

Sustainable development: Evaluation and forecasting of Norway spruce production and growing stock in Slovakia in the context of bioeconomy

Martin Moravčík¹, Michal Dzian^{2*}, Hubert Paluš², Ján Parobek²

¹National Forest Centre, Forest Research Institute Zvolen, T. G. Masaryka 22, SK-96001 Zvolen, Slovak Republic

²Technical University in Zvolen, Faculty of wood sciences and technology, T. G. Masaryka 24, SK-96001 Zvolen, Slovak Republic

Abstract

The paper deals with the identification of the long-term potential of forest stands with the prevailing Norway spruce representation and the elaboration of a forecast of the development of spruce growing stock and felling possibilities until 2050. The analysis of historical data has confirmed a decrease in the area of spruce by 13.2% since 2010 and its growing stock by 16.4% over the same period. These developments indicate a reduction in felling possibilities in the coming decades. The evaluation of spruce felling since 2012 showed that the planned felling volume was exceeded by 11.3 mil. m³, i.e. annually at average by 1.25 mil. m³. This exceeding was caused by incidental felling, which accounted for an average of 84% of total felling. The forecast of spruce growing stock and felling until 2050 was derived differently for two scenarios based on the development of growing stock and actual cutting percentages in the decade 2012–2020 (scenario A) and cutting percentages according to planned felling (scenario B). In the case of scenario A, there would be a significant reduction in spruce growing stock from the current volume of 114.8 mil. m³ by 36% in 2040. In the case of scenario B, a decrease in spruce growing stock would be more modest. Ten-year felling volume of spruce under the scenario A forecast will result in the amount of 42.6 mil. m³ (first decennium), 32.0 mil. m³ (second decennium) and 25.7 mil. m³ (third decennium).

Key words: spruce stands; sustainable production; scenario; incidental felling; *Picea abies*

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1. Introduction

The wood-based bioeconomy is grounded on the concept of whole biomass utilization from the forest with wood performing essential social, economic, and environmental functions in the circular bioeconomy and sustainable development (Chisika et al. 2021). Therefore, exploring the forest-based circular bioeconomy in the context of wood resources is essential for balancing the relationship between society, environment, and economic development processes. The idea of bioeconomy has become increasingly popular over the past decades and it is in line with the EU bioeconomy strategy which defines five main goals including sustainable management of natural resources, reduction of dependence on non-renewable, unsustainable resources, and limitation and adaptation to climate change (EC 2018). Much of the current literature deals with the issue of reducing the consumption of fossil resources. In this context, two main points of view on bioeconomy concept were developed. Hausknost et al. (2017) acknowledge a ‘biotechnology-centric’ and

a ‘bioresource-centric’ narrative. The “biotechnology-centric” narrative emphasizes the development of new molecular biotechnology, while the “bioresource-centric” narrative emphasizes the importance of developing industries and value chains based on renewable natural resources. The concept is based on the premise that natural resources are limited and therefore must be used efficiently. It follows from ecological modernization discourses, which argues that the economic growth and development can be reconciled with environmental protection (Kleinschmit et al. 2014). Different kind of resources could have the potential to become a valuable resource for a forest-based bioeconomy. Additionally, promoting sustainable development and the production of new products can create new value chains with positive social, economic and environmental impacts on the management of forests. Advanced biotechnology associated with the circular bioeconomy can lead to the development of new bioeconomy products. There are opportunities to create new revenue streams and value chains during the processing of a wood. For instant deadwood can be

*Corresponding author. Ing. Michal Dzian, PhD., e-mail: michal.dzian@tuzvo.sk

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processed into various products like charcoal, pellets, briquettes, electricity, or chips. That is why, deadwood and biomass waste value chains should be established with focus on the added value.

In some European countries coniferous wood represents significant renewable resources and has influence on sustainable development and forest-based circular opportunities. The Norway spruce (*Picea abies* [L.] H. Karst.) is common and economically important coniferous tree species in North and Central Europe. In Slovakia it grows in mixed forests and in monocultures up to the upper limit of the forest at altitudes of 1,500–1,550 m above sea level. Spruce forest stands produce a significant volume of high quality logs that belong to the most important forestry products in the Slovak Republic, accounting for 61,3% of the softwood supplies and 31% of the total wood supplies, respectively (Moravčík et al. 2021). Spruce wood is versatile and applicable in construction, carpentry, furniture, pulp and paper, chemical industry and energy. In the future, limited production is expected due to the fact that up to 38.5% of spruce forests are situated in national parks (i.e. twice as much as in case of the rest of forests – 9.1%).

The direct silvicultural approach could reduce the probability of damage, especially site preparation followed by planting trees in mineral soil (Nordlander et al. 2011; Karlsson et al. 2023; Kozhoridze et al. 2023; Kupka et al. 2023). Depending on local conditions and silvicultural practices, the applicability and efficacy of various protective measures may, however, vary (Luoranen et al. 2017; Willoughby et al. 2020). Spruce forests are often damaged by abiotic harmful agents (especially wind) and subsequently by biotic harmful agents (especially bark beetles) in case of their insufficient protection (Kunca et al. 2012; Braun et al. 2023; Tresch et al. 2023). As a result of the long-term effects of these harmful agents, the proportion of spruce on the total tree species composition has decreased by 4.6% since 1980 (Moravčík et al. 2021). Maintaining an optimum representation of spruce in the forests of the Slovak Republic is highly required from an ecological point of view, but also to ensure the wood production function and the economic viability of the forest-based industry not only at the national level but also as an important component of foreign trade balance. As there has been a downward trend in the representation of spruce in production forests in favour of other tree species for several years, it is important to know the actual situation and the projected development of spruce growing stock and production in Slovakia. Recently, it became evident that forestry is not able to grow this tree species until its rotation in the sufficient conditions, and consequently effectively exploit wood production potential in terms of quality and volume, mainly due to the premature decomposition of spruce forests. Rotation as the framework production period of forest stands is determined taking into account their rotation maturity and fulfilment of the required functions of the forest. The data on rota-

tions are given in the annex to Act no. 326/2005 Coll. on forests as amended according to natural conditions (sets of forest types) and tree composition. For spruce stands, the rotation period values range from 100 years in commercial forests up to 200 years in some protection forests. These values were calculated and determined in the 1970s and 1990s before climate change, but they are too high in current conditions. The felling of spruce wood is increasingly more and more determined by natural and climatic factors, as well as the restrictive provisions of nature conservancy authorities (Moravčík et al. 2021) rather than purposeful planned forest management measures.

The concept of a bioeconomy is based on the use of renewable biomaterials, with the goal of decreasing the extraction of non-renewable resources. For determination of full potential of wood resources for sustainable development there is a need for more studies to be conducted on the forest-based bioeconomy, mainly in the context of specific national or regional conditions. On one side there is a growing demand for bio-based raw materials, in particular softwood, on the other side demand on spruce wood is becoming increasingly difficult to meet due to climate change and limited availability (Szichta et al. 2022). Therefore, it is necessary to assess the feasibility and sustainability of a bioeconomy based on spruce wood production and growing stock. The aim of this study is to identify the long-term potential of growing forest stands and to develop a forecast of the development of spruce growing stock and its felling possibilities until 2050.

2. Methodology

The analyses of the development of the area and the growing stock of spruce in the forests of the Slovak Republic were carried out using the data of Summary information on the state of forest (SISF) for the years 2010–2020 (MPaRV SR, 2022), likewise the data on the planned tending and regeneration felling of spruce wood. Classified into age classes, data for total felling of spruce for the years 2012–2020 divided into planned (tending felling and regeneration felling) and incidental were obtained from the forest management records. For the analyses, only the forests available for wood supply – (FAWS) were considered, thus omitting the categories of forests within the 5th degree of protection (non-intervention management regime), the strictest protection zone of water resources, forest stands on extremely unfavourable sites and forests above the upper limit of tree vegetation with a predominant presence of dwarf pine.

A modified methodological procedure according to Greguš (1989) was applied to develop the forecast of spruce growing stock and felling until 2050. In addition to Greguš (1989), Kanka (1983), Priesol (1987, 1992) and Žihlavič (1985) dealt with the above mentioned

issue. Following this approach, the timber allowable cut is proportional to the growing stock in forests and cutting percentages. Thus, the values of these two variables have the greatest influence on the derived allowable cut of timber. Considering the felling volume and the level of accidental felling in spruce stands, two basic scenarios based on the following two assumptions were determined:

Scenario A: it is assumed that the current extent of spruce stand damages by the action of harmful agents will continue at the same trend as in the previous decade (2010–2020) as a result of the impacts of climate change and the limitations of standard forest management. To derive the forecast, average cutting percentages adjusted by polynomial function and corresponding to actual (planned and incidental) volume of felling in the years 2012–2020 were applied using the following formula:

$$DFP_{ia} = \frac{TYF_{ia}}{GS_{sw}} \cdot 100 \quad [1]$$

where:

i – index indicating the age class

DFP_{ia} – decennial felling percentage according to the actual volume of spruce felling

TYF_{ia} – actual volume of ten-years spruce felling until 2020

GS_{sw} – growing stock of spruce in m^3

Scenario B (comparative): it is assumed that the felling of spruce will be equal to the volume of planned felling and corresponding felling percentages (according to SISF). According to above mentioned assumption the spruce felling is forecasted as follow:

$$DFP_{ip} = \frac{TYF_{ip}}{GS_{sw}} \cdot 100 \quad [2]$$

where:

DFP_{ip} – decennial felling percentage according to the planned volume of spruce felling

TYF_{ip} – planned volume of ten-years spruce felling until 2020

The calculation of allowable cut value was carried out in 10-year intervals for the three following decades (2021–2030, 2031–2040 and 2041–2050). For the first decade 2021–2030, the area and growing stock of spruce (GS_{sw1}) by age classes were applied. Spruce felling (F_1) was calculated for each age class according to the formula:

$$F_1 = \frac{GS_{sw1}}{100} \cdot DFP_1 \quad [3]$$

The changes in growing stock in the age classes for another decades (2030 a 2040) were calculated by subtracting the volume of felling (F_1) from the growing stock (GS_{sw1}) and multiplying by the increment coefficient (IC)

according to respective tables depending on the tree species, age and values of stand class and stocking in each age class. The new volume of growing stock calculated in this way was shifted to the nearest upper age class as the expected growing stock of GS_{sw2} for the each next decade (2030 and 2040).

The area of age classes after regeneration felling, calculated from the share of the volume of regeneration felling and the growing stock of spruce per hectare of the particular age class, was moved to the 1st age class. The same procedure was followed to calculate the volume of regeneration felling for the periods F_2 and F_3 (for the second and third decade) and updating the expected GS_{sw3} represents growing stock for the decade 2041–2050.

3. Results

3.1. Development of spruce forest area and growing stock

The analysis of the previous development (period 2010–2020) shows that the share of spruce area decreased by 13.2% from 445 thousand ha to 385 thousand ha in 2020 (Fig. 1). Moreover, the growing stock decreased by 16.4% over the same period, from approximately 137 mil. m^3 to the current 115 mil. m^3 (Fig. 2).

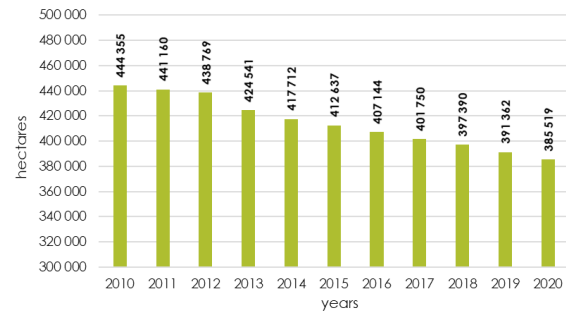


Fig. 1. Development of spruce area since 2010.

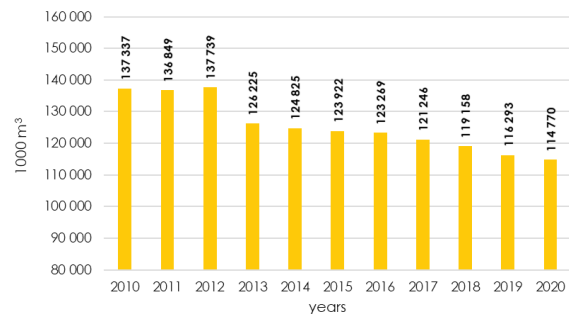


Fig. 2. Development of spruce growing stock since 2010.

The representation of different age classes was uneven (Fig. 3). The share of spruce annually decreased in the older stands at the age of 61–110 years (age classes

7–11). On the other side, a share of the oldest stands above 111 years (age classes 12–15+) stayed equal and increased especially in the younger stands (age classes 1, 2, 5 and 6).

The same trends in age classes can also be observed in the development of growing stock of spruce (Fig. 4). Above mentioned trends of the area representation and growing stock of spruce with a significant decrease in the middle and older ages, indicate a reduction in the felling possibilities of spruce wood in the coming decades.

The current uneven age structure of spruce is characteristic of all forests in Slovakia. It is a consequence of the intensive management of forests, including intensive felling associated with the subsequent successful regeneration of the forest in the first half of the last century (Moravčík et al. 2022). This led to the creation of a group of forest stands with an above-normal areal representation with the present age of 70 to 120 years. For the above-mentioned reasons, the average age of forest stands has increased in the second half of the last century and in 2021 reached 71 years. Currently, the average age is already stagnating or even decreasing in spruce stands. Since 2010 it has decreased by 4.2 years to 64 years. Since 2014, the average age of European beech stands has also decreased slightly to 72.7 years. Beech and spruce are the most represented tree species in the forests of the SR (together they account for 56.3%). This decrease is signalling an onset of reversal trend in the development of the average age level. On

the other hand, the average age of some other tree species, especially oak, ash, larch and maple, is continually increasing at various pace. Compare to beech and spruce tree species these species are relatively resistant to the action of harmful agents and there were no such large-scale disasters as in the spruce and some beech forests (National Forest Centre 2023).

The above-mentioned uneven age structure of forests causes cyclic changes in the development of wood production indicators, such as the forest area of different age classes, growing stock, increments, and also the felling possibilities. These possibilities are assessed through the area and volume of growing stock in mature stands. Therefore, the trend of the development of the spruce representation area in different age classes has a major influence on the development of growing stock (Fig. 4). A significant decrease in the forest area and growing stock of spruce in middle and older age classes indicate a reduction in the felling possibilities of spruce wood in the coming decades.

According to the analysis of spruce felling since 2012, the results indicate that the volume of annual planned felling has been exceeded every year (Fig. 5). During the above mentioned nine years, real felling of spruce wood was higher by 11.3 mil. m³ compared to the planned felling. On average per year, it is more by 1.25 mil. m³.

The mentioned overfelling (Fig. 6) was caused by incidental felling. It represents an average of 84% of the total annual wood felling.

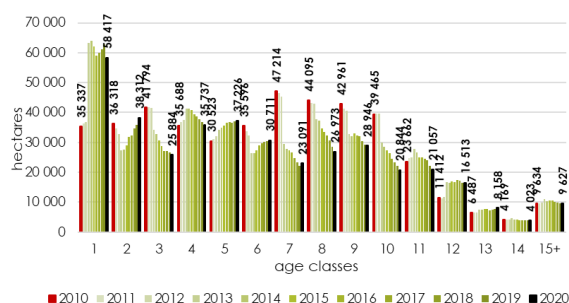


Fig. 3. Development of spruce area in age classes (ha). Explanation: The data shown in the figure refer to the years 2010 and 2020.

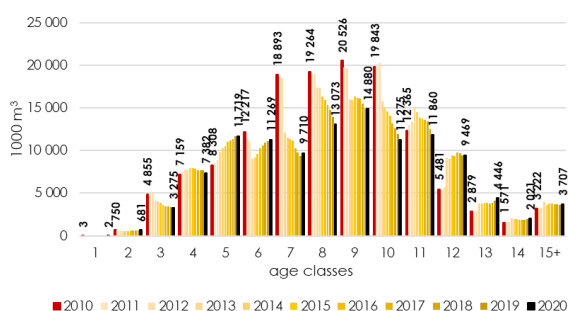


Fig. 4. Development of spruce growing stock in age classes (1,000 m³). Explanation: The data shown in the figure refer to the years 2010 and 2020.

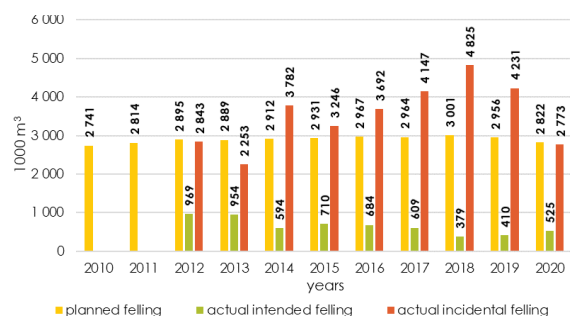


Fig. 5. Comparison of planned and actual (intended and incidental) spruce felling.

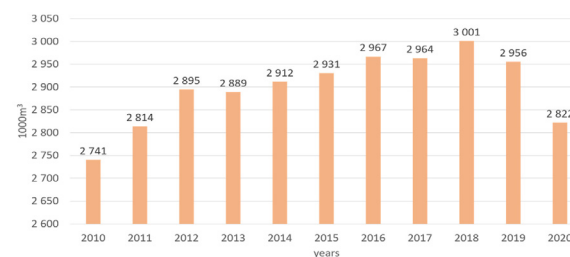


Fig. 6. Volume of spruce overfelling since 2012.

On average, less than 0.65 mil. m³ annually represents performed planned felling both regeneration and tending. The highest average annual overfelling were in middle age classes in forest stands 41–90 years old. Particularly, the most in the 8th age class (369 thousand m³) and in the 7th age class (302 thousand m³). Fig. 7 presents the average volume of timber harvested beyond the planned amount, broken down by age classes, for the years 2012–2020. This data highlights that the most significant volume of incidental felling, which greatly exceeded the planned volume, primarily occurred in spruce stands within the middle age classes of 5 to 9, corresponding to ages 41 to 90 years. Consequently, spruce forests in the Slovak Republic have been experiencing decay at around 50–60 years of age. This suggests that the current rotations for spruce, which are set at 100 years or more, are unsustainably high.

Fig. 8 shows the average percentages of actual (performed planned and incidental) felling spruce timber by age classes, as well as the percentages of planned felling. Annual percentages of actual felling were significantly exceeded, especially in the 5th–9th age classes, due to incidental felling.

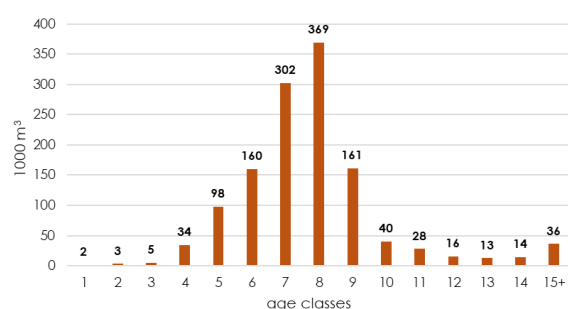


Fig. 7. Average annual spruce overfelling in age classes.

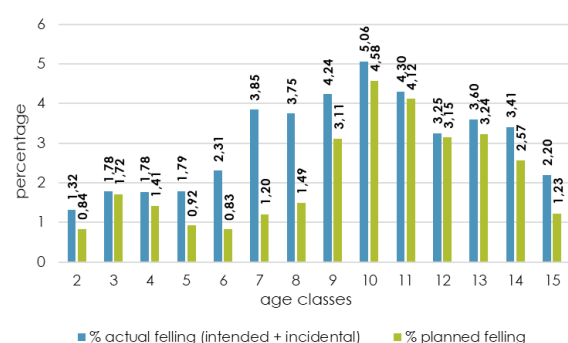


Fig. 8. Average cutting percentages for the actual and planned spruce felling.

3.2. Forecast of spruce forest area and growing stock development until 2050

The future forecast of spruce felling development was developed considering two scenarios as mentioned

above. The scenario A assumes that due to climate change and restrictions to normal forest management, mainly due to nature protection, the damage to spruce forest stands by the action of harmful agents will continue at approximately the same extent as in the previous decade. To derive the related forecast, average cutting percentages adjusted by polynomial function corresponded to actual volume of felling (performed planned and incidental) in the years 2012–2020. In this case, a significant reduction in spruce growing stock is expected from the current 114.8 mil. m³ to 86.9 mil. m³ (by 24%) in 2030 and to 74.3 mil. m³ (by 36%) in 2040. In the case of scenario B, under which it is assumed that the felling volume would correspond to the volume of planned felling and the related felling percentage, the decline in wood stock would be more moderate, by 10.6% (to 102.6 mil. m³) in 2030, or by 15.5% (to 96.9 mil. m³) in 2040, respectively (Fig. 9).

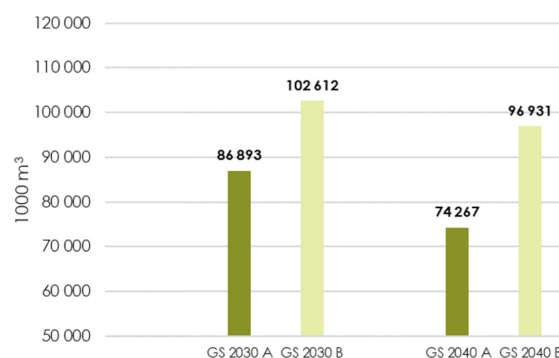


Fig. 9. Comparison of forecasted spruce growing stock in 2030 and 2040 under scenario A (GS 2030 A and GS 2040 A) and B (GS 2030 B and GS 2040 B).

Considering the scenario A, the decennial spruce felling carried out in period 2021–2030 in the volume of 42.6 mil. m³ would drop later on in the years 2031–2040 to 32.0 mil. m³ and to 25.7 mil. m³ in the years 2041–2050. Under the scenario B, the volume of spruce felling in the next three decades would be lower reaching 29.3 mil. m³, 26.0 million m³ and 23.8 mil. m³, respectively (Fig. 10).

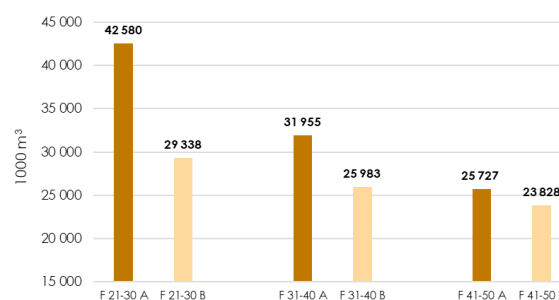


Fig. 10. Comparison of forecasted spruce felling in 2030, 2040 and 2050 under scenario A (F 21–30 A, F 31–40 A, F 41–50 A) and B (F 21–30 B, F 31–40 B, F 41–50 B).

From the point of view of maintaining representation of spruce in forest stands, scenario B seems to be more advantageous compared to scenario A. However, as a result of the ongoing persistence of the action of harmful agents due to climate change and due to current stand and management conditions, scenario B is not likely to be fulfilled.

4. Discussion

From the presented results on the state and development of forest stands with a representation of spruce, it is particularly obvious that under present conditions forestry is not able to grow this tree species until its rotation period and thus effectively make use of its production potential in terms of quality and volume. Natural and climatic factors, as well as limiting conditions of nature protection, rather than purposeful planned management measures, decide on the spruce felling more and more intensively. As a result, significant economic losses occur, as wood from incidental (sanitation) logging is of lower quality, its processing and use is limited, and its value may in many cases be several times lower compared to the wood harvested under planned logging.

For these reasons, it is necessary to adopt and implement effective measures for a fundamental change in the management of spruce stands used for wood raw material production. It is also necessary to adapt management models and management measures in spruce stands to the changing climate conditions while considering the related intensity of their damaging as the current models for spruce stands based on the rotation periods over 100 years do not take these circumstances into account. As stated by Härkönen et al. (2019) Europe is transitioning to a low-carbon economy by 2050, which entails a transition from fossil fuels to renewables. This transition can also result in an increase in planned felling by more than 20%. It is therefore important to pay attention to the question of the length of rotation period for spruce in Slovakia. In the areas with the original presence of spruce, it is possible to consider the implementation of management activities towards close to nature forest management in spruce stands with a diversified structure and usually in a mixture with other forest tree species in the long-term forecast. Tudoran et al. (2021) pointed out the need to diversify the structure of spruce stands mixed with other trees. The management of mixed spruce stands brings positive and significant associated effects regarding forest protection. Especially in laboratory conditions, a decrease in spruce stands attacked by the spruce bark beetle spruce can be observed in cases when spruce was grown in combination with beech. In other forest areas with a predominance of spruce, forest management should be aimed at improving the use of their production potential (i.e. reducing the degradation due to damages) through a significant shortening of rotation

periods, reconstruction and gradual rebuilding of their structure towards nature closer forest types. Jagodziński et al. (2020) also pointed out a possible link between the altitude and the amount of sequestered carbon. Based on this study (Jagodziński et al. 2020) it seems to be also beneficial to consider changing the structure of spruce stands in Slovakia.

The mentioned reduction in the growing stock and felling volume of the most economically advantageous spruce wood in the coming decades will have negative effects on the economy of forest managers. These impacts will deepen even more significantly in the case of the implementation of the Strategy of the environmental policy of the Slovak Republic until 2030 (ME SR 2020), according to which the area of areas without any human interventions (5th degree of nature protection) in national parks should extend to 50% by 2025 and to 75% of the park areas by 2030. The current area representation of spruce in national parks without the 5th degree of protection is 101.9 thousand ha (38.5%); i.e. twice as much as in remaining forests (18.1%) and the spruce growing stock is 28.3 mil. m³. In case if 75% of the forest area would be shifted under the 5th degree of protection (no management activities), then it would theoretically represent 76.4 thousand ha of spruce forest area and 21.2 mil m³ of the spruce growing stock. Obviously, this would also have a significant impact on the reduction of the results of forecast of spruce felling possibilities presented in this study.

5. Conclusion

As the existing spruce stands already comprises investments in their establishment and cultivation and they accumulate high reserves of carbon dioxide it should not be socially acceptable for these stands (especially in unnecessarily large protected areas) to die out uncontrollably so that their biomass would be transformed into greenhouse gases without being used by those to whom these benefits belong. In such a case, an unused rare and renewable wood raw material would otherwise be used for the production of ecologically acceptable wood products that, in contrary, can only be replaced in the production process by non-renewable raw materials with a much larger carbon footprint and with all the negative impacts on climate change. In the following years, the presented reduction of timber growing stocks and felling possibilities will be reflected negatively in the reduction of spruce wood supplies for the wood processing industry (approximately in the volumes resulting from the data shown in Fig. 10). Based on the results of this study and the request of the Slovak Wood Processors Association, in 2023 the Ministry of Agriculture of the Slovak Republic assigned to the National Forest Centre, a task aimed at developing a detailed forecast of the development of felling possibilities in the Slovak Republic, including their

breakdown by tree species and the structure of assortments. The results should be presented at the beginning of the year 2024.

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