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State of the raw wood growing stocks and prediction of further development of cutting in the context of coniferous stands calamity in the Czech Republic

*Dalibor Šafařík, David Březina, Jakub Michal, Petra Hlaváčková**

Department of Forest and Wood Products Economics and Policy, Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic

**Corresponding author: petra.hlavackova@mendelu.cz*

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Abstract: The extremely dynamic development of calamities caused by the effects of global climate change followed by the spread of under-bark insect pests mainly in coniferous stands and the ongoing incidental felling have raised concerns in the woodworking industry about the developments in the source material with respect to ensuring production in a short-term view. Since the overall standing stock in spruce stands of all age classes in the Czech Republic amounts to 399.6 million m^3 (2017–2026) and the theoretical outlook of the logging potential based on the percentage of logging accounts for 112.62 million m^3 (2017–2026), the concerns might be deemed justified. The article presents an updated view of the current situation based on official statistics and offers an analytic prediction of the possible development, considering the possible consequences, even in the production of the forestry sector. The statistical data on the current situation have been compiled for the last two decades of development. The results show that with a continued high rate of bark beetle calamities, assuming a total annual cutting with a permanent limitation on the planned harvests of more than 30 million m^3, the complete stands of spruce from age class 5 onwards could be harvested in approximately 14–16 years.

Keywords: bark beetle calamity; development of logging; forestry; Norway spruce; logging potential; unplanned cutting; woodworking industry

Global climate change and its impacts on European forests are currently a major concern for the forestry sector and for all the related sectors (see e.g. Linder et al. 2014; Ding et al. 2016; Ruiz-Benito et al. 2020; Bárta et al. 2021). As mentioned by Bárta et al. (2021), massive bark beetle outbreaks have caused the widespread loss of coniferous, mainly economic, spruce stands in Central Europe in recent decades.

The current development of the state of Czech forests caused by the effects of global climate change and the associated extreme spread of bark beetle infestations, and the ongoing droughts, which have been increasing since 2016, pose a significant threat in the prognoses of the use of the raw material for the entire woodworking industry and the other downstream sectors, which expect growth in the

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upcoming years based on the prognoses. To support the statement, we can mention that, in the European Union, the supplies of raw wood from the forestry sector (for the woodworking industry) amounted to almost 36% in 2019, while the secondary processing (recycled material) for the production of goods made of wood, pulp, and paper amounted to nearly 47%. As for the utilisation of biomass in the energy sectors in the Czech Republic, its proportion in the overall energy basis is only 2.7%, while the proportion amounts to 7.5–13.1% in some other countries, such as Germany, Finland, or Denmark. The information published in the Panorama of Manufacturing Industry of the Czech Republic in 2018 (Ministry of Industry and Trade 2019) also confirms the fast-growing trend in building wooden houses in the building industry. The increase in this segment was 36% year-on-year, which represented an increase in the construction by more than 1 060 wooden houses compared to 2017. The merits of the assertion of the increasing capacities of woodworking companies can be supported by the increase in the production of Cross-Laminated Timber (CLT), Konstruktionsvollholz (KVH), Laminated Strand Lumber (LSL), and Laminated Veneer Lumber (LVL) building materials. This growth is also visible from Stora Enso's reports from July and August 2019 that mention an increasing trend in the current processing capacities in more regions of the Czech Republic (an increase in Ždírec by 120 000 m^3) and in the opening of a new plant in Sweden with the capacity of 100 000 m^3 in reaction to the immense global demand for CLT boards. Reportlinker (2019) also expects a rise in the demand for LSL and LVL boards. According to the report, the market with layered materials reached a value of 2.33 billion USD in 2018. The demand is expected to rise to 4.23 billion USD by 2024. Although the biggest proportion of the market is in North America, growth prospects are also foreseen in Asia, Europe, Latin America, the Middle East, and Africa (Michal 2020).

In 2018, there was a dramatic deterioration of the production conditions in forests and the downstream forest-based sector. The year 2018 was adverse due to extreme weather conditions, unevenly distributed precipitation and extreme temperature events, which led to the further progression of bark beetle disasters and the consequent economic problems in the whole primary production sector of forest management as well as in the complex of downstream sectors (Šafařík et al., 2019). At the beginning of 2018, it was still assumed, based on the preceding development and the available logging capacities, that the total raw timber harvest in the Czech Republic would reach the maximum of 17.5–18.0 mil. m^3 (Ministry of Agriculture, 2022). However, those figures deviated from the final logging value of 2018 by approx. 27% as it reached 23.01 mil. m^3 due to the bark beetle disaster. Of this figure, the salvage cutting resulting from the bark beetle disaster amounted to 13.06 mil. m^3, which is an increase of 123% compared to 2017 and twenty times the regular annual logging caused by bark beetles. This issue and its aspect have already been addressed by Šafařík et al. (2019).

The Ministry of Agriculture of the Czech Republic in the Forest Management Section states that seven of the thirteen regions of the Czech Republic were most affected by the bark beetle calamity, although the infestation occurred throughout the entire national territory. The maximum annual logging capacity currently available in the Czech Republic is estimated at 30-35 million m^3. The average monthly output is 2.5–3 million m^3 (Ministry of Agriculture, Forest Management Section 2019).

The forest calamity management strategy of the Ministry of Agriculture of the Czech Republic states that in extreme summer months, the monthly need to process harvested bark beetle infested wood can exceed 3 million m^3 in some regions (Ministry of Agriculture, Forest Management Section 2019).

The aim of the paper is to analyse and predict the possible development of the logging possibilities and its impact on the forestry and the related sectors based on the current data and the current situation in the forests in the Czech Republic. The hypothesis chosen for the paper was: In the case of the continued rate of bark beetle calamities, with the total annual harvest of 30 million m^3 even with a reduction in the planned harvests, the total growing stock of spruce of age class 5 and older will be harvested in approximately 14–16 years. The statistical data on the current situation have been compiled for the last two decades of development. A wood supply model with the current increment will be used for the solution.

MATERIAL AND METHODS

The methodological procedure for determining whether the stated hypothesis could be confirmed,

https://doi.org/10.17221/76/2022-JFS

rejected or modified using the current increment harvest model was divided into two phases. The first phase was secondary research aimed at assessing the current state of the problem by means of a literature search of the available external and internal materials. The methodology published by Šafařík et al. (2019) was used to analyse the literature sources.

The primary research used the methods of a comparative analysis and prediction, as well as the methods used by the Forest Management Institute in Brandýs nad Labem (Czech Republic) and the European Forest Dynamic Model (EFDM).

The main external materials were the Reports on the State of Forest and Forest Management in the Czech Republic (Ministry of Agriculture 2022). Data and information from the reports were used:

(*i*) to identify the beginning of the conifer stand dieback and bark beetle calamity in the Czech Republic, which is determined as the year 2015 due to the extremely dry summer;

(*ii*) to establish a three-year time horizon to model the development of the total and unplanned harvests;

(*iii*) to model the overview of the cutting possibilities by region and the assortment structure;

(*iv*) to calculate the theoretical outlook for the potential wood supply in the Czech forests by region, regeneration and cleaning and thinning and tree species groups. The woody species were divided into two groups for the analysis. The group referred to as spruce include spruce, pine and other conifers. The group referred to as oak includes oaks, beeches and other broadleaves species;

(*v*) to model the theoretical outlook of the species composition in the Czech Republic and the regions and to determine the basic assortment structure.

From the internal materials, the analysis was mainly based on the partial outputs of the project "Potential of structural changes in sustainable forestry and wood processing" NAZV QK1820358 solved by the Department of Forest and Wood Products Economics and Policy of the Faculty of Forestry and Wood Technology, Mendel University in Brno in the years 2018–2020 (Research, Development and Innovation Information System 2022). The outputs of the project that have been used for the analysis in this paper include calculations of the material and value flows of raw timber in the forestry and downstream industries.

According to the methodology of Šafařík et al. (2019), the input data on timber cutting in the Czech Republic until 2017 were divided into two groups of tree species - coniferous and deciduous. The input data were:

(*i*) a comparative analysis of the impact of salvage logging on the timber market in the Czech Republic was performed,

(*ii*) a correlation between the cutting indicators and the relationship of the main commercial assortments was established,

(*iii*) an overview of the cutting possibilities and a development model of the total timber cutting were compiled,

(*iv*) a prediction of the development of the cutting possibilities and the raw material base was made, including standardised needs of the forest-based industry, considering the expected increase in the dendro-mass left in the stands for decomposition.

Currently, the Forest Management Institute in Brandýs nad Labem is dealing with this issue. The growing stock estimates are based on the data obtained within the project "Monitoring the Status and Development of Forest Ecosystems" (Sledování stavu a vývoje lesních ekosystémů, SSVLE), which was launched in 2016 and follows the second cycle of the National Forest Inventory of the Czech Republic 2011–2015 (NIL2). Based on a mandate from the Ministry of Agriculture, the Forest Management Institute is carrying out this survey in the period between the end of NIL2 to the beginning of the next NIL cycle, i.e. between 2016–2020. The methodology and scope of the data collection, the SSVLE corresponds to NIL2 (ÚHÚL 2020).

In addition, the European Forestry Dynamics Model (EFDM) methods were used. The EFDM simulates the forest development and estimates the volume of wood harvested for any given forest area. This estimate can be broken down by, for example, species, habitat quality, management regime and ownership category.

The EFDM was conceived as a flexible system for harmonised forestry modelling. It has been developed to process data from Europe's National Forest Inventories. As these data are not standardised or necessarily available outside the country of their ownership, the EFDM was developed as a modular system in freely available software R (Packalen et. al 2014). In applying the findings and information from the paper, the EFDM methods were also used, which emerged from a collaboration between the European Commission's Joint Research Centre and its partners in EU Member States to develop

https://doi.org/10.17221/76/2022-JFS

a forestry dynamics model. The model works with an interface of different climate, economic, and management scenarios. The input data for the scheme at the national level are information gathered from the National Forest Inventory (NIL 2).

Various indicators can be used to access the performance of the forestry sector. For the purpose of this paper, an index measuring the gross value added (*GVA*) and the production of the forestry sector in value terms (*PFS*) has been used. The calculation is as follows [Equation (1)]:

$$Index = \frac{GVA}{PFS} \quad (1)$$

where:

GVA – gross value added;

PFS – production of the forestry sector in value terms.

The data for the calculation were obtained from the "Economic Accounts for Forestry and Logging" for the period 2015–2019. These data are publicly available on the website of the Czech Statistical Office (ČSÚ 2022) and are also presented in the Status Reports on Forest and Forest Management of the Ministry of Agriculture of the Czech Republic (Ministry of Agriculture 2022).

According to the ČSÚ (2022), *PFS* represents the total final production of the forestry sector that leaves the sector. This is mainly wood production. *GVA* represents the final effect of the forestry sector measured by the difference between the final output of the forestry sector and the intermediate consumption. It is expressed in basic prices.

For the conversion of Czech crowns to Euros, the exchange rate prices of the Czech National Bank (ČNB) for the period 2015–2019 were used (ČNB 2022).

RESULTS

The perspective of the future 10-year development of the area distribution of the individual age classes of coniferous trees of the spruce group is presented in Table 1.

Figure 1 shows the predicted development in the spruce standing stock in 2017–2057 to the significant decline in the potential wood supply in 2027–2046. Figure 2 illustrates the predicted development in the 10-year spruce potential wood supply in 2017–2057 derived from the cutting percentage and confirms the decline in the potential wood supply in 2027–2046. A theoretical overview of the assortment possibilities for the spruce group is shown in Figure 3. Figure 4 presents the theoretical outlook of the assortment possibilities for the oak species group. Figure 5 presents the theoretical outlook for the 10-year cutting possibilities (of cutting percentage) for the oak woody species.

Table 1. Prediction of the development of the area distribution of spruce age classes in the period 2017–2057

Age class	Decade			
	1st	2nd	3rd	4th
1	102 825	179 737	128 831	114 584
2	102 908	102 825	179 737	128 831
3	116 500	102 906	102 823	179 734
4	91 217	116 483	102 887	102 811
5	100 764	91 184	116 379	102 800
6	86 710	100 706	91 096	116 145
7	75 610	86 346	100 458	90 854
8	109 424	74 965	85 735	99 855
9	117 011	106 157	72 976	83 632
10	91 872	102 160	92 651	64 437
11	91 622	64 093	73 467	66 256
12	66 800	46 429	35 656	41 921
13	34 292	21 075	17 632	14 573
14	17 861	9 372	7 205	6 210
15	8 438	7 439	4 381	3 242
16	3 823	4 525	3 761	1 567
17+	2 690	3 964	4 693	2 913
Total	1 220 36	1 220 367	1 220 36	1 220 367

Source: ÚHÚL (2019) in Šafařík et al. (2019)

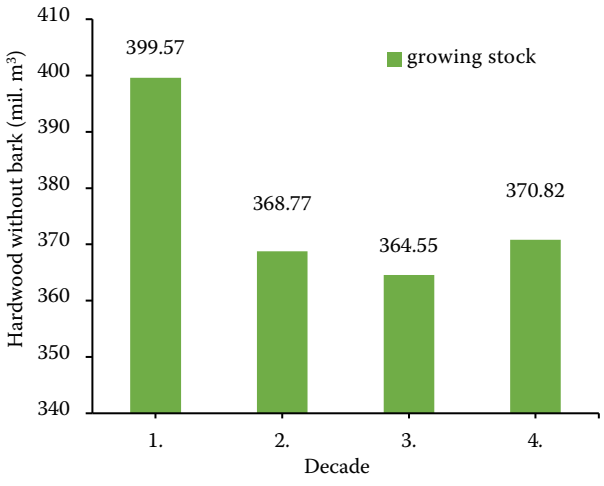

Figure 1. Prediction of the development of spruce growing stock in stands in the period 2017–2057

Source: ÚHÚL (2019) in Šafařík et al. (2019)

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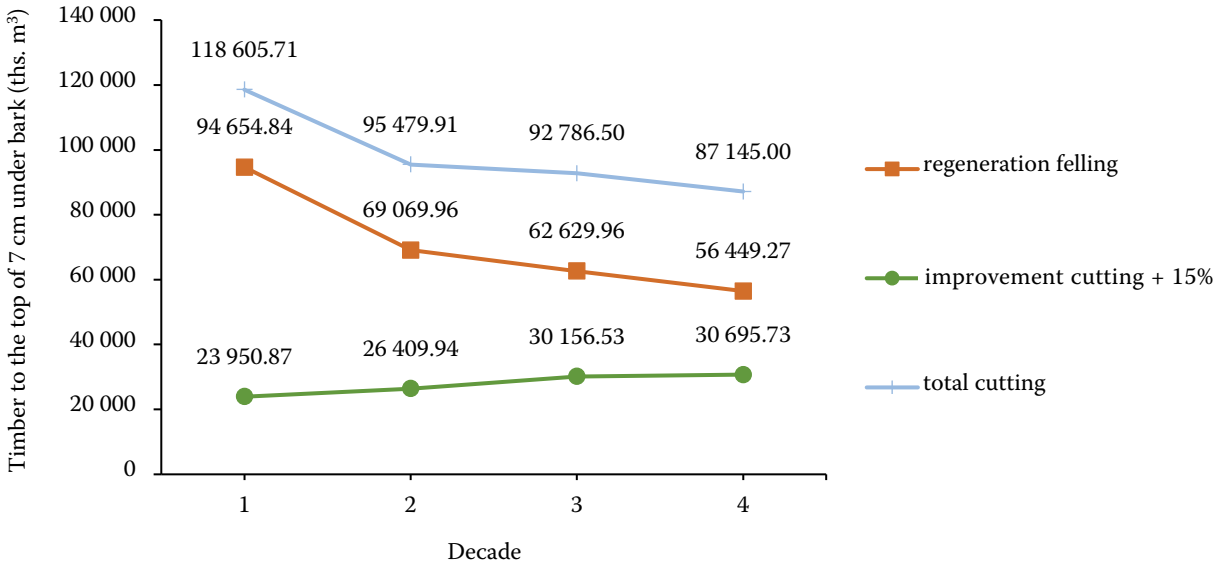

Figure 2. Prediction of spruce cutting potential in the period 2017–2057

Source: ÚHÚL (2019) in Šafařík et al. (2019)

The development of timber cutting in the Czech Republic in 2000–2020 by tree species is presented in the graph in Figure 6. It is clear from the graph in Figure 6 that, if the bark beetle calamity continues at the same rate and intensity, the total annual harvest will reach more than 35 million m^3 with a permanent reduction in the planned harvest.

The development of the composition of the wood assortment in the period 2000–2020 is shown in the graph in Figure 7. The forecast of the 10-year timber cutting in relation to the current trends for period of 2017–2027 is presented in Figure 8.

The graph in Figure 9 shows the correlation between the development of the salvage cutting and the total cutting.

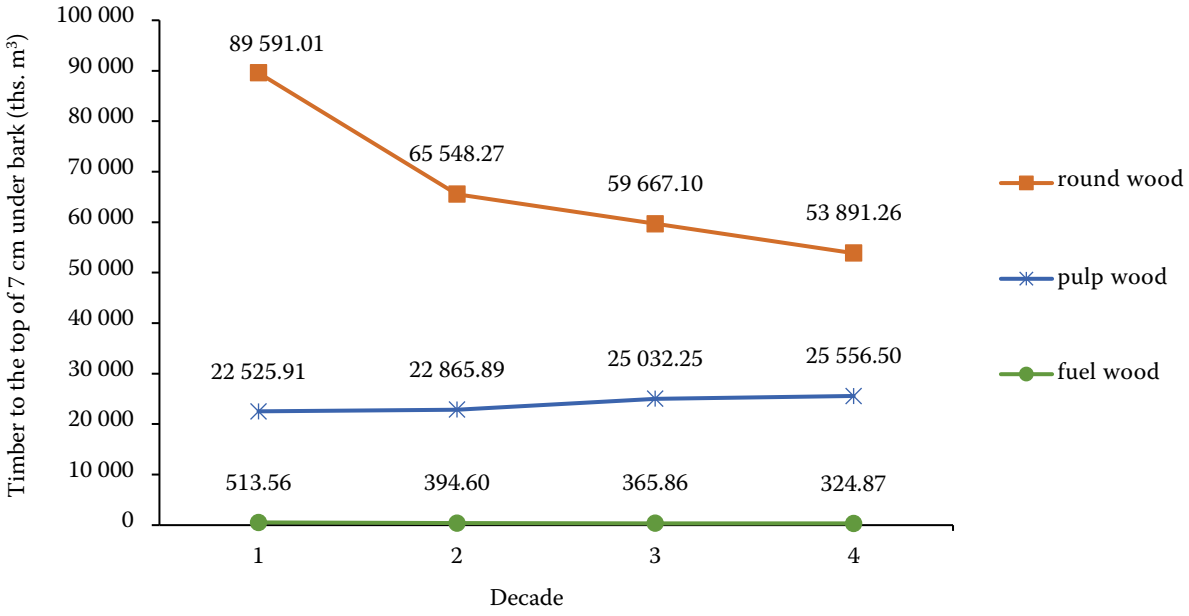

Figure 3. Prediction of assortment possibilities for spruce in the period 2017–2057

Source: ÚHÚL (2019)

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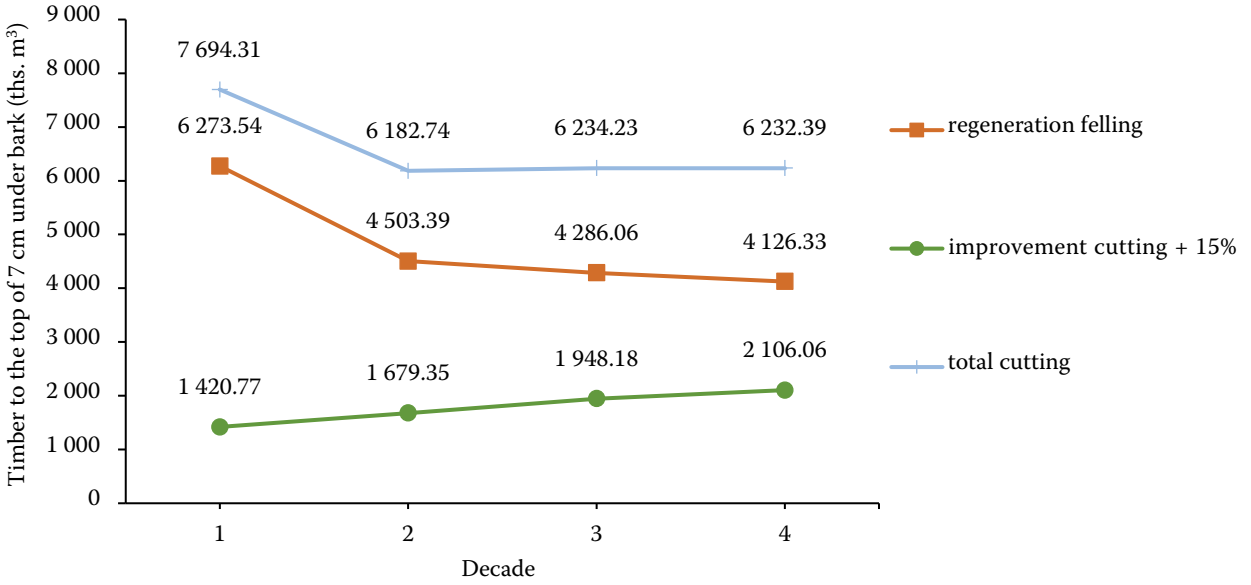

Figure 4. Prediction of oak cutting potential in the period 2017–2057

Source: ÚHÚL (2019)

The dependence of the salvage cutting and the total cutting was supplemented with a trend (logarithmic) with the highest coefficient of determination R^2 = 0.9643 (i.e. correlation coefficient of R = 0.9819, this shows a strong dependence).

The graph in Figure 10 shows the correlation between the export value of the raw timber and the total cutting.

The dependence of the raw wood exports of the raw timber was supplemented with a trend (polynomial) with the highest coefficient of determination R^2 = 0.8599 (i.e. a correlation coefficient of R = 0.9273, this shows a strong dependence).

Table 2 shows the gross balance of the consumption and export of the raw timber up to 2019. It shows that there is approximately 1–2 million m^3 available for additional imports of certain wood species and assortments, mainly pine.

Based on the analyses of the data and information from the Reports on the State of Forest and

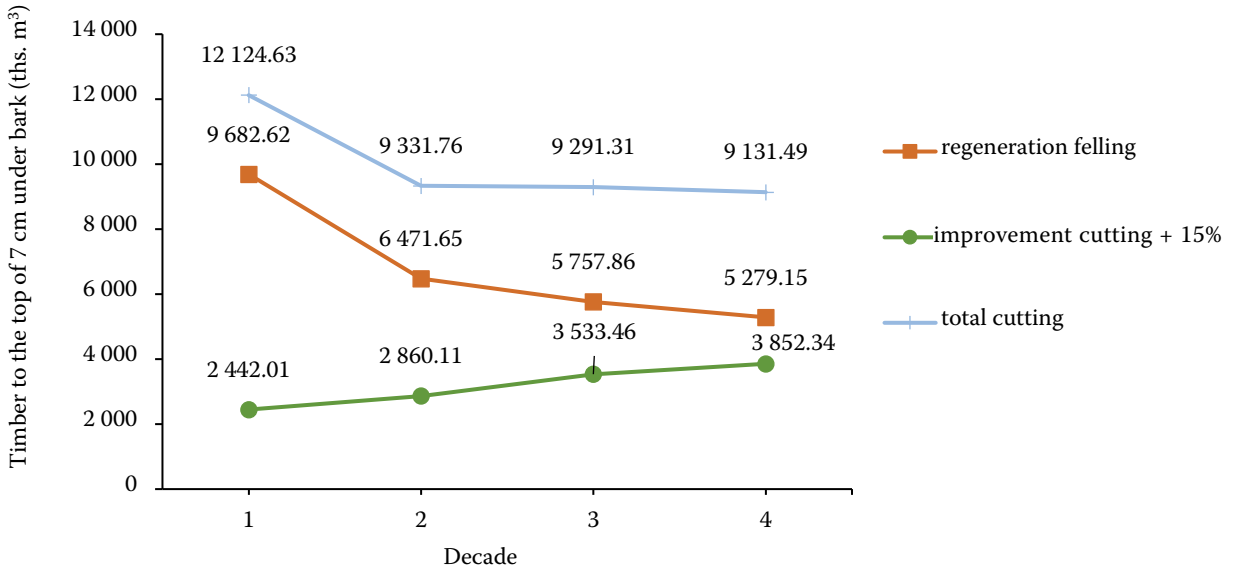

Figure 5. Prediction of oak 10-year cutting potential

Source: ÚHÚL (2019)

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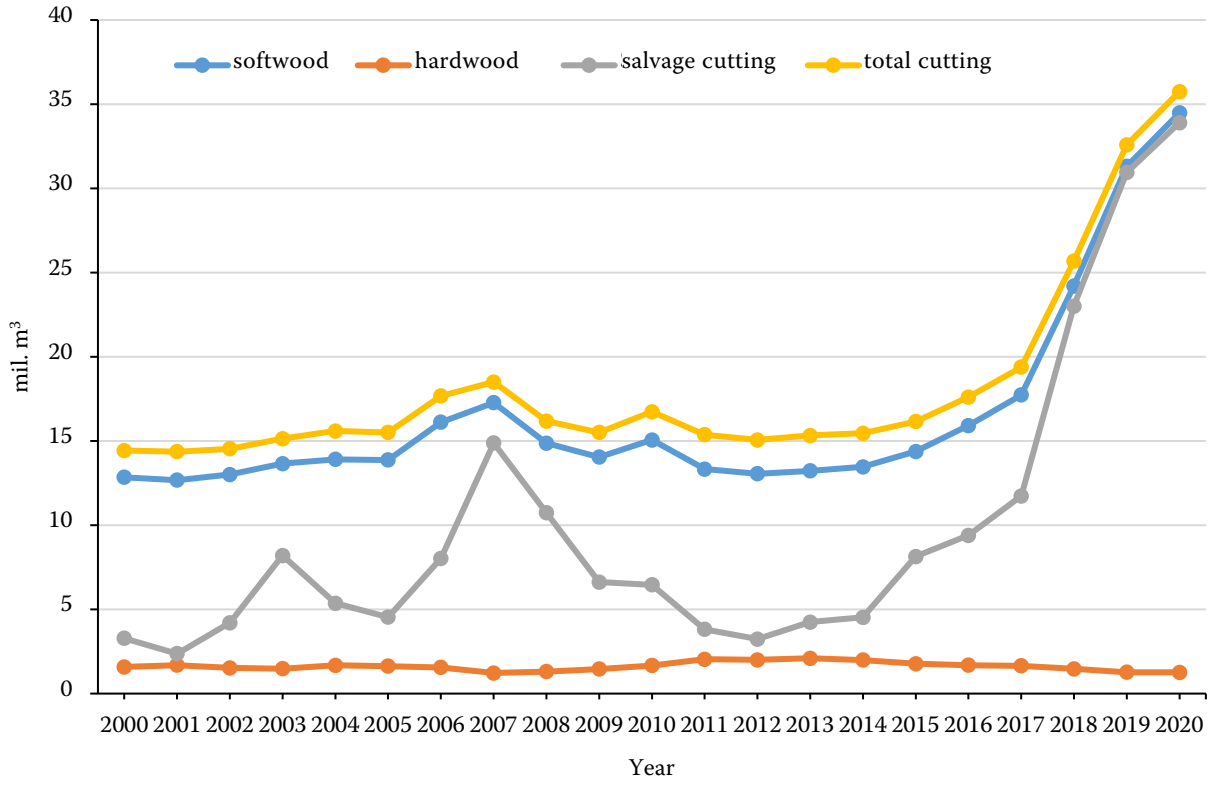

Figure 6. Development of timber cutting in the Czech Republic in the years 2000–2020 by tree species

Source: own processing

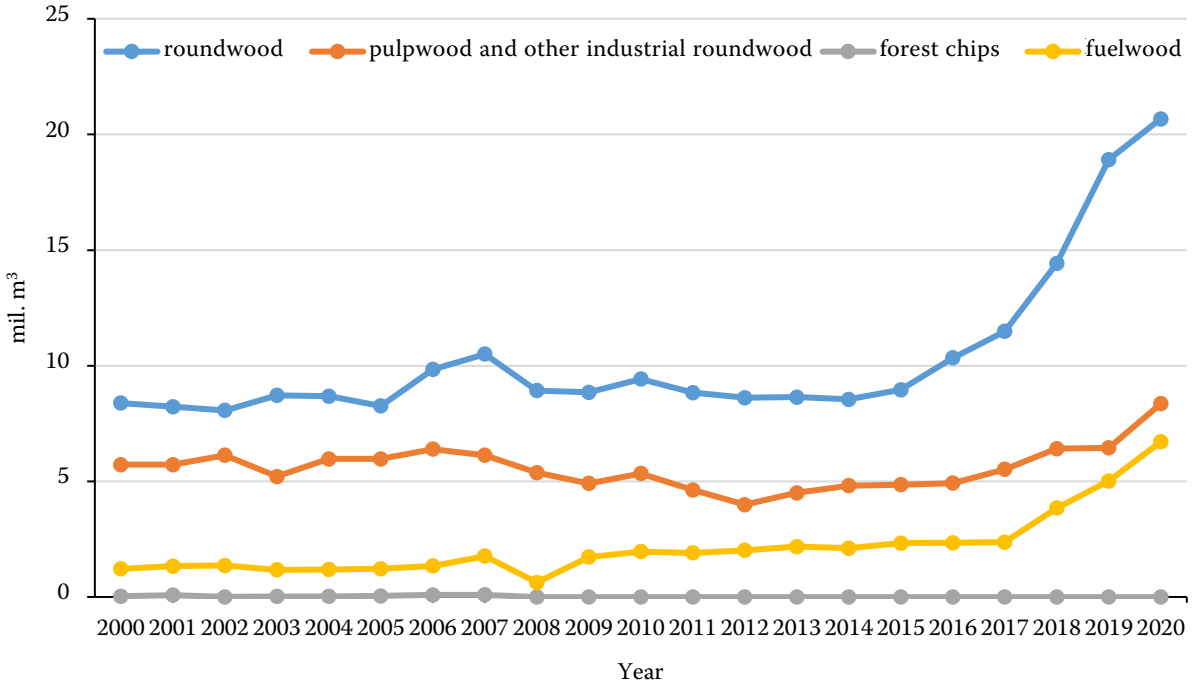

Figure 7. Development of assortment composition of wood in the years 2000–2020

Source: own processing

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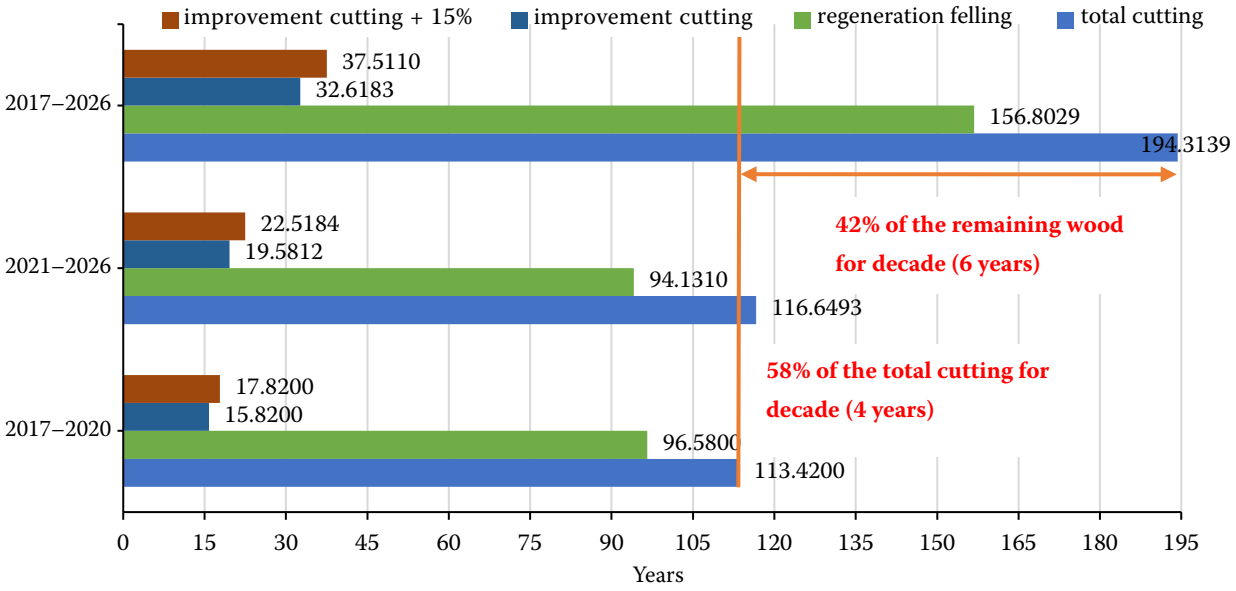

Figure 8. Prediction of 10-year timber cutting depending on current developments for the period 2017–2026

Source: own processing

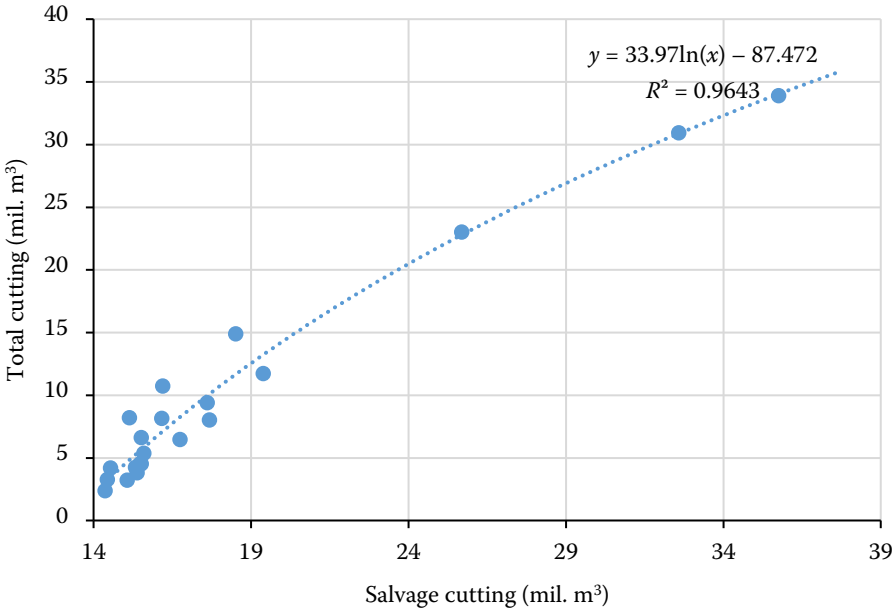

Figure 9. The dependence between the development of salvage cutting and of total cutting

Source: own processing

Forest Management in the Czech Republic (Ministry of Agriculture 2022), the following conclusions can be drawn:

(*i*) based on the increasing trend of unplanned cutting in the period 2000–2017, a share of the unplanned cutting of at least 61% can be assumed in the period 2019–2028 in the total cutting in the Czech Republic. This statement is supported by the strong correlation between the development of the salvage cutting and the total cutting (see Figure 9). Significant differences between the individual regions of the Czech Republic can also be expected. The reason for this is the different temporal and spatial pattern of the unplanned cutting of wood infested with bark beetles.

(*ii*) if the year 2017 is taken as the basis for the forecast, with an annual harvest of 19.39 million m^3 and an 85% share of spruce, a constant or increasing

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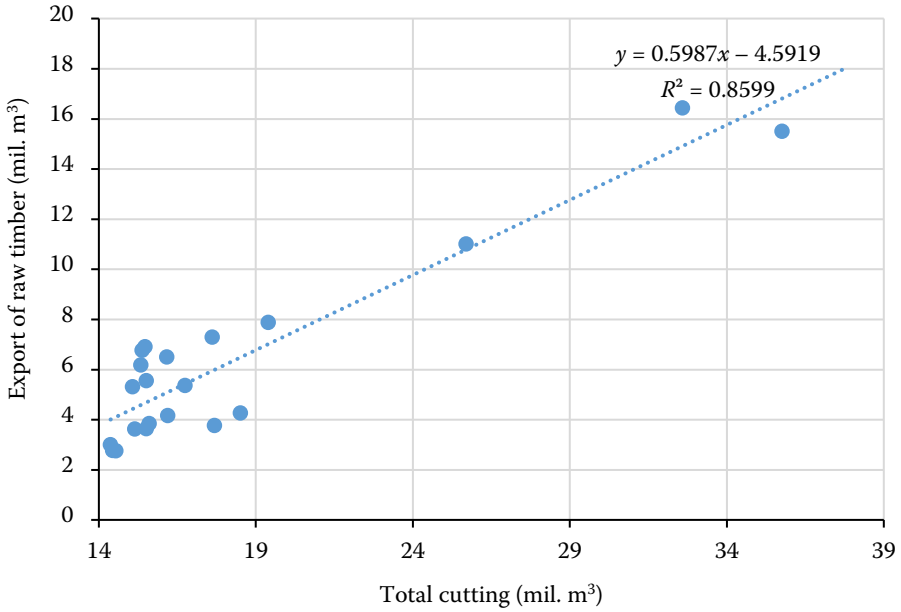

Figure 10. The dependence between the export of raw timber and total cutting

Source: own processing

trend in these shares can be assumed. If the annual volume of cutting between 2019 and 2028 reaches 22–25 million m^3, which corresponds to the current maximum cutting capacity available in the Czech Republic, then the annual share of spruce in the cutting will be at least 20 million m^3, excluding other predominantly broadleaved species.

(*iii*) from the results of the analysis of the cutting potential and timber flows, it is possible to predict a more significant decline in the cutting potential from 2027 onwards, based on the unplanned harvest to date, the decline in the increment and harvest percentage. This is assuming a minimum 10-year total volume of 42.4 million m^3, corresponding to an annual decline of 4.3 million m^3.

(*iv*) in the period of 2027–2036 (i.e. in the second decade), the 1st age class will be reduced by approximately 80% and the total standing stock will fall below 600 million m^3 of wood. From the middle of the second decade, around 2030, a sharp decline in the production of coniferous roundwood for sawmilling can also be expected.

In terms of the assortment structure, it was found that the sawmill log production (roundwood) has been decreasing since 2016. This is, of course, due to the increase in the incidental cutting due to the bark beetle calamities, and hence the increase in the production of pulpwood and fuelwood. As already noted, and as illustrated in Figure 10, there is a moderate correlation between the increase in the exports of the roundwood assortment and the increase in the volume of unplanned cutting. There is a low correlation between the increase in the pulpwood and fuelwood assortment and the increase in the unplanned harvest volume. This is explained by the higher transfer earnings from the sawmill logs. This suggests that the Czech Republic can expect an increase in the growing stocks of less marketable assortments (pulpwood and fuelwood) in the period of 2019–2028. The assortment structure in 2019 is shown in Table 3.

In view of the current political situation in Europe, a sufficient fuelwood capacity will become a major issue soon. Approximately 2.5 million m^3 of fuelwood is currently consumed annually. Ac-

Table 2. Gross balance of consumption and export of raw timber up to 2019

Item	mil. m^3
Total annual cutting	30–32
Domestic consumption*	15–16
Intra-Union trade end exports including growth excluding EEA	15–16

*including the increase in capacity of LabeWooD and Mondi Štětí; EEA – European Economic Area

Table 3. The assortment structure

Assortment	mil. m^3
Roundwood	8.8–9
Pulpwood	4.5–5
Fuelwood	6–7

https://doi.org/10.17221/76/2022-JFS

Table 4. Relationship of total forestry sector production to gross value added in the sector

Item	2015	2016	2017	2018	2019
Total forestry sector production (mil. EUR)	2 476.05	2 491.50	2 718.21	2 748.50	2 720.80
Total gross value added of the sector (mil. EUR)	1 131.54	1 119.67	1 225.56	1 108.95	933.39
Index	0.457	0.449	0.451	0.403	0.343

Source: Ministry of Agriculture (2022); own processing

cording to the figures in Table 3, the consumption could be increased by approx. 3.5–4.5 million m^3. This is wood to the top of tree 7 cm under the bark.

The development of the index assessing the performance of the forestry sector in the period of 2015–2019 is shown in Table 4. The index shows the relationship between the total production of the forestry sector and the gross value added of the sector.

The data presented in Table 4 are based on the "Economic Accounts for Forestry and Logging" for the period of 2015–2019. The found index clearly shows that value added has not grown in the production growth. This was caused by the onset of the bark beetle calamity, whereby the incidental cutting gradually increased from 2015 onwards, with a peak in 2020 (34.49 million m^3). The consequence was a large amount of marketable bark beetle timber and a decline in the prices. An increase in the prices for the raw timber has only started to recover in the second quarter of 2021. This increase will only be visible on the indicator (gross value added) in 2021–2022.

DISCUSSION

The phenomenon of incidental logging in forest stands has occurred to some extent since time immemorial. It follows that incidental logging constitutes an inseparable part of the natural ecosystem and cannot, and should not, be prevented entirely.

However, human society and its development has interfered with the natural circumstances on our planet to such an extent that the natural conditions and regularities, which had been established for millions of years, began to undergo significant changes in the last decades. (Suchomel, Gejdoš 2014) Incidental logging is one of the factors affecting the situation on the market with timber and timber-based products. In forestry practice, the term incidental logging denotes two completely different types of logging: common incidental logging (scattered incidental logging, such as individual dead trees and fractures or groups thereof, whose year-on-year amount is more or less the same) and calamity logging (incidental logging of a significant extent, i.e. over 20 % of the 10-year allowable cut or affecting more than 2% of the entire area of the territorial unit). Common incidental logging seems not to affect the implementation of the annual planned logging because they are incorporated in the plan to the expected extent without situating them in specific stands and are carried out year-round. Consequently, the annual planned logging is decreased by the expected volume of the common incidental logging. Calamity logging, on the other hand, leads to a rebalancing of the planned logging, whose volume is realised by the calamity logging. With smaller extents, only regeneration felling is stopped, but leads to limitations in tending felling to a large extent (Simanov 2014). The authors (Schelhaas 2008; Kulla, Sitková 2012) have already pointed to the large proportion of incidental logging caused by the wilting of non-native spruce stands, disturbances, and ongoing climate change. The latter has recently led to considerations of the need of finding and applying functional adaptation forestry measures, which could effectively eliminate the foreseen negative impacts of global climate change (e.g. Lindner et al. 2014; Puettmann et al. 2015). The expected negative impacts of climate change pose a challenge for forest stands in the Czech Republic (Hlásny et al. 2011; Lindner et al. 2014).

Multi-aged, well-structured forest stands are considered the basis for the elimination of the risks (Schütz 2011; Kulla, Sitková 2012; Brang et al. 2014; O'Hara 2014). The amount of funds required to recover areas affected the calamity is limited in the monitored period (the turn of 2021–2022) by the low revenue from the sales of spruce timber caused by the significant surplus of the calamity timber on the market. Given the current state, a decline in the natural regeneration of basic target woody plants can be expected due to the areal dieback of the mature spruce

https://doi.org/10.17221/76/2022-JFS

stand; this decline, however, can be replaced with the natural regeneration of pioneer basic woody plants, or reinforcing and soil-improving woody plants depending on the character of the site (Švéda et al. 2020). In the case of forest rehabilitation in large-scale clearings upon disturbances, procedures using the elements of succession, including stands of pioneer species, are recommended. This relates to the procedures and woody plants which were deemed economically inferior and undesirable until recently (Šafránek et al. 2018).

The common theme is mainly the choice of woody plants that are more resistant against climate changes, in which the application of natural regeneration and pioneer woody plants are an important constituent of the target species composition. Those mainly include the silver birch, rowan, alder, aspen, and larch. (Švéda et al. 2020).

The results verified that changes in the assortment structure and raw wood growing stock in the forests will have a major impact on the woodworking industry. If we also take the growing trend of existing woodworking capacities into account due to the increasing demand for various wood products (as stated by e.g. Michal 2020 or Szichta et al. 2022), as well as the increasing demand for wood in terms of energy use (e.g. Kovalyshyn et al. 2019), it is clear that wood for the woodworking industry will be in short supply in the future.

CONCLUSION

The aim of the paper was to analyse and predict the possible development of the cutting possibilities and the impact on the forestry and downstream industries. For the solution, analysis, a prediction and a wood supply model with the current increments were used. This aim was met.

Based on the analyses and findings, the following conclusions can be drawn: From the results, the stated hypothesis for this paper has been confirmed. In the case of a continued rate of bark beetle calamity and a total annual harvest of 30 million m^3 with a reduction in the planned harvests, the total growing stock of spruce of age class 5 and older will be harvested in approximately 14–16 years.

Based on the development in the previous years, it was predicted that, in the period of 2019–2028, the minimum share of unplanned cutting in the total cutting in the Czech Republic will be 61%. This statement is supported by the strong correlation between the development of the salvage and total cutting. Significant differences between the individual regions of the Czech Republic can also be expected, the most affected regions will probably be the Moravian-Silesian, Olomouc, South Moravian, (southern) Vysočina and South Bohemian regions.

In terms of the assortment structure, there has been a decline in the sawlog production. This is, of course, due to the increase in the incidental cutting due to the bark beetle calamity, and hence an increase in the production of pulpwood and fuelwood. A low correlation was found between the increase in the export of the roundwood assortment and the increase in the pulpwood and fuelwood assortment and the increase in the unplanned harvest volume. This can be explained by the higher transfer earnings from sawlogs. This suggests that an increase in growing stock of less marketable assortments can be expected in the Czech Republic in the coming periods.

An analysis of the relationship between the total production output and gross value added revealed that the gross value added in the sector declined over the period of 2015–2019 and, hence, the performance of the forestry sector has also declined. The decline in the performance of the forestry sector at the peak of the calamity, together with the decline in the cutting after the calamity subsides, points to a serious structural problem in the resources and economic viability of the entire forest sector and the related industries.

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