Potential of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) cultivation on the territory of South Bohemia[1] [2] [3]

Jan Mondek
Ústav pro hospodářskou úpravu lesů Brandýs nad Labem, pobočka České Budějovice, Lipová 15, Rudolfov, Czech Republic
mondek.jan@email.cz

Abstract

Presented dissertation thesis is focused on Douglas-fir silviculture in the Czech Republic, its production potential, effects on understorey vegetation and comparing growth responses to historical climate extremes with Norway spruce, which has recently ceased to be vital due to climate change and is slowly disappearing from forest of lower and middle vegetation altitudinal zones. Data on stand groups in which Douglas-fir is present were obtained from the Data Bank of the Forest Management Institute. Their hectare standing volume was calculated according to the age at different habitats by modified Korf's function (KORF 1939) for the Douglas-fir and some of the main commercial tree species of the Czech Republic and these tree species were also compared to each other. It was gradually found that Douglas-fir reaches the highest production on nutrient rich and acid habitats in the 5th FVZ. However, its production is also not negligible in other FVZs (3rd, 4th and 6th) and on humid habitats as well. Selected 4 localities (Sedlice, Vodňany, Vráž and Kamýk) in southern Bohemia on stands with various mixtures of Douglas-fir and Norway spruce (in several cases also with other tree species) were analysed in detail, starting by understorey vegetation, the canopy light transmission, basic taxonomy data including radial increments. Douglas-fir affects the composition of ground vegetation communities less negatively than Norway spruce in the monitored stands, which had a generally closed structure. The production of Douglas-fir and Norway spruce was calculated and compared here too, when Douglas-fir showed a clear production advantage. Based on the analysis of radial growths of both tree species, Douglas-fir better tolerates dry periods during the summer vegetation season.

Keywords: *Pseudotsuga menziesii*, *Picea abies*, stands production, Forest vegetation zone, Group of forest (Site) type, climate change, plant communities, light properties, increment, Písek region.

[1] This paper was prepared at Ph.D. thesis at Czech University of Life Sciences Prague, Faculty of forestry and wood sciences, Department of Silviculture (2022)

[2] It is translation of the modified text Mondek J. (2022): Potenciál pěstování douglasky tisolisté (Pseudotsuga menziesii (Mirb.) Franco) na území jižních Čech. – URL: https://www.infodatasys.cz/proj009/Mondek_2022.pdf.
Translation Jiří Viewegh, editing Karel Matějka

[3] Further information including new references on the topic of introduced tree species, especially Douglas fir, is collected on the website https://www.infodatasys.cz/proj009/default.htm - Introduced tree species in the forests of the Czech Republic (in Czech).

Abbreviations used

A	soil humus horizon
COP	total volume yield
CHMI	Czech Hydrometeorological Institute
E_0	moss layer
E_1	herb layer (vegetation up to 1 m)
E_2	shrub layer (vegetation from 1 m up to 3 m)
E_3	tree layer (vegetation over 3 m)
GPS	global position system
IFER	Institute of Forest Ecosystem Research Ltd.
KM	haplic kambisol
KM luv	haplic kambisol
KM mod	haplic kambisol
LHC	forest management plan area
LHO	forest management outline
LHP	forest management plan
LM mod	haplic albeluvisol
FVZ (LVS)	forest vegetation (altitudinal) zone
PDOP	position dilution of precision
pH	potential of hydrogen
S-JTSK	System of Unified Trigonometric Cadastral Network (geographic coordination system)
SIL	summary status forest and hunting information (in CZ)
FTG (SLT)	group of forest site types
SNR	signal-to-noise ratio
ŠLP	school/university training forest
ŠP	school/university training forest district
TVP	permanent research plot
ÚHÚL	Forest Management Institute
VÚLHM v.v.i.	Forestry and Game Management Research Institute
WGS-84	World Geodetic System 1984

Tree species abbreviations:

BK	European beech (*Fagus sylvatica*)
BO	Scotch pine (*Pinus sylvestris*)
DB	Pedunculate and Sessile oaks (*Quercus*) – undifferentiated
JD	(European) Silver fir (*Abies alba*)
DG	Douglas-fir (*Pseudotsuga menziesii*)
MD	European larch (*Larix decidua*)
SM	Norway spruce (*Picea abies*)

1. Introduction

The Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) belongs to the most widely commercially used tree not only in the native range, but also in many countries of other continents (e.g. HERMANN ET LAVENDER 1999, KUBEČEK ET AL. 2014, PODRÁZSKÝ ET AL. 2011, PODRÁZSKÝ ET KUPKA 2011). It has become one of the most important introduced tree species in Europe, due to its high production, adaptability and wide ecological niche within the framework of large European conditions spectrum (ESSL 2005, SCHMID ET AL. 2014, ULBRICHOVÁ ET AL. 2014).

In Czech commercial forests, it is a rather less represented tree species, as it occupies only 0.22 % of the entire forest area (REMEŠ ET AL. 2010). In contrast, France, Germany and Italy forests have its higher relative and absolute proportions (SCHMID ET AL. 2014). Nevertheless, Douglas fir is a potentially important introduced tree species in Czech forest management, and its importance will probably continue to grow in the future (KUBEČEK ET AL. 2014, MONDEK ET BALÁŠ 2019, NOVÁK ET AL. 2018, SLODIČÁK ET AL. 2014, VAŠÍČEK 2014).

The significant or superior produce of this tree species is demonstrated by a number of mainly internal and also foreign publications, but also by its effect on the habitat is shown, which is less unfavourable compared to other (autochthonous) conifers (e.g. AUGUSTO ET AL. 2003, MARTINÍK 2003, MATĚJKA ET AL. 2015, MENŠÍK ET AL. 2009, PODRÁZSKÝ AT AL. 2001a, b, 2002, 2009a, b, 2010, 2011, 2014b, 2016a, PODRÁZSKÝ ET REMEŠ 2005, VIEWEGH ET AL. 2014). Even from this point of view, Douglas fir deserves considerable attention in Czech forestry research.

Resistance to drought in younger stands and long-term drought in mature stands is also attractive for our territory as another characteristic of this tree, in connection with higher average temperatures expected and registered drought periods (Urban et al. 2011). A "drought spruce" or "spruce for drought" is Douglas fir often referred abroad (PODRÁZSKÝ ET AL. 2011). Therefore, it can be an important to Norway spruce replace on suitable localities of Central European commercial forests (FISCHER ET NEUWIRTH 2012, KUBEČEK ET AL. 2014, NOVÁK ET AL. 2019, PODRÁZSKÝ 2016, PODRÁZAKÝ ET AL. 2016b, REMEŠ ET AL. 2020, SERGENT ET AL. 2010, VITALI ET AL. 2015), to help mitigate the predicted softwood supply decline in the near future (PALÁTOVÁ ET AL. 2017, PODRÁZSKÝ ET AL. 2014a, PULKRAB ET AL. 2015) on Czech forestry sector (RIEDL ET AL. 2019). A fundamental information lack about the possibilities of this tree species commercial use is in practical (terrain) forestry (PODRÁZSKÝ ET AL. 2013b), even though the first plantations are reported in 1844 (KANTOR ET AL. 2002).

For these reasons, a comprehensive assessment of Douglas fir role in Czech forest ecosystems is highly relevant.

2. Dissertation goals

(1) to determine in which groups of forest types Douglas fir achieves the highest production,
(2) to compare a Douglas fir production with other dominant commercial used tree species on the same habitats,
(3) to find out in which groups of forest types Douglas fir still significantly tolerates (and achieves higher production) unfavourable habitats moisture conditions.
(4) to find out if Douglas fir can withstand a longer summer drought

3. Task analysis

3.1 Douglas fir range area

3.1.1 Douglas fir native range

Douglas fir is native to the Pacific coast of the North America, from British Columbia to Mexico. It is considered one of the most commercially important tree species in the world, with an extensive native range in North America (Fig. 1) and successful plantings around the world (e.g. Europe, Argentina, New Zealand, Iran; KUBEČEK ET AL. 2014). American foresters Burns and HONKALA (1990) and HARLOW ET AL. (1996) state Douglas fir as one species with two varietas: *Pseudotsuga menziesii* var. *menziesii* (coastal Douglas fir or green Douglas fir) growing on the Pacific coastal area of the Rocky Mts., and *Pseudotsuga menziesii* var. *glauca* (inner Douglas fir or grey Douglas fir) growing in the mountainous region of the inland part of Rocky Mts. Alternatively, in the area of the smooth transition between these two varieties, they distinguish the hybrid form *Pseudotsuga menziesii* var. *glauca* f. *caesia* (blue Douglas fir).

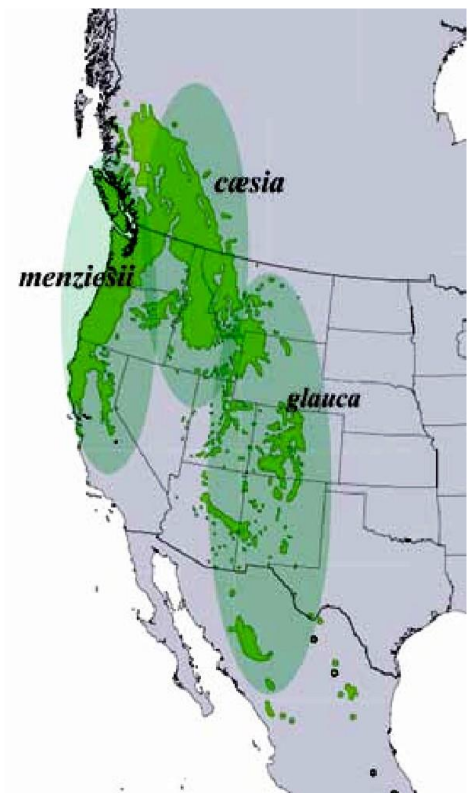

Fig. 1. Pseudotsuga menziesii native range varieties and form, according to Burns and Honaka (1990) and Harlow et al. (1996). (source: Pianka 2012)

Douglas fir is a case of one of the most successful introductions within world forestry. The reason is its unrivalled production potential and considerable stability of its stands. Douglas fir is placed on 14.3 million hectares in the U.S. and on 4.5 million hectares stand area in Canada (HERMANN ET LAVENDER 1999).

According to some European, including Czech taxonomists, the species *Pseudotsuga menziesii* (Mirb.) Franco is exclusively separate species, and *Pseudotsuga glauca* Mayr is also a separate species (MUSIL ET HAMERNÍK 2007).

MUSIL AND HAMERNÍK (2007) state that Douglas fir occurs natively on the coastal region of North America western part, i.e. the western USA periphery and southwestern Canada, where it forms various degrees of *P. glauca* hybrids towards the east (Fig. 1). It grows from the coast to an altitude of 760 to 1,250 m a.s.l. in the northern part of the area; in southern part, from an altitude of 240 m a.s.l., but most from 630 to 1,830 m a.s.l. with occasional local elevations up to 2,300 m a.s.l. The coastal part of the area has a maritime climate with mild, humid winters and cool, relatively dry summers. Temperatures have a small amplitude and the frost period is short. Abundant precipitations (even over 2,000 mm.year^{-1}) are concentrated to the winter months. The climate is already harsher in the eastern Cascade Mts. (Table 1).

Table 1. Climatic data for 5 sub-areas of Douglas fir native range
(source: https://dendro.cnre.vt.edu/dendrology/USDAFSSilvic/105.pdf)

Area	Temperature average		Frost-free period	Precipitation average	
	july	january		year	snow
	°C	°C	days	mm	cm
Northwest Pacific					
coastal	20 - 27	-2 to +3	195 - 260	760 - 3400	0 - 60
Cascade Mts. and Sierra Nevada	22 - 30	-9 to +3	80 - 180	610 - 3050	10 - 300
Rocky Mts.					
north	14 - 20	-7 to +3	60 - 120	560 - 1020	40 - 580
central	14 - 21	-9 to -6	65 - 130	360 - 610	50 - 460
south	7 - 11	0 to +2	50 - 110	410 - 760	180 - 300

3.1.2 Introduction to Europe

In the Tertiary period, the genus *Pseudotsuga* was one of the trees found in Europe. During the Quaternary Ice period it disappeared from Europe as many others. The new introduction to Europe was made by David Douglas in 1827 when he planted Douglas fir seedlings in Dropmore Park in England, where they are still found up till now as the oldest individuals in Europe. Douglas fir was first planted in alleys and then in forest stands in the late 19th century. Thanks to its wide ecological plasticity to different environmental conditions, it forms stable stands (LARSON 2010).

The biggest boom with Douglas fir afforestation occurs after the Second World War in Western Europe. France (half European plantings), Germany and Great Britain – three countries in where can be found 80% plantings in Europe (DA RONCH ET AL. 2016). In the second half of the 20th century, it was one of the most important commercial trees used for afforestation and forest regeneration in France. Douglas fir covers there more than 400,000 hectares, with an annual planting of around 5 million seedlings (FERRON ET DOUGLAS 2010).

The situation is similar in most Western European countries. Good experience with it and its considerable use is in Germany, as well as Italy, Belgium and the Netherlands. Its great potential in timber production and drought tolerance is mainly used in Italy (CASTALDI ET AL. 2017). The conditions are very good for it as a tree of Pacific maritime climate at British Isles. Within Europe, France dominates with 400,000 hectares and Germany with 300,000 hectares of stand area

(SLODIČÁK ET AL. 2014). The Douglas fir distribution on Europe is shown in Fig. 2. In 2018 it covers an area of 830,000 hectares in Europe (BRUS ET AL. 2019). The range of suitable sites may even expand in the future, especially in mountainous and sub-mountainous areas (PÖTZELSBERGER ET AL. 2019).

3.1.3 Situation in the Czech Republic

Great attention was paid to Douglas fir also in the territory of the former Czechoslovakia, especially in the past period and on the part of private forest owners. Unfortunately, nature protection authorities and environmental organizations were and are very strongly against planting introduction allochthonous tree species in commercial forests (PODRÁZSKÝ ET AL. 2009a, 2013b, ŤAVODA 2007, ŤAVODA ET LENGYELOVÁ 1996).

In recent decades, therefore, annual plantings of Douglas fir have declined; on the other hand, the stands average age is increasing, and their standing volume significantly (KOUBA ET ZAHRADNÍK 2011, PODRÁZSKÝ ET AL. 2013c). Douglas fir stands cover 6,893 hectares in the Czech Republic at present (source: https://eagri.cz/public/app/uhul/SIL/Default.cshtml) and approximately 1,200 hectares in Slovakia (CHEPKO ET AL. 1996) and other plantings take place to lesser extend every year. Private forest owners have been particularly interested in plantings this tree in recent years in connection with the current problems with Norway spruce

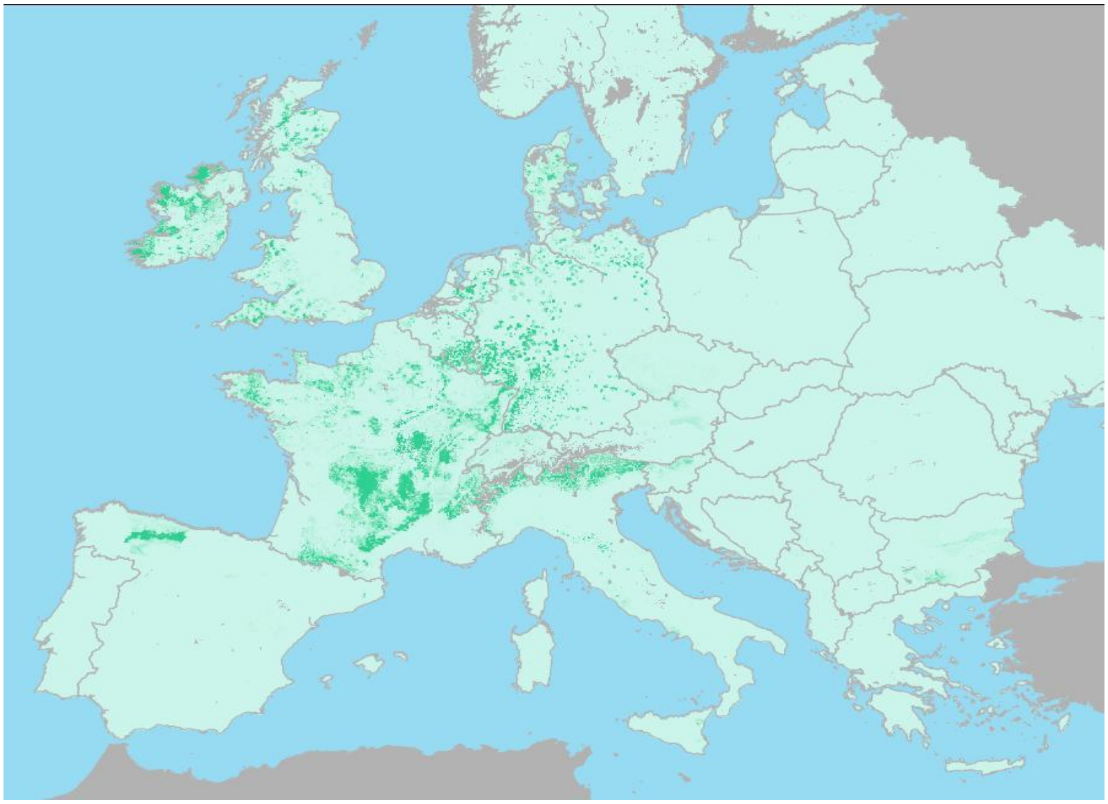

Fig. 2. Douglas fir distribution in Europe (source: http://www.forestry.gov.uk/forestry/infd-8qnk35)

Also, in the Czech Republic and Slovakia, Douglas fir is considered long-term as one of the most promising tree species for commercial stands (HOFMAN 1964, MONDEK ET BALÁŠ 2019, PETRÁŠ ET MECKO 2008, PODRÁZSKÝ ET AL. 2009a, ŤAVODA 2007). In the second half of the 20th century, several provenance experiments were established to study this tree species variability, which demonstrated the significant importance of origin region choosing and the considerable endogenous Douglas fir variability. Regions from which seed can be collected from the original area with the highest success probability for subsequent plantings are confirmed (BERAN 1993, 1995, CAFOUREK 2006, HOFMAN 1964, KŠIR ET AL. 2015, ŠIKA 1974, 1975, 1985, ŠIKA ET HEGER 1972, ŠIKA ET PÁV 1990, ŤAVODA ET KRAJŇÁKOVÁ 1993, ŤAVODA ET LENGYELOVÁ 1996). Successful introduction and breeding can then continue on this basis (MARTINÍK ET PALÁTOVÁ 2012).

Around the beginning of the millennium, interest in Douglas fir was increasing again due to the forest stands stabilization and the valuable timber production. This change is related to higher interest in the forest management economy and also with problems of Norway spruce stands vitality and stability at lower altitudes especially (PODRÁZSKÝ ET AL. 2013d). The Norway spruce cultivation is considered to be the source of the forest stands reduced stability and the forest diversity decline in significant part of Europe (AUGUSTO ET AL. 2003, MÁLIŠ ET AL. 2010), when we compare the differences between natural European beech and Norway spruce stands (VACEK ET MATĚJKA 2010). It is documented that Norway spruce influence increases with the time since its initial planting in an unnatural habitat, i.e. since the time of the species composition change (AMBROS 1990, HADAČ ET SOFRON 1980, POLENO 2001, ŠOMŠÁK 2003, ŠOMŠÁK ET BALKOVIČ 2002). The replacement of the natural species composition trees by Norway spruce is also considered to be the cause of forest soils extensive acidification (OULEHLE ET HRUŠKA 2005).

3.2 Douglas fir production

Douglas fir wood mass production has always been given the greatest attention. The older publications document this tree species suitability and high production capacity (e.g. BERAN ET ŠINDELÁŘ 1996, HOFMAN 1964, PAGAN 1999). A significant increase in the stands production by Douglas fir introduction into the stand mixture is also documented by more recent studies. For example, KANTOR ET AL. (2001a, b) documented in mixture stands (Douglas fir, Scotch pine, European larch, Pedunculate oak, European beech, European hornbeam and small-leaved lime) of middle age (68 years) the Douglas fir dominant production position. At this age, individual trees volume was up to 2.9 m^3; at the age of 100, one can expect one tree volume up to 6 m^3. The authors recommend Douglas fir admixture in stand mixtures about 10 – 30 %.

KANTOR (2008) carried out a detailed growth analysis of 29 mixed stands aged 85 to 136 years on fertile habitats of the Mendel University Forest at Křtiny. He studies parameters of the Douglas fir and Norway spruce 10 tallest individuals. Douglas fir reached two to three times the volume of Norway spruce or European larch, when determining the volume of individual trees. In one case, the mean volume of 10 tallest individuals in the stand reached 9.12 m^3 for Douglas fir, 3.17 m^3 for Norway spruce and 3.70 m^3 for European larch. Using tree ring analysis, he determined the annual volume increase of one Douglas fir individual in the amount of 0.12 to 0.16 m^3. This can respond an increase of up to 1.5 m^3 in one decade.

Using the same method, the Douglas fir production ability on acidic habitats was analysed at Forestry Technical School Training Forest in Hůrky (KANTOR ET MAREŠ 2009). A total of 17 mixed stands aged 88 to 121 years with a significant Douglas fir presence were studied. They again analysed the 10 tallest individuals of Douglas fir, Norway spruce, Scotch pine and European larch in individual stands. Again, the highest production potential was clearly demonstrated for Douglas fir, as KANTOR (2008) already demonstrated. The mean volume of the tallest individual in the stand reached 6.30 m^3 for Douglas fir, 1.93 m^3 for Norway spruce and 2.25 m^3 for European larch, in one case. Using tree ring analysis, the authors determined the annual volume increment of one individual Douglas fir 0.06 to 0.10 m^3.

MARTINÍK ET KANTOR (2007, 2009) analysed the Douglas fir aboveground biomass (in the first case biomass amount only; in second one a nutrient content) in two medium-aged stands (69 and 75 years old) on the fertile habitats of the Mendel University Forest at Křtiny. They demonstrated the high importance of the tree position in stand structure for growth parameters, assimilation apparatus formation and the nutrients fixing by aboveground biomass component. They regard its high ability to exploit nutrients from the soil as a significant risk when Douglas fir cultivating. This can lead to habitat depletion ultimately. As prevention, they recommend Douglas fir cultivation in an admixture with habitat native trees and leaving a maximum of unusable biomass after harvesting *in situ*.

The high Douglas fir production potential was also documented on the territory of Czech University of Life Sciences Training Forest at Kostelec nad Černými lesy. Douglas fir is planted here since the 80th of 19th century. Its stand area reaches approximately 10.5 hectares here, currently. The oldest studied stand has been located at an altitude of 410 m a.s.l., with 650 mm average of annual precipitation sum and 8 °C average annual temperature. Standing volume has been determined at the age of 97. Standing volume on permanent research plots has been within range of 830 and 1030 $m^3.ha^{-1}$, according to Douglas fir and Norway spruce representation ratio. Douglas fir here represented 14 – 30 % of the individuals, 32.4 – 42.4 % of the basal area, and 36.6 – 58.3 % of the stock. The number of Douglas fir regeneration has been within range of 16,000 – 31,000 individuals per 1 hectare after a chemical preparation. However, this regeneration in so far closed stand with a Norway spruce significant admixture has disappearing fast (REMEŠ ET AL. 2006, 2010).

Another locality on the area of Czech University of Life sciences Training Forest represents change native tree species stand (pedunculate oak, European hornbeam and small-leaved lime) at the age of 69 to monoculture of Norway spruce (61 years) and Douglas fir (45 years). This plot is located at an altitude of 420 m a.s.l., the range 550 – 650 mm of average annual precipitation sum and 8.5 °C average annual temperature. The plot can be characterized by FTG 3K (*Querceto-Fagetum acidophylum*) and haplic albiluvisol as a soil type. The stock reaches a value of 266 $m^3.ha^{-1}$ for hardwoods, 507 $m^3.ha^{-1}$ for Norway spruce and 579 $m^3.ha^{-1}$ for the youngest Douglas fir. The average annual increment was determined at 4.43 $m^3.ha^{-1}.year^{-1}$ for hardwoods, 8.45 $m^3.ha^{-1}.year^{-1}$ for Norway spruce and 12.87 $m^3.ha^{-1}.year^{-1}$ for Douglas fir (PODRÁZSKÝ ET AL. 2009a, PODRÁZSKÝ ET REMEŠ 2010).

So far, the last published study with data sourced on Czech University of Life Sciences Training Forest demonstrates the production and soil-forming function of various tree species stands on afforested agricultural land. The stock of Norway spruce, Scotch pine, silver birch and Douglas fir stands at the age of 39 years was compared. This plot is located at an altitude of 430 m a.s.l., the average annual precipitation sum is 600 mm and the average annual temperature is 7.5 °C. Stagned luvisol to stagnosol is the soil type. The mean stem values of the Scotch pine reached a height of 20.6 m and diameter of breast height of 19.5 cm, analogously for Norway spruce 20.1 m and 19.5 cm, for silver birch 24 m and 21.4 cm and for Douglas fir 21.6 m and 23.8 cm, which was with the number of trunks 1408 (SM), 1157 (BO), 440 (BR) and 928 (DG) $pcs.ha^{-1}$, 352.1 (SM), 349.4 (BO), 157.1 (BR) and 438.6 (DG) $m^3.ha^{-1}$, which show Douglas fir to be clearly the most productive tree species in given conditions (PODRÁZSKÝ ET AL. 2009a, b, 2010).

BARTOŠ ET KACÁLEK (2011) documented at various localities in Podorlicko region, that it is always necessary to respect the habitat suitability when afforesting agricultural land by different trees. They resulted that during the first years after planting, Norway spruce and Douglas fir growth is almost equal. European larch can dominate Douglas fir depending on the humidity and general soil conditions.

Research on the value assessment of Douglas fir production is rare. PODRÁZSKÝ ET AL. (2013a) published the only significant article for the Czech territory. They evaluated volume and value production from LHP data for 2010 – 2019 sourced from Secondary Forestry School training Forest at Hůrky. For the analysis, stands were selected from habitat characterized by FTG 3K (*Querceto-Fagetum acidophylum*). A total 375 parts of the stand were analysed in this way: 92 parts Douglas fir represented in the age of 30 – 124 years, 130 parts European beech represented in the age of 30 – 160 years, 164 parts oak (both – Pedunculate and Sessile – undifferentiated) represented in the age of 34 – 160 years and 120 parts European larch in the age of 32 – 160 years. Standing volume of the analysed tree species was calculated to the value at full stocking on one hectare. Korf's function (KORF 1939) was used to study the production parameters course. Common value increment for Douglas fir was equal to 26,622 CZK $ha^{-1}.year^{-1}$, oak 19,926 CZK $ha^{-1}.year^{-1}$, Norway spruce 19,494 $ha^{-1}.year^{-1}$, European larch 14,427 CZK $ha^{-1}.year^{-1}$ and 9,360 CZK $ha^{-1}.year^{-1}$ for European beech at the time of culmination. The mean value increment for individual tree species was determined as follows: Douglas fir 13,098 CZK $ha^{-1}.year^{-1}$, Norway spruce 10,698 CZK $ha^{-1}.year^{-1}$, European larch 7,831 CZK $ha^{-1}.year^{-1}$, oak 7,751 CZK $ha^{-1}.year^{-1}$ and European beech 5,293 CZK $ha^{-1}.year^{-1}$. Nevertheless, Douglas fir production was under evaluated due to lack of real data. Assortment tables for Douglas fir are not in the Czech Republic, tables for spruce were then used. So, when compared to the other monitored tree species, both volume and value production were significantly higher. A higher potential value production was also documented in toll-ripened stands (REMEŠ ET AL. 2010). Norway spruce has reached a level about 70%, of the Douglas fir value production.

Significantly higher Douglas fir production value then others monitored tree species was also in middle-aged stands. In the above-mentioned stands, PODRÁZSKÝ ET AL. (2009a), PODRÁZSKÝ ET REMEŠ (2010) and REMEŠ ET AL. (2010) declare mean annual increment value of 66 % for Norway spruce and of 34 % for mixed hardwood stands considering to Douglas fir production value.

A comparative studies Douglas fir production with the other main commercial tree species demonstrate that when this tree species is introduced into stands mixtures, it results to substantial increase of forest stands production. Not only the volume but also production value is increasing significantly, when compared to Norway spruce. SCHELHAAS (2008) reported that the use Douglas fir and European beech mixtures changed the competitive pressure on Douglas fir and consequently height/diameter ratio and wind damage risk. His study suggests that the current trend to more nature-oriented management could lead not only to the wind disasters reduction, but also to the total production increase.

If we evaluate the Douglas fir production, it is necessary to consider differences among individual trees. This can differ significantly, if we evaluate e.g. the highest individual or the whole stands (KOUDELA 2013). Author evaluated parameters of Douglas fir and Norway spruce production of the whole stands situated in Czech University of Life Sciences Training Forest on different habitats. Results are shown in Table 2. Table document the greatest disparity between the mean stem and standing volume compared to Norway spruce in water influenced habitats. The Douglas fir mean stem volume reaches 316 % and standing volume 150 % of the Norway spruce values. He justifies it by stands lower density, greater lightness and a more balanced production per unit crown projection area for Douglas fir. This fact increases the importance of choosing a suitable admixture and determining the optimal mixing degree in Douglas fir forests.

Table 2. Parameters of individual DG and SM trees and stands on Czech University of Life Sciences Training Forest at Kostelec nad Černými lesy area in the age of 100 years (Koudela 2013)

Habitat /stands amount	**Breast high diameter [cm]**		**high [m]**		**Mean stem volume [m³]**		**Standing volume [m³ ha⁻¹]**	
	DG	**SM**	**DG**	**SM**	**DG**	**SM**	**DG**	**SM**
Water influenced DG 14, SM 359	53,0	33,0	39,4	28,9	3,57	1,13	893,7	653,5
[%]	*160*	*100*	*136*	*100*	*316*	*100*	*150*	*100*
Acidic DG 17, SM 658	47,4	32,7	32,0	28,0	2,50	1,10	698,6	631,0
[%]	*145*	*100*	*114*	*100*	*227*	*100*	*111*	*100*
Nutrient medium and rich DG 46, SM 987	50,1	35,3	34,5	29,3	3,20	1,40	768,8	669,8
[%]	*142*	*100*	*162*	*100*	*229*	*100*	*115*	*100*

PETRÁŠ ET MECKO (2008) also show the great importance of a suitable mixture in order to fully utilize the Douglas fir cultivation potential. They evaluated volume and value production of individual tree species pure stands with comparable yield class indices based on models of growth tables.

The above cited analyses show a higher volume and value Douglas fir production potential when compared to other commercial tree species (cultivated in the Czech Republic) in the same habitats at a comparable age. This potential can be further increased by planting Douglas fir in a suitable admixture.

3.3 Douglas fir wood mass utilization

Douglas fir is one of the most valuable and important species for wood mass production in the world. The combination of high-quality wood mass with high production ranks it at the top of the world production (PERIĆ ET AL. 2011).

During cultivating Douglas fir arises some problematic aspects, as well as for other introduced tree species, these are wood raw material usability and its application on the market. However, Douglas fir is known by high quality and versatile useable heartwood (ZEIDLER 2013). Sapwood is relatively narrow; its colour is whitish to pale yellow. Heartwood colour is very variable, from yellow-brown to red. It depends on the habitat and growth rate (BORMANN 1984, WAGENFÜHR 2004, WIEMANN 2010). The tree rings are distinct; the transition from early to late wood is abrupt (PANSHIN ET DE ZEEUW 1980). The wood is solid, medium hard and tough; it dries and processes well. It is moderately resistant to rots, but impregnates poorly (BORMANN 1984). It is used in the production lumber, plywood and pulps. It is an excellent building timber (ALDEN

1997, BORMANN 1984). It is considered an excellent material for glued beams producing (RENDLE 1969). Douglas fir is the most important tree species for lumber production (BORMANN 1984).

The situation in the Czech Republic and Slovakia is significantly different. West of our border, Douglas fir is highly valuated (THOMAS ET AL. 2022). The price of this timber is at the level of Norway spruce or European larch at least. Our producers having connection to the German or Austrian market take advantage of this fact (PODRÁZSKÝ ET AL. 2013a). Those who do not have these contacts (the majority) have great difficulties to sale Douglas fir timber and often sell it well below the price general in western European market. This situation is similar in Slovakia. The demand is zero practically and Douglas fir timber produced in Slovak forests is mostly exported (ŠMIDRIAK 2010).

This situation is greatly aggravated by the wood processing industry inability to adapt. The greater part of the Douglas fir Czech forests production is exported abroad without any attempt to process. This situation is changing very slowly only. It is necessary to mention that Douglas fir timber is comparable to other conifers produced in our territory in terms of mechanical and chemical processing and subsequent use; this is also confirmed by European sources. According to RIEGLER (2008), Douglas fir surpasses Norway spruce in terms of quality and usability. The partial replacement of Norway spruce by Douglas fir should not be a significant problem from the point of view of wood processing and utilization. On the contrary, it could be an opportunity a benefit.

3.4 Douglas fir effect on the soil

Douglas fir has higher requirements for soil nutrient, but also has a more favourable litter decomposition and transformation compared to Norway spruce (THOMAS ET AL. 2022). This fact was already proven by the PODRÁZSKÝ ET AL. (2001a, b, 2022) first studies, which dealt with the Douglas fir influence on the soil environment. The studies were carried out on the habitats characterized by FTG 3K (*Querceto-Fagetum acidophylum*) and 3S (*Querceto-Fagetum oligo-mesotrophicum*) in the Czech University of Life Sciences Training Forest. There is a more pronounced humus accumulation with higher soil acidity characteristic, when compared to the natural species composition (Sessile oak, European hornbeam, and small-lived linden). But when compared to Norway spruce stands on the same habitat, the effect on the forest soils state was considerably more favourable, especially humus forms.

Similar conclusions were published by MARTINÍK (2003). He studied a 73-year-old mixed stand, classified as FTG 3B (*Querceto-Fagetum trophicum*) on the Mendel University Training Forest territory at Křtiny. Depending on the Douglas fir presence in the stand mixture, mineral nutrient and soil-chemical attributes were monitored. He documented soil quality change as the Douglas fir proportion increases in the deciduous stand mixture. There is a reduction in the content of basic cations (Ca, Mg) in the A-horizon. This is a consequence of the stand intensive increment, which then binds a considerable amount of nutrients in the biomass. According to European standards, mineral nutrient was close to optimal. The author recommends an individual or group Douglas fir admixture in forest stands.

MENŠÍK ET AL. (2009) studied forest stands on the territories of Forestry Technical School Training Forest at Hůrky and Mendel University Training Forest at Křtiny. They compared the soil condition on acidic (FTG 3K – *Querceto-Fagetum acidophylum*) and nutrient rich (FTG 4H – *Fagetum illimerosum trophicum*) habitats in a mixed stands of Norway spruce + European beech and Norway spruce + Douglas fir. Douglas fir stands accumulated 25.0 $t.ha^{-1}$ of forest floor (humus), while Norway spruce stands 79.4 – 79.6 $t.ha^{-1}$. When comparing individual tree species in the same habitats, they found out more favourable soil reaction values in the holo-organic and organo-mineral horizons of Douglas fir stands; C/N values were also favourably affected by Douglas fir.

PODRÁZSKÝ ET REMEŠ (2005, 2008) also documented the Douglas fir beneficial effects compared to Norway spruce studying on above mentioned stands in Czech University of Life Sciences Training Forest. The soil reaction, soil sorption complex characteristics, soil organic matter dynamics and nitrogen were considerably more favourable in the humus forms profile. The Douglas fir influence was less favourable comparing with deciduous stands, significantly more favourable comparing with Norway spruce on the contrary and approaching by affecting the giant fir. However, it seems that the effects of giant fir are more favourable when compared to Douglas fir (PODRÁZSKÝ ET AL. 2016a).

CREMER ET PRIETZEL (2017) also address the same issue related to the Douglas fir cultivation in mixtures, who state that, mixed stands could maintain fertility, mitigate soil acidification, nutrient leaching, and at the same time reduce the depletion of soil basic cations, compared pure conifer stands.

Douglas fir has a significant effect on the state of humus forms also on afforested farm land. This was published by PODRÁZSKÝ ET AL. (2009a, b, 2010). Humus forms in 39-year-old stands of Douglas fir, Norway spruce, Scotch pine and silver birch were compared with Scotch pine and Norway spruce mature forest on permanently forested land and with an adjacent field. It was proven that the most favourable soil chemistry indicators (pH, basic nutrient content, sorption complex saturation with bases, cation exchange acidity and hydrolytic acidity) were precisely in the Douglas fir stand. A decrease in the accessible phosphorus content was found out due to intensively Douglas fir cultivation. Humus layer have not formed in the silver birch stand up to that time, which has been similar to the neighbouring field. He humus condition has been much more favourable in all stands on afforested farm land in comparison to the mature coniferous stands. Douglas fir can be evaluated as less acidifying in terms of its effect on the soil, when compared to other conifers. Amelioration effect is associated with a higher nutrients' uptake, but also with a return in the litter form, similar to European beech and other amelioration deciduous trees. Only if a nutrient is in critical deficiency, it can be permanently fixed in biomass. However, these fluxes are not quantified, tools exist only – modelling the individual elements accumulation in the stand biomass in combination with, e.g. the MAGIC model (ZETTERBERG ET AL. 2016).

PODRÁZSKÝ ET KUPKA (2011) studied the state of the A-horizon pedo-physical characteristics. They documented that the tree composition, stand cutting or farm land afforestation have a certain influence on forest soils hydro-physical characteristics. Farm land afforestation leads to a significant reduction in soil volume and specific gravity, but also to a significant increase in porosity and aeration. The probable reason is the root systems activity and edaphon, organic and mineral soil mixing. Stands cutting show a markedly reverse trend. Douglas fir showed significant effects at least from the monitored tree species. This is due to its intensive growth (high requirements for nutrients and water) and the speed of its litter decomposition. Therefore, afforestation contributes to better landscape retention; on the contrary, forestry measures do not significantly threaten the forest soils retention apparently. If we neglect the higher requirements for the Douglas fir on water in transpiration terms, so by its cultivation in a suitable chosen mixture, we will not significantly affect the forest soils water regime.

On a larger landscape scale, the current tree species composition of forest stands (BO, DG, JD, BK, and DB) has less influence on the soil condition and ground layer than geographic conditions, parent rock and forest operations, with an exception of Norway spruce, which has a more pronounced influence on the habitat (AUGUSTO ET AL. 2003). Most of the studies are focused on individual localities and the individual trees influence is thus emphasized. However, it unequivocally demonstrates that Douglas fir has a very favourable influence on soil properties, when comparing with the dominantly regenerating conifers, the Norway spruce especially. VITORRI-ANTISARI ET AL. (2014) even reports that mature Douglas fir plantings improve organic C and P conditions in the litter compared to native European beech in northern Apennines at 1028 m a.s.l. However, the emphasis is placed on Douglas fir planting in mixes stands with native tree species (PODRÁZSKÝ AT AL. 2015). In this way, its potential to increase mobile nitrogen levels in the soil can be significantly limited (PODRÁZSKÝ ET AL. 2014b, 2020, ZELLER ET AL. 2010), it can be assumed that soil properties will be maintained at a relatively favourable level taking into account the individual habitats conditions.

3.5 Douglas fir impact on the environment and biodiversity

There is still relatively little data regarding the Douglas fir influence on other the environment and biodiversity components of forest ecosystems in the Czech Republic. PODRÁZSKÝ ET AL. (2011) studied the ground floor composition on a set of 44 areas in different habitats with a different tree species composition, including Douglas fir. A significant but already noticeable increase in the species number was demonstrated in the Douglas fir stands, when compared with other tree species, with Norway spruce especially. Simultaneous communities shift towards (nutrient) richer habitats was found up with regard to the nitrogen level in the soil, mainly. This corresponds with results of abroad authors (e.g. AUGUSTO ET AL. 2003). MATĚJKA ET AL. (2015), PODRÁZSKÝ ET AL. (2014b) and VIEWEGH ET AL. (2014) also demonstrate similar findings on significantly larger localities set (over 100).

The investigation results in all studies demonstrate the Douglas fir influence, which are much less clear and phytocoenoses deviating the from the natural state than in the case of a Norway spruce. The Douglas fir is thus significantly more environmentally friendly from the point of impact on the ground floor view.

Another function also appears to be important for Douglas fir. This is the support the static forest stands stability. MAUER ET PALÁTOVÁ (2012) studied the root system development in stands at the age of 10, 20, 30, 60, and 80 years on the mesotrophic (nutrient rich) habitats of the Mendel University Training Forest. They confirmed that the development of a compact root system, which ensures considerable stability of individuals, occurs from a young age. MAUER ET VANĚK (2014) also analysed the architecture and health status of the Douglas fir root system. They state that the Douglas fir has the ability to pump water from deep soil horizons and thus not compete with other trees standing next to it. They recommend this tree species use as a melioration and reinforcement from 2nd to 7th forest vegetation zone (FVZ). They also show that there are no differences between the Douglas fir root systems from natural and artificial regeneration. Douglas fir can thus be an important forest stands stabilizing element. This also confirmed by other sources (SERGENT ET AL. 2010). However, with more significant Douglas fir introduction into forest stands, there remains a risk that is related to the natural Douglas fir stands dynamics and its communities, namely an increased nitrification rate and potential nitrogen loss, especially in its pure stands (ZELLER ET AL. 2010). Nitrification here does not mean the soil enrichment by nitrogen, but rather the bacterially controlled process of nitrogen ammoniac form transformation into the nitrate form, which the

Douglas fir supports indirectly through the dynamics of its litter and possible directly through bacterial symbionts. Douglas fir has a high potential for long-term effects on ecosystems in terms natural regeneration. Acidic habitats occur to its massive (natural) regeneration, which can be used for the subsequent stand regeneration without problems (Bušina 2007, Kantor et al. 2010). Problems with weed competition may occur in mesophilous habitats (Hart et al. 2010). Douglas fir is also able to regenerate on open rocks with shallow soil and on the forest roads edges (Kroerzer 1999). Kramer et al. (2006) generally conclude that there is relatively little difference in the effect on Douglas fir regeneration at low to very high ungulate games levels. Douglas fir can be integrated into shelterwood systems without considerable problems and successfully cultivate from natural regeneration using suitable silviculture measures (Eberhard et Hasenauer 2018). This Douglas fir ability is referred to as invasiveness, in European point of view (Carrillo-Gavilán et al. 2012, Tschopp et al. 2015), and thus Douglas fir is classified as an invasive alien species. Danihelka et al. (2012) classify this species as naturalized neophyte. However, it must be emphasized that this Douglas fir attribute is not a real problem on most habitats. Douglas fir does not show an invasive attribute in Europe at present (Pötzelsberger et al. 2020). It is also not written in the "List of invasive trees in the Czech Republic" (Pergl et al. 2016, Pyšek et al. 2012). The problem can arise in the case of unmanaged forests with a minimal silvicultural treatment, i.e. in protected areas especially. Douglas fir is really not a desirable species there and must be removed by silvicultural measures. However, this its ability will not be a problem in commercial forests, this must be emphasized repeatedly. As with other introduced trees, it is recommended to cultivate it with caution in the nature conservation interests (Brundu et al. 2020, Kuneš et al. 2019).

3.6 Douglas fir reproductive resources

The suitability of different methods of presowing Douglas fir seeds treatment was studied by Martiník et Palátová (2012). They compared 7 sections of the grey variant (*Pseudotsuga glauca*) and 7 sections of the green varieta (*Pseudotsuga menziesii*). They demonstrated the suitability, necessity and usefulness of presowing treatment various methods, for the maximum use of seed resources. They also demonstrated differences between provenances. These differences must be respected in the case of further introduction from the areas of its native range (Mauer et al. 2014).

It will be necessary to reevaluate the acquisition of Douglas fir reproductive material in the future with increased interest. One of the ways is to import the seed from the areas of native range; another possibility is to obtain it from European areas with intensive cultivation of this tree species. The first mentioned way is verified by the evaluation of existing provenance plots, mostly managed by Forestry and Game Management Research Institute. The results of older (Hofman 1964, Šika 1974, 1975) and more recent studies (Kšir et al. 2015) demonstrate that the provenance area of the Pacific coast, Vancouver region and the territory of British Columbia (from the lower altitudes with a mild climate) are the most suitable for introduction into Czech forests. Import from this area is certainly possible if the approved principles are kept.

The material import from Western Europe would be more problematic, since there is a risk of the disease and pest introduction, especially the so-called needle casts, which was introduced to Western Europe precisely by introduction from America. They represent a significant problem in this area and it would be completely unnecessary to endanger the domestic populations of this tree species. The health status and vitality of the younger stands has recently been worsened by the increased rhabdocline needle cast (*Rhabdocline pseudotsugae*) and Swiss needle cast

(*Pheaocryptopus gaeumannii*) occurrence, in a mixture stands with Norway spruce (PŮBALOVÁ ET HOLKUP 2015). JANKOVSKÝ ET AL. (2014) point out that, it is necessary to carry out sensitivity testing to Swiss needle cast, before any use of planting material. It is definitely worth considering using the domestic population, which has been growing for a century in our conditions, which has already undergone a certain pressure of our environment and therefore selection, and shows an exceptionally good condition and growth. Although it is stated that the quality of the directly obtained seed material is usually not good, it is sufficient for successful natural regeneration and it would be worthwhile to develop programs for obtaining reproductive material of both generative and vegetative origin.

3.7 Use of Douglas fir in relation to climate change

Douglas fir growth is influenced by climate, soil moisture regime and soil nutrient status (ECKHART ET AL. 2019). In its native range, reduced water availability has been shown to limits its growth more than temperature or the length of the growing season (LITTELL ET AL. 2008). On the other hand, it shows lower growth success on heavy soils with higher water content (PERIĆ ET AL. 2011). A significant reduction in growth and wilting signs associated with a soil moisture deficit are also evidenced by the study of SERGENT ET AL. (2014).

Domestic and foreign published sources have confirmed higher resistance to drought and better use of available soil water (e.g. EILMANN ET RIGLING 2010, NADEZHDINA ET AL. 2014, THOMAS ET AL. 2022, URBAN ET AL. 2009, 2011). Douglas fir pumps water from deeper soil layers much more efficiently than Norway spruce and transposes more water during dry periods (ŠACH ET AL. 2019, THOMAS ET AL. 2022). MARTINEZ-MEIER ET AL. (2008) performed a genetic control of Douglas fir tree rings growth in response to a drought and heat wave that occurred in Europe in 2003. Douglas fir appeared to be plastic enough to acclimate to the drought and heat wave and thus managed to recover during 2004. Additionally, the level of heritability estimated indicates that Douglas fir has an adaptive capacity that could be useful for several generations.

Head and drought waves will become more and more frequent intense in our latitude in the future (GIORGI ET COPPOLA 2007, MACKŮ ET KOSOVÁ 2020, SCHÄR ET AL. 2004). Climate change in Central Europe can be associated with acute stress, which can reduce forest trees and whole stands growth and vitality significantly. Stress behaviour is the key for cultivation in view of changing climate, for trees such as Douglas fir, cultivated in Europe, far from its native range (RAIS ET AL. 2014). Douglas fir is considered a promising species to maintain the production of Central European lowland forests to the predicted increase in long dry periods (MOSER ET AL. 2016). EILMANN ET AL. (2013), GIORGI ET COPPOLA (2007), JANSEN ET AL. (2014), NEOPHYTOU ET AL. (2016) and SCHÄR ET AL. (2004) also agree on the same. The climate change consequences in the near future will seriously affect forest ecosystems (GEORGE ET AL. 2019), and the adoption of number adaptation measures is in order, including to a lesser extent the use of introduced tree species and subsequently so-called assisted migration (GÖMÖRY ET AL. 2020, NADEZHDINA ET AL. 2014).

Compared to autochthonous tree species, Douglas fir has great potential to cope predicted climate changes on localities where European beech and Norway spruce are already suffering from increasing drought especially. It could replace dead Norway spruce in mixed European beech stands (FISCHER ET NEUWIRTH 2012). A mixed forest of Douglas fir and European beech has been proposed as one of the possible future forest types in northwestern Europe, but the effects of this mixed forest on soil properties in relation to pure stands of the above-mentioned tree species are unknown (DAWUD ET AL. 2017). THURM ET PRETZSCH (2016) even state that the Douglas fir and European beech mixture has real potential to become the most productive forest community in Central Europe.

An urgent task for projected climate change is to improve our understanding of forest adaptation potential. The long-term predictions are needed, if the frequency and intensity of summer droughts continue to increase for sensitive, but economically important tree species such as Norway spruce. The Norway spruce growth at lower and medium altitudes is strongly endangered during ongoing climate change (VACEK ET AL. 2019c). Although Douglas fir is reported as a drought-tolerant species, our understanding of its growth responses to drought extremes is still limited (VITALI ET AL. 2017). So far, it is considered for a tree species resistant to the effects of climate factors. The exception is damage caused by early and late frosts, which occur commonly in the Central European area (GALLO ET AL. 2017, 2017). Young stands are particularly sensitive to this (CHAKRABORTY ET AL. 2019a, ŠINDELÁŘ 2003). Douglas fir is also susceptible to excessive transpiration during winter, the so-called physiological drought (HOFMAN 1964).

3.8 The Douglas fir growing potential in the Czech Republic

The Douglas fir use in oligo-mesotrophic habitats in the Czech Republic is expected, where it could to some extent replace the Norway spruce economic production, in the future, in connection with global climate change. It acts similarly to white fir (*Abies alba*) in the Czech conditions, from the point of habitats view and especially vegetation conditions (VIEWEGH ET AL. 2014). Its use is planned mainly in mixtures with European beech, Sessile and Pedunculate oaks, sycamore, white fir and European larch (POLENO ET AL. 2009), as the forest stands stability increases with a higher number of tree species (VACEK ET AL. 2020a).

The Douglas fir planting should focus mainly on the substitution of Norway spruce stands that are unsuitable for the habitat. Although Douglas fir will remain a minor tree species, it can contribute greatly to the production achievement and forestry environmental goals. The cultivation principles are summarized by SLODIČÁK ET AL. (2014).

3.8.1 Negative influence and risks of Douglas fir cultivation in the Czech Republic

Most of the potentially negative Douglas fir cultivation consequences (especially significant nutrient take-off due to its intensive growth) can be eliminated to a large extent by cultivating it in a mixture with other tree species. Its optimal proportion is stated to be in the range of 20 – 40 % individuals in the stand, preferably of good quality and regularly distributed over the stand. It is also suitable to leave the logging residues in order to minimize the nutrient removal and organic mass losses.

The Douglas fir intensive growth is also related to its high requirements of water. If we neglect the higher water requirements from the point of its transpiration view, then by cultivating it in a suitable chosen mixture, we will not significantly affect the forest soils water regime (PODRÁZSKÝ ET KUPKA 2011).

Douglas fir supports the microbial community activity in the soil environment more, compared to Norway spruce. This results to faster decomposition of its litter and significantly nitrogen dynamics in the surface humus and the uppermost mineral soil layer increase. This fact can be eliminated again by Douglas fir cultivating in mixtures with tree species corresponding to the habitat (PODRÁZSKÝ ET AL. 2020).

The orientation to the wood raw material, which is not so common in our country, although the potential for use is at least comparable to our conifers, then remains a question. It can be beneficial for the forest owners and managers and also significantly contribute to the forestry competitiveness in the Czech Republic from the point of stability and vitality of Czech forests view.

3.8.2 The Douglas fir cultivation positive benefit in the Czech Republic

The attention paid to Douglas fir is fully justified. This was confirmed by the analysis of research results made in the Czech Republic mainly. Douglas fir is a tree species with a great potential for use in forest management, similar as in a number of European and non-European countries. The most significant is its comparison with Norway spruce.

Norway spruce is the most important part of Czech forestry on the retreat, from the point of the health state and effects on the forest ecosystem view. Its presence in Czech forests and its share in harvesting will probably decrease significantly in the coming decades (PODRÁZSKÝ ET AL. 2013b). Douglas fir appears to be its possible and full-fledged replacement for a number of reasons:

- Douglas fir has a significantly higher production potential than other autochthonous tree species (incl. Norway spruce) at lower and medium altitudes;
- Douglas fir has the character of an ameliorating tree species; it has a less significant effect on the soil condition; it has a significant lower acidification effect in coniferous stands;
- Douglas fir affects the biodiversity of ground layer vegetation less negatively; it is comparable to natural communities;
- Douglas fir has a significant stabilizing effect in terms of stands static;
- Douglas fir cultivation demands will not differ significantly from these of Norway spruce or of other conifers (incl. the use of natural regeneration nursery technologies).

The Douglas fir application potential, including model impacts on production and its value, was carried out by PODRÁZSKÝ (2015) and PODRÁZSKÝ ET AL. (2016b, c). In the case of the Douglas fir cultivation, based on the current legislation and LHP recommendations, i.e. not during its introduction as a dominant tree species, the following potential benefits were modelled:

- the potential forest area (while complying with the ecological limits designated by the legislation) can range from 149,616 to 163,713 hectares, i.e. 5.7 – 6.2 % of the Czech Republic stand area. This is a considerable increase, given that currently this tree species occupies only 0.22 % of stand area (REMEŠ ET AL. 2010);
- the potential economic effect expressed by the synthetic criterion of the forest production gross profit can be calculated in the amount of 683 to 776 million CZK per year (depending on the target management choice).

4 Methods

4.1 Nationwide data on Douglas fir in the Czech Republic

The aim was to collect available numerical data on Douglas fir stands in the Czech Republic, present them clearly in graphs and evaluate this tree species production. Data free published by Forest Management Institute (situated in Brandýs nad Labem) were used for the analysis of the Douglas fir stand area development in the Czech territory and its representation over last 20 years. The data included information on stand area and age classes by administrative regions. These data are available on website of Ministry of Agriculture of the Czech Republic in SIL application – “Summary information on the state of forests and hunting in the Czech Republic” (https://eagri.cz/public/app/uhul/SIL/Default.cshtml). The numbers given here are from the currently valid LHP and LHO as of 12/31 of the given calendar year.

Data bank of the Forest Management Institute containing data of all LHP and LHO as of 12/31/2020 provided the selection for the analysis of the production characteristic and the distribution of the Douglas fir stand area in the Czech territory into FVZ and ecological series (so-called anonymized data). The data of all stands where Douglas fir occurs in the Czech Republic was obtained using an EXCEL table. This table covered information about: storey, storey area, age, stand density, forest (site) type, tree species, (tree) species composition, tree species area, tree species mid-diameter, mean tree (species) height and total tree (species) stock.

4.1.1 Evaluation of the Douglas fir representation in the Czech forests

Bar charts in Microsoft EXCEL were used to analyse Douglas fir occurrence in the Czech forests. For the analysis of the stand area development, percentage representation development and stand area divided according to age classes, according to the individual regions territory of the Czech Republic, the values were taken from https://eagri.cz/public/all/uhul/SIL/Default.cshtml.

The forest (site) type variable from anonymized data was used to divide stand area according to ecological series, as well as for the division into individual forest vegetation (altitudinal) zones (FVZ). Azonal communities (with pines) were released in order to divide stand area into individual FVZ. Small deviations of FVZ in water-influenced habitats were neglected.

4.1.2 Evaluation of stock development over time (growth analysis according to LHP and LHO data)

All evaluation of anonymized data was carried out using the Microsoft EXCEL program, for statistical calculations the Statistica program, ver. 14 (TIBCO Software Inc.).

Growth models were created to analyse production characteristic. Dot charts with smoothed lines of the dependence tree species hectare stock on age were used.

A simplified KORF (1939) function (1) was used for the values in the charts (graphs):

$$V = exp\left(a + \frac{b}{věk^{c}}\right) \quad (1)$$

with a constant value of c = 1

The tree species hectare stock (converted to full representation) for statistical calculations was obtained by recalculating the quantity "total tree species stock" using the quantities "representation" and "storey area" from anonymized data. Parameters *a* and *b* were obtained by non-linear estimations using the Gauss-Newton method (KUBÍČEK ET AL. 2005). To indicate the accuracy of these calculated parameters, the values of determination coefficient (r^2), the input data number (n) and their standard deviation (σ) were also given.

The growth model parameters were sought for individual dominant economic tree species (SM, BK, JD, MD, BO and DB) and Douglas fir, which was used to compare their production in all FVZ regardless of edaphic categories (which were grouped into habitat groups). Habitat groups were defined as sets of edaphic categories, especially according to the soil supply by water, possibly nutrients, as follows:

- extreme – X, Z, Y
- acidic – M, K, N, I, S
- nutrient rich – F, C, B, W
- humid + flooded – L, U, V

- gleyed (stagnic) – O, P, Q
- wetland – G, T, R

The data of three tree species were then excluded from further processing. Scotch pine was included because of its occurrence in various FVZ – the Czech Forest (Site) Ecosystem Classification (VIEWEGH ET AL. 2003, VIEWEGH 2005) created a separate category for Scotch pine, marked "0" (called "pine habitat") covering lowland, hilly, upland, sub-mountainous and mountainous pines communities. The oaks were eliminated for two reasons. The most important one was due to lack of the relevant species distinction (there are no data for pedunculate oak and for sessile oak – everything is taken as the oak only). Another reason was that oaks are mainly located in the lower FVZ (1^{st} – 3^{rd}). European larch is in demand in the woodworking industry, but its annual litter acidifies the humus layer and organomineral horizon more than Norway spruce (ALRIKSSON ET ERIKSSON 1998, PODRÁZSKÝ ET ŠTĚPÁNÍK 2002, PODRÁZSKÝ ET ULBRICHOVÁ 2004). Therefore, the data were further processed only for Douglas fir (DG), Norway spruce (SM), white fir (JD) and European beech (BK). Production was then jointly determined in individual FVZ (2^{nd} – 7^{th}) (there was not enough initial data for the 1^{st} FVZ) without taking habitat groups into account. Production together for these economic tree species on individual habitat groups regardless of FVZ was continued to calculate. The calculations for the mentioned economic tree species were subsequently continued individual for FVZ (3^{rd} – 6^{th}) and for individual different habitats, on the basis of the above-mentioned calculations. Due to the comparison of the Douglas fir and Norway spruce, calculations were made separately for each FVZ (3^{rd} – 6^{th}) and also for edaphic categories K, S, B, H, D, V, O and P. Some FVZs lacked the required data amount, so they had to be omitted.

FVZs with the highest and lowest Douglas fir production were selected to compare total volume production (CVP) in 140 years. The same regression equation (1) was used to model the dependence of mean height and mean diameter on age. A mean stem (a stem with the parameters – mean height (*h* in *m*) and mean diameter (*d* in *cm*)) has a volume V_m, which was calculated according to the volume equation for the respective tree species.

For Douglas fir:

$$V = \pi \frac{(d/100)^2}{4} h \left[0{,}10798 + \frac{0{,}71858}{\log(10d)} + 0{,}04065 \frac{h}{d} - \frac{10^{5{,}947 - 2{,}174 \log(10d) - \frac{5{,}228}{\log(10h)} + \frac{11{,}867}{\log(10d)\log(10h)}}}{1000} \right] \quad (2)$$

equation according to REMEŠ (2020), with a correction.

For Norway spruce:

$$V = 0{,}00004013841\,(d+1)^{1{,}821816}\, h^{1{,}132062} - 0{,}00928540767\,(d+1)^{-1{,}02037409}\, h^{0{,}896100664} \quad (3)$$

according to PETRÁŠ ET PAJTÍK (1991)

The volume of the cone (eq. 4) and the volume of mean stem were added to the respective age using volume equations (2, 3) using the mean diameter and height model:

$$V_0 = (\pi(d/200)^2)h/3 \quad (4)$$

The cone volume (4) is an approximation of the mean stem volume for smaller individuals, where the volume equations (2) and (3) are inaccurate or have not been validated for such smaller individuals. For further calculations, the cone volume is used until the age when the calculated value of V_0 is higher than the volume according to the relevant volume equation. The number of individuals per hectare was obtained by dividing the stock per hectare and the mean stem (cone) volume at the respective age. The default value of the individuals number per hectare (theoretical maximum) for given tree species and habitat was always taken from Decree No. 456/2021, i.e. for Douglas fir 2,500 pcs.ha^{-1} and for Norway spruce 3,000 pcs.ha^{-1}. The maximum volume of thinning in individual years was estimated by the multiple of the decrease in the individual number per hectare between individual years and the mean stem (cone) volume. However, value modelled in this way may be overestimated since individuals with lower growth or damage are mostly removed during thinning. Total volume production was obtained by summing the thinning volume with the hectare stock (final stock) at the respective age. Since it is assumed that Douglas fir will be cultivated in mixtures with other economic tree species, theoretical stock situations were calculated with different mixtures representation of economic tree species in 120 years at selected FTG.

4.2 Permanents research plots

4.2.1 Suitable stands selection

LHP data were obtained from Czech State Forests in order to select suitable stands for establishment of permanent research plots. The territory of the Forest District Vodňany was chosen due to the highest number of mature stands with a different Douglas fir representation, after evaluating these data. The basic criteria for specific stands selection to situate the permanent research plots were: single-storied stand, minimum age of 80 years, well-developed ground layer vegetation and minimum estimated stand canopy of 50 % with a variable Douglas fir representation in stand mixture.

4.2.2 Permanent research plots establishment

Total of 25 permanent research plots (TVP) were established in 4 localities at the beginning of autumn 2019 in South Bohemia in the Písecko area (Fig. 3). Individual localities were named after the nearby villages of Kamýk, Sedlice, Vodňany and Vráž. Permanent research plots were situated in forest stands according to following five variants, always in repetitions:

- monoculture – Douglas fir over 90%
- predominant tree species - Douglas fir representation in the range of 50 – 90 %
- basic tree species – Douglas fir representation in the range of 30 – 50 %
- admixed and interspersed tree species – Douglas fir representation in the range of 10 – 30 %
- individually admixed tree species – Douglas fir representation up to 10%

Each permanent research plot has the circle shape with a radius of 12.616 m, i.e. a size of 500 m^2. Individual permanent research plots were situated randomly depending on Douglas fir presence in the stand so that, there was distance of at least 25 m between them and permanent research plots of one variant were located in at least three different forest stands.

All the centres of these plots were stabilized and their coordinates were centred using the Trimble Geo 7X instrument with the TerraSync program (version 5.81). Each measured point was taken from 30 places with a setting of min. elevation = 5°, max PDOP = 7 and min. SNR = 30. Subsequently, the points orientation was refined by post-processing in the GPS Pathfinder Office program (version 5.85) using differential corrections from the reference station Strakonice (http://www.vrsnow.cz). Table 3a demonstrates the coordinates with the indicated accuracy of the individual permanent research plots centres and their affiliation to the locality.

Table 3b includes basic stand characteristics according to LHP (age is related to the year of the field measurement at 2019). The basic stand characteristics of Sedlice, Vodňany and Kamýk localities were taken from the LHP made for LHD Vodňany (code 209 000) valid from 1/1/2018 to 31/12/2027, and of the Vráž locality from the LHP made for LHC Čížová (code 207 002) with validity from 1/1/2011 to 31/12/2020.

Fig. 3. Research area location in the Czech Republic

Table 3a. Centre coordinates of individual permanent research plots

No TVP	Locality	S-JTSK [m]		WGS-84 [°]		Accuracy [m]
		X	Y	N	E	
1	Sedlice	1118023,7	790129,4	49,3601769	13,9166661	1,0
2		1118018,3	790188,5	49,3601492	13,9158500	1,0
3		1118144,5	790058,4	49,3591936	13,9178708	0,9
4		1118177,8	790065,5	49,3588878	13,9178408	0,5
5		1118111,4	790064,3	49,3594811	13,9177258	0,6
6		1117851,6	790272,3	49,3615247	13,9143808	1,1
7		1117822,4	790261,4	49,3617994	13,9144717	0,6
8		1118676,3	790858,4	49,3534319	13,9080189	0,6
9	Vráž	1119089,7	775519,1	49,3692978	14,1178706	0,8
10		1119114,0	775509,5	49,3690936	14,1180472	1,6
11		1119177,2	775367,8	49,3687094	14,1201022	0,7
12	Vodňany	1139650,4	780901,7	49,1794511	14,0843428	0,9
13		1139628,4	780907,9	49,1796389	14,0842161	0,5
14		1139946,5	780078,2	49,1778564	14,0960969	1,6
15		1142235,0	781574,5	49,1555908	14,0801978	2,1
16		1142262,1	781573,2	49,1553511	14,0802678	0,5
17		1142274,8	781612,1	49,1551881	14,0797644	2,7
18		1142204,5	781558,7	49,1558817	14,0803528	2,0
19		1142125,6	781608,7	49,1565208	14,0795225	0,8
20	Kamýk	1135744,2	765804,2	49,2331622	14,2820347	0,9
21		1135763,8	765828,5	49,2329575	14,2817411	1,1
22		1135825,5	765895,0	49,2323258	14,2809547	2,0
23		1138891,5	764060,0	49,2072956	14,3117094	0,9
24		1138849,3	764169,9	49,2075361	14,3101353	2,5
25		1137514,6	763651,0	49,2200656	14,3146669	0,5

Table 3b. Basic stands data according to LHP

No TVP	Locality	Part of a stand	area [ha]	age	Stand density	DG proportion [%]
1, 2, 3, 4, 5	Sedlice	185Ca9	10,63	88	8	8
6, 7		185Ba12	5,31	119	7	15
8		188Ca10	3,93	94	8	10
9, 10, 11	Vráž	15Da8c	4,17	83	8	10
12, 13	Vodňany	716Aa10	0,15	96	7	100
14		717Ba12	1,3	116	8	2
15, 16, 18		621Ca9	3,62	85	9	12
17		621Da11	0,29	111	9	10
19		619Ca9	1,98	86	9	12
20, 21	Kamýk	306Fa11	0,35	104	9	20
22		306Da11	1,98	104	8	10
23, 24		118Ba11a	4,42	110	8	15
25		206Ga9	3,81	89	10	1

Table 3c. Basic habitat parameters on individual TVP

No TVP	Locality	altitude [m a.s.l.]	Exposure	slope [°]	Soil type	Forest (site) type	Temperature average [°C]
1	Sedlice	537	NE	2	KM	4S2	7,11
2		546	NE	2	KM	4S2	7,06
3		530	E	2	KM	4S1	7,17
4		530	E	2	KM luv	4S1	7,21
5		538	E	2	KM luv	4S1	7,16
6		521	N	10	KM luv	4B7	7,15
7		520	N	10	KM luv	4S1	7,18
8		533	SW	1	KM luv	4S1	7,15
9	Vráž	455	S	3	LM mod	3K3	7,57
10		456	E	1	LM mod	3S6	7,59
11		443	S	1	LM mod	3S1	7,62
12	Vodňany	560	W	1	LM mod	4K2	7,05
13		562	W	2	LM mod	4K2	7,05
14		531	W	5	Km mod	5S1	7,18
15		516	W	5	KM mod	4S2	7,31
16		517	W	10	KM mod	4S2	7,30
17		513	W	10	KM mod	4S2	7,32
18		520	W	10	KM mod	4S2	7,32
19		506	W	5	KM mod	4K4	7,36
20	Kamýk	515	SE	1	KM luv	4S1	7,28
21		513	SE	2	KM luv	4S1	7,28
22		509	SE	5	KM luv	4S1	7,30
23		586	NW	15	KM mod	4S2	6,89
24		587	NW	7	KM mod	4S2	6,91
25		518	S	5	KM luv	4S1	7,25

The monitored stands are located mainly in the 4th FVZ on mesophilous and acidic habitats, various exposures with slopes from 1 to 15 degrees and at altitudes from 443 to 587 m a.s.l. The altitude in the studied region is shown in Fig. 4. The average temperature on individual TVP for period 1961 – 1990 was calculated according to MATĚJKA (2012) and KINDLMANN ET AL. (2012, pp. 87-97) in the PlotOA program (https://infodatasys.cz/software/hlp_PlotOA/PlotOA.htm). The average temperature in the studied region is shown in Fig. 5. The most represented soil types are haplic cambisol and haplic albeluvisol. An overview of the basic habitat parameters on individual TVP is given in Table 3c.

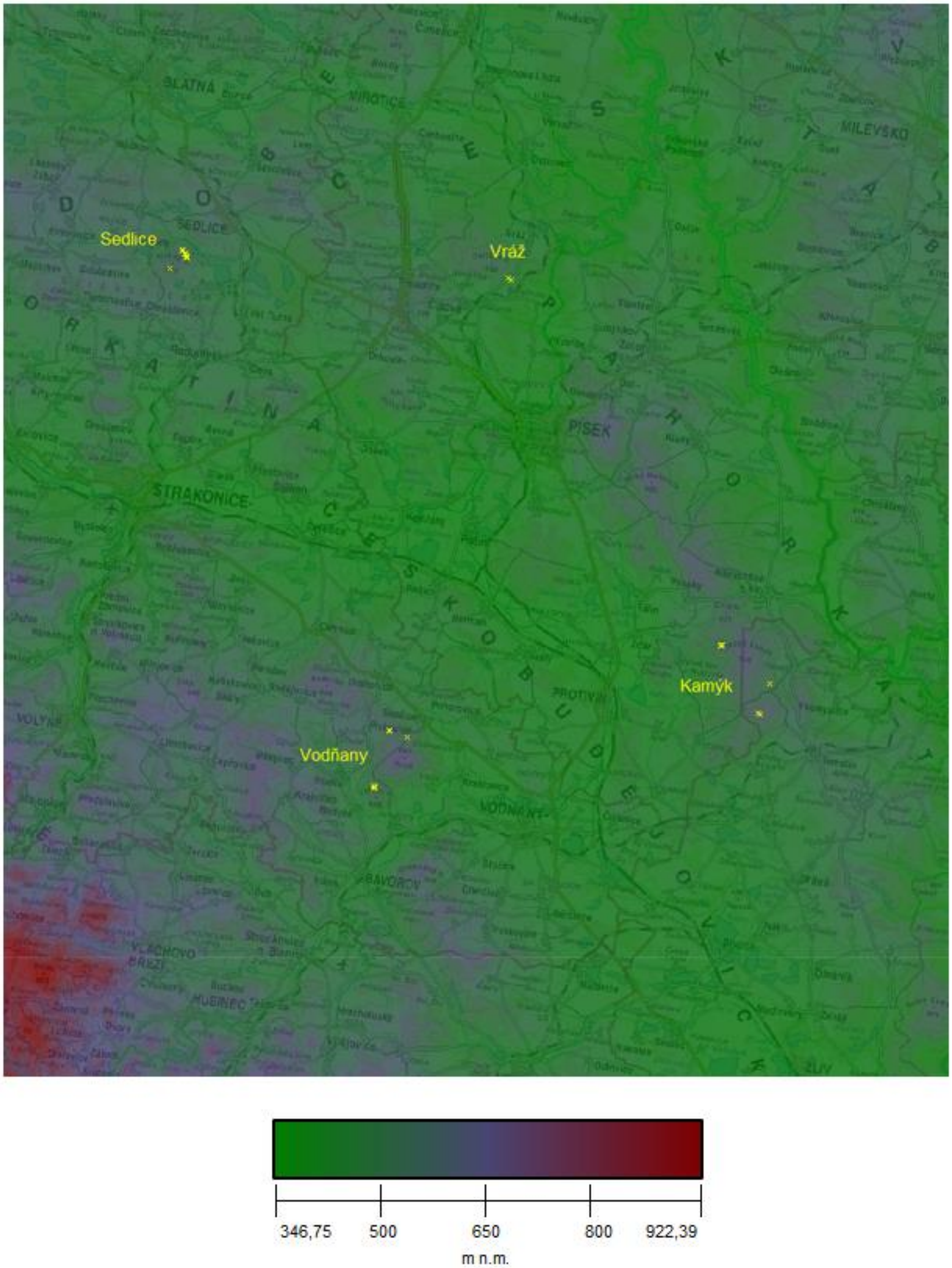

Fig 4. Studied area altitudes with individual permanent research localities

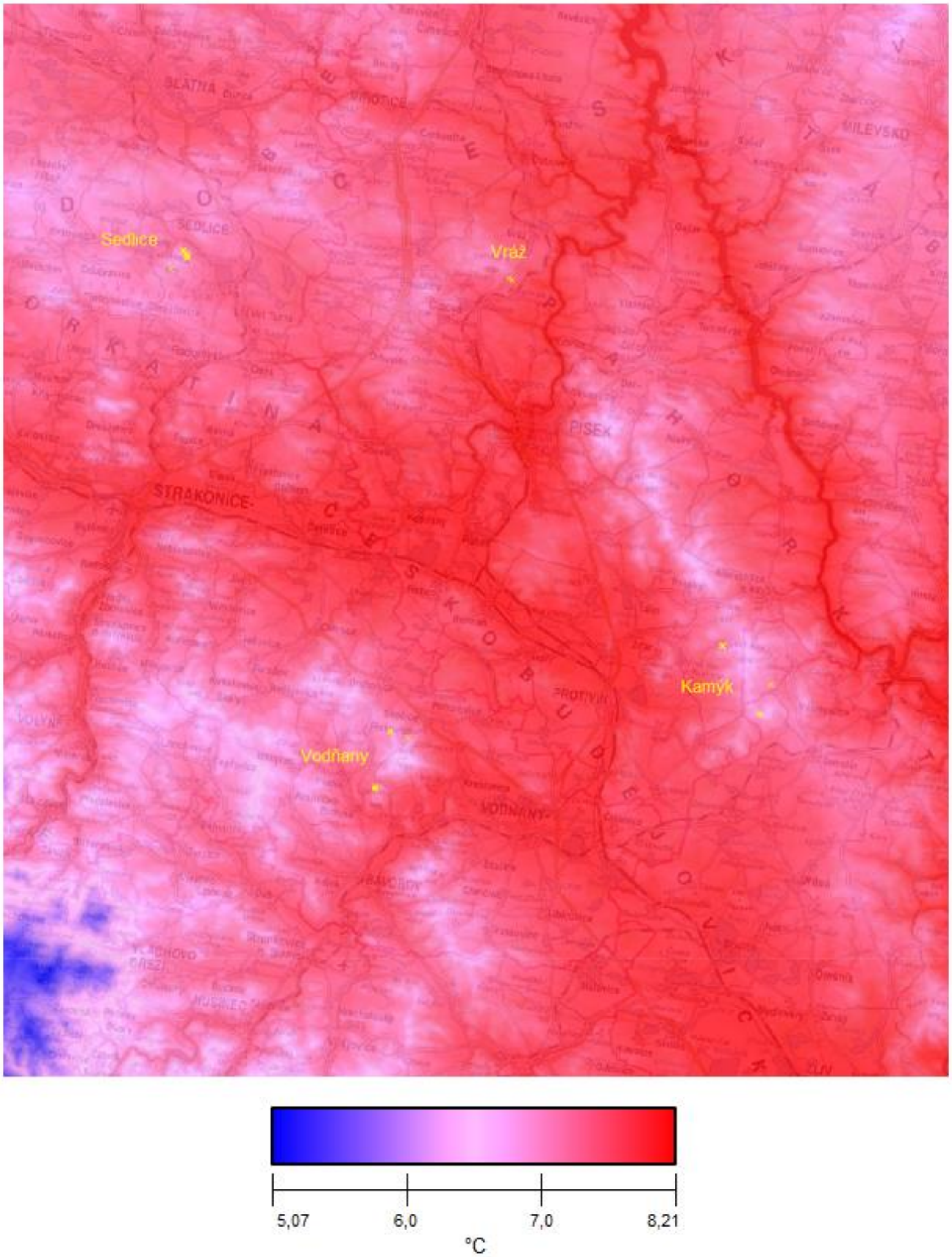

Fig. 5. Studied area average temperature with individual permanent research localities

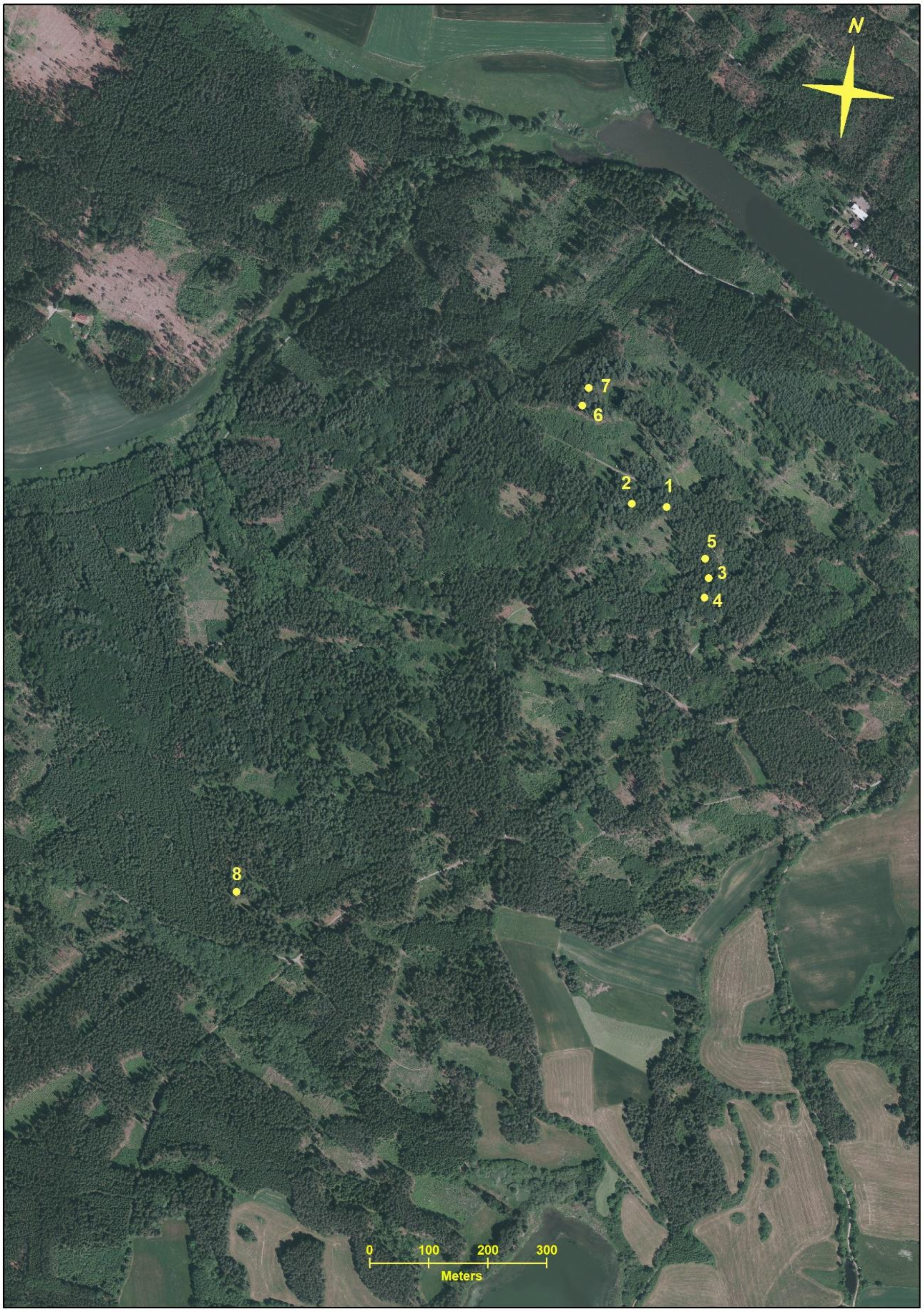

Fig 6. Permanent research plots 1-8 location (Sedlice location) based on orthophoto from 2019

Fig 7. Permanent research plots 9-11 location (Vráž location) based on orthophoto from 2019

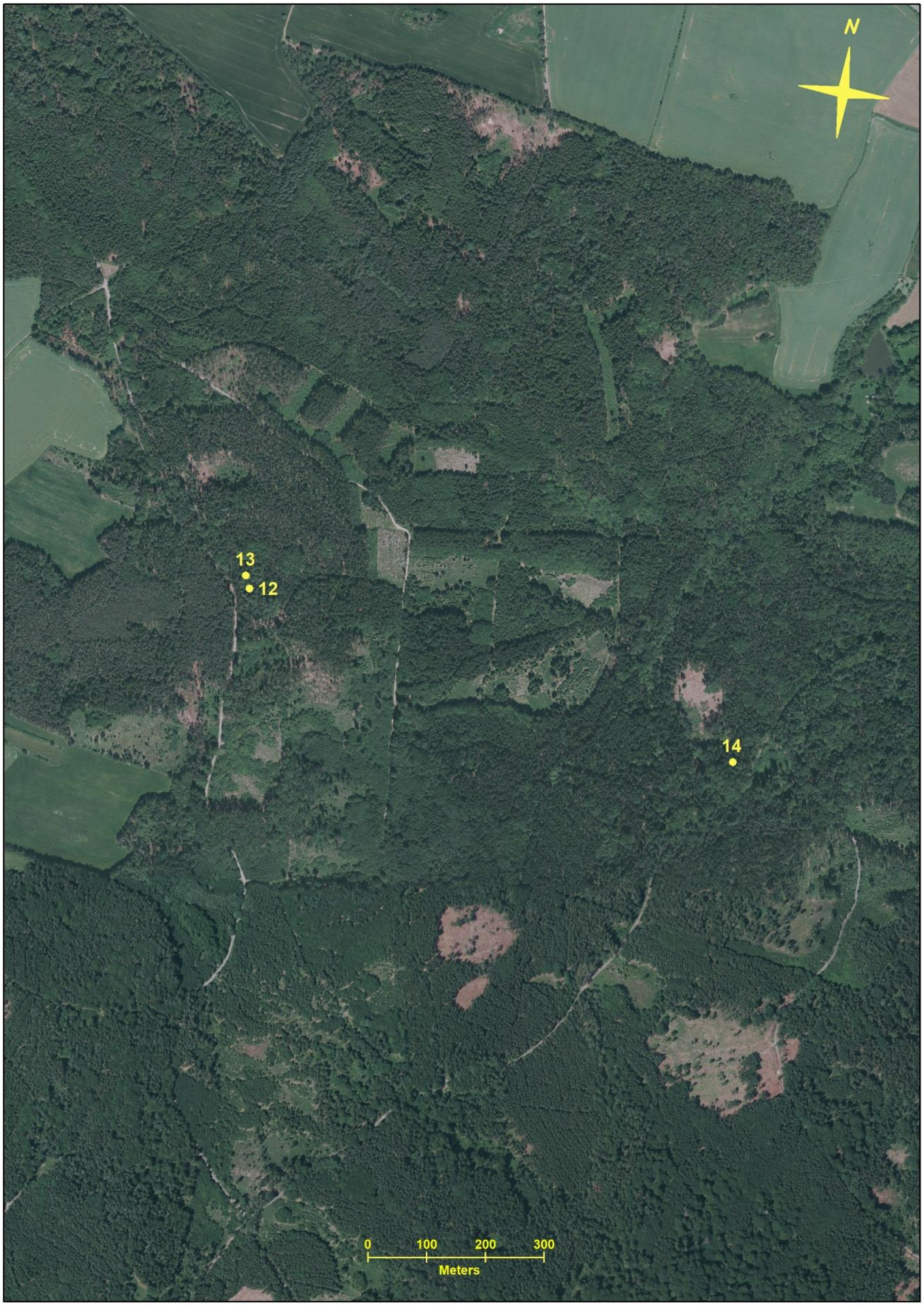

Fig. 8. Permanent research plots 12-14 location (Vodňany location) based on orthophoto from 2019

Fig. 9. Permanent research plots 15-19 location (Vodňany location) based on orthophoto from 2019

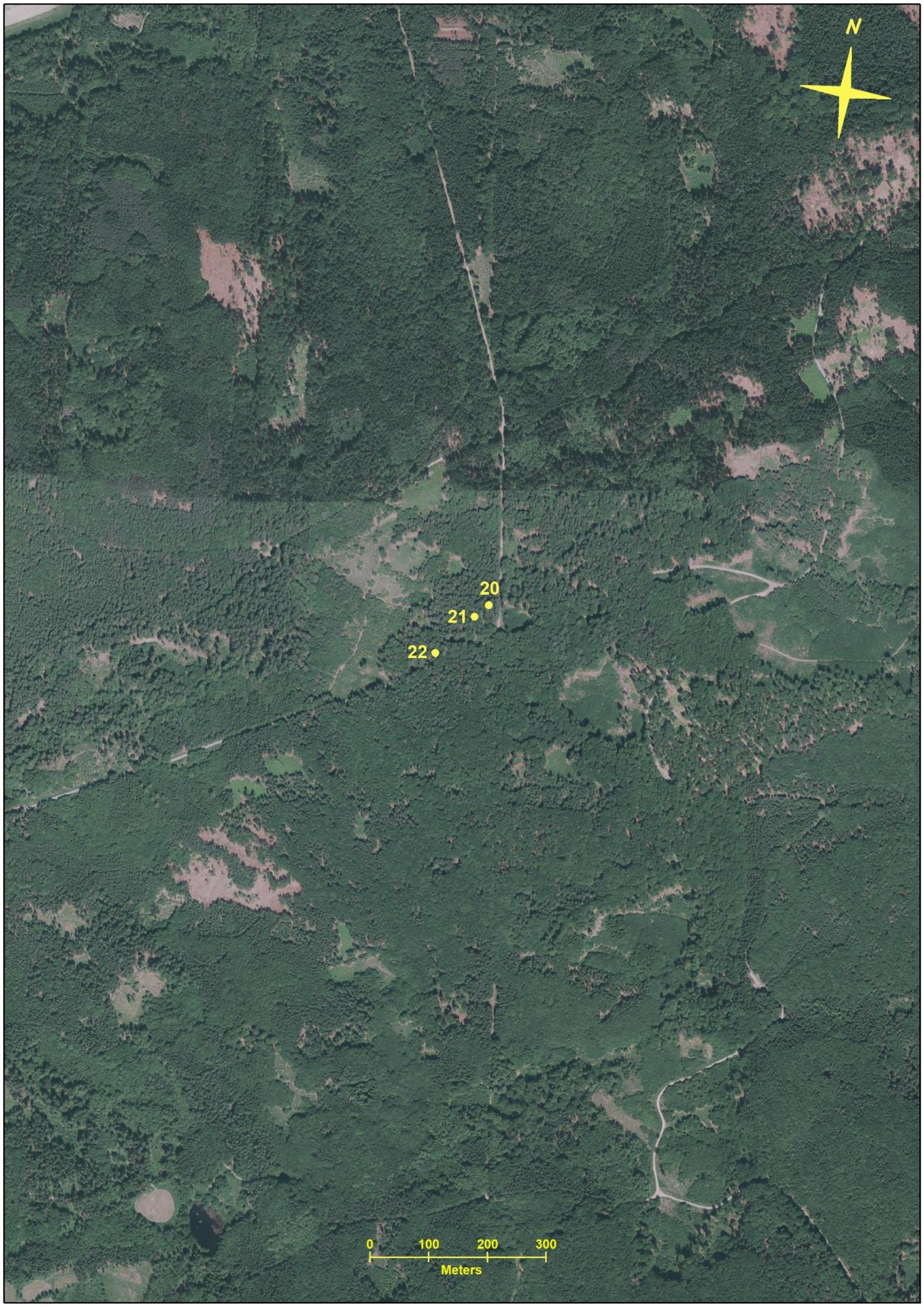

Fig. 10. Permanent research plots 20-22 location (Kamýk location) based on orthophoto from 2019

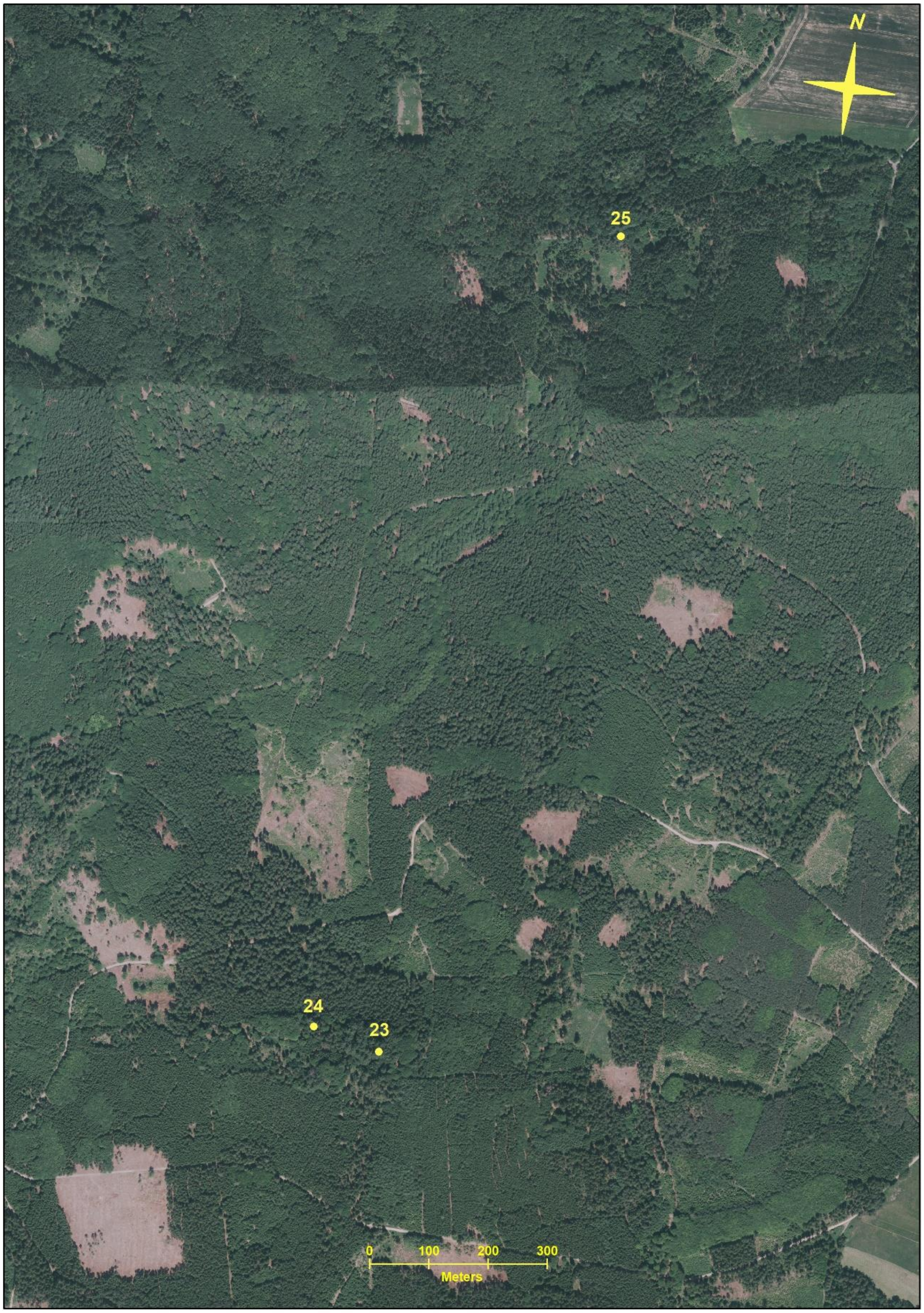

Fig. 11. Permanent research plots 23-25 location (Kymýk location) based on orthophoto from 2019

All TVP were located in forest complexes. Locality Sedlice: TVP Nos. 1-5 were located on a very gentle slope, at a distance 20-50m of larger clearing; TVP No. 6 and 7 were located on a slope with a stream at a distance of 20 – 50 m. TVP No. 8 was located almost on the plain with a small clearing at a distance of 20 m south. Locality Vráž: TVP Nos. 9-11 were situated on a very gentle slope, stand margin is more than 300 m away southern and a large clearing was far of 50-70 m northern. Locality Vodňany: TVP Nos. 12 and 13 were situated almost on the plain; no clearing was in the immediate vicinity and stand margin was about 200 m far from; TVP No. 14 was situated on a gentle slope with 70 m far from the larger clearing; TVP Nos. 15-19 were situated on a gentle slope and stand margin was more than 300 m; nearest clearing was about 120 m away from TVP No. 16, southeast. Kamýk locality: TVP Nos. 20-22 were situated on a gentle slope and nearest clearing was 70-100 m northwest; TVP Nos. 23 and 24 were located on a slope just below the ridge, the nearest clearing was more than 200 m far from; TVP No. 25 was situated on a gentle slope, clearing was 20 m south. Figs. 6 – 11 show localities of individual TVP based on an orthophoto made in 2019.

4.2.3 Data collection on permanent research plots (TVP)

4.2.3.1 Phytocoenological relevés making

Phytocoenological relevés was carried out due to document of the plant community species composition, and Douglas fir influence on its composition. A phytocoenological relevé was made at each TVP in August 2019. The following layer were monitored: E_0 – moss and lichens layer, E_1 – all vegetation up to 1 m, E_2 – all vegetation in the range of 1 to 3 m and E_3 – all vegetation above 3m. The coverage of individual species and the total coverage by individual layers were estimated according to ZLATNÍK (1978) – Table 4.

Table 4. The Zlatník's scale

label	Coverage (%)
r	1-2 individuals
+	up to 1
1	1-5
-2	5-15
2	15-25
-3	25-37
3	37-50
-4	60-62
4	62-75
-5	75-89
5	89-100

4.2.3.2 Hemispheric photographs making

Hemispheric photographs were also taken to more accurately determine the tree canopy and the diffuse radiation amount penetrating into the undergrowth. Canon EOS 6D camera with a Sigma F3.5 EX DG fisheye lens was taken, which was placed on a Vanguard Alta Pro 2 tripod. This set was completed with a two-axis level and a compass (Fig 12); see https://infodatasys.cz/proj008/hemisphericalphotos.htm.

Five points were randomly selected for photography on each TVP, and each point was focused using the Trimble Geo 7X device in the same way as the centres of individual TVP (see Chapter 4.2.2). A pair of photographs was taken at a height of 100 and 133 cm above the soil surface at each sensing point. These photos therefore show the canopy of the tree layer – E_3 – and part of the shrub layer - E_2 – depending on the height of these photos making. Thus, a total of 5 photographs pairs were making at each TVP. The camera lens was oriented so that it pointed vertically upwards and the upper photo edge was always to north. Automatic shutter and aperture settings were used. The photos were processed and evaluated at the IDS firm (www.infodatasys.cz).

Fig. 12. Set for making hemispheric photographs (foto K. Matějka)

4.2.3.3 Tree layer structure measurement

Field-Map technology (IFER) was used to determine the tree layer structure of Douglas fir and Norway spruce mixed stands. The positions of all trees with a total diameter greater than or equal to 7 cm and their crown projections were aligned using this technology. The breast height diameters were measured by a Mantax Blue caliper (Haglöf, Sweden) in at least two mutually perpendicular directions with an accuracy of 1 mm. The height if individual measured trees and the height of their living crowns were measured with an accuracy of 0.1 m by laser altimeter Vertex Laser – VL 5 (Haglöf, Sweden).

4.2.3.4 Increment core sampling

The 14 TVP were selected for the analysis of radial growth. Data were obtained by increment core sampling using a Pressler's auger (Mora, Sweden) at a breast height. The sampling took place in the fall of 2019. Twenty-five incremental cores were collected from living subdominant and dominant Douglas fir and Norway spruce in each of the five above-mentioned variants of Douglas fir representation in the stand. So, 250 increment cores were taken at least. The increment cores were taken from the trees always down the slope and to the centre of the tree or to depth of 30 cm at least. The sampling trees were situated directly on the plot or in its immediate vicinity. The taken increment cores were immediately fixed by gluing them into wooden pads and they were ground and smoothed before actual measurement. The widths of individual tree rings were measured with an accuracy of 0.01 mm by an Olympus binocular microscope on a LinTab measuring table (Rinntech) recorded using the TsapWin program (Cukor et al. 2020). The taken increment rings were processed in the FLD laboratory including growth indices calculations (by Vojtěch Hájek).

4.2.4 Data evaluation of TVP

4.2.4.1 Phytocoenological relevés evaluation

Phytocoenological relevés were recorded into the DBreleve program (MATĚJKA 2020). The data were transformed in this program, so that the sum of all species respective layers coverages in relevé corresponded to the total this layer coverage (the species representativeness was used hereafter). Phytocoenological relevés of all permanent plots (25) were processed to determine the species constancy (MORAVEC ET AL. 2000) and plot's homogeneity *sensu* RAUNKIAER (1905). Characteristic types of TVP (at all locations) were classified by Braun-Blanquet's floristic units (according to CHYTRÝ ET AL. 2013). The next phytocoenological relevé classification were made by the TWINSPAN method (HILL 1979), which is a part of the CANOCO software package (TER BRAAK ET ŠMILAUER 2012), up to the 6th level of dichotomous division.

The DCA method (based on HILL 1979) was used to analyse the variability of the species composition on all TVP. This method belongs to CANOCO software package (TER BRAAK ET ŠMILAUER 2012).

The CCA method (HÄRDLE ET SIMAR 2007), which is a part of the CANOCO software package (TER BRAAK ET ŠMILAUER 2012), was used to analyse the effect of three species on the herb layer composition. The E_1 layer vegetation data was one variables group. Combined data represented tree species in $E_2 + E_3$ layers all species were as the second variables group. The *Sorbus aucuparia* species was excluded due to very rare occurrence on TVP No. 2.

The methods principle used in above mentioned operations is described in Appendix 1.

4.2.4.2 Evaluation of light conditions below the tree layer

Hemispheric photos were processed by the CanopyPhotos program (MATĚJKA 2018a, 2021). This program made it possible to create their database with a complete description, where processing protocol and obtained results were subsequently recorded. The images geometry was set in accordance to the parameters of the lens used. These parameters were determined by laboratory resting (LANG 2014, LANG ET AL. 2010). The processing basis was the automatic classification of hemispheric photographs, which consists in assigning each of its pixels to one of two classes. The first class is "Canopy", i.e. the tree crowns, foliage, or other shade, and the second class is "Sky", i.e. the sky and gaps. This classification was based on the hemispheric photographs taken at the height of 1 m above soil surface. A hemispheric photograph taken in the field and classified hemispheric photograph is shown in Fig. 13.

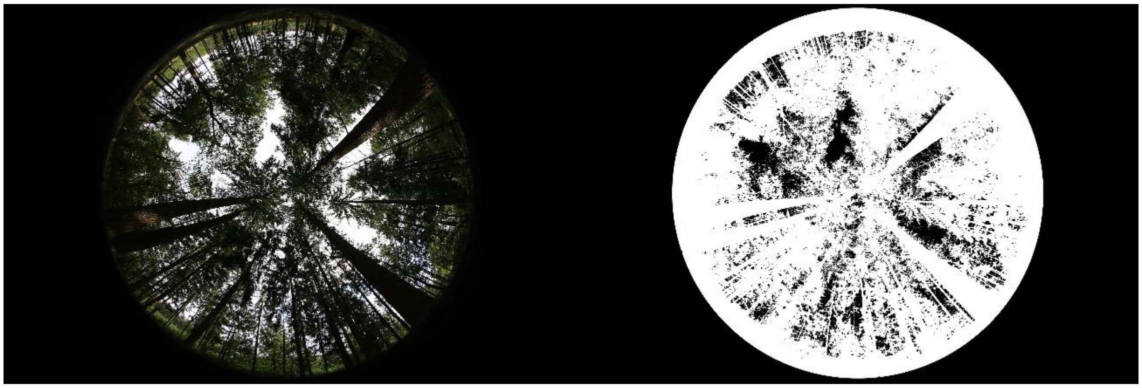

Fig. 13. A sample of a hemispheric photograph taken in the field and a classified hemispheric photograph (foto K. Matějka)

The gaps distribution in a classified hemispheric image is described as a relative frequency of "Sky" class pixels depending on the angle from the vertical (zenith angle). The percentage of diffuse radiation (L) (5) was calculated as a weighted arithmetic mean of the share of the bright pixels number (N_{Sky}) at a given angle from the vertical (α) (MATĚJKA 2021):

$$L = \int_0^{\pi/2} \cos(\alpha) N_{Sky}(\alpha) d\alpha \bigg/ \int_0^{\pi/2} \cos(\alpha)(N_{Sky}(\alpha) + N_{Canopy}(\alpha)) d\alpha \quad (5)$$

Only the proportion of each hemispheric photograph that is close to vertical was used to determine the crown canopy (C) (6). Therefore, it is only pixels with $\alpha \leq \alpha_0$ ($\alpha_0 = 22°$ was set for the calculations). Since a pixel with a zenith angle α is projected onto a horizontal plane at crown height h at a distance h × tg (α), the size of the pixel is proportional to the derivate of this value, i.e. to the function $w(\alpha) = h/\cos^2(\alpha)$. Therefore, the canopy is calculated as weighted share of the of the number N_{Canopy} pixels from the total number of pixels weighted by the function w(α) (MATĚJKA 2021):

$$C = 1 - \int_0^{\alpha_0} \cos^{-2}(\alpha) N_{Sky}(\alpha) d\alpha \bigg/ \int_0^{\alpha_0} \cos^{-2}(\alpha)(N_{Sky}(\alpha) + N_{Canopy}(\alpha)) d\alpha \quad (6)$$

4.2.4.3 Tree layer structure evaluation

Mensuration data measured by Field-Map technology were exported to DBF (dBase/FoxPro) format tables. The following indicators were calculated separately for each TVP in the Microsoft Visual FoxPro 9 environment:

- mean of breast height diameter as the arithmetic mean of all tree diameters of a given tree species on TVP;
- mean height as the arithmetic mean of all the given tree species heights on TVP;
- mean height of the living crown deployment as the arithmetic mean of all the living crown deployment heights of given tree species on TVP;
- mean crown projection as the arithmetic mean of all crown projections of the given tree species on TVP;
- number of individuals per hectare as the sum of targeted given tree species individuals on TVP converted to 1 hectare;
- mean of basal area at breast height (b.h.) as the sum of all given tree species basal area (b.h.) on TVP divided by the number of these individuals;

- hectare basal area (b.h.) as the sum of all given tree species basal area (b.h.) on TVP converted to 1 hectare;
- individual tree species representation as a share of tree species basal area (b.h.) and stand basal area (b.h.);
- mean of individual tree species volume as a proportion of tree stock per hectare and individual number per hectare;
- stock per ha for individual tree species as the sum of all volumes of targeted on individuals of a given tree species on a TVP calculated according to volume equations (see (2) and (3)). In this way obtained volume was subsequently recalculated to an area of 1 ha.
- A map was made from the data measured by Field-Map technology using the QGIS 3.18 Zürich program for each TVP, which shows the position of the measured trees and their crown projections. The canopy was calculated using the displayed crown projections. If any crown projection extended out of the TVP, part of this crown projection that was located in the TVP was included in calculation only. If there was an overlap of some crown projection, this overlap was counted for one of them only. The canopy value obtained in this way can be lower compared to reality, since trees whose trunk is out of the TVP but whose crown projection extends in the TVP, are not taken into account.
- A comparison was also made between the calculated and actual hectare stocks of Douglas fir and Norway spruce on all TVPs with the model calculated according to the modified formula of Korf's function (eq. 1).

4.2.4.4 Increment core evaluation

A total of 247 increment cores were evaluated of which 126 belonged to Douglas fir and 121 to Norway spruce (Table 5).

The sequence of tree rings was synchronized (to remove errors caused by missing tree rings) using statistical tests in the PAST application (KNIBBE 2007) and then subjected to visual inspection according to YANAGUCHI (1991) for individual series of increment cores. If a missing ring was found, a 0.01 mm wide ring was inserted in such position. The age trend was removed from individual growth curves and average growth curves were created by ARSTAN program (Cook, Tree Ring Laboratory) for each variant. The age trend was removed in two steps, in the first step using a negative exponential function, in the second step using a Spline function with a time window of 0.67 n (GRISSINO-MAYER ET AL. 1992). The result of the entire standardization process is a series of annual growth indices for each tree.

Table 5. Number of analysed increment cores belonging to a TVP

TVP	Lokality	DG	SM
1	Sedlice	12	16
3		12	15
4		12	0
5		0	16
9	Vráž	12	0
10		0	13
12	Vodňany	13	0
14		15	0
15		0	9
16		0	9
19		13	9
21	Kamýk	12	9
23		0	25
24		25	0
total		126	121

The analysis of negative annual indicators (see below) was carried out according to Desplanque et al. (1999) and Schweingruber (1996). For each tree, the annual indicator was tested as an extremely narrow tree ring, which does not reach 40 % of the four previous year's average increase. The occurrence of a negative year was proven when such a strong growth reduction occurred in at least 20 % of the trees in the TVP.

Growth index data between 1965 and 2019 were chosen for further analysis, as this period is covered by data for all trees except for the 3 youngest individuals, whose data were excluded from processing. Growth index curves were correlated for all pairs of individuals. Person's linear correlation coefficient (r) was used. These correlation coefficients form a symmetric correlation matrix. This matrix was used for ordination analysis using the PCA method (the STATISTICA program was used for the calculation, the graphs were created in the PlotOA program). At the same time, this matrix was used to calculate the distance matrix (between objects i and j), where $d_{ij} = 1 - r_{ij}$. Distance matrix was used for cluster analysis (classification of individuals) by Ward's method. The CLUSTER program from DBreleve package (Matějka 2020) was used.

The CHMI data (www.chmu.cz) were chosen for the evaluation tree rings dependence on weather. There are 5 meteorological stations of CHMI in the wider interest area. However, the Kocelovice station has been measuring since 1975 and similarly The Temelín station has been providing results since 1989, which was too short period for our measurements and therefore these stations were rejected. The results from the stations Strakonice (indicative C1STRA01), Nadějkov – Větrov (C2NADV01) and Vráž (C1VRAZ01) could be used for the purposes of this study. The first of them, Strakonice, is situated on the increasing urban agglomeration edge, and this fact is emphasized by a significant decrease in air humidity during the last 30 years (-7.4 %). Nadějkov – Větrov station is relatively more distant of TVPs. The Vráž station, situated near the research areas, had the highest potential for use its data, i.e. due to a similar altitude (433 m a.s.l.) and, moreover, a high forests landscape. The mutual position of the 4 research sites (TVPs) and the main CHMI stations are shown in Fig. 14 and Vráž station is shown in Fig. 15.

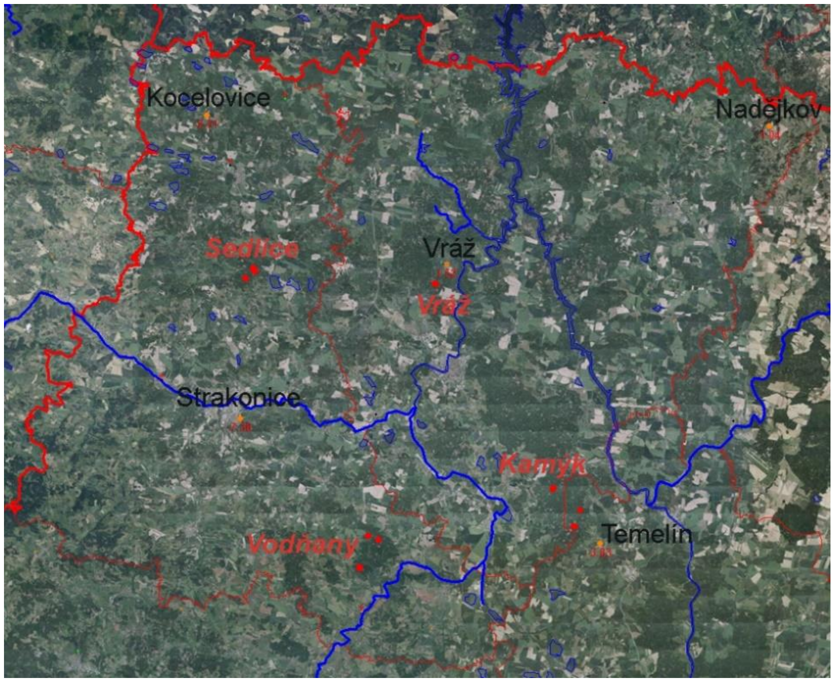

Fig. 14. The location of 4 research habitats (Sedlice, Vráž, Vodňany, Kamýk) together with the nearest meteorological stations of the CHMI (Kocelovice, Nadějkov, Vráž, Strakonice, Temelín)

Fig. 15. Meteorological station Vráž (C1VRAZ01; foto K. Matějka)

Climatic characteristic from the Vráž station were evaluated using a time floating window with variable length (number of days) and position (described by the serial number of the last day of the year). This two-dimensional floating window application is based on methods used in the R package astrochron (https://rdrr.io/cran/astrochron/man/mwCor.html) or in SAGEMAN ET HOLLANDER (1999). Relative to this window, the average weather characteristics of that year (with any overlap to the previous year) were calculated for each year. The correlation coefficient between the average value for the weather and the radial growth index was calculated for individual samples of both tree species. The set of resulting correlation coefficients was compiled into graphs, from which the position of the correlation coefficient extreme values can be seen. The position of the floating time window is defined by the window end day (horizontal coordinate) and the window width – the number of days (vertical coordinate). In this way can be estimated in which time interval the given climatic characteristic had the greatest influence on the growth of the given tree species.

5 Results

5.1 Nationwide data and their analysis

5.1.1 Analysis of the Douglas fir occurrence in the Czech forests

A total 6,893.43 ha of Douglas-fir forest area were registered in the Czech Republic to 12/31/2020. This corresponds to 0.26% of all Czech forests. Information on the Douglas fir area development in the Czech Republic in the period 2000 – 2020 is shown in Fig. 16. Douglas fir increased between the end 2000 and end 2020 by total of 2,614 ha, i.e. by an average of 131 ha per year, i.e. by a total of 0.09%. Above-average increase area occurred in the years 2002, 2008, 2009, 2011, 2018, 2019 and 2020.

The current age Douglas fir structure in the Czech Republic can be seen in Fig. 17. The most represented age class is the first, followed by fifth and second. Mature stands are less and overmatures minimum. It is evident that the more massive Douglas fir was spread in Czech forests roughly since sixties last century.

Current information on the Douglas fir area in the territory of individual administrative regions is shown in Fig. 18. The largest stand area occupied by Douglas fir is in South Bohemian region, followed by Pilsen and Central Bohemian regions. Conversely the lowest stand area occupied by Douglas fir is in the Liberec, the Ústí and Prague regions.

Douglas fir relative coverage of Czech administrative regions is shown in Fig. 19. The order of the individual administrative regions changes somewhat in the relative numbers, if the region size and its forest cover are primarily taken into account. The highest Douglas fir coverage is in the South Bohemian region again, followed by Pilsen and Central Bohemian regions. Prague region is the 4th. On the contrary, the Liberec and Ústí regions have the smallest Douglas fir relative coverage.

The current Douglas fir stand area percentage distribution in the Czech Republic into FVZ (forest vegetation zone) is shown in fig 20. Douglas fir has the largest stand area in the 3rd FVZ, namely 2,467 ha, followed by the 4th and the 5th FVZ. A relatively larger percentage distribution is still in the 2nd and 6th FVZ. The 1st, 7th and 8th FVZ's have relative stand area minimal.

Fig. 21 shows current Douglas fir forest area division into ecological series. Almost a half of all Douglas fir stands in the Czech Republic are planted on nutrient habitats – 48.68 % (*series* *trophicum*), in a frame of this habitats the vast majority belongs (according to forestry classification, VIEWEGH ET AL. 2003, VIEWEGH 2005) to S edaphic category (*categoria oligo - mesotrophica*) – 62.42%, B edaphic category (*categoria trophica*) – 23.20% and H edaphic category (*categoria illimerosa trophica*) – 10.15%. Douglas fir stands are also highly represented on acidic habitats (*series acidophylum*) – 36.92% and in the frame of this habitats K edaphic category (*categoria acidophila*) dominates – 81.97% and it is followed by I edaphic category (*categoria illimerosa acidophila*) – 12.08%. It also worth noting the Douglas fir occurrence on stagned (gleyed) habitats (*series variohumida*) – 9.84% and in a frame of this habitats its occurrence in O edaphic category (*categoria variohumida trophica* – 57.50%, and P edaphic category (*categoria variohumida acidophila*) 37.73%. Douglas fir occurs on other habitats minimally (Fig. 21).

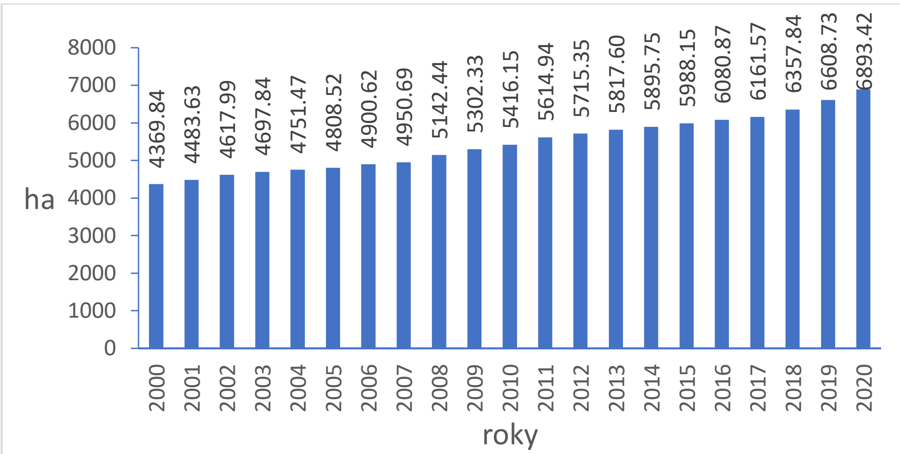

Fig. 16. Douglas-fir stands area development in the Czech Republic in the period of 2000 – 2020 (source: https://eagri.cz/public/app/uhul/SIL/Default.cshtml)

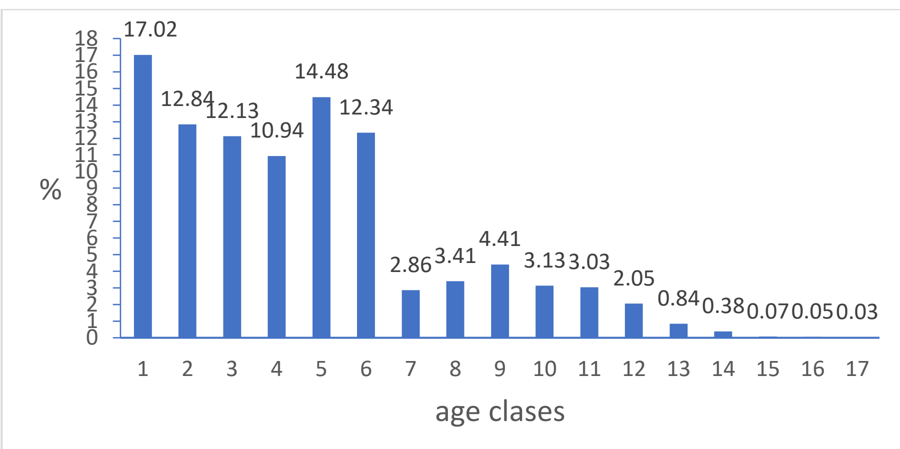

Fig. 17. Douglas-fir stands area composition in the Czech Republic by age classes in 2020 (source: https://eagri.cz/public/app/uhul/SIL/Default.cshtml)

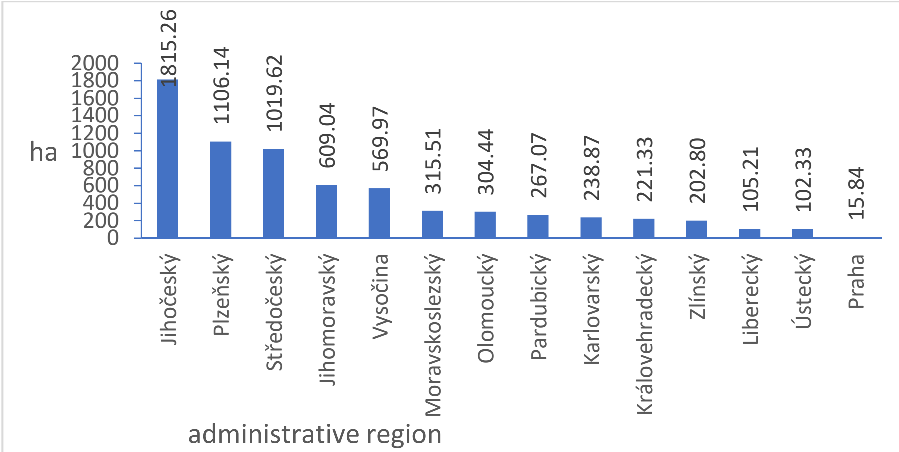

Fig. 18. Douglas-fir stands area composition in individual administrative regions of the Czech Republic in 2020 (source: https://eagri.cz/public/app/uhul/SIL/Default.cshtml)

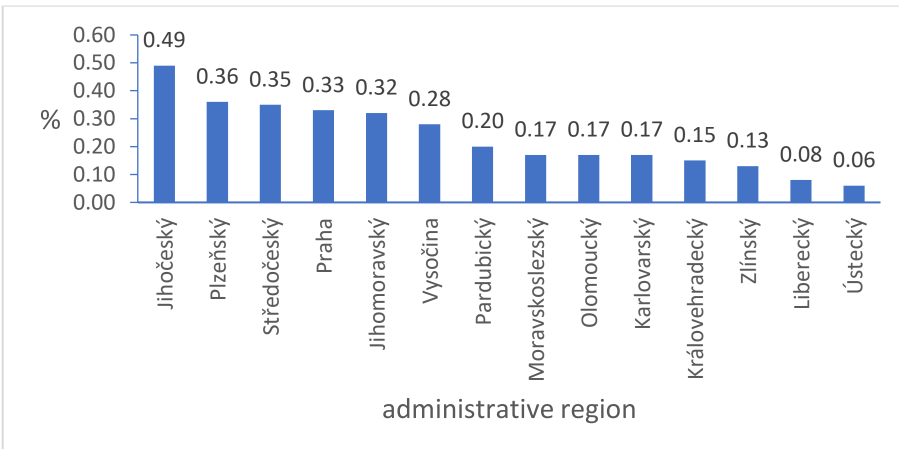

Fig. 19. Douglas fir relative coverage of Czech administrative regions in 2020 (source: https://eagri.cz/public/app/uhul/SIL/Default.cshtml)

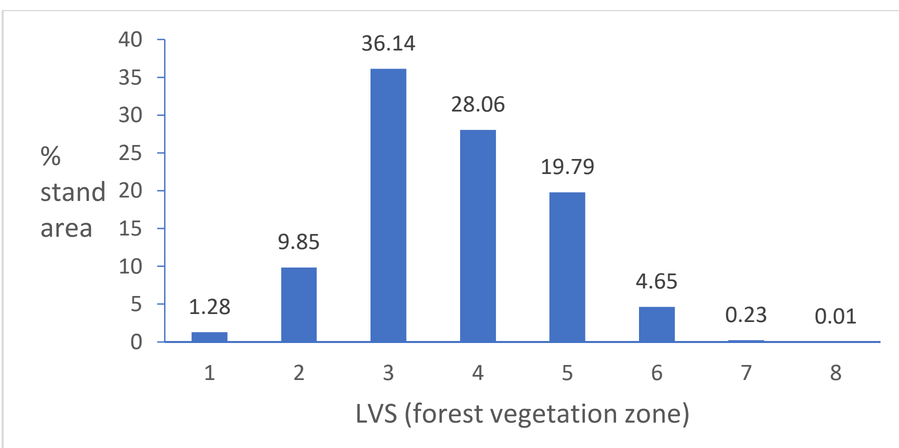

Fig. 20. Douglas-fir stand area percentage distribution in the Czech Republic into FVZ in 2020

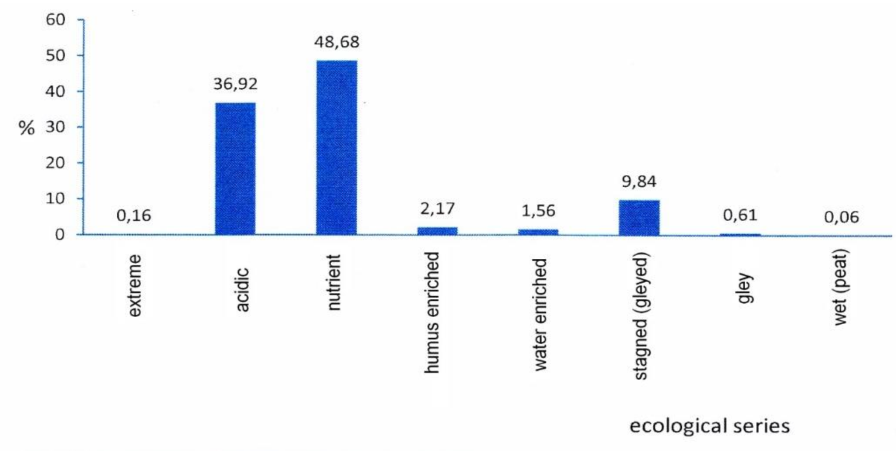

Fig. 21. Douglas-fir stands area composition in ecological series in 2020

5.1.2 Selected production characteristics analysis in the Czech forests

5.1.2.1 Production of the main commercial tree species of the Czech Republic

Taking into account the part of stands in the Czech Republic in which Douglas fir occurs, we can compare the Douglas fir production and other tree species on the basis of mixed stands. This comparison was made using a regression curves (see Chap. 4.1.2). The used growth model in the form of a simplified Korf's function describes the growth of the analysed tree species with approximately the same error, as evidenced by the determination index values in the range of 0.83 (DB) to 0.88 (SM).

The development curves of the yield per hectare of Douglas fir and the main commercial tree species in relation to age, regardless of FVZ and FTG, are shown in Fig. 22. It shows the always oak (species not distinguished) lowest yield. The following Scotch pine and European beech curves show Scotch pine higher yield per hectare at a younger age then European beech. European beech yield per hectare gradually increases and is approximately the same Scotch pine in the range of 120 – 160 years, above this European beech surpasses Scotch pine. The European larch yield per hectare is initially higher of Norway spruce and silver fir, but this tendency disappears around its 60th year. The Norway spruce and silver fir yield per hectare almost overlap. As it turns out, the Douglas fir yield per hectare is the highest from a young age.

Average hectare standing volumes in 100 years according to the growth model are shown in Table 6 (data sourced from LHP of part of stands where Douglas fir grows together with compared tree species). It turns out that the Douglas fir has the highest standing volume, followed by silver fir, and closely followed by Norway spruce in 100 years. European larch has a slightly lower hectare standing volume, and Scotch pine has about 100 $m^3.ha^{-1}$ less of the European larch. European beech lags behind Scotch pine by 20 $m^3.ha^{-1}$ only. Oaks have about 250 m^3 less hectare standing volume in 100 years than Douglas fir. Table 6 also shows the stand areas of the main Czech commercial tree species.

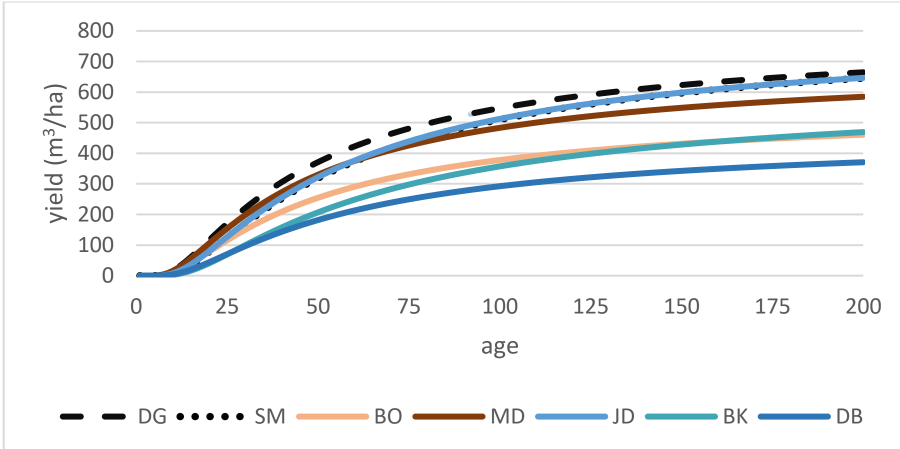

Fig. 22. The main Czech commercial tree species yield per ha model of development in relation to age

Table 6. Average hectare standing volumes in 100 years according to the growth model (data sourced from forest management plans of part of stands where Douglas fir grows together with compared tree species) and stand areas of the main Czech commercial tree species (as of 31/12/2020).
r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation 1, Chapter 4.1.2).

Tree species	DG	SM	BO	MD	JD	BK	DB
Standing volume [m^3 ha^{-1}]	547	510	378	483	512	357	292
r^2	0,8536	0,8763	0,8439	0,8482	0,8623	0,8723	0,8319
n	46886	37723	17812	19946	9102	20906	9174
σ	209	190	149	182	200	132	117
a	6,6938	6,7051	6,3303	6,5617	6,7043	6,4241	6,1531
b	-38,8661	-46,9941	-39,5360	-38,1214	-46,5029	-54,5833	-47,5115
Area in ha	6893	1267213	413170	100632	30016	235755	188837

5.1.2.2 Selected tree species production according to FVZ

Fig. 23 demonstrates the lowest Douglas fir hectare standing volume in the 1st FVZ, which results from the climatic characteristics of this FVZ (Viewegh 2005). Curves showing hectare standing volume in 2nd and 7th FVZs follow. The hectare standing volume is also low in these FVZs, so it can be concluded that Douglas fir cultivation in the 1st, 2nd and 7th FVZs is not very suitable. The hectare standing volume in the 3rd, 4th, 6th and 5th FVZs (other curves) with gradually increasing production already indicate the suitability of its cultivation in these FVZs.

The curves of Norway spruce hectare standing volumes in above mentioned FVZs (Fig. 24) show a similar distribution as for Douglas fir. Although the graphic trends seem very similar, Table 7 shows that Douglas fir has a higher hectare standing volume than Norway spruce in each reported FVZs. The hectare standing volume of Douglas fir and Norway spruce are then further compared with European beech and silver fir from the 2nd to the 7th FVZ.

The European beech hectare standing volume from 2nd to 7th FVZ (without taking into account the edaphic conditions; Figs. 25 to 30) is significantly lower than that of the other three conifers, of which the Douglas fir standing volume is the highest. Also, its hectare standing volume is the lowest of all reported FVZ in the 7th FVZ. This fact is completely understandable, since it becomes distinctly sub-dominant tree in this FVZ. The mutual fluctuation of the Norway spruce and sliver fir hectare standing volume overlaps in the 3rd FVZ (Fig. 26) is interesting. In the 4th FVZ (Fig. 27), these three conifers hectare standing volume approaches at a higher age, after all, Douglas fir has it higher than silver fir and Norway spruce roughly between 10 and 100 years. The trend started in 4th FVZ continues in the 5th and 6th FVZs (Figs. 28 and 29) – mutual convergence of these three conifers hectare standing volume. But Douglas fir begins to be less productive than silver fir at a higher age (over 120) in the 6th FVZ. Apparently due to climatic conditions, silver fir shows a more significant decrease in the hectare standing volume in the 7th FVZ. It is mutually balanced for Douglas fir and Norway spruce, although it is insignificantly higher for Douglas fir.

Douglas fir, Norway spruce and European beech have the highest hectare standing volume in the 5th FVZ (Table 8 – highlighted in yellow), but Norway spruce has it lower than Douglas fir by 31 $m^3.ha^{-1}$ and European beech by up to 210 $m^3.ha^{-1}$.

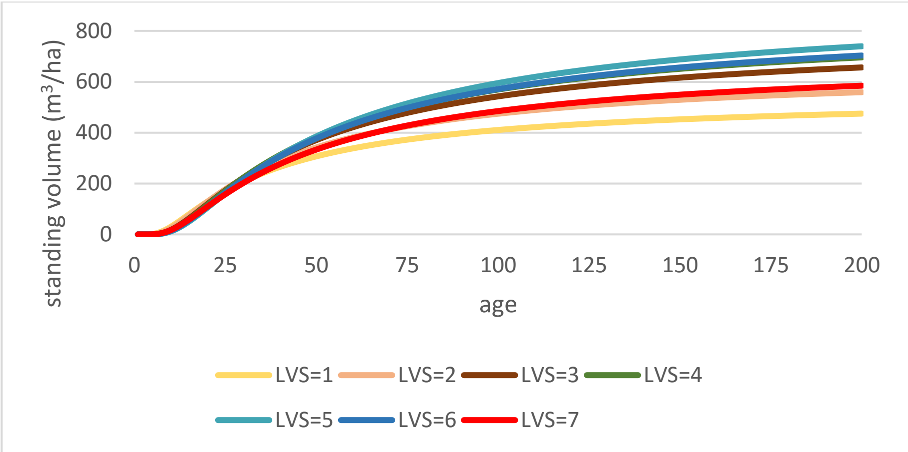

Fig. 23. Douglas-fir standing volume per ha model of development on 1st – 7th FVZ in relation to age

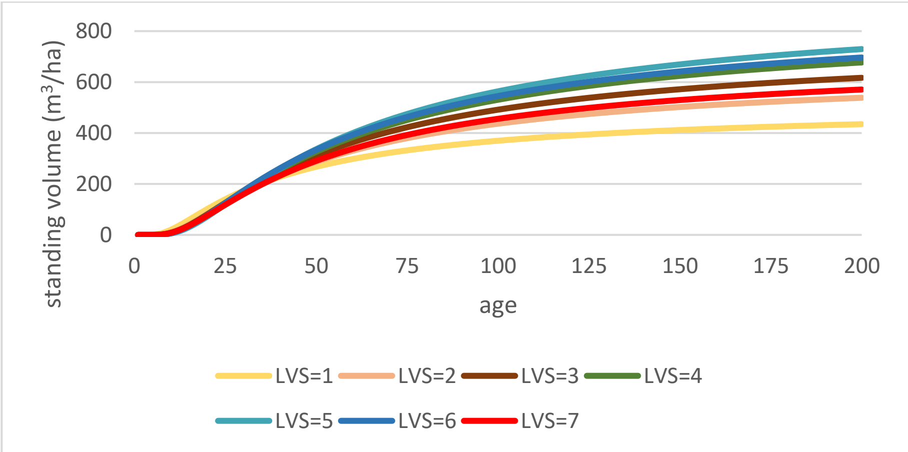

Fig. 24. Norway spruce standing volume per ha model of development on 1st – 7th FVZ in relation to age

Table 7. DG and SM hectare standing volume of the 1st – 7th FVZs in 100 years

r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).

FVZ	Standing volume in 100 years [$m^3 ha^{-1}$]			
	DG		SM	
1	410	r^2 = 0,7895 n = 763 σ = 175 a = 6,3083 b = -29,1168	370	r^2 = 0,7866 n = 294 σ = 150 a = 6,2364 b = -32,3527
2	474	r^2 = 0,8263 n = 4559 σ = 195 a = 6,4902 b = -32,8217	437	r^2 = 0,8480 n = 2681 σ = 171 a = 6,4982 b = -41,8968
3	543	r^2 = 0,8658 n = 16224 σ = 212 a = 6,6772 b = -38,1001	492	r^2 = 0,8871 n = 12643 σ = 188 a = 6,6513 b = -45,3508
4	569	r^2 = 0,8652 n = 12831 σ = 214 a = 6,7456 b = -40,1046	531	r^2 = 0,8909 n = 10973 σ = 194 a = 6,7617 b = -48,7578
5	595	r^2 = 0,8666 n = 9463 σ = 212 a = 6,8237 b = -43,5506	564	r^2 = 0,8884 n = 8457 σ = 197 a = 6,8505 b = -51,5930
6	571	r^2 = 0,8623 n = 2271 σ = 202 a = 6,7632 b = -41,5396	545	r^2 = 0,8966 n = 2093 σ = 186 a = 6,7912 b = -49,0039
7	485	r^2 = 0,8387 n = 101 σ = 180 a = 6,5581 b = -37,4536	456	r^2 = 0,8701 n = 93 σ = 165 a = 6,5719 b = -44,9643

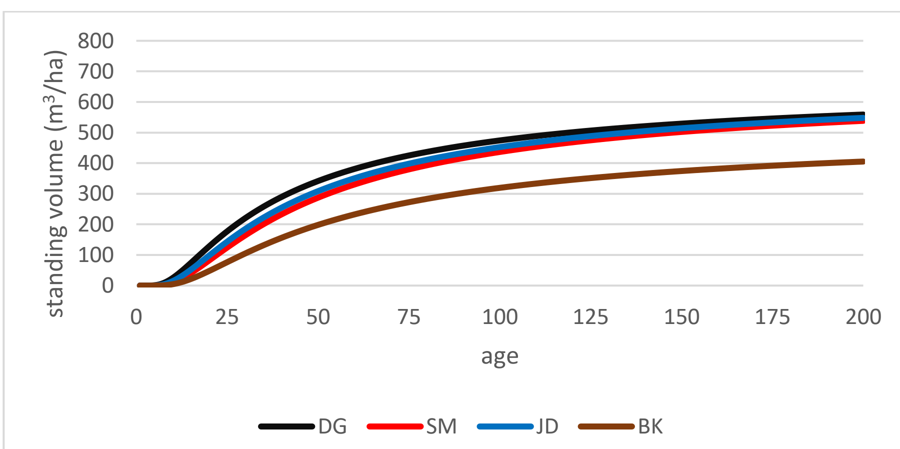

Fig. 25. DG, SM, JD and BK standing volume per ha model of development on 2nd FVZ in relation to age

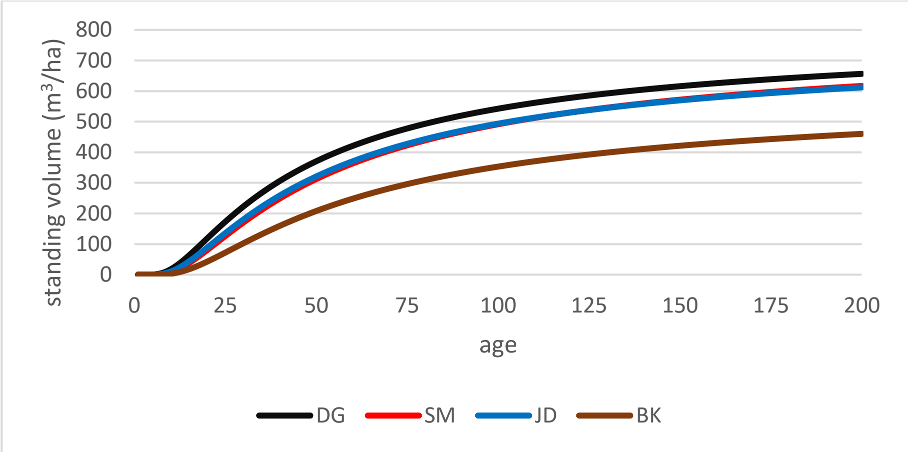

Fig. 26. DG, SM, JD and BK standing volume per ha model of development on 3rd FVZ in relation to age

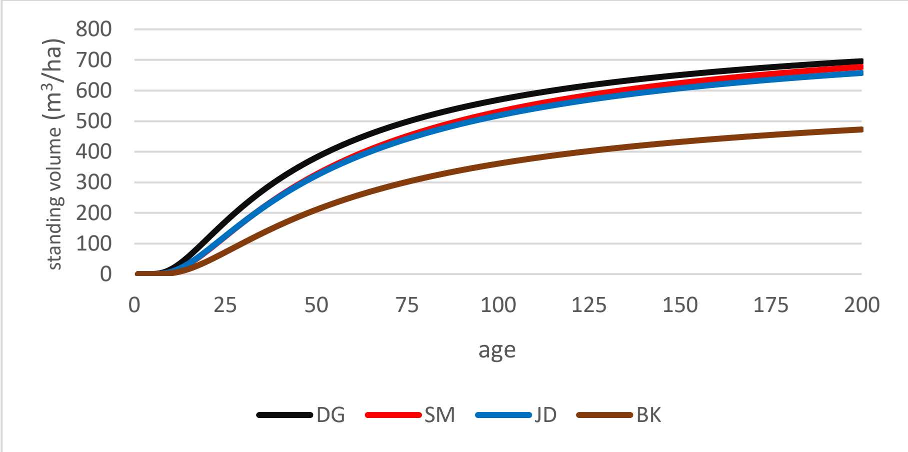

Fig. 27. DG, SM, JD and BK standing volume per ha model of development on 4th FVZ in relation to age

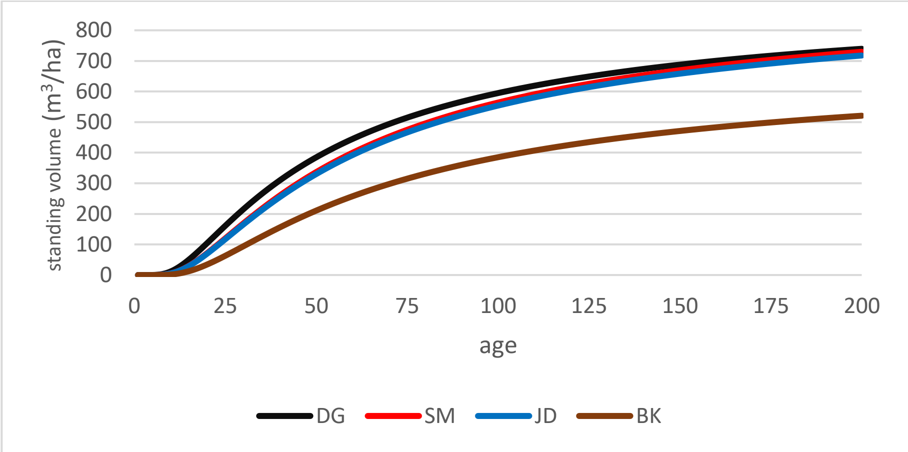

Fig. 28. DG, SM, JD and BK standing volume per ha model of development on 5th FVZ in relation to age

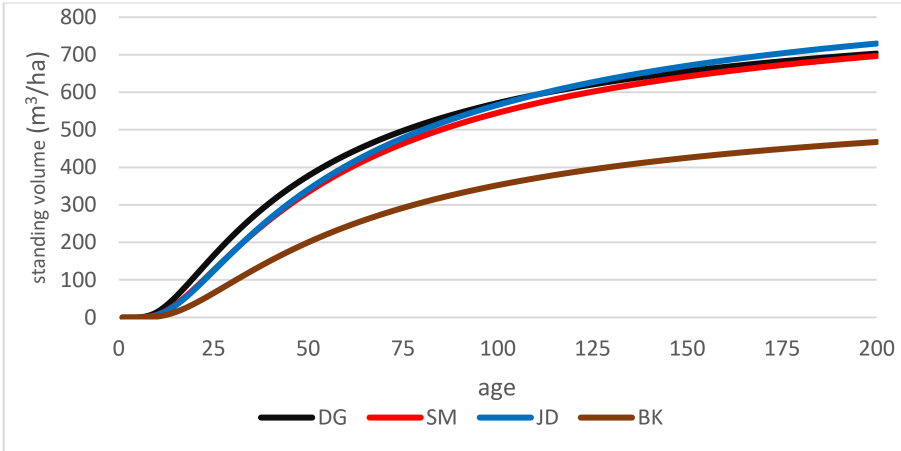

Fig. 29. DG, SM, JD and BK standing volume per ha model of development on 6th FVZ in relation to age

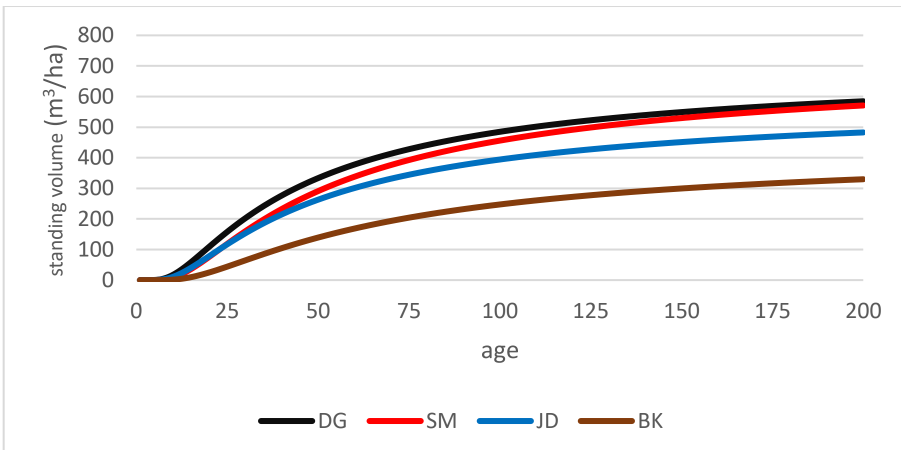

Fig. 30. DG, SM, JD and BK standing volume per ha model of development on 7th FVZ in relation to age

Table 8. DG, SM, JD and BK hectare standing volume of the 2nd – 7th FVZ in 100 years
r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).

FVZ	Standing volume in 100 years [$m^3 ha^{-1}$]							
	DG		SM		JD		BK	
2	474	r^2 = 0,8263 n = 4559 σ = 195 a = 6,4902 b = -32,8217	437	r^2 = 0,8480 n = 2681 σ = 171 a = 6,4982 b = -41,8968	453	r^2 = 0,8627 n = 457 σ = 191 a = 6,4978 b = -38,2940	319	r^2 = 0,8556 n = 1282 σ = 127 a = 6,2430 b = -47,6633
3	543	r^2 = 0,8658 n = 16224 σ = 212 a = 6,6772 b = -38,1001	492	r^2 = 0,8871 n = 12643 σ = 188 a = 6,6513 b = -45,3508	494	r^2 = 0,8653 n = 2676 σ = 204 a = 6,6321 b = -43,0481	353	r^2 = 0,8806 n = 6837 σ = 136 a = 6,3963 b = -52,9429
4	569	r^2 = 0,8652 n = 12831 σ = 214 a = 6,7456 b = -40,1046	531	r^2 = 0,8909 n = 10973 σ = 194 a = 6,7617 b = -48,7578	518	r^2 = 0,8747 n = 3009 σ = 201 a = 6,7264 b = -47,6173	361	r^2 = 0,8799 n = 6465 σ = 133 a = 6,4283 b = -53,9758
5	595	r^2 = 0,8666 n = 9463 σ = 212 a = 6,8237 b = -43,5506	564	r^2 = 0,8884 n = 8457 σ = 197 a = 6,8505 b = -51,5930	554	r^2 = 0,8537 n = 2149 σ = 202 a = 6,8347 b = -51,7649	385	r^2 = 0,8724 n = 4699 σ = 128 a = 6,5570 b = -60,3446
6	571	r^2 = 0,8623 n = 2271 σ = 202 a = 6,7632 b = -41,5396	545	r^2 = 0,8966 n = 2093 σ = 186 a = 6,7912 b = -49,0039	566	r^2 = 0,8973 n = 610 σ = 191 a = 6,8467 b = -50,7667	352	r^2 = 0,8545 n = 1221 σ = 120 a = 6,4300 b = -56,5423
7	485	r^2 = 0,8387 n = 101 σ = 180 a = 6,5581 b = -37,4536	456	r^2 = 0,8701 n = 93 σ = 165 a = 6,5719 b = -44,9643	394	r^2 = 0,9262 n = 74 σ = 156 a = 6,3820 b = -40,5289	247	r^2 = 0,8399 n = 62 σ = 93 a = 6,0859 b = -57,5653

5.1.2.3 Selected tree species production by habitat group

The silver fir hectare standing volume is the lowest in extreme habitats (without takin into account FVZ) (Fig. 31) due to completely understandable reasons – quite unsuitable soil and climatic conditions. European beech is doing much better in these habitats, but its hectare standing volume is visibly lower than that of Douglas fir and Norway spruce, whose hectare standing volumes are approximately the same.

The European beech per hectare standing volume is lowest in acidic, nutritious, humid (+ flooded) and gleyed (stagnic) habitats groups (without taking into account FVZ) (Figs. 32 to 35). Norway spruce and silver fir have it almost identical (they differ in 100 years in units of $m^3 ha^{-1}$ – Table 9) and Douglas fir has it only slightly higher compared to them. The silver fir hectare standing volume in 100 years slightly exceeds Douglas fir on humid + flooded habitats groups (Fig. 34) and again slightly in 40-year-old Norway spruce stands.

Table 9 shows that the compared tree species have the highest hectare standing volume in 100 years on the humid + flooded habitat group (edaphic categories L, U and V). The differences among conifers are negligible (even identical between DG and JD), but significantly lower for European beech.

Wetland habitat group (edaphic categories G, T and R) is not shown due to insufficient initial data.

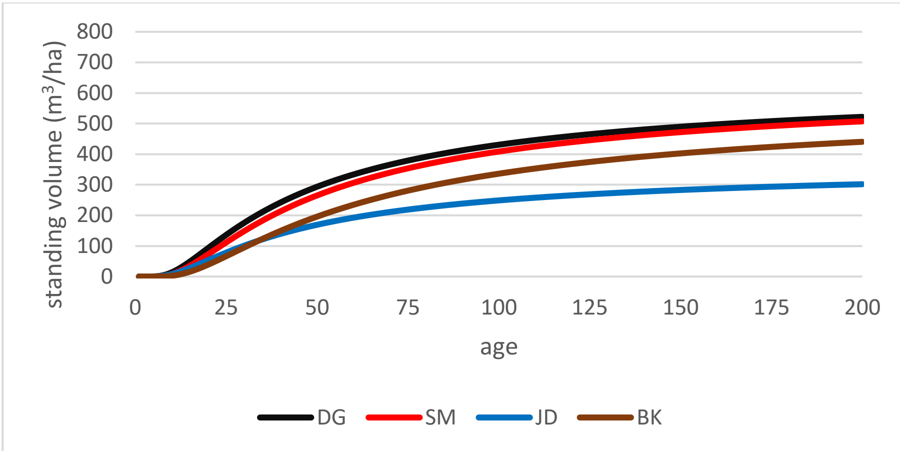

Fig. 31. DG, SM, JD and BK standing volume per ha model of development on extreme habitats group (X, Z and Y edaphic categories) in relation to age

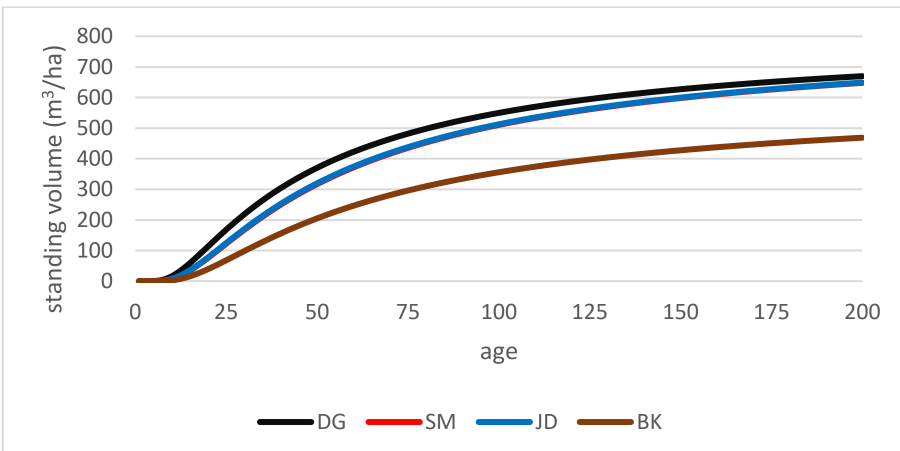

Fig. 32. DG, SM, JD and BK yield per ha model of development on acidophilous habitats group (M, K, N, I and S edaphic categories) in relation to age

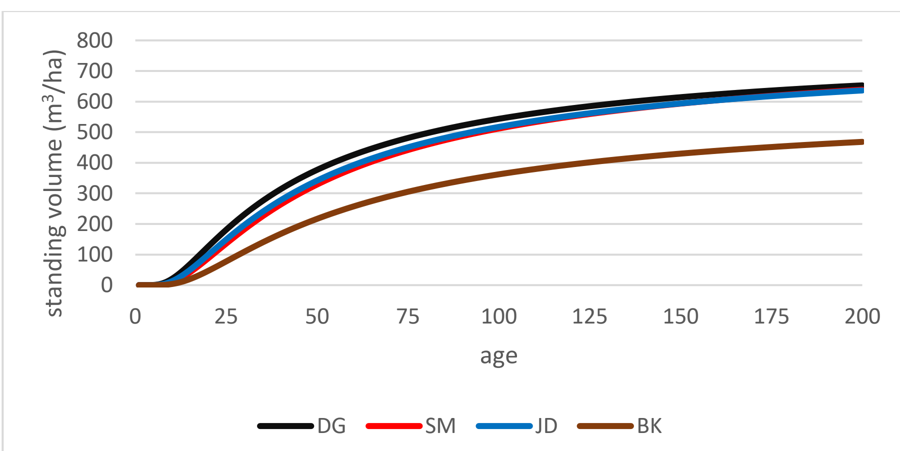

Fig. 33. DG, SM, JD and BK standing volume per ha model of development on mesotrophic and maple habitats group (F, C, B, W, H, D, A and J) in relation to age

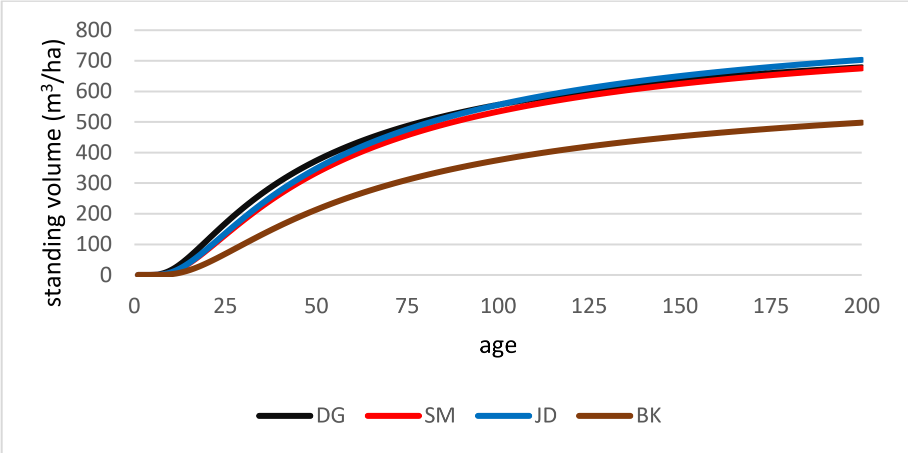

Fig. 34. DG, SM, JD and BK standing volume per ha model of development on humid (flooded) habitats group (L, U and V edaphic categories) in relation to age

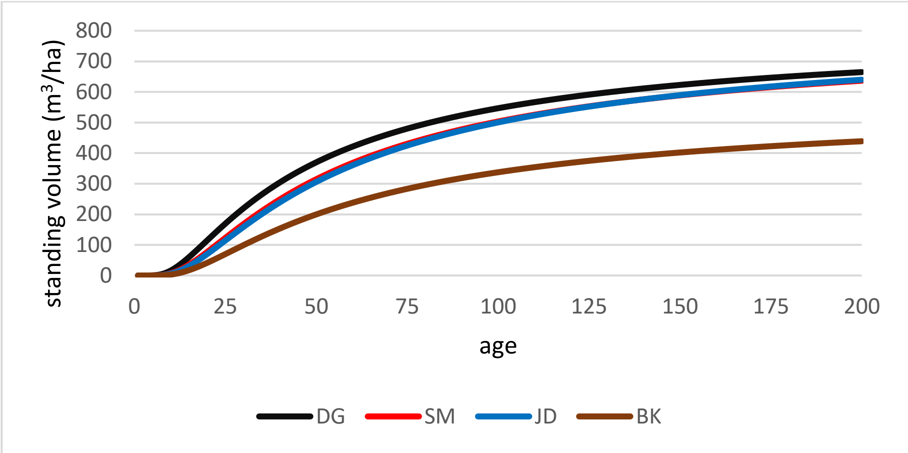

Fig. 35. DG, SM, JD and BK standing volume per ha model of development on gleyed (stagnic) habitats group (O, P and Q edaphic categories) in relation to age

Table 9. DG, SM, JD a BK hectare standing volume of habitat groups in the age of 100 years
r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).

Habitat group	Standing volume in age of 100 years [m^3 ha^{-1}]							
	DG		SM		JD		BK	
extreme	431	r^2 = 0,6885 n = 93 σ = 216 a = 6,4496 b = -38,3749	409	r^2 = 0,7060 n = 70 σ = 208 a = 6,4456 b = -43,2738	249	r^2 = 0,8329 n = 74 σ = 118 a = 5,9027 b = -38,5564	336	r^2 = 0,8054 n = 65 σ = 173 a = 6,3580 b = -54,0241
acid	550	r^2 = 0,8615 n = 31226 σ = 208 a = 6,7047 b = -39,5306	510	r^2 = 0,8852 n = 25374 σ = 189 a = 6,7122 b = -47,6875	512	r^2 = 0,8674 n = 5702 σ = 200 a = 6,7116 b = -47,2409	356	r^2 = 0,8760 n = 13804 σ = 128 a = 6,4259 b = -55,1675
nutritious	544	r^2 = 0,8319 n = 9130 σ = 222 a = 6,6648 b = -36,6604	512	r^2 = 0,8520 n = 6812 σ = 204 a = 6,6808 b = -44,2670	517	r^2 = 0,8723 n = 1878 σ = 221 a = 6,6630 b = -41,4569	362	r^2 = 0,8712 n = 4621 σ = 148 a = 6,4061 b = -51,3928
Humid + flooded	556	r^2 = 0,8100 n = 886 σ = 208 a = 6,7193 b = -39,8193	534	r^2 = 0,8510 n = 748 σ = 193 a = 6,7499 b = -46,9501	556	r^2 = 0,8430 n = 172 σ = 213 a = 6,7899 b = -46,9211	375	r^2 = 0,8230 n = 302 σ = 142 a = 6,4927 b = -56,4958
Gleyed (stagnic)	547	r^2 = 0,8592 n = 5158 σ = 187 a = 6,6949 b = -39,0821	503	r^2 = 0,8770 n = 4370 σ = 166 a = 6,6913 b = -46,9979	500	r^2 = 0,8309 n = 1236 σ = 167 a = 6,7075 b = -49,2223	337	r^2 = 0,8548 n = 2013 σ = 106 a = 6,3465 b = -52,4993

5.1.2.4 Selected commercial tree species production on selected habitat groups in individual FVZ

Other part of the results will be focused on taking account production in some FVZ (3^{rd} – 6^{th}) and selected habitat groups. Marginal FVZ (2^{nd} and 7^{th}) were excluded from the comparison due to the conifers cultivation inappropriateness (2^{nd} FVZ) on the one hand, and due to the significantly mountainous and partially soil-protective character of the forests (7^{th} FVZ) on the other hand. In the same way, extreme and wetland vegetation groups were excluded, because these habitats are usually either landscape protection area or are directly reserves.

The 3^{rd} FVZ of the acidic habitats group (Fig. 36) shows a significantly lower hectare standing volume for European beech, almost the same for Norway spruce and silver fir and somewhat higher for Douglas fir. Data from edaphic categories K and S contribute the most to the results, as Douglas fir is represented the most in them (see Chapter 5.1.1).

The 3^{rd} FVZ of the nutrient habitats group (Fig. 37) shows an almost identical development trend of hectare standing volume at the age of the compared tree species as in the above-mentioned acidic habitats, but the model actual production itself in 100 years is higher here. It is the highest of the monitored habitats groups of the 3^{rd} FVZ for Douglas fir and Norway spruce (Tables. 10 - 13).

The 3^{rd} of the humid (+ flooded) habitats group (Fig. 38) shows a significantly lower European beech hectare standing volume again. The European beech per hectare standing volume in 100 years is higher here in the acid one by units of $m^3.ha^{-1}$ only, whereas it is the highest in all monitored habitats categories 3^{rd} FVZ for silver fir (Tables 10 – 13). Missing results for Douglas fir and Norway spruce are due to insufficient data amount.

The 3rd FVZ of the gleyed (stagnic) habitats group (Fig. 39) shows an almost identical trend of the hectare standing volume development at the age of the compared tree species as in the acidic and nutrient habitats of this FVZ. But the hectare standing volume in 100 years is the lowest of the 3rd FVZ here (Tables 10 – 13).

The 4th FVZ of the acidic and nutrient groups of habitats (Figs. 40 and 41) shows an almost identical trend in the development of hectare standing volume according to age of the compared tree species as in the 3rd FVZ, but respective hectare standing volume in 100 years is higher for European beech forest in by units m^3ha^{-1} only, while it is already in the range of roughly by 20 – 40 $m^3.ha^{-1}$ for conifers (Tables 10 – 13).

The humid (+ flooded) habitats group of 4th FVZ (Fig. 42) shows a significantly lower hectare standing volume of European beech forest, and an almost identical hectare standing volume of the compared conifers. However, this standing volume of European beech in 100 years is higher by units than in the 3rd FVZ, while it is lower by 10 – 20 $m^3.ha^{-1}$ in 100 years in conifers (Tables 10 – 13).

The 4th FVZ of the gleyed (stagnic) group of habitats (Fig. 43) shows an almost identical trend in the development of the hectare standing volume in relation to age of compared trees as in the gleyed (stagned) habitats of the 3rd FVZ, but respective hectare standing volume in 100 years is higher by approximately 15 $m^3.ha^{-1}$ for European beech, while it is already higher in the range of roughly by 30 – 50 $m^3.ha^{-1}$ for conifers (Tables 10 – 30).

The 5th FVZ of the acidic and nutrient groups of habitats (Figs. 44 and 45) shows an almost identical trend in the development of hectare standing volume at the age of the compared trees as in the acidic and nutrient habitats in the 4th FVZ. There is no such difference between the compared conifers only. The respective hectare standing volume in 100 years is higher for all compared trees in the range of roughly by 20 – 40 $m^3.ha^{-1}$ than in the 4th FVZ in the same habitats (Tables 10 – 13).

The 5th FVZ of the humid (+ flooded) group of habitats (Fig. 46) shows an almost identical development trend of the hectare standing volume according to age of the compared trees as in 4th FVZ of the same habitats. The respective hectare standing volume in 100 years is almost the same for European beech and silver fir. Furthermore, it is by 10 – 15 $m^3.ha^{-1}$ higher for Norway spruce and Douglas fir (Tables 10 – 13).

The 5th FVZ of the gleyed (stagnic) group of habitats (Fig 47) shows an almost identical development trend of the hectare standing volume according to age of the compared trees as in the 4th FVZ of the same habitats. The respective hectare standing volume in 100 years is by 10 $m^3.ha^{-1}$ higher for European beech than in the 4th FVZ of the same habitats. Furthermore, it is by 15 $m^3.ha^{-1}$ lower for silver fir and by 10 – 20 $m^3.ha^{-1}$ higher for Douglas fir and Norway spruce (Tables 10 – 13).

The 6th FVZ of the acidic habitats group (Fig. 48) shows an almost identical development trend of the hectare standing volume according to age of the compared trees as in the 5th FVZ of the same habitats. The hectare standing volume in 100 years is lower for all compared trees than in the 5th FVZ of the same habitats, with an exception for silver fir. It is lower by approximately 30 $m^3.ha^{-1}$ for Douglas fir and Norway spruce and by 40 $m^3.ha^{-1}$ for European beech. The exception – silver fir has hectare standing volume higher by a mere 5 $m^3.ha^{-1}$ (Table 10 – 13).

The 6th FVZ of the nutrient habitats group (Fig. 49) again shows a lower hectare standing volume of European beech than for the compared conifers. It is quite understandable, since silver fir is already a subdominant tree species in this FVZ. The Norway spruce and Douglas fir curves are almost identical. The hectare standing volume in 100 years is lower by 40 $m^3.ha^{-1}$ for European beech, by 80 $m^3.ha^{-1}$ for Douglas fir and 50 $m^3.ha^{-1}$ for Norway spruce compared to the 5th FVZ of the same habitats (Table 10 – 13). The development model of the silver fir hectare standing volume is not presented due to insufficient initial data amount.

The 6th FVZ of the humid (+ flooded) habitats group (Fig. 50) shows the hectare standing volume development according to age of European beech only. The development models of the hectare standing volume of Douglas fir, Norway spruce and silver fir are not presented due to the insufficient initial data amount. The respective hectare standing volume in 100 years for European beech increased by only units of $m^3.ha^{-1}$ compared to the 5th FVZ of the same habitats.

The 6th FVZ of the gleyed (stagnic) habitats group (Fig. 51) shows an almost identical development trend of the hectare standing volume according to age of the compared trees (with an exception of silver fir – insufficient initial date amount) as in the gleyed (stagnic) habitats in the 4th and 5th FVZs. The respective hectare standing volume in 100 years increased for all compared trees, compared to 5th FVZ of the same habitats, with an exception for Douglas fir, where it remained at the same level. It increases by 25 $m^3.ha^{-1}$ for Norway spruce and by 10 $m^3.ha^{-1}$ for European beech (Table 10 – 13).

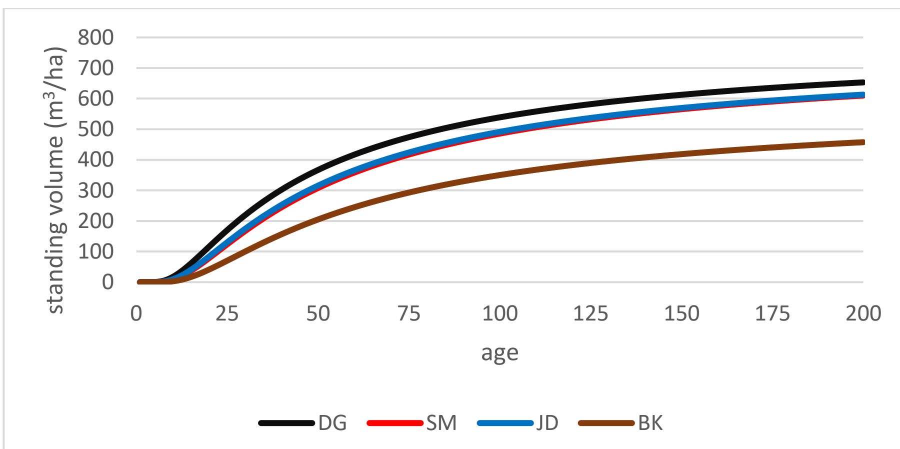

Fig. 36. DG, SM, JD and BK standing volume per ha model of development on acidic habitats group (M, K, N, I and S edaphic categories) of the 3rd FVZ in relation to age

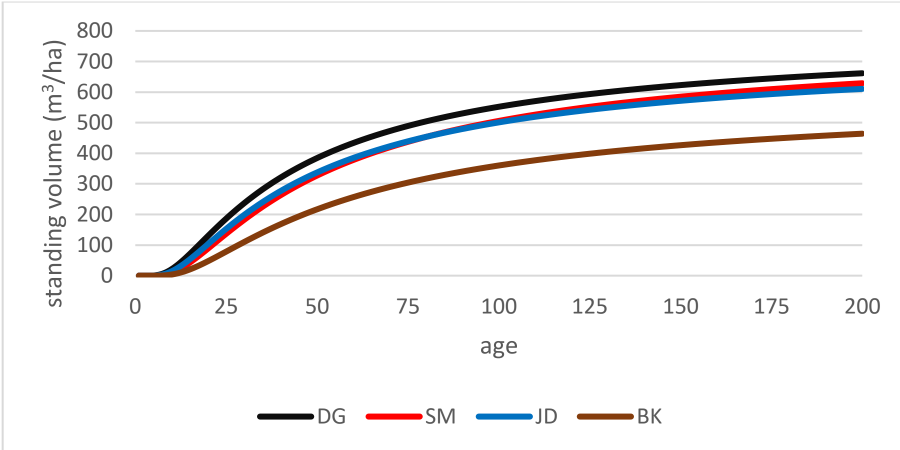

Fig. 37. DG, SM, JD and BK standing volume per ha model of development on nutrient rich habitats group (F, C, B, W, H, D, A, and J edaphic categories) of the 3rd FVZ in relation to age

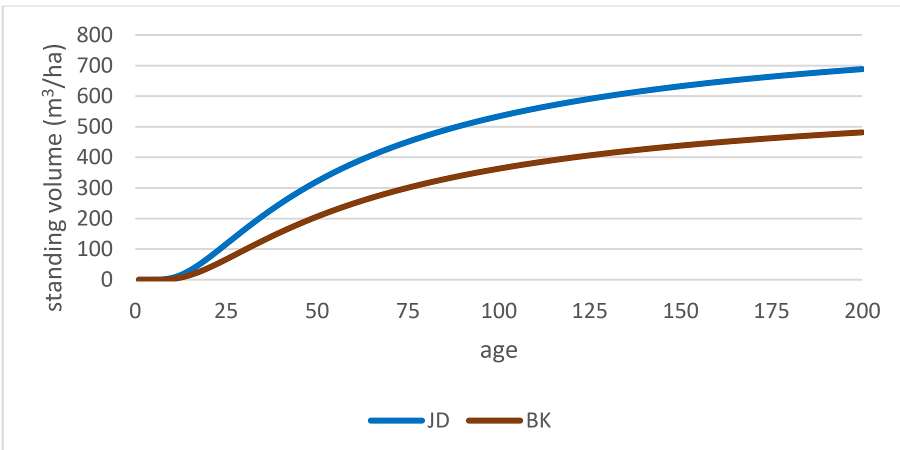

Fig. 38. JD and BK standing volume per ha model of development on humid + flooded habitats group (L, U and V edaphic categories) of the 3rd FVZ in relation to age (SM and DG did not have insufficient data to make the result representative)

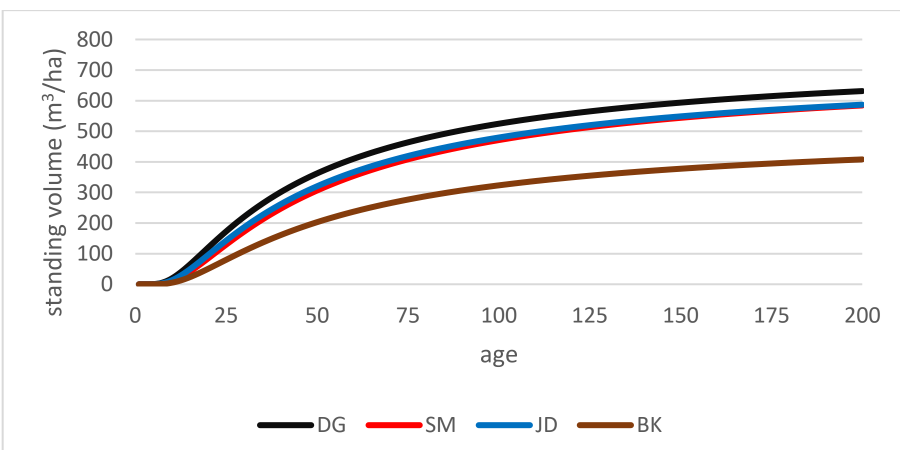

Fig. 39. DG, SM, JD and BK standing volume per ha model of development on gleyed (stagnic) habitats group (O, P and Q edaphic categories) of the 3rd FVZ in relation to age

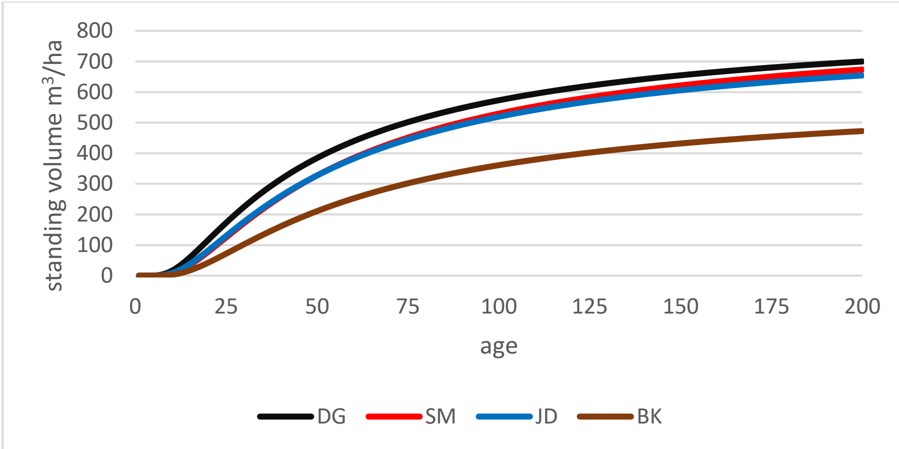

Fig. 40. DG, SM, JD and BK standing volume per ha model of development on acidophilous habitats group (M, K, N, I and S edaphic categories) of the 4th FVZ in relation to age

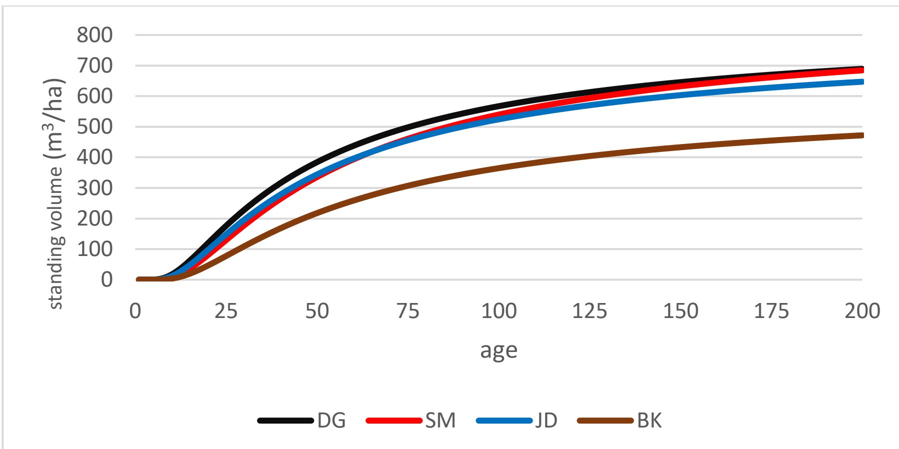

Fig. 41. DG, SM, JD and BK standing volume per ha model of development on nutrient rich habitats group (F, C, B, W, H, D, A, and J edaphic categories) of the 4th FVZ in relation to age

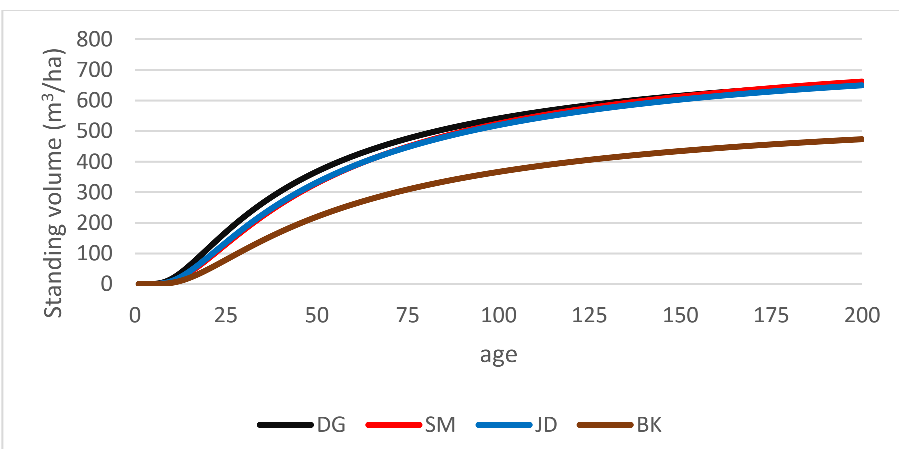

Fig. 42. DG, SM, JD and BK standing volume per ha model of development on humid (ash) habitats group (L, U and V edaphic categories) of the 4th FVZ in relation to age

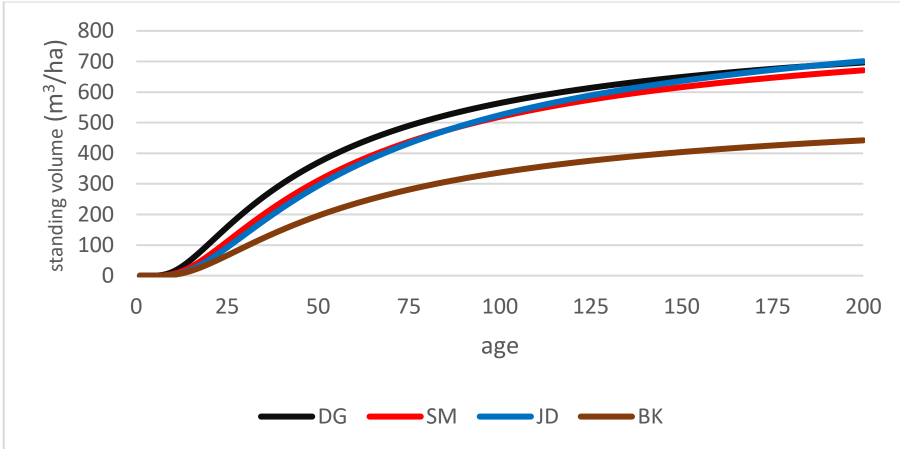

Fig. 43. DG, SM, JD and BK standing volume per ha model of development on gleyed (stagnic) habitats group (O, P and Q edaphic categories) of the 4th FVZ in relation to age

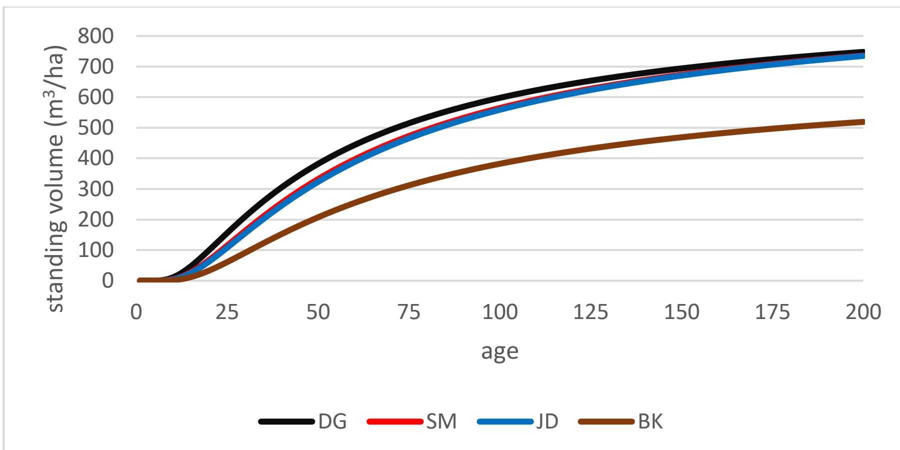

Fig. 44. DG, SM, JD and BK standing volume per ha model of development on acidophilous habitats group (M, K, N, I and S edaphic categories) of the 5th FVZ in relation to age

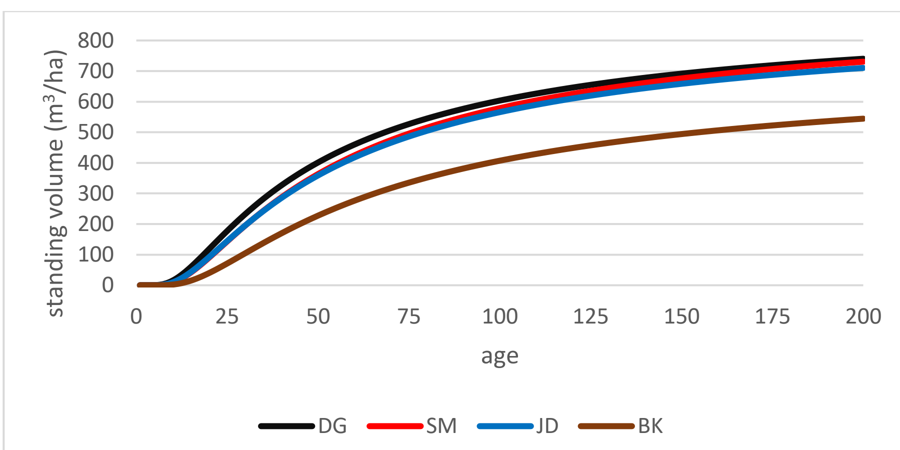

Fig. 45. DG, SM, JD and BK standing volume per ha model of development on nutrient rich habitats group (F, C, B, W, H, D, A, and J edaphic categories) of the 5th FVZ in relation to age

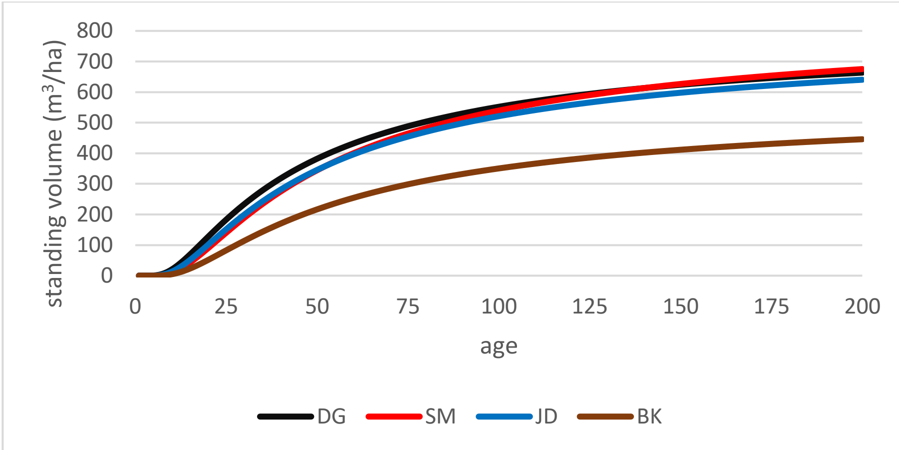

Fig. 46. DG, SM, JD and BK standing volume per ha model of development on humid (ash) habitats group (T, U and V edaphic categories) of the 5th FVZ in relation to age

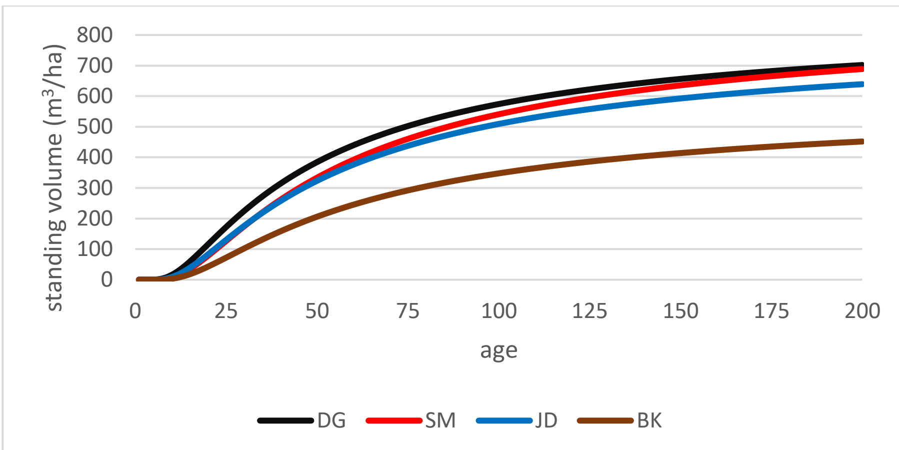

Fig. 47. DG, SM, JD and BK yield per ha model of development on gleyed (stagnic) habitats group (O, P and Q edaphic categories) of the 5th FVZ in relation to age

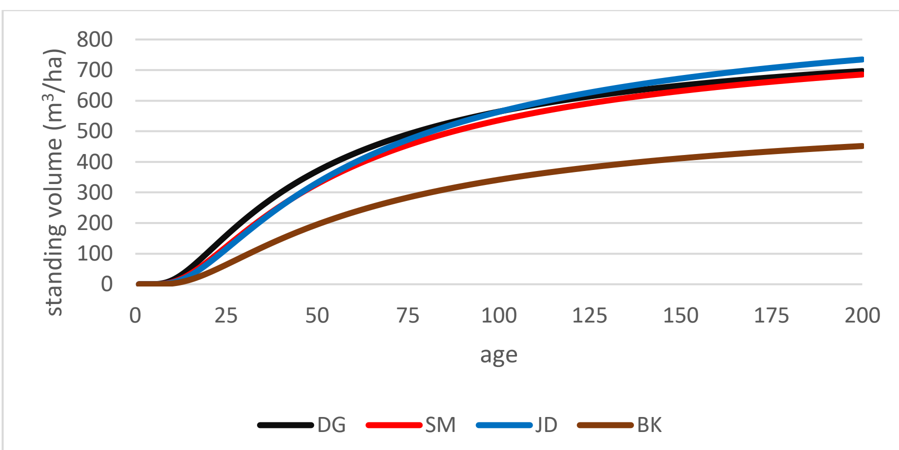

Fig. 48. DG, SM, JD and BK standing volume per ha model of development on acidophilous habitats group (M, K, N, I and S edaphic categories) of the 6th FVZ in relation to age

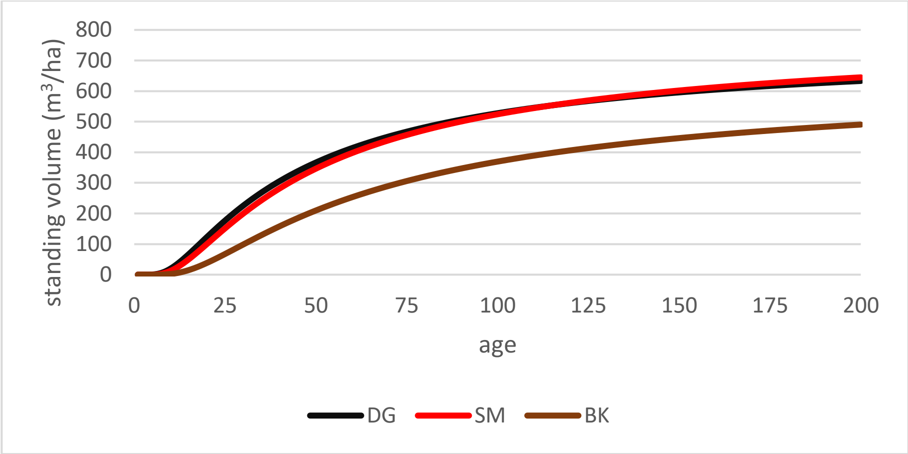

Fig. 49. DG, SM, JD and BK standing volume per ha model of development on nutrient rich habitats group (F, C, B, W, H, D, A, and J edaphic categories) of the 6th FVZ in relation to age

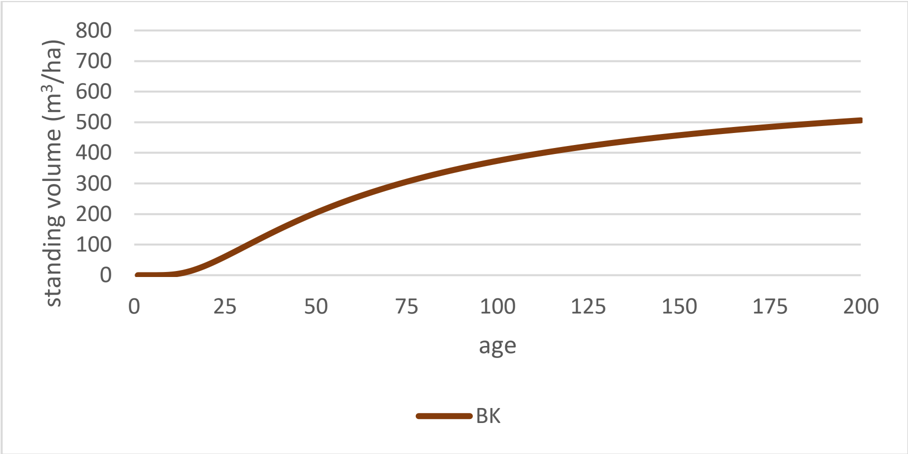

Fig. 50. BK standing volume per ha model of development on humid (+ flooded) habitats group (T, U and V edaphic categories) of the 6th FVZ in relation to age

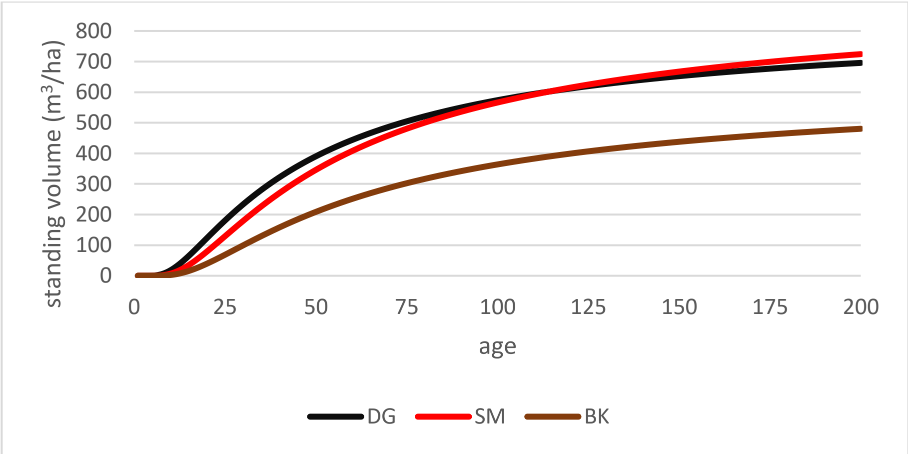

Fig. 51. DG, SM, JD and BK standing volume per ha model of development on gleyed (stagnic) habitats group (O, P and Q edaphic categories) of the 6th FVZ in relation to age

Table 10. DG hectare standing volume on the habitat groups of 3rd – 6th FVZ in 100 years. r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).

DG	Standing volume in 100 years [$m^3 ha^{-1}$]							
FVZ	acidic		nutrient		Humid (+ flooded)		Gleyed (stagnic)	
3	539	r^2 = 0,8759 n = 11556 σ = 207 a = 6,6739 b = -38,4613	552	r^2 = 0,8357 n = 3439 σ = 222 a = 6,6756 b = -36,1930	-		525	r^2 = 0,8623 n = 992 σ = 194 a = 6,6331 b = -37,0357
4	573	r^2 = 0,8731 n = 7875 σ = 217 a = 6,7508 b = -39,9408	567	r^2 = 0,8553 n = 2792 σ = 227 a = 6,7300 b = -38,9403	541	r^2 = 0,8819 n = 165 σ = 198 a = 6,6802 b = -38,6797	564	r^2 = 0,8457 n = 1920 σ = 182 a = 6,7575 b = -42,2326
5	598	r^2 = 0,8668 n = 7049 σ = 212 a = 6,8411 b = -44,8128	604	r^2 = 0,8658 n = 1118 σ = 264 a = 6,8112 b = -40,8301	552	r^2 = 0,8181 n = 281 σ = 188 a = 6,6814 b = -36,7808	574	r^2 = 0,8887 n = 914 σ = 186 a = 6,7541 b = -40,1216
6	564	r^2 = 0,8715 n = 1386 σ = 205 a = 6,7576 b = -42,2137	528	r^2 = 0,8068 n = 74 σ = 182 a = 6,6328 b = -36,4309	-		574	r^2 = 0,8625 n = 592 σ = 193 a = 6,7376 b = -38,5267

Table 10 shows that Douglas fir achieves the highest 100-year hectare standing volume in the 5th FVZ for all compared habitats groups. It reaches the highest values on the 5th FVZ of nutrient habitats – 604 m^3ha^{-1}.

Table 11. SM hectare standing volume on the habitat groups of 3rd – 6th FVZ in 100 years. r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).

SM	Standing volume in 100 years [$m^3 ha^{-1}$]							
FVZ	acidic		nutrient		Humid (+ flooded)		Gleyed (stagnic)	
3	486	r^2 = 0,8974 n = 9061 σ = 183 a = 6,6415 b = -45,5829	506	r^2 = 0,8597 n = 2607 σ = 199 a = 6,6619 b = -43,5745	-		471	r^2 = 0,8820 n = 790 σ = 169 a = 6,5859 b = -43,0652
4	530	r^2 = 0,9011 n = 6769 σ = 196 a = 6,7532 b = -48,0954	540	r^2 = 0,8754 n = 2280 σ = 211 a = 6,7662 b = -47,5250	524	r^2 = 0,9140 n = 149 σ = 192 a = 6,7275 b = -46,5412	519	r^2 = 0,8772 n = 1703 σ = 161 a = 6,7660 b = -51,3839
5	564	r^2 = 0,8913 n = 6305 σ = 196 a = 6,8663 b = -53,0728	579	r^2 = 0,8818 n = 979 σ = 225 a = 6,8267 b = -46,5663	539	r^2 = 0,8544 n = 252 σ = 178 a = 6,7395 b = -44,8913	541	r^2 = 0,8996 n = 829 σ = 167 a = 6,7766 b = -48,3609
6	536	r^2 = 0,9039 n = 1290 σ = 189 a = 6,7763 b = -49,2314	524	r^2 = 0,7985 n = 79 σ = 184 a = 6,6763 b = -41,4282	-		566	r^2 = 0,9072 n = 529 σ = 180 a = 6,8315 b = -49,2485

Table 11 shows that Norway spruce has the highest 100-year hectare standing volume in the 5th FVZ of acidic, nutrient and humid habitats groups. It reaches the highest value in 5th FVZ of nutrient habitat – 579 $m^3.ha^{-1}$.

Table 12. JD hectare standing volume on the habitat groups of 3rd – 6th FVZ in 100 years. r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).

JD	Standing volume in 100 years [m^3 ha^{-1}]							
FVZ	acidic		nutrient		Humid (+ flooded)		Gleyed (stagnic)	
3	491	r^2 = 0,8739 n = 1850 σ = 199 a = 6,6396 b = -44,2713	501	r^2 = 0,8477 n = 604 σ = 221 a = 6,6120 b = -39,5473	534	r^2 = 0,8085 n = 71 σ = 226 a = 6,7881 b = -50,7724	480	r^2 = 0,8583 195 790 σ = 186 a = 6,5768 b = -40,3886
4	520	r^2 = 0,8907 n = 1653 σ = 206 a = 6,7145 b = -46,1574	524	r^2 = 0,8885 n = 742 σ = 222 a = 6,6831 b = -42,1183	519	r^2 = 0,9140 n = 83 σ = 227 a = 6,6997 b = -44,7237	525	r^2 = 0,7886 n = 548 σ = 150 a = 6,8420 b = -57,9249
5	559	r^2 = 0,8502 n = 1490 σ = 199 a = 6,8733 b = -54,7856	566	r^2 = 0,8800 n = 349 σ = 230 a = 6,7933 b = -45,5116	521	r^2 = 0,8032 n = 87 σ = 188 a = 6,6677 b = -41,1317	509	r^2 = 0,8579 n = 219 σ = 173 a = 6,6872 b = -45,4415
6	564	r^2 = 0,9046 n = 387 σ = 194 a = 6,8644 b = -53,0116	-		-		-	

Table 12 shows that silver fir has the highest hectare standing volume in 100 years in the 6th FVZ for acidic habitats, where it reaches 566 $m^3.ha^{-1}$.

Table 13. BK hectare standing volume on the habitat groups of 3rd – 6th FVZ in 100 years. r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).

BK	Standing volume in 100 years [m^3 ha^{-1}]							
FVZ	acidic		nutrient		Humid (+ flooded)		Gleyed (stagnic)	
3	350	r^2 = 0,8866 n = 4735 σ = 130 a = 6,3935 b = -53,5409	360	r^2 = 0,8691 n = 1691 σ = 147 a = 6,3935 b = -50,7134	363	r^2 = 0,7882 n = 74 σ = 161 a = 6,4598 b = -56,5618	323	r^2 = 0,8457 195 347 σ = 117 a = 6,2441 b = -46,5754
4	361	r^2 = 0,8884 n = 3828 σ = 132 a = 6,4271 b = -53,7883	365	r^2 = 0,8752 n = 1752 σ = 148 a = 6,4145 b = -51,5697	366	r^2 = 0,9279 n = 89 σ = 142 a = 6,4152 b = -51,1444	337	r^2 = 0,8431 n = 777 σ = 95 a = 6,3634 b = -54,3262
5	382	r^2 = 0,8661 n = 3471 σ = 124 a = 6,5583 b = -61,2388	407	r^2 = 0,8952 n = 669 σ = 157 a = 6,5906 b = -58,1666	369	r^2 = 0,8324 n = 101 σ = 118 a = 6,3407 b = -48,1285	348	r^2 = 0,8939 n = 421 σ = 106 a = 6,3750 b = -52,3886
6	342	r^2 = 0,8667 n = 830 σ = 119 a = 6,3929 b = -55,9399	370	r^2 = 0,8315 n = 77 σ = 126 a = 6,4787 b = -56,6425	373	r^2 = 0,8165 n = 73 σ = 155 a = 6,5296 b = -60,5751	357	r^2 = 0,8571 n = 266 σ = 111 a = 6,4525 b = -55,5824

Table 13 shows that the European beech has the highest hectare standing volume in 100 years in 5th FVZ of nutrient habitats groups, which is reached by 407 $m^3.ha^{-1}$.

5.1.2.5 Douglas fir and Norway spruce production according to selected FTG

The development courses of the standing volume in relation to the age of Douglas fir and Norway spruce were selected in some edaphic categories and some FVZ (see VIEWEGH 2005). These were selected for the highest values in given category. The same were applied to FVZs. Insufficient data from which the course of curve could be modelled were in some edaphic categories and FVZs.

All compared FTGs (3 – 6K) of K – edaphic category (*oligotrophica*) show (Fig. 52) that Douglas fir always has a higher hectare standing volume than Norway spruce. The highest values are reached by both trees in the 5th FVZ. In the 6th FVZ it is already lower, roughly at the level of the 4th FVZ.

In the S-edaphic category (*oligo-mesotrophica*), it is shown (Fig. 53) that in all compared FTGs (3 – 6S) Douglas fir also always has a higher hectare standing volume than Norway spruce, although the difference is negligible in some cases. The highest values are reached by both trees in the 5th FVZ, but the differences between the trees are negligible and they almost coincide around the age of 180 years. It is already lower in the 6th FVZ. It only reaches the level of Douglas fir in the 3rd FVZ for both trees.

Douglas fir has always a significant hectare standing volume than Norway spruce in the 3rd FVZ, B-edaphic category (*mesotrophica*) (Fig. 54). The Douglas fir higher value is almost negligible in the 4th and 5th FVZs and at the age of approximately 150 years, the situation balances out and for both trees it reaches the level of the Douglas fir hectare standing volume in the 3rd FVZ. The hectare standing volume of the both trees is higher in the 5th FVZ, but the difference between them is in the order of $m^3.ha^{-1}$ units, and at the age of approximately 180 years the volumes of both trees are comparable.

Fig. 55 for H-edaphic category (*illimerosa mesotrophica*) shows that Douglas fir has always again a significantly higher hectare standing volume than Norway spruce in the 3rd FVZ. In the 5th FVZ, values are lower than in the 4th one, and the mutual differences between these two tree species show higher values for Douglas fir in this FVZ, until the age of approximately 150 years, after which their difference becomes negligible. The highest hectare standing volume in this category (H) is achieved by both tress species in the 4th FVZ, and Norway spruce values start to be higher than those of Douglas fir at about in 170 years, although insignificantly. Insufficient data for 6th FVZ made not possibility to model the hectare standing volume development.

The Douglas fir has a higher hectare standing volume in the 4th and 5th FVZs of D - edaphic category (*deluvia*) than Norway spruce (Fig. 56). However, it is higher in the 4th FVZ than in the 5th one up to the age of approximately 75 years, and the situation is the opposite after this age.

V-edaphic category (*humida*) demonstrates the higher Douglas fir hectare standing volume than that of Norway spruce (Fig. 57). But the Norway spruce hectare standing volume begins to rise and exceeds Douglas fir in the age of about 140 years negligibly. The values differences between compared FVZs (7th and 5th) are negligible.

The Douglas fir hectare standing volume is similar in all mentioned FVZs (4th – 6th) and simultaneously higher than that of Norway spruce in O - edaphic category (*variohumida oligotrophica*) (Fig. 58). But Norway spruce begins to rise and exceeds Douglas fir in the age of 80 years and quite significantly so at an older age in 6th FVZ.

Douglas fir hectare standing volume exceeds those of Norway spruce up to the age of 80 years in all FVZs (4th – 6th) of P - edaphic category (*variohumida acidophila*) (Fig. 59). The values in the 5th FVZ are negligibly higher than in the 6th one, but they nearly balance out to those of Norway spruce from about the age of 120 years.

The values of hectare standing volume in 100 years are shown in Table 14a for Douglas fir and Table 14b for Norway spruce. Blank spaces in the tables indicate insufficient data for either the edaphic category or the FVZ.

The highest values of Douglas fir and Norway spruce standing volume on K, S, B, H, V, O and P edaphic categories of 3rd- 6th FVZ show that they are always on the same edaphic category for the respective FVZ for both compared tree species. So, for the 3rd FVZ, it is on B-edaphic category (Douglas fir 575 m^3ha^{-1}; Norway spruce 524 m^3ha^{-1}). For the 4th FVZ, it is on H-edaphic category (Douglas fir 580 m^3ha^{-1}; Norway spruce 561 m^3ha^{-1}). For the 5th FVZ, it is on B-edaphic category (Douglas fir 616 m^3ha^{-1}; Norway spruce 597 m^3ha^{-1}). For the 6th FVZ, it is on O-edaphic category (Douglas fir 578 m^3ha^{-1}; Norway spruce 594 m^3ha^{-1}). Douglas fir is the winner of the entire comparison with its 616 m^3ha^{-1} on 5B FTG. Missing values in Tables 14a, b are due to insufficient data to count.

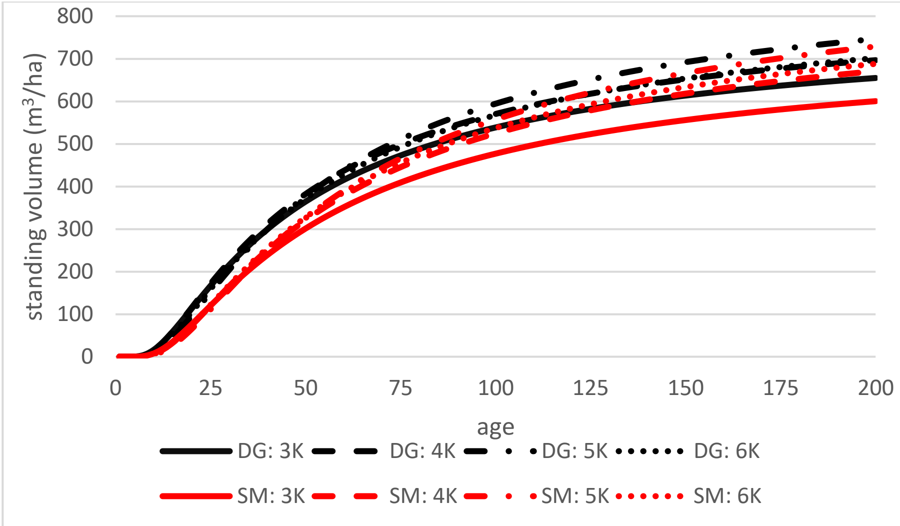

Fig. 52. DG and SM standing volume per ha model of development on 3K, 4K, 5K and 6K FTG in relation to age

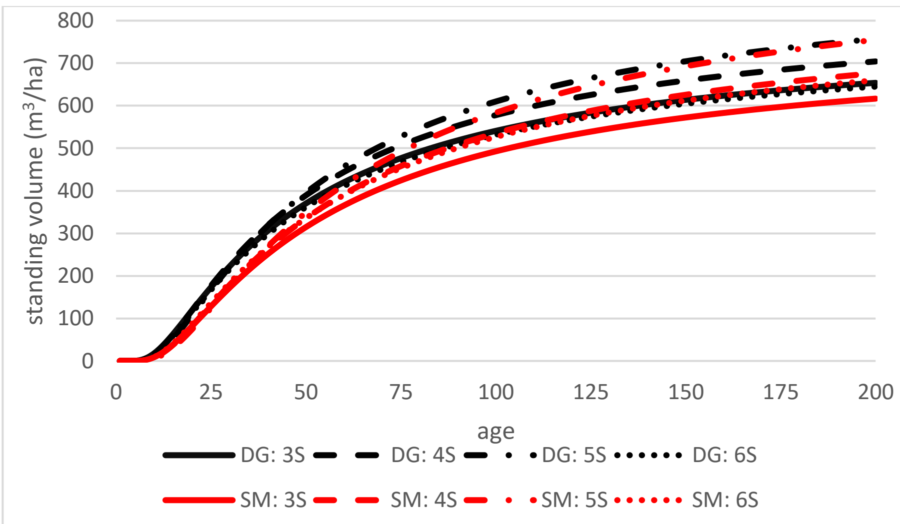

Fig. 53. DG and SM standing volume per ha model of development on 3S, 4S, 5S and 6S FTG in relation to age

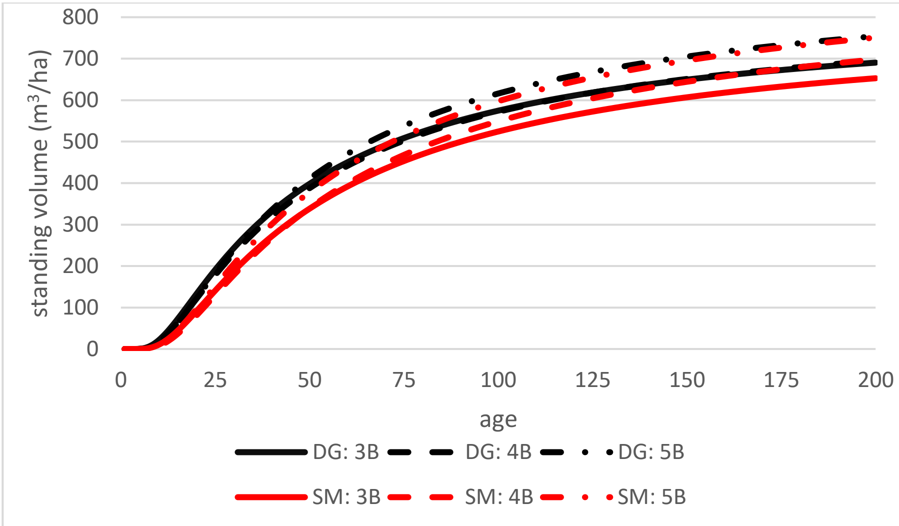

Fig. 54. DG and SM standing volume per ha model of development on 3B, 4B and 5B FTG in relation to age

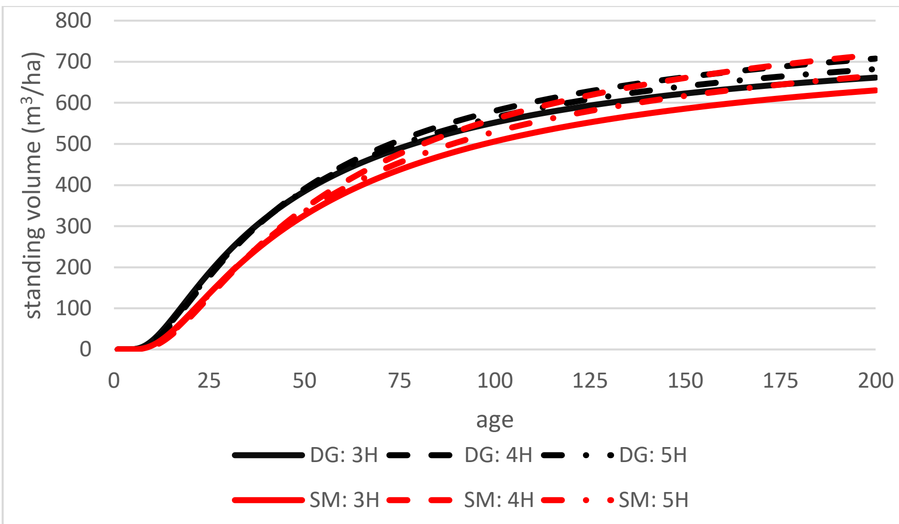

Fig. 55. DG and SM standing volume per ha model of development on 3H, 4H and 5H FTG in relation to age

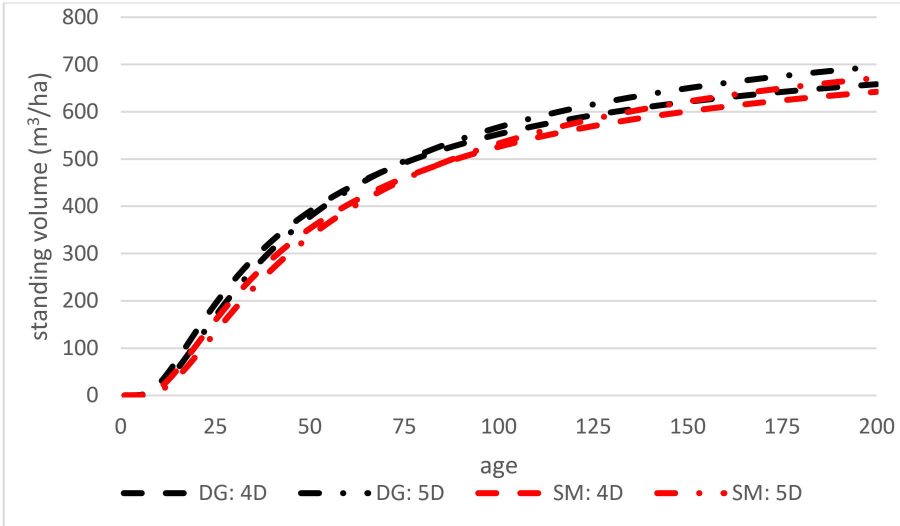

Fig. 56. DG and SM standing volume per ha model of development on 4D a 5D FTG in relation to age

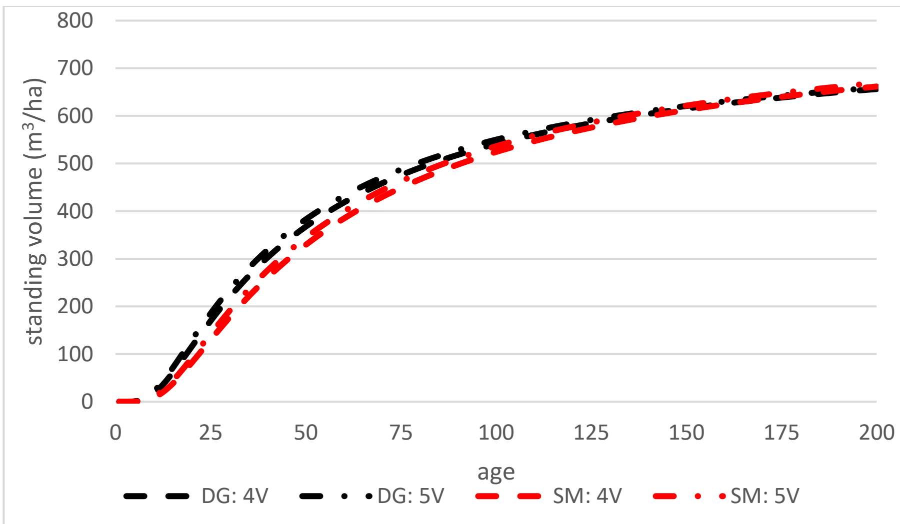

Fig. 57. DG and SM standing volume per ha model of development on 4V a 5V FTG in relation to age

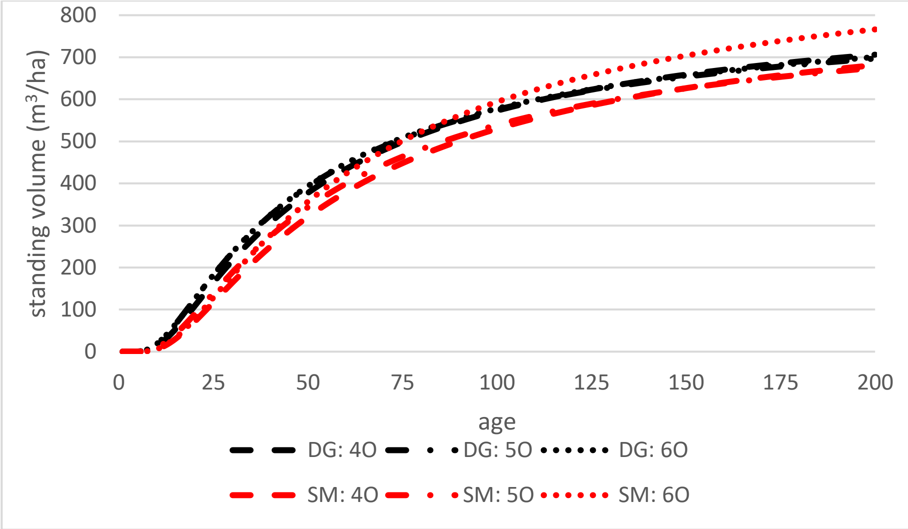

Fig. 58. DG and SM standing volume per ha model of development on 4O, 5O a 6O FTG in relation to age

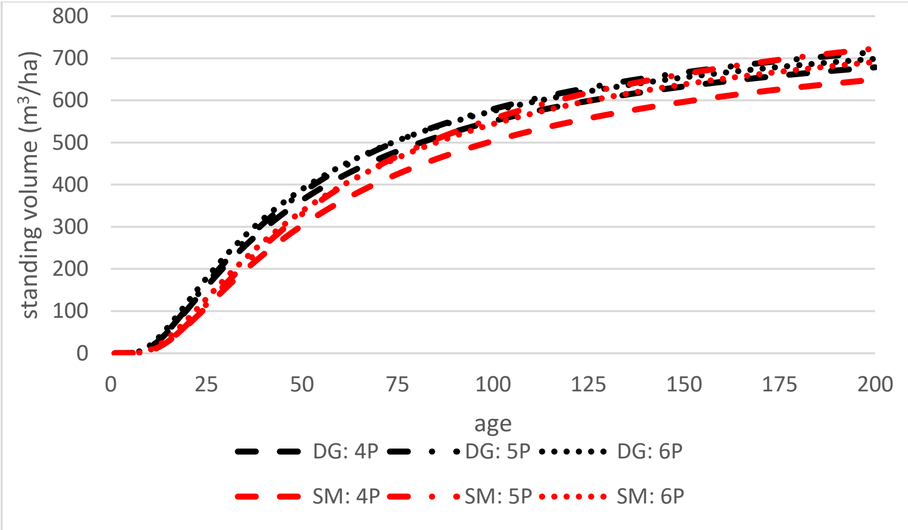

Fig. 59. DG and SM standing volume per ha model of development on 4P, 5P a 6P FTG in relation to age

Table 14a. DG hectare standing volume on chosen FTG in 100 years. r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).
)1 details in VIEWEGH 2005

DG	FVZ)1							
Edaphic category)1	3		4		5		6	
K	539	r^2 = 0,8812 n = 4711 σ = 205 a = 6,6799 b = -39,0823	570	r^2 = 0,8768 n = 3186 σ = 211 a = 6,7466 b = -40,0360	594	r^2 = 0,8735 n = 3966 σ = 208 a = 6,8437 b = -45,6045	568	r^2 = 0,8818 n = 912 σ = 204 a = 6,7650 b = -42,3633
S	541	r^2 = 0,8718 n = 5378 σ = 212 a = 6,6724 b = -37,9123	578	r^2 = 0,8705 n = 3998 σ = 223 a = 6,7544 b = -39,4951	610	r^2 = 0,8643 n = 2473 σ = 219 a = 6,8459 b = -43,2638	532	r^2 = 0,8883 n = 273 σ = 195 a = 6,6619 b = -38,5881
B	575	r^2 = 0,8296 n = 1467 σ = 230 a = 6,7209 b = -36,6965	572	r^2 = 0,8577 n = 2002 σ = 227 a = 6,7379 b = -38,8742	616	r^2 = 0,8774 n = 728 σ = 239 a = 6,8282 b = -40,4932	-	
H	552	r^2 = 0,8659 n = 1211 σ = 208 a = 6,6752 b = -36,1528	580	r^2 = 0,8681 n = 339 σ = 231 a = 6,7602 b = -39,6413	564	r^2 = 0,9717 n = 148 σ = 188 a = 6,7146 b = -37,8667	-	
D	-		553	r^2 = 0,9048 n = 131 σ = 223 a = 6,6645 b = -34,9826	567	r^2 = 0,8965 n = 86 σ = 205 a = 6,7481 b = -40,7049	-	
V	-		541	r^2 = 0,8819 n = 165 σ = 198 a = 6,6802 b = -38,6797	550	r^2 = 0,8130 n = 250 σ = 187 a = 6,6728 b = -36,2841	-	
O	-		573	r^2 = 0,8586 n = 965 σ = 195 a = 6,7685 b = -41,7329	575	r^2 = 0,8899 n = 483 σ = 190 a = 6,7383 b = -38,3431	578	r^2 = 0,8273 n = 274 σ = 189 a = 6,7437 b = -38,4207
P	-		551	r^2 = 0,8285 n = 815 σ = 171 a = 6,7287 b = -41,7129	579	r^2 = 0,8959 n = 382 σ = 184 a = 6,7818 b = -41,9809	575	r^2 = 0,8945 n = 309 σ = 196 a = 6,7446 b = -39,0628

Table 14b. SM hectare standing volume on chosen FTG in 100 years. r^2 – coefficient of determination; n – number of parts of a stand; σ – standing volume standard deviation estimate; a, b – growth model parameters (see equation (1), Chapter 4.1.2).)1 details in VIEWEGH 2005

SM	FVZ)1							
Edaphic category)1	3		4		5		6	
K	477	r^2 = 0,8970 n = 3622 σ = 178 a = 6,6276 b = -45,9922	525	r^2 = 0,9053 n = 2725 σ = 188 a = 6,7546 b = -49,1824	557	r^2 = 0,8931 n = 3549 σ = 191 a = 6,8600 b = -53,7110	537	r^2 = 0,9214 n = 861 σ = 187 a = 6,7814 b = -49,5029
S	493	r^2 = 0,8983 n = 4295 σ = 189 a = 6,6486 b = -44,8466	535	r^2 = 0,8993 n = 3464 σ = 203 a = 6,7509 b = -46,7878	584	r^2 = 0,8943 n = 2214 σ = 208 a = 6,8839 b = -51,4789	527	r^2 = 0,9017 n = 238 σ = 189 a = 6,7169 b = -45,0434
B	524	r^2 = 0,8517 n = 1149 σ = 206 a = 6,7005 b = -43,8165	549	r^2 = 0,8796 n = 1609 σ = 211 a = 6,7883 b = -47,9965	597	r^2 = 0,8929 n = 637 σ = 233 a = 6,8497 b = -45,7039	-	
H	506	r^2 = 0,8803 n = 918 σ = 187 a = 6,6660 b = -43,9277	561	r^2 = 0,8831 n = 292 σ = 220 a = 6,8216 b = -49,2470	530	r^2 = 0,8142 n = 125 σ = 176 a = 6,7301 b = -45,8058	-	
D	-		526	r^2 = 0,8932 n = 111 σ = 212 a = 6,6646 b = -39,9478	533	r^2 = 0,9041 n = 81 σ = 197 a = 6,7403 b = -46,1833	-	
V	-		524	r^2 = 0,9140 n = 149 σ = 192 a = 6,7275 b = -46,5412	536	r^2 = 0,8498 n = 231 σ = 176 a = 6,7275 b = -44,2869	-	
O	-		530	r^2 = 0,8930 n = 857 σ = 176 a = 6,7752 b = -50,2538	539	r^2 = 0,8968 n = 437 σ = 172 a = 6,7397 b = -45,0408	594	r^2 = 0,8896 n = 242 σ = 182 a = 6,8964 b = -50,9708
P	-		504	r^2 = 0,8581 n = 729 σ = 147 a = 6,7302 b = -50,8245	557	r^2 = 0,9246 n = 348 σ = 165 a = 6,8453 b = -52,3300	544	r^2 = 0,9263 n = 280 σ = 178 a = 6,7781 b = -47,9180

5.1.2.5.1 Total volume yield and final standing volume on selected FTGs

The two FTGs with the highest (5S and 5B) and the lowest (3K and 6S) Douglas fir standing volumes in 100 years were chosen as an example of total volume yield (COP) in 140 years (Table 15.). As already stated in Table 14a, the Douglas fir hectare standing volume maximum in 100 years is on 5B FTG (also for Norway spruce), this corresponds to a COP of 1615 $m^3.ha^{-1}$. Norway spruce COP is 1367 $m^3.ha^{-1}$ in this FTG. The Douglas fir hectare standing volume minimum in 100 years is 1411 $m^3.ha^{-1}$ is in 6S FTG. Norway spruce COP is 1258 $m^3.ha^{-1}$ in this FTG. The Norway spruce hectare standing volume in 100 years is 3K FTG, which corresponds to a COP of 1083 $m^3.ha^{-1}$. Douglas fir COP value is 1354 $m^3.ha^{-1}$ in this FTG. The Douglas fir COP with value of

1556 m^3.ha^{-1} in 5S FTG was given as an example. This leads to logical conclusion that the Douglas fir COP is always higher than Norway spruce.

Table 15. Total volume yield on chosen FTG (m^3.ha^{-1}) in 140 years

FTG	DG			SM		
	Tending felling sum	Final standing volume	Total volume yield	Tending felling sum	Final standing volume	Total volume yield
3K	752	602	1354	538	544	1082
5S	866	690	1556	648	676	1324
5B	923	692	**1615**	686	681	1367
6S	818	594	1411	659	599	1258

5.1.2.5.2 The hectare standing volume simulation with different DG, SM, BK and JD composition in 120 years on chosen FTGs

Table 16 shows theoretical situations of commercial trees different representation in the vegetation mixture. A mixture of BK7, DG2 and SM1 was determined for the 3rd FVZ (regardless of the edaphic category. For the 4th FVZ (regardless of edaphic category), a mixture of BK6, DG2, SM1 and JD1 was determined, and the 5th FVZ (regardless of edaphic category) was determined by a mixture of SM4, JD4 and DG2.

Table 16. Total volume production model (in m^3 ha^{-1}) of mixed stands (DG, SM, BK and JD) in chosen FTG in 120 years

FTG	composition	DG standing volume	SM standing volume	BK standing volume	JD standing volume	Total standing volume
3K	BK 7, DG 2, SM 1	115	52	269	-	436
4K	BK 6, DG 2, SM 1, JD 1	122	57	232	56	467
5K	SM 4, JD 4, DG 2	128	244	-	253	625
3S	BK 7, DG 2, SM 1	115	53	267	-	435
4S	BK 6, DG 2, SM 1, JD 1	123	58	239	56	476
5S	SM 4, JD 4, DG 2	131	254	-	241	627
3B	BK 7, DG 2, SM 1	122	56	281	-	460
4B	BK 6, DG 2, SM 1, JD 1	122	59	240	57	478
5B	SM 4, JD 4, DG 2	132	258	-	250	640
3H	BK 7, DG 2, SM 1	117	54	282	-	454
4H	BK 6, DG 2, SM 1, JD 1	124	61	246	55	486
5H	SM 4, JD 4, DG 2	120	229	-	208	557
4D	BK 6, DG 2, SM 1, JD 1	117	56	233	56	462
5D	SM 4, JD 4, DG 2	121	230	-	200	551
4V	BK 6, DG 2, SM 1, JD 1	115	57	239	56	467
5V	SM 4, JD 4, DG 2	117	231	-	222	570
4O	BK 6, DG 2, SM 1, JD 1	123	58	226	60	466
5O	SM 4, JD 4, DG 2	123	232	-	218	573
4P	BK 6, DG 2, SM 1, JD 1	118	55	212	55	440
5P	SM 4, JD 4, DG 2	124	243	-	222	590

The highest total hectare standing volume is based on chosen FTG of the 5th FVZ and gradually decreases according to FVZ up to the 3rd one. The exception is FTG 4P, where it is at the level of the 3rd FVZ. The difference between the highest total hectare standing volume in FTG 5B and the lowest in FTG 5D was 89 $m^3.ha^{-1}$. The difference between the highest total hectare standing volume in FTG 4H and the lowest one in FTG 4P was 46 $m^3.ha^{-1}$. The difference between highest total hectare standing volume in FTG 3B and the lowest in FTG 3S was 35 $m^3.ha^{-1}$. It turns out that the highest differences of the total hectare standing volume are in the 5th FVZ and gradually decreases towards the 3rd FVZ. The highest average value of the total hectare standing volume is 595 $m^3.ha^{-1}$ in the 5th FVZ, 468 $m^3.ha^{-1}$ in the 4th FVZ and 446 $m^3.ha^{-1}$ in the 3rd FVZ. The difference between the average value of the total hectare standing volume in 5th and 4th FVZs is 124 $m^3.ha^{-1}$, between 5th and 3rd FVZs is 146 $m^3.ha^{-1}$ and between 4th and 3rd FVZs is 22 $m^3.ha^{-1}$.

5.2 Measurements on permanent research plots (TVP)

5.2.1 The characteristics of plant communities

Table of phytocoenological relevés is in Appendix 1. It contents a total of 72 vascular plant species, of which 19 are woody species. *Pseudotsuga menziesii* has the highest representation in the tree layer – on 24 TVP; *Picea abies* slightly less – on 19 TVP. A frequency above 50 % in the herb layer have: *Fagus sylvatica, Luzula luzuloides, Viola reichenbachiana, Impatiens parviflora, Oxalis acetosella, Mycelis muralis, Rubus fruticosus* agg., *Calamagrostis arundinacea, Rubus idaeus, Sorbus aucuparia* and *Avenella flexuosa*. Douglas fir natural regeneration was found on the most of the permanent research plots. Since the moss layer species were identified tentatively only, no further attention was paid to them and they were not used in numerical analysis.

It was found that the permanent research plots selected in different localities of the commercial forest are rather difficult to classify into the syntaxonomic units presented by CHYTRÝ ET AL. (2013). Therefore, the classification was proceeded with the omission of the allochthonous introduced species occurring in E_1- layer. Permanent research plots of colder localities might belong to the association *Luzulo luzuloidis-Fagetum sylvaticae* Meusel 1937, and its variant *Veronica officinalis* (code LBE01a – according to CHYTRÝ ET AL. 2013). The species that point to this unit are: *Fagus sylvatica, Luzula luzuloides, Viola reichenbachiana* and *Oxalis acetosella*. Permanent research plots in warmer localities, Vráž locality especially, apparently might belong to the association *Luzulo luzuliodis-Quercetum petraeae* Hilitzer 1932 and its variant of *Luzula pilosa* (code LDA01b). Species indicating acidic habitats are common there and can often occur in a wide range of FVZs (*Sorbus aucuparia, Avenella flexuosa, Galium rotundifolium, Quercus robur, Calamagrostis epigeios, Carex pilulifera, Vaccinium myrtillus, Dryopteris filix-mas* and *Quercus petraea* agg.).

The localities could be characterized as inhomogeneous, according to RAUNKIAER (1905) - I > II > III ≥ IV < V. The TVP classification according to species constancy into 5 frequency classes was as follows: I = 42 species; II = 12 species; III = 11 species; IV = 5 species and V = 3 species; therefore 42 > 12 > 11 > 5. Since 5 (in Vth frequency class is not less than 3, the TVP of all localities are inhomogeneous.

5.2.1.1 Classification by the TWINSPAN procedure

The TWINSPAN procedure classifies the phytocoenological relevés of individual TVP into two subgroups (Fig. 60; detail classification TWINSPAN table is in Appendix 2). Group signed *0 has *Fagus sylvatica* and *Galium rotundifolium* as indicators, which introduce middle altitudinal forest localities on acidic soils, while the *1 group indicators *Calamagrostis epigeios* and *Sorbus* *aucuparia* indicates the relationships the present forest to grassland communities (either the species persists here from the past as cut plot or their penetration from surrounding clearings). The division at this highest level largely copies the TVP division into individual localities. Vodňany and Kamýk localities predominate relevés of *0 group and Sedlice and Vráž localities are in relevés of *1 group. Therefore, the influence of individual dominant tree species composition is not visible here.

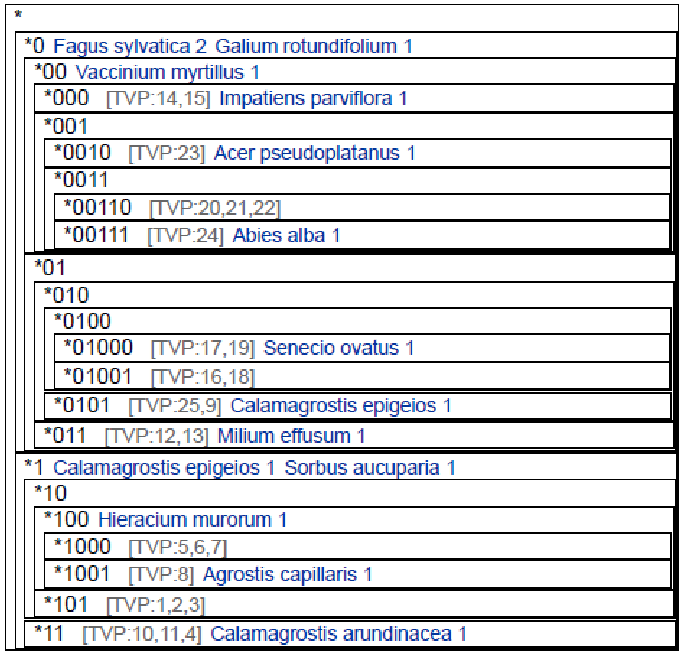

Fig. 60. Permanent research plots classified by TWINSPAN

5.2.1.2 DCA ordination analysis – variability of plant communities

The distribution of individual TVP (Fig. 61) and species (Fig. 62) was created by DCA ordination analysis. The share of species variability captured by the first two ordination axes is 30.2%.

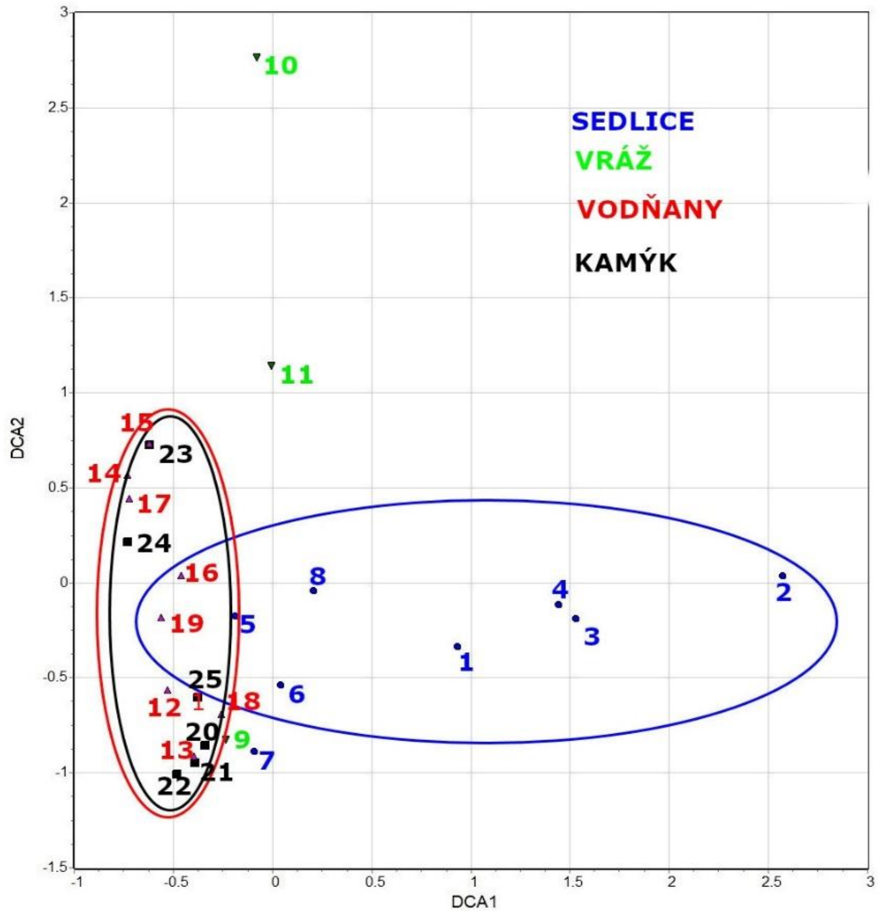

Fig. 61. Permanent research plots distribution in ordination space of the DCA first two axes. The plots presence to localities is indicated

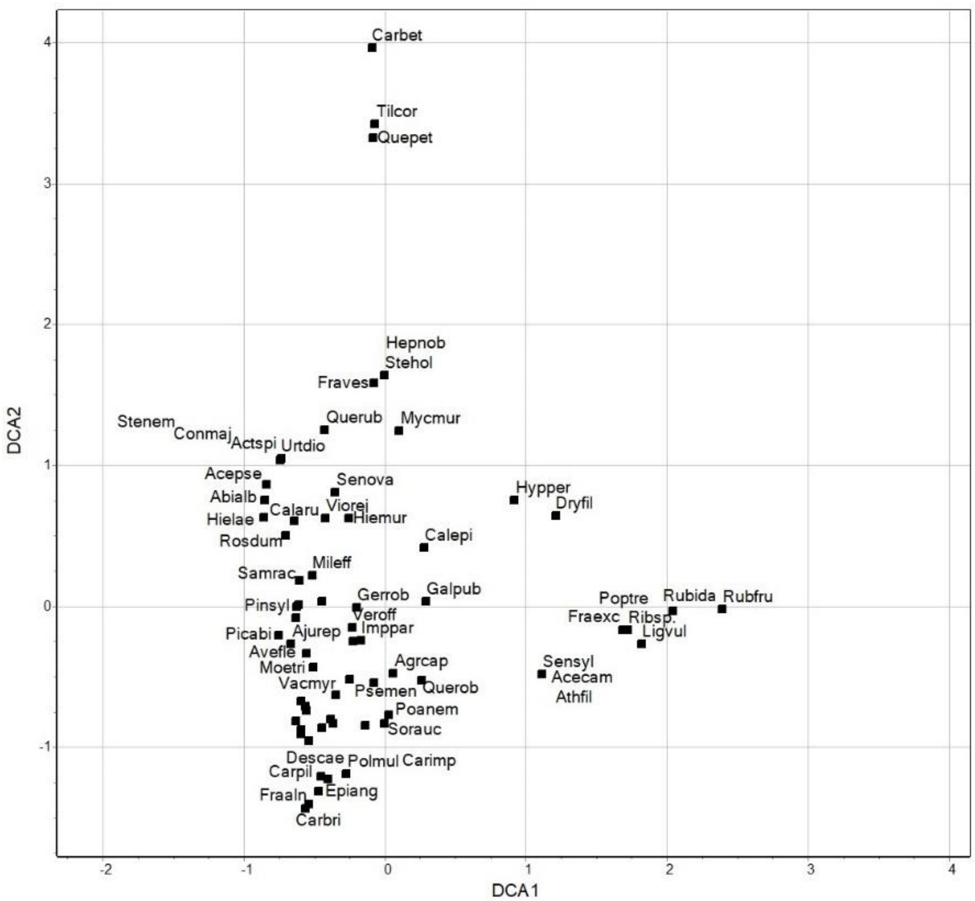

Fig. 62. Species distribution in ordination space of the DCA first two axes

The Sedlice (8 TVP) and Vráž (3 TVP) localities are strongly different from the other localities as Vodňany (8 TVP) and Kamýk (6 TVP). The species composition of Sedlice locality show nutrient richness and also nitrification due to weakly reduced canopy and faster humus decomposition (variability along the DCA 1 axis). The three TVP of Vráž localities are rather mesotrophic in terms of nutrients, and TVP No. 10 and 11 show a higher occurrence of more thermophilous vegetation in E_1 layer (*Carpinus betulus, Fragaria vesca, Hepatica nobilis, Quercus petraea* agg., *Stellaria holostea* and *Tilia cordata*) and more light-loving species (e.g. *Fragaria vesca* and *Tilia cordata*) (variability along the DCA 2 axis). Thus, these TVP could belong to a different classification unit, in contrast to TVP No. 9, the same locality, which shows species poorer in nutrients (e.g. *Luzula luzuloides*) and more cold-loving (e.g. *Galium rotundifolium*).

The Vodňany (8 TVP) and Kamýk (6 TVP) localities show the same species presence amplitude and thus (Fig. 61) this shows their great similarity. These are plots with species amplitude from habitats with alternating humidity (e.g. *Frangula alnus* and *Carex brizoides*), through nutrient poor (e.g. *Carex pilulifera* and *Vaccinium myrtillus*) to mesotrophic habitats (e.g. *Actaea spicata* and *Convallaria majalis*).

However, overall localities distribution with their TVP belonging to 2 different classification units, including the transition between them, indicates different climatic and partly also soil conditions. It should be also remembered that TVPs were in commercial forests with a different approach to management for hundred years.

5.2.1.3 CCA ordination analysis – the effect of tree species on the community structure

The influence of individual tree species on the herb payer structure was ascertained by CCA ordination analysis (Fig. 63). The results show that 64.3 % of the species variability is determined by tree species composition, with a permutation test significance of 0.2 %.

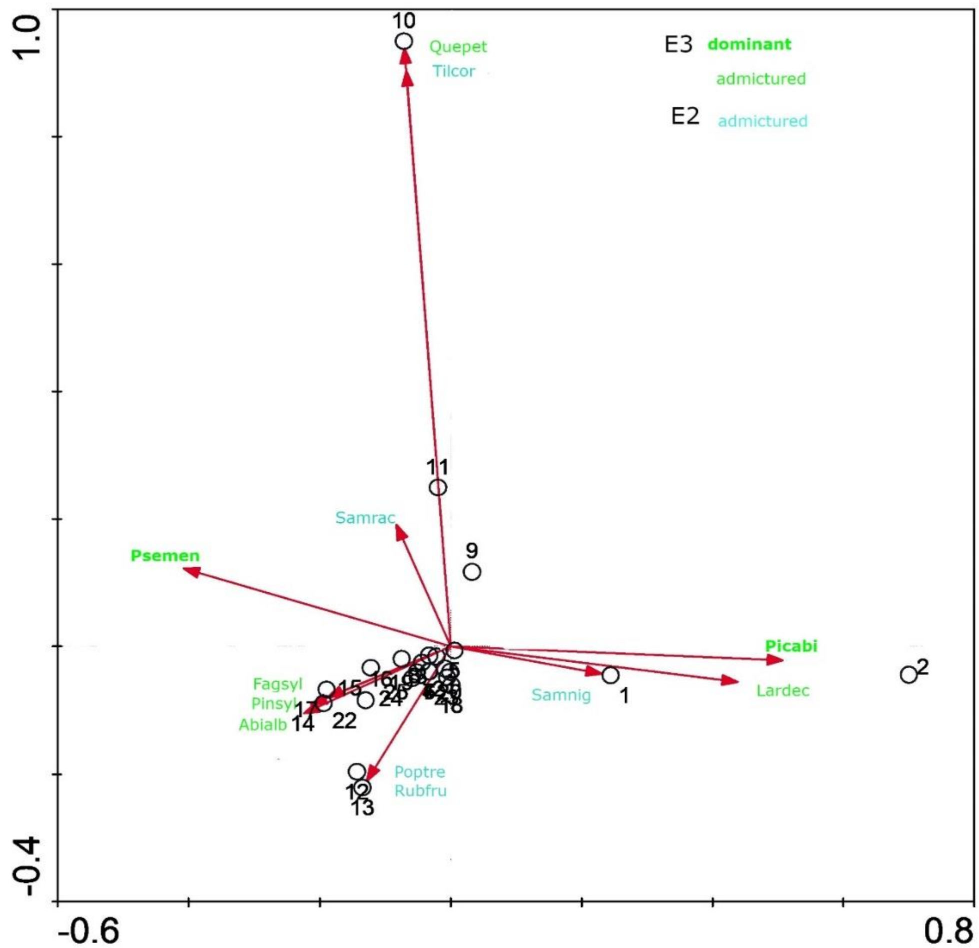

Fig. 63. CCA analysis of the E3 and E2 layers tree species on herb layer composition in relation to individual TVP. The axes (1 and 2) express 27.5 % of the variability. (The dominant tree species of the E3 layer are shown in bold; the mixed ones in this layer are shown in non-bold – both in green. The trees of the E2 layer are marked here in non-bold cyan. The TVP placements (1 – 25) then show E1 layer vegetation.

The first CCA axis is related to the influence of *Pseudotsuga menziesii* dominance on the left side of ordination space and *Picea abies* on the opposite site. These two trees therefore have a fundamental influence on the herb layer composition. The second ordination axis is related to higher *Quercus petraea* agg. and *Tilia cordata* presence in the tree layer, with which the *Carpinus betulus* occurrence is also associated (this species has its occurrence limit north of Vodňany, further south it no longer occurs naturally); it distinguishes oaks and European beeches stands well. *Rubus idaeus, Rubus fruticosus* agg., or *Senecio fuchsia* etc. are more prominent in the communities under the Norway spruce dominant, which is clear proof of allochthonous Norway spruce stands. No specific species are significantly presented under the Douglas fir dominant (Fig. 64).

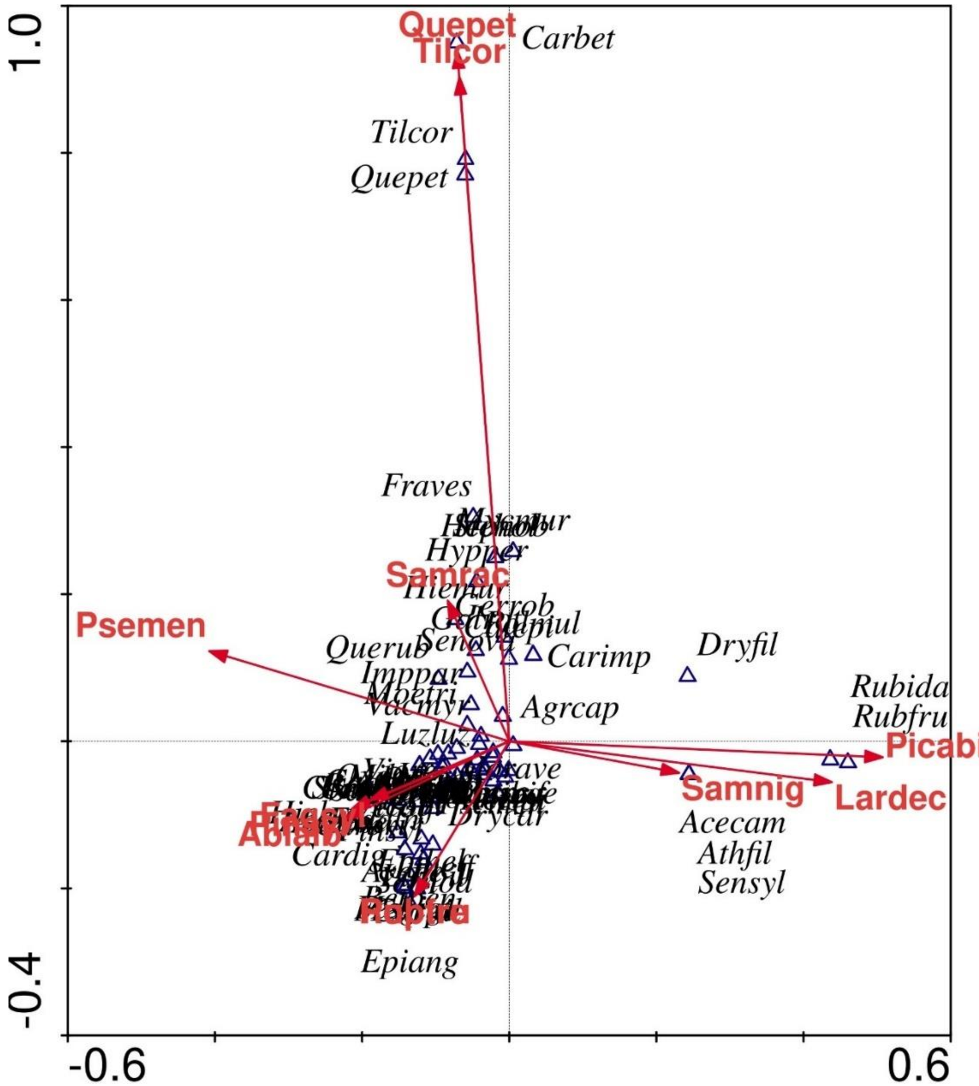

Fig. 64. Species distribution of the E_1 layer in the ordination space of the CCA first two axes in relation to E_2 and E_3 layers

The Vráž locality (TVPs No. 9-11) shows a different position compared to other localities (Fig. 64). The forest vegetation layer of this locality shows that the local TVPs are outside the vegetation unit of the other TVPs. This is apparently due to the fact that the vegetation of the TVP No. 10 belongs to the association *Luzulo luzuloidis-Quercetum petrae* var. *Luzula luzuloides* and vegetation of the TVP No. 11 is transitional between the associations *Luzulo luzuloidis-Quercetum petrae* var. *luzula lizuloides* and *Luzulo luzuloidis-Fagetum sylvaticae* var. *Luzula pilosa*. The vegetation of TVP No. 9 already belongs to the association *Luzulo luzuloidis- Fagetum sylvaticae* var. *Luzula pilosa*, as was indicated above in the evaluation results of the Phytocoenological relevés table (Appendix 1).

The Sedlice locality (TVP Nos. 1 and 2 primarily) is also different from most other localities, although its vegetation belongs to the same association and variant as the Kamýk and Vodňany localities. It is apparently caused by management influence (the area is approximately 100 m far from clearing edge). The Sedlice locality (Fig. 64) showed a greater presence of nitrophilous (even ruderal) species (e.g. *Rubus idaeus, R. fruticosus* agg., and *Sambucus nigra*). The reason may be the possible penetration of larger light amount from the surroundings and the presence of admixed *Larix decidua* (in E_3), which is quite light-permeable.

The TVPs No. 12 and 13 (Vodňany location) also show a lower crown canopy, which is manifested by the presence of *Populus tremula* and *Rubus fruticosus* agg. in E_2 layer and *Epilobium angustifolium* in E_1 layer (Fig. 64). Species of original natural tree stands are more abundant in the herb layer on TVPs dominated by Douglas fir. Conversely, the greater species presence anthropically spread in non-native stands are on TVPs dominated by Norway spruce completely opposite orientation along the CCA 1 axis).

5.2.2 Stand light conditions

The stand light conditions (especially bellow the dominant trees (E_3)) significantly affect the herb layer composition and natural regeneration, as well as the woody plants growth. Hemispheric photographs were used to quantify light conditions. The monitored stands have had a closed structure generally; however, lateral illumination has been applied as a result of cutting in nearby stand groups in some cases. The diffuse radiation proportion in individual photos has been in the range of 9 to 37 % (arithmetic mean 24 %) and the canopy has ranged from 44 to 90 % (mean 66%). The average values of diffuse radiation share on individual TVPs (with 5 photos on the TVP) have been in the range of 13% (in the Kamýk locality; TVP No. 23) and 36% (in the Vodňany locality; TVP No. 13). The average canopy values have been in the range of 49% (in the Vodňany locality; TVP No. 15) and 78% (in the Kamýk locality; TVP No. 23). A detailed overview of the individual layers coverage and incident light amount is in Table 17.

The overall canopy has had an increasing character – Vodňany < Sedlice < Vráž < Kamýk. The highest light conditions variability has been recorded in the Kamýk locality on TVPs No. 23 and 25.

The canopy estimate made in the field has been compared (E_3; tree layer coverage) with the value calculated from the hemispheric photos (C – variable): E_3 = 1.11%, C = 8.62%, with r^2 = 0.672 (Fig. 65).

Table 17. The individual layers coverage, the diffuse radiation share and the results of hemispheric photos (HF) analysis on TVPs

TVP	Locality	coverage [%]					Diffuse radiation share [%]
		E_0	E_1	E_2	E_3	Canopy according to HF	
		[%]					
1	Sedlice	3	40	20	70	64	33
2		3	75	0	50	52	35
3		5	20	0	65	75	18
4		8	20	0	70	75	18
5		5	10	0	70	66	22
6		5	40	10	60	68	32
7		15	35	0	70	65	29
8		60	45	1	60	65	21
9	Vráž	5	15	0	80	76	15
10		10	40	5	75	74	16
11		10	55	20	70	68	21
12	Vodňany	30	80	5	40	52	34
13		15	40	1	45	56	36
14		20	50	0	60	53	35
15		20	80	20	55	49	31
16		5	40	1	50	62	24
17		8	8	1	50	54	27
18		1	5	0	85	73	24
19		5	80	5	55	58	25
20	Kamýk	5	15	0	80	71	17
21		8	10	0	75	74	17
22		5	40	35	60	70	17
23		3	15	0	80	78	13
24		15	15	5	75	76	17
25		0	55	3	60	67	25

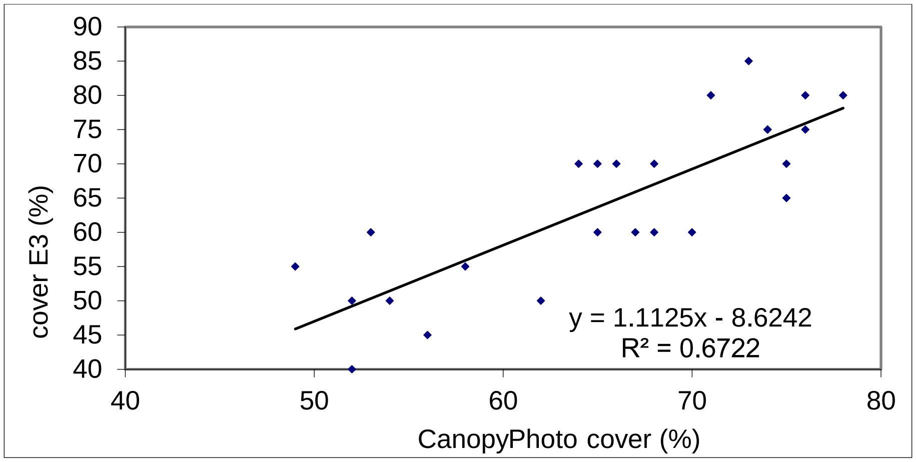

Fig. 65. Comparison of canopy estimates made in the field (E_3 cover) with the calculated value from CanopyPhotos cover

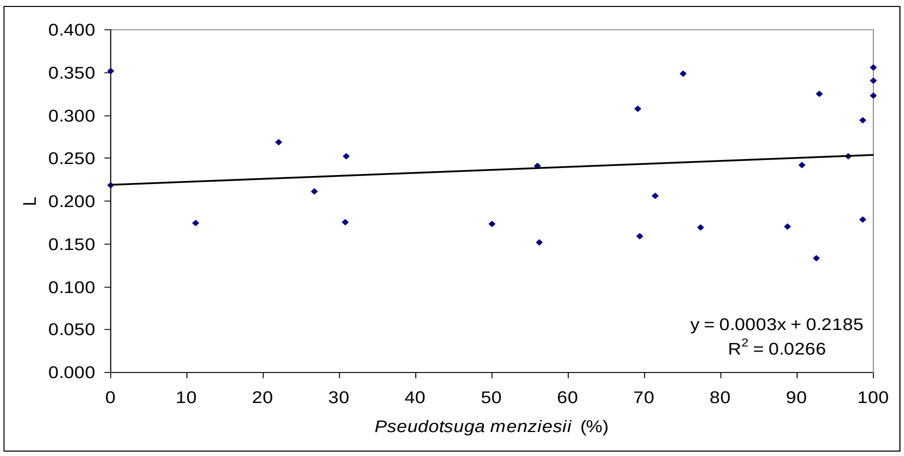

Fig. 66. Comparison of the diffusion radiation amount in the understory (L) with the relative abundance of *Pseudotsuga menziesii* in the tree layer

Manmade cultivated stands of Douglas fir and Norway spruce on TVPs have had a similar structure. It could be due to the fact that the stands of both tree species had been managed by a similar way. Therefore, the stand canopy and light conditions in understory do not depend on the tree layer composition (Fig. 66). Since the total all tree composition in the tree layer is always 100 %, it is obvious that a lower Douglas fir presence results to a higher other tree species presence – mostly to Norway spruce (Appendix 1).

The herb layer development strongly depends on the light conditions bellow the tree and shrub layers (Fig. 67). The total herb layer coverage is reduced significantly, if the diffuse radiation shares bellow the above-mentioned layers is lower approx. 25 % compared to free area. It is a generally valid rule. It has been described in forests of various vegetation stages throughout the Czech Republic (Matějka 2018b).

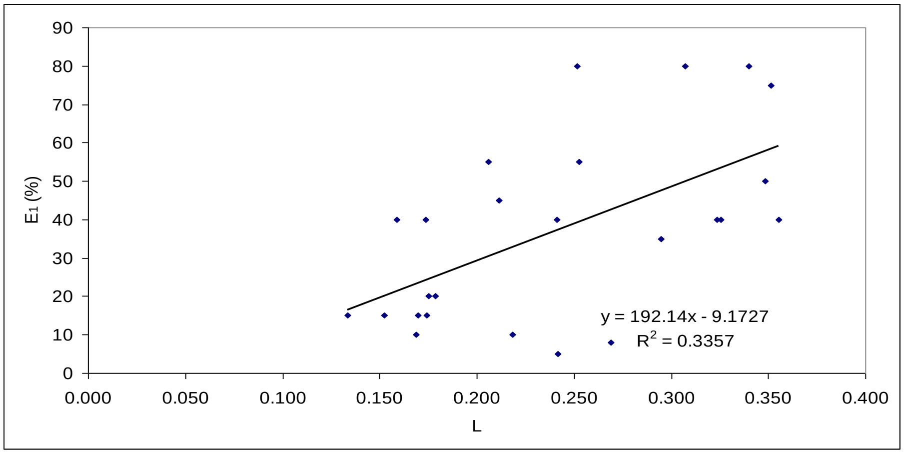

Fig. 67. Dependence of the herb layer total coverage (E1) on the diffuse radiation amount in the understory (L)

5.2.3 Tree layer structure on TVPs

The Douglas fir breast height diameter ranged from 43.9 cm to 101.4 cm on all TVPs (Tables 18 – 21); its tree height average ranged from 31.4 m to 46.9 m and basal area (G) ranged from 11.28 $m^2.ha^{-1}$ (at a 23% presence in the stand) to 81.76 $m^2.ha^{-1}$ (at a 100% presence in the stand). The Norway spruce breast height diameter ranged from 21.5 cm to 49.9 cm; tree height average ranged from 24.1 m to 34.7 m and basal area (G) ranged from 1.43 $m^2.ha^{-1}$ (at 1.7 % presence in the stand) up to 58.20 $m^2.ha^{-1}$ (at 100 % presence in the stand). Stands coverage ranges from 50% to 83%.

Table 18. Sedlice locality – tree layer structure: 1 – TVP No.; 2 – age; 3 – canopy [%]; 4 – tree species; 5 – individuals amount per plot; 6 – d.b.h. average [cm]; 7 – tree height average [m]; 8 – living crown deployment average height [m]; 9 – crown projection average [m^2]; 10 – individuals amount per 1 ha; 11 – basal area on TVP (g) [m^2]; 12 – G [$m^2.ha^{-1}$]; 13 – presence [%]; 14 – mean-tree volume [m^3]; 15 – hectare standing volume [$m^3.ha^{-1}$]

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	88	74	DG	12	57,0	38,4	23,5	43,0	240	0,28	66,53	94,0	4,28	1027
			SM	2	36,6	32,9	21,3	21,3	40	0,11	4,21	6,0	1,54	62
2	88	56	SM	11	41,9	31,5	18,4	21,2	220	0,14	31,68	66,6	2,00	440
			DG	2	62,3	40,0	22,2	59,5	40	0,31	12,21	25,7	4,76	190
			MD	1	48,2	33,6	24,9	18,6	20	0,18	3,65	7,7	-	-
3	88	70	SM	20	30,5	28,3	19,0	14,1	400	0,08	31,61	64,3	1,08	432
			DG	3	44,1	30,9	19,9	37,3	60	0,19	11,28	23,0	2,78	167
			BO	2	35,6	29,5	22,1	9,6	40	0,11	4,23	8,6	-	-
			DB	1	35,8	23,3	18,9	14,3	20	0,10	2,01	4,1	-	-
4	88	66	DG	10	53,5	38,3	22,5	55,4	200	0,24	47,73	100,0	3,76	753
5	88	70	SM	30	33,7	29,7	20,3	14,4	600	0,10	58,20	100,0	1,33	795
6	119	73	DG	12	63,8	40,8	22,5	38,3	240	0,34	81,76	100,0	5,59	1343
7	119	65	DG	6	71,6	42,2	24,3	52,4	120	0,41	49,28	81,5	6,78	814
			SM	4	40,7	31,6	19,6	22,6	80	0,14	11,15	18,5	2,03	162
8	94	56	SM	7	49,9	34,7	18,4	30,6	160	0,16	24,97	56,5	2,04	326
			DG	3	63,6	38,0	20,0	37,2	60	0,32	19,21	43,5	4,72	283

The Sedlice locality (Table 18): Douglas fir d.b.h. average ranged from 44.1 cm to 71.6 cm; the tree height average ranged from 30.9 m to 42.2 m, and the basal area (G) ranged from 11.28 $m^2.ha^{-1}$ (at 23% presence in the stand) to 81.76 $m^2.ha^{-1}$ (at 100% presence in the stand). The highest mean-tree volume 6.78 m^3 was recorded on TVP No. 3., the lowest one was 2.78 m^3 on TVP No. 3, on the contrary. Norway spruce d.b.h. average ranged from 30.5 cm to 49.9 cm; the tree height average ranged from 28.3 m to 34.7 m, and the basal area (G) ranged from 4.21 $m^2.ha^{-1}$ (at 6% presence in the stand) to 58.20 $m^2.ha^{-1}$ (at 100% presence in the stand). The highest mean-tree volume 2.04 m^3 was recorded in the TVP No. 8, the lowest one 1.08 m^3 was recorded in TVP No. 3. Admixture tree species (European larch, Scotch pine and pedunculated oak) were also recorded in this locality in addition to above mentioned two tree species. The coverage ranged from 56% to 74%. The positions of trees and their crown projections on individual TVPs of the Sedlice locality are shown in Figs 68 to 75.

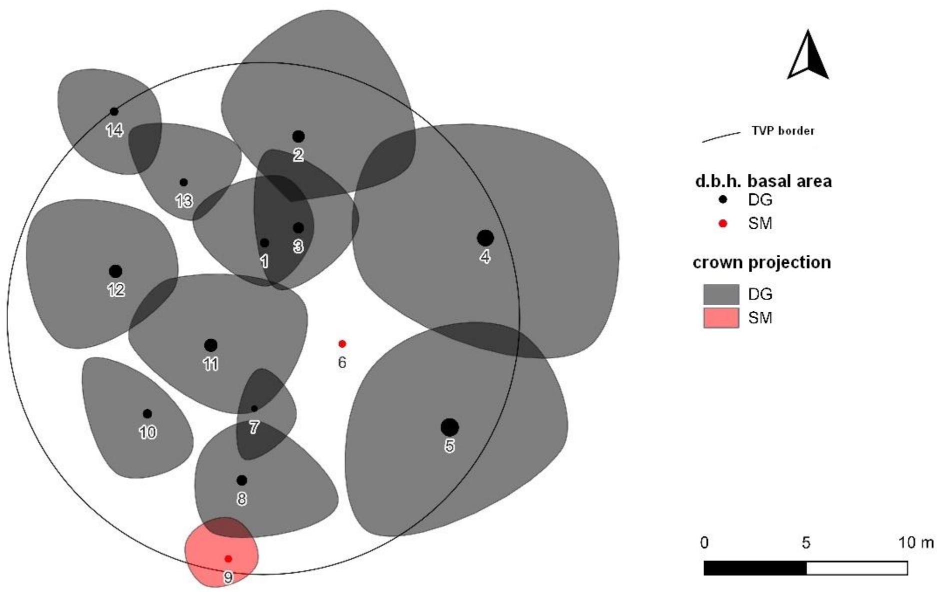

Fig. 68. Trees position and their crown projections on permanent research plot No. 1, Sedlice locality

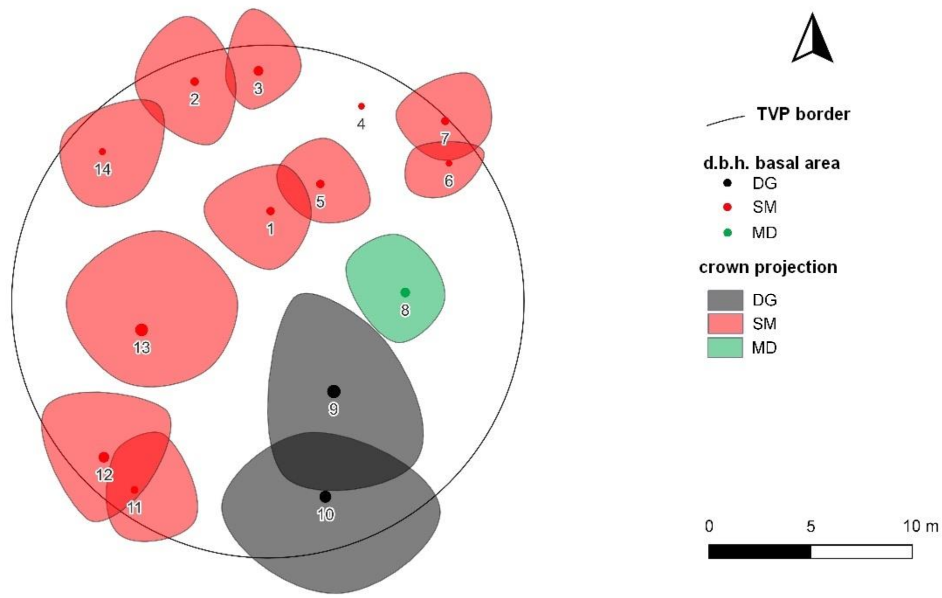

Fig. 69. Trees position and their crown projections on permanent research plot No. 2, Sedlice locality

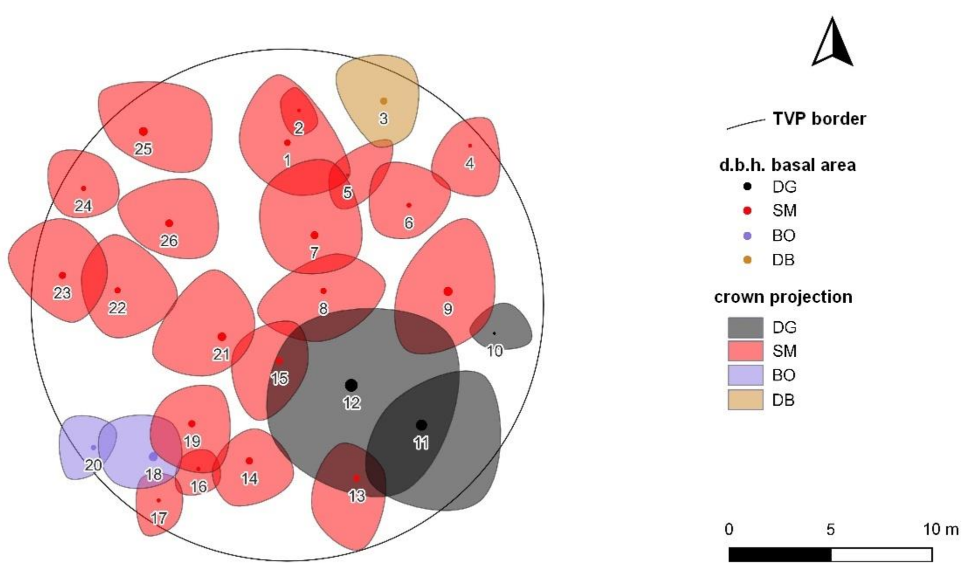

Fig. 70. Trees position and their crown projections on permanent research plot No. 3, Sedlice locality

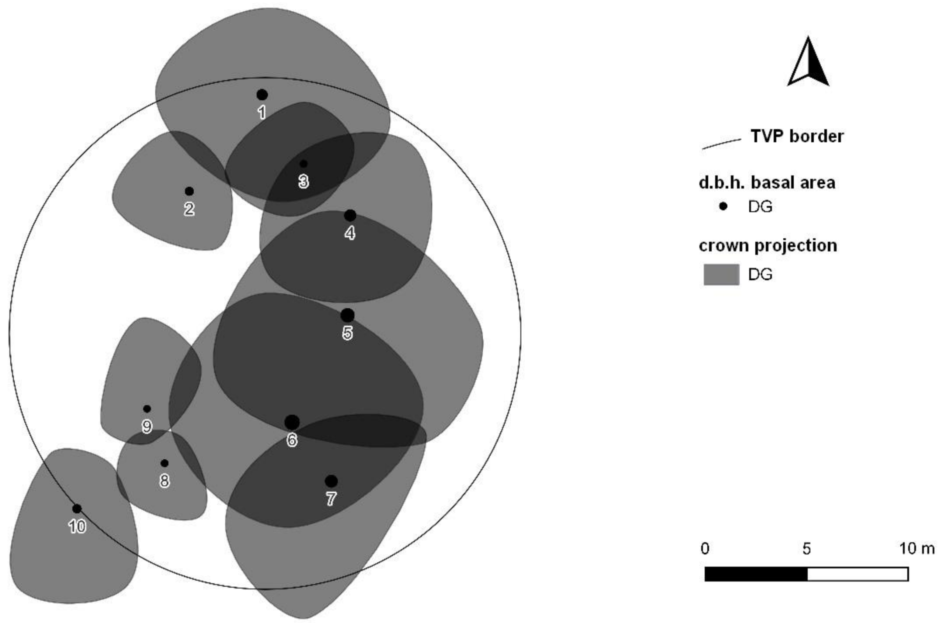

Fig. 71. Trees position and their crown projections on permanent research plot No. 4, Sedlice locality

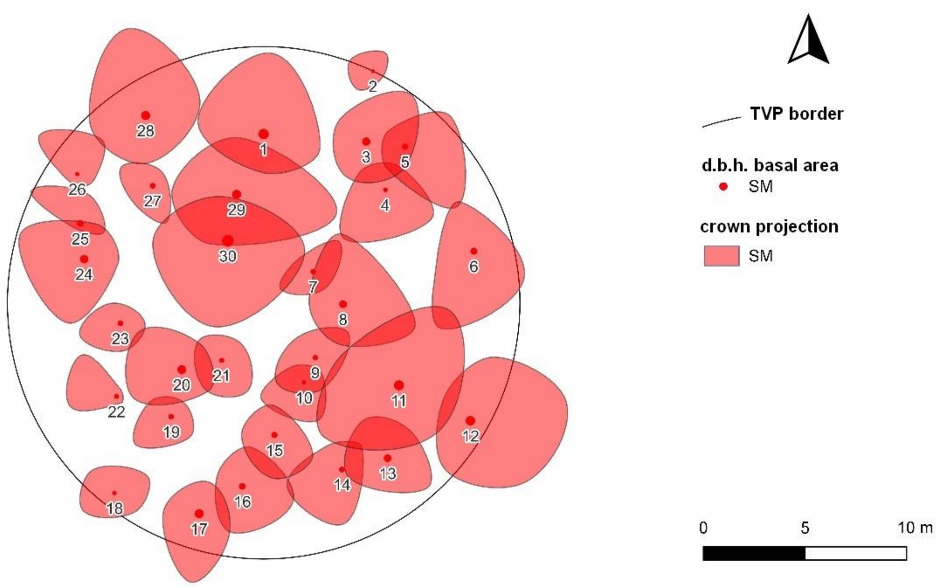

Fig. 72. Trees position and their crown projections on permanent research plot No. 5, Sedlice locality

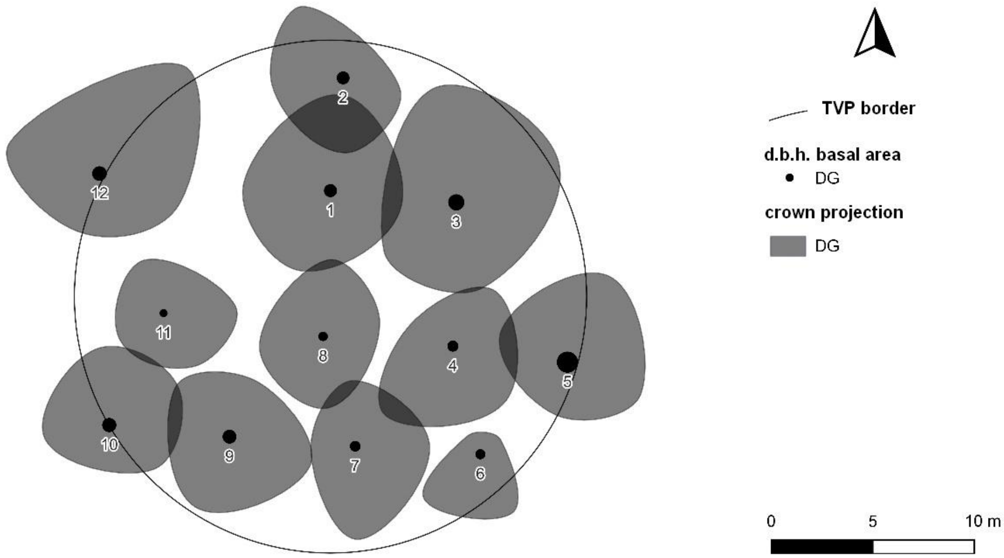

Fig. 73. Trees position and their crown projections on permanent research plot No. 6, Sedlice locality

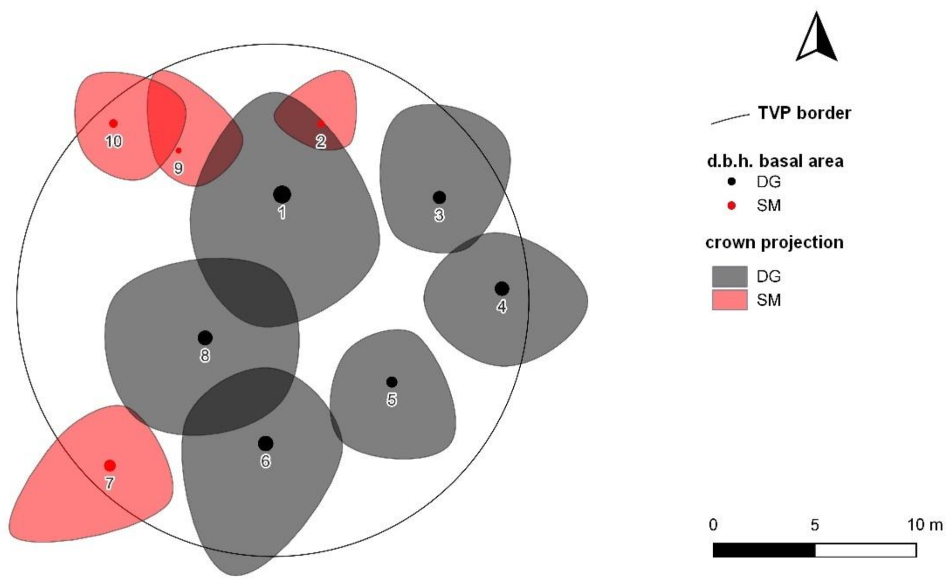

Fig. 74. Trees position and their crown projections on permanent research plot No. 7, Sedlice locality

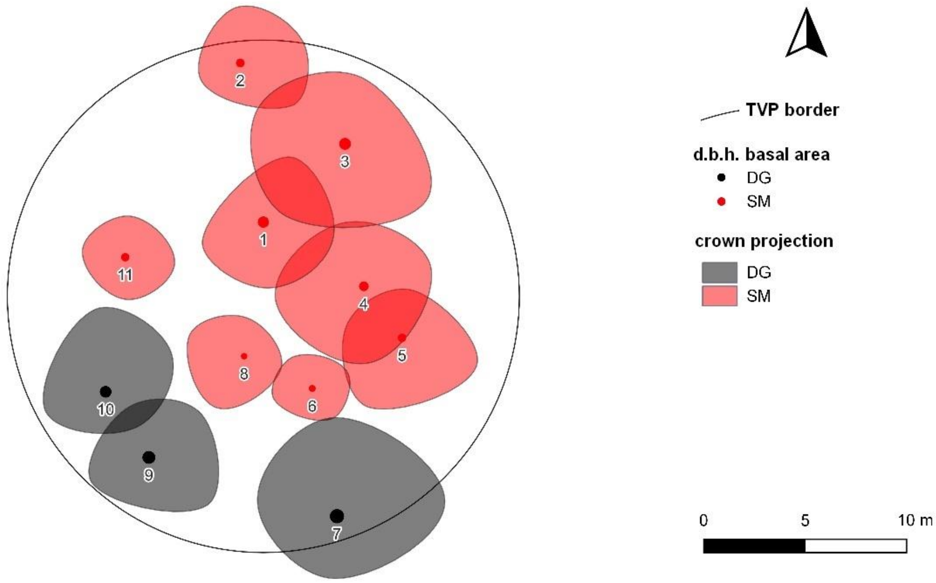

Fig. 75. Trees position and their crown projections on permanent research plot No. 8, Sedlice locality

The Vráž locality (Table 19): the Douglas fir d.b.h. average ranged from 43.9 cm to 68.9 cm; the tree height average ranged from 32.5 m to 38.7 m, and basal area (G) ranged from 22.95 $m^2.ha^{-1}$ (at 45.5% presence in the stand) to 35.01 $m^2.ha^{-1}$ (at 67.6% presence in the stand). The highest mean-tree volume 5.75 m^3 was recorded on TVP No. 11 and the lowest was 2.16 m^3 on TVP No. 10, on the contrary. The Norway spruce d.b.h. average ranged from 21.5 cm to 27.9 cm; the tree height average ranged from 24.1 m to 27.0 m, and the basal area (G) ranged from 11.76 $m^2.ha^{-1}$ (at 25.7% presence in the stand) to 24.50 $m^2.ha^{-1}$ (at 48.6% presence in the stand). The highest mean-tree volume 0.86 m^3 was recorded at TVP No. 11 and the lowest one was 0.48 m^3 on TVP No. 9 on the contrary. Admixed tree species (Scotch pine, pedunculated oak, European beech and silver birch) were recorded also in this locality. The stand canopy ranged from 50% to 70%. The trees positions and their crown projections on individual TVPs of the Vráž locality are shown in Figs. 76 – 78.

Table 19. Vráž locality – tree layer structure: 1 – TVP No.; 2 – age; 3 – canopy [%]; 4 – tree species; 5 – individuals amount per plot; 6 – d.b.h. average [cm]; 7 – tree height average [m]; 8 – living crown deployment average height [m]; 9 – crown projection average [m^2]; 10 – individuals amount per 1 ha; 11 – basal area on TVP (g) [m^2]; 12 – G [$m^2.ha^{-1}$]; 13 – presence [%]; 14 – mean-tree volume [m^3]; 15 – hectare standing volume [$m^3.ha^{-1}$]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
9	86	70	SM	15	21,5	24,1	17,5	10,1	300	0,04	11,76	25,7	0,48	145
			DG	10	44,2	35,4	21,2	30,5	200	0,16	32,78	71,6	2,42	485
			BO	1	22,2	22,6	19,2	5,3	20	0,04	0,77	1,7	-	-
			DB	1	17,6	18,5	1,6	15,9	20	0,02	0,49	1,1	-	-
10	86	70	SM	12	26,8	27,0	16,7	14,3	240	0,06	13,91	26,9	0,75	180
			DG	11	43,9	32,5	19,6	23,7	220	0,16	35,01	67,6	2,16	474
			BO	1	29,1	28,9	23,8	7,4	20	0,07	1,33	2,6	-	-
			BK	1	31,2	29,1	16,2	19,8	20	0,08	1,53	3,0	-	-
11	86	50	SM	17	27,9	24,3	15,0	12,7	340	0,07	24,50	48,6	0,86	291
			DG	3	68,9	38,7	21,0	38,0	60	0,38	22,95	45,5	5,75	345
			BR	2	30,5	20,7	16,1	16,1	40	0,07	2,95	5,9	-	-

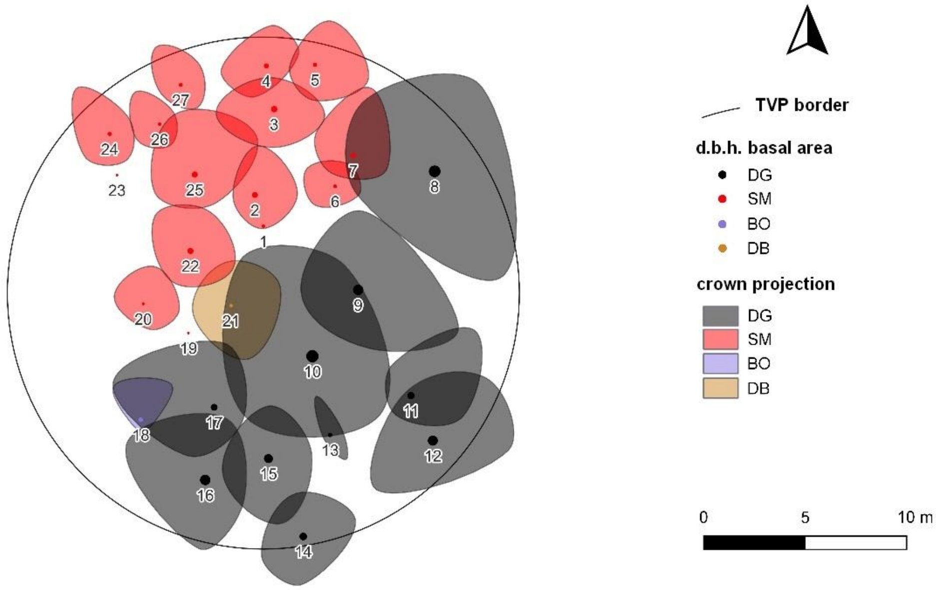

Fig. 76. Trees position and their crown projections on permanent research plot No. 9, Vráž locality

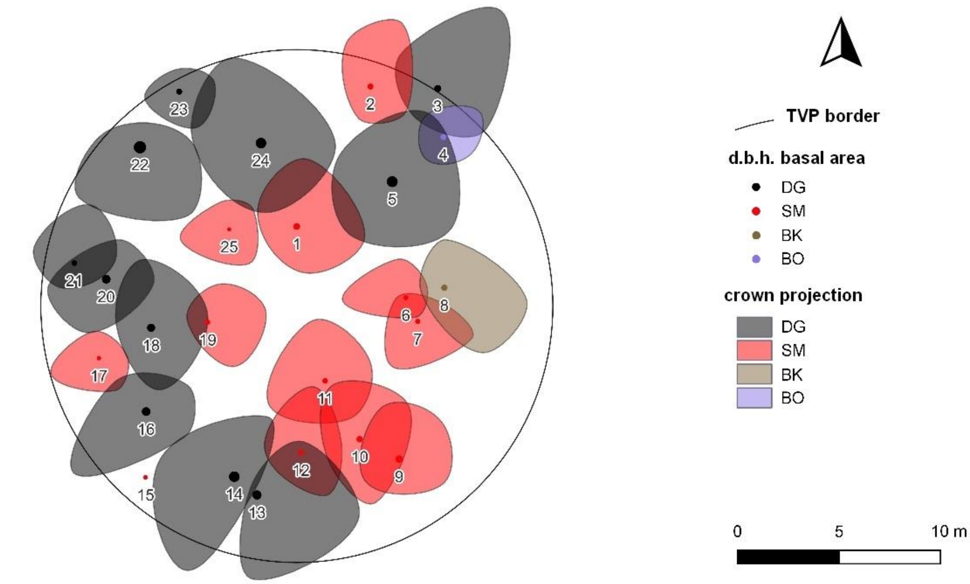

Fig. 77. Trees position and their crown projections on permanent research plot No. 10, Vráž locality

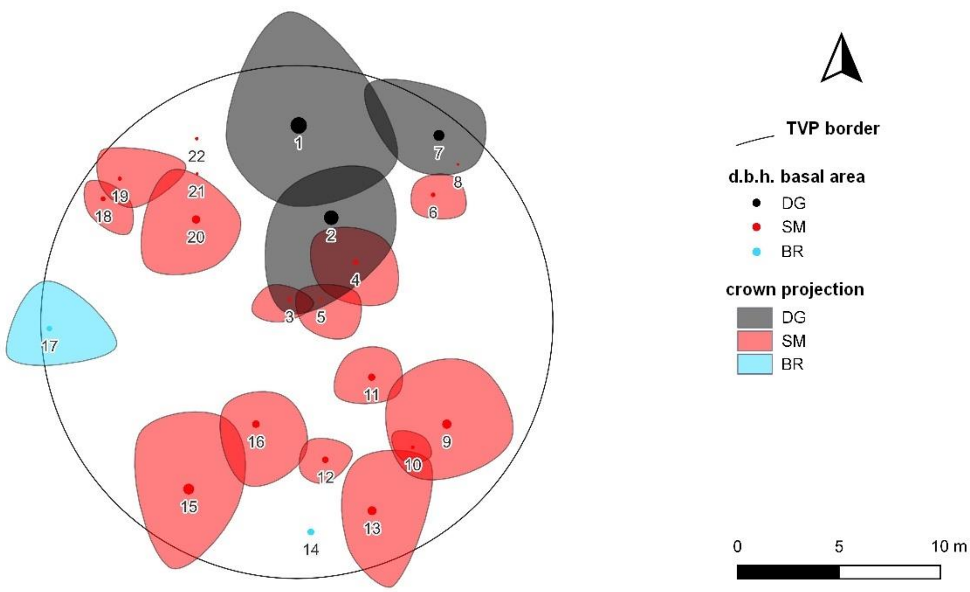

Fig. 78. Trees position and their crown projections on permanent research plot No. 11, Vráž locality

Table 20. Vodňany locality – tree layer structure: 1 – TVP No.; 2 – age; 3 – canopy [%]; 4 – tree species; 5 – individuals amount per plot; 6 – d.b.h. average [cm]; 7 – tree height average [m]; 8 – living crown deployment average height [m]; 9 – crown projection average [m^2]; 10 – individuals amount per 1 ha; 11 – basal area on TVP (g) [m^2]; 12 – G [$m^2.ha^{-1}$]; 13 – presence [%]; 14 – mean-tree volume [m^3]; 15 – hectare standing volume [$m^3.ha^{-1}$]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
12	96	62	DG	13	56,9	37,7	19,5	32,3	260	0,28	71,57	100,0	4,11	1069
13	96	75	DG	11	58,9	36,2	18,6	43,1	220	0,29	63,27	97,2	4,14	910
			SM	1	34,2	28,3	15,7	12,9	20	0,09	1,84	2,8	1,16	23
14	116	70	SM	13	38,1	30,7	20,1	20,0	260	0,12	31,21	43,8	1,70	442
			DG	5	54,4	34,2	18,5	45,9	100	0,28	27,80	39,0	4,13	413
			JD	4	41,2	29,5	17,4	17,4	80	0,15	12,24	17,2	-	-
15	85	64	SM	11	30,1	27,3	15,7	13,7	220	0,08	16,51	33,3	0,98	215
			DG	7	47,1	33,6	19,7	25,5	140	0,18	25,10	50,6	2,47	345
			BO	4	33,1	28,8	19,4	14,8	80	0,09	7,10	14,3	-	-
			MD	1	23,6	25,8	22,1	1,7	20	0,04	0,87	1,8	-	-
16	85	67	SM	26	25,4	25,0	15,6	11,0	520	0,05	28,44	58,9	0,69	357
			DG	3	61,6	35,5	18,6	38,0	60	0,30	17,99	37,3	4,14	248
			BO	2	24,1	24,2	18,0	6,0	40	0,05	1,84	3,8	-	-
17	111	81	SM	8	48,4	32,6	18,8	35,7	160	0,20	32,24	50,7	2,88	461
			DG	4	57,8	31,4	20,4	37,8	80	0,30	24,37	38,3	4,41	353
			JD	3	37,0	29,2	18,5	26,9	60	0,11	6,74	10,6	-	-
			BK	1	13,8	10,2	1,6	13,7	20	0,01	0,30	0,5	-	-
18	85	77	DG	16	53,2	34,9	20,5	29,7	320	0,24	75,93	89,2	3,51	1124
			BK	5	28,9	22,9	10,6	24,9	100	0,07	7,18	8,4	-	-
			SM	1	30,2	27,3	17,5	10,9	20	0,07	1,43	1,7	0,89	18
			MD	1	19,9	26,4	18,2	8,4	20	0,03	0,62	0,7	-	-
19	86	57	SM	16	31,1	27,3	15,9	16,9	320	0,08	26,96	63,1	1,11	356
			DG	3	49,4	35,0	19,3	29,3	60	0,21	12,68	29,7	3,14	188
			BO	1	44,4	32,2	22,6	22,1	20	0,15	3,10	7,3	-	-

The Vodňany locality (Table 20): the Douglas fir d.b.h. average ranged from 47.1 cm to 61.6 cm; tree height average ranged from 31.4 m to 37.7 m, and the basal area (G) ranged from 12.68 $m^2.ha^{-1}$ (at 29.7% presence in the stand) to 75.93 $m^2.ha^{-1}$ (at 89.2% presence in the stand). The highest mean-tree volume 4.41 m^3 was recorded at TVP No. 17, and the lowest one 2.47 m^3 on TVP No. 15. The Norway spruce d.b.h. average ranged from 25.4 cm to 48.4 cm; the tree height average ranged from 25.0 m to 32.6 m, and basal area (G) ranged from 1.43 $m^2.ha^{-1}$ (at 1.7% presence in the stand) to 32.24 $m^2.ha^{-1}$ (at 50.7% presence in the stand). The highest mean-tree volume 2.88 m^3 was recorded on TVP No. 17 and the lowest one was 0.69 m^3 on TVP No. 16. The admixed tree species (silver fir, Scotch pine, European larch and European beech) were recorded also in this locality, in addition to these above-mentioned tree species. The stand coverage ranged from 57% to 81%. The trees positions and their crown projections on individual TVPs of the Vodňany locality are shown in Figs. 79 – 86.

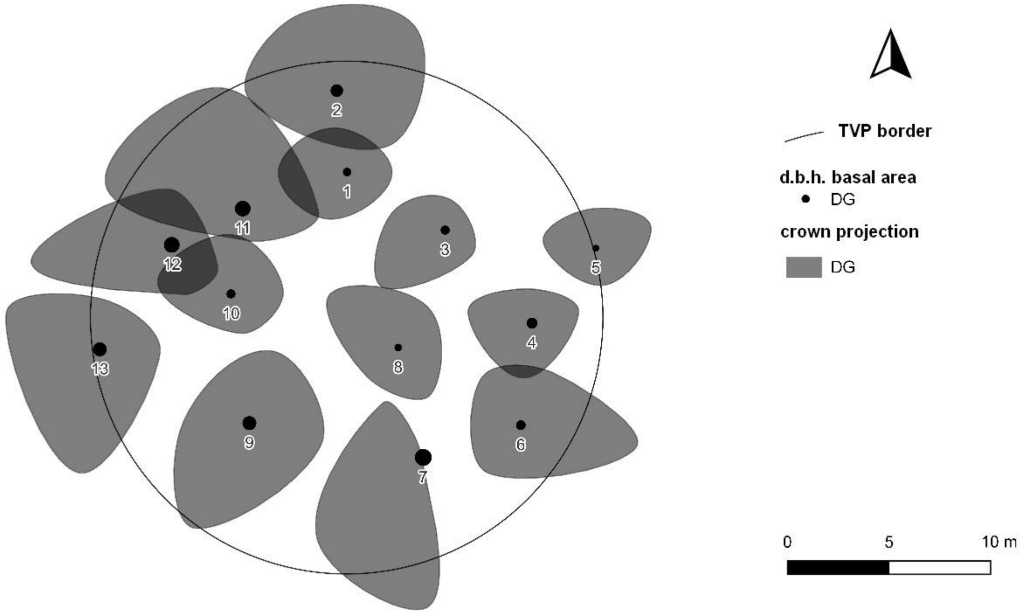

Fig. 79. Trees position and their crown projections on permanent research plot No. 12, Vodňany locality

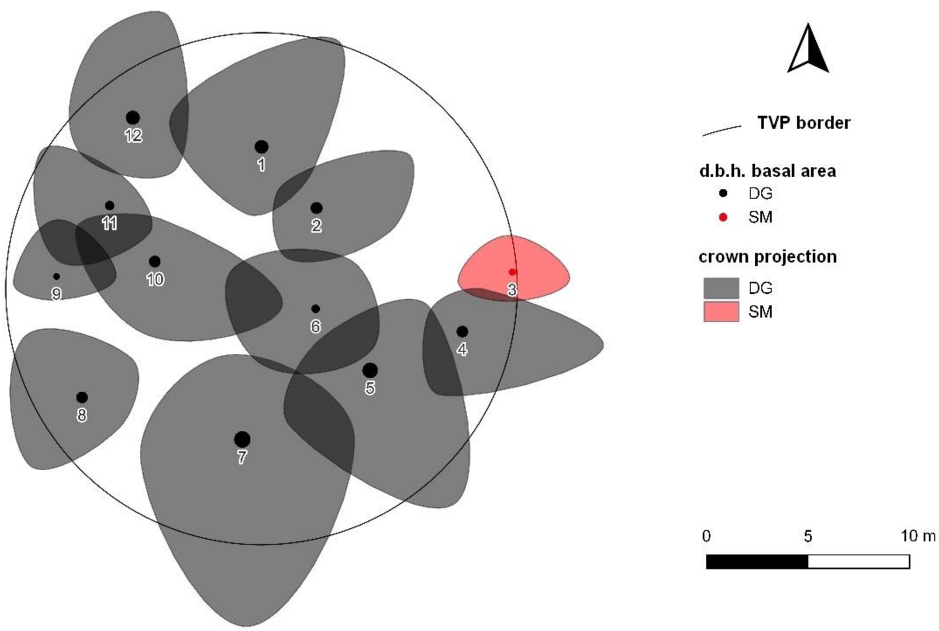

Fig. 80. Trees position and their crown projections on permanent research plot No. 13, Vodňany locality

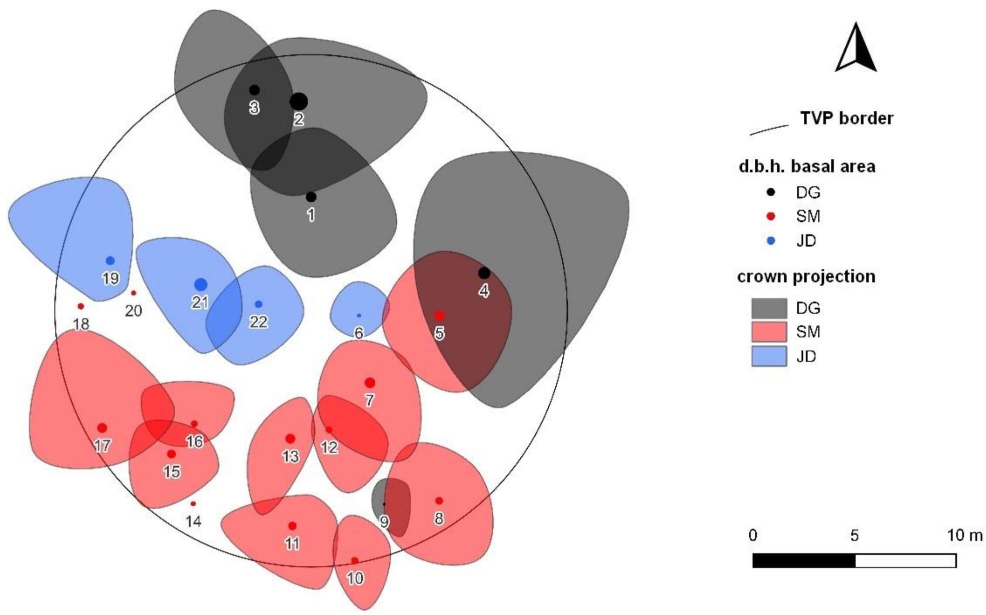

Fig. 81. Trees position and their crown projections on permanent research plot No. 14, Vodňany locality

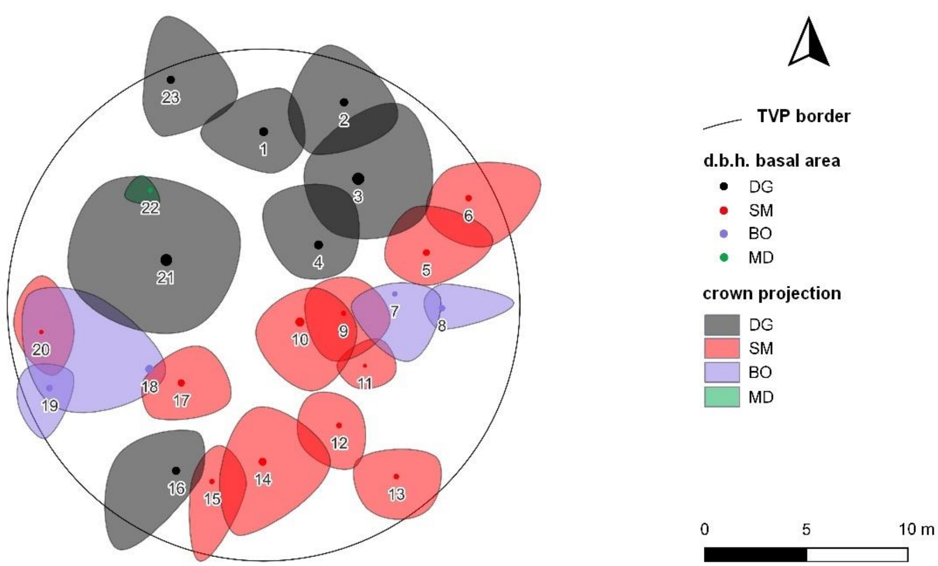

Fig. 82. Trees position and their crown projections on permanent research plot No. 15, Vodňany locality

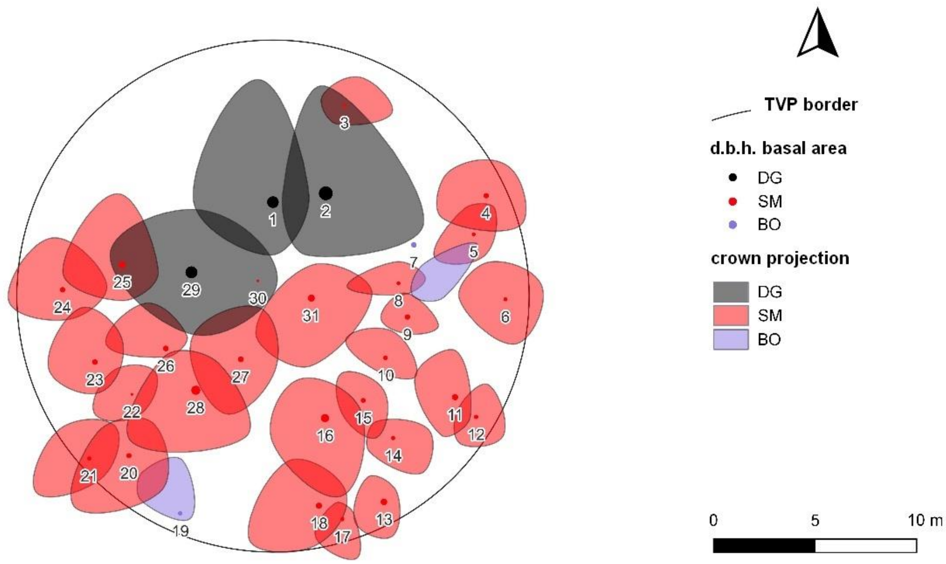

Fig. 83. Trees position and their crown projections on permanent research plot No. 16, Vodňany locality

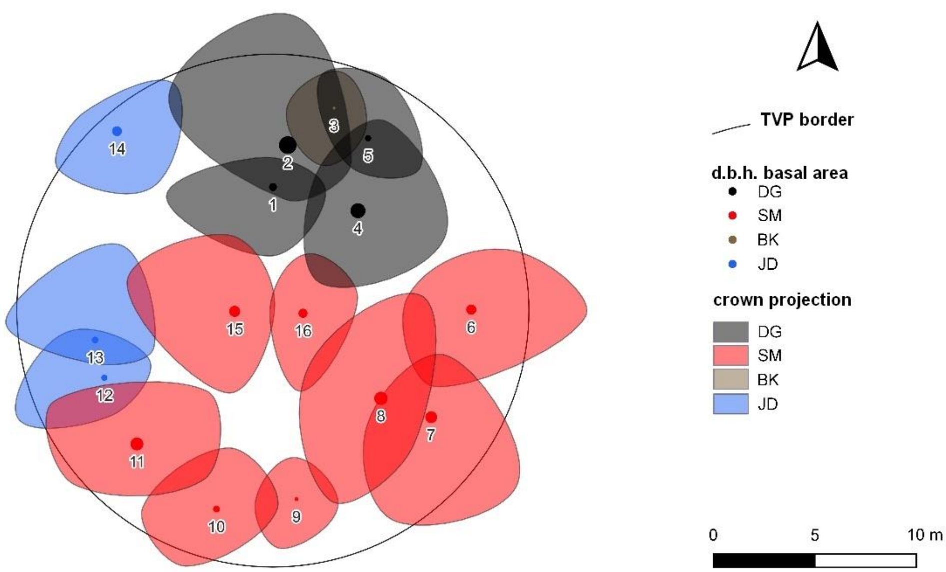

Fig. 84. Trees position and their crown projections on permanent research plot No. 17, Vodňany locality

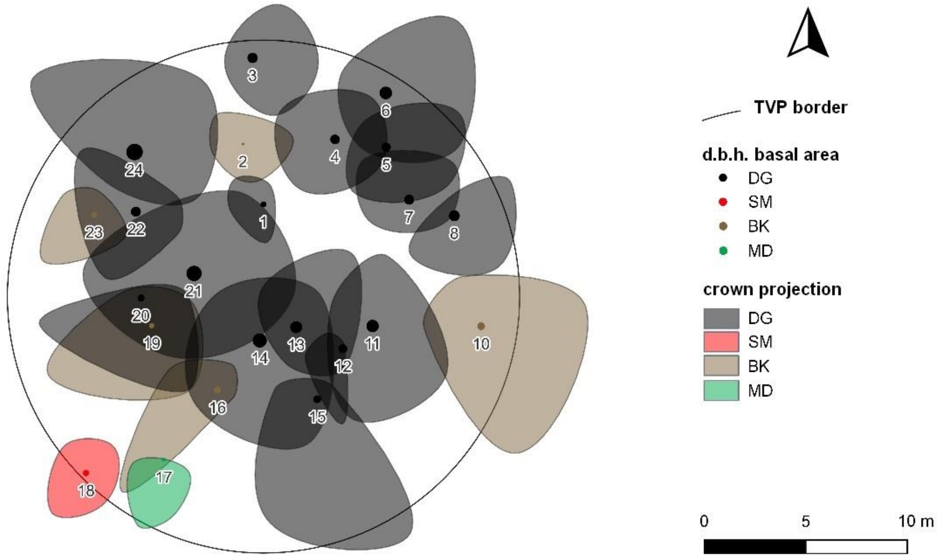

Fig. 85. Trees position and their crown projections on permanent research plot No. 18, Vodňany locality

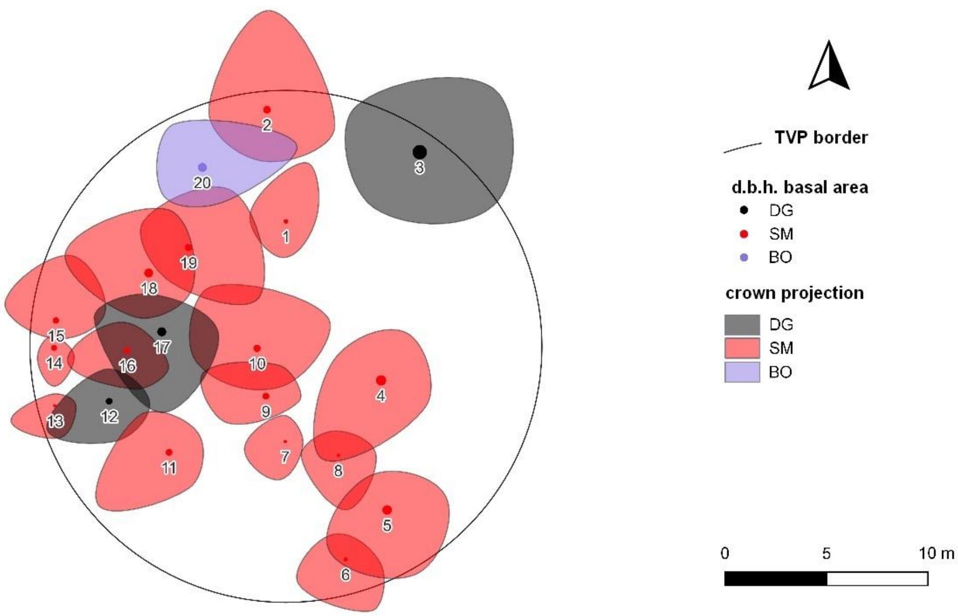

Fig. 86. Trees position and their crown projections on permanent research plot No. 19, Vodňany locality

Table 21. Kamýk locality – tree layer structure: 1 – TVP No.; 2 – age; 3 – canopy [%]; 4 – tree species; 5 – individuals amount per plot; 6 – d.b.h. average [cm]; 7 – tree height average [m]; 8 – living crown deployment average height [m]; 9 – crown projection average [m^2]; 10 – individuals amount per 1 ha; 11 – basal area on TVP (g) [m^2]; 12 – G [$m^2.ha^{-1}$]; 13 – presence [%]; 14 – mean-tree volume [m^3]; 15 – hectare standing volume [$m^3.ha^{-1}$]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
20	104	55	SM	10	32,7	27,0	15,9	18,0	200	0,09	18,50	34,8	1,28	257
			DG	3	85,2	46,9	21,4	68,1	60	0,58	34,71	65,2	10,19	612
21	104	83	SM	14	36,0	31,7	19,1	18,7	280	0,11	30,59	39,6	1,61	451
			DG	5	66,7	40,6	23,6	49,9	100	0,39	39,50	51,1	6,57	657
			BK	3	19,4	22,0	7,5	25,8	60	0,04	2,33	3,0	-	-
			BO	1	48,2	31,1	21,4	24,7	20	0,18	3,65	4,7	-	-
			MD	1	27,8	30,4	19,3	10,4	20	0,06	1,21	1,6	-	-
22	104	67	SM	10	37,0	31,0	19,5	18,4	200	0,12	23,98	38,6	1,79	358
			DG	4	72,0	42,1	20,1	61,2	80	0,43	34,76	55,9	7,35	588
			BO	1	42,6	35,0	28,2	16,5	20	0,14	2,85	4,6	-	-
			BK	1	18,9	17,4	7,0	41,1	20	0,03	0,56	0,9	-	-
23	110	81	DG	14	54,6	39,1	22,9	34,5	280	0,25	70,79	89,5	4,05	1135
			SM	2	43,1	32,9	14,5	20,3	40	0,15	5,82	7,4	2,06	82
			BK	2	27,4	17,1	3,1	81,4	40	0,06	2,48	3,1	-	-
24	110	76	SM	10	47,3	31,8	14,0	29,5	200	0,19	37,50	55,1	2,61	522
			JD	5	41,2	28,0	14,5	30,2	100	0,14	14,46	21,2	-	-
			DG	1	101,4	41,4	8,1	113,2	20	0,81	16,15	23,7	12,15	243
25	89	66	DG	10	45,2	38,4	21,5	34,2	200	0,17	34,02	82,7	2,73	546
			SM	5	29,3	25,8	14,8	17,5	100	0,07	7,13	17,3	0,87	87

The Kamýk locality (Table 21): the Douglas fir d.b.h. average ranged from 45.2 cm to 101.4 cm; the tree height average ranged from 38.4 m to 46.9 m, and basal area (G) ranged from 16.15 m^2ha^{-1} (at 23.7 % presence in the stand) to 70.79 m^2ha^{-1} (at 89.5 % presence in the stand). The highest mean-tree volume of 12.15 m^3 was recorded at the TVP No. 24 and the lowest one was 2.73 m^3 on the TVP No. 25. The Norway spruce d.b.h. average ranged from 29.3 cm to 47.3 cm, the tree height average ranged from 25.8 m to 32.9 m, and basal area (G) ranged from 5.82 $m^2.ha^{-1}$ (at 7.7% presence in the stand) to 37.50 $m^2.ha^{-1}$ (at 55.1% presence in the stand). The highest mean-tree volume 2.61 m^3 was recorded on TVP No. 24 and the lowest one was 0.87 m^3 on TVP No.25. The admixture tree species (Scotch pine, European larch, silver fir and European beech) were recorded also in this locality, in addition to these above-mentioned tree species. The stand coverage ranged from 55% to 83%. The trees positions and their crown projections on individual TVPs of Kamýk locality are shown in Figs. 87 – 92.

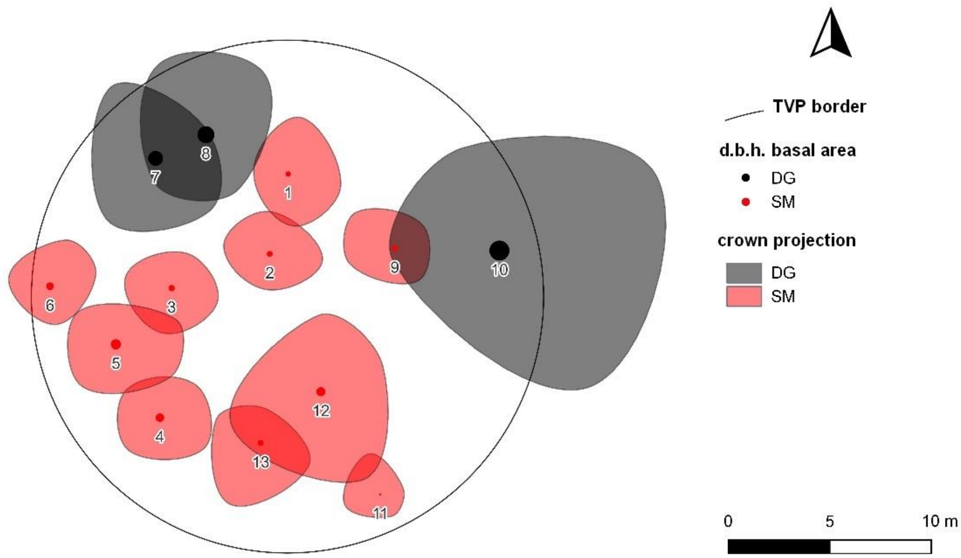

Fig. 87. Trees position and their crown projections on permanent research plot No. 20, Kamýk locality

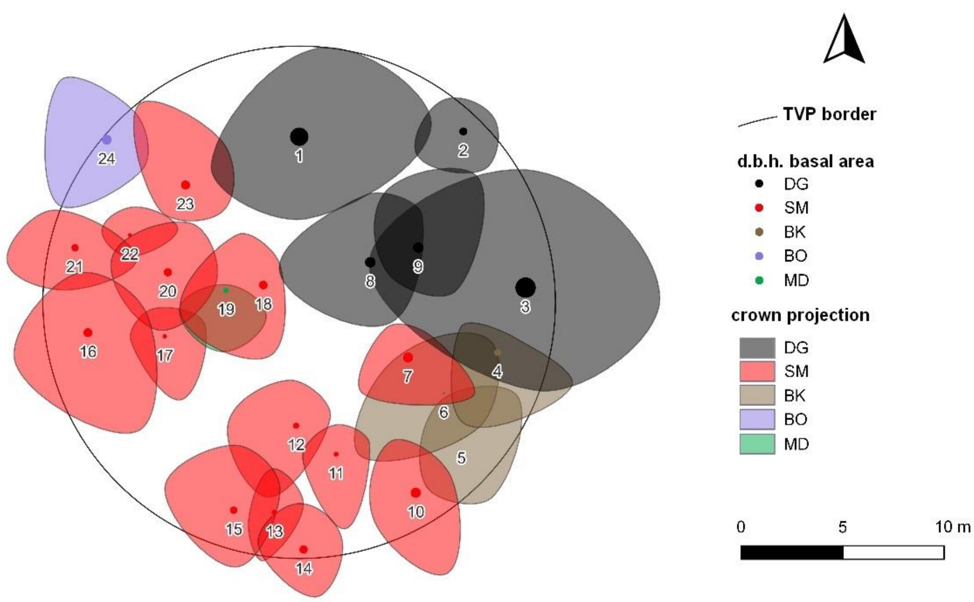

Fig. 88. Trees position and their crown projections on permanent research plot No. 21, Kamýk locality

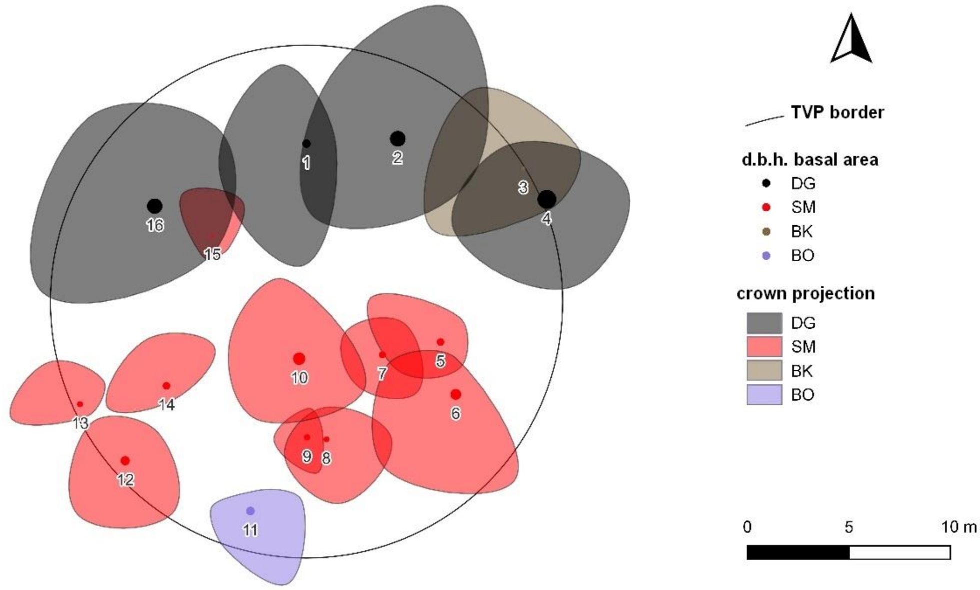

Fig. 89. Trees position and their crown projections on permanent research plot No. 22, Kamýk locality

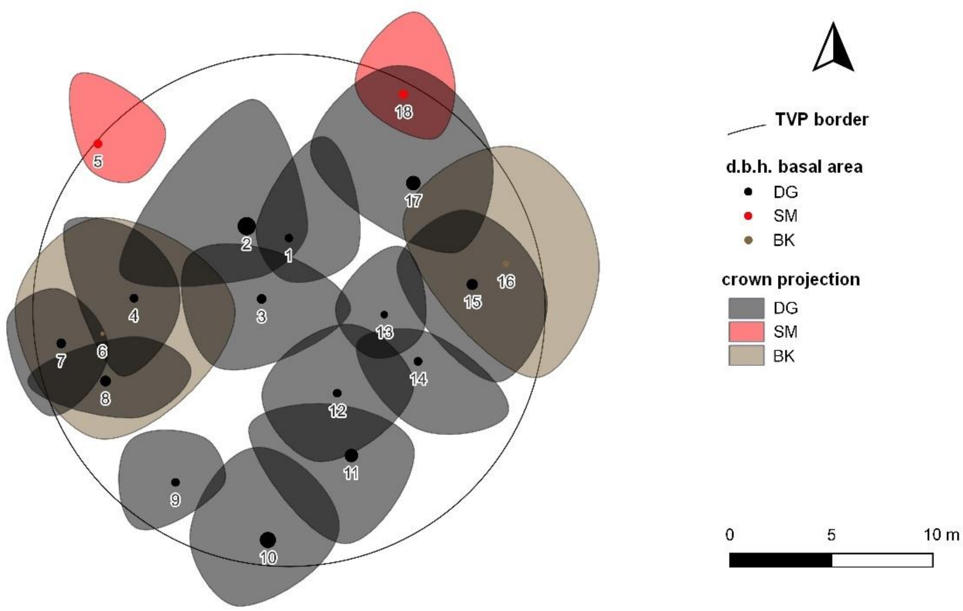

Fig. 90. Trees position and their crown projections on permanent research plot No. 23, Kamýk locality

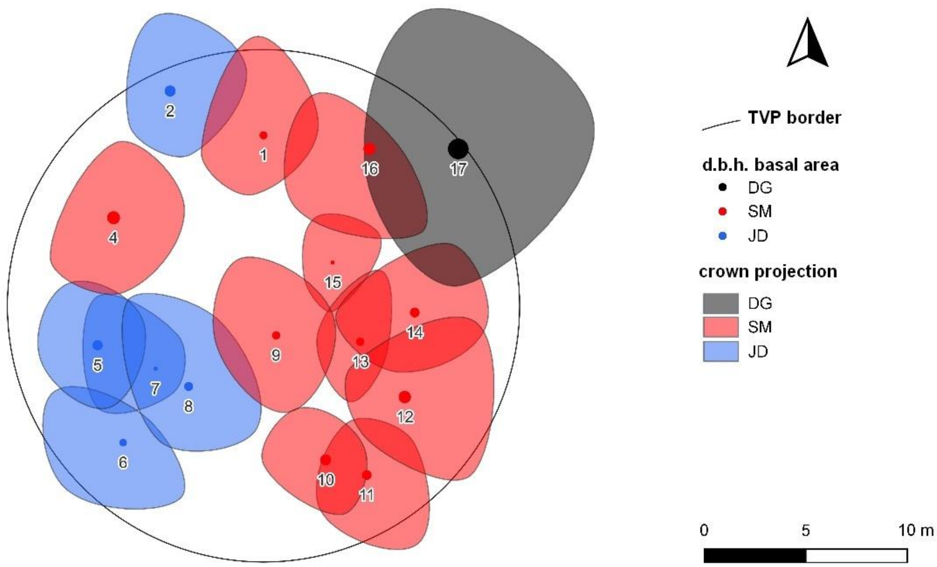

Fig. 91. Trees position and their crown projections on permanent research plot No. 24, Kamýk locality

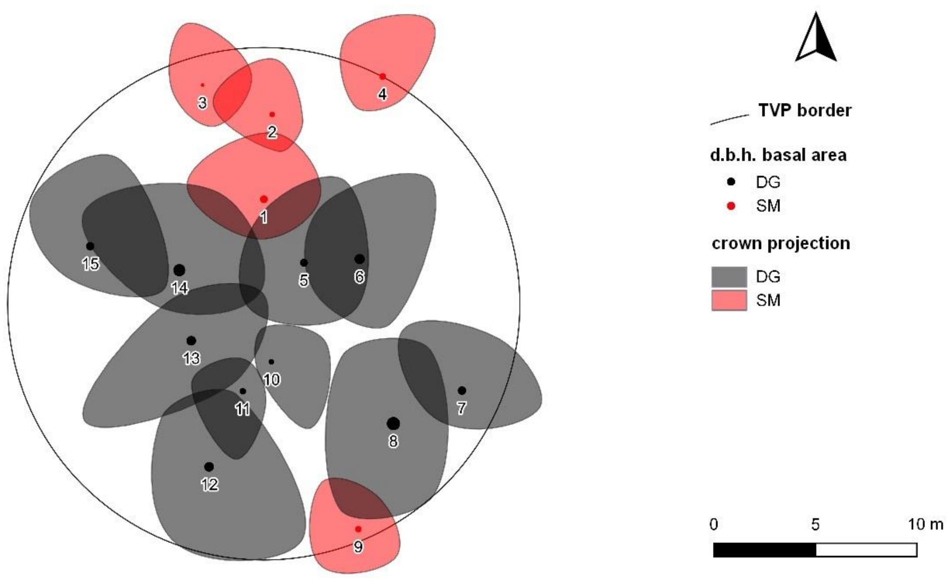

Fig. 92. Trees position and their crown projections on permanent research plot No. 25, Kamýk locality

5.2.3.1 DG and SM hectare standing volume comparison on TVPs with model ones

A comparison of Douglas fir and Norway spruce hectare standing volume from real measured data with the data obtained from the Forest Management Institute data storage (Table 22) shows that a higher hectare standing volume was found on the monitored plots (TVPs 1-25) than corresponds to the average values in the Czech Republic (taken forest groups with the Douglas fir presence only), which are described by the model (see Chapter 4.1.2), up to 734 $m^3.ha^{-1}$ for Douglas fir at FTG 4B and up to 293 $m^3.ha^{-1}$ for Norway spruce at FTG 4S. Even if other tree species were presented on some TVPs, this fact was excluded and the Douglas fir and Norway spruce presence was recalculated for this calculation according to the presence on TVP.

Table 22. DG and SM hectare standing volume comparison on TVPs with model ones in relation to age according to selected FTG from data the entire Czech Republic [in $m^3.ha^{-1}$]

TVP No.	FTG[1]	age	Tree spec.	composition	Real standing volume	Model standing volume	difference
1	4S	88	DG	94,0	1027	515	-512
			SM	6,0	62	30	-32
2	4S	88	DG	25,7	190	141	-49
			SM	66,6	440	335	-105
3	4S	88	DG	23,0	167	126	-41
			SM	64,3	432	323	-109
4	4S	88	DG	100,0	753	548	-205
5	4S	88	SM	100,0	795	502	-293
6	4B	119	DG	100,0	1343	609	-734
7	4S	119	DG	81,5	814	502	-312
			SM	18,5	162	107	-55
8	4S	94	DG	43,5	283	245	-38
			SM	56,5	326	294	-32
9	3K	86	DG	71,6	485	362	-123
			SM	25,7	145	114	-31
10	3S	86	DG	67,6	474	344	-130
			SM	26,7	180	122	-58
11	3S	86	DG	45,5	345	231	-114
			SM	48,6	291	223	-68
12	4K	96	DG	100,0	1069	561	-508
13	4K	96	DG	97,2	910	545	-365
			SM	2,8	23	14	-9
14	5S	116	DG	39,0	413	250	-163
			SM	43,8	442	274	-168
15	4S	85	DG	50,6	345	273	-72
			SM	33,3	215	164	-51
16	4S	85	DG	37,3	248	201	-47
			SM	58,9	357	290	-67
17	4S	111	DG	38,3	353	230	-123
			SM	50,7	461	284	-177
18	4S	85	DG	89,2	1124	481	-643
			SM	1,7	18	8	-10
19	4K	86	DG	29,7	188	159	-29
			SM	63,1	356	306	-50
20	4S	104	DG	36,6	347	215	-132
			SM	64,3	522	351	-171
21	4S	104	DG	51,1	657	300	-357
			SM	39,6	451	216	-235
22	4S	104	DG	55,9	588	328	-260
			SM	38,6	358	210	-148
23	4S	110	DG	89,5	1135	536	-599
			SM	7,4	82	41	-41
24	4S	110	DG	23,7	243	142	-101
			SM	55,1	522	308	-214
25	4S	89	DG	82,7	546	455	-91
			SM	17,3	87	87	0

[1] details in VIEWEGH ET AL. 2003 (resp. VIEWEGH 2005)

5.2.4 Comparison of Douglas fir and Norway spruce growth on permanent research plots (TVPs)

Variability of radial growth curves according to tree ring analyses is considerable for both species. It is appropriate to classify these curves by cluster analysis (Fig. 93). Individual cluster can be characterized according to the type of tree species that predominates in the cluster. Using the dendrogram, 7 basic classification classes were identified with which it is possible to use further. Some classes are specific to one tree species, only in class *110 both species are represented equally.

There is a specific individual presence of different classification classes on TVPs. Tables show them for Douglas fir (Table. 23) and for Norway spruce (Table 24). The fact that this difference between the plots is statistically significant can be tested by χ^2-test for the respective contingency tables, with a probability of error of the first type $\alpha < 0.001$ for both species.

Table 23. *Pseudotsuga menziesii* individuals of individual classification groups on permanent research plots (TVP)

group	TVP No									total
	1	3	4	9	12	14	19	21	24	
*00				3						3
*010					1					1
*011					4	10	3	1		18
*100							2			2
*101	4	3	3	1	1	2	2	8	20	44
*110	7	2	3	2	1		4	1	3	23
*111	1	7	6	6	6	2	2	2	2	34
total	12	12	12	12	13	14	13	12	25	**125**

Table 24. *Picea abies* individuals of individual classification groups on permanent research plots (TVP)

group	TVP									total
	1	3	5	10	15	16	19	21	23	
*00	12	11	13	6						42
*010	1	1		5	9	9	6			31
*011	1		1							2
*100	1	1	2				2	5	16	27
*101		1							2	3
*110	1						1	4	5	11
*111		1		1					1	3
total	16	15	16	12	9	9	9	9	24	**119**

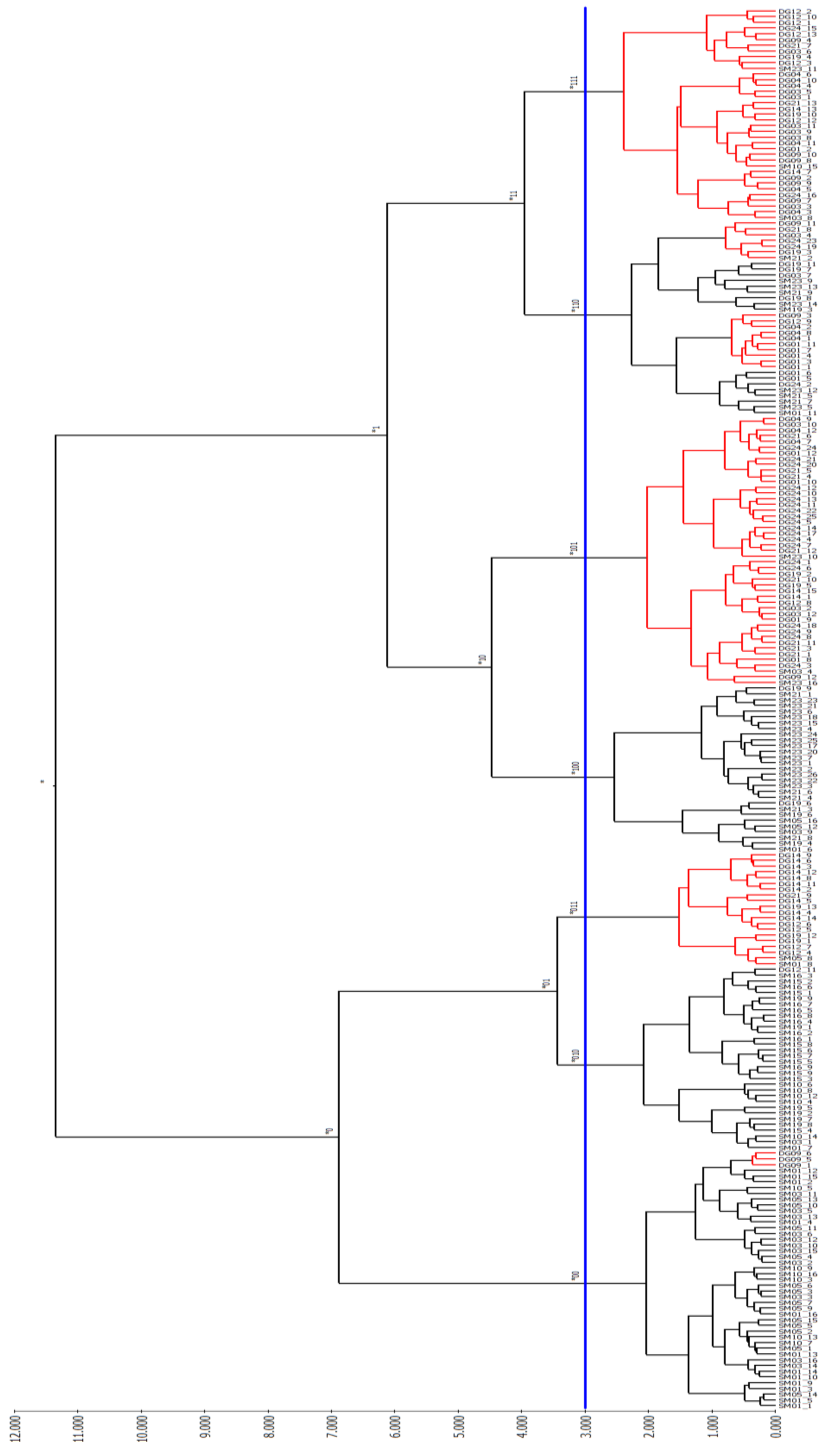

Fig. 93. The average growth curves classification by Ward's method. Norway spruce-dominated stands are black, Douglas fir stands are red. The clustering level (significance level) that was used to define individual clusters is indicated by a blue horizontal line.

The Norway spruce maximum increment was recorded in 1967, 1985, 1988, 1989, 1997, 2002, and also during the period 2009 – 2014). The decrease occurred in 1976, 1993, 2000, 2007, 2015 and 2018 – 2019 om the contrary (Fig. 94).

The situation was different with Douglas fir. Maximum values were recorded in 1966, 1997, 2002, 2009 and 2014, while minimum values were recorded in 1976, 1979, 2013 and 2018. An only slight decrease was recorded in 2003 (Fig. 95).

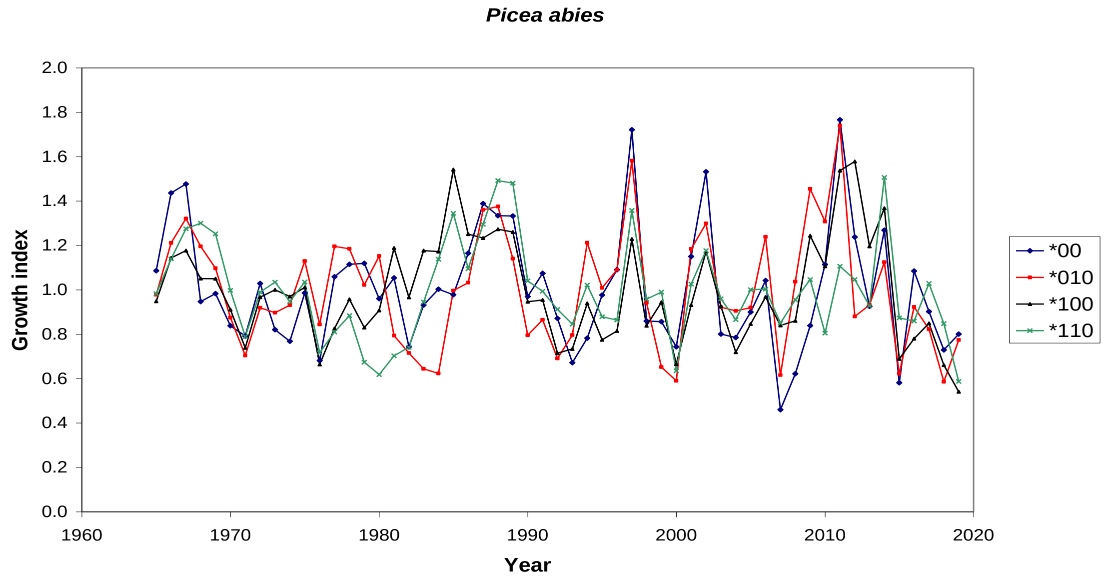

Fig. 94. Interannual variability of the Norway spruce increment in individual main classification groups of individuals demonstrated in Fig. 93

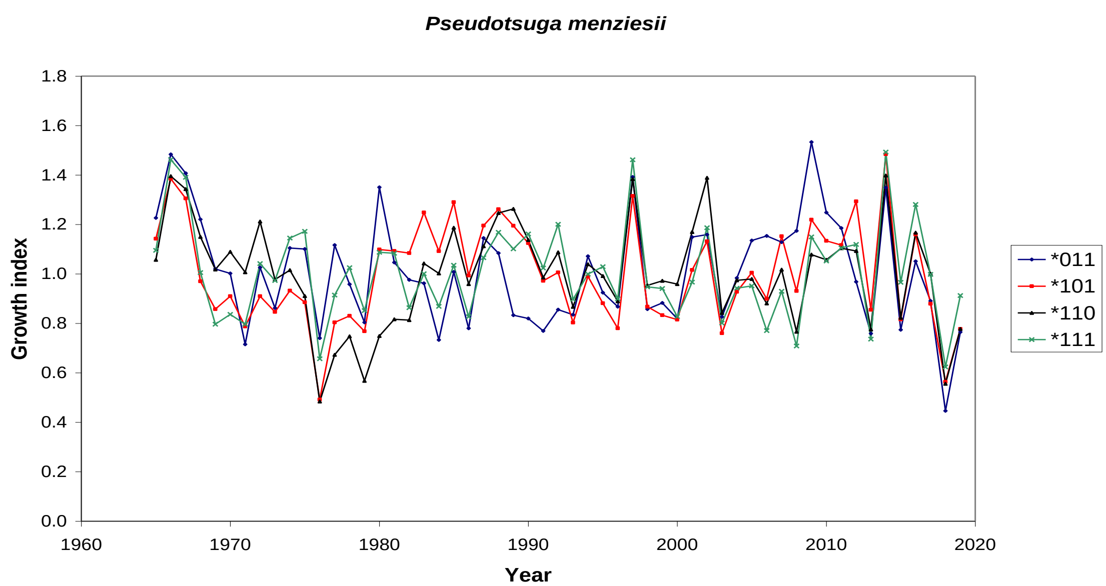

Fig. 95. Interannual variability of the Douglas fir increment in individual main classification groups of individuals demonstrated in Fig. 93

The ordination analysis of individual trees according to their increment cores shows a significant difference between the two trees types, which is manifested by the respective points shift in the ordination space and thus also the mutual shift of the distribution ellipses (Fig. 96).

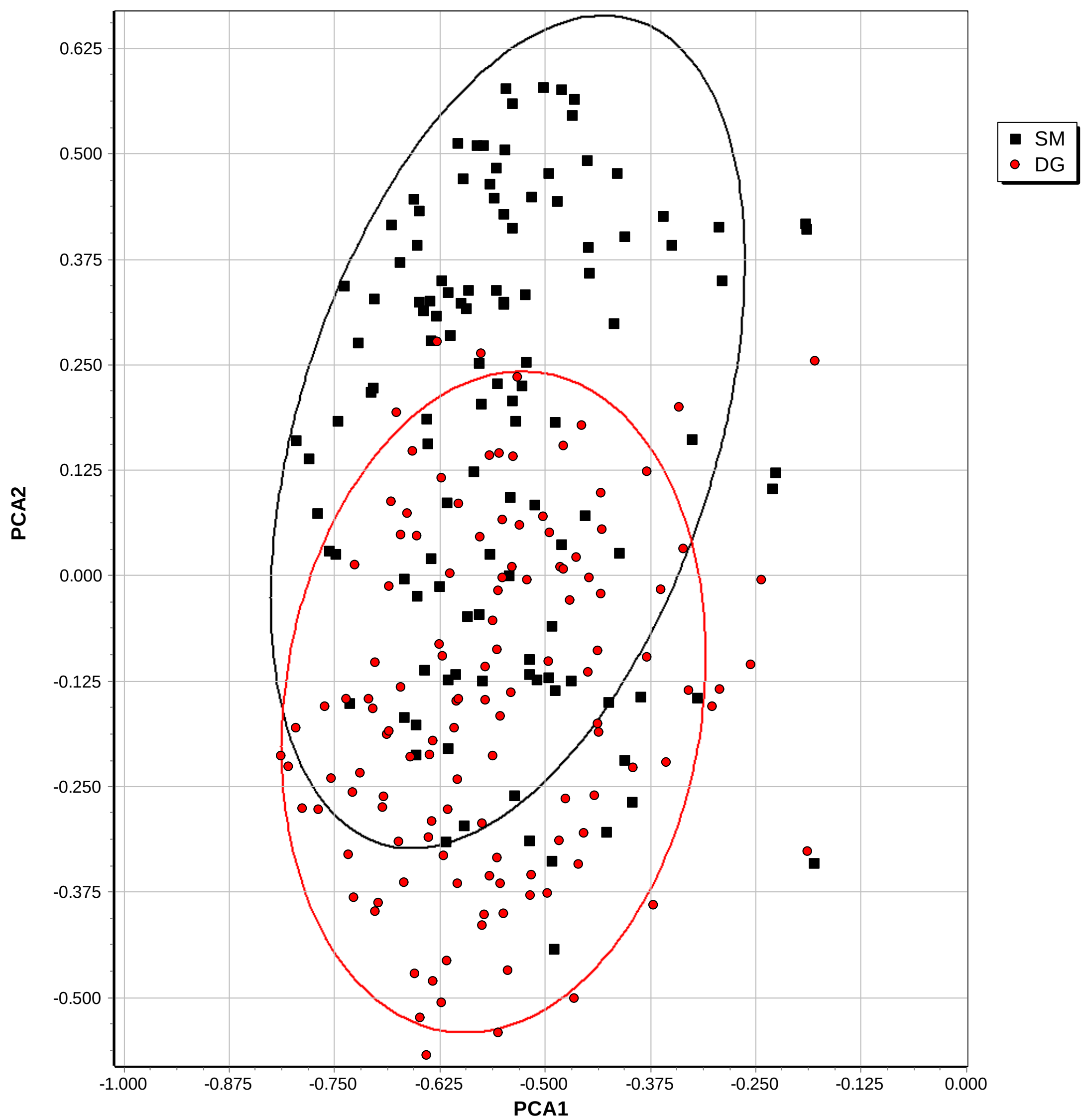

Fig. 96. Position of Norway spruce and Douglas fir individuals in the PCA ordination space based on their growth correlations. The distribution ellipses shown contain 95 % of the relevant points.

Douglas fir growth is markedly different by localities and TVPs. While on TVP No. 14 (Vodňany locality) the Douglas fir growth dynamic is similar to the Norway spruce growth dynamic, it is significantly different on TVPs No. 21 and 24 (Kamýk locality) especially. The locality influence on the growth dynamics of both species is significant, whereas the locality significance is greater for Norway spruce than for Douglas fir. This may indicate that Norway spruce is growing in unsuitable environmental conditions at Písek region (Figs. 97 and 98).

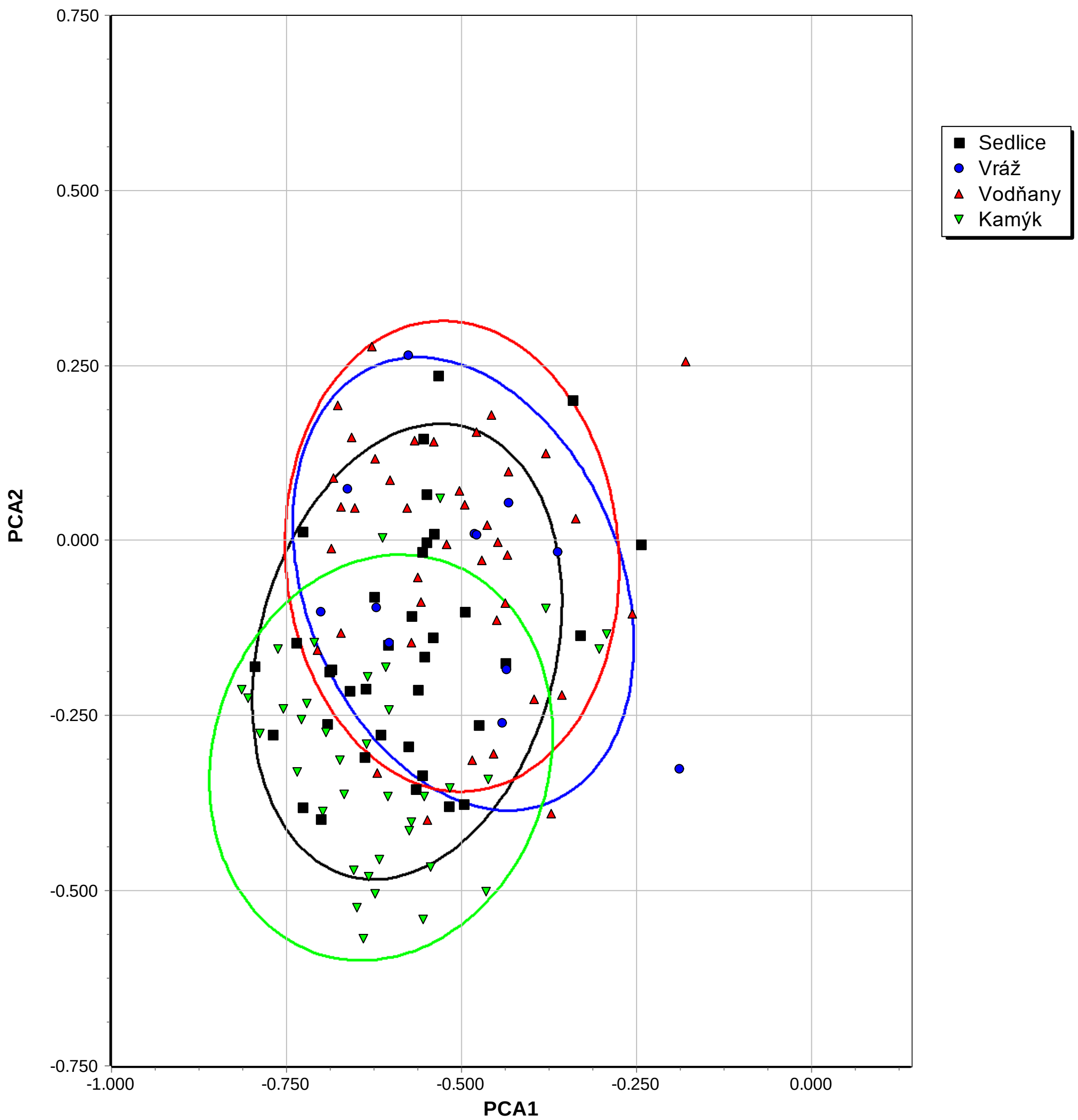

Fig. 97. The position of Douglas fir individuals in the PCA ordination space based on correlations of its growth with belonging to TVP. The distribution ellipses shown contain 95 % of the relevant points.

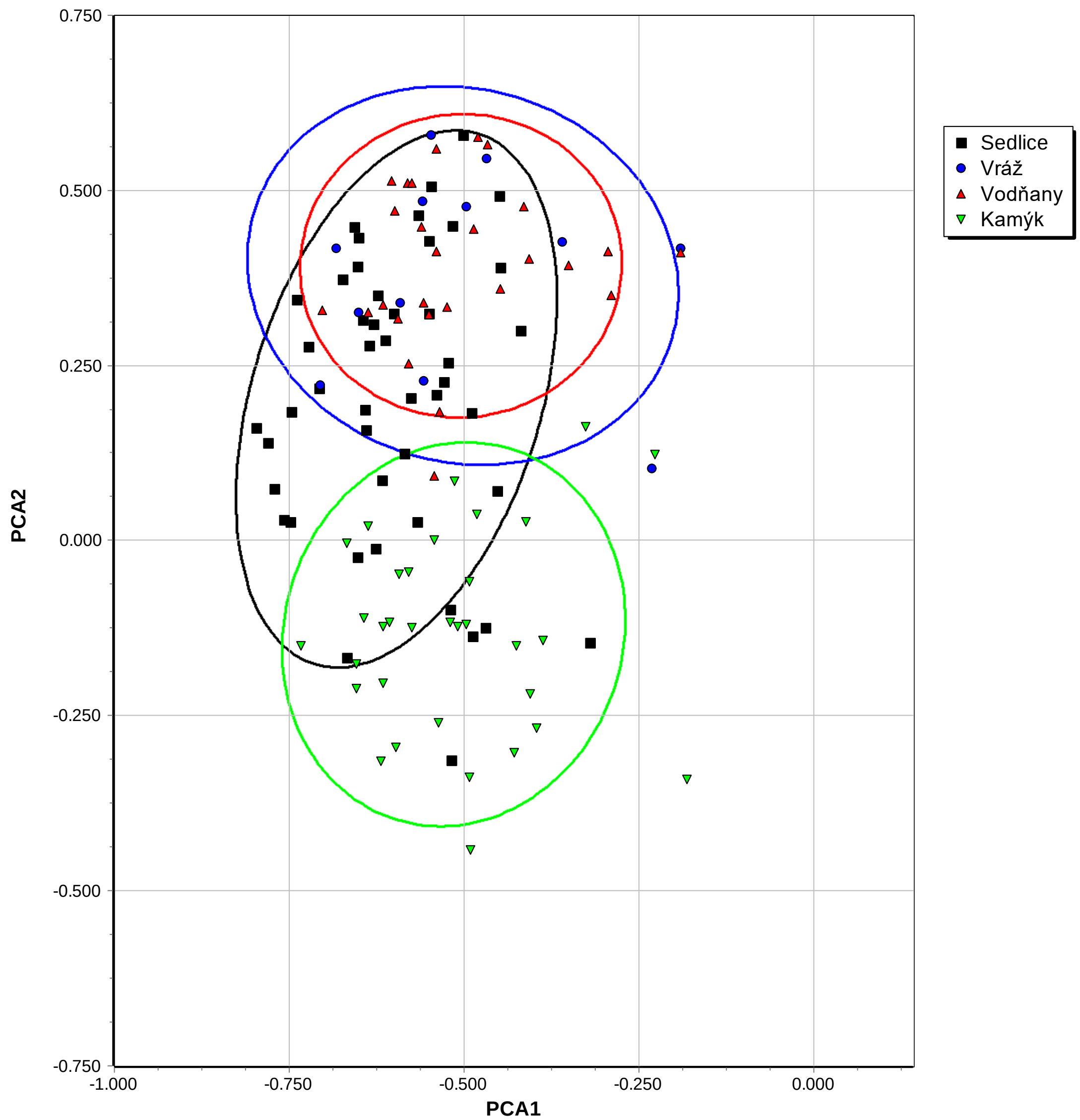

Fig. 98. The position of Norway spruce individuals in the PCA ordination space based on the correlations of its growth with belonging to the TVP. The distribution ellipses shown contain 95 % of the relevant points.

The climate was changing during the observed period (1961 – 2019) by CHMI in the region. Data measured by local branch office at Vráž show a significant increase the annual air temperature average (+0.029 °C per year, P close to 100%); the same applies to annual absolute minimums (+0.050 °C per year, P = 94.5% and maximums (+0.035 °C, P = 99.0%). The annual precipitation sums were highly variable without any trend. The situation is similar for relative air humidity average, where minimum averages were recorded in 1973 (72.5%), 1986 (73.0%; humidity was in the entire period 1982 – 1990) and 2015 (73.7%). In contrast, the maximum average was in 2001 (82.7%). The period 2001 – 2019 can be characterized by a significant trend of decreasing air humidity (-0.34% per year).

The average air temperature has a stronger effect on the Douglas fir growth, for which a decrease in growth was found at higher temperatures between May 25th and June 24th. Growth is positively affected by higher temperatures between the beginning of February and April 10th on the contrary, which is usually associated with an earlier start of growth. The high average temperatures from mid-July to mid-August are associated with reduced growth for Norway spruce. This tree species suffers from high summer temperature at Písek region, since the Norway spruce optimum occurrence is at higher altitudes (Figs. 99 and 100).

Minimum air temperatures are related to the Norway spruce growth weakly only. The positive effect of higher air temperatures minimum on the Norway spruce growth was indicated in two periods – from mid-March to mid-April and from mid-June to mid-July. On the other hand, The Norway spruce growth depression is caused by low minimum temperatures in the winter season (November to January approximately), which may be related to frost damage of the tree species and this is probably potentiated by its grow in an area with often insufficient snow cover. Higher minimum air temperatures from mid-March to mid-April are associated with an increased Douglas fir increment, which clearly shows on the significance of the growing season early onset (Figs. 101 and 102).

The maximum air temperatures average again affects the Douglas fir growth more than the Norway spruce growth. The growth depression occurrence of Norway spruce is in case of high maximum temperatures. This is a connection with the high temperature's occurrence in June (the period of the most intensive growth) and until mid-August (high temperatures will probably end radial growth prematurely) in the current year. Even more pronounced is the negative effect of high maximum temperatures average in a longer period from July of the previous year to January of the current year – such high temperatures cause stress apparently, which the trees must deal with in the following year. The most significant positive effect of the high average daily air temperatures maximum for Douglas fir is in the early spring period – February to the first half of April, which again indicates the effect of the growing season beginning (Figs. 103 and 104).

Higher precipitation sums are associated with a positive effect on the growth of both tree species and to a similar extend. For Norway spruce, it is necessary to evaluate the total precipitation for the entire growing season (until the first half of August). The importance of sufficient precipitation at the growing season beginning (in April) is very weakly indicated only. The high precipitation amount in July is most significant for Douglas fir. The importance of sufficient rainfall in April and the first part of May is also indicated (Figs. 105 and 106).

For both tree species, the air humidity influence on their growth is highly significant. This effect is more pronounced than in the case of separate precipitation. High air humidity in the second half of summer (for a period of 2 to 3 months) has a positive effect, for both species equally (Figs. 107 and 108). Higher air humidity in this period indicates sufficient total precipitation, but also their more even distribution. A higher precipitation amount can be achieved by short-term intense rain, a significant part of which will run off and not be captured in the soil. However, such torrential rain will not cause a more permanent increase of air humidity. Therefore, air humidity should be evaluated regularly as part of climate analyses (and not only in relation to the trees growth).

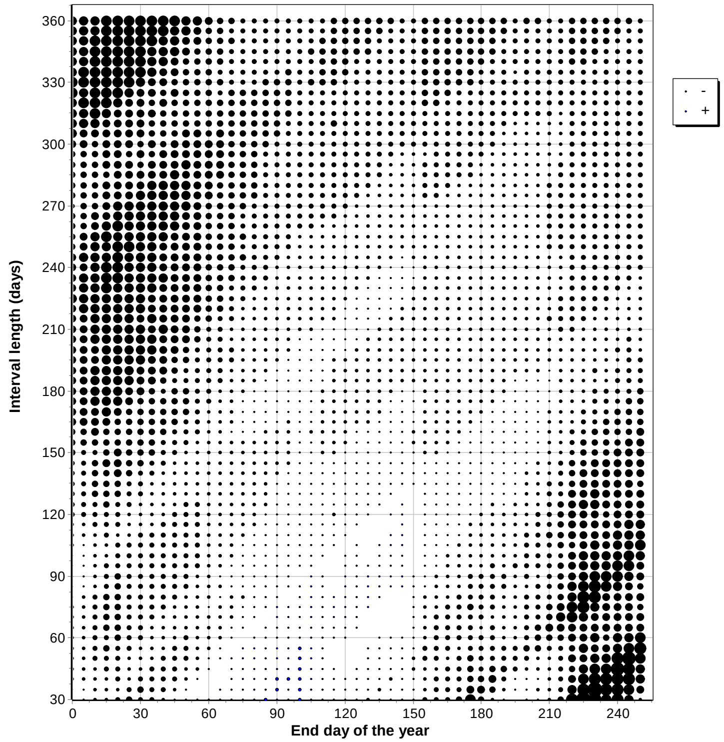

Fig. 99. Correlation between air temperature average and the Norway spruce radial increment index (minimum
r = -0.23, maximum r = 0.07; extreme value was recorded for the days interval in a year 195-225)

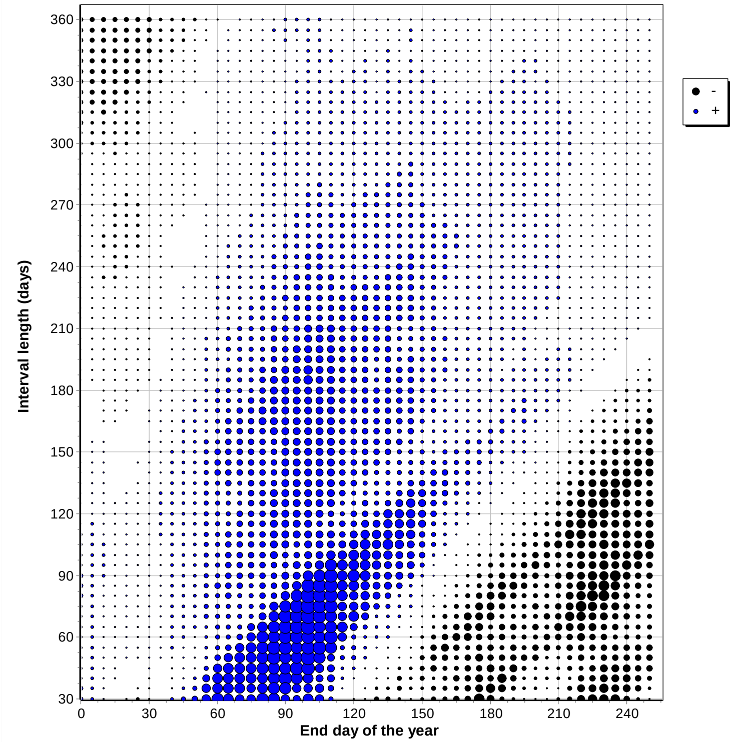

Fig. 100. Correlation between air temperature average and the Douglas fir radial increment index (minimum
r = -0.20 for the days interval 145-175 in a year; maximum r = 0.23 for the days interval 195-225 in a year)

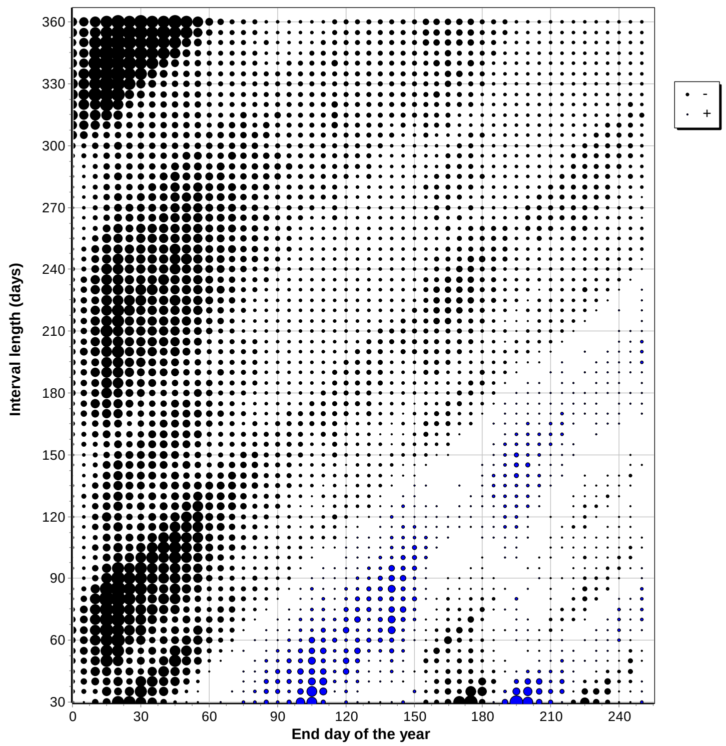

Fig. 101. Correlation between the average air temperature daily minimum and the Norway spruce radial increment index (minimal r = -0,12; maximal r = 0,11)

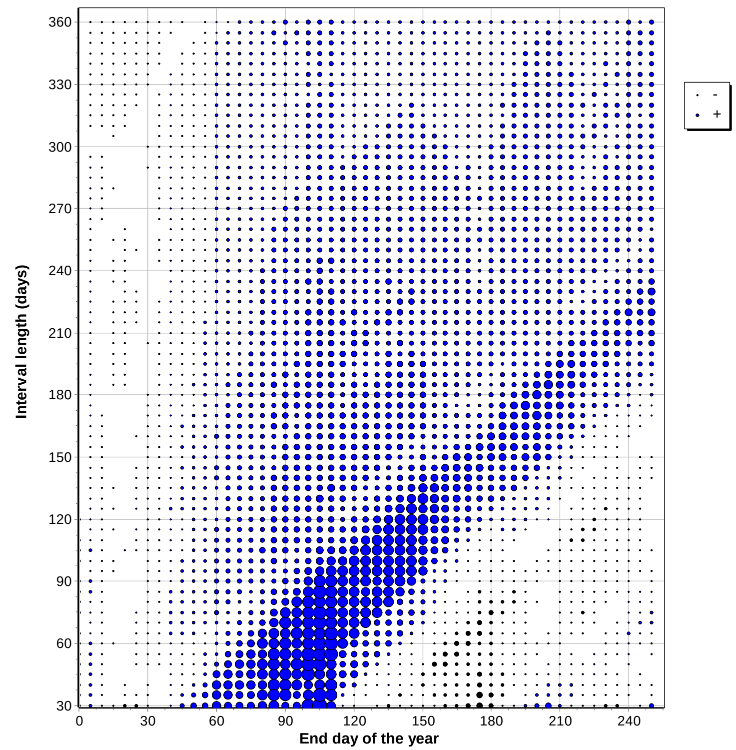

Fig. 102. Correlation between the average air temperature daily minimum and the Douglas fir radial increment index (minimal r = -0.15 for days interval 145-175 in a year; maximal r = 0.25 for days interval 75-105)

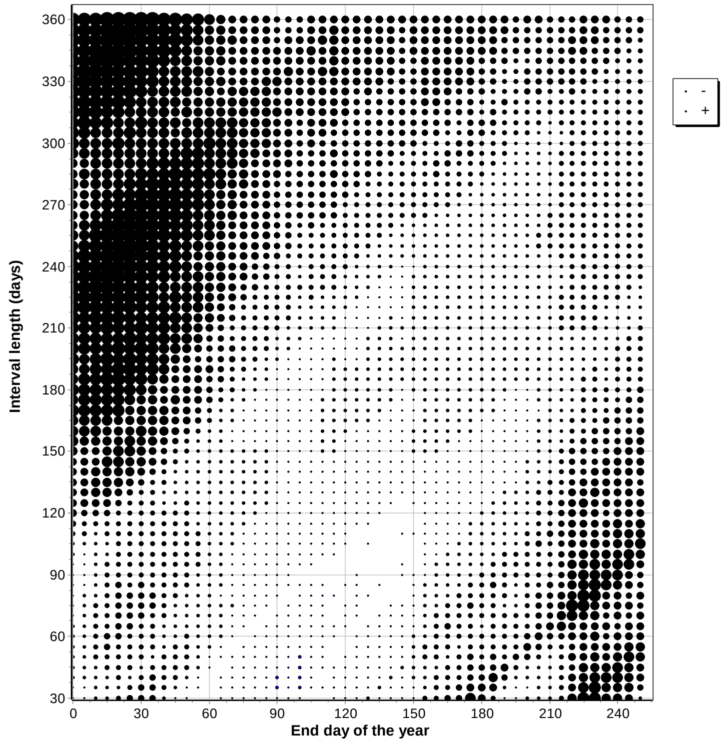

Fig. 103. Correlation between the average air temperature daily maximum and the Norway spruce radial increment index (minimal r = -0.24; maximal r = 0.07)

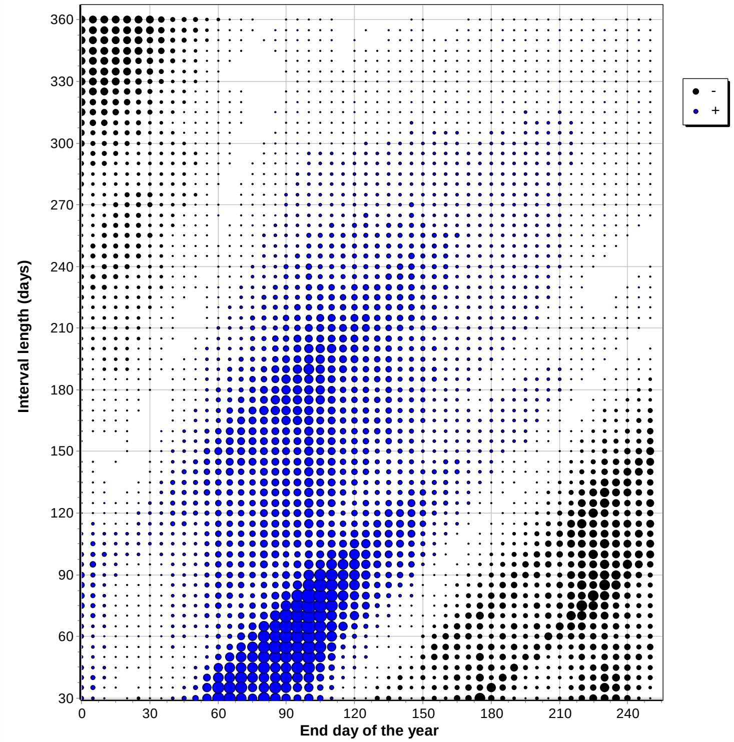

Fig. 104. Correlation between the average air temperature daily maximum and the Douglas fir radial increment index (minimal r = -0.18 for days interval 145 – 230; maximal r = 0.22 for days interval 30 – 100)

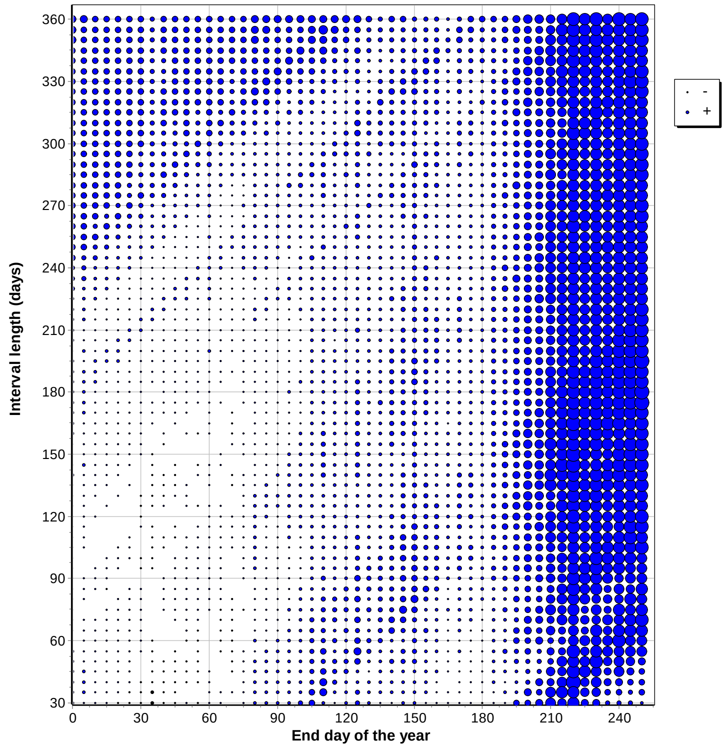

Fig. 105. Correlation between total precipitation and the Norway spruce radial increment index
(minimal r = -0.09; maximal r = 0.29)

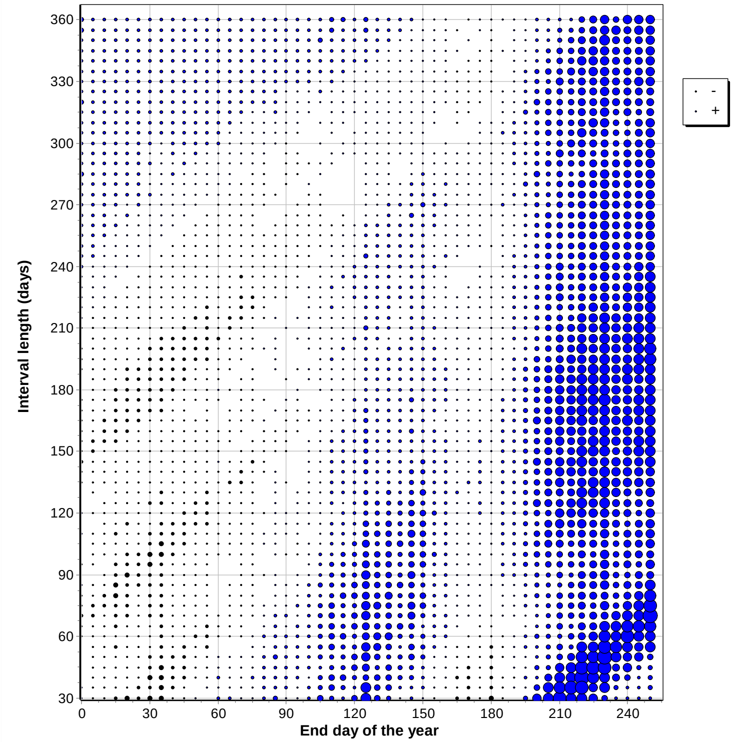

Fig. 106. Correlation between total precipitation and the Douglas fir radial increment index (minimal r = -0.14; maximal r = 0.29)

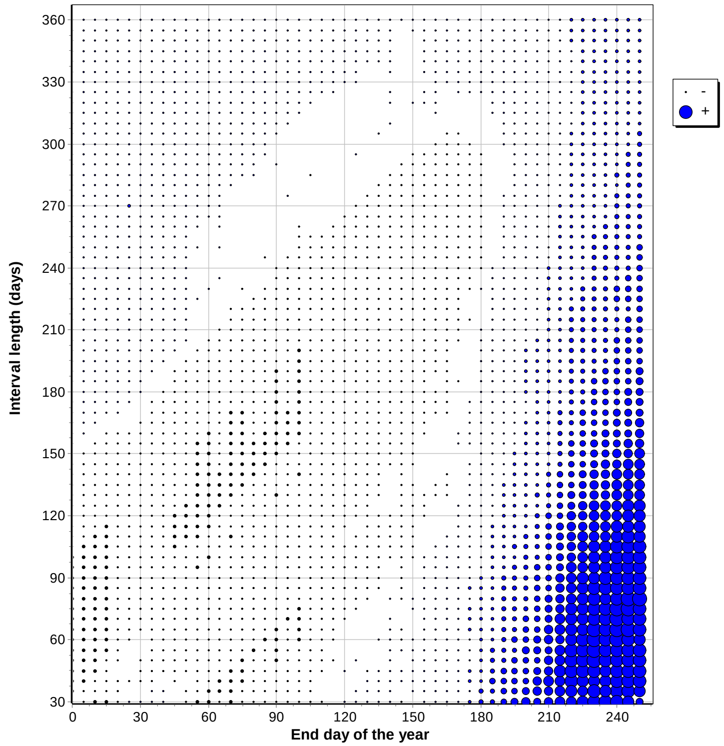

Fig. 107. Correlation between average air humidity and the Norway spruce of radial increment index (minimal r = -0.11; maximal r = 0.32)

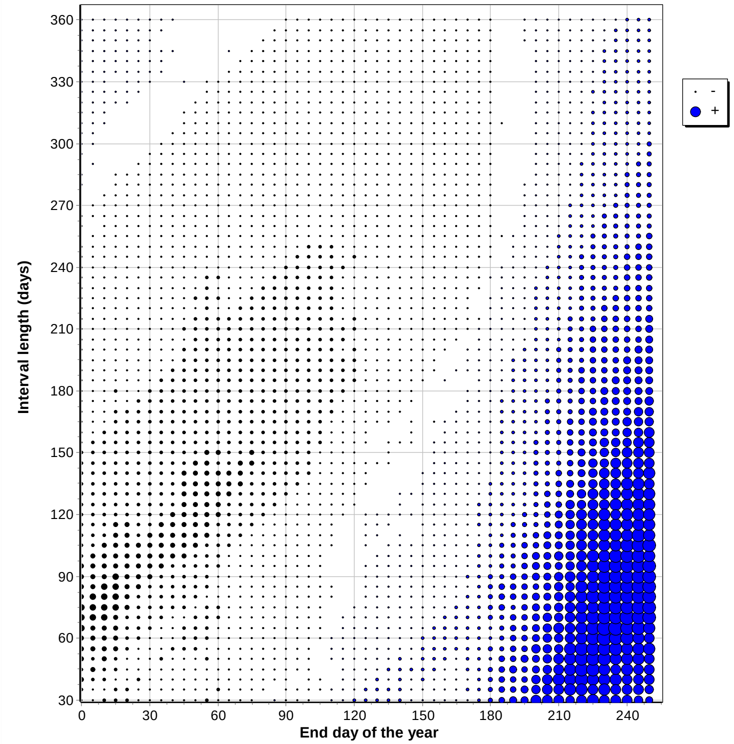

Fig. 108. Correlation between average air humidity and the Douglas-fir of radial increment index (minimal r = -0,17 for days interval -65 – 10; maximal r = 0,30 for days interval 170-230)

6 Discussions

6.1 Douglas-fir cultivation suitability in the Czech forests

The more massive Douglas fir spread in the Czech forests has been occurring since the sixties of the 20th century. REMEŠ ET AL. (2010) reports the Douglas fir presence in Czech forests at 0.22%. Douglas fir grows on the Czech territory on an area of 6,893.43 ha currently, which corresponds to a presence of 0.26%. The average increase in the growth area of this tree has been over the last 20 years by 131 ha per year. The most significant increase trend is in the last 3 years (2018, 2019 and 2020). It has the highest presence in the South Bohemian Region, followed by Plzeň and Central Bohemian Regions.

This trend leads to a change in the age structure. VAŠÍČEK (2014) states the 5th age class as the most presented, followed by the 1st and 2nd ones. The largest stand area is occupied by Douglas fir in the 1st age class, followed by the 5th and 2nd ones, currently. There are orders of magnitude fewer mature stands, and an absolute minimum of overmature ones. It is most widespread in the 3rd FVZ, followed by the 4th and 5th. Almost half of all Douglas fir stands grow on nutrient habitats. Acidic habitats are also highly presented, and gleyed (stagned) habitats are important.

Production of the main Czech commercial trees (d.b.h. ≥ 7 cm), i.e. Scotch pine, Norway spruce, European larch, silver fir, European beech and oaks (species undifferentiated – pedunculate, sessile) turns out to be lower than Douglas fir, although at later ages this this difference is not too great for silver fir and Norway spruce. This is indicated by the already known fact that Douglas fir exceeds these main European commercial tree species by its production in removal age especially, as reported by e.g. BERAN ET ŠINDELÁŘ (2006), CASTALDI ET AL. (2017), HOFMAN (1964), KANTOR ET AL. (2001a, b), KOUBA ET ZAHRADNÍK (2011), LARSON (2010), LU ET AL. (2018), PODRÁZSKÝ ET AL. (2013c, d), PRETZSCH ET SCHÜTZE (2016), SCHELHAAS (2008), SICARD ET AL. (2006) and WÖRDEHOFF ET AL. (2011). From this, it could seem that it would be ideal from the point of view of production to plant Douglas-fir at the expense of other tree species lagging behind it in terms of production capabilities (BO, BK and DB). However, it turns out that, on the contrary, it is necessary to cultivate these “less productive” trees in mixtures appropriate to the habitat (BMEL 2014, DAWUD ET AL. 2017, KANTOR 2008, KANTOR ET MAREŠ 2009, LANDESFORSTEN 2021, PODRÁZSKÝ ET REMEŠ 2010, SCHÜTZ ET POMMERING 2013, THURM ET PRETZSCH 2016). A mixture of Douglas fir with deciduous trees is recommended (especially with European beech) in order to avoid significant changes in habitat characteristics (DE WALL ET AL. 1998, THOMAS ET AL. 2015, THURM ET AL. 2016). This was also confirmed in this dissertation during the calculations of Douglas fir theoretical mixtures with various native commercial trees.

A more detailed production capabilities assessment of the main Czech commercial tree species (with the exclusion some of them – see Chapter 4.1.2), taking into account the individual FVZ, shows that in all the listed FVZs (2nd – 7th), European beech has the lowest production in 100 years and Douglas fir has the highest, although its production in some FVZs do not differ significantly from the Norway spruce and silver fir production (2nd, 4th, 5th and 6th FVZs) and in the case of the 7th FVZ it does not differ from the Norway spruce production only. This would indicate that it would be more appropriate to cultivate Douglas fir (of course in mixtures) from the 3rd to 6th FVZs precisely.

A more detailed production capabilities assessment of the main Czech commercial tree species (with exclusion some of them – see Chapter 4.1.2), taking into account habitat groups (see

Chapter 4.1.2), shows that the lowest production for all tree species is in extreme habitats. All tree species reach the highest production in moist habitats. So, the moist habitats (edaphic categories L, U and V) are the optimal for cultivation these trees. Since there is a minimum of these habitats in The Czech Republic, all other habitats with excluding extreme and wet become favourable ones. Considering that extreme habitats mostly have a soil conservation character; it is inappropriate to plant Douglas fir here at all from a production point of view. However, MAUER ET VANĚK (2014) recommend to plant it there, since it thanks to its root system, Douglas fir could be beneficial for soil protection function.

A more detailed production capabilities assessment of the main Czech commercial tree species (with exclusion some of them – see Chapter 4.1.2), taking into account individual FVZ and habitat groups (see Chapter 4.1.2) shows that the highest Douglas fir production in Czech forests is reached in the 5th FVZ on acidic and nutrient habitats, K, S, B, and H (D) edaphic categories mainly. Whereby its higher production than for Norway spruce is reached on the same habitat groups in 3rd and 4th FVZs (but lower than in above mentioned habitats). The possibility of Douglas fir cultivation appears also on wet, 4V and 5V FTGs, and gleyed (stagned) habitats, 4O, 4P, 5O, 5P, 6O and 6P FTGs. The gleyed (stagned) habitats can be considered tolerant to a longer drought period, but for mature stands only, because stands of the 1st age class suffer from drought (BRANDL ET AL. 2020, MAUER ET AL. 2014, STOJAN 2006). The Douglas fir cultivation in these FVZs (or FTGs) is also confirmed by data from Western Europe, where many authors state that this tree grows in foothill and mountain localities optimally (e.g. PÖTZELSBERGER ET AL. 2019, THOMAS ET AL. 2015). It is probably due to the humidity conditions of these localities. On the other hand, its cultivation in lower northern Germany, the Netherlands and Scotland landscapes is again related to favourable moisture conditions – oceanity and flat terrain (BOMMER ET AL. 1999, DE WALL ET AL. 1998, PAGE 1970, PRETZSCH ET SCHÜTZE 2016, WÖRDEHOFF ET AL. 2011). Also, it is necessary to mention the question of the Douglas fir stands stability, which was not solved yet and whose importance was pointed out by BLAŠČÁK (2003).

The Norway spruce is the most important tree species for Czech forestry so far, however which has undergone a significant (even catastrophic) reduction in its presence during the last few years. Scotch pine, oaks, European beech, silver fir and European larch from autochthonous trees therefore remain for the wood production. The Douglas fir cultivation in selected stands was included among the so-called improvement trees due to its production and soil protection function (KACÁLEK ET AL. 2017).

6.2 Douglas fir on selected habitats in southern Bohemia

The classification of all 25 TVPs into the units according to CHYTRÝ ET AL. (2013) is not unambiguous. The main reason may be that these are heavily anthropogenic habitats with Douglas fir and Norway spruce plantings, while these units were processed on natural forests. The first named species is allochthonous due to its non-European origin and the second is allochthonous there due to its non-native range occurrence. Even so, the vegetation of herb layer preserved its natural character rarely. The Vráž locality shows signs of lower elevation vegetation. It is 50 – 100 m lower than the other localities. According to the Czech Forest (Site) Ecosystem Classification (VIEWEGH ET AL. 2003, very detail in VIEWEGH 2005), this locality is assigned to the 3rd FVZ – oak-beech, while the other localities belong to the 4th FVZ – beech. The units *Luzulo luzuloidis-Fagetum sylvaticae* Meusel 1937, variant *Veronica officinalis* and *Luzulo luzuloidis-Quercetum petreae* Hilitzer 1932, variant *Luzula pilosa* indicate acidophilous beech and acidophilous oak forests. The units of the Czech Forest (Site) Ecosystem Classification also describe the same, when

TVPs in localities are classified either directly as the acidic edaphic category – K or as the category oligo-mesotrophic – S. Only TVP No. 6 in the Sedlice locality is classified as nutrient (rich) category – B. Belonging to another taxonomic unit of the Vráž locality was also confirmed by DCA analysis.

It is the anthropogenic plantings that affect E_1 layer either by impoverishing some species occurring in natural habitats or, conversely, by introducing anthropogenic species.

The dominant woody species of the tree layer significantly influences the understory species composition, i.e. Douglas fir and Norway spruce have an effect on the plant community composition as shown by the CCA results. However, Norway spruce changes the community composition more significantly than Douglas fir. At the same time, the light conditions under the stands of the both tree species are similar on the monitored TVPs, which were also proven by results of detecting the light penetration through the tree layer using hemispheric photos. In addition, the findings were also confirmed here that the total herb layer coverage is greatly reduced if the diffuse radiation proportion under the stand is lower than approx. 25% compared to free area (MATĚJKA 2018b). The finding that species growing in the Douglas fir and Norway spruce understory are different, contradicting the results by MATĚJKA ET AL. (2014), PODRÁZSKÝ ET AL. (2011, 2014b) and VIEWEGH ET AL. (2014). The mentioned authors come to the conclusion that mesotrophic to nitrophilous species are found as the understory of Douglas fir stands, while acidophilous species make Norway spruce understory. This above-mentioned discrepancy between their results and mine can be explained by the principle research plots selection. The above-mentioned authors conducted their observations on monocultures plots of both tree species and much differentiated habitats, while the TVPs of this dissertation were selected for purpose of determining the both tree species production and were chosen so that the dominant tree species was either Douglas fir or Norway spruce, including their mixtures with different proportions of both tree species and co-dominant species could also be other tree species (see Table of phytocoenological relevé – Appendix 1). It is the other tree species co-dominance in the tree layer shows that on TVPs with a greater Douglas fir presence, the vegetation of herb layer does not differ much from the potential natural vegetation (confirmed by PCA). On the contrary, Localities with a higher Norway spruce presence show a higher anthropogenic species presence, but very rarely of acidophilous ones. This state may be related to possible forestry activities during the stand development, as necessary management measures.

Beyond to its own influence on the plant community structure by Douglas fir silviculture, it is also necessary to mention the risks of its cultivation. It turns out that this is a species which rejuvenates itself easily and regularly in its stands. So, it can be an invasive species potentially. Another risk may be related to the nitrogen dynamics influence in the ecosystem, which is manifested in the increased species presence of the herb layer demanding on nitrogen.

Differences in radial increment according to individual localities are manifested both in Douglas fir and Norway spruce. This is especially true for Norway spruce, which indicates that it grows in unsuitable conditions and its growth at these altitudes is strongly threatened; as also described in other studies (VACEK ET AL. 2019a). Both species are affected by climate in different ways. Precipitation, temperature and extreme climatic events, e.g. drought, are strongly reflected in the Douglas fir radial increment, which is also introduced by ARREOLA-ORTIZ ET AL. (2010), LACHENBRUCH ET JOHNSON (2020), LITTELL ET AL. (2008) and SERGENT ET AL. (2014). Also in Norway spruce radial increment, which is described e.g. by MIKULENKA ET AL. (2020) and VACEK ET AL. (2020c). Their results were also confirmed in south Bohemia. A significant role is also played by the influence of air temperatures and sum of precipitation, especially their distribution through the year (ACOSTA-HERNÁNDEZ ET AL. 2017, GALLO ET AL. 2020a).

High average air temperatures in summer are associated with reduced Norway spruce growth. Similarly, the negative effect of air temperature on the Norway spruce radial increment was observed in the period from May to July in our localities as well as in lowland Norway spruce forests in another Czech part described by VACEK ET AL. (2019a). The opposite situation was in mountain Norway spruce forests described by CUKOR ET AL. (2020), KRÁL ET AL. (2015) and VACEK ET AL. (2020b), where low temperatures were the limiting factor for Norway spruce growth. In general, the limiting effect of low temperatures was more pronounced in high-altitude localities, while the precipitation importance increased at low altitudes (MÄKINEN ET AL. 2002). As it turns out, high maximum air temperatures have a negative effect until January. Both species cope with this stress in the following year. On the other hand, minimum air temperatures are related to the Norway spruce growth only minimally. A higher sum of precipitation with its uniform distribution throughout the vegetation period is associated with a positive effect.

High average air temperatures in June correlate with a decrease in Douglas fir growth. A similar conclusion was also reached by ECKHART ET AL. (2019) and WILCZYŃSKI ET FELIKSIK (2007), where they also report a lower Douglas fir production in regions with the highest average summer temperature. Higher air temperatures from February to mid-April are the cause of the early start of the vegetation season and this is related to growth. CASTALDI ET AL. (2019) mention that the minimal temperature in February and March also plays a key role for Douglas fir. The high sum of precipitation at the beginning of the vegetation season and in July is most significant for Douglas fir. A similar conclusion was reached by VEJPUSTKOVÁ ET ČIHÁK (2019). While Norway spruce was affected negatively by temperatures in the summer months, the Douglas fir growth was positively correlated with temperatures in February and March. In generally, June and July are the most important months in term of climate influence on radial increment and xylem formation of the both species (LITTLE ET AL. 2008 and PUTALOVÁ ET AL. 2019).

Air humidity has also a big effect on both tree species. This requires sufficient precipitation and its uniform distribution. When choosing localities to replace Norway spruce by Douglas fir, it is necessary to take into account soil properties, local climatic conditions and, in particular, air humidity in connection with the increase of hot and dry periods. Radial increment is also affected by the dry season intensity, both in Norway spruce and Douglas fir, as also reported by SERGENT ET AL. (2014). LITTLE ET AL. (2008), like this study, reported that a temperature increase in period of April to September without a summer precipitation increase or soil moisture reserves causes decline Douglas fir growth probably.

At present, many stands in the Písek region are disintegrating. Norway spruce is a dominant tree species there. It is very weak, no longer resistant to Pine Knot-horm (*Dioryctia abietella* Denis & Schiffermüller 1775) and subsequently European spruce bark beetle (*Ips typographus*) attacks, and is slowly disappearing from the forests in this region due to extreme drought several years ago. A rapid Norway spruce decline has been observed throughout Europe in previous years (GRODZSKI 2010, HLÁSNY ET SITKOVÁ 2010, TOTH ET AL. 2020, VACEK ET AL. 2019b). Large-scale Norway spruce stands disruptions are caused by the increasing frequency of extreme climatic events (long-term drought, wind storms, insect attacks, etc.; KREJČÍ ET AL. 2013, PROKŮPKOVÁ ET AL. 2020, SCHELHAAS ET AL. 2003, ŠIMŮNEK ET AL. 2020). Douglas fir has been shown to cope with this situation and remain more or less vital in habitats with little increment reduction.

Norway spruce has been also significantly less resistant to climatic extremes (4 vs. 7 years) compared to Douglas fir, according to the negative indicator analysis of the year with extremely low radial increment. The positive years for both tree species were 1997 and 2002, and the negative ones were 1976 and 2018. KERN ET AL. (2017) declared the year 200 as the year with extremely negative anomalies for conifers in the Czech Republic and subsequently the year 2001 for Norway spruce, which my measurements also showed. On the other hand, this paper lists 2014 as the most positive anomaly, which was very good for Norway spruce, but not so much for Douglas fir. The year 1993 was also found to be negative for Norway spruce, similarly as Jeseníky Mts. (MIKULENKA ET AL. 2020). Another accordance of my results with other papers is the negative year 2015, which was characterized by extremely high temperatures with a low precipitation amount in summer months throughout Central Europe, which was documented e.g. in Giant Mountains (VACEK ET AL. 2020c). Trees growth from the point of positive and negative anomalies view show a strong dependence on the landscape and soil (KERN ET AL. 2017, ŠIMŮNEK ET AL. 2021).

Since both species show a different response to climatic extremes, it is possible that a mixed stands would be more resilient than monocultures from the point of growth stability view. Various significant indicators of years affecting radial increment also confirm it, when out of a total of 20 years; 3 years only were the same for both tree species. The advantage of mixed forests in terms of stability a resistance to climate change and drought was also confirmed by other studies (HÁJEK ET AL. 2020, PRETZCH ET AL. 2020, VACEK ET AL. 2019c, 2020a). The highest production potential was also observed on species-rich forest stands (higher enumeration base by 13.1%) in this paper. THURM ET PRETZCH (2016) found that Douglas fir and European beech mixtures showed overproduction compared to these species in pure stands. The results suggest also that research on the potential use Douglas fir in a single selection cropping system in Central Europe could be of interest, similarly as for Scotch pine in Spain (GALLO ET AL. 2020b).

As it can be seen from the increments and documented climatic data in comparison with the climatic data of the native range (Table 1), they are apparently the best in land provenances, which are those from the windward slopes of the Rocky Mountains second ridge (from Pacific), although HOFMAN (1964), KŠIR ET AL. (2015), MAUER ET AL. (2014) and ŠIKA (1974, 1975) recommend a coastal provenance to introduce to Czech territory. Coastal provenance would probably suffer from late spring frosts in the (my) observed localities, as evidenced by the earlier onset of vegetation season. This fact points to the importance of seed provenance, as emphasized by many authors (e.g. CLAIR 2006, CHAKRABORTY ET AL. 2019b, NEOPHYTOU ET AL. 2020, ŠIMEK 1992). It is a pity tat until 1959 no one looked into the Douglas fir provenance seed in the Czech Republic (ŠIMEK 1992).

In all localities, the Douglas fir production was higher than that of Norway spruce, as already was shown for both tree species production in the entire Czech Republic. This then resulted in a higher hectare standing volume on relevant TVPs. On average, the Douglas fir hectare standing volume [$m^3.ha^{-1}$] was roughly twice the Norway hectare standing volume at all research localities. However, another problem is looming, that will need to be solved immediately. It was found that the hectare standing volume calculated from the actual measured data according to the volume equations (formulas (2) and (3); Chapter 4.1.2) are higher than those indicated in the data sourced the forest management plans. This would mean that officially reported standing volumes are understated. The reason in most likely the Douglas fir standing volume underestimation, when it is determined by standard forest management procedures, as evidenced PETRÁŠ ET MECKO (2008). There can be several reasons: the absence of a Douglas fir standard assessment standing volume, measurement of heights, etc.

7. Conclusion

The production of the Czech main commercial tree species turned out to be lower than that of Douglas fir. Scotch pine, European beech and oaks lag behind it significantly in terms of production. The European larch and silver fir productions are also lower, but the presence of these conifers in the Czech forests is no so high to replace Norway spruce production, which is perishable during last few years. Losses caused by the Norway spruce production outage could be replaced by Douglas fir, but it is not in the interest of preserving the forests permanent value to plant its monocultures. It was shown that it is suitable to cultivate Douglas fir as an admixture of up to 30% in mixtures with autochthonous tree species, i.e. less productive tree species corresponding to the habitat.

The highest Douglas fir production in the Czech forests is in the 5th FVZ on acid and nutrient habitats, especially on K, S, B and H (D) edaphic categories, also higher production than that of Norway spruce (but lower than above mentioned) is achieved in these habitats in 3rd and 4th FVZs. High Douglas fir production is also on wet habitats, especially in 4V and 5V FTGs and on gleyed (stagned) habitats, especially in 4O, 4P, 5O, 5P, 6O and 6P FTGs. The mentioned gleyed (stagned) habitats can be considered tolerant during a longer drought period, however, for mature stands, since stands of the first age class suffer from drought. Nevertheless, the above-mentioned FTGs of wet and gleyed (stagned) localities do not cover large Czech forests. It was found that Douglas fir hectare stand volumes calculated from measured data from TVPs are significantly higher than those stated from LHPs and LHOs. Officially stated stand volumes of Douglas fir and Norway spruce could thus be underestimated. The results fully confirm goals (1) and (2) (Chapter 2).

The dominant (natural) tree species were changed by management intervention – Douglas fir and Norway spruce plantings and long-term cultivations. The localities of Norway spruce plantations significantly changed understory and due to long-term management, anthropogenic species are also common here. The Douglas fir plantings represent a change of 1st generation probably, therefore understory remains in a relatively preserved state of "close-to-natural" communities. The less adverse effect of Douglas fir on understory confirms goal (3) (Chapter 2).

The locality has a strong influence on Douglas fir and Norway spruce radial increments in the South Bohemia region focused to Písek area. This is especially true for Norway spruce, which indicates its grow here in unsuitable conditions and its existence at these altitudes is strongly threatened. On the other hand, Douglas fir is more resistant to climatic extremes and has also confirmed a higher production. However, both species are potentially affected by climate in different ways. The average air humidity can be considered the most important factor for both species, and the precipitation amount is also important. Mean temperatures showed a weaker significance. It showed that high temperatures together with a precipitation lack in the first part of the growing season affect Norway spruce and Douglas negatively. In this region, Norway spruce coped better with low temperatures and was more dependent on the course of precipitation throughout the year. On the other hand, in contrast that, Douglas fir showed an earlier growing season onset, which could be danger to young stands mainly due to the frost. Goal (4) (Chapter 2) can be considered to be confirmed partially only, although it can be proved on the basis of our research, that Douglas fir will tolerate better dry period during the summer season than Norway spruce, with an exception of younger advance growths, seedlings and plants in 1 age class.

It can be assumed, that the tree species presence in the Czech forests will change as a result of the ongoing climate change and related more frequent climatic extremes occurrence. It is also possible to consider the Douglas fir plant on parts of stands where Norway spruce was cultivated before. Douglas fir grows very successfully as an admixture with other (commercial) tree species, e.g. European beech mainly. The different ratios evaluation of such mixtures could be the further research subject.

It would be appropriate to use the acquired data to calculate the chemical elements dynamics (nutrients especially) taken up by tree species during their growth, as there is currently a lack of knowledge about the element allocation in Douglas fir biomass. We know little about how Douglas fir can affect soil properties in the long term.

Acknowledgment

My thanks to supervisor Prof. Vilém Podrázský for his professional leadership and advices, Drs. Karel Matějka, Anna Prokůpková and Stanislav Vacek and Bc. Vojtěch Hájek for their help in the field. I also thank my employer, the Forest Management Institute, for providing me with the successful development conditions of my thesis and the provision of some necessary data. As well, my thanks to Vodňany Forestry District staff for their cooperation. Last but not least, I thank my relatives and friends, who have had enough patience and often contributed their advices.

8. References

ACOSTA-HERNÁNDEZ A.C., POMPA-GARCÍA M., CAMARERO J.J. (2017): An Updated Review of Dendrochronological Investigations in Mexico, a Megadiverse Country with a High Potential for Tree-Ring Sciences. - Forests, 8(5): 160. DOI: 10.3390/f8050160

ALDEN H. A. (1997): Softwoods of North America. - : U.S.D.A., Forest Service, Forest Products Laboratory, Madison (WI), 151p. - URL: http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr102.pdf.

ALRIKSSON A., ERIKSSON H.M. (1998): Variatinos in mineral nutrient and C distribution in the soil and vegetation compartments of five temperate tree species in NE Sweden. - Forest Ecology and Management, 108: 261-273.

AMBROS Z. (1990): Bylinná synusie jako indikátor změn v abiotickém prostředí smrkových monokultur. - Preslia, 62: 205-214.

ARREOLA-ORTIZ M.R., NÁVAR-CHÁIDEZ J.D.J. (2010): Análisis de sequías y productividad con cronologías de *Pseudotsuga menziesii* Rob. & Fern., y su asociación con El Niño en el nordeste de México. - Investig. Geogr., 71: 7-20.

AUGUSTO L., DUPOUEY J.-L., RANGER J. (2003): Effects of tree species on understory vegetation and environmental conditions in temperate forests. - Annals of Forest Science, 60: 823-831. DOI: 10.1051/forest:2003077

BARTOŠ J., KACÁLEK D. (2011): Douglaska tisolistá – dřevina vhodná k zalesňování bývalých zemědělských půd. - Zprávy lesnického výzkumu, 56(Special Issue): 6-13.

BERAN F. (1993): Fenotypová proměnlivost a růst douglasky tisolisté na školním polesí Hůrka (SLŠ Písek). - Zprávy lesnického výzkumu, 38(3): 5-15.

BERAN F. (1995): Dosavadní výsledky provenienčního výzkumu douglasky tisolisté v ČR. - Zprávy lesnického výzkumu, 40(3-4): 7-13.

BERAN F., ŠINDELÁŘ J. (1996): Perspektivy vybraných cizokrajných dřevin v lesním hospodářství České republiky. - Lesnictví–Forestry, 42: 337-355.

BLAŠČÁK V. (2003): Zkušenosti s pěstováním douglasky tisolisté na LS Vodňany. - Lesu zdar, 9(12): 10-11.

BMEL (2014): Der Wald in Deutschland - Ausgewählte Ergebnisse der dritten Bundeswaldinventur. Bundesministerium für Ernährung und Landwirtschaft (BMEL), Berlin, Germany, 1-52.

BOMMER S., WEIHS U., BEUKE H. (1999): Möglichkeiten zur Einschätzung und waldbaulichen Beeinflussung der Konkurrenzsituation in Buchen-Douglasien-Jungbeständen. - Forst und Holz, 54: 8-14.

BORMANN B.T. (1984): Douglas-Fir an American wood. - USDA Forest Service, Washington, DC, 235, 7.

BRANDL S., PAUL C., KNOKE T., FALK W. (2020): The influence of climate and management on survival probability for Germany's most importance tree species. - Forest Ecology and Management, 458: 117652. DOI: 10.1016/j.foreco.2019.117652

BRUNDU G., PAUCHARD A., PYŠEK P., PERGL J., BINDEWALD A.M., BRUNORI A., CANAVAN S., CAMPAGNARO T., CELESTI-GRAPOW L., DE SÁ DECHOUM M., DUFOUR-DROR J.M., ESSL F., FLORY S.L., GENOVESI P., GUARINO F., GUANGZHE L., HULME P., JÄGER H., KETTLE J.C., KRUMM F., LANGDON B., LAPIN K., LOZANO V., LE ROUX J.J., NOVOA A., NUÑEZ M.A., PORTÉ A.J., SILVA J.S., SCHAFFNER U., SITZIA T., TANNER R., TSHIDADA N., VÍTKOVÁ M., WESTERGREN M., WILSON J.R.U., RICHARDSON D. (2020): Global guidelines for the sustainable use of non-native trees toprevent tree invasions and mitigate their negative impacts. - NeoBiota, 61: 65-116.

BRUS R., POTZELSBERGER E., LAPIN K., BRUNDU G., ORAZIO C., STRAIGYTE L., HASENAUER H. (2019): Extent, distribution and origin of non-native forest tree species in Europe. - Scandinavian Journal of Forest Research, 34: 533-544.

BURNS R.M., HONKALA B.H. (1990): Silvics of North America. Vol. 1. Conifers. Agriculture Handbook 654. - USDA, Forest Service, Washington, DC. 675p.

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. DOI: 10.17221/2083-JFS

CAFOUREK J. (2006): Provenienční pokusy douglasky tisolisté (*Pseudotsuga menziesii* /Mirb./ Franco) v oblasti středozápadní Moravy. In: Neuhöfferová P. (ed.): Douglaska a jedle obrovská – opomíjení giganti. Sborník z celostátní konference, Kostelec nad Černými lesy, Oct 12–13, 2006, pp. 7-15.

CARRILLO-GAVILÁN A., ESPELTA J.M., VILÀ M. (2012): Establishment constraints of an alien and a native conifer in different habitats. - Biological Invasions, 14: 1279-1289.

CASTALDI C., VACCHIANO G., MARCHI M., CORONA P. (2017): Projecting Nonnative Douglas Fir Plantantions in Southern Europe with the Forest Vegetation Simulator. - Forest Science 63: 101-110.

CASTALDI C., MARCHI M., VACCHIANO G., CORONA P. (2019): Douglas-fir climate sensitivity at two contrasting sites along the southern limit of the European planting range. - Journal of Forestry Research, 31: 2193-2204.

CLAIR J.B.ST. (2006): Genetic variation in fall cold hardiness in coastal Douglas-fir in western Oregon and Washington. - Canadian Journal of Botany, 84: 1110-1121.

CREMER M., PRIETZEL J. (2017): Soil acidity and exchangeable base cation stocks under pure and mixed stands of European beech, Douglas fir and Norway spruce. - Plant and Soil, 415: 393-405. DOI: 10.1007/s11104-017-3177-1

CUKOR J., ZEIDLER A., VACEK Z., VACEK S., ŠIMŮNEK V., GALLO J. (2020): Comparasion of growth and wood quality of Norway spruce and European larch: effect of previous land use. - European Journal of Forest Research, 139: 459-472. DOI: 10.1007/s10342-020-01259-7

DANIHELKA J., CHRTEK J. JR., KAPLAN Z. (2012): Checklist of vascular plants of the Czech Republic. - Preslia, 84: 647-811.

Da Ronch F., Caudullo G., De Rigo D. (2016): *Pseudotsuga menziesii* in Europe: distribution, habitat, usage and threats. In: San-Miguel-Ayanz J., de Rigo D., Caudullo G., Houston Durrant T., Mauri A., European Atlas of Forest Tree Species. - European Commission, 151p. URL: http://forest.jrc.ec.europa.eu/media/atlas/Pseudotsuga_menziesii.pdf.

DAWUD S.D., VESTERDAL L., RAULUND-RASMUSSEN K. (2017): Mixed-species effects on soil C and N stocks, C/N ratio and pH using a transboundary approach in adjacent common garden Douglas-fir and beech stands. - Forests, 8(4): 95. DOI: 10.3390/f8040095

DE WALL K., DREHER G., SPELLMANN H., PRETZSCH H. (1998): Struktur und Dynamik von Buchen-Douglasien-Mischbeständen in Niedersachsen - Structure and dynamic of beech-Douglas fir mixed stands in Lower Saxony. - Forstarchiv, 69: 179-191.

DESPLANQUE C., ROLLAND C., SCHWEINGRUBER F.H. (1999): Influence of species and abiotic factors on extreme tree ring modulation. - Trees, 13: 218-227.

EBERHARD B., HASENAUER H. (2018): Modeling Regeneration of Douglas fir forests in Central Europe. - Austrian Journal of Forest Science 135: 33-51.

ECKHART T., PÖTZELSBERGER E., KOECK R., THORM D., LAIR G.J., VAN LOO M., HASENAUER H. (2019): Forest stand productivity derived from site conditions: an assessment of old Douglas-fir stands (*Pseudotsuga menziesii* (Mirb.) Franco var. menziesii) in Central Europe. - Annals of Forest Science, 76: 19. DOI: 10.1007/s13595-019-0805-3

EILMANN B., RIGLING A. (2010): Douglas fir – a substitute species for Scots pine in dry inner-Alpine valleys? In: Opportunities and risks for Douglas fir in a changing climate. Oc. 18-20, 2010 Freiburg, Berichte Freiburger Forstliche Forschung, Freiburg, 85, 10.

EILMANN B., DE VRIES S.M.G., DEN OUDEN J., MOHREN G.M.J., SAUREN P., SASS-KLAASSEN U. (2013): Origin matters! Difference in drought tolerance and productivity of coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.)) provenances. - Forest Ecology and Management, 302, 133-143. DOI: 10.1016/j.foreco.2013.03.031

ESSL F. (2005): Distribution, status and habitat preference of subspontaneous Douglas fir stands (*Pseudotsuga menziesii*) in Austria (Germ.). - Phyton-Annales Rei Botanicae, 45: 117-143.

FERRON J.L., DOUGLAS F. (2010): Douglas-fir in France: history, recent economic development, overviews for the future. In: Opportunities and risks for Douglas fir in a changing climate. Oc. 18-20, 2010 Freiburg, Berichte Freiburger Forstliche Forschung, Freiburg, 85, 11.

FISCHER S., NEUWIRTH B. (2012): Climate sensitivity of Douglas-fir in Eifel and Kellerwald [Klimasensitivität der Douglasie in Eifel und Kellerwald]. - Allgemeine Forst- und Jagdzeitung, 183(1-2): 23-33.

GALLO J., KUNEŠ I., BALÁŠ M., NOVÁKOVÁ O., DRURY M.L. (2014): Occurrence of frost episodes and their dynamics in height gradient above the ground in the Jizerské hory Mts. - Journal of Forest Science, 60: 35-41.

GALLO J., BALÁŠ M., LINDA R., KUNEŠ I. (2017): Growth performance and resistance to near-ground late frosts of *Fagus sylvatica* L. plantation treated by a brassinosteroid compound. - Journal of Forest Science, 63: 117-125. DOI: 10.17221/67/2016-JFS

GALLO J., BALÁŠ M., LINDA R., KUNEŠ I. (2020a): The effects of planting stock size and weeding on survival and growth of small-leaved lime under drought-heat stress in the Czech Republic. - Austrian Journal of Forest Science, 137: 43-66.

GALLO J., BÍLEK L., ŠIMŮNEK V., ROIG S., FERNÁNDEZ J.A.B. (2020b): Uneven-aged silviculture of Scots pine in Bohemia and Central Spain: comparison study of stand reaction to transition and long-term selection management. - Journal of Forest Science, 66: 22-35. DOI: 10.17221/147/2019-JFS

GEORGE J.-P., GRABNER M., CAMPELO F., KARANITSCH-ACKERT S., KAYER K., KLUMPP R.T., SCHÜLER S. (2019): Intra-specific variation in growth and wood density traits under water-limited conditions: Long-term, short-term, and sudden responses of four conifer tree species. - Science of Total Environment, 660: 631-643. DOI: 10.1016/j.scitotenv.2018.12.478

GIORGI F., COPPOLA E. (2007): European climate-change oscillation (ECO). - Geophysical Research Letters, 34(21): L21703. DOI: 10.1029/2007GL031223

GÖMÖRY D., KRAJMEROVÁ D., HRIVNÁK M., LONGAUER R. (2020): Assisted migration vs. close-to-nature forestry: what are the prospects for tree populations under climate change? - Central European Forestry Journal, 66: 63-70. DOI: 10.2478/forj-2020-0008

GRODZKI W. (2010): The decline of Norway spruce *Picea abies* (L.) Karst. stands in Beskid Śląski and Żywiecki: Theoretical concept and reality. - Beskydy 3: 19-26.

GRISSINO-MAYER H.D., HOLMES R.L., FRITTS H.C. (1992): International tree-ring data bank program library: user´s manual. - Laboratory of Tree-Ring Research, University of Arizona, Tucson, USA.

HADAČ E., SOFRON J. (1980): Notes on syntaxonomy of cultural forest communities. - Folia Geobotanica et Phytotaxonomica, 15: 245-258. DOI: 10.1007/BF02851808

HÁJEK V., VACEK Z., VACEK S., BÍLEK L., PRAUSOVÁ R., LINDA R., BULUŠEK D., KRÁLÍČEK I. (2020): Changes in diversity of protected scree and herb-rich beech forest ecosystems over 55 years. - Central European Forestry Journal, 66: 202-217. DOI: 10.2478/forj-2020-0011

HÄRDLE W., SIMAR L. (2007): Canonical Correlation Analysis. In: Applied Multivariate Statistical Analysis, pp. 321-330.

HARLOW W. M. ET AL. (1996): Textbook of dendrology. 8th ed. - McGraw-Hill Inc., New York, 534p.

HART V., NENTVICHOVÁ-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. DOI: 10.17221/77/2009-JFS

HERMANN R.K., LAVENDER D.P. (1999): Douglas-fir planted forests. - New Forests, 17: 53-70.

HILL M.O. (1979): Twinspan - A Fortran program for arranging multivariate data in an ordered two way table by classification of individuals and attributes. - Cornell Univ., Ithaca (NY).

HILL M.O., GAUCH H.G. (1980): Detrended Correspondence Analysis: An Improved Ordination Technique. - Vegetatio, 42: 47-58.

HLÁSNY T., SITKOVÁ Z. (2010): Spruce forests decline in the Beskids. - National Forest Centre – Forest Research Institute Zvolen & Czech University of Life Sciences Prague & Forestry and Game Management Research Institute Jíloviště – Strnady, 182p.

HOFMAN J. (1964): Pěstování douglasky. - SZN, Praha, 253p.

CHAKRABORTY D., MATULLA C., ANDRE K., WEISSENBACHER L., SCHUELER S. (2019a): Survival of Douglas-fir provenances in Austria: site-specific late and early frost events are more important than provenance origin. - Annals of Forest Science, 76: 100. DOI: 10.1007/s13595-019-0883-2

CHAKRABORTY D., SCHUELER S., LEXER M.J., WANG T. (2019b): Genetic trials improve the transfer of Douglas-fir distribution models across continents. - Ecography, 42: 88-101.

CLAIR J.B.ST. (2006): Genetic variation in fall cold hardiness in coastal Douglas-fir in western Oregon and Washington. - Canadian Journal of Botany, 84: 1110-1121.

CHLEPKO V. ET AL. (1996): Biologické aspekty zásad hospodárenia a nápravné opatrenia v lesných oblastiach Slovenska. Záverečná zpráva. - LVÚ, Zvolen, 109p.

CHYTRÝ M. (ed.) (2013): Vegetace České republiky. 4. Lesní a křovinná vegetace. - Academia, Praha, 551p.

JANKOVSKÝ L., DVOŘÁK M., PALOVČÍKOVÁ D., BERÁNEK J. (2014): Choroby a škůdci na douglasce. In: Douglaska – dřevina roku 2014. Sborník z konference 2.-3.9.2014 Křtiny. - Česká lesnická společnost o.s., Praha, pp. 66-81.

JANSEN K., DU B. KAYLER Z, SIEGWOLF R, ENSMINGER I., RENNENBERG H., KAMMERER B., JAEGER C., SCHAUB M., KREUZWIESER J., GESSLER A. (2014): Douglas-Fir Seedlings Exhibit Metabolic Responses to Increased Temperature and Atmospheric Drought. - PLoS ONE, 9(12): e114165. DOI: 10.1371/journal.pone.0114165

KACÁLEK D., MAUER V., PODRÁZSKÝ V., SLODIČÁK M. ET AL. (2017): Meliorační a zpevňující funkce lesních dřevin. - Výzkumný ústav lesního hospodářství a myslivosti, v.v.i., Strnady, 300p.

KANTOR P., KNOTT R., MARTINÍK A. (2001a): Production capacity of Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) in a mixed stand. - Ekológia (Bratislava), 20 (Supplement 1): 5-14.

KANTOR P., KNOTT R., MARTINÍK A. (2001b): Production potential and ecological stability of mixed forest stands in uplands. III. A single tree mixed stand with Douglas fir on a eutrophic site of the Křtiny Training Forest Enterprise. - Journal of Forest Science, 47: 45-59.

KANTOR P., MARTINÍK A, SEDLÁČEK T. (2002): Douglaska tisolistá na školním lesním podniku. - Lesnická práce, 81(5): 210-212.

KANTOR P. (2008): Production potential of Douglas fir at mesotrophic sites of Křtiny Training Forest Enterprise. - Journal of Forest Science, 54: 321-332. DOI: 10.17221/35/2008-JFS

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. DOI: 10.17221/2/2009-JFS

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.

KERN A., MARJANOVIĆ H., DOBOR L., ANIĆ M., HLÁSNY T., BARCZA Z. (2017): Identification of years with extreme vegetation state in Central Europe based on remote sensing and meteorological data. - South-east European forestry: SEEFOR, 8(1): 1-20.

KINDLMANN P., MATĚJKA K., DOLEŽAL P. (2012): Lesy Šumavy, lýkožrout a ochrana přírody. - Karolinum, Praha, 326p.

KNIBBE B. (2007): PAST4: personal analysis system for treering research, Version 4.2. - SCIEM, Vienna.

KNOERZER D. (1999): Zur Einburgerungstendez der Douglasie (*Pseudotsuga menziesii* (Mirbel) Franco) im Schwarzwald. - Zeitschrift für Ökologie und Naturschutz, 8(1-2): 31-39.

KORF V. (1939): Příspěvek k matematické definici vzrůstového zákona lesních porostů. - Lesnická práce, 18: 339-379.

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. - Prague, pp. 52-66.

KOUDELA J. (2013): Pěstební a ekonomický potenciál douglasky tisolisté (*Pseudotsuga menziesii* /Mirbel/Franco.) ve vybraných oblastech ČR. - Diplomová práce, ČZU, Praha, 67p.

KRAMER K., GROOT BRUINDERINK G.W.T.A., PRINS H.H.T. (2006): Spatial interactions between ungulate herbivory and forest management. - Forest Ecology and Management, 226: 238-247. DOI: 10.1016/j.foreco.2006.01.037

KRÁL J., VACEK S., VACEK Z., PUTALOVÁ T., BULUŠEK D., ŠTEFANČÍK I. (2015): Structure, development and health status of spruce forests affected by air pollution in the western Krkonoše Mts. in 1979–2014. - Central European Forestry Journal, 61: 175-187.

KRÁLÍČEK I., VACEK Z., VACEK S., REMEŠ J., BULUŠEK D., KRÁL J., ŠTEFANČÍK I., PUTALOVÁ T. (2017): Dynamics and structure of mountain autochthonous spruce-beech forests: impact of hilltop phenomenon, air pollutants and climate. - Dendrobiology, 77: 119-137. DOI: 10.12657/denbio.077.010

KREJČÍ F., VACEK S., BÍLEK L., MIKESKA M., HEJCMANOVÁ P., VACEK Z. (2013): The effects of climatic conditions and forest site types on disintegration rates in Picea abies occurring at the Modrava Peat Bogs in the Šumava National Park. - Dendrobiology, 70: 35-44. DOI: 10.12657/denbio.070.004

KŠÍR 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.

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.

KUBÍČEK M., DUBCOVÁ M., JANOVSKÁ D. (2005): Numerické metody a algoritmy. - Vysoká škola chemicko-technologická v Praze, 189p.

KUNEŠ I., BALÁŠ M., GALLO J., ŠULITKA M., PINIDIYA ARACHCHILAGE C. (2019): Trnovník akát (*Robinia pseudoacacia*) a jeho role ve středoevropském a českém prostoru: review. - Zprávy lesnického výzkumu, 64: 181-190.

LACHENBRUCH B., JOHNSON R.G. (2020): Different radial growth rate effects on outerwood properties of coastal Douglas-fir in healthy trees vs. trees impacted by Swiss Needle Cast. - Canadian Journal of Forest Research, 51(4): 611-621. DOI: 10.1139/cjfr-2020-0199.

LANDESFORSTEN R.L.P. (2021): Holzarten. In: Ministerium für Umwelt, Energie, Ernährung und Forsten Rheinland-Pfalz, Mainz, Germany.
URL: https://www.wald.rlp.de/de/nutzen/holz/holzarten/

LANG M., KUUSK A., MÕTTUS M., RAUTIAINEN M., NILSON T. (2010): Canopy gap fraction estimation from digital hemispherical images using sky radiance models and a linear conversion method. - Agricultural and Forest Meteorology, 150: 20-29. DOI: 10.1016/j.agrformet.2009.08.001

LANG M. (2014): A program for processing digital hemispherical images HSP. HemiSPherical Project Manager, ver: 1.3.3. User manual. - Tõravere, 21p.

LARSON B. (2010): The dynamics of Douglas-fir stands. In: Opportunities and risks for Douglas fir in a changing climate. Oc. 18–20, 2010 Freiburg. - Berichte Freiburger Forstliche Forschung, Freiburg, 85: 9-10.

LITTELL J., PETERSON D.L., TJOELKER, M. (2008): Douglas-fir growth in mountain ecosystems: water limits tree growth from stand to region. - Ecological Monographs, 78: 349-368.

LU H., CONDÉS S., DEL RÍO M., GOUDIABY V., DEN OUDEN J., MOHREN G.M.J., SCHELHAAS M-J., DE WAAL R., STERCK F.J. (2018): Species and soil effects on overyielding of tree species mixtures in the Netherlands. - Forest Ecology and Management, 409: 105-118. DOI: 10.1016/j.foreco.2017.11.010

MACKŮ J., KOSOVÁ D. (2020): Scenario of the climate change model HadGem in the regional forest development plans. - Zprávy lesnického výzkumu, 65: 28-39.

MÄKINEN H., NÖJD P., KAHLE H.P., NEUMANN U., TVEITE B., MIELIKÄINEN K., RÖHLE H., SPIECKER H. (2002): Radial growth variation of Norway spruce (*Picea abies* (L.) Karst.)

across latitudinal and altitudinal gradients in central and northern Europe. - Forest Ecology and Management, 171: 243-259.

MÁLIŠ F., VLADOVIČ J., ČABOUN V., VODÁLOVÁ A. (2010): The influence of *Picea abies* in forest plant communities of the Veporské vrchy Mts. - Journal of Forest Science, 56: 58-67. DOI: 10.17221/39/2009-JFS

MARTINEZ-MEIER A., SANCHEZ L., PASTORINO M., GALLO L., ROZENBERG P. (2008): What is hot in tree rings? The wood density of surviving Douglas-firs to the 2003 drought and heat wave. - Forest Ecology and Management, 256: 837-843.

MARTINÍK A. (2003): Possibilities of growing Douglas fir (*Pseudotsuga menziesii* /Mirb./ Franco) in the conception of sustainable forest management. - Ekológia (Bratislava), 22 (Supplement 3): 136-146.

MARTINÍK A., KANTOR P. (2007): Branches and the assimilatory apparatus of full-grown trees of Douglas fir (*Pseudotsuga menziesii* /Mirb./ Franco) of a different coenotic position. - Ekológia (Bratislava), 26: 223-239.

MARTINÍK A., KANTOR P. (2009): Analýza nadzemní biomasy douglasky tisolisté. - Lesnická práce, 88(1): 24-25.

MARTINÍK A., PALÁTOVÁ E. (2012): Je předosevní příprava osiva douglasky tisolisté nezbytná? - Zprávy lesnického výzkumu, 57(1): 47-55.

MATĚJKA K. (2012): Klimatické gradienty a modelování lesních vegetačních stupňů v ČR. In: Geobiocenologie a její aplikace v lesnictví a krajinářství, Mendelova univerzita v Brně. URL: https://infodatasys.cz/public/model_lvs_cr_2012.pdf

MATĚJKA K. (2018a): Využití hemisférických snímků pro studium ekologie lesů. - URL: https://www.infodatasys.cz/proj008/hemisphericalphotos.htm

MATĚJKA K. (2018b): Struktura stromového patra a světelné poměry v porostech na výzkumných plochách.[Tree layer structure and light condition in stands of selected research plots]. - URL: https://www.infodatasys.cz/proj008/DemObjects_HF2018.pdf

MATĚJKA K. (2020): Nápověda k programu DBreleve. Databáze fytocenologických snímků, verze 2.5. - URL: https://www.infodatasys.cz/software/hlp_dbreleve/dbreleve.htm

MATĚJKA K. (2021): Nápověda k programu CanopyPhotos. - URL: https://infodatasys.cz/software/hlp_CanopyPhotos/CanopyPhotos.htm

MATĚJKA K., PODRÁZSKÝ V., VIEWEGH J. (2014): Vliv douglasky na stav lesních fytocenóz. In: Slodičák M., Novák J. [Eds.], Pěstební postupy při zavádění douglasky do porostních směsí v podmínkách ČR. - Lesnická práce s.r.o., Kostelec nad Černými lesy, pp. 214-231. URL: https://infodatasys.cz/public/Slodicaketal2014_10.pdf

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(3): 201-210.

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. DOI: 10.17221/94/2011-JFS

MAUER O., VANĚK P. (2014): Douglaska tisolistá (*Pseudotsuga menziesii* /Mirb./ Franco) jako meliorační a zpevňující dřevina, růst douglasky na různých stanovištích od 2. do 7. lesního vegetačního stupně. In: Douglaska – dřevina roku 2014. Sborník z celostátní konference, Křtiny, Sept 2–3, 2014, pp. 26-39.

MAUER O., SYCHRA D., VANĚK P., HOUŠKOVÁ K. (2014): On some aspects of silviculture planting material and Douglas-fir (Pseudotsuga menziesii /Mirb./ Franco) stands establishment. In: Douglas fir – tree of the year 2014. Proceedinngs of the workshop held at Křtiny in September 2-3, 2014, pp. 49-70. - URL: www.infodatasys.cz/proj009/Douglasfir2014tr.pdf

MCCUNE B., GRACE J.B. (2002): Analysis of Ecological Communities. - MjM Software Design, Gleneden Beach (OR), 300p.

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 the Křtiny Forest Training Enterprise. - Journal of Forest Science, 55: 345-356. DOI: 10.17221/9/2009-JFS

MIKULENKA P., PROKŮPKOVÁ A., VACEK Z., VACEK S., BULUŠEK D., SIMON J., ŠIMŮNEK V., HÁJEK V. (2020): Effect of climate and air pollution on radial growth of mixed forests: *Abies alba* Mill. vs. *Picea abies* (L.) Karst. - Central European Forestry Journal, 66(1): 23-36. DOI: 10.2478/forj-2019-0026

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. DOI: 10.17221/9/2019-JFS

MONDEK J., MATĚJKA K., GALLO J., PROKŮPKOVÁ A., HÁJEK V. (2021): *Picea abies* and *Pseudotsuga menziesii* radial growth in relation to climate: case study from South Bohemia. - Austrian Journal of Forest Science, 138: 209-244. URL: https://infodatasys.cz/public/CB2103_Art4.pdf

MORAVEC J. ET AL. (2000): Fytocenologie. - Academia, Praha, 403p.

MOSER B., BACHOFEN CH., MÜLLER J.D., METSLAID M., WOHLGEMUTH T. (2016): Root architecture might account for contrasting establishment success of *Pseudotsuga menziesii* var. *menziesii* and *Pinus sylvestris* in Central Europe under dry conditions. - Annals of Forest Science, 73: 959-970. DOI: 10.1007/s13595-016-0574-1

MUSIL I., HAMERNÍK J. (2007): Jehličnaté dřeviny. - Academia, Praha, 252p.

NADEZHDINA N., URBAN J., ČERMÁK J., NADEZHDIN V., KANTOR P. (2014): Comparative study of long-term water uptake of Norway spruce and Douglas-fir in Moravian upland. - Journal of Hydrology and Hydromechanics, 62: 1-6. DOI: 10.2478/johh-2014-0001

NEOPHYTOU C., WEISSER A.-M., LANDWEHR D., ŠEHO M., KOHNLE U., ENSMINGER I., WILDHAGEN H. (2016): Assessing the relationship between height growth and molecular genetic variation in Douglas-fir (*Pseudotsuga menziesii*) provenances. - European Journal of Forest Research, 135: 465-481. DOI: 10.1007/s10342-016-0946-y

NEOPHYTOU C., VAN LOO M., HASENAUER M. (2020): Genetic diversity in introduced Douglas-fir and its natural regeneration in Central Europe. - Forestry, 93: 535-544. DOI: 10.1093/forestry/cpz055

NOVÁK J., KACÁLEK D., PODRÁZSKÝ V., ŠIMERDA L. [Eds.] (2018): Uplatnění douglasky tisolisté v lesním hospodářství ČR. - Lesnická práce, s.r.o., Kostelec nad Černými lesy, 216p.

NOVÁK J., DUŠEK D., KACÁLEK D. (2019): Growth of juvenile Douglas-fir mixed with native tree species on different forest sites. - Zprávy lesnického výzkumu, 64: 133-139.

OULEHLE F., HRUŠKA J. (2005): Tree species (*Picea abies* and *Fagus sylvatica*) effects on soil water acidification and aluminium chemistry at sites subjected to long-term acidification in the Ore Mts., Czech Republic. - Journal of Inorganic Biochemistry, 99: 1822-1829. DOI: 10.1016/j.jinorgbio.2005.06.008

PAGAN J. (1999): Lesnícka dendrológia. - Technická univerzita vo Zvolene, 378p.

PAGE G. (1970): Quantitative site assessment; some practical applications in British forestry. - Forestry, 43: 45-56.

PALÁTOVÁ P., DUDÍK R., HUŠBAUER J. (2017): Czech wood and potential of its consumption in the Czech republic. In: More wood, better management, increasing effectiveness: Starting points and perspective. May 24, 2017 Prague, Czech republic, Czech University of Life Sciences Prague, Department of Systems Engineering, Kamýcká 129, 165 21 Prague, Czech republic, pp. 33-37.

PIANKA S. (2012): Gatunki drzew obcego pochodzenia na leśnych powierzchniach doświadczalnych Brandenburgii. - Rocznik Polskiego Towarzystwa Dendrologicznego, 60: 21-42.

PANSHIN A.J., DE ZEEUW C. (1980): Textbook of wood technology. 4. Ed. - Mc-Graw-Hill, New York, 722p.

PERGL J., SÁDLO J., PETRUSEK A., LAŠTŮVKA Z., MUSIL J., PERGLOVÁ I., ŠANDAS R., ŠEFROVÁ H., ŠÍMA J., VOHRALÍK V., PYŠEK P. (2016): Black, Grey and Watch Lists of alien species in the Czech Republic based on environmental impacts and management strategy. - NeoBiota, 28: 1-37. DOI: 10.3897/neobiota.28.4824

PERIĆ S., TIJARDOVIĆ M., JAZBEC A. (2011): Results of research on douglas fir provenances in ecologicaly different contineneta parts of Croatia [Rezultati istraživanja provenijencija zelene duglazije u ekološki različitim područjima kontinentalne Hrvatske]. - Šumarski List, 135(13): 190-201.

PETRÁŠ R., PAJTÍK J. (1991): Sústava česko-slovenských objemových tabuliek drevín. - Lesnícky Časopis, 37: 49-56.

PETRÁŠ R., MECKO J. (2008): Rastový a produkčný potenciál douglasky na Slovensku. In: Pěstování nepůvodních dřevin. Kroměříž 26.6.2008. - ČLS, Kroměříž, pp.59-64.

PODRÁZSKÝ V., REMEŠ J., LIAO C.Y. (2001): Vliv douglasky tisolisté (*Pseudotsuga menziesii* /Mirb./ Franco) na stav lesních půd. In: Pulkrab K., Kobliha J., Podrázský V. [Eds.], Krajina, les a lesní hospodářství. I. Sborník z celostátní konference, Praha, pp. 24-29.

PODRÁZSKÝ V., REMEŠ J., MAXA M. (2001): Má douglaska degradační vliv na lesní půdy? - Lesnická práce, 80: 393-395.

PODRÁZSKÝ V., REMEŠ J., LIAO C.Y. (2002): Vliv douglasky tisolisté (*Pseudotsuga menziesii* (Mirb./ Franco) na stav humusových forem lesních půd – srovnání se smrkem ztepilým. - Zprávy lesnického výzkumu, 46: 86-89.

PODRÁZSKÝ V., ŠTĚPÁNÍK R. (2002): Vývoj půd na zalesněných zemědělských plochách – oblast LS Český Rudolec. - Zprávy lesnického výzkumu, 47: 53-56.

PODRÁZSKÝ V., ULBRICHOVÁ I. (2004): Restoration of forest soils on reforested abandoned agricultural lands. - Journal of Forest Science, 50: 249-255.

PODRÁZSKÝ V., REMEŠ J. (2005): Retenční schopnost svrchní vrstvy půd lesních porostů s různým druhovým složením. - Zprávy lesnického výzkumu, 50: 46-48.

PODRÁZSKÝ V., REMEŠ J. (2008): Půdotvorná role významných introdukovaných jehličnanů – douglasky tisolisté, jedle obrovské a borovice vejmutovky. - Zprávy lesnického výzkumu, 53: 27-34.

PODRÁZSKÝ V., REMEŠ J., HART V., TAUCHMAN P. (2009a): Douglaska a její pěstování – test českého lesnictví. - Lesnická práce, 88: 376-381.

PODRÁZSKÝ V., REMEŠ J., HART V., MOSER W.K. (2009b): 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., REMEŠ J. (2010): Production and environmental functions of Douglas-fir on the School Training Forest Kostelec nad Černými lesy territory. In: Spiecker H., Kohnle U., Makkonen-Spiecker K., Brill C. [Eds.], Opportunities and Risks for Douglas fir in a Changing Climate, Freiburg, Oct 18–20, 2010, p. 64.

PODRÁZSKÝ V., REMEŠ J., TAUCHMAN P., HART V. (2010): Douglaska tisolistá a její funkční účinky na zalesněných zemědělských půdách. - Zprávy lesnického výzkumu, 55: 12-17.

PODRÁZSKÝ V., KUPKA I. (2011): Vliv douglasky tisolisté (*Pseudotsuga menziesii* /Mirb/ Franco) na základní pedofyzikální charakteristiky lesních půd. - Zprávy lesnického výzkumu, 56 (Special): 1-5.

PODRÁZSKÝ V., VIEWEGH J., MATĚJKA K. (2011): Vliv douglasky na rostlinná společenstva lesů ve srovnání s jinými dřevinami. - Zprávy lesnického výzkumu, 56 (Special): 44-51.

PODRÁZSKÝ V., ZAHRADNÍK D., PULKRAB K., KUBEČEK J., PEÑA J.B. (2013a): Hodnotová produkce douglasky tisolisté (*Pseudotsuga menziesii* /Mirb/ Franco) na kyselých stanovištích Školního polesí Hůrky, Písecko. - Zprávy lesnického výzkumu, 58: 226-232.

PODRÁZSKÝ V., KOUBA J., ZAHRADNÍK D., ŠTEFANČÍK I. (2013b): Změny v druhové skladbě českých lesů – výzva pro lesnický i dřevozpracující sektor. In: Dřevostavby 2013. Volyně 27. – 28.3.2013, VOŠ a SPŠ, Volyně, pp. 3-7.

PODRÁZSKÝ V., ČERMÁK R., ZAHRADNÍK D., KOUBA J. (2013c): Production of Douglas-fir in the Czech Republic based on national forest inventory data. - Journal of Forest Science, 59: 398-404.

PODRÁZSKÝ V., KUBEČEK J., ČERMÁK R., ŠTEFANČÍK I. (2013d): Zhodnocení dosavadního výzkumu douglasky tisolisté v České republice – přehled. In: Baláš M., Podrázský V., Kučeravá B. [Eds.], Proceedings of Central European Silviculture, Kostelec nad Černými lesy, July 2–3, 2013, pp. 192-203.

PODRÁZSKÝ V., ZAHRADNÍK D., REMEŠ J. (2014a): Potential consequences of tree species and age structure changes of forests in the Czech republic – Review of forest inventory data. - Wood Research, 59: 483-490.

PODRÁZSKÝ V., MARTINÍK A., MATĚJKA K., VIEWEGH J. (2014b): Effects of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) on understorey layer species diversity in managed forests. - Journal of Forest Science, 60: 263-271. DOI: 10.17221/49/2014-JFS

PODRÁZSKÝ V. (2015): Potential of Douglas‑fir as a partial substitute for Norway spruce – review of the newest Czech literature. - Beskydy, 8(1): 55-58.

PODRÁZSKÝ V., NOHA M., KUBEČEK J. (2015): Contribution for determination of the optimal share of Douglas-fir in the forest stands. In: Houšková K., Černý J. [Eds.], Proceedings of Central European Silviculture. - Mendelova univerzita v Brně, pp. 208-217.

PODRÁZSKÝ V. (2016): Potential substitution of Norway spruce by the Douglas-fir in the Czech Republic. In: Kacálek D., Novák J., Nováková K., Součková J. [Eds.], Forest functions in Changing Environments, Dobruška, Aug 30-31, 2016, pp. 99-104.

PODRÁZSKÝ V., FULÍN M., PRKNOVÁ H., BERAN F., TŘEŠTÍK M. (2016a): Changes of agricultural land characteristics as a result of afforestation using introduced tree species. - Journal of Forest Science, 62: 72-79. DOI: 10.17221/96/2015-JFS

PODRÁZSKÝ V., REMEŠ J., SLOUP R., PULKRAB K., NOVOTNÝ S. (2016b): Douglas-fir – partial substitution for declining conifer timber supply – review of Czech data. - Wood Research, 61: 525-530.

PODRÁZSKÝ V., PULKRAB K., SLOUP R., KUBEČEK J. (2016c): Douglaska jako částečné řešení nedostatku jehličnatého dřeva. - Lesnická práce, 65(7): 26-28.

PODRÁZSKÝ V., KUPKA I., PRKNOVÁ H. (2020): 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. DOI: 10.2478/forj-2020-0007

POLENO Z. (2001): Influence of transformation of spruce monocultures on state and development of forest soil and herbal vegetation. - Zprávy lesnického výzkumu, 46: 6-15.

POLENO Z., VACEK S., PODRÁZSKÝ V., REMEŠ J., ŠTEFANČIK I., MIKESKA M., KOBLIHA J., KUPKA I., MALÍK V., TURČÁNI M., DVOŘÁK J., ZATLOUKAL V., BÍLEK L., BALÁŠ M., SIMON J. (2009): Pěstovani lesů III. Praktické postupy pěstovaní lesů. [Silviculture III. Practical methods in silviculture]. - Lesnická práce, s.r.o., Kostelec nad Černými lesy, 952p.

PÖTZELSBERGER E., ECKHART T., HASENAUER H. (2019): Mapping the growth potential of Douglas-fir in Austria and Germany. - Austrian Journal Forest Science, 136: 69-86.

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. DOI: 10.1007/s40725-020-00129-0

PRETZSCH H., SCHÜTZE G. (2016): Effect of tree species mixing on the size structure, density, and yield of forest stands. - European Journal of Forest Research, 135: 1-22. DOI: 10.1007/s10342-015-0913-z

PRETZSCH H., GRAMS T., HÄBERLE K.H., PRITSCH K., BAUERLE T., RÖTZER T. (2020): Growth and mortality of Norway spruce and European beech in monospecific and mixed-species stands under natural episodic and experimentally extended drought. Results of the KROOF throughfall exclusion experiment. - Trees 34: 957-970. DOI: 10.1007/s00468-020-01973-0

PROKŮPKOVÁ A., VACEK Z., VACEK S., BLAŽEJOVÁ J., SCHWARZ O., BULUŠEK D. (2020): Dynamics of natural regeneration of mountain forests after wind disturbance: model study for the Krkonoše Mts. (Czech Republic). - Zprávy Lesnického Výzkumu, 65: 72-81.

PŮBALOVÁ M., HOLKUP J. (2015): Problematika introdukovaných dřevin v lesích ČR. - Centrum aplikovaného výzkumu a dalšího vzdělávání, o.p.s. Písek, nakladatelství JIH, České Budějovice, 53p.

PULKRAB K., SLOUP R., PODRÁZSKÝ V. (2015): Production potential of the forests in the Czech republic. - BioResources, 10: 4711-4725. DOI: 10.15376/biores.10.3.4711-4725

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. DOI: 10.2478/forj-2019-0004

PYŠEK P., CHYTRÝ M., PERGL J., SÁDLO J., WILD J. (2012): Plant invasions in the Czech Republic: Current state, introduction dynamics, invasive species and invaded habitats. - Preslia, 84: 576-630.

RAIS A., VAN DE KUILEN J.-W.G., PRETZSCH H. (2014): Growth reaction patterns of tree height, diameter, and volume of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) under acute drought stress in Southern Germany. - European Journal of Forest Research, 133: 1043-1056. DOI: 10.1007/s10342-014-0821-7

RAUNKIAER C. (1905): Types biologiques pour la géographie botanique. - Kongelige Danske Videnskabernes Selskabs Forhandlinger, 5: 347-438.

REMEŠ J., PODRÁZSKÝ V., HART V. (2006): Růst a produkce nejstaršího porostu douglasky tisolisté (*Pseudotsuga menziesii* /Mirbel/ Franco) na území ŠLP Kostelec nad Černými lesy. In: Neuhöfferová P. [Ed.], Douglaska a jedle obrovská – opomíjení giganti. Sborník z celostátní konference, Kostelec nad Černými lesy, Oct 12-13, 2006, pp. 65-69.

REMEŠ J., PULKRAB K., TAUCHMAN P. (2010): Produkční a ekonomický potenciál douglasky tisolisté na vybrané lokalitě ŠLP Kostelec nad Černými lesy. In: Prknová H. [Ed.], Aktuality v pěstování méně častých dřevin v České republice. Sborník referátů, Kostelec nad Černými lesy, Oct 21, 2010, pp. 68-69.

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(4): 431. DOI: 10.3390/f11040431

RENDLE J. (1969): World Timbers: North & South America, including Central America and the West Indies. - Ernest Benn Limited, London, 192p.

RIEDL M., JARSKÝ V., PALÁTOVÁ P., SLOUP R. (2019): The Challenges of the Forestry Sector Communication Based on an Analysis of Research Studies in the Czech Republic. - Forests, 10(11): 935. DOI: 10.3390/f10110935

RIEGLER J. (2008): Die Douglasie aus Sicht der Verarbeiters. - BFW Praxis Information, 16: 23-25.

SAGEMAN B.B., HOLLANDER D.H. (1999): Cross correlation of paleoecological and geochemical proxies: A holistic approach to the study of past global change. In: Barrera E., Johnson C.C. [Eds.], GSA Special Paper 332, pp. 365-384.

SCHÄR C., VIDALE P.L., LÜTHI D., FREI C., HÄBERLI C., LINIGER M.A., APPENZELLER C. (2004): The role of increasing temperature variability in European summer heatwaves. - Nature, 427: 332-336. DOI: 10.1038/nature02300

SCHELHAAS M.-J., NABUURS G.-J., SCHUCK A. (2003): Natural disturbances in the European forests in the 19th and 20th centuries. - Global Change Biology, 9: 1620-1633. DOI: 10.1046/j.1365-2486.2003.00684.x

SCHELHAAS M.-J. (2008): The wind stability of different silvicultural systems for Douglas-fir in the Netherlands: a model-based approach. - Forestry, 81: 399-414. DOI: 10.1093/forestry/cpn028

SCHMID M., PAUTASSO M., HOLDENRIEDER O. (2014): Ecological cosequences of Douglas-fir cultivation in Europe. - European Journal of Forest Rresearch, 133: 13-29. DOI: 10.1007/s10342-013-0745-7

SCHÜTZ J.P., POMMERENING A. (2013): Can Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) sustainably grow in complex forest structures? Forest Ecology and Management 303, 175-183. DOI: 10.1016/j.foreco.2013.04.015

SCHWEINGRUBER F.H. (1996): Tree Rings and Environment Dendroecology. - Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland, 609p.

SERGENT A.S., ROZENBERG P., MARCAIS B., LEFEVRE Y., BASTIEN J.C., NAGELEISEN L.M. ET AL. (2010): Vulnerability of Douglas-fir in a changing climate: study of decline in France after the extreme 2003´s drought. In: Spiecker H., Kohnle U., Makkonen-Spiecker K., Brill C. [Eds.], Opportunities and Risks for Douglas fir in a Changing Climate, Freiburg, Oct 18-20, 2010, pp. 21-22.

SERGENT A.S., ROZENBERG P., BRÉDA N. (2014): Douglas-fir is vulnerable to exceptional and recurrent drought episodes and recovers less well on less fertile sites. - Annal of Forest Science, 71: 697-708. DOI: 10.1007/s13595-012-0220-5

SHAW P.J.A. (2003): Multivariate Statistics for the Environmental Sciences. - Hodder Arnold, London, 233p.

SICARD C., SAINT-ANDRE L., GELHAYE D., RANGER J. (2006): Effect of initial fertilisation on biomass and nutrient content of Norway spruce and Douglas-fir plantations at the same site. - Trees 20: 229-246. DOI: 10.1007/s00468-005-0030-6

SLODIČÁK M., NOVÁK J., MAUER O., PODRÁZSKÝ V. [Eds.] (2014): Pěstební postupy při zavádění douglasky do porostních směsí v podmínkách ČR. - Lesnická práce, Kostelec nad Černými lesy, 272p.

STOJAN J. (2006): Produkční potenciál douglasky tisolisté na školním polesí SLŠ Hranice. - Bakalářská práce, LF MZLU, Brno, 44p.

ŠACH F., ČERNOHOUS V., KACÁLEK D. (2019): Water regime of Douglas-fir and forest stands with Douglas-fir: review. - Zprávy lesnického výzkumu, 64: 149-154.

ŠIKA A., HEGER B. (1972): Vyhodnocení prvních provenienčních pokusů s douglaskou tisolistou v českých zemích. - Práce VÚLHM, 41: 105-121.

ŠIKA A. (1974): První výsledky mezinárodního provenienčního pokusu s douglaskou v Čechách. - Časopis Slezského muzea, Opava, XXIII.

ŠIKA A. (1975): Rozdíly v odolnosti proveniencí douglasky vůči zimnímu vysýchání. - Práce VÚLHM, 46: 171-183.

ŠIKA A. (1985): Reprodukční možnosti douglasky tisolisté v ČSR z domácích zdrojů. - Práce VÚLHM, 67: 41-62.

ŠIKA A., PÁV B. (1990): Výškový růst douglasky na provenienčních plochách ČR v různých fázích vývoje. - Lesnictví, 36: 367-380.

ŠIMEK J. (1992): Pěstovaní douglasky tisolisté na LZ Tábor. - Lesnická práce, 71: 330-333.

ŠIMŮNEK V., VACEK Z., VACEK S. (2020): Solar Cycles in Salvage Logging: National Data from the Czech Republic Confirm Significant Correlation. - Forests, 11(9): 973. DOI: 10.3390/f11090973

ŠIMŮNEK V., VACEK Z., VACEK S., RIPULLONE F., HÁJEK V., D'ANDREA G. (2021): Tree Rings of European Beech (*Fagus Sylvatica* L.) Indicate the Relationship with Solar Cycles During Climate Change in Central and Southern Europe. - Forests, 12(3): 259. DOI: 10.3390/f12030259

ŠINDELÁŘ J. (2003): Aktuální problémy a možnosti pěstování douglasky tisolisté. - Lesnická práce, 82(3): 14-16.

ŠMIDRIAK V. (2010): Možnosti využitia dreviny duglasky tisolistej /*Pseodutsuga menziesii* (Mirbel/Franco) v Slovenskej republike. - DF TU Zvolen. DF-3580-6890, 110p.

ŠOMŠÁK L., BALKOVIČ J. (2002): Cyclic succession and plant biodiversity within the secondary spruce forests in the Hnilec river watershed. - Phytopedon, 1: 45-51.

ŠOMŠÁK L. (2003): Effect of secondary spruce forests on phytoenvironment in the Slovenské Rudohorie Mountains. - Folia Oecologica, 30: 41-59.

THOMAS F.M., BÖGELEIN R., WERNER W. (2015): Interaction between Douglas fir and European beech – investigations in pure and mixed stands. - Forstarchiv, 86, 83-91. DOI: 10.4432/0300-4112-86-83

THOMAS F.M., RZEPECKI A., WERNER W. (2022): Non-native Douglas fir (*Pseudotsuga meziesii*) in Central Europe: Ecology, performance and nature conservation. - Forest Ecology and Management, 506: 119956. DOI: 10.1016/j.foreco.2021.119956

THURM E.A., PRETZSCH H. (2016): Improved productivity and modified tree morphology of mixed versus pure stands of European beech (*Fagus sylvatica*) and Douglas-fir (*Pseudotsuga menziesii*) with increasing precipitation and age. - Annals of Forest Science, 73: 1047-1061. DOI: 10.1007/s13595-016-0588-8

THURM E.A., UHL E., PRETZSCH P. (2016): Mixture reduces climate sensitivity of Douglas-fir stem growth. - Forest Ecology and Management, 376: 205-220. DOI: 10.1016/j.foreco.2016.06.020

TSCHOPP T., HOLDEREGGER R., BOLLMANN K. (2015): Auswirkungen der Douglasie auf die Waldbiodiversität. - Schweizerische Zeitschrift fur Forstwesen, 166(1): 9-15.

ŤAVODA P., KRAJŇÁKOVÁ J. (1993): Reprodukčné schopnosti a odolnosť potomstiev duglasky z domácich vysokohodnotných porastov. In: Dendrologické dni (zborník referátov). - VŠP Nitra, 59.

ŤAVODA P., LENGYELOVÁ A. (1996): Možnosti introdukcie drevin v lesných oblastiach Slovenska. In: Chlepko et al. [Eds.], Biologické aspekty zásad hospodárenia a nápravné opatrenia v lesných oblastiach Slovenska. Záverečná správa. - LVÚ Zvolen, 109p.

ŤAVODA P. (2007): Ekologické nároky a rozšírenie douglasky tisolistej na Slovensku. In: Ekológia a environmentalistika. Mezinárodná vedecká konferencia, Zvolen, May 22–23, 2007, pp. 194-202.

TER BRAAK C.J.F., PRENTICE I.C. (1988): A Theory of Gradient Analysis. Advances in Ecological Research, Vol. 18, pp. 271-371. Reprinted in: ter Braak C.J.F., 1987: Unimodal models to relate species to environment. - Wageningen, PhD thesis, Agricultural Mathematics Group, pp. 101-146.

TER BRAAK C.J.F., ŠMILAUER P. (2012): Canoco reference manual and user's guide: software for ordination version 5.0. Microcuomputer Power, Ithaca.

Toth D., Maitah M., Maitah K., Jarolínová V. (2020): The Impacts of Calamity Logging on the Development of Spruce Wood Prices in Czech Forestry. - Forests, 11(3): 283. DOI: 10.3390/f11030283

ULBRICHOVÁ I., KUPKA I., PODRÁZSKÝ V., KUBEČEK J., FULÍN M. (2014): Douglaska jako meliorační a zpevňující dřevina. - Zprávy lesnického výzkumu, 59: 72-78.

URBAN J., ČERMÁK J., NADEZHDINA N., KANTOR P. (2009): Growth and transpiration of the Norway spruce and Douglas fir at two contrasting sites. Water issues in dryland forestry. - Sede Boqer, Israel, Ben Gurion University, 47p.

URBAN J., ČERMÁK J., KANTOR P. (2011): Srovnání radiálního růstu a transpirace douglasky tisolisté a smrku ztepilého. In: Aktuality v pěstování méně častých dřevin v České republice. Sborník referátů konference v Kostelci nad Černými lesy 21.10.2011. - ČZU, Praha, pp. 77-81.

VACEK S., MATĚJKA K. (2010): State and development of phytocenoses on research plots in the Krkonoše Mts. Forest stands. - Journal of Forest Science, 56: 505-517. DOI: 10.17221/127/2010-JFS

VACEK S., HŮNOVÁ I., VACEK Z., HEJCMANOVÁ P., PODRÁZSKÝ V., KRÁL J., PUTALOVÁ T., MOSER W.K. (2015): Effects of air pollution and climatic factors on Norway spruce forests in the Orlické hory Mts. (Czech Republic), 1979–2014. - European Journal of Forest Research, 134: 1127-1142. DOI: 10.1007/s10342-015-0915-x

VACEK S., ČERNÝ T., VACEK Z., PODRÁZSKÝ V., MIKESKA M., KRÁLÍČEK I. (2017): Long-term changes in vegetation and site conditions in beech and spruce forests of lower mountain ranges of Central Europe. - Forest Ecology and Management, 398: 75-90. DOI: 10.1016/j.foreco.2017.05.001

VACEK S., PROKŮPKOVÁ A., VACEK Z., BULUŠEK D., ŠIMŮNEK V., KRÁLÍČEK I., PRAUSOVÁ R., HÁJEK V. (2019a): Growth response of mixed beech forests to climate change, various management and game pressure in Central Europe. - Journal of Forest Science 65: 331-345. DOI: 10.17221/82/2019-JFS

VACEK S., VACEK Z., ULBRICHOVÁ I., REMEŠ J., PODRÁZSKÝ V., VACH M., BULUŠEK D., KRÁL J., PUTALOVÁ T. (2019b): The effects of fertilization on the health status, nutrition and growth of Norway spruce forests with yellowing symptoms. - Scandinavian Journal of Forest Research, 34 (4), 267-281. DOI: 10.1080/02827581.2019.1589566

VACEK Z., VACEK S., SLANAŘ J., BÍLEK L., BULUŠEK D., ŠTEFANČÍK I., KRÁLÍČEK I., VANČURA K. (2019c): Adaption of Norway spruce and European beech forests under climate change: from resistance to close-to-nature silviculture. - Central European Forestry Journal, 65: 129-144. DOI: 10.2478/forj-2019-0013

VACEK Z., PROKŮPKOVÁ A., VACEK S., CUKOR J., BÍLEK L., GALLO J., BULUŠEK D. (2020a): Silviculture as a tool to support stability and diversity of forests under climate change: study from Krkonoše Mountains. - Central European Forestry Journal, 66: 116-129. DOI: 10.2478/forj-2020-0009

VACEK Z., VACEK S., PROKŮPKOVÁ A., BULUŠEK D., PODRÁZSKÝ V., HŮNOVÁ I., PUTALOVÁ T., KRÁL J. (2020b): 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. DOI: 10.12657/denbio.083.001

VACEK Z., CUKOR J., LINDA R., VACEK S., ŠIMŮNEK V., BRICHTA J., GALLO J., PROKŮPKOVÁ A. (2020c): Bark stripping, the crucial factor affecting stem rot development and timber production of Norway spruce forests in Central Europe. - Forest Ecology and Management, 474: 118360. DOI: 10.1016/j.foreco.2020.118360

VAŠÍČEK J. (2014): Douglaska tisolistá v číslech. In: Douglaska – dřevina roku 2014. Sborník z celostátní konference, Křtiny, Sept 2-3, 2014, pp. 15-19.

VEJPUTKOVÁ M., ČIHÁK T. (2019): Climate response of douglas fir reveals recently increased sensitivity to drought stress in Central Europe. - Forests, 10(2): 97. DOI: 10.3390/f10020097

VIEWEGH J. (2003): Klasifikace lesních rostlinných společenstev (se zaměřením na Typologický systém ÚHÚL). - Česká zemědělská univerzita v Praze, Praha, 208p. URL: https://www.infodatasys.cz/typolog/typolog-cz.htm

VIEWEGH J. (2005): Czech Forest (Site) Ecosystem Classification. - Czech University of Life Sciences Prague, 170 s. URL: https://www.infodatasys.cz/typolog/typolog-en.htm

VIEWEGH J., PODRÁZSKÝ V., MATĚJKA K. (2014): Charakterystyka roslinnosci runa ksztaltujacej sie pod drzewostanami daglezjovymi (*Pseudotsuga menziesii* (Mirbel) Franco) w lasach gospodarczych Republiki Czeskiej. - Sylwan, 158: 277-284. URL: https://www.infodatasys.cz/public/Sylwan_158_277.pdf

VITALI V., BÜNTGEN U., BAUHUS J. (2017): Silver fir and Douglas fir are more tolerant to extreme droughts than Norway spruce in south-western Germany. - Global Change Biology, 23: 5108-5119. DOI: 10.1111/gcb.13774

VITALI V., FORRESTER D.I., BAUHUS J. (2018): Know your neighbours: drought response of Norway Spruce, Silver Fir and Douglas Fir in mixed forests depends on species identity and diversity of tree neighbourhoods. - Ecosystems, 21: 1215-1229. DOI: 10.1007/s10021-017-0214-0

VITTORI ANTISARI L.V., FALSONE G., CARBONE S., MARINARI S. VIANELLO G. (2014): Douglas-fir reforestation in North Apennine (Italy): Performance on soil carbon sequestration, nutrients stock and microbial activity. - Applied Soil Ecology, 86: 82-90. DOI: 10.1016/j.apsoil.2014.09.009

VYHLÁŠKA Č. 456/2021 SB.: Vyhláška o podrobnostech přenosu reprodukčního materiálu lesních dřevin, o evidenci o původu reprodukčního materiálu a podrobnostech o obnově lesních porostů a o zalesňování pozemků prohlášených za pozemky určené k plnění funkcí lesa.

WAGENFÜHR R. (2004): Bildlexikon Holz. - Fachbuchverlag, Leipzig, 370p.

WIEMANN M.C. (2010): Characteristics and Availability of Commercially Important Woods. In: Wood handbook – Wood as an engineering material. - General Technical Report FPL-GTR-190. U. S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison (WI), pp.2.1-2.45.
URL: http://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf.

WÖRDEHOFF R., SPELLMANN H., EVERS J., NAGEL J. [Eds.] (2011): Kohlenstoffstudie Forst und Holz Niedersachsen, Vol. 6. - Universitätsverlag Göttingen, 104p.

WILCZYŃSKI S., FELIKSIK E. (2007): Local chronologies and regional diversity of dendrochronological signal od douglas fir in Poland. - Geochronometria, 26: 69-80.

YAMAGUCHI D.K. (1991): A simple method for cross-dating increment cores from living trees. - Canadian Journal Forest Research, 21: 414-416.

ZEIDLER A. (2013): Přínos perspektivních introdukovaných dřevin z hlediska vlastností dřeva. (Habilitační práce) - ČZU Praha, 187p.

ZELLER B., ANDRIANARISOA S., JUSSY J.H. (2010): Impact of Douglas-fir on the N cycle: Douglas fir promote nitrification? In: Spiecker H., Kohnle U., Makkonen-Spiecker K., Brill C. [Eds.], Opportunities and Risks for Douglas fir in a Changing Climate, Freiburg, Oct 18-20, 2010, p.85.

ZETTERBERG T., OLSSON B.A., LOFGREN S., HYVONEN R., BRANDTBERG P.-O. (2016): Long-term soil calcium depletion after conventional and whole-tree harvest. - Forest Ecology and Management, 369: 102-115. DOI: 10.1016/j.foreco.2016.03.027

ZLATNÍK A. (1978): Lesnická fytocenologie. - SZN, Praha, 495p.

9. Appendix

Appendix 1: Phytocoenological relevés table

TVP	14	15	23	22	21	20	24	19	17	18	16	9	25	13	12	7	6	5	8	3	2	1	11	10	4	Frequency (%)	Frequency class
TWINSPAN classification group	*000	*000	*0010	*00110	*00110	*00110	*00111	*01000	*01000	*01001	*01001	*0101	*0101	*011	*011	*1000	*1000	*1000	*1001	*101	*101	*101	*11	*11	*11		
altitude (m)	531	516	586	509	513	515	587	506	513	520	517	455	518	562	560	520	521	538	533	530	546	537	443	456	530		
exposure	Z	Z	SZ	JV	JV	JV	SZ	Z	Z	Z	Z	J	J	Z	Z	S	S	V	JZ	V	SV	SV	J	V	V		
slope (°)	5	5	15	5	2	1	7	5	10	10	10	3	5	2	1	10	10	2	1	2	2	2	1	1	2		
soil type	Km mod	KM mod	KM mod	KM luv	KM luv	KM luv	KM mod	KM mod	KM mod	KM mod	KM mod	LM mod	KM luv	LM mod	LM mod	KM luv	KM luv	KM luv	KM luv	KM	KM	KM	LM mod	LM mod	KM luv		
coverage E3 (%)	60	55	80	60	75	80	75	55	50	85	50	80	60	45	40	70	60	70	60	65	50	70	70	75	70		
coverage E2 (%)	0	20	0	35	0	0	5	5	1	0	1	0	3	1	5	0	10	0	1	0	0	20	20	5	0		
coverage E1 (%)	50	80	15	40	10	15	15	80	8	5	40	15	55	40	80	35	40	10	45	20	75	40	55	40	20		
coverage E0 (%)	20	20	3	5	8	5	15	5	8	1	5	5	0	15	30	15	5	5	60	5	3	3	10	10	8		
species richness (S)	19	27	19	15	11	19	9	22	18	14	16	28	26	21	27	13	15	17	16	15	9	16	21	21	21		
species diversity (H)	1,34	1,75	1,93	2,02	2,26	1,88	2,05	2,47	1,79	1,32	2,34	1,92	2,66	2,92	2,75	1,85	2,24	2,44	1,66	2,37	1,10	2,07	2,99	3,00	2,76		
equitability (e)	0,316	0,369	0,455	0,516	0,654	0,441	0,648	0,555	0,428	0,347	0,584	0,399	0,565	0,664	0,577	0,500	0,572	0,597	0,415	0,607	0,347	0,516	0,681	0,682	0,628		
DCA1	-0,736	-0,624	-0,626	-0,485	-0,394	-0,345	-0,734	-0,564	-0,726	-0,262	-0,465	-0,238	-0,379	-0,399	-0,533	-0,097	0,039	-0,194	0,203	1,524	2,569	0,930	-0,009	-0,082	1,441		
DCA2	0,568	0,734	0,728	-1,002	-0,945	-0,850	0,221	-0,180	0,444	-0,691	0,039	-0,823	-0,597	-0,911	-0,562	-0,882	-0,535	-0,171	-0,038	-0,184	0,039	-0,332	1,145	2,768	-0,112		
P. menziesii composition (%)	45	38	74	30	58	71	8	17	11	77	28	45	58	45	40	69	60	0	16	20	0	65	50	52	69		
P. abies composition(%)	2	2	3	0	17	9	58	38	25	0	22	35	3	0	0	1	0	70	44	45	3	2	18	0	1		
E3:																											
Pseudotsuga menziesii	+4	+4	+4	-3	+4	-5	-2	+2	+2	+5	-4	-4	+4	+4	-4	+4	-4		+2	+2	1	-5	-4	+4	+4	96	V
Picea abies	1	1	1		+2	-2	+4	+3	+3		+3	+3	1			+		+4	-4	+3	-4	1	+2		+	76	IV
Abies alba	+2						-2		+2																	12	I
Pinus sylvestris		-2/+2		+2																						8	I
Fagus sylvatica			1	-2	+				1	-2																20	I
Quercus petraea agg.												+											1	-3		12	I
Larix decidua																					+	1				8	I
E2:																											
Fagus sylvatica		+2		+4				1					1										r	1		24	II
Sambucus racemosa		+												+	1								+2			16	I
Pseudotsuga menziesii		+2															1		1							12	I
Picea abies							-2		1																	8	I
Populus tremula														+												4	I
Rubus fruticosus agg.														1												4	I
Sorbus aucuparia																					r					4	I
Sambucus nigra																						+2				4	I
Tilia cordata																								-2		4	I
E1:																											
Pseudotsuga menziesii	+	1/-2	+	-2	-2	+4	1/+	+3	+	-2/+5	+/+3	1	+/-2	-2/-3	-3/1	+2/+3	+3	-2	+3	-2	1	+/+3	1	1	+	100	V
Fagus sylvatica	1/+	+	1	+3	+2	+3	1	-5	-2	+2	-2	+	+4	1	+	+	r	r		r			+		r	84	V
Oxalis acetosella	+	-2	1	1	1	+	1	+3	1	+	1		1	+	-2			r	r				r	1		72	IV
Vaccinium myrtillus	+	+	+	+	1	+2	+									1			+					+	r	44	III
Dryopteris carthusiana	r	r	+	+	+	r		r					r		r	r					r					44	III
Mycelis muralis	r	r	+		r	r		r	r	r	1	+						1	+	+		1	1	1	r	68	IV
Calamagrostis arundinacea	-4	+5	-3			1	+2	+4	+3	-2	+3	+		1	+2								+2	r	r	60	III
Luzula luzuloides	r	r		+2	+2	1		1	+	+	+	4	1/-2	-2	1	+2	-2	-2	-2	1		1		1	1	84	V
Abies alba	+	r					r		+	r																20	I
Impatiens parviflora	+	r						r		+	r	r	-3	1	+		r	+	r	1	r	+	+	1	+	72	IV
Quercus rubra	r	r																					r			12	I
Milium effusum	r		1	r										+	1								+	+		28	II
Carex digitata	+		r						r	r		r			+					r						28	II
Acer pseudoplatanus	r		r																							8	I
Dryopteris filix-mas	r			r									r					r			1	1	1	r	+	36	II
Avenella flexuosa	-2				1		+	+	+		+	r		+2	1			r			r	+			+	52	III
Sorbus aucuparia	+					r						+	r		+	-2	-2	+	+	+		+	r	r	r	56	III
Melampyrum pratense	r										r	- +		+2	+3			r								24	II
Hieracium murorum	r											r				r	r	r	r					r		28	II
Viola reichenbachiana		+4	-3	r				-2	1	r	-2	r	-2	+	1		+	1/-2		1	+	1	+	1	1	76	IV
Rubus fruticosus agg.		r	r	r				r				r	+	+	r		r		1	-2/+2	-5	-3	1	+	-2	64	IV
Galium rotundifolium		+	r		r	r		-2	r		1	-2	-2	r	+									1		48	III
Galeopsis pubescens		r	r			r					r		r												r	24	II
Quercus petraea agg.		r		r	r	r						+	+		r								1	+2		36	II
Picea abies		r		1		+	-2	+	r		r	r	+			r	r									44	III
Quercus robur		r						r	r	r		+				1	+	1	1	+		r			+	48	III
Senecio ovatus		r						r	r				r										r			20	I
Fragaria vesca		+						r				+		r									+	+	r	28	II
Pinus sylvestris		r						r						r												12	I
Rosa dumalis		r						r																		8	I
Veronica officinalis		+										r	+	r	r		r								r	28	II
Sambucus racemosa		r											r													8	I
Convallaria majalis		+																								4	I
Stellaria nemorum		r																								4	I
Urtica dioica		r																								4	I
Carex pilulifera			r		r	r	r	r				+		1/-2	+	r		r	+							44	III
Rubus idaeus			r			r		1			r		1	+	r		r	r	r	1	-2	r	+	r		60	III
Maianthemum bifolium			r			+										r										12	I
Moehringia trinervia			r						1	r	+	1	+													24	II
Actaea spicata			r																							4	I
Carex brizoides				1		+																				8	I
Frangula alnus				r		r																				8	I
Geranium robertianum				r								1	+										+			16	I
Deschampsia caespitosa						+																				4	I
Luzula pilosa								r	+	1	1			1	1											24	II
Ajuga reptans								r																		4	I
Epipactis helleborine									r				r		r											12	I
Hieracium laevigatum									r																	4	I
Poa nemoralis										r			+		+	r	+2		r	r		r				32	II
Calamagrostis epigeios												+	1			1	-3		-5	1	1	1	-2	-2	+	44	III
Betula pendula												r		r	+											12	I
Agrostis capillaris												r							r							8	I
Tilia cordata												+											1	+2		12	I
Cardamine impatiens												r														4	I
Polygonatum multiflorum												r														4	I
Scrophularia nodosa													r	r	r											12	I
Hypericum perforatum													r							r				r	r	16	I
Atropa bella-donna													+													4	I
Epilobium angustifolium														1												4	I
Juncus effusus															+		+									8	I
Festuca gigantea															r											4	I
Melica nutans															+											4	I
Populus tremula																		r	r						1	12	I
Corylus avellana																		r								4	I
Ligustrum vulgare																				r						4	I
Acer campestre																						r				4	I
Athyrium filix-femina																						r				4	I
Senecio sylvaticus																						+				4	I
Hepatica nobilis																							r			4	I
Stellaria holostea																							+			4	I
Carpinus betulus																								r		4	I
Fraxinus excelsior																									r	4	I
Ribes sp.div.																									r	4	I
E0:																											
Pleurozium schreberi	-3	+2	+	+	1		+	1	r	r	r	1		-2	-2	-2	r	+	+4	+	r		-2	-2	r	88	V
Polytrichum formosum	-2			-2	-2	+2		r				+		-3	-3		+		-3					+		44	III
Thuidium abietinum	1-2	1		+	-2	+		+	+		+					+3										36	II
Plagiomnium affine			+			+	+3		+		+															20	I
Atrichum undulatum													+							+						8	I
Dicranum scoparium																			1							4	I

Appendix 2: Classification table made by TWINSPAN

```
Cut levels:  0,00  1,00  10,00 31,62 56,13
species                  shortcut   TVP number                the classification
                                                              group of the species

                                   11222221111 211        11
                                   4530124796895235678123401
Ajuga reptans             Ajurep   --------1----------------  000001
Atropa bella-donna        Atrbel   ------------1------------  000001
Cardamine impatiens       Carimp   -----------1-------------  000001
Moehringia trinervia      Moetri   --1----1-1111------------  000000
Hieracium laevigatum      Hielae   -------1-----------------  000001
Polygonatum multiflorum   Polmul   -----------1-------------  000001
Betula pendula            Betpen   -----------1-11----------  000010
Epilobium angustifolium   Epiang   --------------2----------  000010
Epipactis helleborine     Epihel   -------1----11-----------  000010
Festuca gigantea          Fesgig   -------------1-----------  000010
Luzula pilosa             Luzpil   -------1111--22----------  000010
Melica nutans             Melnut   -------------1-----------  000010
Scrophularia nodosa       Scrnod   ------------111----------  000010
Pinus sylvestris          Pinsyl   -1------1-----1----------  000011
Abies alba                Abialb   11----11--1--------------  00010
Rosa dumalis              Rosdum   -1------1----------------  00010
Sambucus racemosa         Samrac   -1----------1------------  00010
Acer pseudoplatanus       Acepse   1-1----------------------  000110
Convallaria majalis       Conmaj   -1-----------------------  000110
Stellaria nemorum         Stenem   -1-----------------------  000110
Urtica dioica             Urtdio   -1-----------------------  000110
Actaea spicata            Actspi   --1----------------------  000111
Carex brizoides           Carbri   ---1-2-------------------  000111
Deschampsia caespitosa    Descae   ---1---------------------  000111
Frangula alnus            Fraaln   ---1-1-------------------  000111
Carex digitata            Cardig   1-1----1--11-1--------1---  00100
Senecio ovatus            Senova   -1-----11---1-----------1  00100
Galium rotundifolium      Galrot   -1111--121-2211--------2-  00101
Melampyrum pratense       Melpra   1--------1-1-321---------  00101
Fagus sylvatica           Fagsyl   211223223211312111---11-1  001100
Oxalis acetosella         Oxaace   12111221311-2211--1----21  001100
Picea abies               Picabi   -1-1-22111-11---11-------  001100
Dryopteris carthusiana    Drycar   111111--1---11---1--1----  001101
Calamagrostis arundinacea Calaru   4421--223311-32-------113  00111
Galeopsis pubescens       Galpub   -111-----1--1---------1--  00111
Geranium robertianum      Gerrob   -----1-----11-----------1  0100
Veronica officinalis      Veroff   -1---------1111-1-----1--  0100
Avenella flexuosa         Avefle   2---1-1111-1-221---11-1--  01010
Carex pilulifera          Carpil   --111-1-1--1-121-11------  01010
Milium effusum            Mileff   1-1--1-------21--------11  01010
Fragaria vesca            Fraves   -1------1--1--1-------111  01011
Pseudotsuga menziesii     Psemen   1212222133212332333322122  01011
Quercus petraea agg.      Quepet   -1-111-----111---------32  0110
Vaccinium myrtillus       Vacmyr   1112111----------21---11-  0110
Maianthemum bifolium      Maibif   --11-------------1-------  0111
Quercus rubra             Querub   11----------------------1  0111
Impatiens parviflora      Imppar   11------111131211-1112121  100
Mycelis muralis           Mycmur   11111--11111---1--12-1122  100
Viola reichenbachiana     Viorei   -32--1-1221122121--212221  100
```

Luzula luzuloides	Luzluz	11-122-1111322222222-222-	1010
Rubus idaeus	Rubida	--11----11--21111-1122-11	1010
Agrostis capillaris	Agrcap	-----------1------1------	1011
Juncus effusus	Juneff	-------------1--1--------	1011
Poa nemoralis	Poanem	----------1-11--2111-1---	1100
Quercus robur	Querob	-1-----11-11---11211-11--	1100
Hieracium murorum	Hiemur	1----------1---1111----1-	11010
Sorbus aucuparia	Sorauc	1--1-------111-12211-1111	11010
Dryopteris filix-mas	Dryfil	1----1------1--1---22-112	11011
Hypericum perforatum	Hypper	------------1--------111-	11011
Rubus fruticosus agg.	Rubfru	-11--1--1--1111-1-1353212	11011
Calamagrostis epigejos	Calepi	-----------12---323222123	11100
Populus tremula	Poptre	---------------1--1---2--	11100
Acer campestre	Acecam	-------------------1-----	11101
Athyrium filix-femina	Athfil	-------------------1-----	11101
Corylus avellana	Corave	---------------1---------	11101
Ligustrum vulgare	Ligvul	---------------------1---	11101
Senecio sylvaticus	Sensyl	-------------------1-----	11101
Tilia cordata	Tilcor	-----------1-----------32	11110
Carpinus betulus	Carbet	-----------------------1-	11111
Fraxinus excelsior	Fraexc	----------------------1--	11111
Hepatica nobilis	Hepnob	------------------------1	11111
Ribes spec. div.	Ribsp.	----------------------1--	11111
Stellaria holostea	Stehol	------------------------1	11111
		0000000000000001111111111	
		0000000111111110000000111	
		0011111000000110000111	
		01111000011 0001	
		00010011	
		The classification group of the plot	