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Change in forest species composition and its projections into the economy of forest owners

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Abstract: Increasing the proportion of broadleaved trees in stands during regeneration raises questions about how these trees will be reflected in the economics of forest owners and whether these owners can influence certain economic aspects during stand management. In this respect, the paper focuses mainly on the revenue side of forestry and, crucially, analyses the selling prices of assortments of tree species groups as offered in public tenders of state forests under the outsourcing business model. The price level of spruce is used as a benchmark for comparisons in the analyses. It is clear that the cultivation of species-diverse forests entails an increase in the representation of a higher number of tree species and, presumably, increased stand stability. However, a concomitant consequence may be an increase in costs and a reduction in returns for forest owners. Here, the revenue from timber sales can be improved by appropriate adjustment of the species composition through educational interventions. All this is in the context of the economic viability of forestry, as declared in a number of strategic and forest policy documents, which essentially depends on the timber production function of forestry and the subsequent processing of timber.

Keywords: average costs; forest management; public procurement; timber prices; wood species

In the last few years, the efforts of stakeholders to contribute to the debate on the necessity of changing the species composition of forests have accelerated (among others Čermák 2016). Thanks to the phenomena attributed to climate change, the Czech forestry of the 21st century has come under great pressure. In this context, foresters are blamed for the failure to cope with the bark beetle calamity, the deterioration of forest health, the clinging to spruce cultivation in monoculture stands of the same age, the reduction of biodiversity, high numbers of game animals, and much more (Hnutí Duha 2022).

The legislative environment for forest management in the Czech Republic (CR) is one of the most restrictive in Europe (Oliva 2004; Nichiforel et al. 2020). Forest owners are defined by management boundaries that may imply yield constraints consisting of regulation of harvesting options and increased costs against forest owners in other countries given by obligations in forest restoration and education. All of this is topped by a rich structure of control institutions whose requirements further limit the owners' decision-making options.

Today it is clear that the predominance of monocultured, same-species stands, as promoted by foresters in the past centuries, is coming to an end. However, instead of criticising the historical decisions to promote a high proportion of spruce in the species composition of the forest, we should analyse the current state of the environment, and,

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based on expert knowledge, guide our future decisions on the direction of forest management. The reasons why spruce was preferred in the past are as follows: easy regeneration, easy management, high and stable demand for raw material, easy processing, high profit for forest owners, and high demand for coniferous construction timber. Population growth required a more efficient use of natural resources (Schwarz 1997).

In light of today's knowledge, our ancestors should have aimed for a target species composition based on the habitat conditions and the production potential of the natural tree species. However, their requirements for the forest differed significantly from today. Forests were actively managed, and forestry science in the late 18th century, in the concept of forest as capital, was primarily concerned with maximising the returns from the forest estate. Forest economists responded to the demands of landowners as expert forest managers. The emergence of the Forest Rental Theory and the Land Rental Theory provided answers to questions about the return from holding this type of property. The Land Rental Theory worked with profit as the rent on the capital invested in land and forest and required that the ratio between the capital invested and the rent earned be as favourable as possible. The returns were compared to the interest that the money spent would have earned if it had been deposited in a bank – hence this theory is also called 'the profitability school'. The net return on the forest was the difference between the sum of the gross returns and the sum of the expenses, converted by compound interest to the term of the lease. The Forest Rental Theory was based on the principle that the forest is an 'asset of unimaginable time', or also a 'gift of nature'. When a forest was harvested, the cost of restoring it was deducted from the proceeds of the timber from the clearing. The aim of management was to maintain the forest in a state that would allow continuous harvesting of timber within the framework of 'rental equilibrium', while at the same time maximising the difference between the revenues achieved and the costs incurred.

At the time of the establishment of today's spruce plantations, there was no talk of climate change, soil degradation, biodiversity loss or the provision of ecosystem services. At the time when the forests were being restored mainly with spruce, the socio-economic formation and the concept of social well-being in the country were at a completely different level.

The extent of the transformation of forest stands is discussed in research mapping their originality in the Czech Republic. For example, according to Adam et al. (2017), in 2012 there were only 2 467 ha of native forests, 7 529 ha of natural forests and 19 575 ha of close-to-nature forests in the Czech Republic. This is only a fraction of the total area of 2 923 thousand ha of forests in the Czech Republic (ÚHÚL 2024). Most of the forests should, therefore, be considered as forests influenced by man or forest management.

According to Simanov (2011), the basic economic principle of forest management is self-financing, which means covering all its costs with revenues from timber, other commodities and services. As timber sales account for up to 95% of all forestry revenues, timber sales are an essential condition for its existence. Changes in the species composition of Czech forests are described by Podrázský et al. (2013) as a challenge for the forestry and wood processing sector. According to this author, the supply of coniferous cuttings of pine and primarily spruce will decrease.

The comparison of individual management methods according to the input costs on the one hand and the yields on the other hand, represents, if the results are interpreted correctly, a source of information that can be used to guide management measures in the forest. For example, cost differentiation according to a set of forest types is preferred by Plíva (2000) as a tool for sustainable forest management. Costs should be placed where we can expect a significant return, and conversely, for economically unproductive sites, foresters should prefer to develop ecosystem functions.

The issue of methods and costs of forest restoration is compounded by the impact of the ongoing bark beetle calamity and is one of the priorities that need attention. While a number of studies have analysed the costs of reforestation, not much has been published on the implications for future yields. The fundamental and long-term impact on harvest and assortment balance and on the economic outcome of forest management (FM), which in many cases exceeds the capacity of current and especially future resources of forest owners, is highlighted by Kupčák et al. (2019b). A decline in available coniferous roundwood resources for the processing industry in the coming decades is also predicted by Šafařík et al. (2022). The authors here also remind us of the economic viability of FM, declared

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in a number of strategic and forest policy documents which essentially depends on the timber production function of FM and subsequent timber processing. Kupčák et al. (2019a) also present model-based forecasting of financial indicators under random harvesting within a forest management unit; the models evaluate economic factors and processes in particular: from forest regeneration to thinning within 40 years. Dudík (2021) deals comprehensively with aspects of birch cultivation and its use in the Czech Republic, while other authors more or less analyse the costs of forest regeneration options (Novotný, Šišák 2016; Šišák et al. 2017; Švéda et al. 2020). Sujová et al. (2021) deal with the issue of data on timber resources and consumption in the Czech Republic; among others, they analyse the possibilities of recalculating the timber resources consumed in the Czech Republic using data on processing capacities and foreign trade.

In the context of these aspects, the paper analyses the selling prices of assortments of groups of timber species in selected contracts within the framework of public procurement at the state enterprise Lesy České republiky (Forests of the Czech Republic), in the context of changes in the species composition of stands and anticipation of demand from timber processors. The price level of spruce is used as a benchmark for comparisons in the analyses.

MATERIAL AND METHODS

The species composition of forests in the Czech Republic is characterised by a predominance of coniferous forests. According to the National Forest Inventory carried out in 2016–2020, coniferous trees dominate the forests of the Czech Republic with a share of 70.6% of the stock, while the share of deciduous trees is 29.4%. Among conifers, spruce (50.7%) and Scots pine (13.3%) have the highest stock of woody matter in stands. Among broadleaved species, beech (9.5%) and oak (6.8%) have the highest stock.

In the 1950s, the species composition of economic forests was identified as the cause of the high proportion of accidental logging, and since then it is gradually changing in favour of broadleaved trees. While in 1950 conifer representation was 85.8% and by 2009 it had fallen to 74.12% (a decrease of 11.68%), the share of broadleaved trees increased from 12.5% to 24.83% (a growth of 12.33%) over the same period (Simanov 2011).

Detailed information on species composition is continuously provided by the annual Reports on the State of the Forest and Forest Management of the Czech Republic, issued by the Ministry of Agriculture of the Czech Republic, also called 'Green Reports' (Zelené zprávy). The development of the area distribution of tree species in the Czech Republic in the period 2000–2022 is shown in Table 1. For abbreviations of tree species in the text and tables, we refer to the relevant decree – Decree No. 84/1996 Coll., on forest management planning.

However, a closer look at the financial returns from the sale of individual trees reveals a lack of relevant information. While for species such as spruce, pine and larch, we have publicly available statistics on assortment prices, for other species, the published statistics are scarce (CSO 2024). However, birch and other broadleaved trees now account for more than 10% of the forest area and this area will continue to grow. However, this information is not available for broadleaves, which have accounted for

Table 1. Evolution of the area distribution of tree species in the Czech Republic in the period 2000–2022

Year	Area of cropland (%)										
	spruce	fir	pine	larch	other conifers	coniferous	oak	beech	birch	other deciduous	deciduous
2000	54.1	0.9	17.6	3.8	0.2	76.5	6.3	6.0	2.9	7.1	22.3
2010	51.9	1.0	16.8	3.9	0.2	73.9	6.9	7.3	2.8	8.1	25.1
2015	50.6	1.1	16.5	3.9	0.3	72.3	7.1	8.2	2.8	8.4	26.5
2019	49.5	1.2	16.1	3.8	0.3	71.0	7.4	8.8	2.8	8.8	27.7
2020	48.8	1.2	16.1	3.9	0.4	70.4	7.5	9.0	2.8	8.9	28.2
2021	48.1	1.2	16.0	3.9	0.4	69.6	7.6	9.3	2.8	9.0	28.7
2022	46.8	1.3	16.0	3.9	0.4	68.4	7.8	9.6	2.9	9.2	29.5

Source: ÚHÚL (2024)

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more than 50% of the regeneration in recent years (CSO 2024). This makes it all the more necessary to address the economics of growing these trees.

However, the question is how to get relevant information on timber prices. According to Holman (1999), a free market is a system where prices are determined by agreement between seller and buyer without any intervention or regulation. This market is open to everyone with a minimum of restrictions.

The supply side of hardwood prices generally exists (albeit with reservations about the uniformity of supply), but the situation is worse in the Czech Republic with the demand side. There is a lack of companies that would buy long-term and significant volumes of hardwood (excluding species such as beech and oak) on the market.

The availability of relevant information on timber prices was tested through the commodity exchange, standing timber auctions, auctions of valuable assortments and complex contracts of the state enterprise Lesy České republiky.

Having found that the commodity exchange – which trades finished grades, mining residues and auctions standing crops – does not provide a sufficient source of information (CMKBK 2024). Predominantly, 83% coniferous timber was traded in 2022 (CMKBK 2024). While standing timber auctions are an important source of data, this source is only relevant for obtaining information on timber prices for stands that are unmixed or have a small admixture of other tree species. Spruce, pine and beech stands accounted for the majority of trades. Unfortunately, in 2021, the state enterprise Lesy České republiky restricted access to statistics on the results of standing auctions, so only auction participants can record the data. Of the auctions monitored in autumn 2023, we recorded three auctions for comparison only. One was for aspen poplar at the Forest Administration Jindřichův Hradec – the starting price of 9.84 EUR·m^{-3} was equal to the sale price, the beech auction at the Forest Administration Buchlovice brought a sale price of 82.76 EUR·m^{-3} and the auction at the Forest Administration Brandýs nad Labem for spruce (70% representation) and pine (22% representation) brought a sale price of 67.32 EUR·m^{-3}. However, no generalised conclusions about timber prices can be drawn from these results. One relevant source of information on prices of finished products is provided by auctions of valuable products organised by private trading companies in the Czech Republic. The auctions are mainly for the best quality oak or larch. There was no interest in beech. For example, at an auction in Holešov on January 24, 2024 (ALSOL 2024), oak carvings were sold for 1 881.60 EUR·m^{-3}. However, such prices do not provide information on the market price of common roundwood assortments.

A relevant source of information on timber prices can be the complex contracts of the state enterprise. Competitors offer prices for timber at the stump according to species groups and assortment groups. This source is publicly available for winning bids where a multi-year commercial contract is concluded between the bidder and the state company, pursuant to Act No. 340/2015 Coll. on the Register of Contracts (Digital and Information Agency 2023). Even in these contracts, however, it is not possible to obtain specific prices for individual timber species, but we can at least derive timber prices for individual species groups. Although their systematisation is not perfect, and there are specifics of the classification of timber species into groups, conditional on their representation in the species composition, the result provides us with relevant data.

As a source of information on timber prices, the results of public procurement by the state enterprise Lesy České republiky (Lesy České republiky 2024) under multi-year tenders were analysed. An analysis of the classification of timber species into timber species groups was carried out on a selected sample of signed contracts. The contracts were for the following territorial units (CUUs): Frýdlant, Lovosice, Doksy, Stříbro, Plešivec, Mělník, Broumov, Podkrkonoší, Černá Hora – East, Velká Bíteš, Bystřice pod Hostýnem, Bruntál – North, Lanškroun.

For the price analysis, selected contracts competed in the years 2021–2023, and separately all contracts valid from 2024 were used. For groups of timber species, for contracts concluded before January 1, 2024, the price of timber was calculated for the same time level (3rd quarter of 2023) according to the methodology of indexation of timber prices specified in the contract. A total of 31 timber price lists were used for the analysis. For contracts concluded for the period from January 1, 2024, the tender prices were used; here, 35 timber price lists were used. To allow further comparison, harvests classified as planned were evaluated for the interpretation of the results. Therefore, the price evaluation excluded offers of timber prices in the dryland, bark beetle, trap and live timber grades as classified in each commercial contract.

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The actual comparisons of timber prices as univariate real variables by species (in tenders up to 2023 and from 2024) were made by calculating averages and medians (where spruce = 100%). After testing the price evaluation, the median values were used to interpret the results. The median represents the middle value of a ranked sequence of values, as opposed to the average, which is the sum of the values divided by their number. In the authors' opinion, the median gives more relevant resulting values.

RESULTS

As mentioned above, in the analysis of selected contracts concluded within the framework of multi-year contracts between the state enterprise Lesy České republiky and competitors of public procurement, the first step was the analysis of the classification of trees into individual groups. Although the classification of trees into groups of trees in public contracts has certain rules, the individual partial bids contain local deviations which are not justified in the documentation. It can, therefore, be assumed that this is a decision of the contracting authority, which is thus reacting to the representation of a particular tree species in a given part of the tender. The coniferous species show a relatively consistent result, with only the classification of Douglas fir being an outlier.

For example, for forestry contracts valid from January 1, 2022, on the contracts Frýdlant, Lovosice, Doksy, Plešivec, Mělník, Broumov, Podkrkonoší, Černá Hora – East, Velká Bíteš, Bystřice pod Hostýnem, Bruntál – North, and Lanškroun, there are three groups of trees for conifers: spruce, pine and larch.

Each group includes the following list of tree species:

- The spruce group includes SM (*Picea abies*), SMP (*Picea pungens*), SMC (*Picea mariana*), SMS (*Picea glauca*), SMO (*Picea omorika*), SME (*Picea engelmannii*), SMX (spruce – other), JD (*Abies alba*), JDO (*Abies grandis*), JDJ (*Abies concolor*), JDK (*Abies nordmanniana*), JDV (*Abies procera*), JDX (fir – other), DG (*Pseudotsuga menziesii*);
- The pine group includes BO (*Pinus sylvestris*), BOC (*Pinus nigra*), BKS (*Pinus banksiana*), VJ (*Pinus strobus*), LMB (*Pinus cembra*), BOP (*Pinus contorta*), BOX (pine – other), KOS (*Pinus mugo*), BL (*Pinus uncinata* ssp. *Uliginosa*), TS (*Taxus baccata*), JAL (*Juniperus communis*), JX (coniferous – other);
- The species classified as larch are MD (*Larix decidua*) and MDX (larch – other).

Only in the case of the contract Silver, Douglas fir is classified as a pine tree.

Concerning the forestry contracts for 2024, Douglas fir is classified in the spruce tree groups in 26 contracts. In six cases, Douglas fir was assigned to the pine species group, and in the remaining three cases it was assigned to the larch species group. In eight contracts, larch was also assigned to the spruce species group. In three cases, larch was assigned to the pine species group.

The variability is even higher for deciduous trees. The most commonly used species groups are beech, oak, birch, hardwoods and softwoods. Considering the 2024 contracts, birch is listed as a separate tree group only in one case. In the other cases, it is aggregated in some way with the other broadleaves (mostly softwoods).

As can be seen from the concluded contracts, each contains several groups of trees. The maximum number of tree groups in the contracts is seven. Of these, three are coniferous, and 1–4 are deciduous.

The classification of trees into groups affects not only the pricing of orders but also the subsequent valorisation of prices. Coniferous woods are valorised within the groups of woods on a quarterly basis using the statistics of the Czech Statistical Office (CSO). The groups of spruce, pine, larch, and deciduous woods are valorised by sliding indices using the statistics of beech and oak prices. However, the price development over time, especially for the broadleaved group, does not replicate the price index and prices responded to in the CSO statistics for beech and oak. This also affects the interpretation of the results presented below.

In addition to these distortions, the CSO statistics were affected by the coniferous tree calamity (especially in 2019 and 2020 – when the selling prices of coniferous assortments were very low compared to the period before the calamity) and the energy crisis at the end of 2022 in the case of broadleaf assortments. Here, firewood prices followed the price curve of other energy commodities. Hardwood fuel was sold at similar prices to beech logs in late 2022, oscillating around prices of up to 120 EUR·m^{-3}. Statistics, through the publication of annual average wood prices, have mitigated these values considerably. However, the representation and weight given to the timber species in the harvested model for a given species and weight group also has an impact on the bid prices.

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So where do the tree groups stand in the public tender? Selected bid prices of public contracts of the state enterprise Lesy České republiky for the period from 2021 to 2024 were analysed. Outside 2024, the prices were recalculated to the same price level using the appropriate indexation model. The year 2024 was evaluated from the offers valid on January 1, 2024. We took spruce as a benchmark and compared the other groups of trees with this benchmark (Figures 1 and 2).

The results of the public tenders show that the highest revenues can be achieved when spruce stands (except for the lowest weights) are sold; the pine group, when compared, is approximately 70% of the price level of spruce. For the larch group, its price level depends on the average weight of the timber harvested. Weak timber of low weight does not reach the price level of pine, while the strongest timber is sold at prices higher than spruce.

For deciduous trees, the interpretation of the results is more difficult. For the hardwoods that can be classified as deciduous hardwoods, the prices of previous years' orders (excluding 2024) were clearly affected by the energy crisis, and their price increased. The price of firewood as a substitute for other energy commodities was the driver of the increase. This has been reflected in price increases in the lowest weights, which are placed on the market in the form of hardwood fibre or fuel. The competitors' bids for 2024 no longer reflect such a price variation. Of the broadleaved species, oak is highly valued and appreciated at the highest weights, where valuable assortments are expected to be produced.

The hardwood group is mostly represented in the competition model by alder, poplar, lime and, in some cases, also birch. The price offer here is significantly influenced by the weight of the tree group relative to the competition matrix and also by the volume competed for. Nevertheless, the results can be interpreted in such a way that the lowest harvested weights, i.e. generally first-cut timber, imply costs for the forest owner. Revenues from timber sales do not cover the cost of harvesting. At the higher weights, they amount to around 30–35% of spruce prices.

The results of the timber group prices up to 2023 and from 2024 onwards are interpreted for harvested timber weight groups ranging from up to 0.09 m^3 over to 1.00 m^3 (see Tables 2 and 3). The average weight is determined for each group of trees, where the numerator is the volume of timber harvested

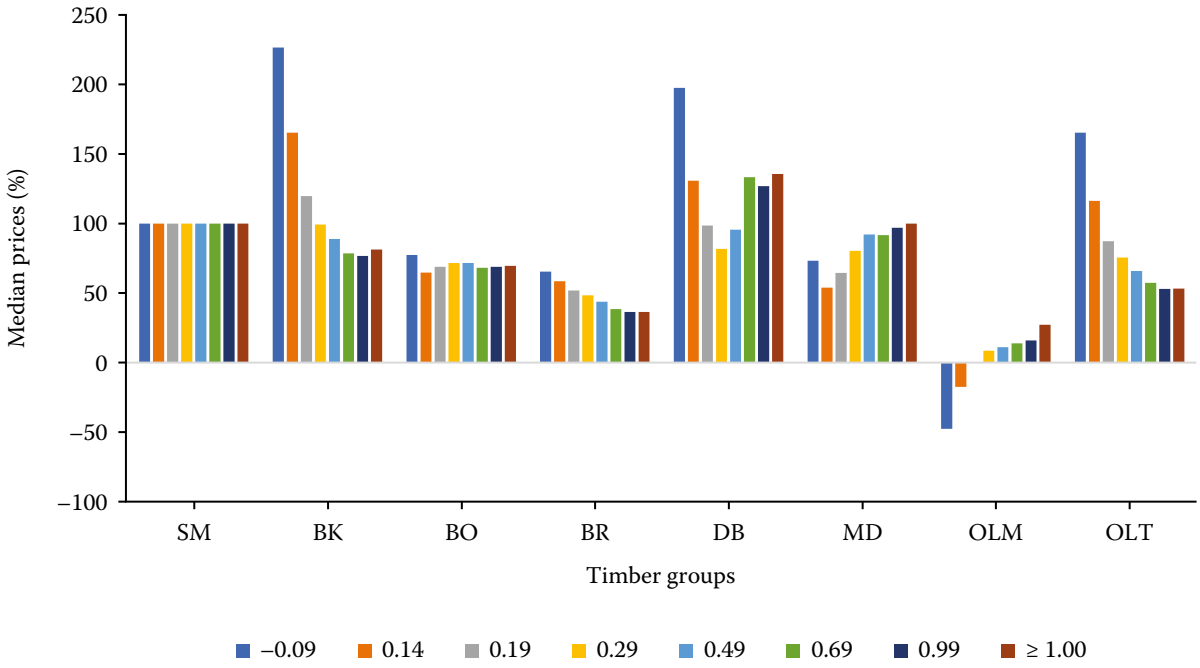

Figure 1. Comparison of timber tender prices to 2023 (median, spruce = 100%)

SM – spruce; BK – beech; BO – pine; BR – birch; DB – oak; MD – larch; OLM – deciduous softwood; OLT – deciduous hardwood

Source: Authors' own processing

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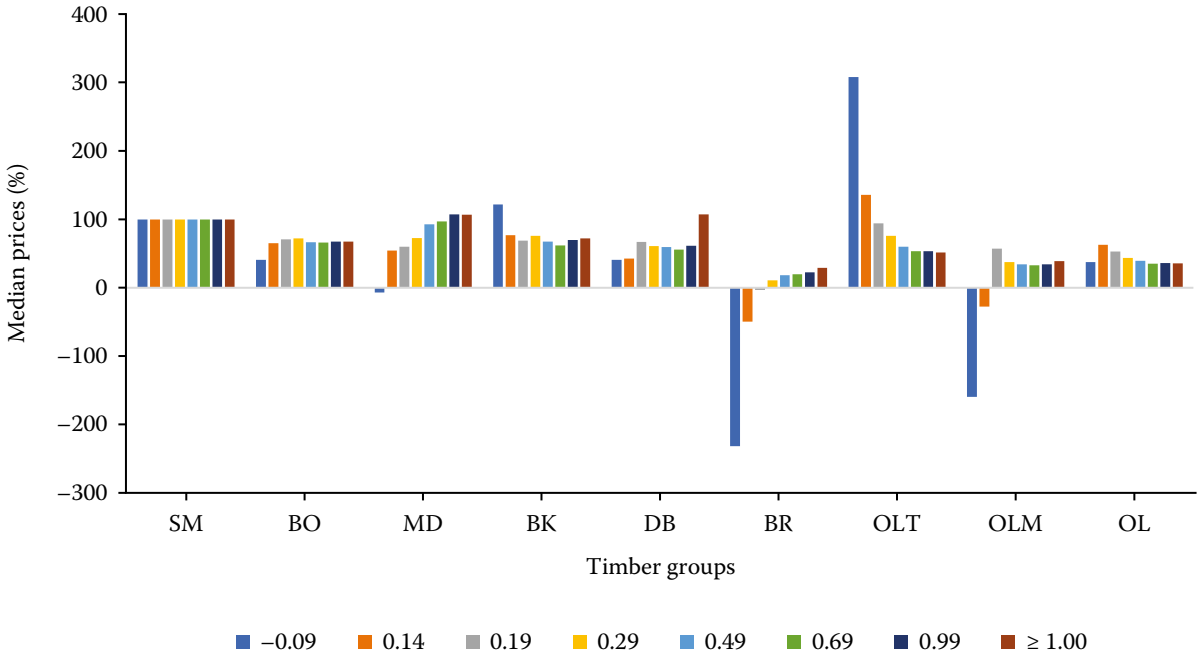

Figure 2. Comparison of timber tender prices from 2024 (median, spruce = 100%)

SM – spruce; BO – pine; MD – larch; BK – beech; DB – oak; BR – birch; OLT – deciduous hardwood; OLM – deciduous softwood; OL – deciduous other

Source: Authors' own processing

in the stand and the denominator is the number of trees harvested. The comparison of timber tender prices by weight to spruce prices up to 2023 and from 2024 is shown in Figures 1 and 2.

The price of timber in harvesting operations up to 0.09 m^3 shows abnormal variations. These are influenced by the price of hardwood fuel in the graph of the public procurement in 2021–2023. In tenders from 2024 onwards, the abnormally low prices for birch and softwoods are probably due to speculation by some competitors, the weight of the range and the species in the tender.

However, the question is how to analyse timber revenues during stand growth. No statistics provide an answer to this. The results of the tenders in 2021–2023 show that, due to the energy crisis, hardwood in the BK group of trees, which includes beech, maple and ash, the DB group of trees, which includes oak and walnut, and the OLT group of trees, which includes other hardwoods (the main representative being hornbeam, elm and in some cases birch) have been valued in younger stands. The beech group is 155% of the price of spruce, which is more or less used for pulp or agglomer-

Table 2. Median prices of timber groups by weight (EUR·m^{-3}) in tenders in 2021–2023

Timber groups	Median prices by weight							
	−0.09	0.14	0.19	0.29	0.49	0.69	0.99	≥ 1.00
Spruce – SM	20.50	29.40	40.60	53.80	65.80	77.80	85.90	86.70
Pine – BO	15.80	19.00	28.00	38.50	47.10	53.10	59.20	60.30
Larch – MD	15.00	15.80	26.20	43.20	60.60	71.20	83.20	86.60
Beech – BK	49.10	51.00	54.00	57.80	63.40	66.40	71.40	73.60
Oak – DB	40.40	38.40	40.10	44.00	62.90	103.60	109.10	117.50
Birch – BR	13.40	17.20	21.00	26.10	28.80	30.00	31.30	31.60
Deciduous hardwood – OLT	33.80	34.20	35.50	40.60	43.30	44.60	45.60	46.20
Deciduous softwood – OLM	−4.60	−1.80	1.90	6.70	11.50	14.50	17.40	19.10

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Table 3. Median prices of timber groups by weight (EUR·m^{-3}) in tenders from 2024

Timber groups	Median prices by weight							
	–0.09	0.14	0.19	0.29	0.49	0.69	0.99	≥ 1.00
Spruce – SM	4.90	14.10	24.40	37.50	52.90	65.30	69.20	72.10
Pine – BO	2.00	9.20	17.30	27.10	35.20	43.20	46.80	48.60
Larch – MD	–0.30	7.70	14.60	27.20	48.90	63.30	74.10	77.00
Beech – BK	6.00	10.80	16.80	28.40	35.60	40.30	48.40	52.00
Oak – DB	2.00	6.00	16.40	22.80	31.60	36.40	42.40	77.30
Birch – BR	–11.40	–7.00	–0.80	4.00	9.60	12.80	15.70	20.80
Deciduous hardwood – OLT	15.20	19.10	22.90	28.50	31.80	34.80	37.10	37.40
Deciduous softwood – OLM	–7.80	–3.90	14.00	14.00	18.00	21.60	23.60	28.20
Deciduous other – OL	1.80	8.80	13.00	16.30	21.00	23.00	24.90	25.60

Source: Authors' own processing

ated board production. The other species, whether pine, larch or birch, lag behind in this low-weight category. The softwood group (marked OL, which includes alder, poplar and lime) is the worst performer, with yields even significantly lower, reaching 5% of the price of spruce.

The ranking changes slightly for the groups of trees of the clearing age represented by the weight of a single harvested trunk of ≥ 1.00 m^3. The highest-ranked tree group is DB, with 135% of the spruce price, and larch with 102% of the spruce price. The other hardwoods lag behind, with the most significant drop being in other hardwoods, which end up being processed mostly as fibre or firewood. Softwood is still significantly lower at 23% of the spruce price. Even birch does not achieve high monetisation at the toll age, which may be due to the lack of processing capacity, unlike in northern Europe. It is, therefore, clear from the competitors' offers that the well-marketed timber species in demand on the market bring the highest profit to the forest owner.

If we can optimise the cost side of forest management, we should optimise the revenue side in the same way. Maximising the growth of individual trees and achieving their target thickness in the shortest possible time will give us the effect of the most cost-effective sales assortments. More than before, it will be important to look for an economic harvesting period for each tree species that will ensure sufficient resources for the forest owner. The shifting average regeneration periods recorded in the statistics do not reflect this approach to stand management. This is most evident in beech stands, where the predominant stock is found in older stands that have not been regenerated for a long time (Table 4; Figure 3). The cur-

Table 4. Tree stock in stands by age (thousand m^3)

Tree groups	Stock by age					
	up to 40 years	up to 60 years	up to 80 years	up to 100 years	up to 120 years	over 120 years
Spruce	39 879	61 232	70 175	98 368	74 450	44 575
Fir	522	994	865	2 105	2 324	2 212
Pine	9 427	13 952	15 862	24 974	23 186	20 102
Larch	4 010	6 047	6 903	8 776	5 504	3 172
Other coniferous	480	804	317	475	370	759
Oak	2 175	4 634	6 609	10 786	7 805	8 113
Beech	2 976	5 565	7 354	9 889	8 879	15 115
Deciduous hardwood	2 010	3 557	5 758	5 537	2 817	2 255
Birch	1 899	2 104	2 794	1 974	492	156
Deciduous softwood	1 431	4 966	5 528	3 047	1 338	928

Source: ÚHÚL (2024); authors' own processing

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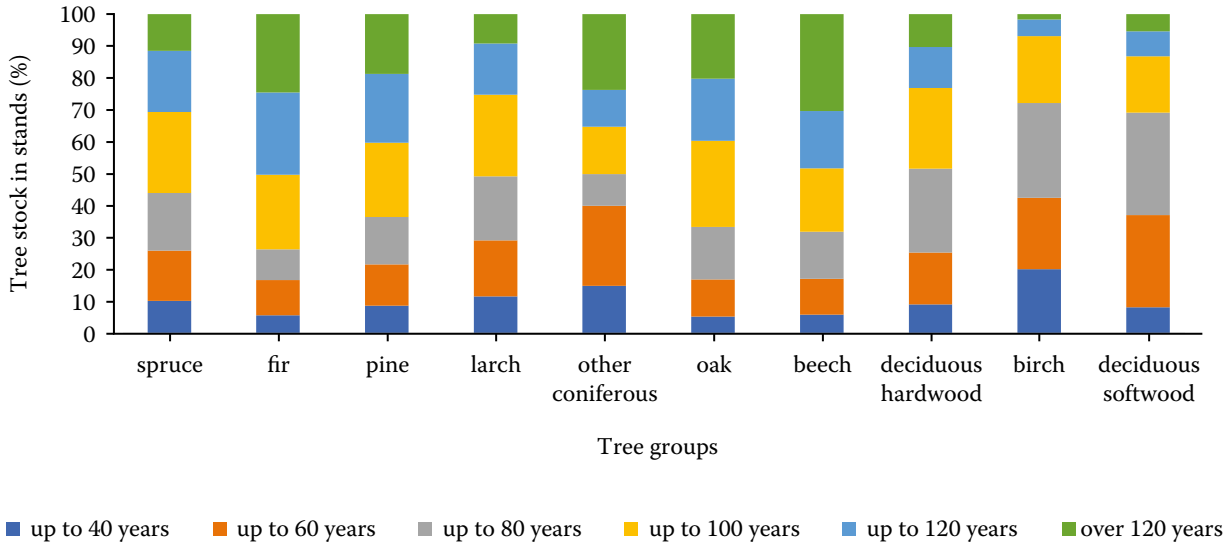

Figure 3. Proportion of stock of tree groups by age

Source: ÚHÚL (2024); authors' own processing

rent management of these stands shows an inability to harvest this tree species at its optimum (after the peak of growth) and place it on the market.

DISCUSSION

The origins of the economic context of forest management can be traced back to the mid-18th century in the forestry literature. They are mainly motivated by economic interests and, in Central Europe, are mainly associated with forestry in Germany and Austria-Hungary, where the most economically profitable tree species and the establishment of monocultures were preferred (Kupčák 2006). On the other hand, there is an interesting contemporary controversy on the species composition of stands – e.g. von Carlowitz (1713) in the publication 'Sylvicultura oeconomica' recommends mixed stands; Döbel (1746) in 'Jägerpractica' calls for the cutting down of broadleaves from conifers when they make up more than half of the stand; Moser (1757) in 'Grundsätze der Forstökonomie' calls for the conversion of mixed stands to pure stands, using thinning to simplify management. Finally, Hartig (1791) in 'Anweisung zur Holzzucht Förster' recommends pure stands because there is no desire for diversity and management should be simple and easier to operate; later, however, he favours mixed stands.

Currently, for example, Leugner (2019) recommends a fine mixing structure with a wide range of tree species in his methodology for restoring calamity groves. Other proposals and recommendations for dealing with the bark beetle calamity also include requirements for changing the species composition of forests (Lesy České republiky 2020). Deciduous trees with the most diverse species composition should be preferred to coniferous trees. Recently, among other broadleaved species, birch has received attention as a tree species with the potential for higher representation in stands. Dudík (2021), within the framework of birch stand development models, suggests growing birch not only as a pioneer tree but also as a target tree on suitable sites. He then compares the marketability of birch assortments with the prices of beech assortments. When economically evaluating the silviculturing of forest tree species according to sales revenues and unit prices, also the rotation of the tree species should be taken into account.

However, the above ideas and approaches may also be fundamentally related to current problems in the context of rising costs of plantation rearing together with a shortage of skilled labour capacity. Prioritising selected tree species, especially at the thinning stage, can affect timber sales revenues for many decades to come. This issue is not given due attention. The qualification of the personnel involved is not sufficient and is rather deteriorating due to the state of vocational training. For many decades, coniferous plantations have predominated, except in a small part of the area where beech and oak have a tradition.

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Even in the Green Reports of the Ministry of Agriculture of the Czech Republic, the problem of the lack of qualified workers has been pointed out since at least 2017, as stated for example in MoA (2020): 'The shortage of workers and temporary workers in the forestry professions for forest work continues to be a major problem for forestry entrepreneurs as well. The number of graduates from forestry apprenticeships has been steadily declining due to the lack of interest of young people in forestry work, mainly because of the strenuous physical work and low earnings compared to other job opportunities.' MoA (2021) claims that 'The problem of shortage of workers for forestry work is still deepening in the forestry sector, and this is the case for virtually all forest owners or employers. In particular, workers and forestry apprenticeship graduates are in short supply.'

As mentioned, the cost of pruning has been rising for a long time and will be accelerated in the coming years by the increase in the area of stands restored after the bark beetle calamity, the limited rearing of stands at the time of the bark beetle calamity and the requirements for their rearing. Over the last ten years, the direct costs of first interventions and planting activities have almost doubled (Table 5). This is due to increased demand for this activity, state support in the form of subsidies, lack of qualified staff, and the increasing difficulty of the activity due to the species diversity of the stands. In our own analysis, it was found that for species-diverse stands, which arise after the restoration of bark beetle areas, taking into account labour consumption standards, the price of pruning, expressed in direct costs, exceeds 840 EUR·ha^{-1} (price level 2022 based on our own findings). We attribute the stagnation of the price of this activity in 2019–2021 to the fact that educational interventions were not carried out much, and therefore the supply and demand for this activity was more or less balanced.

The comparison of the costs of forest regeneration and subsequent care until the provision of crops was evaluated by Šišák et al. (2017) for the main tree species according to the set of forest types using the management intensities as defined by Plíva (2000). Artificial regeneration with straight-rooted spruce appeared to be the least costly, while the economically most costly was the regeneration of beech. Novotný (2016) analyses the economics of harvesting methods and subsequent forest restoration of a typical property in the Bohemian-Moravian Highlands. He concludes that the cost of the assortment method (combination of chainsaw, harvester, and forwarder) brings the lowest costs due to the preservation of natural regeneration. The economical harvesting method, in combination with natural regeneration, appears to be the most optimal on all suitable spruce management sites. It is clear that forest regeneration and crop management are the most costly in the life cycle of a stand.

Increasing the share of broadleaves in forest regeneration will gradually be reflected in the supply of these species on the timber market. Given the growth characteristics of the tree species, the time from reforestation to the supply of sawmill-ready assortments varies considerably. Fast-growing species such as poplar allow the harvesting of sawmillable species from the second age class onwards, whereas hardwoods (oak, beech and others) have sawmill use at a much later age. In addition, while coniferous timber is sawn from 12 cm onwards, the limit for processing broadleaved timber is most often 20 or 25 cm at the tenon.

According to Simanov (2021), there are several views on the development of log prices, the most likely of which is that the price of sawlogs is not formed in the Czech Republic because most logs are exported

Table 5. Average forest owners' own costs over time

Performance – activity		Average cost of selected outputs (EUR per technical unit)							
		1995	1998	2013	2016	2019	2020	2021	2022
Forest restoration	ha	2 273	2 252	2 659	3 120	3 992	4 070	3 977	4 049
Care of forest cultures	ha	189	280	355	349	468	509	524	602
Pruning	ha	186	249	355	398	577	597	575	676
Forest protection	ha	9	4	4	7	16	16	12	12
Total cultivation activity	ha	–	–	72	79	130	148	164	188

Source: MoA (2022)

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or cut in the Czech Republic by multinational firms. The price of logs is thus the result of the commercial policy of the dominant buyers combined with the quantity of timber currently offered on the market.

The supply side of broadleaved timber in the Czech Republic has long been affected by the impossibility of ensuring a steady supply of workable broadleaved timber at an acceptable price in the required quality. This limits the creation of processing capacity and other hardwoods often end up as energy wood or as raw material for the production of agglomerated panels. The issue of value added in the timber industry of the Czech and Slovak Republics, including the use of specific indicators assessing the impact of trade on the economy of the sector, is analysed by Janáková Sujová et al. (2023).

CONCLUSION

The diversity of forests in the Czech Republic is typologically classified by assigning a specific habitat to a forest vegetation stage, edaphic category and water influence stage. As a result, 175 forest type groups have been identified in the Czech Republic, grouping forest types according to their ecological affinity and then grouping them into target management files. These sets should represent the basic parameter for foresters for taking management measures; already, Plíva (2000) defines basic recommendations for these sets concerning the fulfilment of ecological, but also economic, functions. The intensity of management then determines the rationality of the money invested in the management of such forests in terms of future yield.

Forest owners should strive to cultivate forests that are diverse in species, space and age, which are more likely to provide stable stands. The forest owner has a relatively large scope to influence the species composition of the stand and the yield from the forest during the growing season.

Increasing the share of broadleaved trees in forest regeneration will gradually be reflected in the supply of these species on the timber market. The calamity in the Czech Republic in 2016–2023 has significantly affected these processes – accelerated them, and, as mentioned, the supply of coniferous spruce and pine sawlogs will decrease at the expense of broadleaved ones.

In view of the above, the issue of changes in forest species composition and its projections into the economics of management of owners – moreover, given the long-term nature of processes in forest management, can be considered highly topical. The reduction in the stock of coniferous wood in stands and the consequent reduction in harvesting possibilities in the coming decades may have an impact on the overall level of revenues. Coniferous wood now accounts for more than 83% of timber sales. If the harvesting pool were to change in favour of broadleaved species, as shown by the trend in species composition in reforestation, we could expect timber sales to fall by more than 20% (if 50% of the coniferous range were harvested, relative to today's raw timber price levels). This negative impact could be offset by a change in the structure of the timber industry or by significant technological innovation in the use of broadleaved timber in the Czech Republic and the surrounding Central European area.

With rising costs for forest owners and currently non-existent payments for ecosystem services, this could very realistically mean that Central European self-financing forestry will become an uncompetitive sector surviving on subsidies.

The conclusion and recommendation for forest restoration and cultivation from the economic point of view is as follows: When choosing the future tree species composition, pay attention to all tree species that have economic potential. Let us work not only with hard broadleaves, but also with a significant mix of conifers, especially spruce, fir and larch (and of course Douglas fir if this does not conflict with nature conservation interests) on suitable sites. However, it will be necessary to look for economic obsolescence, as defined by Pulkrab et al. (2014) for example, for all tree species. Pioneer tree species from the range of softwoods such as birch or alder can only be considered promising in the future if they are also marketable in an appropriate sawmill quality. The use of self-regulatory processes or the correct timing of educational interventions will also be key, which can significantly reduce the harvesting of weak, lower-value species. It is, therefore, desirable to focus on pruning, where there is also a high potential for adjusting the species composition of individual stands.

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