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ORIGINAL PAPER

Salvage felling in the Slovak Republic's forests during the last twenty years (1998–2017)

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Abstract

Global climate change also influences the forest damaging agents occurrence and thus a forest health. Forest trees that are damaged by agents are in managed forests processed by salvage felling. The amount of an annual salvage felling represents the occurrence of a damaging agents occurrence in a certain year. In 2015, the area of forests in Slovakia reached 2.014 mil. ha. Within the 20 years (from 1998 to 2017), the total felling reached 162.52 mil. m^3, out of this 47.99 % were ascribed to a salvage felling. Abiotic agents were the most damaging agents (42.28 mil. m^3 of damaged wood), out of it a wind was the most important one. Biotic damaging agents were the second important group (32.165 mil. m^3), whereas bark beetles on spruce were the most important. The third group and the less damaging one was anthropogenic agents group (3.555 mil. m^3) with an air pollution as the most important damaging agent. There was no statistically significant difference in the volume of processed trees within salvage felling caused by abiotic and biotic damaging agents. However, these two groups caused significantly higher damages than the third group of anthropogenic damaging agents. There were two major wind damages, Alžbeta in 2004 and Žofia in 2014 with damaged wood 5.3 mil. m^3 and 5.2 mil. m^3, respectively. They occurred in southern, central and northern part of Slovakia. As damaged wood was not processed from strict nature conservation areas, the secondary damaging agents, mostly *Ips typographus* on Norway spruce reproduced as much that after some years it cumulatively reached or even exceeded damages from those two major windthrows episodes.

Key words: *Picea abies* L. (Karst.); *Pinus sylvestris* L.; damaging agents; windstorms; bark beetles

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1. Introduction

The forests in Slovakia cover about 2 mil. ha and that is over 40% of the total Slovak area. The European beech (*Fagus sylvatica* L.) is the most common forest tree species with its 33.2% coverage. Next forest tree species are Norway spruce (*Picea abies* L. (Karst.)), oaks (*Quercus* spp.), pines (*Pinus* spp.) and silver fir (*Abies alba* Mill.) with their coverage 23.4%, 10.6%, 6.8% and 4.1%, respectively (Anonymous 2016).

During the last several decades, forests in Central Europe have been influenced by many impacts such as an industrialization, an air pollution (Crippa et al. 2015) and recently also by intensive climate changes (Hlásny et al. 2014). At the end of 80s of 20th century the political system in Slovakia as well as in neighboring countries, has changed and a management of not state forests, that were from the end of 40s to the end of 80s of 20th century managed by state, have returned back the management of proper owners (Anonymous 2016). At the beginning of new millennium, there has been a strong pressure to increase the number of new nature conservation areas and limited forest management was stated in valuable ones. All these factors have regularly shaped the forest management with regard to minimize expenses (Anonymous 2016).

As forest ecosystems belong to the most natural ecosystems at least in Central Europe, they can show up more natural signs of this climatic change trends than

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**Corresponding author. Andrej Kunca, e-mail: kunca@nlcsk.org* other ecosystems (Zúbrik & Kunca 2006; Santini et al. 2013). Due to a climate change as well as other disturbing factors the coverage of major tree species changed e.g. Norway spruce decreased from 26.3% in 2005 to 23.4% in 2015 and on the other hand a European beech coverage increased from 31.0 to 33.2%. Changes in other forest tree species were far less dramatic within that short period (Anonymous 2016).

These are just several predisposing factors that may be taken into consideration in connection with large-scale forest damage events in Slovakia as well as in many other European countries. The paper sums up the forest disturbance events which have occurred in Slovakia within the last 20 years (1998–2017).

2. Methods

The systematic records of forest damaging agents in Slovakia started in 1960 at the Forest Research Institute in Zvolen. At that time, an annual statistical form named L116 was created and it was in practice with just little adjustments up to 2011, when a new law on forest records has come into force (Kunca et al. 2014b). Statistical report L116 gradually upgraded some agents until 2011, when it turned into the law (Law No. 297/2011 Z. z. on forestry management records). So, finally, there were 56 damaging agents or damages in L116 report separated into three major groups:

A) abiotic – 7 agents: a wind, a snow, a rime, a drought, a frost, a flooding, unknown abiotic agents,

B) biotic – 44 agents: *Ips typographus* L., *Pityogenes chalcographus* L., *Scolytus intricatus* Ratz., *Tomicus minor* Htg., *Tomicus piniperda* L., *Ips sexdentatus* Born., *Ips acuminatus* Gyll., *Pityokteines curvidens* Germ., *Ips cembrae* Heer., *Xyloterus lineatus* Ol., other bark beetles, *Lymantria dispar* L., *Tortrix viridana* L., *Operphtera brumata L.*, *Erannis defoliaria* Cl., *Bupalus piniaria* L., *Calliteara pudibunda* L., *Melolontha sp.*, *Cephalcia abietis* L., *Pristiphora abietis* Christ., *Lymantria monacha* L., *Diprion pini* L., *Neodiprion sertifer* Geoffr., *Choristoneura murinnana* Hübner, *Dreyfusia nordmannianae* Eckst., *Rhyacionia buoliana* (Denis & Schiffermuller), *Dendrolimus pini* L., *Sachiphantes viridis* Ratz., *Adelges laricis* Vall., *Coleophora laricella* Hübner, *Leucoma salicis* L., *Armillaria* sp., *Heterobasidion annosum* Fr. (Bref.), rots, *Ophiostoma* sp., *Lophodermium pinastri* (Schrad.) Chevall., other needlecasts, cankers, rusts, mildews, unknown fungal diseases, games, rodents, weeds,

C) anthropogenic agents – 5 agents: an air pollution, a fire, a wood stealing, a grazing, an unknown anthropogenic agents.

Both, a statistical form L116 as well as the following statistical report set in law from 2011 were based on the volume of the total felling and the salvage felling which is considered as one of the main pointer of the forest health. A relative salvage felling, that is calculated as the volume of the salvage felling divided by the total felling and multiplied by 100 (to express it as a percentage), served as a mean to compare the annual salvage felling. The salvage felling had to be justified by damaging agents.

Foresters were obliged to fill up the annual statistical form L116 at the end of the year and pass it to the National Forest Centre - Forest Research Institute in Zvolen by 60 days after the end of the year. While some agents can be quite easily determined e.g. wind damages, others have to be proven by laboratory analyses e.g. air pollution.

Researchers summarized obtained data by the damaging agents, regions and tree species and results were published in the annual report on the occurrence of damaging agents in the last year with a short term prognosis for the next 5 years. The data come from the forest area that was 2.014 mil. ha in 2015 (Anonymous 2016). The report is distributed to all state district administrations, larger non-state subjects and major libraries. Altogether 300 publications have been distributed annually within the last 20 years.

The new law on forestry records has become effective in 2011, and salvage felling realized in 2012 was already evaluated by the new method. The major change of the damaging agent's records was that information came up from all forestry subjects, salvage felling was measured in less details and data were collected first by state district administrations and then centralized at the National Forest Centre in Zvolen. There were 48 agents, out of it there were 5 in the group of abiotic agents, 37 in the group of biotic agents and 6 in the group of anthropogenic agents.

In the results we merged damages caused by *Ips typographus* and *Pityogenes chalcographus* into a group Bark Beetles on Spruce and *Tomicus* spp. and *Ips sexdentatus* a *Ips acuminatus* as Bark beetles on Pines.

Data in the analyses were processed with just simple statistical methods of Microsoft Excel and STATISTICA program. The influence of parameters were set by ANOVA procedures, a statistical significance of variables was stated by Tuckey test.

The second source of information on the occurrence of damaging agents and disturbance events was a consultancy service for foresters provided by the National Forest Centre - Forest Research Institute Zvolen, settled at the Department of Forest Protection and Game Management. The service has been working since 1957 under different names, since 1994 it has been called the Forest Protection Service (Kunca et al. 2014b). Specialists on biotic, abiotic and anthropogenic agents have been involved in national and international research projects and the knowledge and experiences obtained in the research have been passed to foresters. If a major disturbance damaged the larger forest area, foresters have been obliged to send that information to both the state administration and to the Forest Protection Service specialists. Foresters have to report the damaged volume, the area and the main damaged trees species. That is the main source of data about the sudden natural disturbances (Kunca et al. 2014b).

3. Results

3.1. Salvage felling

According to the Green report (Anonymous 2016), the current overall wood resources are estimated to be approximately 487.12 mil. m^3, with the overall spruce resources 111.88 mil. m^3. The total felling in Slovak forests reached 162.52 mil. m^3 (Table 1) and that is 33.99% of the total resources. In ratio to the average total felling, its annual volume fluctuated between 68.09–125.40%. Salvage felling reached 78.00 mil. m^3 (Table 1), which is 47.99% of the total felling in 1998–2017. In this period, the annual salvage felling fluctuated in the range of 54.01–160.86% of the average salvage felling. There were 9 years when annual salvage felling exceeded average salvage felling (Fig. 1).

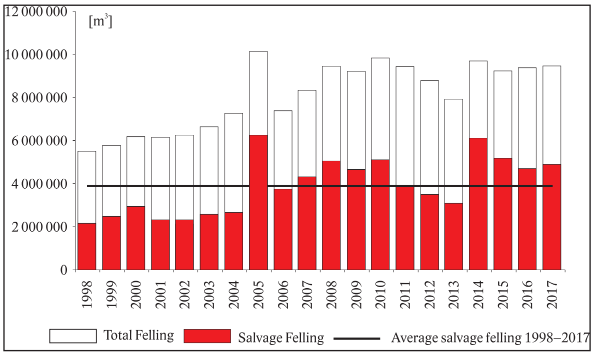

Fig. 1. Development of both total and salvage felling in the Slovak Republic over the period 1998–2017.

On November 19, 2004 windthrow Alžbeta damaged 5.3 mil m^3. That was the estimation done by the organization responsible for monitoring forest resources and inventorying them (Lesoprojekt). Most of the damaged wood was processed in 2005, much less amount in 2006. Anyway, the damaged wood in strictly conservation areas could not be processed and under its bark the beetles easily several times reproduced. From 2007 the bark beetles from conservation areas started to infest standing trees and by 2010 sanitary felling was caused mostly by bark beetles in Norway spruce stands. The wet and cold weather in 2010 slowed down development of bark beetles and the amount of bark beetles damages went down. On May 15, 2014 windthrow Žofia damaged 5.2 mil. m^3. As it occurred in May, most of the damaged wood was processed by the end of 2014, the rest was processed by 2016. As it was after windthrow Alžbeta, the damaged wood in strictly conservation areas could not be processed and the bark beetles from unprocessed wood spread into standing healthy forests and in 2017 started to infest them.

3.2. Damaging agents

The salvage felling was caused by three major groups of damaging agents. Abiotic and biotic damaging agents largely dominated over anthropogenic damaging agents with proportion of 52.6%, 43.0% and 4.4%, respectively. The biggest variation was performed within the abiotic damaging agents, the lowest with the anthropogenic damaging agents (Table 2). While the amount of processed wood damaged by anthropogenic damaging agents was gradually decreasing, the one damaged by abiotic damaging agents had 2 culmination peaks (in 2005 and 2014) and the one damaged by biotic agents culminated in 2009 and in 2017 was still rising up (Fig. 2).

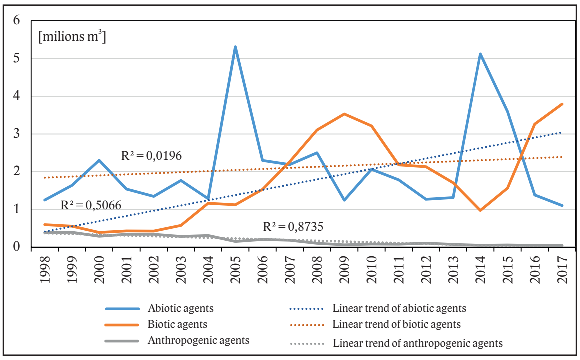

Fig. 2. Development of volume of processed wood from salvage felling caused by the three major groups of damaging agents.

There were statistically significant differences between averages of damaged wood caused by abiotic, biotic, and

Table 1. Volume of total felling and salvage felling in the Slovak Republic within the period 1998–2017.

Felling	Sum	Annual average	Standard deviation	Minimum	Maximum
			[mil. m^3]		
Total felling	162.52	8.13	1.57	5.53	10.19
Salvage felling	78.00	3.90	1.32	2.11	6.27
Relative salvage felling [%]	47.99	—	—	—	—

Table 2. Wood volume affected by major groups of damaging agents in the Slovak Republic forests within the period 1998–2017.

Major groups of damaging agents	Sum	Average	Standard deviation	Minimum	Maximum
			[mil. m^3]		
Abiotic Pest Agents	42.280	1.703 a	1.218	1.102	5.311
Biotic Pest Agents	32.165	1.547 a	1.150	0.390	3.793
Anthropogenic Pest Agents	3.555	0.128 b	0.127	0.045	0.391
Total	78.000	—	—	—	—

anthropogenic damaging agents ($p<0.01$). By post-host tests, damages by anthropogenic damaging agents were significantly lower than damages by biotic or abiotic damaging agents ($p<0.01$). However, there was no statistical difference between damages caused by abiotic and biotic damaging agents ($p>0.05$).

Wind caused significantly higher damages than the rest of abiotic damaging agents ($p<0.01$). Differences between other groups of abiotic damaging agents were not significant ($p>0.05$) (Table 3).

As for biotic damaging agents, damages of bark beetles on spruce were significantly higher than damages caused by other biotic damaging agents ($p<0.01$). Differences between other groups of biotic damaging agents were not significant ($p>0.05$) (Table 4).

Air pollution caused significantly higher damages than other anthropogenic damaging agents ($p<0.01$). Differences between other anthropogenic damaging agents were not significant ($p>0.05$) (Table 5).

Within the 20-year long period, a wind was the most serious damaging factor (Table 3). The most serious windthrow occurred on November 19, 2004, and it got the name Alžbeta. By the professional estimation of the Lesoprojekt, state governmental organization, it damaged 5.3 mil. m^3 of wood, mostly in Norway spruce forests of central and northern Slovakia (Kunca & Zúbrik 2006). The second similarly damaging windthrow occurred on May 15, 2014. By the professional estimation of the National Forest Centre - Institute for Forest Resources and Information in Zvolen, it damaged 5.2 mil. m^3 of Norway spruce forests of Central and southern Slovakia (Fig. 4). It got the name Žofia (Kunca et al. 2016). That amount of damaged wood covered not only managed forests, but also forests in conservated areas. At the state level that was not separated into these two categories (managed forests, conservation forests). Far less damaging windthrow occurred on June 22–23, 1999 in European beech forests of western Slovakia and on August 23, 2007 in Norway spruce forests of central Slovakia. Each of them damaged 1 mil. m^3. These 4 windthrows represented for 33% of all windthrows during that time.

Bark beetles outbreak were represented by *Ips typographus*. The outbreak started in 2006 2 years after windthrow Alžbeta in the same regions as windthrows occurred (Fig. 5). It was caused because of strict forests nature conservation the damaged wood was not processed. In that wood bark beetles cumulated and suddenly spread into the surrounding forests.

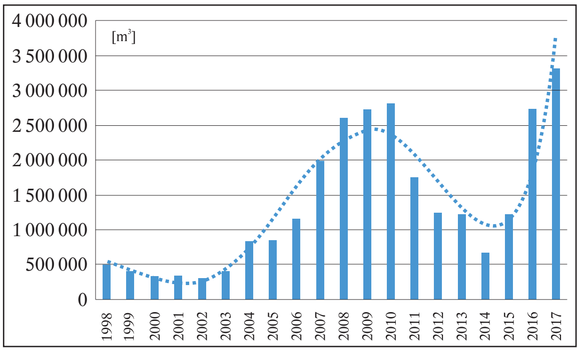

Fig. 3. Recorded volume of spruce wood infested by bark beetles in the Slovak Republic within the period 1998–2017.

By 2014 the situation with bark beetles has gradually stabilized, the salvage felling caused by bark beetles on

Table 3. Processed volume of wood from salvage felling due to selected abiotic damaging agents in the Slovak Republic forests within the period 1998–2017.

Major group of abiotic damaging agents	Sum	Average	Standard deviation	Minimum	Maximum
			[mil. m^3]		
Wind	37.558	1.540 a	1.251	0.934	0.5177
Snow	1.488	0.041 b	0.099	0.014	0.460
Icing + Glaze	0.638	0.004 b	0.106	0	0.467
Drought	2.070	0.102 b	0.030	0.045	0.169
Other abiotic damaging agents	0.510	0.016 b	0.023	0.007	0.115

Comment: Values in a column indicated by the same letter do not differ significantly.

Table 4. Processed volume of wood from salvage felling due to selected biotic damaging agents in the Slovak Republic forests within the period 1998–2017.

Major group of damaging agents	Sum	Average	Standard deviation	Minimum	Maximum
			[mil. m^3]		
Spruce wood infested by bark beetles	27.588	1.187 a	0.990	0.321	3.319
Pine wood infested by bark beetles	0.424	0.004 b	0.031	0.001	0.089
Armillaria spp.	2.873	0.128 b	0.094	0.010	0.295

Comment: Values in a column indicated by the same letter do not differ significantly.

Table 5. Processed volume of wood from salvage felling due to selected anthropogenic damaging agents in the Slovak Republic forests within the period 1998–2017.

Major group of damaging agents	Sum	Average	Standard deviation	Minimum	Maximum
			[mil. m^3]		
Air pollution	3 133 873	156 694 a	122 961	24 969	359 540
Fire	109 712	5 486 b	5 576	834	20 736
Wood stealing	239 075	11 954 b	5 656	5 127	29 527
Other agents	71 996	3 600 b	3 000	0	18 584

Comment: Values in a column indicated by the same letter do not differ significantly.

Norway spruce decreased to 0.7 mil. m^3. The windthrow Žofia in 2014 triggered the same process of bark beetles outbreak as occurred after 2004, and in 2017 the salvage felling caused by bark beetles on Norway spruce increased to 3.2 mil. m^3 (Fig. 3).

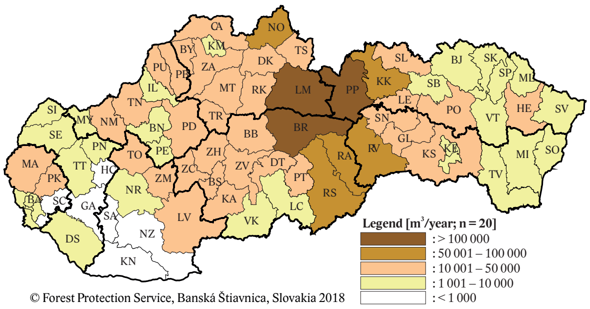

Fig. 4. Distribution of wood volume processed in the salvage felling caused by wind (average from years 1998–2017).

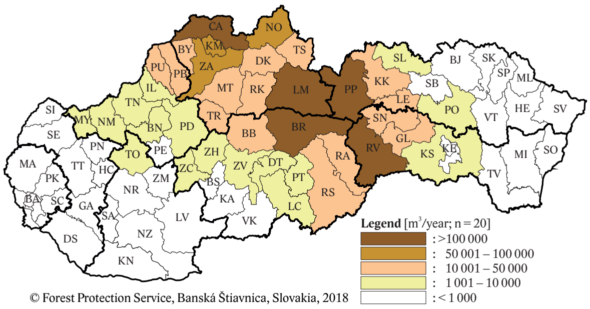

Fig. 5. Distribution of wood volume processed in the salvage felling caused by *Ips typographus* and *Pityogenes chalcographus* on spruce (average from years 1998–2017).

4. Discussion

The salvage felling belongs to tools for evaluating the forest health in some countries (Kolk et al. 2013; Kunca 2014; Knížek et al. 2015; Kärhä et al. 2018; Zahradník & Zahradníková 2019). That felling is also known as a sanitary or a sanitation logging and is initiated by disturbances that could be separated into three main groups of abiotic, biotic and anthropogenic agents. Obviously, there are many agents within these groups. Some state administrations select the agents that are obligatorily monitored and their damages have to be annually reported from certain territory. Based on variable natural conditions in Europe, there are alike established variable divisions of Europe regions (Schelhaas et al. 2003; Spiecker 2003; Zúbrik et al. 2013). As that set of agents is not harmonized in European Union by some international authority, it usually differs from state to state or from region to region. While a fire belongs to the most important agents in the Mediterranean countries, windstorms play the most important role as primary agents in the Atlantic and Continental temperate zone of Europe (Spiecker 2003). Out of this, single monitored agents varies not only by territory but also in time. In Slovakia a number of monitored agents within 20 years changed from 56 in 1998 to 48 in 2012 (Kunca 2005; 2014). In spite of differences in number and set of monitored agents, a salvage felling must be caused by some of the abiotic, biotic or anthropogenic agents and these three major groups are harmonized at least in the European Union (Schelhaas et al. 2003; Spiecker 2003).

A relative salvage felling is an important parameter that is calculated in order to be able to compare salvage fellings in different regions. The salvage felling in Slovakia from 1998 to 2017 was caused by both, major and minor disturbances. The proportion of annual salvage felling on the total felling during 1998–2017 was as much as 47.99% (min. 33.7% max. 63.2%), and that is 5.9 times more than European long term annual average of disturbances, that Schelhaas et al. (2003) calculated at the level of 8.1 % over the years 1950-2000. It should be taken into account that Schelhaas et al. (2003) measured just major disturbances, and neglected smaller damages. A salvage felling in neighboring mountainous countries was also quite variable and high. Knížek et al. (2015) states that salvage felling in the Czech Republic within those 10 years period varied between 20% (in 2012) and 75% (in 2007) with its average at 41%. In Slovakia the salvage felling within 10 years period (2004–2013) was 53.2% (Kunca et al. 2015) and it was higher level than during 20 years period (47.99%). It is clear that longer period compensate short term fluctuation of any variable.

In spite of the high relative salvage felling or the proportion of major disturbances on total felling in Slovakia, major European disturbances did not reach Slovakia. The windstorm Vivian in 1990 damaged 120 mil. m^3 in western Europe (König et al. 1995). At the end of 1999 there were three windstorms (namely Anatol, Lothar and Martin) that damaged 180 mil. m^3 of wood in forests of different European regions (Sacre 2002). There was one of the biggest windstorms in Europe that occurred on January 8, 2005 in southern Sweden and Denmark and on January 9, 2005 in Estonia. It is known as Gudrun and only in southern Sweden it damaged 75 mil. m^3 of wood (Schlyter et al. 2006; Langström et al. 2009). Recently, in 2017, there were two larger windstorms in western and central Europe. On August 11, 2017 the windstorm damaged more than 10 mil. m^3 of wood in western Poland (Trebski 2017). On October 29, 2017 windstorm Herwart damaged wood in Germany as well as in the Czech republic where it is estimated that 2.5 mil. m^3 were damaged (Lubojacký & Knížek 2017).

None of them reached Slovakia except for windstorm Kyrill in 2007, but it is considered just as a minor windstorm disturbance in Slovakia with its only 0.4 mil. m^3 of damaged wood. However, in Western Europe it damaged 55 mil. m^3, predominantly in Germany and the Czech Republic (Kunca et al. 2014a). The directions of low pressure paths and storm damages in European region are demonstrated on maps by Gardiner et al. (2008;

2011), at the regional level in Slovakia wind directions are described by Konôpka et al. (2008).

Short term analysis of damaging agents in Slovakia (1998–2017) points out that group of abiotic damaging agents were the most important factors influencing salvage felling (Table 2). From the specific damaging agent's point of view, the wind was the factor that damaged the biggest amount of wood (Table 5). The wind speed on November 19, 2004 (during windthrow Alžbeta) reached 140 km/h, in the gusts even 230 km/h. The wind speed on May 15, 2014 (during windthrow Žofia) went only 77 km/h, in gust 165 km/h, but damages were nearly the same as during windthrow Alžbeta. It happened because there were 2 weeks continuous rain and the soil was completely wet while in 2004 the soil was at least partially frozen.

The wind similarly participated on the salvage felling in the highest proportion in many Central European countries, as well as in other parts of Europe for the last several decades (Spiecker 2003; Schelhaas et al. 2003; Zach et al. 2008; Grodzki 2010; Kolk et al. 2013; Knížek et al. 2015). Schelhaas et al. (2003) stated that windstorms represent 53% of disturbances in Europe, while in Slovakia within 1998–2017 it was just 48.15%, so close to the European average.

Bark beetles on spruce (*Ips typographus* and *Pityogenes chalcographus*) were the second most important damaging agent in Slovakia. The bark beetles on spruce damaged 35.37% of total amount of salvage felling. It is long well-known that European spruce bark beetle is the secondary damaging agent and is often followed by windthrow and last decades driven also by climate change (Pfeffer & Skuhravy 1995; Christiansen & Bakke 1988; Blennow & Olofsson 2008; Gardiner et al. 2008; Marini et al., 2013). Moreover, there are several examples that bark beetles on spruce following wind, fire, drought, snow or ice (Groot et al. 2018) was subsequently more dangerous pest than previous primary agents (Christiansen & Bakke 1988; Kunca et al. 2011; Nikolov et al. 2014;). Catastrophic bark beetle outbreak after windstorms have occurred in the Czech republic in the Šumava Mountains after windstorms of 1868 and 1870 (Pfeffer & Skuhravy 1995), in Sweden in 1969 (Nilsson et al. 2004) or recently in Sweden in 2005 or 2007 (Langström et al. 2009), in Lithuania (Zolubas & Dagilius 2009) or in Far East Russia (Soukhovolsky 2009; Tarasova 2009). Windstorm Alžbeta from November 19, 2004 in Slovakia can be added to that list of examples. When Windstorm Alžbeta in 2004 damaged 5.3 mil. m^3 (Koreň 2005; Kunca & Zúbrik 2006), the broken and uprooted trees were not processed completely by the beginning of the growing season 2007. Slovak law on nature conservation prevented that kind of management of damaged wood, so secondary damaging agents, mainly European spruce bark beetle, started to multiply its population abundance (Kunca et al. 2011; Nikolov et al. 2014). According to Nikolov et al. (2014) broken and uprooted trees kept their bark attractiveness for colonization by bark beetles even 2 years after the windthrow. These two years bark beetles multiplied in that damaged wood and in spring 2007 all beetles swarmed and were searching for new trees in the surrounding standing trees. The bark beetles calamity started in a great amount. The attractive wood material for bark beetles was later supported by new damaged wood from the Snowfall Tamara in January 2006 and then from Windstorms Kyrill on January 9, 2007 and from Windstorm Filip on August 23, 2007. Their damages reached together 1.9 mil. m^3 (Kunca et al. 2015). The culmination of the wood volume damaged by bark beetles was in 2010. That year was very wet and that could slow down the bark beetle development. Averaged annual precipitation per one meteorological station reached 1140 mm in 2010 (long-term average is 751 mm) and that was the biggest amount since 1880 when precipitation started to be measured in Slovakia (Pecho et al. 2010; Zeleňáková et al. 2017).

The European spruce bark beetle outbreak after windstorms Alžbeta and Žofia were predicted by researchers (Zúbrik 2005; 2006) but that risk was not accepted by environmental state administrations as the primary factor for applying the management of damaged and surrounding forests. It was the nature protection that determined the forest management that finally resulted in large-scale European spruce bark beetle outbreak in the natural, semi natural and artificial monocultures of Norway spruce. This was the further example how difficult it is to harmonize nature conservation management with regards to forest functions, climate change scenarios and scientific knowledge about it all (Spiecker 2003; Zubizarreta-Gerendiain et al. 2017).

The global climate change concept expects the occurrence of weather extremes that will limit the life in the regions. So, a drought is supposed to be the most important stress factor influencing forests as well (Hlásny et al. 2014; Pešková et al. 2015). However, forests in Central Europe resist the drought as a prime damaging agent. However, it is a serious predisposing factor that weakens tree defense mechanisms against bark beetles as well as against *Armillaria* infection or other biotic damaging agents.

The structure of forest damaging agents is determined by several factors; one of them is a forest tree species composition. The biggest proportion of damaged wood volume in Slovakia occurred on Norway spruce. National ecological survey (Anonymous 2016) reports that Norway spruce originally grew on 4.9% of forest land instead of present 23.4%. Due to windstorms and biotic damaging agents damages the Norway spruce coverage decreased from 26.3% in 2005 to 23.4% in 2015 (Anonymous 2016). Out of this, 18.5% (372 th. ha) of Norway spruce has been growing on unsuitable sites and so they are highly predisposed to any damaging agents. That is very clear that Norway spruce damaging agents are more active than damaging agents of other forest trees, which proportion grown on unsuitable sites is much less (Anonymous, 2016). The artificial spread of Norway spruce in Slovak territory, as well as in other Central European countries, is a heritage from 19th and 20th century. At that time, planting forest trees was a state program and Norway spruce provided very valuable wood quality, although on the account of ecological stability of forests, which was not well known at that time. Anyway, since Norway spruce is under European conditions still economically extremely important tree species, it will be accepted in reasonable proportion in temperate zone in long-term prospect. However, this species must be managed with special attention to its specific threats, ergo implementing forest protection measures mitigating wind and bark beetle risks (Kunca et al. 2007; Konôpka & Konôpka 2008).

5. Conclusions

A wind and bark beetles on Norway spruce were the most important damaging agents in Slovakia within two decades (1998–2017). It was evaluated by the salvage felling that was caused by forest harmful agents. The recent dramatic increase of forest damages caused by bark beetles relates to large-scale wind-break disasters. The damaged wood from those windthrows was not processed in time and completely because of restrictions of forest management in nature conservation areas. In general, Norway spruce is the most effected forest tree species. It is likely that Norway spruce proportion in Slovakia, as well as in Central European countries will decrease in the future due to climate change, biotic damaging agents and the nature protection preferences. New forests in the localities damaged by wind, snow or biotic damaging agents are established prevailingly with regards to suitable ecological conditions for trees and climate change scenarios and if possible, natural regeneration is preferred. These approaches in forest stand regeneration together with silvicultural and protection measures would gradually decrease amount of salvage felling in long-term prospect (Konôpka & Konôpka 2011; Vakula et al. 2015).

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ORIGINAL PAPER

Salvage Felling in the Czech Republic‘s Forests during the Last Twenty Years

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Abstract

The incidence of salvage felling is a significant indicator of stands‘ health and stability. Health is mainly indicated by biotic and anthropogenic factors, while abiotic effects are primarily an indicator of a stand’s stability. All these factors influence each other and subsequently they can result in salvage felling. For the Czech Republic, there have been relevant data for the period since 1964. After the transformation of forestry and later also restitutions carried out in the early 1990s as well as transformation of state-owned forests as of 1st January 1992, there were changes in reporting of harmful agents in forests. Currently, there are three sources of data about the incidence of salvage felling – data from the Statistical Yearbook (standard collection of data from respondents), data from the Report on the State of Forests and Forestry in the Czech Republic for years 1998–2016 which contains information on the incidence of salvage felling in the respective years, and data reported to the Forest Protection Service of the Forestry and Game Management Research Institute which, however, only covers data for approximately 70% of the Czech Republic´s area in the twenty-year period assessed in this text. During this period, the volume of salvage felling amounted to 89.2 million m^3 which represents 28.4% of total felling in this period. The largest share is caused by abiotic effects (18.6%), next by biotic agents (9.6%) and anthropogenic are only responsible for 0.2%. In the last two years, the volume of salvage felling caused by biotic agents was higher than the volume of salvage felling caused by abiotic and anthropogenic agents for the first time. In terms of biotic agents, almost the whole volume is represented by bark beetle wood as a result of spruce stands infestation by the European spruce bark beetle – *Ips typographus* (L.) and double-spined bark beetle – *Ips duplicatus* (Sahl.), and to a small extent also by other species of bark beetles on spruce, pine and occasionally other wood tree species. An important factor is the spatial distribution which was mostly random, except for the last three years, and occurred irregularly across the Czech Republic. Certain regions were affected more in some years, while in others they saw a smaller intensity and a bigger impact was observed in other regions. In the last three years, however, mainly the incidence of the *Ips typographus* L., has concentrated in North Moravia and Silesia. Currently, it is also spreading in South Moravia and Bohemia and in districts along the state borders with Austria and Germany, with the most serious situation in this region being the one in the Bohemian-Moravian Highlands.

Key words: salvage felling; Czech Republic; harmful agents; windstorms; bark beetles; drought; *Ips typographus*

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Introduction

Forests in the Czech Republic cover approximately one third of the territory (2,670 thousand ha in total). In the last three centuries, there have been considerable changes in terms of the area, age as well as species structure. Mixed and broadleaved stands were replaced by spruce and – less frequently – pine monocultures, often even-aged. The spruce currently accounts for 50.5% of stands, and pine for 16.4% respectively. This has led to decreased stand stability in respect to damage caused by abiotic agents (wind, snow, glaze, drought) and recently also by anthropogenic effects (air pollution). Coniferous monocultures provide favourable conditions for insect pests gradation, mainly for bark beetles, which is often responsible for salvage felling. In the monitored period, there was basically no salvage felling due to damages caused by folivorous insects. The worsening of the situation and increase in salvage felling is significantly affected by the global climate change, especially occurrence of extreme conditions (especially windstorms, long droughts and extremely high temperatures in the vegetative period).

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Extensive damages of forest stands have also been known from the past. It is not easy to evaluate their contribution to the then felling. For the time period starting at the turn of the 18th and 19th century, we know, at best, their extent and location (Kudela 1980). Some of these cases were rather extensive and they may have made a significant share to the overall felling. Herein, we should mention at least the windstorm disaster and subsequently a bark beetle outbreak in Šumava in the years 1868–1878 (Jelínek 1981) which extended to 7–11 million m^3 depending on the source (Pfeffer 1952; Simanov 2014). Even more catastrophic was the *Lymantria monacha* (L.) outbreak in the years 1917–1927 (Komárek 1931) when 15–20 million m^3 on the area of more than 600 thousand ha was affected (Skuhravý 2002; Kudela 1980; Simanov 2014). This also proves that also folivorous insect can significantly contribute to salvage felling. (However with the development of modern monitoring methods and protective measures – namely chemical interventions, often aerial ones – this phenomenon has been largely eliminated and it is now only limited to sporadic cases of a small extent.) An abnormal growth of gradation of various insect species and subsequent outbreaks occurred mainly in the 1970s and 1980s (Liška et al. 1991). Nevertheless, the factor of timely and effective interventions against folivorous insects decreased their contribution to salvage felling to a minimum. Therefore the most extensive damage was the one caused by ait pollution which affected a majority of borderline mountain forests, especially in the north from the west to the east, which led (in combination with bark beetles) to actual deforestation (except for the eastern area). Currently, the consequence of this disaster can be seen mostly indirectly (soil acidification, insufficient nutrition) and the actual damage caused by air pollution is rather marginal. In the long run, salvage felling in the last forty years was mainly caused by abiotic agents especially wind) and bark beetles (on spruces, the most important is European spruce bark beetle).

2. Methods and data collection

The methods of systematic data collection were elaborated in the late 1950s, but in was never used in the originally prepared form, only in the slightly adjusted one (Šrot 1962, 1964, 1965; Mentberger 1964). In 1959, a unified countrywide control, register and prognosis protection service was established based on the agreement of the Forestry Administration of the Ministry of Agriculture, Forestry and Water Management with the Forestry and Game Management Research Institute in Strnady (together with the Forestry Research Institute in Banská Štiavnica). L 116 reports (incidence of harmful agents in general) and L 117 reports (incidence of outbreak pests) were introduced. For their filling and sending, Directives for Reporting Occurrence of Forest Harmful Agents, and for Control and Prognosis of Outbreak Pests were adopted on 8th November 1963 and became effective as of 1st January 1964. In practice, only L 116 reports covering all basic harmful agents, both abiotic and biotic, were used. Data of L 116 reports in Czechia have been available at the Forestry and Game Management Research Institute since 1964. In the course of time, there have been changes in the range of reported events, some of the categories vanished. Major changes came about in the 1990s. There were three reasons. Firstly, it was the transformation of forestry, including the privatization. Gradually, up to 40% forests were given back to municipalities and citizens (currently, after the completion of privatization and recovery of forests to churches, the figure reached approximately 50%). As a result, we have only had available data from approximately 70–75% of the whole area of Czech forests (the figures fluctuates over years) since 1992. Secondly, the Forest Protection Service was founded in 1995. It modified previously used reports about harmful agents. Thirdly, another change occurred in 1998 when reporting and registers were introduced based on districts instead of forest estates.

Actual data come, to a certain extent, from three sources. The data of overall felling comes from the Report on the State of Forests and Forestry in the Czech Republic in the respective years (1998-2016) which uses data provided by the Czech Statistical Office. The information on the overall felling in 2017 was provided by the Czech Statistical Office before the official publication, so it may slightly vary from the final official figure. The most problematic information is the volume of salvage felling. There are three possible sources where to obtain them. Firstly, it is the above mentioned Czech Statistical Office which recognizes four categories of salvage felling based on its cause – natural disasters, emissions, insects and others. Secondly, salvage felling is also reported in the above mentioned Report on the State of Forests and Forestry in the Czech Republic for the given year. These figures may vary, however, and sometimes they do significantly (see Table 1). Thirdly, data can also be found in the register based on reports send by forest owners which get processed by the Forest Protection Service. This source fully covers state-owned forests (state-owned enterprises “Lesy České republiky, s. p.” and “Vojenské lesy a statky, s. p.”; forests in national parks: the Krkonoše National Park, Šumava National Park, Podyjí National Park and České Švýcarsko National Park; forests owned by universities: Czech University of Life Sciences in Prague and Mendel University in Brno; and Forests of the President´s Office in Lány) as well as a part of private and municipal forests (mostly larger forest properties). In total, approximately 70% of the whole forest area is covered. Variability in the data from different sources is probably caused by different methodological approaches. While the Czech Statistical Office collects the data directly from respondents, the data in the Report on the State of Forests and

Forestry in the Czech Republic are based on the register of the Forest Protection Service and their calculations are completed by estimation for the rest of the Czech territory. This evaluation used the data as reported by forest owners and categorized based on individual districts, but not recalculated for the rest of the territory. We are convinced this is methodologically the most appropriate approach, as the re-calculation based on estimates does not take into consideration the structure of tree species, age structure etc. and as it is done mechanically, to a certain extent, it can result in inaccuracy. The volume suggested by the Czech Statistical Office's data is considerably higher and we do not consider it to be completely accurate.

Table 1. Size of salvage felling according to data from different sources (CSO – Czech Statistical Office; MA – Ministry of Agriculture; FPS – Forest Protection Service).

Years	Salvage felling		
	CSO	MA	FPS
	mil. m^3		
1998	—	2.68	2.68
1999	—	2.62	2.62
2000	3.29	2.29	2.59
2001	2.37	1.55	1.55
2002	4.21	2.96	2.96
2003	8.19	7.87	4.95
2004	5.38	5.15	3.61
2005	4.54	3.85	2.88
2006	8.03	7.37	6.71
2007	14.89	15.48	10.84
2008	10.75	10.13	7.10
2009	6.63	6.13	5.71
2010	6.46	6.09	4.24
2011	3.82	3.83	2.57
2012	3.24	3.25	3.67
2013	4.25	4.17	2.84
2014	4.53	4.38	3.01
2015	8.15	6.89	5.17
2016	9.40	4.96	6.07
2017	—	—	7.44

Abiotic agents include the following factors: damage caused by wind, snow, icing and glazed frost, drought and other factors. Other factors can be defined as a cause of salvage felling which could not be specified or a significant combination of several factors when categorization under one of them might skew the resulting data.

Anthropogenic agents only include damage by air pollution. Fire damage is not included, as their significance and extent in respect to salvage felling is usually marginal in the Czech Republic; furthermore it would be complicated to distinguish between cases with an abiotic and anthropogenic cause. Another omission relates to spruce yellowing which gets reported to the Forest Protection Service, but its categorization is not unambiguous and furthermore, the extent is not very significant.

Biotic agents only include several harmful agents. The most significant cause is the incidence of bark beetle on spruces (dominantly, *Ips typographus* (L.), partly also *Ips duplicatus* (Sahl.) and *Pityogenes chalcographus* (L.). Bark beetles on pines include *Ips acuminatus* (Gyll.), *Tomicus minor* (Hart.) and *Phaenops cyanea* (F.). Bark beetles on other tree species do not affect the volume of salvage felling given the actual extent. Folivorous insects did not contribute to occurrence of salvage felling in the monitored time period. As for fungal pathogens, wood decaying fungi are represented by *Armillaria ostoyae* (Romagn.) Herink. Other important species of wood decaying fungi such as *Stereum sanguinolentum* (Alb. Et Schwein.) Fr., *Heterobasidion parviporum* Niemelä et Korhonen and *H. annosum* (Fr.) Bref. are not mentioned as they have not been monitored.

The data were analysed in the STATISTICA 12 program using basic statistics. As the data do not have normal distribution, Kruskal-Wallis ANOVA at 5% level of the significance ($p<0.05$) was used. Results are followed by the post hoc test.

3. Results

3.1. Salvage felling

According to the National Forest Inventarization, the current overall wood resources are estimated to be approximately 942.2 million m^3, with the overall spruce resources (which is the most frequent subject to salvage felling) equalling 510.7 million m^3 (Anonymous 2017a). The total felling in Czech forests reached 314.43 million m^3, i.e. 33.37% of the total resources in 1998–2017. In ratio to the average total felling, its volume fluctuated between 89.06–117.74%. Salvage felling reached 89.18 million m^3, i.e. 28.36% of the total felling in 1998–2017. In this period, the salvage felling figures fluctuated in the range of 34.75–243.05% in relation to the average salvage felling.

Table 2. Volume of total felling and salvage felling in the Czech Republic within the period 1998–2017.

Felling	Sum	Annual average	Standard deviation	Minimum	Maximum	Number of years
	mil. m^3					
Total felling	314.43	15.72	1.25	14.00	18.51	20
Salvage felling	89.18	4.46	2.29	1.55	10.84	20

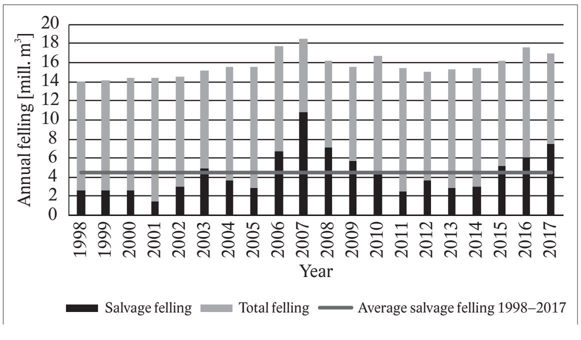

Fig. 1. Development of both total and salvage felling in the Czech Republic over the period 1998–2017.

3.2. Harmful agents

Salvage felling is caused by three groups of harmful agents. Abiotic and biotic agents are the leading ones, and they largely contribute to salvage felling. Anthropogenic agents are currently of a very little importance (although they ranked among the most important ones in the 1970s and 1980s). In the last twenty years, the share of these groups on the volume of salvage felling was as follows: abiotic agents – 65.49%, biotic agents –33.77% and anthropogenic agents – 0.74%.

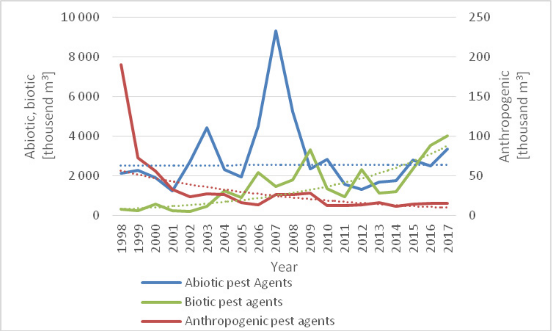

Fig. 2. Development of volume of processed wood from salvage felling cased by the three major groups of harmful agents.

The results of the Kruskal-Wallis ANOVA proved a statistically significant difference between the amount of damage caused by abiotic, biotic and anthropogenic harmful agents (p = 0.0000). The Post hoc test (Multiple comparisons p value) revealed statistically significant differences between anthropogenic and biotic (p = 0.0000) and abiotic (p = 0.0000) harmful agents. No statistically significant difference was proved between biotic and abiotic harmful agents (p = 0.1170).

Using Kruskal-Wallis ANOVA as well as the Median test showed that the major causal agent of forest damages are abiotic harmful agents compared to the minor cause – anthropogenic harmful agents.

The results of the a Kruskal-Wallis ANOVA proved a statistically significant difference between the amount of damage caused by abiotic harmful agents (wind, snow, icing + glaze, drought, other abiotic harmful agents) (p = 0.0000). The Post hoc test (Multiple comparisons p value) revealed the following: a statistically significant difference was proved between wind and snow (p = 0.0003), wind and icing + glaze (p = 0.0000), wind and other abiotic harmful agents (p = 0.0000), snow and other abiotic harmful agents (p = 0.0179), drought and icing + glaze (p = 0.0001), drought and other abiotic harmful agents (p = 0.0000). A statistically significant difference was not proved between wind and drought (0.1067), snow and icing + glaze (p = 0.0617), snow and drought (p = 0.9811), icing + glaze and other abiotic agents (p = 1.0000).

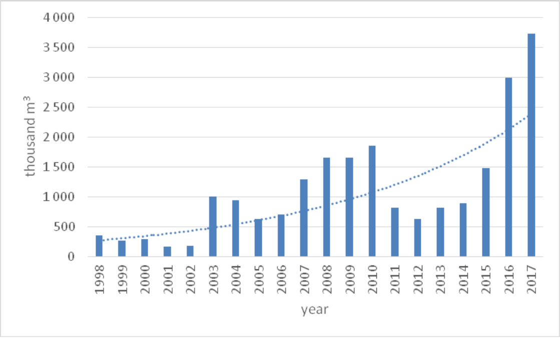

Fig. 3. Recorded volume of spruce wood infested by bark beetles in the Czech Republic within the period 1998–2017.

Table 3. Volume of processed wood by major groups of harmful agents in the Czech Republic forests within the period 1998–2017.

Major groups of harmful agents	Sum	Median	Standard deviation	Minimum	Maximum
	mil. m^3				
Abiotic Harmful Agents	58.406	2.343	1.853	1.238	9.316
Biotic Harmful Agents	30.116	1.241	1.142	0.203	4.048
Anthropogenic Harmful Agents	0.662	0.021	0.040	0.012	0.191
Total	89.184	1.233	1.714	0.012	9.316

Table 4. Volume of processed wood from salvage felling due to selected abiotic and anthropogenic harmful agents in the Czech Republic forests within the period 1998–2017.

Major group of harmful agents	Sum	Median	Standard deviation	Minimum	Maximum
	mil. m^3				
Wind	43.757	1.580	1.844	0.953	8.842
Snow	5.414	0.117	0.561	0.042	2.590
Icing + Glaze	1.273	0.043	0.083	0.011	0.362
Other abiotic harmful agents	0.893	0.035	0.029	14.00	0.110

Table 5. Volume of processed wood from salvage felling due to selected biotic harmful agents in the Czech Republic forests within the period 1998–2017.

Major group of pests /pathogens	Sum	Median	Standard deviation	Minimum	Maximum
	mil. m^3				
Bark beetles on spruce	22.102	0.856	0.919	179.00	3.727
Bark beetles on pine	0.140	0.005	0.005	0.002	0.022
Armillaria spp.	3.830	0.186	0.137	0	0.521

Table 6. The selected major harmful agents in the Czech Republic forests within the period 1998–2017.

Harmful agents	Total volume of processed wood from salvage felling	
	mil. m^3	%
Wind	43.757	65.78
Bark beetles on spruce	22.102	33.23
Air pollution	0.62	1
Total	66.521	100

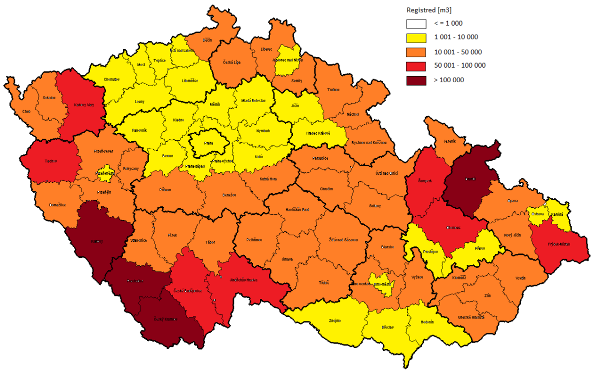

Fig. 4. Distribution of wood volume processed in the salvage felling caused by wind (average from years 1998–2017).

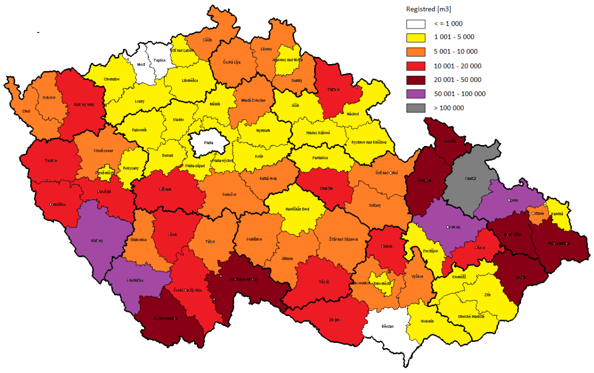

Fig. 5. Distribution of wood volume processed in the salvage felling caused by spruce bark beetles (average from years 1998–2017).

Among one-off factors, windstorms cause the most serious damage. One of the strongest ones in the history was the Kyrill windstorm in 2007 (according to the Forest Protection Service, its effect resulted in almost 9 million m^3 damage, but the report did not cover the whole territory of the Czech Republic). Only damage caused by the Vivian and Wiebke windstorms in 1990 is comparable with the consequence of the Kyrill windstorm. In 1976, 1984, 1985 and 1986, damage due to windstorm reached approximately 5–6 million m^3. Usually, it is around 1 million m^3, but there are several more years when the range of 2–4 million m^3 was reported (this related to the monitored period starting from 1964).

Looking at the period of 1998-2017, snow proved to be an intensive harmful agent in 2006 when the volume of damaged stands reached 2.6 million m^3. Large damage was seen only in the years 1979 and 1980 (3.1 million m^3, a 3.2 million m^3 respectively). In the years 1967, 1970 and 1981, the level of 1.5 million m^3 damage was exceeded, and in 1968 and 1982 the volume of damage was 1 million m^3. In other monitored years, it fluctuated under the level of 500 thousand m^3 or around it.

Drought is a typical phenomenon of the recent years, but its negative consequences were also obvious in the past. During the period of harmful agents monitoring (since 1964), such effects were observed in 1993–1995, when the total of 4.2 million m^3 of damaged wood was reported. Usually, the volume of stands damaged by drought reaches the maximum of approximately 0.2 million m^3, but in some years, the range increases to 0.3–0.6 mil, m^3, specifically in the second half of the 1970s, in the mid 1980s and in the middle of the first decade of the 3rd millennium.

Damage due to air pollution culminated in the late 1970s and significantly dropped in the early 1990s. At that time, annual volumes of recorded damaged wood exceeded 0.5 million m^3, while in 1980 and 1981, they even exceeded 1 million m^3. In the period of 1998–2017 covered in this study, they only amounted to approximately tens of thousands of m^3 and the significance of this type of damage was thus rather marginal (Zahradník et al 2018).

Ips typographus is the most important biotic harmful agent. Its gradation has lasted since 2003 with minor variations. Since 2015, the volume of recorded bark beetle wood has continued to grow and it has reached its record level. Since 1964 there have been two more rather significant gradations – in the years 1983–1988 (volume of 6.65 mil. m^3) and 1993–1996 (volume 6.75 mil. m^3) (Liška et al. 1991; Zahradník 1997, 2008).

Table 7. Summary of major disturbance in the Czech Republic from 1998 to 2017.

Type of disturbance	Data of its occurrence	Volume [mil. m^3]
Windstorm „Lothar“	26–27 December 1999	2
Snowfall „Tamara“	January 2006	2.6
Windstorm „Kyrill“	9 January 2007	10–12
Windstorm „Emma“	1–5 March 2008	3
Windstorm „Niklas“	28–29 June 2015	0.5
Windstorm „Herwart“	29 October 2017	3
Ips typographus (L.)	2003–2004	1.9
Ips typographus (L.)	2007–2010	6.5
Ips typographus (L.)	2015–2017	8.2
Ips typographus (L.)	2003–2017	21.1
Drought	2015–2017	3.1

Discussion

The volume of salvage felling caused by various harmful agents is a significant indicator of forest stands' health and stability (Anonymous 2017a; Knížek et al. 2017; Kunca 2017). The most important indicator is the total volume of salvage felling which is an objective piece of information on forced felling due to harmful agents, because the volume of total felling (or, to be more specific, intentional felling), depends on numerous factors including timber sales, planned volumes of felling etc.

and it can fluctuate considerably. There are three categories of agents affecting salvage felling – abiotic, anthropogenic and biotic (Schelhaas et al., 2003; Spiecker 2003). In the Czech Republic, the total of 30 harmful agents are monitored currently – with 5 of them being abiotic factors, 2 anthropogenic (as classification of spruce yellowing among anthropogenic agents is questionable) and 23 biotic agents (or agent groups) and additionally some other types, depending on what is relevant in the given year (Knížek et al. 2017). Monitored harmful species change over time – in 1962, there were only 17 types of outbreak pests. This also varies in neighbouring countries. For example, the monitoring in Slovakia covers 53 harmful agents (Kunca 2017) and in Poland as many as 109 (Anonymous 2017b).

In the Czech Republic, as seen in the long run, the most important factor contributing to salvage felling can be seen in abiotic effects, mainly wind (Zahradník et al. 2018). However, windbreaks do not afflict the Czech Republic only, but other Central European countries as well (Simanov 2014; Kunca & Zúbrik 2006; Trębski, 2017). These disasters can largely affect the volume of salvage felling and its share in the total felling, as they can amount to millions of m^3, even exceeding 10 million m^3 in individual countries. They occur randomly and in a various extent across Central Europe.

Out of biotic harmful agents in the post-war history, bark beetle on the spruce is considered to be the most important one, namely *Ips typographus*, and in Moravia and Silesia also *Ips duplicatus* (Skuhravý 2002; Knížek et al. 2017). Other species of bark beetles often accompany the previous two and their incidence is often reported together with *Ips typographus* – this applies to *Pityogenes chalcographus* and *Ips amitinus*. The situation is similar in the neighbouring countries (Liška 2018). Only in Poland, there is also an important role of folivorous insects, mainly in pine stands where it has outbreaks in large areas, but due to insecticide application, this only contributes to salvage felling marginally (Anonymous 2017b).

In the Czech Republic in the last two years – 2016 and 2017 – the volume of salvage felling due to biotic agent exceeded for the first time the volume of salvage felling caused by abiotic agents (Knížek et al. 2017; Knížek & Liška 2018); anthropogenic agents only played a marginal role in the monitored period (Knížek & Liška 2018). Air pollution, as the major part of anthropogenic damage, became significant in the 1970s and 1980s and not only in Czechoslovakia, but also in Germany (the former German Democratic Republic) and Poland.

In the monitored period, the percentage of salvage felling on the total felling in the Czech Republic has fluctuated in the range of 35–143%, and the average was 139%. In Slovakia, this share in the years of 2004–2013 ranged from 38.8 to 65.9%, and the average was 53.2% (Kunca et al. 2015).

Windstorms have caused more frequent and extensive damage in the Czech Republic in the past twenty to thirty years, yet this also applies to the rest of Europe. The Vivian windstorm of 1990 damaged 120 million m^3 wood in Western Europe (König et al. 1995). Another important windstorm was Lothar in 1999 together with Anatol and Martin which damaged approximately 180 million m^3 in Western Europe (Sacre 2002). At the turn of August and September 2005, Denmark, Estonia and South of Sweden were afflicted by the Gudrun windstorm which damaged 75 million m^3 of wood in Southern Sweden only (Schlyter et al. 2006; Langström et al. 2009). These windstorms did not affect the Czech Republic though. The Kyrill windstorm of January 2007 afflicted a large part of Europe (from the United Kingdom and France to Belarus, Ukraine and Slovenia) and damaged 55 million m^3 of wood. This windstorm also damaged stands in the Czech Republic. Unlike the previous above mentioned windstorms which did not hit our territory, this one had a serious impact here and caused damage of 10–12 million m^3. At the beginning of March 2008, the Czech Republic was struck by the Emma windstorm which damaged approximately 3 million m^3 (Simanov 2014). The latter two windstorms affected the volume of salvage felling in the respective years and they also marked the beginning of the subsequent bark beetle outbreak which had a further effect on the salvage felling volume (Knížek et al. 2017). The most recent important windstorm resulting in extensive damage was Herwart in October 2017 which damaged approximately 2.5 million m^3 in the Czech Republic (Lubojacký & Knížek 2017). There were many other windstorms with a bigger or lesser effect on the volume of salvage felling. Local windstorms (sometimes of a large extent) were also Alžběta which hit the High Tatra Mountains in Slovakia in the extent of more than 5 million m^3 (Koreň 2005; Kunca 2005; Kunca & Zúbrik 2006) and the groups of windstorm of 11.–12. August 2017 in Poland which caused damage of approximately 10 million m^3 and major windbreaks (Trębski 2017).

Significant elements influencing the level of damage by wind are not only the wind force, but also its direction, the tree species and the age of the stand. These factors were studied in the Czech Republic by Vicena (1964) as well as Vicena et al. (1979). The predominant directions of wind in Slovakia were explored by Konôpka et al. (2008) who pointed out considerable regional differences in the ,direction of predominant wind. On the European level, this topic was covered similarly by Gardiner et al. (2008, 2011).

Schelhaas et al. (2003) stated that windbreaks constitute up to 53% of forest stands disturbance in Europe. In the Czech Republic, it was 49% in the monitored period. As the frequency of windstorms has been rising recently, and similarly forest damage caused by these windstorms has been increasing as well, this comparison does not seem completely appropriate.

Although wind has been the crucial abiotic factor contributing to salvage felling in the long run, there are also time periods when other factors can manifest themselves rather significantly. In 2006, the volume of snowbreaks exceeded 2.5 million m^3, while wind only accounted for less than 0.5 million m^3 in the same year. Even abiotic agents, often seen as generally less significant, can unexpectedly result in large damage and exceed the effect of windbreaks. An example is the case of icing in 1996 (which is not included in the monitored period) when the related damage reached 2 million m^3 (Novotný 2017). Another highly important harmful agent is among biotic agents – it is the *Ips typographus* (L.). Its outbreak usually follows windbreaks, and sometimes it is linked with the stands' damage by draught (Christiansen & Bakke 1988; Pfeffer & Skuhravý 1995; Blennow & Olofson 2008; Grodzki 2010; Marini et al. 2013; Mezei et al. 2014; Sproul et al. 2015).

Belated treatment of breaks is unambiguously linked with one of the most serious *Ips typographus* outbreaks in Šumava (Jelínek 1988; Skuhravý 2002). Similarly, breaks are also mentioned as the cause of *Ips typographus* outbreaks in other countries, for example in Sweden in 1969 (Nilsson et al. 2004) as well as in 2005 and 2007 Langström et al. 2009), in Lithuania (Zolubas & Dagilius 2009) and Siberia (Soukhovolsky 2009; Tarasova 2009). The situation was similar also in Slovakia after the Alžběta windstorm in 2004 (Koreň 2005; Kunca 2005; Kunca & Zúbrik 2006).

Drought as a predisposition factor for the bark beetle development was mentioned by Hendrych (1930) and Kalandra & Kolubajiv (1949). The bark beetle outbreaks of 1983–1988 and 1993–1996 are associated with abnormal drought as well (Zahradník 1997; Skuhravý 2002). Also the contemporary outbreak which started in 2003 was triggered by the extraordinarily dry and hot year of 2003, and it escalated after similar weather conditions in 2015 (Knížek et al. 2016). The bark beetle outbreak in Germany in the years 1938–1941 was caused by abnormal drought combined with high temperatures (Hodapp 1954). Similarly, the extensive outbreak in Southern Norway and Central Sweden after a windstorm in 1969 was linked with the fact that spruces were weakened by drought (Butovitsch 1971). Drought as a stressor possibly leading to subsequent bark beetle infestation was also pointed out by Maslov (2001) who wrote that the flow rate on the River Nemen was only 14% after precipitation reached only 40% of the standard rate and this situation was followed by bark beetle outbreak.

Conclusions

Wind has been the most important harmful agent in the last twenty years. We are currently witnessing the largest outbreak of *Ips typographus* and associated species, especially *Ips duplicatus*. It started in 2003 and has lasted up to present days, with minor oscillations. Progression of this outbreak escalated in 2015 after an abnormally dry and hot year, and it has continued to grow. In the years 2016 and 2017, it kept rising permanently, and in 2017 it reached the historical peak in the volume of recorded bark beetle wood. In the above-mentioned two years, it was also the first moment in history, when the volume of salvage felling caused by biotic agents exceeded the salvage felling caused by abiotic agents. The situation in spruce stands of an older age (above 60) is critical in many locations, regardless of the altitude. The most affected region is North Moravia and Silesia, where clearings as large as tens of hectares emerge after the bark beetle infestation and merge gradually. The situation is similarly bad in neighbouring countries, too – in Slovakia, in spruce areas of Poland, in Austria and Germany, especially in Bavaria (Liška 2018). There is nothing consoling about this fact, though. It is a serious phenomenon which gets multiplied by frequent and extensive breakages and mainly by a long-term precipitation deficit which decreases stand vitality, and also by high temperatures in the vegetation period which accelerate the bark beetle growth and increase the number of generations per year. The bark beetle outbreak thus significantly affects the volume of salvage felling, more than ever in the past.

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ORIGINAL PAPER

Tree-ring widths as an indicator of air pollution stress and climate conditions in different Norway spruce forest stands in the Krkonoše Mts.

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Abstract

The negative effect of air pollution on mountain spruce stands culminated in the 70s – 90s of the 20th century, when an extensive dieback and disturbance of stands occurred in the Krkonoše Mts., the Czech Republic. Dendrochronological analysis was used on ten permanent research plots established in 1976–1980 to document the dynamics of radial increment of Norway spruce (*Picea abies* [L.] Karst.). The objective was to determine the effect of SO_2, NO_X and O_3 concentrations and precipitation and temperatures on spruce radial growth in climax forests, waterlogged forests and cultivated forests. The results document the strong depression of diameter increment in the period 1979–1991 caused by synergism of climatic extremes and high SO_2 pollution in the 80s and 90s of the 20th century. After 2000 climate had prevailing effect on radial growth. Spruce increment was in positive correlation with temperature, particularly with temperature in the growing season and annual temperature of the current year. In general, temperature had a more significant effect on increment than precipitation, mainly in climax and peaty spruce stands. Diameter increment was in significant negative correlation with SO_2 and NO_X concentrations in all types of stands. Overall, peaty spruce stands were the most vulnerable to air pollution stress. Low radial increments were caused also by climate extremes, historically by strong frosts and winter desiccation in early spring, nowadays in time of climatic changes by extreme drought. Spruce stands have the ability of quickly responding by tree-ring width to both negative and positive impulses related with air pollution and climate.

Key words: *Picea abies*; dendrochronology; SO_2 concentration; climate factors; Central Europe

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1. Introduction

The effect of air pollutants on mountain spruce stands in Central Europe had been observed since the 50s of the 20th century and culminated in the 70s – 90s of the 20th century (Vacek et al. 1996; Modrzyński 2003; Hůnová et al. 2004; Vacek et al. 2017a) while this effect has persisted to a smaller extent until now (Godek et al. 2015; Kolář et al. 2015; Vacek et al. 2015). The impacts of the extensive forest decline in the Sudetes Mts. system and especially in the Black Triangle area will be observable for many decades (Kandler & Innes 1995; Grodzińska & Szarek-Lukaszewska 1997; Lozenz et al. 2008). A great expansion of the power generation industry along the frontiers of Germany, the Czech Republic and Poland and the prevailing airflow from the west caused a substantial increase in air pollution in the area of interest of the Jizerské hory, Krkonoše and Orlické hory Mts. (Grübler 2002; Vacek et al. 2003, 2007; Blaś et al. 2008; Vacek et al. 2013a; Kolář et al. 2015). Large plots of mostly spruce stands above 1,000 m a.s.l. suffered great damage or died in these areas and due to air pollution disturbance ca. 21,000 ha of stands were felled there (Vacek et al. 2007). Similar destruction of forest ecosystems occurred also in the Polish part of the Sudetes Mts. range (Slovik et al. 1995; Modrzyński 2003; Godek et al. 2015). Such damage was aggravated by strongly acid deposition often related with frequent occurrence of horizontal precipitation and limited buffering capacity of Podzols on the bedrock built of granite, mica schists and phyllites (Hruška & Cienciala 2003; Podrázský et al. 2003; Vacek et al. 2006; Matějka et al. 2010). This air pollution disaster was an impulse for a radical reduction of the air pollution load, mainly of SO_2 concentrations, after 1989 (Vacek et al. 2007; Stjern 2011; Lomský et al. 2012).

Very high concentrations of emissions and especially of SO_2 had a great impact on the radial growth of the

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**Corresponding author. Zdeněk Vacek, e-mail: vacekz@fld.czu.cz* studied peaty spruce stands as a consequence of huge physiological stress because these stands are located at the boundaries of their ecological valence (Vacek et al. 2015). Tree-ring width is considerably reduced by heavy air pollution (Sander & Eckstein 2001; Wilczyński 2006) that can result even in a complete disintegration of forest stands in extreme cases (Lomský & Šrámek 2002). The variability of tree-ring width is also influenced by other environmental agents, mainly climatic factors (temperature, precipitation, wind, wet snow, icing, winter desiccation), insect pests (*Ips typographus*, *Ips duplicatus*, *Zeiraphera griseana*, *Cephalcia abietis*, *Pachynematus montanus*), fungal pathogens (*Armillaria mellea*, *Heterobasidion annosum*, *Ascocalyx abietina*), etc. (Schweingruber 1996; Vacek et al. 2007; Štefančík et al. 2012; Trotsiuk et al. 2014). Among the climate factors air temperature is very important for the growth of Norway spruce (*Picea abies* [L.] Karst.)at mountain and high-altitude locations (Büntgen et al. 2007) while it is mentioned as one of the crucial factors of an increase in forest stand increment (Linder et al. 2010). Air temperatures can increase the radial growth of spruce if summer is warm and the growing season is longer (Vaganov et al. 1999; Vacek et al. 2015). Other factors influencing increment and related with climate change at the same are variations in sum of precipitation, increase in atmospheric CO_2 (Churkina et al. 2007; Eastaugh et al. 2011) and increased N depositions (de Vries et al. 2009). However, these factors need not always lead to an increase in increment, but they can sometimes cause its decrease (Etzold et al. 2014).

Growth responses to the above-mentioned environmental agents are sufficiently prompt to be a suitable indicator of forest ecosystem degradation (Godek et al. 2015; Parobeková et al. 2016). The impacts of ongoing climate changes have already been supported by empirical evidence from long-term permanent research plots that has indicated an increase in stand productivity in central and eastern Europe in the latest years (Hlásny et al. 2014; Lindner et al. 2014; Pretzsch et al. 2014; Král et al. 2015; Vacek et al. 2015). This has also been supported by dendrochronological studies that document the radial growth of Norway spruce at high-altitude locations of central Europe (Savva et al. 2006; Büntgen et al. 2007; Treml et al. 2012; Král et al. 2015). More frequent various types of disturbances are a consequence of ongoing climate changes (Splechtna et al. 2005; Seidl et al. 2014; Panayotov et al. 2015). Thus ongoing climate changes may significantly influence growth trends of trees and document their growth response to these changes (Grace et al. 2002; Di Filippo et al. 2012; Pretzsch et al. 2014), therefore the effect of climate changes on forest productivity is traditionally the focus of foresters' interest (Bontemps & Bouriaud 2013; Hlásny et al. 2017). Nevertheless, temporal anomalies in climate can be separated within growth trends as they are similar in all stands of the same tree species in the given area, whether under the influence of air pollution or not, similarly like in biotic pests (Vinš & Mrkva 1973; Ferretti et al. 2002; Sensuła et al. 2015). This is probably the reason why forest stand productivity was studied particularly at smaller spatial scales (Bošeľa et al. 2013; Socha et al. 2016). This study should help elucidate this relatively extensive problem in specific conditions of the Krkonoše Mts. because in spite of better knowledge of the warming effect there are still many questions to be answered (Bošeľa et al. 2016). In addition, particular studies of climate impacts on tree growth substantially differ in the type of data and statistical methods used (Peters et al. 2015).

The objective of the present research is to evaluate the impact of air pollutants and climate factors on the radial growth of climax spruce forests, peaty spruce forests and cultivated spruce stands at sites of acidophilic mountain beech forests in the Krkonoše Mts. The paper covers the following questions: (1) How have air pollutants and climate influenced the radial growth of climax, peaty and cultivated types of spruce stands?; (2) What was the effect of SO_2, NO_X and O_3 concentrations on the radial growth of various types of spruce stands?; (3) How have average monthly air temperatures and monthly sum of precipitation influenced the radial growth of various types of spruce stands since 1975? The greatest effect of air pollutants and climate extremes is assumed in peaty spruce stands and the smallest effect in cultivated spruce stands at sites of acidophilic mountain beech forests.

2. Material and methods

2.1. Study area

The territory of interest consists of 10 permanent research plots (PRP) located in the Krkonoše National Park, in the northern part of the Czech Republic at the frontier with Poland. Within an extensive network of PRP the selected plots were originally established in 1976–1980 when on the other spruce PRP all trees died due to an extreme air pollution disaster. The bedrock of the territory of interest is composed of granite, mica schist and phyllite. The prevailing soil type on PRP is Podzol, Cryptopodzol and Organosol. Average annual sum of precipitation is between 800 and 1,400 mm and average annual temperature is in the range of 3–6 °C (Vacek et al. 2007). Growing season lasts 70–120 days in dependence on the altitude above sea level (710–1,250 m a.s.l.) with average precipitation around 670 mm and temperature of 9 °C. Fig. 1 illustrates the localization of PRP and Table 1 shows basic site and stand characteristics of PRP. These PRP are typical of climax spruce forests, peaty spruce forests and spruce stands at sites of acidophilic mountain beech forests in the Krkonoše Mts.

From the aspect of emissions, SO_2 concentrations had increased since 1972 in connection with the operation of large power stations EPO II in Poříčí near Trutnov and Polish power station Turow, burning low-quality brown coal with a high content of sulphur (Vacek et al. 2007). In

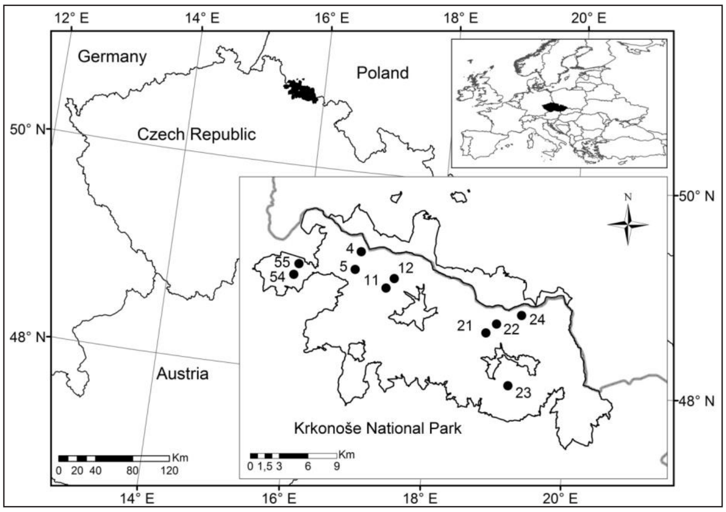

Fig. 1. Location of Norway spruce forest stands on permanent research plots in the Krkonoše Mts.

Table 1. Overview of basic site and stand characteristics of permanent research plots.

ID	GPS	Altitude [m]	Exposition	Slope [°]	Forest site type[1]	Geology	Soils	Air pollution threat zones[2]	Age [year]	Mean breast diameter [cm]	Mean height [m]	Volume [m^3 ha^{-1}]
Climax spruce stands												
5	50°45´69´´N 15°30´68´´E	1,130	N	17	8G	Granite	Gley	B	251	64.0	20.8	296
11	50°44´99´´N 15°33´81´´E	1,220	NE	29	8Z	Granite	Podzol	A	228	47.6	14.3	114
12	50°45´02´´N 15°33´83´´E	1,170	NE	26	8Z	Granite	Podzol	B	228	54.6	21.2	167
21	50°43´18´´N 15°42´45´´E	1,230	S	21	8Z	Schist	Podzol	B	142	47.8	21.9	548
22	50°43´62´´N 15°43´51´´E	1,160	E	32	8Y	Schist	Podzol	B	157	39.0	21.4	387
24	50°43´89´´N 15°45´29´´E	1,250	SE	20	8Z	Schist	Podzol	B	199	49.3	22.2	314
Peaty spruce stands												
4	50°46´62´´N 15°30´54´´E	1,180	SW	12	8R	Granite	Organosol	A	231	46.7	21.4	181
23	50°39´54´´N 15°44´63´´E	1,190	NE	4	8R	Gneiss	Organosol	B	195	33.0	22.2	180
Cultivated spruce stands												
54	50°45´59´´N 15°24´29´´E	710	NE	6	6K	Phyllite	Crypto-podzol	C	113	22.1	12.1	300
55	50°46´14´´N 15°25´06´´E	720	NE	8	6K	Phyllite	Crypto-podzol	C	120	29.2	18.2	407

Explanatory notes: Forest site type[1] according to Czech forest ecosystem classification (Viewegh 2003) used from the Forest Management Institute: 8G – Nutrient-medium wet spruce forest (*Piceetum paludosum mesotrophicum*), 8Z – Rowan-spruce forest (*Sorbeto-Piceetum humile*), 8Y – Skeletal spruce forest (*Piceetum saxatile*), 8R – Raised bog spruce forest (*Piceetum turfosum montanum*), 6K – Acidic spruce-beech forest (*Piceeto-Fagetum acidophilum*); Air pollution threat zones[2]: A – period of forest disintegration – 20 years, B – 40 years, C – 60 years, D – 80 years.

the period from 1980 to 1991 average annual SO_2 concentrations were in the range of 10 to 35 μg m^{-3} and maximum daily concentrations varied from 60 to 280 μg m^{-3} (Drda 1994; Král et al. 2015). A substantial decrease in SO_2 concentrations in the air occurred at the end of the 20th century when the range from 5 to 20 μg m^{-3} was reached (Schwarz 2001). Currently, average concentrations of SO_2 and NO_X are around 3 and 8 μg m^{-3}, respectively, and the O_3 exposure index AOT40F is 25,000–28,000 ppb h^{-1}.

2.2. Data collection

Data for the analysis of growth relations were acquired by taking cores at a height of 1.3 m with the Pressler borer (Mora Sweden) from 30 living dominant and codominant spruce trees that were randomly selected (RNG function in Excel) on each plot of 50×50 m in size (0.25 ha). The samples were taken in upslope/downslope direction in autumn 2015. In a laboratory tree-ring widths were measured to the nearest 0.01 mm with Olympus binoculars on a LINTAB measuring table and recorded by the TsapWin programme (© Rinntech).

To derive stress factors related with air pollutants and climate recorded data from air quality monitoring stations and from meteorological stations were used. Available data from the Desná-Souš Station (772 m a.s.l.; GPS 50°47´21´´N, 15°19´11´´E) were used for an analysis of the air pollution situation according to SO_2 (1975–2015), NO_X concentrations (1992–2012) and AOT40F

(1996–2012). For this evaluation average annual and maximum daily values of SO_2 and NO_X concentrations given in µg m^{-3} and in ppb h^{-1} for AOT40F were employed. The effect of climate with respect to temperature and precipitation conditions was evaluated on the basis of data from meteorological station in Pec pod Sněžkou (1975–2015; 656 m a.s.l.; GPS 50°18´24´´N, 16°21´07´´E). Data on average annual temperatures, growing season temperatures, temperatures in particular months, minimum and maximum temperatures, annual sum of precipitation, sum of precipitation in growing season, precipitation in particular months, minimum and maximum precipitation in 1975–2015 were used to describe the development of temperature and precipitation conditions.

2.3. Data analysis

The studied forest stands were divided into three basic groups: climax spruce forests, peaty spruce forests and cultivated spruce forests at sites of acidophilic mountain beech forests. Tree-ring increment series were individually crossdated (to remove errors caused by missing tree rings) using statistical tests in the PAST application (Knibbe 2007) and subsequently they were subjected to visual inspection according to Yamaguchi (1991). If a missing tree ring was revealed, a tree ring of 0.01 mm in width was inserted in its place. Individual curves from PRP were detrended and an average tree-ring series was created in the ARSTAN programme (© Cook, Tree Ring Laboratory). Negative exponential spline and year splines were used for detrending (Grissino-Mayer et al. 1992). The analysis of negative pointer years was done according to Schweingruber (1990) and Desplanque et al. (1999). For each tree the pointer year was tested as an extremely narrow tree ring that does not reach 40% of the increment average from the four preceding years. The occurrence of the negative year was proved if such a strong reduction in increment occurred at least in 20% of trees on the plot. To express the relationship between climate characteristics (monthly average temperatures and sum of precipitation in particular years) and radial increment the DendroClim software was used (Biondi & Waikul 2004). To analyse the effect of overall meteorological conditions on radial growth, Sielianinov hydrothermal coefficient (K; share of monthly sum of precipitation and average air temperatures) was used (Radzka & Rymuza 2015). To determine the combined effect of average annual temperature and annual sum of precipitation on diameter increment of spruce, regression quadratic model was used.

Data from the evaluation of diameter increment in relation to air pollution and climate factors were statistically processed by the Statistica 12 programme (© Statsoft, Tulsa). The data were tested for normal distribution by the Kolmogorov-Smirnov test. Differences in radial increment were tested by one-way analysis of variance (ANOVA). Subsequently, the differences were tested by post-hoc HSD Tukey's test. Average tree-ring series from PRP were correlated with climate data (precipitation, temperatures in 1975–2015 from the Pec pod Sněžkou Station) and air pollution data (SO_2 concentrations in 1977–2015, NO_x concentrations in 1992–2012 and AOT40F in 1996–2012 from the Desná-Souš Station) by the particular months and years. The principal component analysis (PCA) was run in CANOCO 5 programme (© Leps & Smilauer) to assess the relationship between the radial growth of climax, peaty and cultivated spruce forest stands, maximum and average concentrations of SO_2, precipitation and average temperatures all the year round, in the growing season (from April to September), out of the the growing season (from October of previous year to March of current year), in June to July and in January to March of the current and preceding year. Prior to the analysis the data were logarithmized and standardized. The results of multivariate PCA were visualized in an ordination diagram.

3. Results

3.1. Dynamics of radial growth of spruce forest stands

Comparison of the average tree-ring curves for the ten PRP shows a good fit between them (t-tests ≥ 7.1, Fig. 2). This consistency allowed the compilation of a local standard chronology for the spruce stands in the Krkonoše Mts. After the division of tree-ring width curves into three periods according to air pollution load (before 1960–1978, during 1979–1991 and after SO_2 load in 1991–2015), there were significant differences between these periods ($p<0.001$). Significantly lower increment was observed during air pollution load ($p<0.001$), when annual diameter growth reached only 49% of common growth in peaty stands, 58% in climax stands and 71% in cultivated stands.

The generally highest fluctuations in radial growth expressed by SD (standard deviation) were determined in peaty stands (mean±0.24) occurring at the boundary of ecological minimum while the relatively balanced growth curve was constructed for climax stands (mean±0.17). Specifically, the highest fluctuations in diameter increment (mean±0.43) were observed on climax PRP 11 situated in extreme climatic conditions of the timberline ecotone and turbulent space of the anemo-orographic system in the Labský důl locality. A pronounced effect of air pollutants and a decrease in radial growth persisted in peaty spruce forest for the longest time (1976–1992), but in cultivated spruce forest they persisted for the shortest time (1979–1989; Fig. 2). On the other hand, the regeneration trend in cultivated spruce forests after 1989 was not so pronounced. Its moderate stabilization was observed, but with many fluctuations, which was caused by frequent attacks of bark beetles in these two allochthonous stands, mainly in 1993–1997 and 2005–2007.

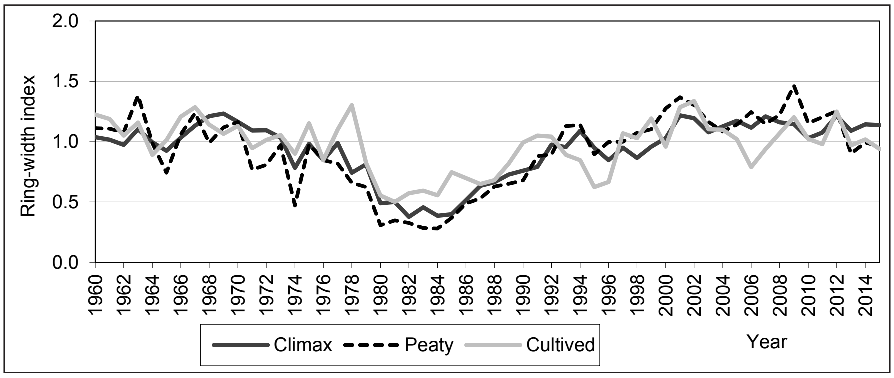

Fig. 2. Standard average tree-ring chronology for climax, peaty and cultivated spruce stands in the Krkonoše Mts. after removing the age trend in Arstan software.

The years 1980 and 1982 were found to be negative pointer years with very low radial increment in climax spruce stand, the years 1974 and 1980 in peaty spruce stand and only the year 1981 in cultivated spruce stand. Besides the period of an extreme air pollution load, low radial increments were caused by climate extremes, especially by extreme frosts and winter desiccation in early spring. With respect to temperatures the negative year 1980 was the coldest year in the history of climate measurements (3.4 °C, average of 1975–2015 – 5.0 °C) along with the coldest April (0.8 °C, average of 1975–2015 – 3.7 °C). In cultivated spruce stand, from the aspect of altitude above sea level with precipitation deficit, the negative year is potentiated by very low precipitation in the growing season (383 mm, average 558 mm). Currently (since 2013), an increment reduction is also caused by the low sum of precipitation in the growing season and by bark beetle feeding enhanced by drought.

3.2. Effect of climate factors and air pollution on radial growth of Norway spruce

Average diameter increment in 1975–2015 significantly more positively correlated with monthly temperatures than with precipitation (Fig. 3). Temperature exerted the highest effect on radial growth in climax spruce forests (6 significant months). Specifically for PRP, climate factors had the lowest influence on peaty spruce stand on PRP 4 (2 values), but they exerted the highest influence on climax spruce stand on PRP 11 in the timberline ecotone strongly influenced by a hilltop phenomenon (8 values) where the highest positive value of the correlation was determined in April of the current year ($r = 0.56$).

Considering the effect of monthly temperatures, average diameter increment was in positive correlation with June and August temperatures of the preceding year and with temperatures in February, March and in the growing season of the current year. The highest positive effect of temperatures on radial growth was observed in April ($r = 0.43–0.45$) and in June ($r = 0.30–0.44$; Fig. 3). In the relationship between monthly sum of precipitation and radial growth there was a significant negative correlation only with precipitation in April of the current year ($r = -0.29 - -0.39$).

The main factor influencing the diameter increment of spruce in study area according to regression quadratic model was identified the temperature (Fig. 4). Annul average temperature had significantly higher effect on radial growth compared to annual sum of precipitation. Diameter increment only slightly increased with increasing precipitation, while optimal growth was observed in

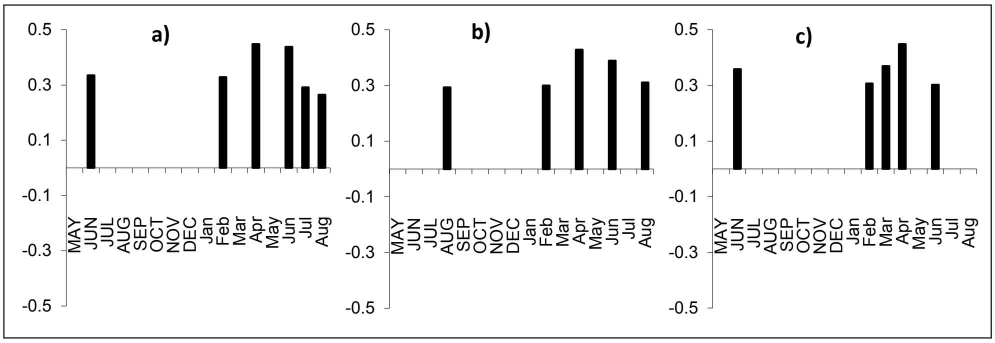

Fig. 3. Coefficients of correlation of the regional residual index tree-ring chronology of spruce with average monthly temperature from May of the preceding year to August of the current year in the period 1975–2015 in a) climax stands, b) peaty stands and c) cultivated stands; statistically significant ($p < 0.05$) values are highlighted in black (positively). Capital letters indicate the months of the preceding year and the lower-case letters the months of the current (given) year.

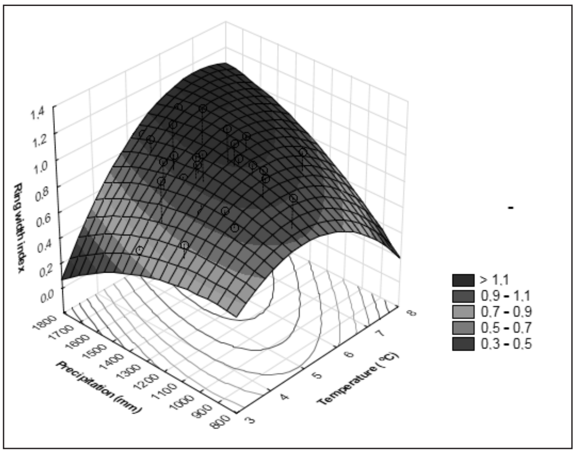

Fig. 4. Response of mean ring width index of spruce to annual sum of precipitation and annual mean temperature for all stands (regression quadratic model, years 1975–2015).

the range of annual air temperature from 5 to 6.5 °C. Only a small difference was found between variants of spruce stands, while the lowest effect of temperature on the growth was observed in a cultivated stand. According to hydrothermal index K, climate (combination of temperature and precipitation) had the significant positive impact on radial growth in April of the current year in peaty ($r = 0.40$, $p < 0.01$) and climax stands ($r = 0.36$, $p < 0.05$).

Correlations between the radial growth of climax, peaty and cultivated spruce forests and climate and air pollution factors are illustrated in Table 2. Of all studied factors maximum and average SO_2 concentrations had the highest negative effect on spruce radial growth ($p < 0.001$). Specifically for PRP, SO_2 concentrations had the highest negative effect on radial growth in peaty spruce stand on PRP 4 and on the growth of climax spruce stands on exposed PRP 11 and on waterlogged PRP 5 ($p < 0.001$), while the lowest effect was found out on PRP 54 ($p > 0.05$). NO_X concentrations were also in significant negative correlation with spruce radial growth. The exposure index AT40F had a negative effect on spruce radial growth, but it was not statistically significant ($p > 0.05$). The effect of temperature on spruce radial growth was significant. The highest effect on radial growth ($p < 0.001$) was exerted by average annual temperature and by average temperature out of the growing season of the current year. The radial growth of climax and peaty spruce stands was in strong correlation with average temperatures in June and July ($p < 0.001$). However, the precipitation did not have any significant effect on the radial growth of spruce stands ($p > 0.05$).

3.3. Interactions between radial growth of spruce, climate and SO_2 concentrations

The results of PCA are represented in an ordination diagram in Fig. 5. The first ordination axis explains 52.4% of data variability, the first two axes together explain 82.6% and the first four axes 92.4%. The x-axis illustrates the radial growth of spruce stands along with SO_2 concen-

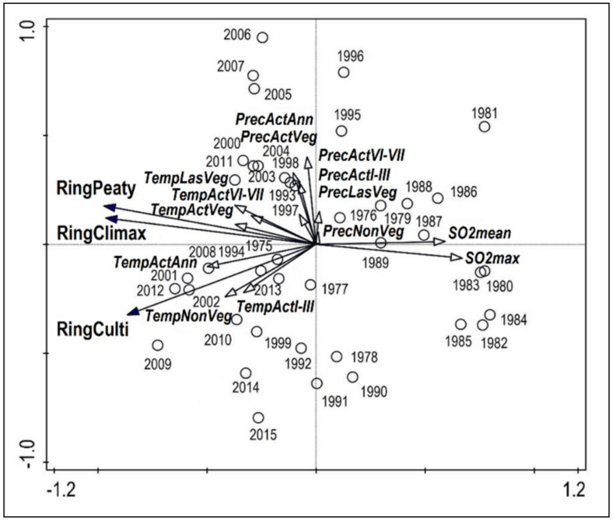

Fig. 5. Ordination diagram of PCA showing relationships between climate data (Temp – mean temperature, Prec – precipitation, Act – current year, Las – preceding year, Veg – growing season, NonVeg – non-growing season, I–III, VI–VII – months), SO_2 concentrations (mean – mean annual concentration, max – maximum concentration) and tree-ring width (Ring – tree-ring width) of climax, peaty and cultivated stands; codes – indicate years 1977–2015.

Table 2. Correlation matrix describing interactions between the radial growth of various spruce stands, precipitation and temperature (1975–2015) and concentrations of SO_2 (1975–2015), NO_X (1992–2012) and AOT40F (1996–2012). Significant correlations are designated by * ($p < 0.05$) and ** ($p < 0.01$).

Ring width index	SO_2 conc. mean [μg m^{-3}]	SO_2 conc. max [μg m^{-3}]	NO_X conc. mean [μg m^{-3}]	NO_X conc. max [μg m^{-3}]	AOT40F [ppb h^{-1}]	Temp. ActAnn [°C]	Temp. ActVeg [°C]	Temp. LasVeg [°C]	Temp. NonVeg [°C]
Climax stands	−0.39**	−0.59**	−0.58*	−0.56*	−0.30	0.53**	0.42**	0.29	0.42**
Peaty stands	−0.48**	−0.62**	−0.61**	−0.63**	−0.33	0.45**	0.38*	0.33*	0.32*
Cultivated stands	−0.31*	−0.48**	−0.64**	−0.58*	−0.36	0.36*	0.14	0.16	0.44**

	Temp. ActI–III [°C]	Temp. ActVI–VII [°C]	Precp. ActAnn [mm]	Precp. ActVeg [mm]	Precp. LasVeg [mm]	Precp. NonVeg [mm]	Precp. ActI–III [mm]	Precp. ActVI–VII [mm]	Ring width
Climax stands	0.34*	0.46**	0.09	0.11	0.09	0.00	0.17	0.01	1.00**
Peaty stands	0.26	0.39**	0.09	0.10	0.07	0.01	0.15	−0.00	1.00**
Cultivated stands	0.34*	0.10	−0.04	0.05	0.09	−0.09	−0.06	−0.02	1.00**

Explanatory notes: $SO_2(NO_X)$mean – mean annual SO_2 (NO_X) concentration, $SO_2(NO_X)$max – maximum SO_2 (NO_X) concentrations, AOT40F – ozone exposure, TempActAnn – mean annual temperature of the given year, TempAct(Las)Veg – mean temperature in the growing season of the given (previous) year, TempNonVeg – mean temperature in the non-growing season, TempActI-III(VI–VII) – mean temperature in January–March (June–July) of the given year, PrecActAnn – annual sum of precipitation of given year, PrecAct(Las)Veg – sum of precipitation in the growing season of the given (previous) year, PrecpNonVeg – sum of precipitation in the non-growing season, PrecActI–III(VI–VII) – sum of precipitation in January–March (June–July) of the given year.

trations and the second y-axis represents the precipitation amount. SO_2 concentrations (average and maximum ones) are negatively correlated with spruce radial growth, especially in peaty and climax spruce stands. Spruce increment is in positive correlation with temperature, mainly with average temperature in the growing season and average annual temperature of the current year. Overall, the effect of temperature on increment is more significant in comparison with precipitation. Precipitation out of the growing season was the smallest explanatory variable in the diagram. In the first half of the studied period (the 80s and 90s of the 20th century) the increment was strongly influenced by SO_2 concentrations while in the second half of the studied period (after 2000) there was a closer correlation between increment and temperature.

4. Discussion

After the start of great air pollution stress in the Krkonoše Mts. in the late 70s and in the early 80s of the 20th century the synergism of air pollution, climate extremes and biotic pests caused substantial deterioration of the health status of spruce forests, which is evident not only on the foliage of these stands but also on the dynamics of radial growth (Král et al. 2015).

The regional standard tree-ring chronology in the Jizerské hory Mts. indicates a slow decrease in radial increment in 1979–1987. The situation was similar in mature spruce stands in mountain areas in the north of the Czech Republic (Sander et al. 1995; Kroupová 2002; Vejpustková et al. 2004; Kolář et al. 2015; Král et al. 2015; Vacek et al. 2015). These authors concluded that a heavy pollution load of mainly SO_2 emissions in the 70s and 80s of the 20th century in combination with climate factors was a cause of the increment decrease. Since the mid-1990s a gradual increase in radial increment has been observed until now. This period has been characterized by mild winters without great temperature extremes, relatively high temperatures in the growing season, more or less normal precipitation and also by a decrease in air pollution but with high NO_X depositions (Vejpustková et al. 2004). In our case the period of increased increment was interrupted by its pronounced decrease in the period 2008–2015.

A low radial increment was confirmed by the analysis of negative pointer years. In 1979 it was a consequence of the fast temperature drop at the turn of 1978/1979, when the temperature dropped by nearly 30 °C within 24 hours; in 1980–1986 it was due to the synergism of air pollution and climate stress, and in 1996 and 2010 it was mainly a result of winter desiccation of the assimilating organs in early spring (necrotic disorders of great extent).

Similar results of the pattern of diameter increment and its response to climate factors were obtained in the Orlické hory Mts., in peaty spruce forests in hilltop parts (1,035–1,075 m a.s.l.) and also in spruce stands in the environs of the Anenský vrch Hill at an altitude of 830–910 m (Rybníček et al. 2009; Vacek et al. 2015). Similarity mainly lies in an increment decrease from the 1970s approximately to the mid-1980s and in its increase in the 1990s of the 20th century. Some negative pointer years, 1979 and 1981, were identical.

By 1977 there was a clear relationship between the occurrence of negative pointer years and climate extremes when the forest stands respond more or less to the specific site and stand conditions in higher parts of the Krkonoše Mts. Similarly like in the Krkonoše Mts. in 1977–1992, this period was critical for spruce stands also in Jizerské hory Mts. in 1979–1986, in Orlické hory Mts. in 1979–1987 and in Krušné hory Mts. in 1977–1989. According to Kroupová (2002) increments of spruce were extremely low (a decrease by 50% on average) in the Krkonoše and Jizerské hory Mts. in 1979–1989. A high frequency of disorders in tree-ring formation was observed. The negative effect of air pollution stress was repeatedly proved in many other papers (e.g. Feliksik 1995; Juknys et al. 2002; Bošela et al. 2014; Vacek et al. 2017b). In the second half of the nineties of the 20th century radial increment was gradually increasing. An evident increase in spruce radial increment in that period was reported from the Orlické hory Mts. (Rybníček et al. 2009; Vacek et al. 2015; Králíček et al. 2017), from the Krkonoše Mts. (Kolář et al. 2015; Král et al. 2015) and from the western Polish Beskids by (Wilczyński & Feliksik 2005). The curves of regional standard chronology from our monitoring in the Krkonoše Mts. are consistent in principal features with the findings of Král et al. (2015), Kolář et al. (2015) from the Krkonoše Mts. and of Šrámek et al. (2008) from the Silesian Beskids. Bošeľa et al. (2016) also documented an increase in stand productivity in the whole of Central Europe in the second half of the 20th century, but they identified the years 1976 and 2003, when there was a very dry period with a negative impact on increment.

The interpretation of radial increment correlations with average monthly temperatures and precipitation is rather complicated because the growth process is influenced by a number of factors, particularly in peaty spruce stands in conditions of extreme frost hollows. A positive effect of rainfall in July of the preceding year and temperatures in July of the current year on radial increment can be explained by conditions in the period when a great part of radial increment is produced. This is consistent with the conclusions of Hlásny et al. (2017), who stated that increment of spruce was influenced mainly by rainfall in June at lower locations and by temperature at high altitudes above sea level.

A positive effect of temperatures in June and July, like in our study, was well documented in Norway spruce at many other mountain and high-altitude locations (Savva et al. 2006; Büntgen et al. 2007; Rybníček et al. 2010; Treml et al. 2012). July has been the warmest month of the year at these locations for a long time. Hence temperatures do not constrain the growth if the water reserve in soil is sufficient. If the water amount is reduced, stress as an increment decrease is usually manifested a year later. Similar results showing a positive effect of temperature in July and August on spruce growth were also obtained in foothills spruce forests in the Western Carpathians (Bednarz et al. 1999), in spruce forests on northern slopes of the Krkonoše Mts. (Sander et al. 1995; Král et al. 2015), in spruce stands in the Orlické hory Mts. (Rybníček et al. 2009; Vacek et al. 2015) and in the Polish Tatras (Feliksik 1972) or in spruce stands in Norway (Andreassen et al. 2006). Positive correlations of spruce radial growth with summer temperatures were also found out at lower altitudes above sea level in the French Alps (Desplanque et al. 1999) or in the Polish Beskids (Feliksik et al. 1994). The relationship between radial growth of spruce and temperature with precipitation during the growing season was described in a similar way in Germany by Kahle & Spiecker (1996), Dittmar & Elling (2004), in Finland by Mäkinen et al. (2001), in Switzerland by Meyer & Bräker (2001), within Central Europe by Zimmermann et al. (2015) and in Poland by Koprowski & Zielski (2006). The latter authors stated that along with climate factors (precipitation and temperature) the radial growth was also influenced by fructification, increased CO_2 level in the atmosphere, nitrogen compounds and UV radiation. Other factors influencing increment are competition (Rohner et al. 2016), nutrient availability (Weber et al. 2015) and biotic agents (Rolland et al. 2001).

The effect of October temperature of the preceding year is usually related with an extension of the short growing season. October and November can provide conditions allowing the root growth in the soil with hitherto favourable temperature above the frost point, supporting needle maturation, shoots and buds (Fritts 2001; Oberhuber 2004; Savva et al. 2006; Rybníček et al. 2010; Treml et al. 2012).

A negative effect of rainfall on radial increment in April of the current year in peaty spruce stands in the Krkonoše Mts. was reported by Král et al. (2015). According to Primicia et al. (2015) these relationships are substantially influenced by the stand structure. We observed this situation on plots that were most severely affected by air pollution and bark beetle disturbance in the late seventies and in the first half of the eighties of the 20th century. These were peaty spruce stands and forest stands in the timberline ecotone. Similar findings from mountain spruce stands at the timberline were reported by Vacek et al. (2010) and Treml et al. (2012) from the Sudetes Mts. range and by Parobeková et al. (2016) from the Low Tatras.

Climate changes and air pollution are integrating influences that affect in forest ecosystems species composition and species distribution, soil environment, health status, water availability and tree growth (Bytnerowicz et al. 2007), which is quite explicitly obvious from results of our study. Thus climate changes and particularly higher temperatures have clear impacts on the whole ecosystem. Higher temperature affects sum of precipitation and modifies the stand production and increases the weathering rate, which enhances the vulnerability of forest ecosystems (Posch 2002). The long-term climate data in the Krkonoše Mts. document that since the beginning of observations average annual temperature has increased by 1.0–1.5 °C and average annual sum of precipitation has decreased by 80–130 mm (Czech Hydrometeorological Institute). It is also necessary to take into account that the proportion of horizontal precipitation has declined considerably since the 1980s due to the destruction of studied forest stands, from 25% to 15% (Vacek et al. 2007). Rising annual temperature increases not only evaporation but also water transpiration by the assimilating organs (Vacek et al. 2015). In general, there occurs a substantial decrease of the water amount in the total water balance, and in some seasons of the year it causes water deficit and reduction in spruce increment (Kmeť et al. 2010; Vacek et al. 2013a, 2013b).

Climate changes can also make the problems of soil acidification worse because they increase the production and subsequent deposition of HNO_3 and NO into soils. They also participate in an increase in the portion of NH_3 converted into ammonium sulphate, which can lead to further soil acidification (Sanderson et al. 2006). The influence of climate changes on growth has a generally positive impact on the increment of forest stands investigated in our study, but on condition that water is not a strongly limiting factor. This finding is consistent with the results of Laubhann et al. (2009), when based on a multivariate analysis the authors found out a statistically significant effect of climate warming on 152 spruce stands across Europe. Solberg et al. (2009) confirmed a positive effect of an increase in temperature on spruce growth if the growth was not limited by water deficit. It explains why worse water availability on the studied plots has caused a decrease in the increment of the studied stands after 2008. Before that year the presented results of this study, if taking into account development after a heavy air pollution stress, are consistent with the expected increased increment due to rising temperature (Myneni et al. 1997; Ceppi et al. 2012). Nevertheless, an increment decrease observed in our study after 2008 is relatively significant and it was highly probably caused by diminished water availability, which was confirmed by Schuster & Oberhuber (2013), who supposed the sum of precipitation, particularly the total precipitation amount in the months of May and June, to be the main factor correlating with radial growth. Radial growth is much more constrained in older trees at diminished water availability (Pichler & Oberhuber 2007) because ecophysiological studies have demonstrated that changes in the tree size are related with changes in physiological processes taking place in trees during their senescence (Mencuccini et al. 2005). Currently, the studied spruce forest stands are influenced mainly by the increasing air temperature (Mérian & Lebourgeois 2011; Bennet et al. 2015). However, a greater constraint stemming from diminished water availability is usually manifested as a limiting factor mainly in lowlands although surprisingly it can also become a limiting factor at higher altitudes where particularly temperature is usually a limiting factor (Etzold et al. 2014). In connection with diminished water availability and more frequent and longer-lasting spells of drought there subsequently arises a risk of bark beetle attacks to spruce stands, which further deteriorates the health status of stands and in extreme cases the complete dieback of tree layer may occur (Kovářová & Vacek 2003; Krejčí et al. 2013).

5. Conclusion

In 1979–1991 in the Krkonoše Mts. the health status of spruce stands and their vitality were considerably deteriorated as a consequence of the synergism of climatic and air pollution stress, especially of high SO_2 concentrations. Since the second half of the nineties of the 20th century the health status of spruce stands has been relatively stabilized, with regard to both their radial increment and the trends of living tree foliage. Forest sanitation in adjacent forest stands contributed to the stabilization of these stands when insect pests, especially the eight-toothed spruce bark beetle, were radically eliminated. Nowadays, the studied mountains stands are influenced mainly by increasing temperature and climatic anomalies. From the analysis of air pollution, climatic and growth factors in the Krkonoše Mts. results, that there still exist predisposing factors that within synergic effects have a potential to evoke gradual decline or dieback of the studied stands. In future the rigorous respect of natural processes in these stands during their management can contribute to the alleviation of negative effects of expected climate changes. In conclusion, the dendrochronological analysis is a useful tool for the evaluation of various disturbances within temporal growth trends.

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ORIGINAL PAPER

Instrumental analysis of health status of *Quercus petraea* stands in the Carpathian Basin

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Abstract

Numerous prognoses indicate that climate change will manifest itself in extreme climatic conditions. Therefore, it will be of high importance to know in what extent can plant communities and certain species adapt to altering environmental conditions. Our examinations were implemented in stands of sessile oak common in the Carpathian Basin. The reason behind it has been that, according to climatic models, the realized niche of this species can be reduced by 80% in some regions by 2050. Examinations were made in 3 points of an approximately 400 km long (East-West) transsect crossing the Carpathian Basin: 3 submontane regions of a subatlantic, a continental and a subcarpathian mountain were involved with 5 age groups in each regions. Health status examinations of sessile oaks have been completed by using FAKOPP 3D acoustic tomograph. Among the three venues trees of the subatlantic area were the healthiest; here, the 100 years old age group showed the lowest deterioration, only 0.68%. The most severely deteriorated stands occur in the continental region where the value in the 60 years old age group reached 4.24%. It seems that, besides annual precipitation, the method of planting also influences the health status of stands, since considerable differences could be observed between coppice and seedling stands.

Key words: sessile oak; Central Europe; acoustic tomograph; age groups; layers

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1. Introduction

It can be generally stated that responses of life forms regarding climate change alter by regions and also by species. Researches fulfil important roles in the exact and reliable predictions about changes occurring in relation of time and space (e.g. Walther et al. 2002; Root et al. 2003; Parmesan & Yohe 2003; Parmesan 2006).

Based on the trend analyses related to the second half of the 20th century and involving the Carpathian Basin temperature rise, decrease of precipitation and more extreme precipitation conditions – regarding both frequency and quantity – can be clearly observed (Domokos 2003).

According to the result of modelling Bartholy & Schlanger (2004) states that (+0.8) – (+2.8) °C temperature change can be expected by 2050 while this value can be as high as (+1.3) – (+5.2) °C by 2100. As for modelling precipitation (−1) – (+7)% and (−3) – (+14)% can be foreseen by 2050 and 2100, respectively. Calculations made within the model indicate that winters and springs will be more humid while summers and autumns will be more arid compared to the present situation.

Several studies state that climate-determined transitional zones will react the most sensitive way on climate change (e.g. Risser 1995). Due to their geographical location ecosystems of the Carpathian Basin can be particularly vulnerable to the currently observed and predicted changes of precipitation (Czóbel et al. 2010). However, responses of these ecosystems to these changes are hardly or not known (Czóbel et al. 2008).

Continental xerophytic and mesophytic oaks usually encompass flatlands in the Carpathian Basin while following the lines of mid-mountains. Extremely arid areas of these mid-mountain ranges with their shallow topsoil are not favourable for the closed stands since water is the limiting factor for these communities (Borovics & Mátyás 2013; Trenyik et al. 2017). Numerous publications mention the fact that some severe drought periods affected the Carpathian Basin since the 1970s due to the extremities of the climate (Pieczka et al. 2011). Parallel to this aridification the decay of main tree species has been

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Corresponding author. Petra Trenyik, e-mail: trenyikpetra@gmail.com, phone: +36 30 5242 789 observed. Among them the deterioration of sessile oak (*Quercus petraea*) has been remarkable. The reason of this process was investigated by numerous researchers such as Jakucs et al. (1988) and Berki (1991). Eventually Vajna (1990) provided the answer for this rather complex issue. In his opinion arid years are responsible for the decay of oak trees. Parasite fungi and folivorous insects appear, in great numbers, on trees weakened by the lack of water. Later it has also been observed that in those stands where the climate is close to the tolerance limit of the stand the vitality of tree species is compromised (Szőllősi et al. 2008).

Some prognoses indicate the narrowing of the realized niche optimal for sessile oak; according to Czúcz et al. (2011) this narrowing process can reach 80 to 100% by 2050.

The FAKOPP 3D Acoustic Tomograph is a mobile instrument suitable for field research. It is suitable for determining the extent of rotting by using a method not destroying tree tissue. Parallel to the fibers the propagation speed of sound can reach 4000 to 5000 m/s; it is 15 times faster than in the air. FAKOPP has been developed based on this considerable difference as well as on the fact that propagation speed of sound waves is in strong correlation with the mechanical characteristics of wood substance (Divós & Divós 2005). This advanced method of examination measures the propagation speed of sound within the tree. The existence of deterioration and cavities are mapped by identifying the change of propagation speed(Divós et al. 2005, 2008).

FAKOPP is generally used in case of park trees in order to examine the health status of one specimen. There was no previous example of using it on sessile oak (*Quercus petraea*) in systematically selected places and age groups, thus our examination can be considered as novum.

Limited amount of international literature can be found about acoustic tomograph examinations. Among them FAKOPP has mainly be used with the goal of examining the accuracy of the instrument. Liang (2008) compared in several cases the extent of deterioration indicated by the instrument and the heartwood formation that could be seen after felling. The result of this examination was that in case of trees where internal check had been found in the trunk the instrument typically slightly overestimates the extent of deterioration. Wang et al. (2007, 2008) drew the same conclusion when examining the health status of *Prunus serotina* trees.

Similar examination were carried out by Wang et al. (2007, 2008) involving 200-year-old red oak (*Quercus rubra*) trees, although they implemented, beside using FAKOPP, visual inspections regarding the health status of trees. After cutting the examined specimens it was experienced that problems could generally be identified by both methods, however the instrument was able to determine the extent and place of deterioration, too.

The objective of our examinations was to reveal, by instrumental measurements, the health status of sessile oaks in 5 different age groups in 3 mid-mountain regions alongside the West-East transsect. Our presupposition was that the health status of oaks is related to the precipitation conditions; as a result of it the changes influence younger age groups as well. The three selected mountain ranges have different climatic features: travelling from West toward East the first, second and third mountain has subatlantic, continental and subcarpathian climate, respectively.

2. Materials and methods

Our examinations have been implemented in three different mountain ranges within the Carpathian Basin. These ranges are situated at the ends and the middle of a 400 km long East-West orientation transsect in the Carpathian Basin. The westernmost among them is the Kőszeg Mountains having subatlantic climate; the middle one is Börzsöny with continental climate and at the eastern end Zemplén Mountains have subcarpathian climate.

Five forest age classes were selected in each mountains; they represented five age groups from 20 to 100 years in 20 years intervals (Table 1). The following standard parameters were taken into account during selection so that data could be comparable: similar altitude above sea level (approx. 400 m), slope angle (<15°) and southern exposure. Furthermore, sessile oak (*Quercus petraea*) shall have be the main species of the stands (at least 70% of the canopy). Local forest management units helped in finding and selecting the suitable stands.

Table 1. The forest management units of the studied forest.

Age group	Kőszeg Mountains	Börzsöny Mountains	Kőszeg Mountains
20 years	Kőszeg 22 C	Diósjenő 27 A	Nagyhuta 109 A
40 years	Bozsok 10 A	Diósjenő 34 C	Nagyhuta 109 B
60 years	Bozsok 16 C	Diósjenő 31 B	Komlóska 53 D
80 years	Bozsok 17 E	Diósjenő 34 B	Makkoshotyka 15 A
100 years	Bozsok 15 C	Börzsöny 43 C	Háromhuta 101 D

Two 20 by 20 metre quadrats were delineated in each subcompartment. Sessile oak trees nearest to the corners of the quadrat as well as the one nearest to the middle of it were appointed as sample trees. Thus five sample trees were selected in each quadrat and 10 in each age group. Trunks of the sample trees were measured in five different heights (40 cm, 80 cm, 120 cm, 160 cm and 200 cm) by horizontally inserting the sensors. Due to the smaller diameter 6 sensors were installed in the two youngest (20 and 40 years) stands while 8 sensors were used in all the other ones. By completing the measures the extent of deterioration was revealed in percentage. Existence, size and location of frost ribs was also documented.

Annual average precipitation data provided by the Hungarian Meteorological Service were also used during the assessment. These data were recorded between

1961 and 2015 at certified weather stations nearest to the selected stands.

For normally distributed data the t-test was applied to identify significant differences between datasets. Statistical analyses were calculated using SigmaPlot2000 (SPSS Inc., Chicago, USA). Regressions and correlations were fitted and computed using SigmaPlot2000.

3. Results

3.1. Twenty years old stands

The stand in continental mountain was the healthiest: the extent of deterioration was only 1.5% within the youngest age group (Fig. 1). The 20-year-old stand of the subatlantic mountain was in slightly worse condition: the measured decay was 1.88% considering all values recorded in the five layers. It can clearly be seen by the figure that the highest rate of decay was measured in the subcarpathian region: the value was 3.46%. Similar trend can be observed as regards of standard deviation calculated within the layers: its range was between 0.29 and 1.77 in the subatlantic mountain; between 0.99 and 3.00 in the continental mountain, while it shows the highest values between 0.65 and 3.52 in the subcarpathian mountain.

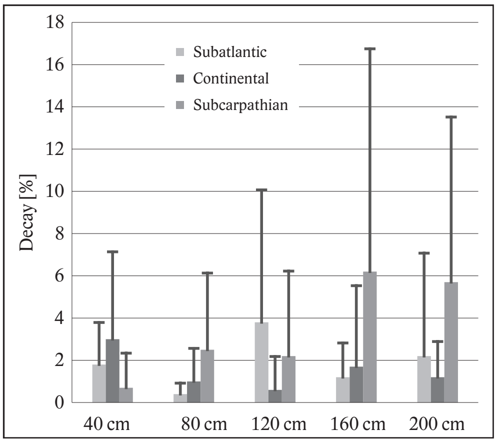

Fig. 1. Average decay and standard deviation of 20 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.2. Forty years old stands

In case of this age group different data of average deterioration were compared to the younger trees. The healthiest stand was found in the subatlantic mountain, where the extent of decay was only 0.9%, followed by 1.54% measured in the subcarpathian mountain and 2.14% decay in the continental mountain (Fig. 2). Deterioration rate was dispersed between 0.1 and 2 in the subatlantic mountain, since the standard deviation reached only 0.77. As for the continental mountain the extent of decay was between 0.7 and 3.7 in the different layers, thus the standard deviation was 1.33. The highest deterioration and standard deviation was recorded in the lowest layer of tree trunks in the continental mountains: the decay reached 3.7% with a standard deviation of 5.85. At the opposite end the smallest deviation and deterioration were observed in the 4th layer of the subatlantic mountain: the decay was only 0.2% with a standard deviation of 0.42.

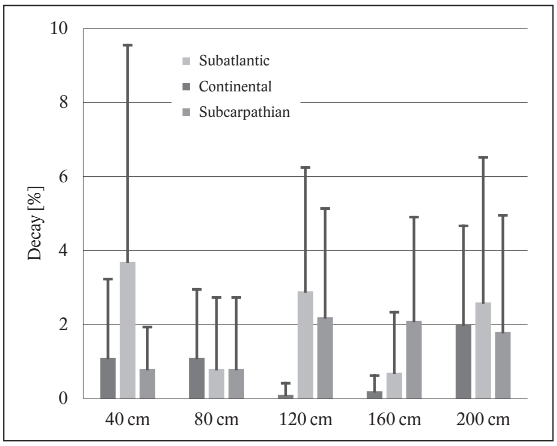

Fig. 2. Average decay and standard deviation of 40 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.3. Sixty years old stands

In case of 60-year-old trees deterioration was clearly the lowest in subatlantic and subcarpathian mountains; on the contrary, remarkably high values were measured regarding oaks of the continental mountain (Fig. 3). Average rate of decay was only 0.8% in the subatlantic mountain with the fluctuation between 0.5 and 1.2% in the different layers. Standard deviation was also low: 0.29. Average level of deterioration was 4.24% accompanied by a high rate of standard deviation (3.00) since the amount of decay was distributed between 1.6 and 9% in the continental mountain. Average deterioration in the subcarpathian mountain was 1.44%; the values were dispersed between 0.5 and 2.2% within the layers and, as a result, lower standard deviation (0.65) was calculated. Both the decay and the standard deviation reached outstanding values (3.7% and 5.85, respectively) in the lowest layer of tree trunks in the continental mountain. It can be stated that in this age group the highest (i.e. 5th) layers show the least amount of deterioration: this value was 1.2%, 1.6% and 1.7% in the subatlantic, continental and subcarpathian mountains, respectively. Low standard deviation were associated to these small deterioration rates: 2.39 in subatlantic, 0.96 in continental and 2.98 in subcarpathian mountain.

As a result of the statistical analysis significant difference has been identified in the 60-year-old age group among the three mountains /continental-subatlantic ($p<0.05$); continental-subcarpathian ($p<0.05$); subatlantic-subcarpathian ($p<0.05$)/.

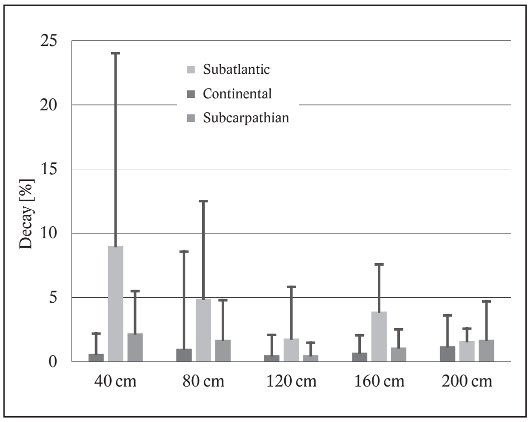

Fig. 3. Average decay and standard deviation of 60 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks

3.4. Eighty years old stands

In each of the three regions greater extent of deterioration was observed regarding this age group and standard deviation values were also higher. Average decay was 3.34% in the subatlantic mountain with the fluctuation between 1 and 5.3% among the layers. Remarkably high decay (between 2.8 and 5.3%) and deviation (between 8.02 and 10.53) was measured in the lower three layers. As regards of the continental mountain average decay level was 1.94% with a standard deviation of 1.29. In this case the lower two layers had the greatest deterioration: 3.4% and 3.1%. Their respective standard deviation values were 4.55 and 4.20. In the subcarpathian mountain the average decay level reached only 1.26% accompanied by 1.61 standard deviation; the rate of deterioration was between 0.2 and 4.1%. The first layer had 4.1% decay and a considerably high standard deviation of 10.92.

We found significant differences between subatlantic and subcarpathian stands ($p<0.05$).

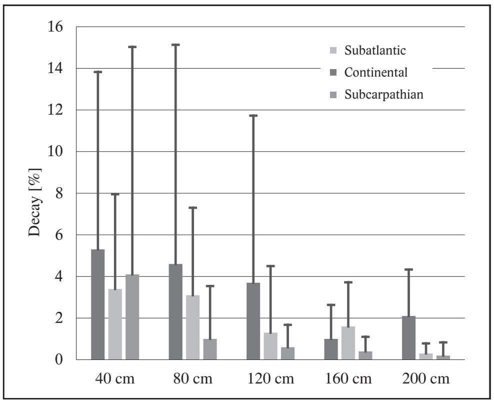

Fig. 4. Average decay and standard deviation of 80 years old Quercus petraea trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.5. Hundred years old stands

As for the oldest examined trees the highest extent of decay was measured in the subcarpathian mountain (Fig. 5). The subatlantic stand was the healthiest: its average decay was only 0.68% dispersed between 0.3 and 1.2% among the layers. The average standard deviation was also low: 0.34. Deterioration of sessile oaks in the continental mountain was measured 2.78% with a low deviation of 1.15. It is due to the fact that decay values fluctuated between 1.8 and 4.6%. Average deterioration in the subcarpathian mountain was 3.42% while the standard deviation was higher: 3.52. The lowest two layers had both the highest decay and deviation. The former was 7.9% and 6.4%; the latter 11.23 and 9.58, respectively.

We found significant differences between continental and subcarpathian stands ($p<0.01$). The assessment of average decay divided by layers of the different mountains provided only one significant difference, namely between the 4th layers of continental and subatlantic stands ($p<0.05$). Statistical analyses were implemented among the different age groups within each of the three mountain types, but no significant differences were found among the stands selected in continental, subatlantic and subcarpathian mountains.

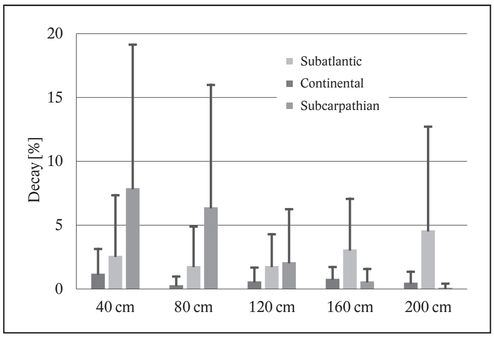

Fig. 5. Average decay and standard deviation of 100 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.6. Assessment of precipitation data

After processing the precipitation data the results were indicated together with the rate of decay (Fig. 6). Based on the average precipitation recorded in the last 50 years the continental mountain proved to be the wettest (686 mm), followed by the slightly drier subatlantic mountain with 632 mm, while the subcarpathian mountain received the least precipitation (590 mm). As far as the health status is concerned the continental mountain provided the highest value of deterioration: 2.52%. The subcarpathian mountain came second with 2.24% and the subatlantic region had the lowest value: 1.52%.

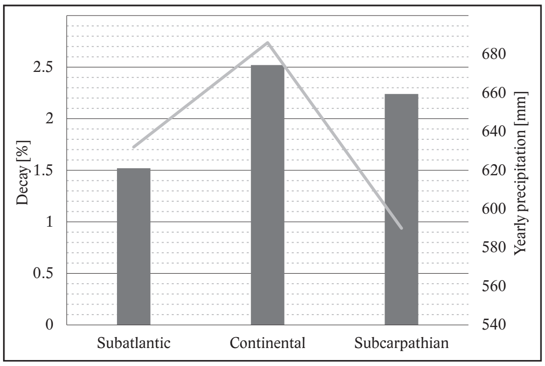

Fig. 6. Average decay (%) of *Quercus petraea* trees and average yearly precipitation (mm) in the examined mountains of the Carpathian Basin.

4. Discussion

Mátyás et al. (2010) and Czúcz et al. (2011) examine the climatic tolerance of tree species in Europe with particular attention to drought-tolerance of species. They concluded that in case of both beech and oak temperature and precipitation are two factors determining the distribution of species and the creation/vanishing of places macroclimatically suitable for these species. Although only precipitation conditions were involved in our examination, higher average decay was observed in the subcarpathian region where the annual amount of precipitation is lower as opposed by the subatlantic mountain where precipitation level is higher and the extent of deterioration is lower.

Berki et al. (2016) examined, via a survey implemented in 30 years, the vitality-decrease of oak trees occurring in arid periods. They found that the health status is around 70 to 90% in wetter areas (100% – completely healthy; 0% – dead) and approximately 50% in zones close to the aridity limit.

Results, released by the Forestry Protection Network of Hungary, based on leaf fall examination showed that beech and hornbeam trees are the healthiest among the stand-forming tree species of the region. Softwoods, poplars and other hardwoods are in moderate health condition while the health status of oak and coniferous forests is the worst.

Researches deal with the health of oak forests not only at stand level but also regarding specimens. Szőlősi et al. (2008) and Mészáros et al. (2007) examined the ecophysiology features that influence the climatic sensitivity of sessile oak (*Quercus petraea*) and Turkey oak (*Quercus cerris*). What kind of physiological reactions do they provide against the climatic fluctuations in their vegetation periods? What are their mechanisms protecting them during potential water utilisation disorders occurring in drought periods? In case of sample trees of both oak species they found that temperature and precipitation conditions during the leaf forming period have considerable influence on the size and mass of assimilating foliage developed in the vegetation period. Drought occurring in the leafing period can have serious effects on not only the rate of leaf forming but also on the annual production of the trees. On the one hand, production of organic matter and its storage determining the physiology for the next year is decreased. On the other hand, trees reaching a weakened health would be exposed to pests and other harmful organisms. In case of the examined oak species the photosynthetic apparatus shows great vulnerability and sensitivity for abiotic stress factors during spring.

Several instrumental examination involved the health status check of sessile oak stands. Trenyik et al. (2016) experienced deterioration patterns similar to our results in case of protected stands older than 100 years. This kind of decay is the most severe around the old root collar. During a FAKOPP examination implemented in different areas on old tree stands, beside the decaying trend characteristic of coppice stands, patterns of deterioration caused by frost ribs could also be identified (Trenyik et al. 2017a). In case of an other instrumental health survey check involving more stands of sessile oak it was concluded that lower average annual precipitation is paired with higher level of decay (Trenyik et al. 2017b).

In our examinations two trends were observed within each mountain regarding the distribution of deterioration among age groups. While generally lower rate of decay was measured in more layers in case of seedling stands, the highest level of deterioration was identified in the lowest layers (with a decrease in higher layers) in case of coppice stands. Following the assessment of our measurements in 3D and that of the notes made during field examinations the first of these trends was attributed to frost ribs and the decay initiated by them. As for the second trend the decay starting from root stock and typical of coppice trees was made responsible (Blake 1983).

5. Conclusions

Monitoring of the health status of forests has a long history, although its importance has increased due to climate change. More and more scientific researches aim to determine the climatic tolerance of certain species. Our examinations corroborate the results of health status checks implemented on oak trees in the Carpathian Basin. We were able to create a more exact and more delicate picture due to the instrumental measurement. Our examinations provided a clear view of the health of different age groups via the extent of decay in the tree trunks.

Our research has not justified the fact that precipitation conditions have strong impact on the health status of sessile oaks (Szőllősi et al. 2008). The reason behind it could be that differences among the average precipitation were small as regards of the involved mountains. That is why it is so important to acquire information on the climatic tolerance of main stand-forming tree species as well as to forecast, as accurately as possible, the impacts of climate change. The role of forest management will be even more significant so that stands with appropriate climate tolerance would be planted to the appropriate places.

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ORIGINAL PAPER

Influence of forest growth conditions on the density of wood in the Amur region

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Abstract
In the system of logging machines, a factor such as the density of wood affects all components of the system. However this dependence can be more noticeable in the performance of wood felling, where logging machines have approximately the same saw body, such as a chain saw. In this regard, the problem of determining the dependence of the chainsaw on the density of wood, substantiation of effective options for the number of chainsaws in the assortment and whiplash method of logging is quite relevant. In the Far East of Russia, in particular, in the Amur region, the forest growth conditions are different from the western ones and therefore the properties of the woof differ from the generally accepted ones. The article describes forest growth conditions that influence the properties of the wood in areas of the Amur region. Using the method of density determination, the density of larch, pine and birch were studied first time in the areas of the region. The dependence of the density on humidity, age, species, season of the year and the area of growth was found out. The research results showed that in the Amur region at a humidity of 70% the density of larch varies from 745 to 1 089 kg m^{-3}, pine from 435 to 1 081 kg m^{-3}, birch from 403 to 878 kg m^{-3}.

Key words*:* Russian Far East; larch; pine; birch; wood density; wood moisture content

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1. Introduction

In modern conditions of economics the manufacturing of ecologically safe products, such as products made of wood, is an important theme for entrepreneurs and investors (Wang et al. 2000). While harvesting and processing wood, it is necessary to take into account the following factors: the thickness of trees in the forests in use and the number of trees per unit area; the lay of the land on which the trees in use grow and are subjected to harvesting, soil conditions (type and properties of soil, ground bearing capacity, and so on) and seasons of the year (Grigoriev 2009; Skurikhin & Korpachev 2004; Kostenko 2012).

It is clear that the density of wood taking into account its different properties, but the density of the wood in the Amur region has been studied first time. The values of the density of wood by the areas of growth were implemented into the work of the customs office of the Amur region dealing with the export of the wood into China.

The Amur region is the region that is rich in woods (Yaborov 2005).The existing practice of their one-sided biomass assessment led to a significant decrease of their potential. The Amur region refers to heavily forested territories, its forest cover is 64%; the forests on the whole territory are mountainous, more than a half grows on the perpetually frozen ground, others are on the soils with a long-term seasonal frozen ground (Romanova & Sorvina 2017).

Annual layers affect the chemical composition of cells, and they, in turn, the composition of the soil and climate in the area of larch growth (Earle 2011). The paper (Ugolev 2002) talks about the influence of anthropogenic factor on the thickness of the wood trunk. Data on wood density are published and considered to be generally accepted in Russia. The density of larch at 12% moisture content is 665 kg m^{-3}, pine 505 kg m^{-3} and birch 640 kg m^{-3} (Yaborov 2005). The relative density of pine wood in different forest conditions depends on its anatomical characteristics and is between 0.340 and 0.580 g cm^{-3} (Ugolev 2002). There is a dependence of the wood density and the width of the annual ring on the age of wood (Fries & Ericsson 2006). The influence of stand density on the growth of trees and qualitative characteristics of wood in plantation pine species in China has been studied (Kang et al. 2004).

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Good proof of the fact that conditions of the forest growth influence the density of the wood. In this work there will be studied the forest growth conditions in the Amur region and first time the values of the density will be found and compared depending on the areas from north ones to southern ones (Stanturf & Madsen 2004). The main parameters and characteristics of the total forest area will be the forest cover of the territory, species composition, stock, quantity of mature and overmature trees, the characteristic of dominating species (Peltola et al. 2009).

The total stock of wood is assessed to be 1.9 bln. m^3 (mature and overmature forest is 50.4%), including 1.5 bln. m^3 of coniferous species. The total rated wood cutting is 17.7%, including 9.6 mln. m^3 of really available forest development (Government of the Amur region). The forest area of the Amur region is 64.4%, the reserve per capita is 19.2 hectares of forests and 1.9 thousand m^3 of wood (Yaborov 2005). The forest cover or the ratio of forest land to total land area is found by the ratio of the forest cover area to the total land area and expressed as a percentage. The value of the forest cover in separate areas of the Russian Federation is different and depends on physiographical, climatic and soil conditions. The dynamics of the forest cover is under influence of anthropogenic activities and natural calamities that lead to the forest destruction.

Thus, the aim of the research is to study the influence of forest growth conditions on the density of the wood in the logging areas of the Amur region.

2. Description of forests in Amur region

High forest cover in the Far East of Russia is 50 – 80%, average forest cover is 30 – 45%; below the average is 10 – 25%; low is 2 – 5%.

Fig. 1. Map of the Far East of the Russian Federation.

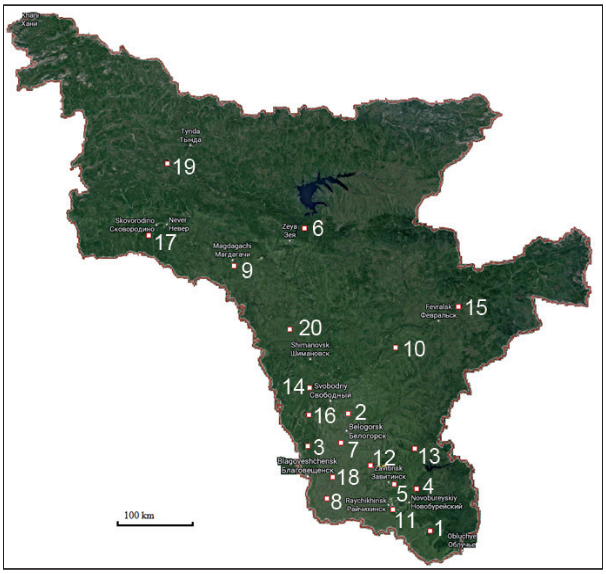

Fig. 2. Map of the Amur region, districts and sampling sites.

Note: 1 – Arkharinsky, 2 – Belogorsky, 3 – Blagoveshchensky, 4 – Bureysky, 5 – Zavitinsky, 6 – Zeysky, 7 – Ivanovsky, 8 – Konstantinovsky, 9 – Magdagachinsky, 10 – Mazanovsky, 11 – Mazanovsky, 12 – Oktyabrsky, 13 – Romnensky, 14 – Svobodnensky, 15 – Selemdzhinsky, 16 – Seryshevsky, 17 – Skovorodinsky, 18 – Tambovsky, 19 – Tyndinsky, 20 – Tyndinsky.

At present time the forest cover of the Far-Eastern Federal District is 38.63%, which is the result of the mergence with other far-eastern subjects of the Russian Federation with forest cover from 7 till 76% (Kostenko 2012).

Taking into account the forested lands of State Forest Fund, the forest cover of the Amur region is 64.4%. The forest cover changes from north-west to the south of the region from 74% till less than 0.3% (Fig. 1, 2). Some administrative areas or 78% of its total area are richly wooded (Yaborov 2005).

For the Far East there was found an optimal forest cover at the level of 50 – 55%, at which the forests fulfill all their functions. In such areas as Tambovsky, Belogorsky, Ivanovsky, Konstantinovsky, Mikhailovsky, Seryshevsky, Oktyabrsky, Zavitinsky, Blagoveshchensky, Svobodnensky, Romnensky, Bureysky the forest cover volatiles between 10 and 50% (Romanova & Sorvina 2017).

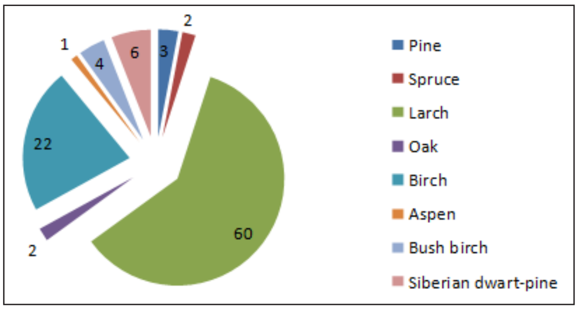

Fig. 3. Forest area by the predominant species in the Amur region.

Table 1. The forest cover of administrative areas.

Administrative district	The land area of the forest fund, [thous. ha]	Forest cover [%]
Arkharinsky	1 107.5	55
Belogorsky	4.8	0.9
Blagoveshchensky	135.9	37.0
Bureysky	411.9	46.7
Zavitinsky	135.2	22.0
Zeysky	8 489.2	74.0
Ivanovsky	2.0	0.6
Konstantinovsky	1.7	0.6
Magdagachinsky	1 402.1	74.0
Mazanovsky	2 474.7	54.5
Mikhailovsky	5.8	2.0
Oktyabrsky	33.0	11.0
Romnensky	801.4	52.0
Svobodnensky	514.0	45.0
Selemdzhinsky	4 435,5	74.0
Seryshevsky	57.6	10.0
Skovorodinsky	1 828.9	74.0
Tambovsky	1.5	0.3
Tyndinsky	8 331.5	70.0
Shimanovsky	1 284.9	69.0
The Amur region	Sum: 31 459.1	Average: 38.6

For experimental studies there were taken the species of the wood from those regions where the assessment of the forest cover was higher (Table 1). By this criterion the following areas were chosen: Zeysky, Skovorodinsky, Magdagachinsky, Selemdzhinsky, Shimanovsky. With average forest cover there were chosen Svobodnensky and Bureysky areas. The average forest cover in these areas was 38.63% (Yaborov 2005). The height above sea level is 300 – 400 m, and in the North of the region up to 1 000 – 1 200 m.

Main forest forming species are larch, birch, spruce, and pine. About 70% of the area is covered with coniferous species. Soft-wooded broadleaved species take 2.7 times less space than coniferous species; hard-wooded broadleaved species take 2.4% of land covered with forests and they are mainly in Zeysko-Bureysky, Belogorsky and Tygdinsky forest areas.

The diversity of the wood species is presented by 20 species, among which 10 species predominate. Coniferous species take 65.1% of the forest cover, hard-wooded broadleaved species take 2.2%, soft-wooded broadleaved species take 23.0%, and bushes take 9.7%. Main forest forming species are presented in the Fig. 3.

Among coniferous species the biggest area is taken by the Dahurian larch (60%), including 80% of the area in the northern parts, 50 – 60% in western parts, from 12% till 35% in central and eastern parts. In raw stock the larch makes 72.1%. The most valuable cedar forests grow in Arkharinsky area and make 0.3% of the forest cover. The cedar is forbidden for cutting and it is protected.

The raw stock value of pines and spruces is lower than their ecological and social value and intensiveness of their cutting is reducing. The area of pines as the most cut down in the region is 3.2% of the forest cover and is in need of protection and reduction of cutting. The pine forests are mostly concentrated to the west of the Selemdzha river. To the east of this border pines can be found in small parts near rivers the Byssa, the Tom' and the Arkhara. The area of the young stock for the last 30 years has increased by 16% and the area and stock of mature trees has decreased 2.5 times.

In the age structure of the forest fund mature and overmature forests predominate (34.2%), middle-aged forests and young forests take the biggest part of the area: 31.8% and 23.4%, respectively. The formation of the young forest is conditioned by forest fires and cuttings. The decrease of the area with mature and overmature forests is caused by cuttings. To provide the continuous use of timber in the region, the proportion of mature, overmature and maturing forests must be at the level of 10 – 15% (Yaborov 2005; Romanova 2017).

In the experimental studies there were involved those species of trees which have a high percentage of the timber stand in the region. Among the coniferous species there is Dahurian larch, the Scots pine and among the broad-leaved trees there is the Asian.

Dahurian larch*(Larix gmelini* (Rupr.) Rupr.) is a unique tree that grows in almost all forms of the land form and it grows in the mountains till 2 – 2.5 thous. meters. Pure forest stand is formed only in the conditions unfavourable for other species: swamps, frozen grounds and steep hills. In all other types of soil it grows together with pine, spruce and birch. The tree of the first size grows till 35 meters of height and 1.5 meters in a diameter. The body of the tree is straight, tapered and usually it is long-butt. The bark is light-grey, while young it is thin pellety, while old it is thick, reddish and fissured. It lives up to 500 years old and more. The tree crown is cone-shaped or pyramidal, crumby. The needle foliage is light green, soft, short; 20 – 60 needles in the bunch drop annually. The network of roots is deep in freshly drained soils and overground in swamped and frozen ones.

Fresh wood of the larch has the moisture of 82%. The maximal moisture at water absorbability is 126%. As with any other tree species the growing larch has seasonal and day fluctuations in moisture which under the common pattern are revealed to a lesser degree.

The average value of the density of the larch wood under standard humidity (12%) is 665 kg m^{-3}, at dry conditions it is 635 kg m^{-3}, the average basic density is 540 kg m^{-3}. The density of the larch wood strongly depends on the type and place of growth. The larch lumber that has the highest density wood grows in Altai (725 kg m^{-3}), in Ural and Cis-Ural areas (675 kg m^{-3}). The least density wood is typical for the European larch (506 kg m^{-3}) (Yaborov 2005; Earle 2011; Besschetnov et al. 2018).

The larch wood is hard, heavy and very tough. The specific gravity of air-dried wood is 0.7 – 0.76, of fresh one is 0.9 – 1.0, it sinks in water. It is used in building and furniture manufacturing, especially in those situations where the toughness and durability are necessary in a damp and humid surrounding. It is used for making low timber sets of buildings, mine log-houses, utility poles, piles and bridges. The firewoods have high calorific effect. The bark is used as tanning bark while currying and dying. The larch resin is used at making valuable varnishes and glues. The medications made from the bark, young shoots and needles are used in medicine (Yaborov 2005).

The Scots pine *(Pinus sylvestris* L.). This species is one of the most wide-spread species that grow in the Amur region. It takes 487.5 thous. ha, and it grows in Tygdinsky, Tyndinsky and Zeysky forest areas. It grows in different types of land area: from flood beds of rivers till mountain peaks. It forms pure forest stands predominantly in mountainous conditions on sandy soils. In flood beds of rivers in argilloarenaceous grounds it grows together with the spruce, aspen, silver-fir; on the plains it grows in combination with the larch, birch, oak and other wood species.

The tree is big: till 40 meters in height and 1.5 meters in a diameter and it lives up to 580 years old. The body is slim, straight with a high crown. The bark in the low part is reddish-brown, thick; in the upper part it is yellowish-orange, thin and smooth. The network of roots is rachidian in rich soils, and overground in sphagnous swamps. The needles are semi circled, paired, tough and green.

The pine is a typical species for sandy soils. It is hardy to soils, does not tolerate salty soils and a lot of water. It is light-demanding and cold enduring. It can suffer from air pollution. The pine that grows in the northern part of Russia, namely, Angarskaya, Karelskaya, Arkhangelskaya, are the best materials for building which have outstanding physical-mechanical properties.

Technical characteristics of the pine: density is 513 kg m^{-3}, density in the fresh wood is 625 kg m^{-3}, specific gravity is 0.51; ultimate static bending strength of wood is 71.8 Mpa, compressive strength along the grain of wood is 34.8 Mpa, ultimate tensile strength along the grain of wood is 84.1 Mpa (data taken at humidity of 12%; 1 MPa = 1 n per mm^2) (Wang et al. 2000; Andersone & Ievinsh 2002; Fries & Ericsson 2006; Kozlov et al. 2009; Peltola et al. 2009; Romanova 2017).

Asian white birch *(Betula platyphylla* Sukacz) grows in all soils, survives in excessive soil water and grows well in dry soils of mountain slopes. In poor soils it forms almost pure stands, in most cases of secondary origin. In relatively rich soils there are mixed forests of spruce, pine, oak, aspen, etc.

In good soils it reaches up to 27 m in height and up to 60 cm in diameter. It lives to 150 years old, sometimes up to 250 years old. The trunk is straight with a wide, spreading and loose crown. The shoots bark is smooth dark, the bark of branches and of the top of the trunk is white (birch bark). At the bottom of the trunk the bark gets dark, almost black and fissured when the tree gets older. The leaves are light green, the root system is shallow.

Properties of birch wood: the density is 0.63 g cm^{-3}, the mechanical hardness is 40 – 48 MPa, flexural strength is 80 – 90 MPa, the compressive strength is 45 – 55 MPa, impact strength is 70 – 80 J m^{-2}, the wear by abrasion is 0.5 – 0.6 mm (Givnish 2002; Yaborov 2005; Moser et al. 2015; Dyachuk 2018).

The forest-growing conditions of wood include the climate of the region with sunlight, average air temperature, precipitation, air humidity, wind speed and soil composition. The temperature and light conditions and water availability necessary for the development of plants and limiting their geographical distribution depend on the climate.

The Amur region is part of the Far-eastern region of the Russian Federation. The territory of the Amur region belongs to the continental transition group of ecosystems with a monsoon climate. This group is influenced by the seas and oceans only in the warm period of the year unlike other groups of the Far East.

The coldest areas of the Amur region are Tyndinsky, Skovorodinsky (north-west of the region) and Selemdzhinsky (east of the region). Selemdzhinsky area is located in a mountain range, in the valley of the river Selemdzha. It is surrounded on three sides by Selemdzhinsky ridge, Yam-Alin and Turan ranges, and here, as a result, chilly and heavier air masses flow, which makes winter temperatures low and annual average temperature sub-zero. The warmest place in the region is the south-west adjacent to the Amur river. This area includes Blagoveshchensk and Poyarkovo.

Winter is the longest season of the year in the Amur region; it lasts from late October to late March or early April. The winter has frosty, low wind weather with little rainfall which results in the low snow cover, low absolute humidity and high relative humidity. In the cold season, the weather is clear: the Amur region takes one of the first places in Russia by the number of sunshine hours in the winter (Yaborov 2005).

In the spring in the Amur region dry winds are often observed. Often dry winds are accompanied by dust or sand storms.

Table 2. Climate in the Amur region.

Districts	Air temperature, average [°C]		Precipitation [mm]	Humidity [%]	Wind speed [m sec^{-1}]	Soils
	January	July	year	year	year	
Tyndinsky	−32.8	17.6	456	70	1.6	Mountain-brown-taiga and mountain-tundra
zeysky	−32.5	17.8	580	72	1.6	Mountain-tundra, mountain-brown-taiga and marsh
skovorodinsky	−29.1	18	482	71	2.3	Mountain-brown-taiga
magdagachinsky	−30.1	18.6	530	69	2	Brown-taiga and marsh
Selemdzhinsky	−33.1	16.8	728	74	1.2	Brown forest, mountain-brown-taiga
shimanovsky	−29.4	20.8	611	71	2	Brown-taiga and marsh
Svobodnensky	−24.3	24.3	575	69	2.4	Brown-taiga
bureysky	−26.7	26.7	685	73	3.3	Brown-taiga and meadow

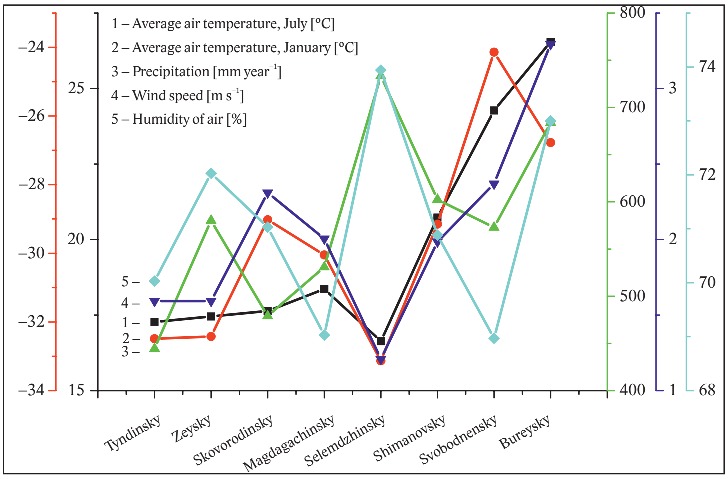

Fig. 4. Climate features in the Amur region.

Summer comes in late May or early June. Summer is moderately hot, in the north it is warm with high clouds and significant rainfall. The first half of the summer is usually warm and sunny, and sometimes too dry. And the second half of the summer is often excessively wet. Intense torrential rains often cause floods in the rivers. The rainiest months of the year for the whole region are July and August: 40 – 50% of annual precipitation falls during these two months.

Amur autumn is the shortest season of the year. In the north of the Amur region it begins in mid-August, in the South in the first days of September. The period with average daily temperatures below +15 °C, but above zero, lasts an average of 40 – 45 days. In the first half of October in the north of the region the average daily temperature drops to sub-zero, in the south it occurs at the end of October, and this means the beginning of winter.

The second ten-day period of September is the average date of the first autumn frosts. Once every 3 – 4 years early frosts in early September destroy the crop. This causes a huge damage to the agriculture of the region.

The first snow in the north of the region falls in September, in the south in the first half of October, but sometimes, the first snowflakes can be seen in the second ten days of September even in the south.

The conditions for soil formation in the Amur region are characterized by a number of features: 1) cold, snow-free winter contributes to deep freezing of the soil; 2) cold, dry, prolonged spring slows down the thawing of the soil and the development of plants; 3) warm and rainy summer (in July and August, half of the annual rainfall falls) leads to waterlogging.

Meadow black soils develop on brown clays of river and lake origin, under meadow and meadow-marsh grassy vegetation. They are characterized by high fertility, the humus horizon is 20 to 40 cm and sometimes 50 cm. The humus content in the top is 4 to 8%. By colour, structure and fertility they resemble the black soil of the European part of Russia. Therefore, the first researchers of the nature of the Amur region and immigrants called them "Amur black soils" (Yaborov 2005). In the areas where the forest cover is the highest, brown-taiga and mountain-brown-taiga soils prevail (see Table. 2). These soils are most favorable for the growth of larch and pine.

Thus, the richer the soil is, the more nutrients the wood gets, it becomes looser, the annual rings become wider, and accordingly its density and weight get less. But logging companies seek to treat the wood which in a small volume will be heavier. Therefore, the worse the soil of wood growth is, the more profitable it is for loggers.

The purpose of the paper is to study the density of wood in the Amur region.

Objectives: 1. To study and analyze the climate of the Amur Region by regions. 2. To study the dependence of the density of wood on the area of growth and other factors.

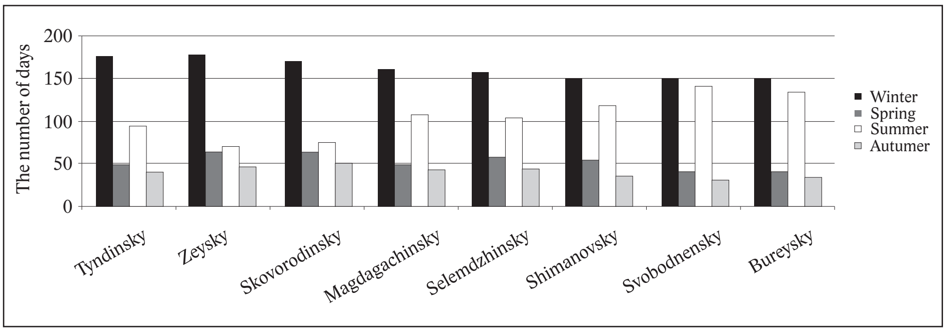

Fig. 5. Duration of seasons of the year in days by districts.

3. Method

For research of density of wood of plantings the experimental material prepare according to GOST 16483.6-80 providing rules of the choice of model trees on these areas and cutting of model trees on ranges. Four samples from each of the 50 trees in each study area were selected for the experiment. 1 600 samples of each wood species, a total of 4 800 pieces. The age of the tree was determined by annual rings when harvesting it directly on the cutting area. The age of these trees ranged from 65 to 110 years. Sites on which logging enterprises of the Amur region conduct harvesting of wood annually. In different climatic conditions and in the mountains and in the lowland, on marshy soils and in very windy places. The location of the trees is varied, both in the lowlands and swamps, and in the mountainous areas. Accordingly, the trees grew in different climatic conditions (different humidity, the number of light days, soil, etc.). Growing trees cut down and determined their age and moisture with tree rings and electrolaser. From the lump (stump) part of the wood samples of 20 × 20 × 20 mm were cut out in the number of 4 pieces from each tree.

The density of wood is characterized by the ratio of its mass to volume. Density is measured in kilograms per cubic meter or grams per cubic centimeter.

In laboratory conditions, the density of wood is determined on samples of rectangular cross-section of 20 × 20 mm in size and height (along the length of the fibers) of 30 mm (all-Union State Standard 16483.1-84). The mass is determined by weighing on an electronic scale with an error of up to 0.01 g, the linear dimensions by a calliper of accuracy class 2, an error of up to 0.01 mm (GOST (all-Union State Standard) 2005; Romanova & Baranov 2016; Romanova 2017).

Determine the conditional density as follows: the sample is kept in distilled water for about 3 days, until it acquires a constant size and determine its volume V_{max} in multiplying the sides of the sample measured with a caliper. The sample is then dried for about 8 hours in a drying Cabinet at 112 °C to a dry state and the mass m_0 is determined by weighing. The formula is used to calculate the conditional density:

$$\rho = m_0 / V_{max} \qquad [1]$$

where m_0 – the mass of the wood sample in a completely dry state, kg; V_{max} – the volume of the sample at humidity above the hygroscopicity limit, m^3.

The density of wood at humidity above the limit of hygroscopicity ($W = 70\%$) was determined by the following formula:

$$P_{w1} = P_{12}\,(1 + 0.01W1) / 1.206 \qquad [2]$$

W_1 – moisture content of wood, %;
P_{12} – wood density at 12% humidity.

The volume is calculated as a product of the results of measurements of width, thickness, and height and expressed in fractions of cubic meter (m^3). In addition, the volume can be measured by the device – a volume meter by the sample displaced liquid (mercury) not wetting the wood. The sample may have an irregular geometric shape.

The density of wood depends on the humidity and to compare, the density values are always made by single humidity. The density, as well as all the other indicators of physical and mechanical properties of wood, should be reduced to a standard humidity of 12% (ρ12%).

For calculations, the density of wood is sometimes used in a completely dry state: in this case, the weight and volume of wood are measured after the sample is dried to a moisture content of zero.

For some purposes, it is convenient to use a value called the conditional density of wood. This indicator is calculated as the ratio of the sample mass in a completely dry state to the sample volume at the hygroscopicity limit ($W_{h.l.} = 30\%$). The relative density of wood does not depend on moisture.

The conditional density is determined as follows: the sample is kept in water until it acquires a constant size and then its volume V_{max} is found. The sample is then dried to a dry state and the m_0 mass is determined by weighing. By dividing the mass by the volume of the sample, the conditional density is calculated.

With increasing moisture content, the wood density increases. Within the annual layer the density of wood is different: the density of late wood is 2 – 3 times greater than the early one. Therefore, the better developed the

Fig. 6. Electronic laboratory scale MWII–200B.

Fig. 7. A calliper, accuracy class 2.

late wood is, the higher its density becomes. Heavier wood is more durable. Density is the amount of wood substance in unit volume. The amount of wood substance is directly dependent on the size of the anatomical elements that perform a mechanical function in a living tree.

By the density at humidity of 12%, the wood species can be divided into three groups: species with small (540 kg m^{-3} or less), medium (550 – 740 kg m^{-3}) and high (750 kg m^{-3} and above) density.

4. Results and discussion

According to All Union State Standard 6483.1-84, experimental studies were conducted on the density of wood of different species growing in the Amur region at normalized humidity. According to the experimental data, diagrams of the wood density dependence on various forest growth factors were made. The studies were conducted in different seasons: winter and summer (GOST (all-Union State Standard) 2005; Romanova & Sorvina 2017; Dyachuk 2018).

In the process of experimental studies, samples were taken from the butt part of the wood. Three types of wood: Daurian larch, pine and Asian white birch were under study. Forest areas of the Amur region became the places of research where the sampling was carried out. The number of samples of 10 for each species of wood from each district of the region, the trees corresponded to the 5th class of age.

Experimental studies have identified the main factors affecting the density of wood: the area of growth, the season (winter, summer), species, age and wood moisture. After analyzing the data using Excel software and building a chart, the dependence of the density of wood on various factors was found out.

Having studied the dependence of density on moisture (through the example of larch, pine and birch growing in Tynda area, Fig. 7), it was concluded that the higher the moisture content of the wood was, the greater its density became. So at humidity of 20% the density of larch was 777.85 kg m^{-3}, of pine it was 688.12 kg m^{-3}, of birch it was 519.11; at humidity of 70% the density of larch was 1 088.99 kg m^{-3}, of pine it was 919.8 kg m^{-3}, of birch it was 915.9 kg m^{-3}; when the humidity was 120%, the density of larch was 1 404.97 kg m^{-3}, of pine 1 186.69 kg m^{-3}, of birch 1 181.66 (Ugolev 2002; Romanova & Baranov 2016).

Table 3. Statistics based on the wood density [kg m^{-3}] from moisture.

Variable	Median	Standard deviation
Density of larch	831	190
Density of pine	641	51
Density of birch	692	139

Analyzing Figure 8, it can be concluded that the wood species influences its density. Larch wood had the most density, birch had the least among the studied. Pine is the species that have an average density, though its density is slightly greater than that of birch.

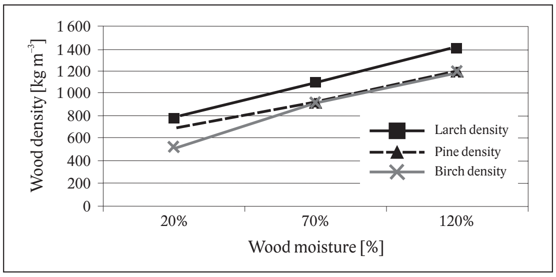

Fig. 8. Dependence of wood density on moisture (Tyndinsky district).

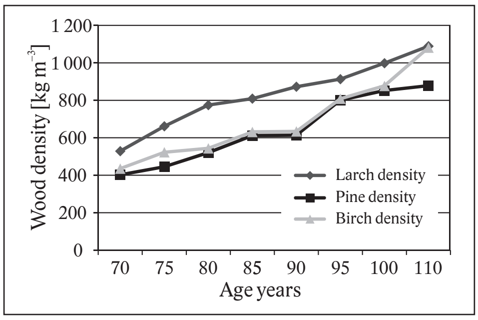

Fig. 9. Dependence of density on the age of wood of different species growing in Tyndinsky districts of the Amur region.

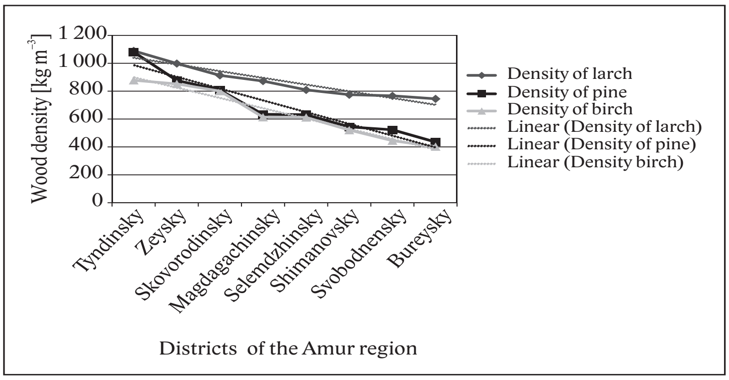

Fig. 10. Wood density dependence on the districts of the Amur region.

Having studied the dependence of the density of wood on age and species (through the example of Tyndinsky area, Fig. 8), it was found out that that the older the tree was, the greater its density was. The density of larch that has grown to 110 years old is 1 089 kg m^{-3} at average humidity, which is 210 times more than the density of larch that is 65 years old. The corresponding dependence was obtained in other areas of the region (Kostenko 2012; Romanova & Baranov 2016; Romanova 2017; Dyachuk 2018).

Table 4. Statistics are based on data on the wood density [kg m^{-3}] and age of the wood.

Variable	Standard deviation
Density of larch	180
Density of pine	184
Density of birch	215

Having studied the dependence of the density of wood on the area of growth, (Fig. 10), it was found out that the further to the north the area is located, the more density the wood has. Using the trend line, the linear dependence equations were made. For larch the equation is y = −72.44x + 1 156.9, the coefficient of determination is 0.97. For birch the equation is y = −84.375x + 1 071.5, the coefficient of determination is 0.92. For pine the equation is y= −73.878x + 973.09, the coefficient of determination is 0.96. The coefficient of determination is close to one, which indicates a direct relationship between the density of wood and the area of its growth.

Having studied the dependence of the density of wood on the time of year, it was found out that the same species of wood of the same age growing in the same area have greater density in winter than in summer. Larch growing in Tyndinsky area has the density of 1 088.99 kg m^{-3} in winter and 968.99 kg m^{-3} in summer. Thus, the density of wood depends on the species, humidity, age, the climate of the environment, i.e. the area of growth, and the time of year.

Table 5. The maximum density of wood [kg m^{-3}]in the Amur region.

Districts	Density of larch	Density of pine	Density of birch
Tyndinsky	1 088.99	1 081.28	878.23
Zeysky	998.26	877.06	852.33
Skovorodinsky	913.25	808.45	800.6
Magdagachinsky	872.62	633.95	613.5
Selemdzhinsky	809.11	631.28	611.6
Shimanovsky	774.54	543.9	521.06
Svobodnensky	766.28	522.93	445.21
Bureysky	745.26	435.49	402.57
Average	871.04	691.79	640.64

Experimental studies have shown that in each area of growth of wood, under different forest conditions, the density of the same wood is different, and it does not meet the generally accepted standards and differs a lot from the north to the south.

In a variety of reference books the density of such species as birch, pine and larch is taken to be 890, 720, 930 kg m^{-3}, respectively, at humidity of 70% (Ugolev 2002; Tyukavina 2017). In our studies, these values range from 402 to 1 088 kg m^{-3} (see Table 4). In each area, the density of wood has its own values, which allows to choose the logging equipment that is different in capacity and cost.

Table 6. Main statistical indicators for wood density [kg m^{-3}].

Variable	Median	Standard deviation
Density of larch	841	123
Density of pine	633	215
Density of birch	613	184

According to experimental data, the dependence equations and the validity coefficient are made: for larch it is y = −48.162x + 1 087.8, R^2 = 0.9242; for pine it is y = −84.375x + 1 071.5, R^2 = 0.9242; for birch it is y = −73.878x + 973.09, R^2 = 0.9648. The validity coefficient is close to 1, which indicates a high convergence of the results (Zaki & Meira 2014; Romanova & Baranov 2016).

Density of wood depends on many factors, including forest growth (Ugolev 2002). Each breed has different density (Kang et al. 2004). Larch has 415 – 635 kg m^{-3} (Fries & Ericsson 2006; Earle 2011), pine has 415 – 505 kg m^{-3} (Wang et al. 2000; Andersone & Ievinsh 2002; Fries A., Ericsson 2006; Peltola et al. 2009), birch has 520 – 640 kg m^{-3} (Kostenko 2012; Romanova 2017; Dyachuk 2018). In the Northern subzone of the taiga conditional density of pine wood is 0.340 – 0.580 g cm^{-3} (Tyukavina et al. 2017).

Experimental studies have found that in each area of wood growth, respectively, under different forest conditions, the density of the same wood is different, and it does not meet the generally accepted standards and has a large run from the North to the South.

In our study, the densities of the larch range from 745 to 1 088 kg m^{-3}, the density of pine from 435 to 1 081 kg m^{-3}, the density of birch from 402 to 878 kg m^{-3}. In each district the density of wood has its own values, which allows us to select the logging equipment of different capacities and cost. The object of research is the forest plantations of the Amur region. The initial data for the statistical analysis are the data of 8 districts of the region and the database consisting of the taxation characteristics of forest plantations. Using the module "classification and regression trees" in the STATISTICA environment, the cluster analysis of the main forest growth factors affecting the density was carried out (Stanturf & Madsen 2004; Zaki & Meira 2014; Moser et al. 2015).

5. Conclusion

The impact of forest growth conditions on the density of wood in the Amur region was studied for the first time. The fundamental factors affecting the density of wood are the length of the seasons, air temperature, precipitation, wind speed, humidity, type of soil on which a certain species of wood grows.

The climate of the region varies from north to south. Winter is the longest season of the year; in the northern areas it lasts 178 days, in the southern ones 154 days. The minimum air temperatures in the southern areas of the Amur region range from −40° to −45 °C, in the northern ones from −50 °C to −55 °C. Depending on the duration of the seasons of the year, the northern and southern areas of the Amur region were identified. Tyndinsky, Zeysky, Skovorodinsky, Magdagachinsky, Selemdzhinsky areas are northern areas of the Amur region, and Shimanovsky, Svobodnensky, Bureysky are southern ones. In areas where the forest area is the highest, brown-taiga and mountain brown-taiga soils prevail. Among coniferous species, the largest area is occupied by Dahurian larch (59.8%). In northern areas it takes up to 80% of the area, in the southern ones 50 – 60%. Considering raw stocks, larch takes 72.1%, pine 2.7%, birch 15.9%.

Studies of the effect of forest growth conditions on the density of wood in the Amur region have shown that the further to the north the area of wood growth is, the greater its density becomes. The density of wood was found out for the first time. The density of larch at humidity 70% is from 530 kg m^{-3} in the southern areas to 1 089 kg m^{-3} in northern areas, the density of pine is from 435 kg m^{-3} to 1 002 kg m^{-3}, the density of birch is from 400 kg m^{-3} to 830 kg / m^3.

Thus, based on the experimental studies, we recommend that to determine the volume (mass) of wood (for example, for export abroad of the Russian Federation through customs) use not the average density, but the density that corresponds to the area of growth.

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REVIEW PAPER

Computed tomography log scanning – high technology for forestry and forest based industry

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Abstract

Heterogeneity in the tree trunks' shapes and quality is not often reached fully using raw material potential in grading processes of tree and stand and the following sawmill processing.

Therefore, optimization of given processes is a current topic of research and is part of the operational practice. In the contribution we submit a survey of solving the given problems in the European and Slovak conditions. A significant impulse for solving problem at a new level is a significant progress in the field of industrial computed tomography. New and fast CT scanners have been developed and they enable to increase valuation by 15% in coniferous trees and by 24% in broadleaf trees. In the contribution we analyze period of returns of CT scanner's implementation into the sawmill process within Slovak context for small, medium-sized and big sawmills. Results show that period of returns for big sawmills is approximately for years, for medium-sized sawmills is eight years when processing coniferous softwood or three to eight years in case of broadleaved processing. In the final synthesis we present a concept of interlinking the 3D scanner and technologies of laser woodcutting with the outcomes allowing to optimize stand grading and maximize profit of the given raw wood in the sawmill processing.

Key words: CT scanner; sawmill; sawing optimisation; log; profit

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1. Introduction

Effective utilization and reproduction of renewable sources including raw wood material is an essential component of successful transformation of society from fossil economy to green economy.

One of the research areas that provide knowledge needed for optimal valuation of raw wood material is the detection of quality and quality wood properties. There are a lot of defectoscopic apparatuses working on different physical principles. The latest technological news is a development and implementation of three-dimensional (3D) computed tomography (CT) of scanners.

The aim of the contribution is: a) in the analytical part to describe a current state of knowledge in the sphere of tree and stand grading, to analyze potential of benefits and a possibility to use 3D scanner in grading and sawmill wood-processing, to summarize economic benefits of the introduction of CT-scanner for round wood processing industry; b) in the synthetically part there is presented a new concept of introduction and application of 3d CT scanner in forestry-wood processing complex and on the basis of a model is derived a period of returns of investment in the CT scanner in the Slovak conditions.

2. Contemporary issues in the selection of trees and forest cover abroad and in Slovakia

2.1. Selection of trees and forest cover

As well as the quantity of trees produced, their quality is also of utmost importance. Wood of higher quality is more expensive, has higher utility value and greater value added. Production research in the area of forestry throughout the world has been intensively studying the issue of produced wood quality since the 1960s. The first assortment tables were published for poplar clones in Hungary (Kulcsar 1965), a methodical description of assortment procedures in relation to value production (Sterba 1983) and assortment tables for beeches (Kleine 1986) in Austria, and for beeches and oaks in

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Corresponding author. Tomáš Gergeľ, e-mail: gergel@nlcsk.org, phone: +421 45 5314 128 the Czech Republic (Pařez 1987). More contemporary research studies include studies on assortment structure in Serbia (Danilović & Janjatović 2005) and assortment yield tables for oaks in the lower Volga region in Russia (Chernykh et al. 2014). The need for national or even regional approaches emerged from the variability of stand characteristics and growth conditions as well as genotypic and phenotypic, shape and qualitative characteristics of trees and forest cover, or rather of wood defects.

There are two basic principles in the process of wood-quality modelling: 1. solid geometry, which simulates a requested assortment structure based on the partial results according to length and diameter of logs and distribution of external and internal features of wood-quality in its longitudinal profile, 2. empirical sorting model, i.e. wood-quality is defined directly from the tree samples during the yielding and manipulation processes and its mathematical models are constructed according to the acquired results. Both approaches were analysed by Petráš & Nociar (1991). According to their study the empirical sorting model has been used in Slovakia ever since. This model was developed as part of the forestry production research in Slovakia, which also included the issue of produced wood quality. On the basis of empirical material measured in the direct assortment process, models used to develop stand assortment tables for trees and forest covers for 8 economically significant trees were designed. Specifically: spruces, firs, pines, oaks, beeches (Petráš & Nociar 1991) as well as larches, hornbeams, birches and poplar clones Robusta and I–214 (Mecko et al. 1993; Mecko et al. 1994; Petráš et al. 2007). Combined with production models of yield tables (Halaj 1990) their models were used to design assortment yield tables (Petráš et al. 1996) and connection with the price of wood and yielding costs as well as for models of value production (Halaj 1990).

Practical methods of qualitative inventorying are usually based on the selective approach, ocular assessment of dimensional and qualitative characteristics of logs as well as of the tree's age. On this basis and on the basis of assortment tables, the forest cover is divided into individual assortments. Inventorying of trees provides the distribution of trees (in m^3, shares in %) into assortments.

Assortment accuracy of trees is shown in (Table 1). Accuracy of the models is based on the analysis of deviations between actual shares of assortments within experimental areas and shares provided by the models derived. In general it can be concluded that the accuracy of assortment models is relatively low – mainly because of very inaccurate estimation of internal wood defects that are estimated from external features.

In the last decade the research in the area of quality accuracy has been stagnating. One of the reasons why is that except for the basic parameters of models – tree thickness, quality and damage of logs – no other significant and effective factors that could improve the accuracy of models were determined.

Internal wood defects caused by biotic factors, mainly fungi, pose another problem of tree assortment. In standing trees, it is possible to take them into account only on the basis of external characteristics of logs and characteristics indicating presence of biotic organisms, e. g. sporocarps (fungi). For research purposes, not only ocular detection of internal wood defects and practical assessment of condition of valuable trees mainly within the territory of built-up areas and botanical gardens is used, but there are also ultrasound decay detectors of tree hollows, e. g. Arbotom 3D Pack (Rinntech e.K.) or ArboSonic 3D (Fakopp Enterprise). However, such detectors have not been used in forestry because of the economic inefficiency of the method which has relatively high time demands.

2.2. Wood quality and detection of defects

Wood quality research in the wood-processing industry has been so far separated from forestry research. In wood storehouses, logs are usually damaged mainly because of inappropriate storing conditions. The most common defects are: drying, formation of cracks, wood-destroying fungi, ligniperdus insects, undesirable odour of wood and photosynthetic degradation. Types of wood degradation and methods of protection are comprehensively dealt with e.g. by Hoadley (2000). The latest research initiative on a European level that deals with the issue of wood quality and wood products was the COST Action E53 in 2006–2010 focusing on:

– scanning of stems and logs for quality assessment of geometrical and qualitative characteristics,
– moisture content and distortion determination,
– strength, stiffness and appearance grading of wooden products.

Although the project proved to be of great importance, there has not yet been created a specialized workplace within the Visegrád Group of countries that would systematically and comprehensively address the issue of wood defect detection using scanning technology and 3D models.

There have been several research studies regarding quality and defects of raw wood assortments and their

Table 1. Accuracy of assortment process – the range depends on the quality trade (of assortments).

Tree species	Assortments tables		Tree species	Assortments tables	
	Tree	Growing		Tree	Growing
Spruce	20 – 34%	o 1 until 2% bigger	Beech	20 – 78%	—
Fir	32 – 43%	—	Hornbeam	13 – 22%	o 1 until 3%
Pine	21 – 35%	—	Birch	10 – 33%	—
Larch	21 – 27%	—	Poplar – I 214	15 – 51%	—
Oak	17 – 28%	o 1 until 8% bigger	Poplar - Robusta	12 – 27%	—
Beech	24 – 37%	—	—	—	—

connection to the production process, as well as the relationships between wood quality – raw material assessment – and marketing and wood trade. Some results can be found in the following publications (Mahút & Réh 1995; Greppel et al. 2009; Klement et al. 2010; Suchomel & Gejdoš 2013).

Wood defects scanning is e.g. dealt with by the WEINIG Group in Tauberbischofsheim (Germany), Microtec CT (Italy) and WoodEye AB (Sweden). These companies develop commercial scanners such as the CombiScan + C, Microtec CT and WoodEye 5 with the following basic characteristics:

The WoodEye 5 scans all four sides of the lumber in both axes, which provides additional information about the space between growth rings, pith position and knot structures. Scanning is based on multi-spectral and laser technology. Rontgen technology is adjustable.

The CombiScan + C scans surface by four-sided laser cameras. Other detecting equipment (colour camera, Rontgen technology, moisture determination) is adjustable. Software enables detection of a wide scale of wood defects in real time.

The Microtec CT Log 360° CT X-ray scans and digitally reconstructs internal characteristics of logs. This enables selection of the optimal cutting solution in real time. The scanner provides smooth, high-quality and full-3D log reconstruction; therefore size and location of internal wood defects can be seen in all three dimensions.

The variable software and hardware capabilities of these scanners represent the best technology in the area of defects detection and raw material assessment.

2.3. Cutting plans and profit optimization

The issue of cutting plans has been the subject of long-term research. As well as mathematical techniques there are also various software applications. Complex solutions are generally provided with the aforementioned scanning devices or as separate commercial products (e.g. Optimik, available at www.rksoft.sk/optimik.php). Contemporary solutions depend on the cutting technologies used, i.e. circular saws, bow saws or band saws.

One ground-breaking technology is laser cutting (Biatec Laser technology s.r.o.) which is challenging and creating new ideas aiming to optimize cutting plans. This technology constitutes a new modern research based approach and its mastering requires creation of an interdisciplinary team consisting of timber industry specialists and forestry specialists in the area of wood defects detection, as well as a specialist in the area of mathematical modelling, imaging (scans) and production process modelling.

Up to this date, combination of forestry and timber industry research in the area of wood quality has been marginal and inhomogeneous. It is a global challenge for the forestry-timber industry. Information and communication technology provides techniques connecting evidence and supply systems of forestry with the systems of wood-processing and of the timber industry and therefore enabling management of anticipated production according to assortments supplied with actual production of wood products. An important role in this interconnecting process is provided by 3D scanning technologies of logs and 2D scanning of timber before processing wood into final products (www.lignosilva.nlcsk.org/files/Science_Business_summit.pdf).

3. Review on current status of log CT scanning

3.1. CT Log Scanner

CT scanners are the most advanced technology used for detection of internal wood defects. They work on the same principle as computed tomography scanners used in medicine. In terms of parameters, they are tailored-made to scan logs on an industry scale. They are non-destructive and applied to sawn trees before they enter the processing phase. Scanning provides a 3D model of a specific cut and gives information about knots, piths and splits. Optimization software evaluates the acquired data.

Predecessors of such scanners are tomography scanners used in medicine since 1972 (Ulzheimer & Flohr 2009). The technology has been significantly improved and perfected in the last years. Naturally, there are tendencies to implement computed tomography also to other – mainly industrial – areas. They are used to control rocket and jet engines as well as to produce specialised components (Bossi et al. 1991). If such technology is to be used in wood processing industry, it is necessary to solve several questions regarding health and safety, radiation, automatization, feed rate, stability and reliability when operating in dusty environment, area with vibrations and in bad weather conditions. Efficiency and size of the whole system is also important. These issues have been dealt with by several authors:

At the present time research and development of defects detection is focused on the improvement of algorithms and making their identification faster. Moreover, the technology of parallel processing is used. (Thomas & Thomas 2013). Revised algorithm processes data with higher resolution and in shorter period. Higher performance means better analysis and results in more accurate detection of defects.

Thawornwong et al. (2003) analysed the application of gattered data from CT scanner in terms of its distinction. Three-dimensional resolution is a result number of total pixels, scan thickness and scan frequency. It is possible to use relatively thick scanning (3.1 megapixels, scanning thickness 5 mm) without significant decrease in profit maximization.

Further automation of defects detection is depended on gathered results of tested algorithms. Brening (2014) deals with the evaluation accuracy reached in automatized knot detections. Error in the knot size has the biggest influence on yield maximization. On the other hand, inaccuracy in the knot position had insignificant influence. Author also studied the connection between appearance of wooden surfaces created by software optimization and human perception of such appearance. He concluded that created models correspond to the human perception of appearance.

Computed tomography to determine the a wood density (Freyburger et al. 2009) is used in modern scanners. Their research focused on the correlation between the Hounsfield scale and wood density. Calibration data set consisted of tropical wood samples representing a large range of densities ranging between 133 kg.m^{-3} and 1319 kg.m^{-3} and was then validated using an independent data set (mainly temperate tree species). Achieved correlation was 0.999.

Krähenbühl et al. (2012) dealt with the knot detection in 3D tomography images. They proposed an algorithm aimed at automatic detection and subsequend analysis of knots based on determining histograms of scanned log images. That is the difference of the standard algotithms based on deformation models. CT Log scanners Microtec has been the most often used in sawmills over the last years.

Implementation of CT scanners into industry was prevented in the past by several issues: (a) the need for high computational power of GPU processors in the utilization of integrative algorithm that provides high quality resolution; (b) complexity of sensor fields and the need for high power of Röntgen radiation that would be able to pass through thick logs; (c) securing resilience of rotating a very large gantry at the speed of 180 rpm. These technological problems were solved. Leaders are CT log scanners Microtec (Giudiceandrea et al. 2011), which have been gradually implemented into sawmills in the last years.

3.2. Operational principles of CT Log Scanner parameters

When scanning logs it is necessary to use technology of spiral tomography. Scanning consists of several steps: scanned object continuously slides into circular orbit source, on one side there is a source of X–ray and on the other side a set of detectors. Each point in a cut is given its own value of ray absorption according to the computed process (Fig. 1). According to the value of absorption, this value is transformed into the image and visualised in shades of grey. The acquired data are then used to reconstruct cuts in required places. The relationship between the length of shift in one rotation and thickness of cut is referred to as pitch. Higher the value is, the more of the scanned object can be covered, but at the same time quality of the resulting image decreases (Fig. 2).

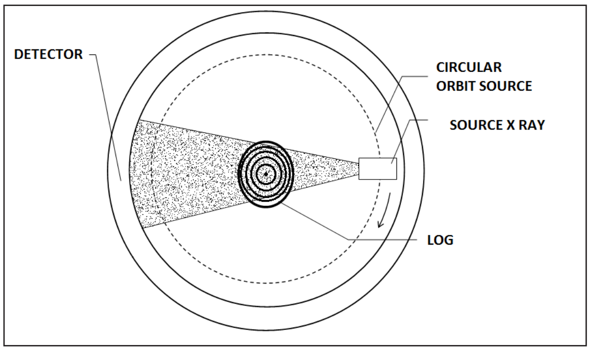

Fig. 1. Principle of scanning logs.

CT scanner is usually located in standard 20ft shipping container. Entering and exiting of a log is provided by conveyor belts. Length of logs is usually limited to 10 m, but theoretically is unlimited. Maximum feed rate is 60 m/min. Diameter of a log is limited to 650 mm for softwood and 550 mm for hardwood. Operating temperature ranges from −30 to 45 °C (Gazo & Chang 2010).

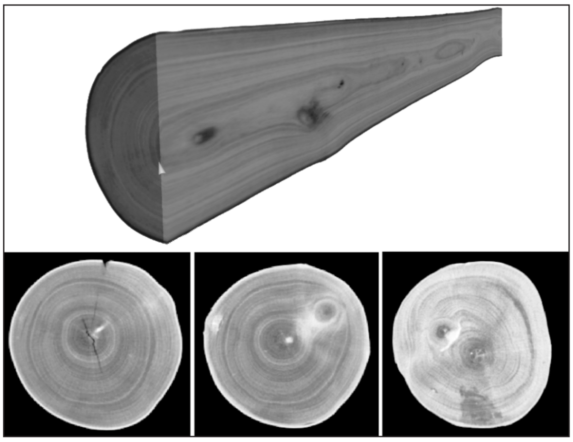

Fig. 2. 3D scanned model of a log and its cross sections.

X–ray tube is a source of radiation. Therefore, employees and environment have to be protected according to the legislation of the country where it is installed. Dosage in the vicinity of such device is under the limit of 10 µSv/ h. This value is guaranteed in the distance of at least 0.1 m from the surface of the device. The device is secured by safety gates connected to the safety device range. If the safety zone is breached, the source of X–rays will turn off.

3.3. Economic return of using the 3D CT scanner

Following the research results mentioned in (Table 2). Economic return of investment in the 3D CT scanner was proposed. Development of improved algorithms to detect wood defects and subsequent log pattern optimisation are results of using the scanners in the wood processing.

That results in increased profit. The specific production conditions for the results of the authors are unknown. Mostly national standards or wood processing standards were used.

Table 2. Table of profits by various researches.

Author of research	Year	Test set [pcs]	Profits [%]
Fredriksson	2015	47 pine	11.3
Rinnhofer et. al.	2003	30 spruce	23.7
Skog	2013	74 spruce	18
Stängle et. al	2016	19 beech	24
Berglund et. al.	2013	408 pine and spruce	16
Hodges	1990	—	17.5
Schmoldt	2000	30 spruce	18
Anonymus	2015	Coniferous and non-coniferous	8

4. Analysis of economic return of using the 3D CT scanner

4.1. Input model parameters

- Costs associated the CT scanner implementations are based on the still existing technology MICROTEC Company. Total costs for installation are €2.5 million. The sum includes CT scanner, software license, delivery, assembly, 10 m conveyor belt, software support for 100 days and putting the device into service.
- Sawmill profitability – coniferous timber: Potential economic return at the investment was proposed in three models according to the extent of produced coniferous timber: small sawmills with timber production up to 50 000 m^3, middle sawmills with timber production up to 100 000 m^3 and large sawmills timber production up to 200 000 m^3.
- Sawmill profitability – broadleaf timber: Similarly, regarding the broadleaf timber, three models were divided as follows: small sawmills with timber production up to 5 000 m^3, middle sawmills with timber production up to 20 000 m^3, large sawmills with timber production up to 50 000 m^3,

  Price – timber: The cost of coniferous timber – based on the market research – was set to €163.51 per m^3 (National Forest Centre Newsletter, 2/2017). Based on the research (Table 2), it was concluded that implementation of CT log scanner increases valuation of coniferous logs by 15%.
- The cost of broadleaf timber – based on the market research – was set to € 200 per m^3 (National Forest Centre Newsletter, 2/2017).
- Expected economic profit: Based on the research (Table 2), it was concluded that implementation of CT log scan increases valuation of coniferous log by 23%. These values were used to calculate payback period.
- In the calculation the value of gross margin is used. It consists of 16% in coniferous trees processing and 45% in broadleaf trees (FinStat, 2017). Income tax 25% (EU average) wasn't taken into account. After that, the expenses were subtracted.

Annual profit was calculated according to Hodges et al. (1990)

$$AVI = \sum_{i=1}^{12} P_i \times SM \times VYI \qquad [1]$$

where:
AVI – Annual Value Increase,
Pi – Price of lumber grade *i,*
SM – Mill size (annual output),
VYI – Percent value profit increase.

4.2. Economic return assessment of investment in 3D CT scanner

Economic return assessment of investment in 3D CT scanner are depicted in Fig. 3 and Fig. 4 according to their corresponding sawmills. Point where the curves cross with broken curve (costs for CT scanner) represents estimated payback period of the investment in years.

Wood processing industry is a sector with longer innovation cycle and therefore the acceptable payback period is 8 or even 10 years. The results show that investment into CT log scanner is profitable for middle and large sawmills. For large sawmills, the payback period ranges around 4 years and for middle sawmills 8 years – coniferous wood processing. Investment for small sawmills

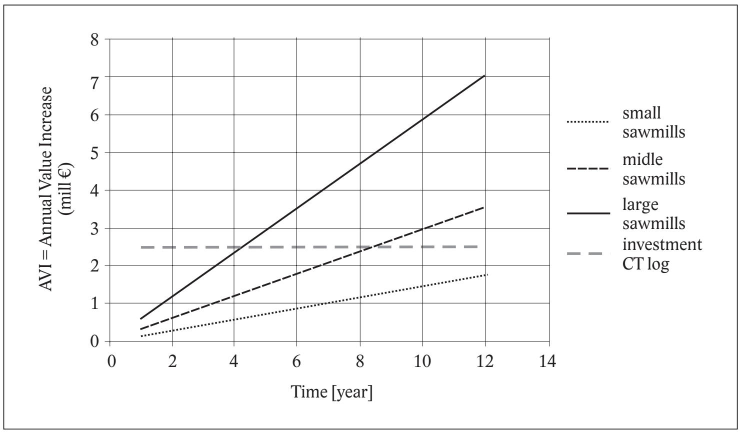

Fig. 3. Payback period of investments into CT scanner for small, middle and large sawmills (coniferous wood).

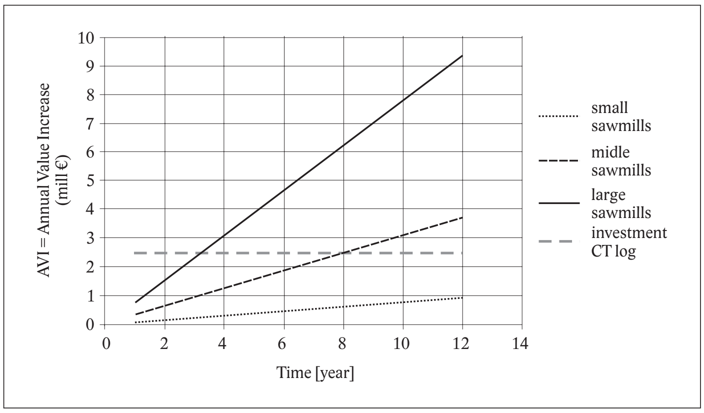

Fig. 4. Payback period of investments into CT scanner for small, middle and large sawmills (broadleaf wood).

would be profitable if the log value increased by 25%.

Concerning processing of broadleaf trees, the investment into CT log scanner is also profitable for middle and large sawmills. Payback period for large sawmills is approximately 3 years and for middle sawmills 8 years. If the log value increased by 18%, the investment into CT log scanner would be profitable for small sawmills as well – payback period approximately 10 years.

If there is a need to take into account income tax, it is necessary to multiply payback period by a coefficient 1.25. In this paper, this is neglected as write-offs theoretically effectively decrease the tax base during the payback period.

Cost efficiency of the use of CT log scanner expressed by the calculation of period of returns is necessary to enrich for other factors. A suitable tool is presented by SWOT analyze of CT scanner implementation in sawmill in the Slovakia which points at the factors which can influence the period of return positively or negatively (Table 3). The analysis shoes that the risk rate is relatively high. In the future to treats are possible to expect especially in securing disposable supply of coniferous logs and oak logs. On the contrary, there is sufficient amount of broadleaf wood (especially beech) and the presence of broadleaf wood species will increase in Slovak forests in the future. The CT scanning is even profitable for broadleaved wood species than for coniferous trees, it can mean an interesting opportunity and a competitive advantage on the market of processors. The change of market conditions is an assumption as customers mostly prefer coniferous timber in the present.

Human potential and its quality are also questionable, but training could prove helpful in various aspects (Vetráková et al. 2013; Hitka & Balážová 2015). Motivation and education in this area are also important. Employees have to be acquainted with standards; they have to be able to evaluate qualitative features of logs, to effectively control the software and to take qualified steps in their corresponding positions (Lorincová et al. 2016).

5. Prospect of log ct scanning for forestry and woodworking

Implementation of intelligent technologies used to detect wood defects (CT for logs) and wood cutting (laser) into the wood-processing industry and their interconnection through information and communication technology provides a basis for a new concept – interconnection of the forestry-timber industries. In the following diagram (Fig. 5) the flow of raw material from producer to customer is displayed. Process flow and data flow in the forestry-woodprocessing sector are shown.

In green rectangles the process flow regarding intelligent technology in wood-processing industry can be seen. Blue rectangles represent innovation in forest man-

Table 3. SWOT analysis of CT logs scanner.

	Helpful	Harmful
	Strengths	Weaknesses
Internal origin	– High-quality and available workforce. – Long-term tradition of wood processing. – Regular customers.	– Need of trained personnel. – Ignorance of market. – Weak companies infrastructure. – High investment costs.
	Opportunities	Threats
External origin	– Potential of higher wood valuation (mainly of broadleaf logs). – Higher work productivity. – Reducing costs for workforce. – Payback period for middle and large sawmills. – Smaller amount of high-quality wood in future. – Extended settings for cutting plans optimisation.	– Unstable and specific market environment. – Lack of coniferous logs in the future. – Short-term contracts with suppliers. – Competition of the energetic sector. – Lower demand for broadleaf timber. – Higher level of automation in sawmill is needed . – Complex connection of production process (hardware, software).

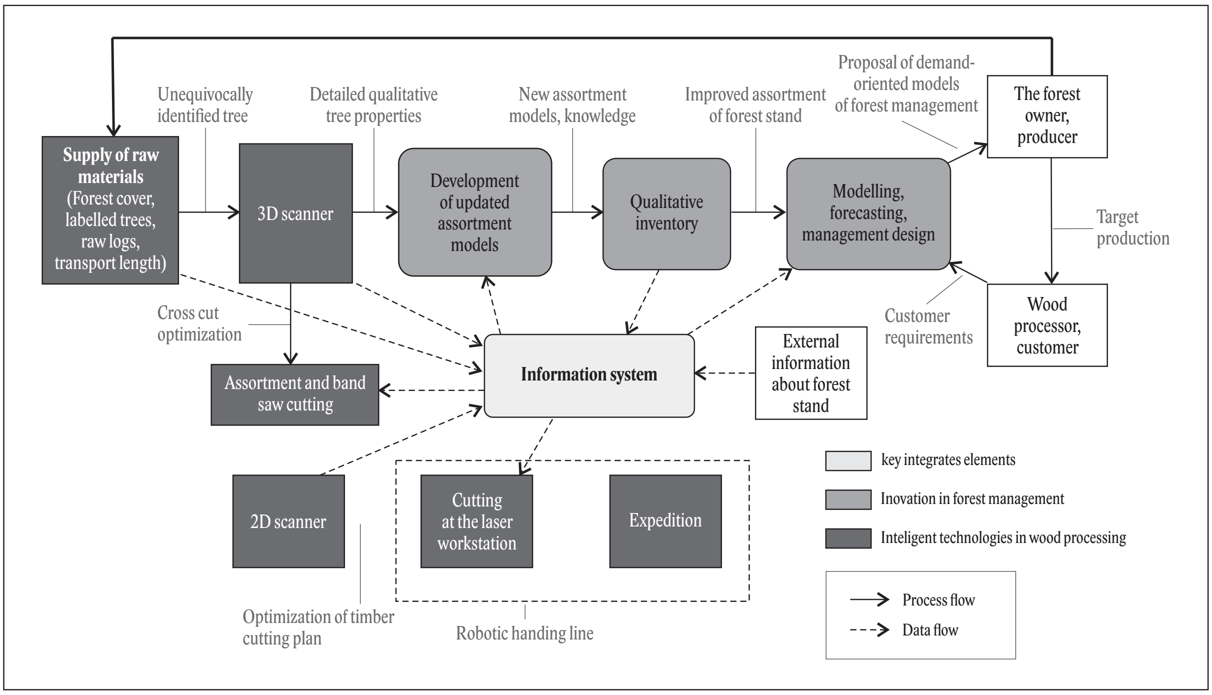

Fig. 5. Process flow and data flow in forestry- woodprocessing sector.

agement. These two flows are connected to a key integrating element – information systems (orange rectangle). The aim is to optimize the chain of production, delivery and processing of wood from cutting to dispatching individual products with outputs in following domains:

- Innovation in forest management focused on the most objective quality assessment of the wood produced
- Specifying tree assortment models in the area of internal wood defects detection by the use of 3D scanner and connection of information to information systems of wood producers
- Application of ICT technologies in the chain of production and wood-processing in the process of optimizing primary and secondary log breakdown
- Optimizing cutting plans for laser cutting
- Implementation and connectivity of new scanning technologies as well as laser cutting technologies with existing technologies on production line of manufacturers.

6. Conclusions

This paper utilizes acquired knowledge of existing researches conducted by foreign authors. It quantifies contributions of the CT scanner in the logs processing. All aforementioned researches show the increase of profit from processed wood ranging from 11.3% to 23.7% regarding coniferous logs. In terms of broadleaf logs, the profit increases by 24%. Potential value of each log differs and it also depends on the current timber price. Increase in the cost difference among individual wood grades means increase in the percentage of valuation. For the profitability verification in concrete conditions, for concrete sawmill, is the complex technological project needed.

The study is supplemented with SWOT analysis, which indicates the value at risk of implementing CT scanning technology into the production process on a relatively high level. The risk can be substantially decreased by the effective management. Such management can also create possibilities and considerable competitive advantages in the trade for both producers and manufacturers. If the wood-processing industry is to be competitive, if it is to effectively process raw material and to increase the quality of products, the implementation of CT scanning technology and new cutting technologies is necessary. Such technologies constitute essential innovation and they will bring the industry to the level of the technological leaders such as the car, industrial engineering and metal-working industries.

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ORIGINAL PAPER

Value added in sawmilling industry in the Czech Republic

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Abstract

The paper deals with sawmilling and timber processing capacities in the territory of the Czech Republic. Selected operations are sawmills with the annual processing capacity over 10,000 m^3, further divided into groups by the annual volume of processed raw material. In total 35 companies, which were chosen at random, were compared based on the indicator of value added per employee. The results show that the value added considerably differed not only among the groups but also within the individual groups of sawmill establishments.

Key words: primary timber processing; sawmills; capacity; economic indicators

Editor: Miloš Pánek

1. Introduction

Primary timber processing is one of long-tradition industries in the Czech Republic with the advantage of continually increasing stock in forest stands (Report on the state of forests and forestry 2016) and sufficient processing capacities. On the other hand, the timber processing industry in the Czech Republic (and similarly in Slovakia) shows certain problems such as "*low finalization of production, high exports of low value added products, and hence the low creation of value added in the sector (Sujová et al. 2015)".* At that, the increasing level of timber processing is one of strategic goals of the European Union (Sujová et al. 2017). In this context, it is important to use at full all available sawmilling capacities as well as their installed output whose increase in value may be the indicator of value added.

Kovalčík (2011) used indicators of gross and net value added to compare forestry sectors in various countries. Of other professional studies focused specifically on timber processing, worth mentioning is for example a publication evaluating wood processing companies in the Czech Republic, Slovakia and Austria (Sujová et al. 2015). Timber industry is also a subject of study published by Kupčák and Šmída (2015), who focused their attention on the largest sawmill operations with foreign owners in the Czech Republic.

The aim of the paper is to verify whether large sawmill operations achieve value added higher than smaller sawmills. For this purpose, the indicator of value added per employee was used, which makes it possible to compare the individual operations. In order to meet the goal, data on the selected companies had to be updated, i.e. existence, financial results and numbers of employees.

2. Material and methods

Data used in the paper were obtained through the secondary research of scientific literature, public registries – Companies Register (value added and number of employees for particular companies in their annual year reports), reports issued by the Ministry of Industry and Trade - so-called Panoramas of manufacturing industries (value added and number of employees for sub-division CZ NACE 16.1), Register of Insolvencies, Trades Register (both to verify whether the company is still active) and Reports on the State of Forests and Forestry. Above mentioned registers are available at web pages isir.justice.cz and or.justice.cz.

Default indicators applied in the paper include manufacturing capacity, value added and calculated value added per employee.

The paper further uses recalculated average values (based on simple arithmetic mean) according to the formula : $\frac{1}{n}\sum_{i=1}^{n} x_i$

Because the arithmetic mean is sensitive to extreme values, which occur within the studied set, the more accurate median was also used. Variation range (R) informs about the variability of the studied sample. It is calculated as a difference between the maximum and the

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**Corresponding author. Petra Palátová, e-mail: petpalatova@gmail.com, phone: +420 604 900 860* minimum values of the selected variable; $R = x_{max} - x_{min}$. In this paper, the variation range points to differences of results reported by companies falling into the same categories (categorization of sawmilling operations see below). For better clarity, the recalculated values are rounded up to entire units.

Value added can be defined as a "*difference between the enterprise outputs and its consumption for the outputs. Outputs are revenues from the sales of own products and services, activation and change in the inventory of own activities, consumption for the outputs consisting of the consumption of materials, energies and services (Pejzl & Slonek 2006)"*. Value added in sawmill production is affected by a number of factors of internal and external character. Internal factors can be considered for example the volume of production, volume of own products sold, sale price setting, manufacturing capacity, associated costs etc. External factors reflect namely the development of input raw material price, access to the sufficient amount of raw material in demanded quantity and quality, development of demand, sector recession or boom (Pejzl & Slonek 2006). In absolute expression, the indicator of value added cannot grasp differences among the facilities, and this is why a relative variant of this indicator is used – value added per 1 employee.

For the purposes of this paper, the author selected sawmill operations with the processing capacity over 10,000 m³, i.e. medium-size sawmills, bigger medium-size sawmills, big sawmills and large-scale sawmills. Below, the categories of sawmill operations are listed by their annual processing capacities according to Detvaj (2003):

- Processing capacity up to 2,499 m³ (very small sawmills),
- Processing capacity from 2,500 – 4,999 m³ (small sawmills),
- Processing capacity from 5,000 – 9,999 m³ (smaller-size sawmills),
- Processing capacity from 10,000 – 19,999 m³ (medium-size sawmills),
- Processing capacity from 20,000 – 49,999 m³ (bigger medium-size sawmills),
- Processing capacity from 50,000 – 200,000 m³ (big sawmills),
- Processing capacity over 200,000 m³ (large-scale sawmills).

Sawmills with the annual processing capacity up to 10,000 m³ are not considered due to the limited extent of the paper. Individual sawmilling facilities were chosen for the assessment from the list of operations according to Pražan (2010). Subsequently, the establishments were divided into groups according to the respective categories by their processing capacity. In the studied period (see Pražan 2010; Pecháček 2016), the category of large-scale sawmills included 5 corporations residing in the Czech territory. At present, there is another facility that could have been included in the category of large-scale sawmills with the processing capacity over 200 000 m³ – LESS & TIMBER in Čáslav. At first, because there are five representatives in the category of large-scale sawmills, five representatives were chosen for all other categories, too. Then, there were included other companies, in order to describe the situation in each category in more detail. Because there is no official database of domestic sawmilling companies, they were chosen again at random from the list of companies according to Pražan (2010), in categories bigger sawmills and medium sawmills to represent around 1/4 of companies mentioned in respective categories, which in total means 34 companies in this article. Data on the companies were surveyed in June 2017.

Although companies in general have the duty to publish their data annually, it was not possible to find data for 2016 for all selected companies and the results would not be comparable. Because of that, 2015 was chosen as the reference year.

3. Results

3.1. Sawmill production and wood impregnation

According to the Classification of economic activities in the Czech Republic, primary timber processing is included in Section C – manufacturing industry, Division CZ NACE 16. In the sub-division CZ NACE 16.1, we find sawmill production and wood impregnation. The sub-division CZ NACE 16.2 includes manufacture of wood, cork, wicker and straw products with the exception of furniture (CZ NACE 2017). In terms of value added, the sub-division CZ NACE 16.1 contributes only with 20.8% to the value added generated within Division CZ NACE 16 (Panorama of the manufacturing industry 2016).

The level of value added in the sub-division 16.1 does not exhibit larger changes between the years. Although the value added per employee is increasing according to data, it should be pointed out that the number of employees between the years is decreasing. Selected information about division CZ NACE 16 and sub-division 16.1 are presented in Table 1.

3.2. Sawmill operations

As to the requirements for primary wood processing, sawmills are represented sufficiently in the Czech Republic, relatively regularly located across the country. Nevertheless, there are distinct differences among them – for example in their processing capacities (maximal in dependence on available technology and actually implemented capacity), structure of assortments, different standard of mechanization and automation, number of employees, customer networks, etc. The capacity of processing itself is then a good criterion in the classification of these facilities, its volume being affected by

Table 1. Indicators selected for Division CZ NACE 16 and sub-division CZ NACE 16.1.

Year	2011	2012	2013	2014	2015	2016
CZ NACE 16						
Value added (VA) in CZK	20 848 068	20 205 569	20 702 359	22 044 295	23 143 349	24 782 688
Number of units	29 495	29 405	27 849	27 553	27 672	27 640
VA/employee in CZK	594 686	586 131	643 256	714 352	741 270	818 392
CZ NACE 16.1						
Value added (VA) in CZK	3 910 139	3 347 464	4 042 997	4 599 906	4 411 053	5 143 072
Number of units	2 240	2 071	1 901	1 765	1 691	1 585
VA/employee in CZK	515 787	461 255	605 034	715 588	691 350	809 676

Source: Ministry of Industry and Trade, 2018.

a number of factors mentioned by Pražan (2010). With respect to the missing information sources about the current processing capacities implemented by the respective companies, the division of operations dwells on the situation in 2009 according to Pražan (2010).

The following data on sawmill operations are ordered by their size according to individual categories:

3.3. Large-scale sawmills

The category of large-scale sawmills includes sawmilling operations with the annual processing capacity over 200,000 m³ (Detvaj 2003). In addition to sawmills with foreign property participation (Mayr-Melnhof Holz Paskov (hereinafter M-M Paskov), Stora Enso Wood Products Ždírec (hereinafter SE Ždírec) and Stora Enso Wood Products Planá (hereinafter SE Planá), the category also includes Dřevozpracující družstvo (Wood Processing Cooperative) Lukavec (DD Lukavec) and the Javořice Sawmill. Tables 2 and 3 present the company names without their legal status (DD Lukavec is a cooperative, Javořice is a joint-stock company and the other three are limited liability companies (ARES 2018).

Table 2. Value added (thousand CZK) in selected sawmill operations – large-scale sawmills.

Sawmill/Year	2011	2012	2013	2014	2015	2016
DD Lukavec	254 757	247 779	274 459	361 542	331 101	N/A
Javořice	6 066	11 030	48 461	98 835	N/A[1]	N/A
SE Ždírec	382 809	360 029	567 876	649 520	596 127	N/A
SE Planá	316 129	258 693	360 177	487 514	436 833	385 727
M-M Paskov	393 258	262 036	561 008	684 934	546 203	741 517
On average	270 604	227 913	362 396	456 469	—	—

Source: Companies Register – annual reports of the individual companies; 2011 – 2017 ("Sbírka listin").

Table 3. Value added converted to 1 employee in selected sawmill operations – large-scale sawmills (in CZK).

Sawmill/Year	2011	2012	2013	2014	2015	2016
DD Lukavec	429 607	425 737	478 152	635 399	581 900	N/A
Javořice	159 632	169 692	452 907	923 692	N/A	N/A
SE Ždírec	1 020 824	949 945	1 200 584	1 402 851	1 245 662	N/A
SE Planá	1 311 739	1 119 883	1 622 419	2 267 507	2 003 821	1 662 616
M-M Paskov	1 618 346	1 056 597	2 235 092	2 604 312	2 008 099	2 657 767

Source: Companies Register – annual reports of individual companies; 2011 – 2017 ("Sbírka listin"), own compilation.

The calculated average value in Table 2 is only a very orientation criterion because it does not take into account possible distinctive deviations between the extreme values – maximum and minimum, in this case the extremely different result in the Javořice Sawmill. The low level of value added in 2011 as well as in the following years was in this sawmill a likely consequence of insolvency in 2010 and the following reconstruction of the establishment. The highest values in absolute expression as well as the highest value per employee were reported by Mayr- Melnhof Holz Paskov, Ltd., in 2016.

3.4. Big sawmills

Representatives of big sawmills (i.e. with the processing capacity from 50,000 – 200,000 m³/year) were the following companies: Jihoobal Dlouhé pole, Holz Schiller, Dřevopar (in all cases a limited liability company – "LLC"), Pila Tetčice (Tetčice Sawmill), Klaus Timber (both with legal status of joint-stock company, further used abbreviation "JSC"). Information about big sawmills are presented in Table 4.

Table 4. Value added (in CZK) in selected sawmill operations for 2015 (big sawmills).

Sawmill	Legal status	Value added (VA)	Number of employees	VA/employee
Jihoobal	LLC	11 419 036	34	335 854
Holz Schiller	LLC	197 989 000	406	487 658
Dřevopar	LLC	8 624 000	64	134 750
Pila Tetčice	JSC	23 323 000	64	364 422
Klaus Timber	JSC	148 405 000	240	618 354
Mean	—	77 952 007	162	*Variation range = 483 604*
Median	—	23 323 000	64	

Source: Companies Register – annual reports of individual companies; 2017, ("Sbírka listin"), own compilation.

The number of employees in the companies in this category confirms that the division of sawmill operations by the number of employees would not illustrate reality as to the establishment size. The lowest and the highest numbers of employees were 34 and 406 persons, respectively. The level of value added per employee greatly differed as well – the lowest being 134,750 CZK and the highest being 618,354 CZK. The variation range was 483,604 CZK.

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[1] The value of the indicator is not accessible.

3.5. Bigger medium-size sawmills

In this category (annual breakdown capacity from 20,000 – 50 000 m^3) there were representative companies see Table 5.

Rising above all the other companies in this category is Matrix, with the highest number of employees and the highest value added per employee at the same time (883,742 CZK). Variation range in the level of value added per employee is higher than in the above category – reaching 606,833 CZK.

Table 5. Value added (in CZK) in selected sawmill operations for 2015 (bigger medium-size sawmills).

Sawmill	Legal status	Value added	Number of employees	VA/employee
Cedro	LLC	6 092 000	22	276 909
Pila Černý	LLC	18 138 000	43	421 814
Pila Sedlo Servis	LLC	7 822 000	13	601 692
Kaiser	LLC	41 179 000	89	462 685
Matrix	JSC	134 329 000	152	883 743
Carman-Wood	LLC	12 146 000	34	357 235
Timber Production	LLC	18 887 000	54	349 759
Empo Holz	LLC	30 978 000	50	619 560
Dřevozávod Pražan	LLC	21 136 000	63	335 492
Mean	—	32 301 000	58	*Variation*
Median	—	18 887 000	50	*range = 606 833*

Source: Companies Register – annual reports of individual companies; 2017, ("Sbírka listin"), own compilation.

3.6. Medium-size sawmills

Representatives chosen for annual breakdown capacity from 10,000 – 20,000 m^3 are 15 companies, mentioned in Table 6.

Table 6. Value added (in CZK) in selected sawmill operations for 2015 (medium-size sawmills).

Sawmill	Legal status	Value added	Number of employees	VA/employee
Pila Benda	LLC	10 082 000	19	530 632
Pila Otaslavice	LLC	2 302 000	10	230 200
Pila Hrachovec	LLC	4 458 954	15	297 264
Optima Lanškroun	LLC	4 384 000	14	313 143
Level O2	JSC	6 463 000	30	215 433
Skapo	LLC	3 310 000	14	236 429
Pila Füllsack	LLC	10 615 000	36	294 861
Pila Krnov	LLC	5 121 000	22	232 772
Gatro	LLC	6 407 000	26	246 423
Pila Zámrsk	LLC	3 859 000	15	257 267
Pila Facek	LLC	10 091 000	31	325 516
Pila Karel Vlček	LLC	20 440 000	45	454 222
B. Turner	LLC	4 763 000	11	433 000
Benko, dřevařský podnik, Kopidlno	LLC	15 523 000	74	209 770
Nema	LLC	19 199 000	54	355 537
Mean	—	8 467 864	28	*Variation*
Median	—	6 407 000	19	*range = 320 862*

Source: Companies Register – annual report of individual companies; 2017, ("Sbírka listin"), own compilation.

These establishments feature the least differences in the number of employees. Value added per employee does not differ too much either, which is documented by the lowest value of variation range within all the categories of sawmill operations (320,862 CZK).

The following Table 7 presents an information summary.

Table 7. Summary table (large-scale sawmill operations excluded).

Sawmill operation category	Number of employees	Value added per 1 employee in CZK	Value added – mean value in CZK	Average number of employees (mean value)
	(Minimum/Maximum)			
Big	34/406	134 750 / 618 354	77 952 007	162
Bigger-medium	13/152	276 909 / 883 742	31 403 000	58
Medium	10/74	209 770 / 530 632	8 467 864	28

Source: own compilation based on data from previous tables.

4. Discussion

The sector of primary timber processing has a long tradition in the Czech Republic and its current advantage is the sufficient base of raw material. However, sawmills are focused on making low-value-added products such as sawn timber, whose considerable volume is exported to neighbouring countries. Moreover, the exports show increasing trends (see for example Report on the State of Forests and Forestry 2013, 2016) and the issue of low products finalizations has been discussed for several years already. The National Forestry Programme (2008) informs that more than a half of extracted timber is exported as raw or half-finished material to foreign countries. In 2012, the Czech Republic even became the largest exporter of raw timber in the European Union (Šafařík 2013). Raw timber exports seem illogical also because various studies indicate that the country has sufficient processing capacities (see for example Pecháček 2016; APICON 2016); this means in other words that raw material, which is exported now, could be effectively manufactured in the home country.

In spite of this, the Ministry of Industry and Trade (Panoramas of Manufacturing Industries 2013, 2014, 2016) has been pointing out an opposite problem in its reports – i.e. lack of manufacturing capacities for several years. According to information from 2014, the lack of manufacturing capacities is the main reason why low-value-added products are primarily offered on the market (Panorama of the manufacturing industry, 2014). A declaration from 2016 contains a formulation about the plan to establish a forest and forest products industries fund, which would support the emergence of new sawmills and other timber processing operations in line with the increasing demand for raw wood (namely in terms of marketing) (Panorama of Manufacturing Industry, 2016). However, such a fund does not exist so far.

Another interesting fact is that although the discussions about the size and capacity of sawmill operations have been permanently continued, the statements published by Pražan (2017) still hold true: "*there is in fact no official or commonly used calculation to determine the capacity of an establishment, most manufacturers of saw-*

mill technologies indicating the maximum output of breakdown lines. Most plausible is the historically achieved amount of processed raw material reported by individual companies". The achieved level of breakdown is a base for data in this paper, too; nevertheless, obtainment of current data from the companies is somewhat problematic.

Factors influencing the sawing capacity were discussed, for example, in paper by Bomba et al. (2016), depending primarily on the number of employees, the primary technology, level of mechanisation etc. Technical efficiency in production in sawmilling industry was discussed by Šedivka (2009).

Cardinal role in determining actual and potential processing capacity plays the availability of raw material at a required amount and quality. Since the establishments are often located near populated areas, there are also some restrictions concerning manufacturing processes (noise, illumination) that may reflect into working on shifts at night or in early morning hours (Pražan 2017).

Other limitations for sawmilling facilities follow out from the setting of customer-supplier relations and reflect both in the manufacturing process and in the costs. This concerns for example supplies of certified raw material and products through PEFC and FSC systems when the companies choose a particular certification scheme with respect to requirements on the part of prominent customers. The certification of so-called consumer chains is dealt with for example by Dudík & Riedl (2015), Paluš et al. (2017, 2018).

Matrix, the company which achieved the highest value added in its category (as well as the highest value added per employee), deals in its manufacturing programme also with the reputable assortments of oak and larch sawn timber whose conversion into money is high. Thus, the level of value added is possibly affected by these factors in addition to the wide range of business activities.

The company Dřevopar exhibited the lowest value added per employee of all studied operations. In the last years of 2015 and 2016, the level of value added was lower than corresponding to the previous development. This shows that even the indicator of value added might have suggested the company's upcoming problems. Since the end of year 2017, the company has been in insolvency and current information (March 2018) signals that the company is standing before the decision on bankruptcy. With respect to the studied period (i.e. data being assessed in June 2017), the company remained in the list.

As a criterion for comparison, the author selected the indicator of value added per employee. The initial assumption about a markedly higher indicator of value added in large-scale sawmills was obvious in enterprises with the foreign participation; otherwise considerable variations were observed both among the groups of facilities and within the respective groups.

Holz Schiller provides the highest number of jobs (406 persons) while Pila (Sawmill) Otaslavice provides the lowest number of jobs (10 persons). The lowest indicator of value added was recorded in the company Dřevopar (134,750 CZK per employee) and the highest one in Mayr-Melnhof Holz Paskov (2,657,767 CZK per employee). The variation range of the indicator of value added per employee was the highest in the large-scale sawmills, the results being considerably affected by those of Pila (Sawmill) Javořice. In the studied year of 2015, bigger medium-size sawmills exhibited the highest variation range (606,833 CZK) and the lowest variation range was recorded in the last surveyed category – medium-size sawmills (320,862 CZK).

Except year 2014, there is always a higher value added per employee on average in CZ NACE 16 than in CZ NACE 16.1. All categories, except the only company – Matrix – do not reach the value added per employee higher than is the average of CZ NACE 16.1 in 2015. Large-scale sawmills, namely S-E Ždírec, S-E Planá and M-M Paskov reach at least double values of this indicator.

The indicator of value added encompasses all profit-making activities of companies. However, value added for sawmill production cannot be singled out from publicly available statistics. Value added is affected by range of business activities, size of the company, technical equipment, availability and type of processed raw material, etc. The fact remains that methods should be sought for how to increase value added in the primary sector of wood processing. One of them is promotion of wood product to the wider public.

Because the demand for wood is a driven demand depending on the situation in other industries, that use wood as a raw material (like pulp and paper industry, furniture making industry etc.), the development of value added in the wood-processing industry might be affected also by situation in these industries. The research could further deal with the comparison of value added in sawmilling in countries with similar conditions to those in the Czech Republic, like Austria and Germany. Price determination in the Czech Republic is also correlated with the price development in the above mentioned countries.

5. Conclusion

The paper is focused on selected sawmill operations, which were divided into categories by their processing capacity. Considered were companies with the annual breakdown capacity larger than 10 000 m^3 and there were 34 establishments surveyed in total.

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