of Douglas-fir in individual age classes.

Subsequently, the standing volumes per ha in age classes were computed as a ratio of those two variables.

A relationship between the standing volume V_t ($m^3 \cdot ha^{-1}$) and age t was modelled using Korf's growth function (Korf 1939), adapted by Kouba (2005) and Kouba, Zahradník (2009). This function is recognized as one of the three most widely used and best three-parameter functions worldwide (Zeide 1993):

$$V_t = A \times \exp \frac{k}{(1-n) \times t^{1-n}} = A \times \exp \frac{k}{(1-n)} \times t^{1-n} = = A \exp\phi(t) \qquad (1)$$

$$\phi(t) = \frac{k}{(1-n) \times t^{1-n}} \qquad (2)$$

where:

A, k, n – parameters and $A, k > 0$, $n > 1$.

Current annual increment is represented by the first derivative of the function:

$$V_t' = A \times \exp \frac{k}{(1-n)} \times t^{1-n} \times \frac{k}{t^n} \qquad (3)$$

Age of the current annual increment culmination is calculated as follows:

$$t_1 = \sqrt[n-1]{\frac{k}{n}} \qquad (4)$$

Mean annual increment:

$$\frac{V_t}{t} = \frac{A \exp\phi(t)}{t} \qquad (5)$$

Age of the mean annual increment culmination:

$$t_2 = \sqrt[n-1]{k} \qquad (6)$$

The data were fit by the least squares method, using the Levenberg-Marquardt algorithm (Lev-

Table 1. Parameters of Korf's (1939) growth functions (see Eq. 1)

Species	Year	A	k	n	R^2	t_1	t_2	CAI(t_1)	MAI(t_2)	V_{60}	V_{100}
								($m^3 \cdot ha^{-1} \cdot yr^{-1}$)		($m^3 \cdot ha^{-1}$)	
Douglas-fir	2000	770.39	88.395	2.1598	0.987	24.54	47.67	10.53	6.82	398.05	534.73
	2010	859.38	42.631	1.9998	0.994	21.33	42.66	10.90	7.41	422.05	560.89
Grand fir	2000	742.25	235.542	2.3877	0.979	27.35	51.21	11.60	7.05	416.24	558.35
	2010	814.52	76.032	2.1412	0.996	22.83	44.50	11.70	7.62	436.86	575.26
Northern red oak	2000	429.83	116.380	2.2439	0.985	23.91	45.79	6.64	4.20	242.00	317.06
	2010	494.25	58.590	2.0760	0.996	22.29	43.95	6.68	4.44	254.21	336.74
Pedunculate and sessile oaks	1970	352.73	497.042	2.4432	0.996	39.77	73.85	3.99	2.39	138.47	225.50
	2000	343.87	154.140	2.3053	0.995	25.02	47.44	5.42	3.37	195.68	257.45
	2010	331.77	274.452	2.4640	0.995	25.01	46.30	6.07	3.62	207.90	265.92
Black locust	2000	151.46	47,264.286	3.9208	0.980	24.96	39.85	6.21	2.70	136.55	147.97
	2010	157.30	12,901.321	3.5731	0.978	24.13	39.59	5.81	2.69	137.67	151.77

A, *k*, *n* – parameters, R^2 – coefficient of determination, t_1 and t_2 – age of culmination of current and mean increments, and values CAI(t_1) and MAI(t_2) in under bark (u.b.), V_{60} – values of stand volumes u.b. at the age of 60 and 100 years in the Czech Republic

enberg 1944; Marquardt 1963). In the same way, we evaluated other introduced tree species and native oaks considered important to Czech forestry (Kouba, Zahradník 2011) and compared their results with Douglas-fir in our study (Table 1).

These species are grand fir (*Abies grandis* [D. Don] Lindl), northern red oak (*Quercus rubra* L. syn. *Quercus borealis* Michx.) and black locust (*Robinia pseudoacacia* L.). The principal native commercial tree species were not studied.

RESULTS

Age class structure

Distribution of Douglas-fir age classes is summarized in Fig. 1 (absolute area of particular age classes – 10 years) and Fig. 2 (relative age classes as a percentage of all Douglas-fir forests distribution). Data from Forest Management Plans document a continuous increase in the area planted with Douglas-fir until the 1980s, after which the area planted with this species has not materially increased. This trend is even more pronounced when results from the National Forest Inventory (NIL – in Czech) are evaluated.

The data consistently document a decrease in the area planted with Douglas-fir over the past 4 decades, despite different methods of assessment. The highest annual rate of planting occurred more than 70 years ago.

Trends of ages of individual samples in the inventory also confirm this pattern for Douglas-fir (Fig. 3a). Planting of introduced tree species on public lands has been restricted in recent decades, contributing to an increase in average age. This increase in average age has been observed since the early 1980s.

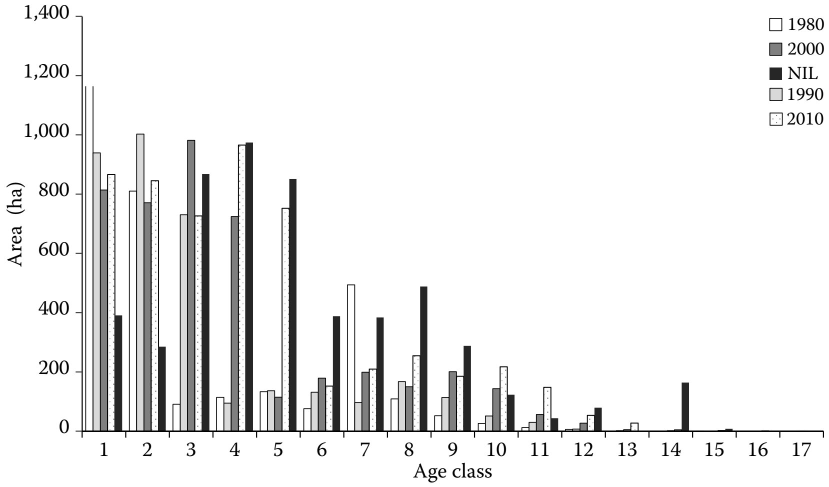

Fig. 1. Forest land area structure of Douglas-fir in the Czech Republic by 10-year age classes, 1980–2010

1980–2010 – summary of management plans, NIL – National Forest Inventory, not fully comparable

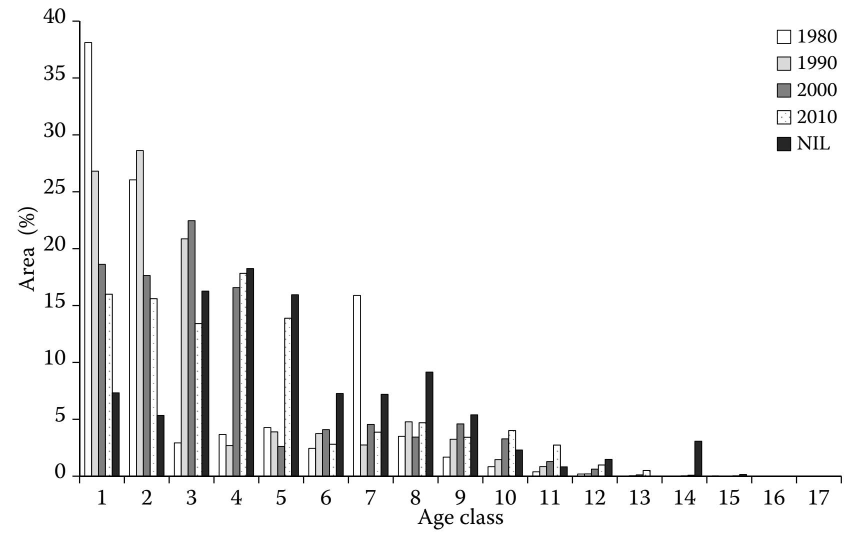

Fig 2. Relative distribution of Douglas-fir on forest land in the Czech Republic, by age classes as a proportion of total Douglas-fir forest area

1980–2010 – summary of management plans, NIL – National Forest Inventory, not fully comparable

Development of growth and production parameters

The area planted with Douglas-fir has continually increased, although at a slower rate more recently, reaching a total of approximately 5,600 ha today (Fig. 3b). This area is only 0.22% of the total forest area in the Czech Republic, and far less than the potential for its cultivation and successful management. The considerable increase in the registered standing volume reflects in part the increasing area planted (Fig. 4a), but more importantly the per hectare increase in volume due to the aging of forest stands and Douglas-fir's reaching its maximum productivity. Fig. 4b shows that the mean standing volume is increasing even faster than the total standing volume (Fig. 4a).

The high production potential of this tree species was evident in the large standing volume estimates and superior current as well as mean annual increment (Fig. 5). These values are much higher than those for comparable nonnative as well as native tree species.

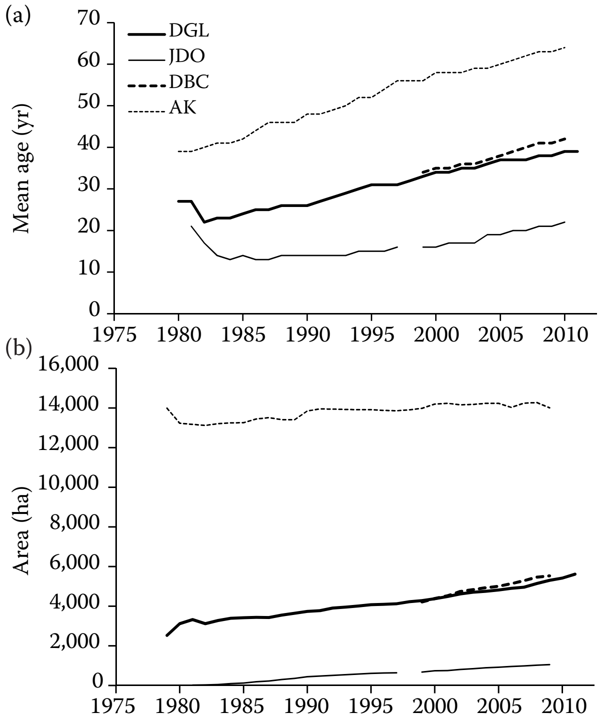

Fig. 3. Average age (a), and total area (b) of Douglas-fir (DGL), grand fir (JDO), northern red oak (DBC) and black locust (AK) stands in the Czech Republic

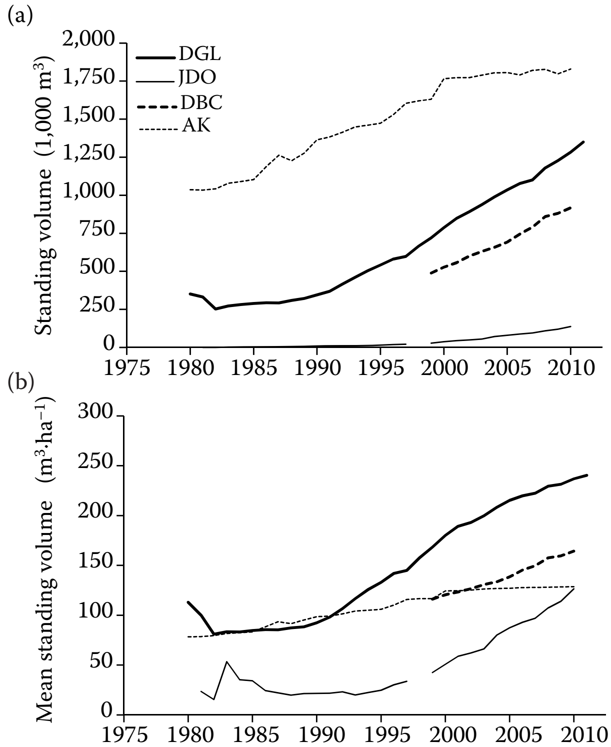

Fig. 4. Total standing volume (a), and mean standing volume under bark (u.b.) (b) of Douglas-fir (DGL), grand fir (JDO), red oak (DBC) and black locust (AK) stands in the Czech Republic

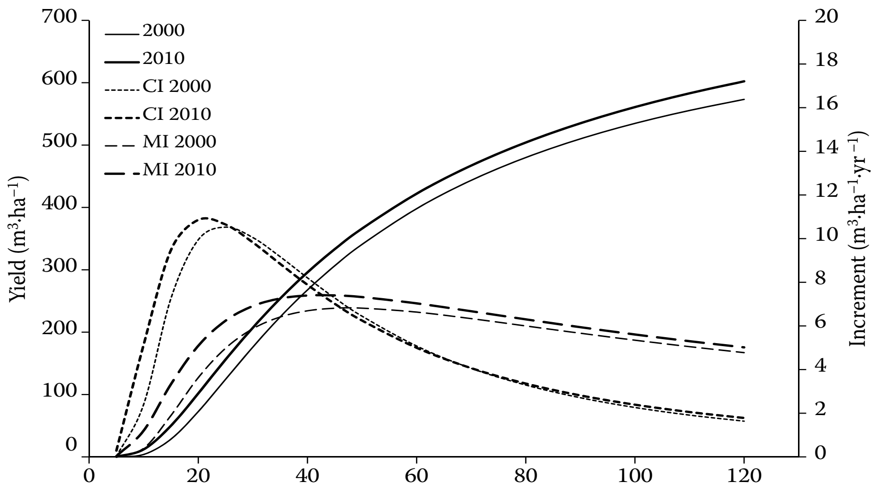

Fig. 5. Volume yield of Douglas-fir stands ($m^3 \cdot ha^{-1}$ u.b.) and current (CAI) and mean (MAI) increments ($m^3 \cdot ha^{-1} \cdot yr^{-1}$ u.b.) in the Czech Republic, by age, for stands measured in 2000 and 2010

DISCUSSION AND CONCLUSIONS

The average age of Douglas-fir stands in the Czech Republic has been increasing in recent years. This trend reflects a decrease in the annual rate of Douglas-fir plantings throughout the country, as reported by the forest inventories. Besides the restrictions imposed by the nature protection authorities in response to the public's concerns, the relatively small amount of volume of this species results in low interest in the species on the part of the Czech forest product sector.

This lack of interest of the local sector contradicts the growing potential of Douglas-fir in the Czech Republic (Beran, Šindelář 1996), and is not reflected by trends in other European countries (Ferron, Douglas 2010). This combination of public concerns and lack of supply is also evident for other introduced tree species (Kouba, Zahradník 2011).

Another factor is to be emphasized: landowners and forest product users might be more interested in the species if they understood that Douglas-fir could contribute even more on less productive sites than other species that are currently present on those sites, despite the lower absolute volume of the increase compared to domestic (natural, native) species.

The analysis of data from the Czech Statistical Office suggests an increasing potential as of 2011 for an economically viable harvest, with total cutvolumes of 19,328 m^3 for Douglas-fir, compared to 2,897 m^3 for grand fir and other exotic fir species, 20,960 m^3 for nonnative oak species and 23,896 m^3 for black locust (Kouba, Zahradník 2011). In the next few years, the share of Douglas-fir harvest should even increase. The harvest percentage for Douglas-fir reaches 1.51% (in the Czech Republic 2.68% for conifers, 1.40% for broadleaves), suggesting that the bulk of the stands are in the pre-commercial stage. In 2010, in the most recent year for which data were available, Douglas-fir was planted on 157 ha only.

For comparison, Kouba (1991) examined results of Douglas-fir production from the inventories of Bavaria in 1971/1972 (Franz 1973) and Rheinland-Pfalz, Germany in 1989 (Schmittinger 1990).

With the Bavarian data, Kouba (1991) found Korf's asymptote A = 1038.63, age of the current increment culmination of t_1 = 26.58, age of the mean increment culmination of t_2 = 51.62 and the volume of growing stock at 90 years V_{90} = 661.36 $m^3 \cdot ha^{-1}$ outside bark. In Rheinland-Pfalz (1989), Kouba (1991) estimated the following values: A = 1771.19, t_1 = 34.28, t_2 = 72.3 and V_{90} = 582.56 $m^3 \cdot ha^{-1}$ u.b. Based on these data which reflect superior growing conditions on their sites, we conclude that Douglas-fir productivity in the Czech Republic is at an acceptable level locally and not out of line with regional values.

Furthermore, our results correspond in general with the outputs of other experiments and studies that document the production superiority of Douglas-fir (Kantor et. al. 2001a, b; Martiník 2003; Martiník, Kantor 2007; Kantor 2008; Podrázský et al. 2009; Kantor et al. 2010). There are not comparable data for the other introduced tree species referred to in our study.

In summary, Douglas-fir has a great potential for contributing a larger share of the productivity of Czech commercial forests, while at the same time contributing to their ecological stability replacing partially the labile Norway spruce forests (Podrázský et. al. 2009, 2011).

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