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Article

Trends of Forest Harvesting Ages by Ownership and Function and the Effects of the Recent Changes of the Forest Law in Hungary

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Abstract: To determine the optimum time to harvest the trees is one of the most interesting problems in the economics of forest resources. It is highly debated whether forests in the Northern hemisphere should be used as carbon sinks or harvested more for long- or short-term wood use for carbon storage in long-lived wood products and for the use of bioenergy. In our study we examined the trend of the cutting ages by tree species, ownership and function in the period of 2006–2021 based on the data of the National Forestry Database (NFD). We also examined whether any changes in the effective rotation linked to the change of the Hungarian Forest Act in 2017 could be observed. We concluded that there were two main sub-groups in the case of which different trends applied. In the case of state-owned forests and indigenous species with a long rotation period, the actual harvesting ages had an increasing trend in the last fifteen years, while in the case of some species with short rotation periods and lower levels of naturalness, the cutting ages in private forests had a decreasing trend. The rotation period of black locust (*Robinia pseudoacacia*) showed a decreasing trend with a significant decrease in private production forests between years 2016 and 2021. This implies that since the more permissive regulation, the management of private black locust stands has moved towards the economically more profitable 20 years rotation cycle. We concluded that the new Forest Act of 2017 can be regarded as an important step towards the separation of forest functions, which means that the role of state-owned forests and forests with high nature conservation value is to protect biodiversity, provide ecosystem services and mitigate climate change through carbon storage in trees, dead wood and in the soil, while the role of forest plantations and forests with lower level of naturalness is to provide timber which is a climate-friendly resource, and which can contribute to climate change mitigation through long-term carbon storage in wood products, wooden buildings and through the substitution of fossil products and fossil fuels.

Keywords: forest rotation age; private forests; forest management purposes; cutting age prescriptions; property rights; climate change mitigation; carbon storage; wood products; ecosystem services; forest law

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1. Introduction

To determine the optimum time to harvest the forest stands is one of the most interesting problems in the economics of forest resources [1,2]. This longstanding problem has received attention since the work of Faustmann [3] who determined the financially optimal rotation age. As a tree grows, the volume of wood it produces increases annually up to a certain point, beyond which it starts to decrease with age. Many foresters have traditionally suggested that the goal of forest management must be to produce the maximum wood output; on the other hand, economists argued that the felling age should be postponed until the time at which benefits received from the wood output are exactly equal to the rate of interest [1]. The optimal harvesting of a multiple age class forest system has also received much attention in the forestry economics literature and existence of an optimal harvesting policy has been established [4]. According to the concept of a normal forest, any optimal logging policy must converge in harvesting age to a constant rotation period and the associated age class distribution converges to a normal forest [5,6]. Suzuki [6] introduced the notion of the 'normal forest in the wide sense' which is a stable steady state forest inextricably linked to the concept of sustainable forest management. A cut-parameter dependent on the age of the compartment called "gentanritsu" (or "gentan") was introduced in order to determine the forest area that is cut at a time-period [6,7]. Assuming a time-dependent change for the management objective, Yoshimoto [7] introduced a nonstationary Poisson process to capture the harvesting behavior for gentan probability estimation. He applied a time-dependent average growth function for stochastic modelling and introduced a time-dependent change in economic factors [8]. Until the mid-1990s, forest growth modelling was a dominant topic in the Hungarian forest sciences. Király applied the concept of a normal forest to beech stands in Hungary and developed a mathematical description of a normal forest [9,10].

Forest-based products and services play a critical role in the envisaged transition towards a European circular bioeconomy [11]; forests are increasingly seen as natural and recreational spaces [12,13] and as the source of multiple ecosystem services [14]. The need to adapt forests to a rapidly changing climate [15]; the progressing "biodiversity crisis" [16]; and the transition towards an economy with a greater reliance on renewable energy and materials [17,18] are interconnected challenges faced by European forests and forest policy makers [14] and put the issue of optimal harvesting age into a new context. The capacity of forests to remove carbon dioxide (CO_2) from the atmosphere at large scale is considered key in climate mitigation pathways [19].

Although there is scientific consensus that the tropical old-growth forests are vital for the world's global atmosphere [20], it is highly debated whether forests in the Northern hemisphere should be used as carbon sinks (increased carbon storage in the forest) or harvested more for long- or short-term wood use (timber harvest increased for wood products and bioenergy) [21–25]. Some studies argue that the inclusion of carbon benefits prolongs the optimum cutting age, and the optimal trajectory for carbon sequestration consists in keeping timber standing for as long as possible [26,27]. However, under the risk of destructive events and natural disturbances which will become more frequent with climate change [19], standing trees might not always be the best solution for long term carbon storage. Romero et al. [28] state that the consideration of carbon uptake as a public good generates a divergence between the private and social optima, and presents a methodology based upon compromise programming to determine optimal forest rotation ages in the context of multiple use to remove the divergence between the two optima. Loisel [20] shows that for higher risk rates of destructive events, the optimal cutting age for sequestered carbon is more comparable to the economically optimal timber cutting age. Vankooten et al. [29] emphasize that carbon taxes and subsidies affect the optimal forest rotation and carbon benefits are a function of the change in biomass. They conclude that although under some tax regimes it may be socially optimal never to harvest the trees, in general, the inclusion of the external benefits from carbon uptake results in rotation ages only a bit longer than the financially optimal rotation age [29].

According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, the enhanced use of wood products can be a successful measure in climate change mitigation [30]. The report of the European Forest Institute [19] emphasizes that wood products can provide a significant contribution to achieve climate neutrality by 2050, and that in order to maximize the forest-based mitigation potential, different mitigation activities should be combined in an optimal way considering their interactions, synergies, co-benefits, trade-offs and regional applicability. In the last decades, the potential contribution of harvested wood products (HWPs) in reducing greenhouse gas emissions has been extensively investigated and it has become an important issue in international climate negotiations [31–35]. Creutzburg and Lieberherr [36] found that the overwhelming majority of actors involved in forest management consider built-in wood as a better climate change mitigation measure than solely increasing carbon storage in the forest, and private forest owners particularly favor measures for increased wood harvesting and carbon storage in long-lived products.

An overview of regulatory frameworks across 31 European jurisdictions showed a clear variation in the private forest owners' scope for decision making relating to their forests [37]. As shown by the analysis, the restrictions on operational and management rights present a clear differentiation between the participant jurisdictions, and the process of management planning seems to be crucial in both increasing and constraining the degree of freedom for private forest owners [37]. Forest Management Plans tend to be considered as "key instruments in delivering multiple goods and services in a balanced way" [38]. However, the nature of forest management planning varies considerably across Europe [37] from a hierarchical implementation of governmental designed technical norms [39–41] to a space for negotiation or learning between the State and forest owners [42] routed in the "freedom with responsibility" principle [43]. According to Nichiforel et al. [37], private forest owners in jurisdictions with westernized socio-political backgrounds have greater degrees of freedom in making and implementing decisions with regard to their forest lands in comparison to private forest owners from former socialist countries. The overall Property Right Index constructed by Nichiforel et al. [37] shows that Hungary is in the last third of the reviewed 31 European countries regarding the freedom of property rights. With regard to forest management rights, Hungary is in the last three countries of the list, meaning that in our country, rights of private forest owners are relatively restricted.

In Hungary, 43% of the forest area (i.e., 881,941 ha) is private property owned by nearly 450,000 private persons and 2000 firms and managed by nearly 32,000 private forest managers who typically manage small, fragmented areas (with an average management size of around 17 hectares) [44]. Hungarian forest management planning covers all forests, it is conducted by the national Forest Authority, and forest management plans are compulsory and decisive for how forests are managed. The plans are made for 10 years at the forest stand level and also regional level and contain information on the status of the forest stand during the survey related to the planning process, on long-term objectives, on the prescribed cutting age of the forest stand, on plans for short-term operations and information on the last harvesting operations.

In 2017, several changes were made to the Hungarian Forest Act [45] including changes in the regulation of the cutting ages. The new Forest Act differentiates between state-owned and private forests regarding the regulation of harvesting ages. According to the new regulation in the case of privately owned tree plantations and cultivated forests, the cutting age specified in the Forest Management Plan is regarded only as a recommendation. For privately owned transitional forests (i.e., forests with 50%–69% non-native species or 20%–49% intensively spreading species) with the primary purpose of timber production, harvesting can take place ten years before the prescribed cutting age in the case of fast-growing tree species, and twenty years before the prescribed cutting age in the case of slow-growing tree species. This new regulation may modify the management practices of private forest owners and may reduce the cutting ages of private forests with a low state of naturalness.

The objective of our study was to analyze the trend of the cutting ages by tree species, ownership, and management purpose in the period 2006–2021 based on the data of the National Forestry Database (NFD) and group the species by the differences of the trends in their effective harvesting ages. We conducted this analysis to obtain a picture on the main tendencies and links between the species, the ownership form and the goal of management and the length of the effective rotation. We also intended to examine whether the effect of the new forest regulation could be experienced in the harvesting events that took place after the new Forest Act entered into force (i.e., after 2016).

2. Materials and Methods

2.1. The Characteristics of Hungarian Forests

Hungary's forest cover is 2,064,000 hectares which is 20.9% of the country's territory. The forests are composed of 90.5% deciduous tree species and are typically mixed forest communities [44]. More than 40% of the forests have a plantation-like composition of non-native tree species. Most of these plantations are the result of afforestation in the recent decades. Since 2006, the Hungarian forest area increased with 70,100 hectares (Figure 1). Afforestation in the last decades has typically been carried out under unfavorable, degraded site conditions, in landscapes significantly modified by human activities. An example for human activities is the drainage of the Duna-Tisza sand flats in the Great Plain [35]. This area has become a semi-desert habitat since the river flow regulation in the 19th century. In these degraded habitats, only the introduced black locust (*Robinia pseudoacacia*) and pine species (*Pinus sylvestris* and *Pinus nigra*) could be successfully used for afforestation [35]. Plantations of black locust, hybrid poplars and pines (predominantly *Pinus sylvestris* and *Pinus nigra*) account for more than half of the Hungarian annual wood production (3.9 million m^3) [44]. The main tree species of Hungary and the evolution of their area is shown in Figure 1. The predominant species are black locust with 24% of the forest area, white oaks with 21%, Turkey oak (*Quercus cerris*) with 12% and pine species with 10%.

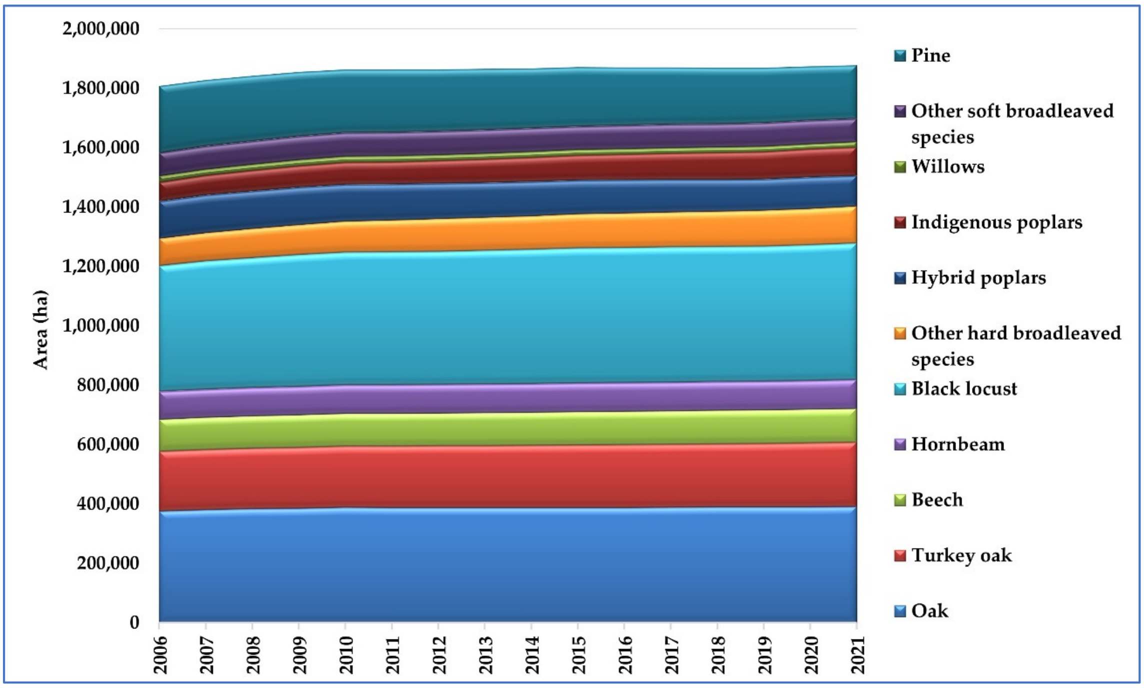

Figure 1. Evolution of the Hungarian forest area by tree species groups between 2006 and 2021.

2.2. The National Forestry Database

In our study we used the National Forestry Database (NFD) as a data source which is an inevitable instrument of forest policy implementation, forest management planning and inspection. NFD is the official database of the Hungarian Forest Authority, and it stores information on the forest stand level. Forest stands in Hungary are units of relatively homogenous tree cover, with a mean area of about four hectares, and they are also called forest sub-compartments (the smallest unit of forest management). In the NFD for each forest sub-compartment of the country, digital maps and more than 300 raw and derived data are available. Among others, data is stored for each sub-compartment on the name of the forest manager, the area and the protection status, site characteristics, details of soil sampling, dendrometrical parameters, tree species composition, planned harvests and harvest prescriptions (including the prescribed cutting age), regeneration and afforestation prescriptions, data on harvests carried out and on regeneration carried out. The hardware architecture of NFD is an Oracle g9 and g10 based system that was developed within the frame of a PHARE-project in 2005 [46]. Physical data medium is only used to upload input data and the introduction of centralized architecture has resulted in uniform methods and higher data quality [46].

Forest management planning activities cover the entire forest area of the country. About one tenth of the forest area of Hungary is subject to forest management planning each year. This means that each forest sub-compartment is planned once in every 10 years. Forest management planning is conducted in each forest district separately, forest management plans are based on field surveys and prescribe tasks and their timelines that must be fulfilled during the next 10-year-long-period. During the field survey, the main stand attributes (such as height, diameter, basal area, age, canopy closure) are sampled. From sampled data, growing stock volume and annual increment are modelled with the use of yield tables for the years between two subsequent forest management planning activities. This means that the modelled annual increment is added and annual harvested volumes (which are officially registered) are subtracted from the growing stock of each sub-compartment year-by-year. The NFD also stores data on the prescribed cutting age of each sub-compartment and on the timing of actual harvest, which we used in our investigation.

2.3. The Method of the Analysis

The objective of our analysis was to examine the trend of the cutting ages by tree species, ownership and management purpose in the period of 2006–2021 based on the data of the NFD and group the species by the differences of the trends in their effective harvesting ages. An econometric analysis was out of the scope of this paper. In our analysis, based on the NFD for all forest sub-compartments we examined whether they were affected by the final harvest in the given year. We regarded as the final harvest all harvesting events where, as a result of the intervention, the area covered by trees decreased within the sub-compartment (gradual renewal cuttings, other harvests) or disappeared completely (clear cuttings) and a new rotation period began. The identification of the forest sub-compartments was based on the forest cadaster identifier, the identifier of the forest manager (owner) and the area of the forest stand. We selected and summed by year the area of forest stands harvested during the given year. A forest sub-compartment can be affected by several final harvest events in a year, although most often there is only one. At the time of the harvests the dominant tree species of the sub-compartment, the age, the management purpose, the yield class and the ownership form are known and stored in the NFD. In the Hungarian practice, the management purpose of the forest stands is closely related to their nature conservation classification, so there was no need to treat these two attributes separately.

According to the above method, in the examined period (2006–2021), it was possible to collect data suitable for analysis of 92%–99% of the entire area affected by harvesting events in the country. In those cases where data was not available, the problem was that the identifier of the stand in the forest cadaster had changed because of management reasons (due to the subdivision or merging of sub-compartments often precisely because of the harvesting event) and the state at the beginning of the year could not be reliably coupled with the state valid at the time of the harvest.

When we had data for all examined years on the area and the stock of forest stands harvested during the given year, we grouped data by tree species, management purpose and forest ownership. Then we calculated the harmonic mean of the harvesting ages weighted by the area harvested.

$$H_{somy} = \frac{\sum_{i=1}^{n} w_i}{\sum_{i=1}^{n} \frac{w_i}{x_i}} \quad (1)$$

H_{somy}: harmonic mean of harvesting ages of forest stands of tree species 's', of ownership type 'o' and management purpose 'm', in year 'y';
n: number of forest sub-compartments harvested in year 'y' of the tree species 's', of ownership type 'o' and management purpose 'm';
x_i: harvesting age of forest sub-compartment 'i';
w_i: area of forest sub-compartment 'i'.

The evolution of the actual harvesting age of each tree species over time was characterized by the trend of the annual harmonic mean values. We used the harmonic mean for the analysis as we regarded it the most characteristic indicator of the cutting age distribution. The reason for this is that the harmonic mean of cutting ages weighted by the yield area of a forest characterized by a cutting age distribution of several discrete values is equal to the cutting age of a normal forest of the same total area and yield area. We analyzed the trend of the harmonic means in the period between 2006 and 2021, applying lineal regression. We used the Statistica software (Version 12, Tulsa, OK, USA) for the calculations. The regression line was set, and the trend analysis was carried out as follows.

$$C_{AGE} = a \times Year + b \quad (2)$$

$$R^2 > 0.5 \text{ and } a > 0 \text{ increasing trend} \quad (3)$$

$$R^2 > 0.5 \text{ and } a < 0 \text{ decreasing trend} \quad (4)$$

$$R^2 \leq 0.5 \text{ no change} \quad (5)$$

C_{AGE}: trendline of the harmonic mean of the cutting ages as a function of the age;
a, b: regression parameters;
R^2: determination coefficient.

To describe definite and strong correlations, the trend of the regression line was regarded as decreasing or increasing only if the determination coefficient value (R^2) was above 0.5. We calculated the confidence intervals of the harmonic means for each year and tree species using the jackknife method [47] and assuming a level of significance of $p < 0.05$. For this analysis, we used a self-developed program code written in the Microsoft Visual FoxPro software (Version 9.0, Redmond, WA, USA). According to our hypothesis, the change of the Forest Act could affect the felling which took place in the period of 2017–2021. Thus, for each species we examined whether confidence intervals for the year 2016 and for the year 2021 did overlap. In case they did not, we regarded that between the two years, a significant change occurred.

3. Results

Figure 2 shows data of the harvesting events where data collection from the NFD was possible (i.e., 92%–99% of the total final harvest; Table A1), the area under harvest and the number of forest sub-compartments affected by final harvesting events are shown by year, grouped by ownership (private and state-owned).

According to the results of the trend analysis in 16 cases out of the 64 examined trendlines, an increasing trend was observed in the period of 2006–2021. In two cases, a decreasing trend was observed, while in 46 cases, the determination coefficient (R^2) value was under 0.5 (Table A2) which was regarded as no trend. In the case of black locust private production forests and indigenous poplar forests with other management purposes, a significant decrease in cutting ages was observed between the years 2016 and 2021 (Table A2). In state-owned forests, the overall tendency observed was the increasing trend of cutting ages. In 10 cases out of 32, an increasing trend was observed while in the remaining cases there was no trend. Decreasing trends of harmonized cutting were observed only in the case of private forests (Figure 3, Tables A1 and A2). Figure 3 shows the value of the regression slope (parameter 'a' of the regression line) in those sub-groups where the R^2 value was above 0.5; negative values mean a decreasing trend while positive values mean an increasing trend.

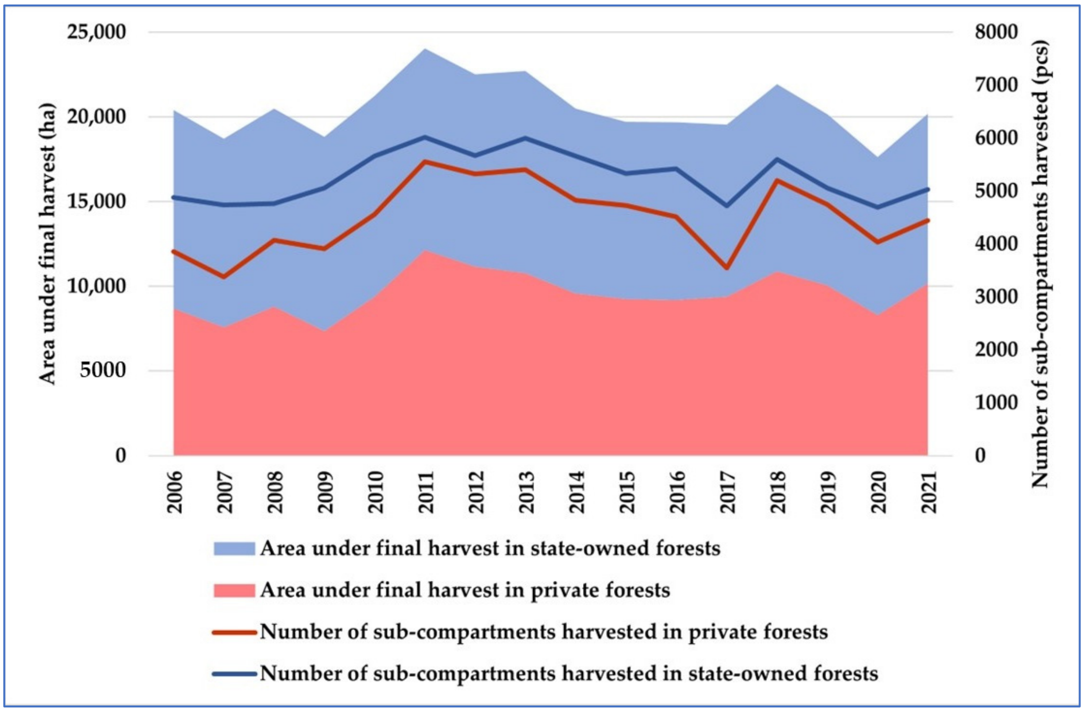

Figure 2. Area under harvest and the number of sub-compartments harvested in state-owned and private forests in the period 2006–2021.

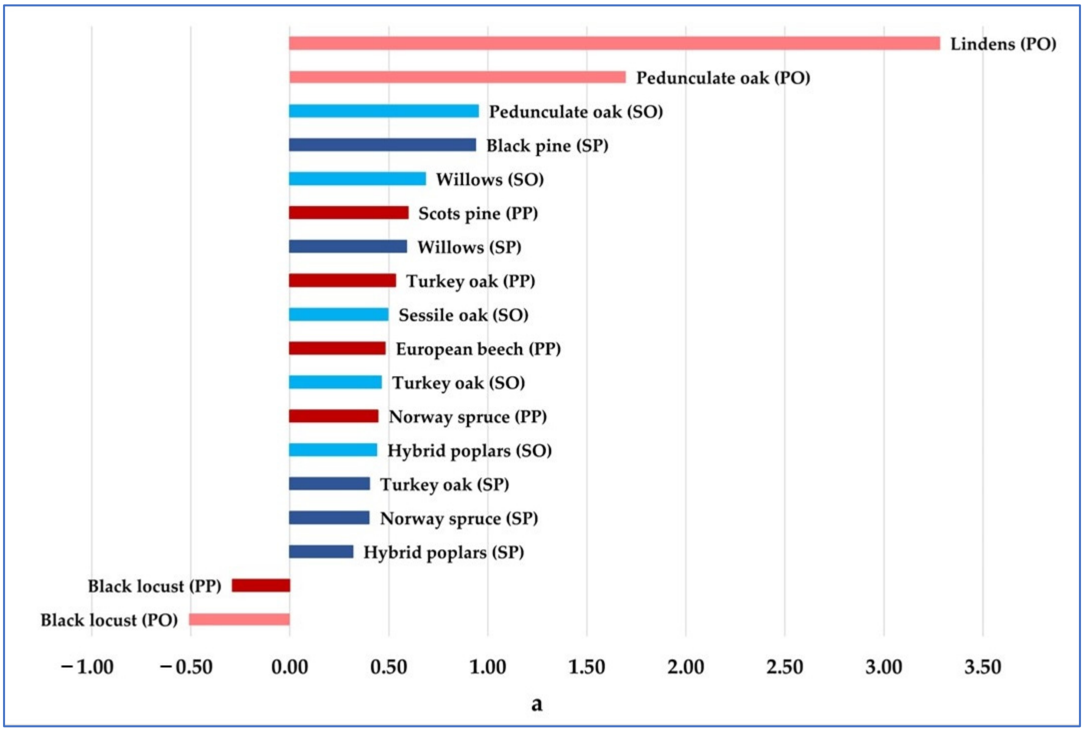

Figure 3. Values of the regression slope (parameter 'a') of the trendline of harvesting ages (where $R^2 > 0.5$) weighted by the area under harvest sorted in descending order and colored by management purpose and ownership. Negative 'a' values mean decreasing trend while positive values mean increasing trend. (SP: state-owned production forests; SO: state-owned forests with other management purpose; PP: private production forests; PO: private forests with other management purpose).

For the largest group of tree species, the harmonic mean of actual harvesting ages showed an increasing trend in some sub-groups (and no trend in the remaining sub-groups) in the 2006–2021 period. The following species belonged to this group: sessile oak (*Quercus petraea*), pedunculate oak (*Quercus robur*), Turkey oak (Figure 4), European beech (*Fagus sylvatica*; Figure 5), willows (*Salix*), lindens (*Tilia*), Scots pine (*Pinus sylvestris*), black pine (*Pinus nigra*), Norway spruce (*Picea abies*) and hybrid poplars (see also Tables A1 and A2). Regarding hybrid poplars, we observed increasing trends in state-owned forests while in private forests no change in the harmonized cutting ages could be observed.

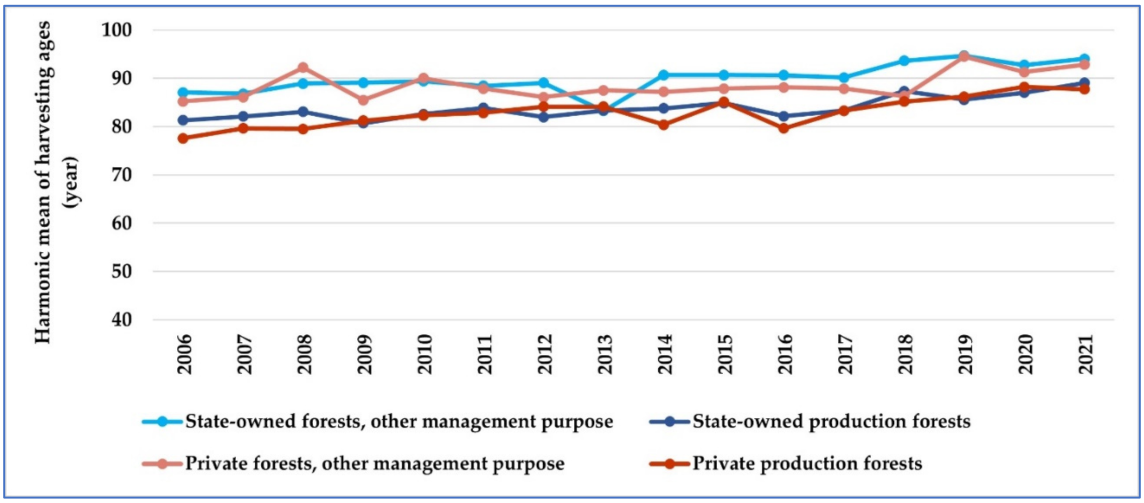

Figure 4. Harmonic mean of harvesting ages (weighted by the area under harvest) of Turkey oak (*Quercus cerris*) stands in the period between 2006 and 2021 grouped by management purpose and ownership.

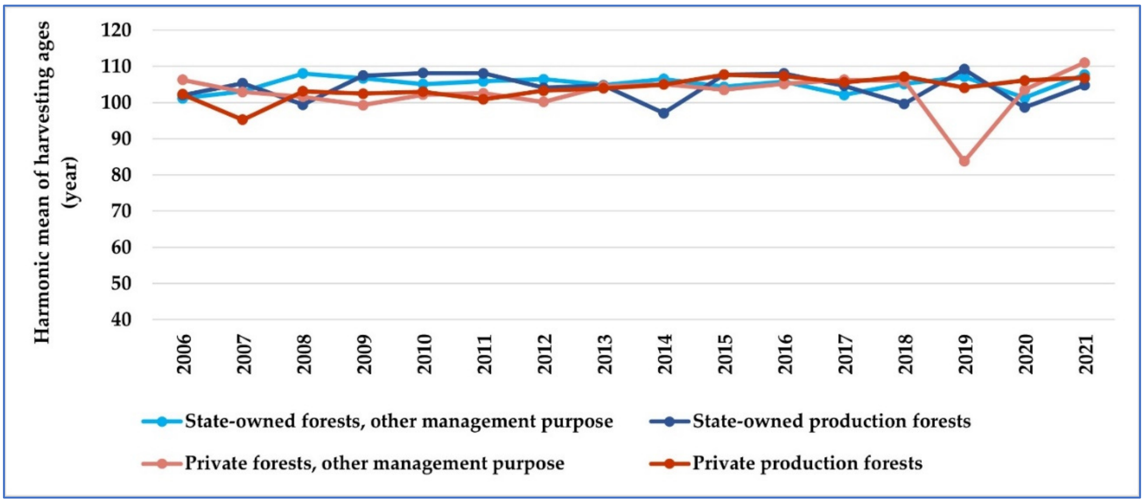

Figure 5. Harmonic mean of harvesting ages (weighted by the area under harvest) of European beech (*Fagus sylvatica*) stands in the period between 2006 and 2021 grouped by management purpose and ownership.

Figure 6 shows the age distribution of the area to be harvested according to the prescribed cutting ages and the age distribution of the area affected by actual harvesting events in the case of Turkey oak. In the figure the age distributions of the areas prescribed for harvest and actually harvested are grouped by yield class. Yield class 1 is the category with the most yield production, and yield class 6 is the less productive category. This means, under the average Hungarian circumstances, that yield class 6 gives approximately half of the harvested timber volume (m^3/ha) at final harvest relative to yield class 1. It could be observed in the case of all tree species that the distribution of prescribed harvests is less balanced than that of actual harvests.

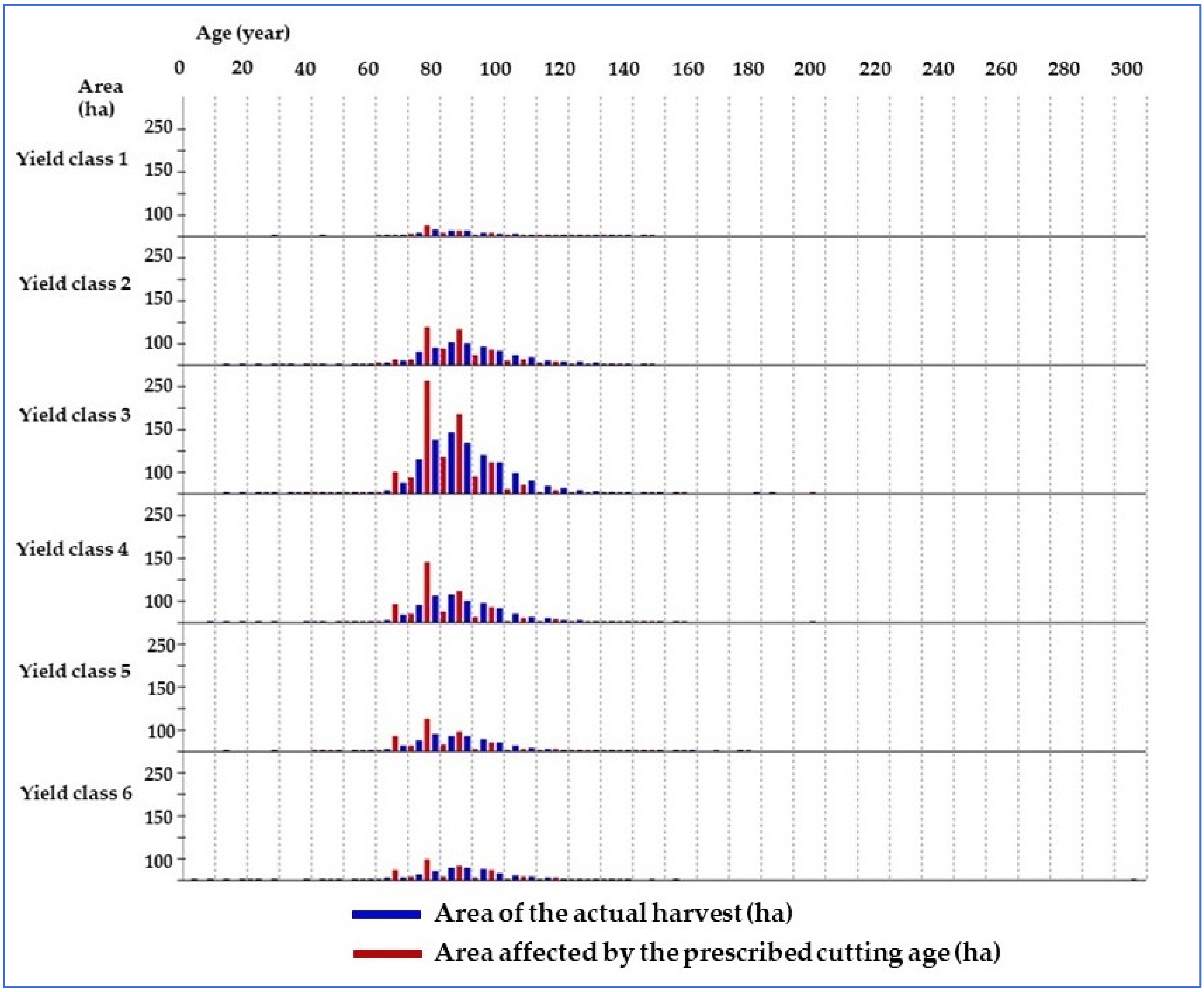

Figure 6. Average area of the 2006–2021 period to be harvested according to the prescribed cutting age and area of the actual harvests of Turkey oak (*Quercus cerris*) stands as the function of the age and grouped by yield classes.

In the case of European hornbeam (*Carpinus betulus*), ash (*Fraxinus*), alders (*Alnus*) and other broadleaved species, no trend was observed in any of the sub-groups (see Table A1). In the case of black locust (Figure 7) the decreasing trend of harvesting ages was observed in private forests in both production and other management purposes in the period of 2006–2021. Between 2016 and 2021, a significant decrease in harmonized cutting ages was observed in private production forests (Table A2). In the case of indigenous poplars (*Populus*; Figure 8), no trend was characteristic in the 2006–2021 period; however, between 2016 and 2021, decreasing trends were observed in private forests. In the case of private forests with other management purposes, a significant decrease was detected (Table A2).

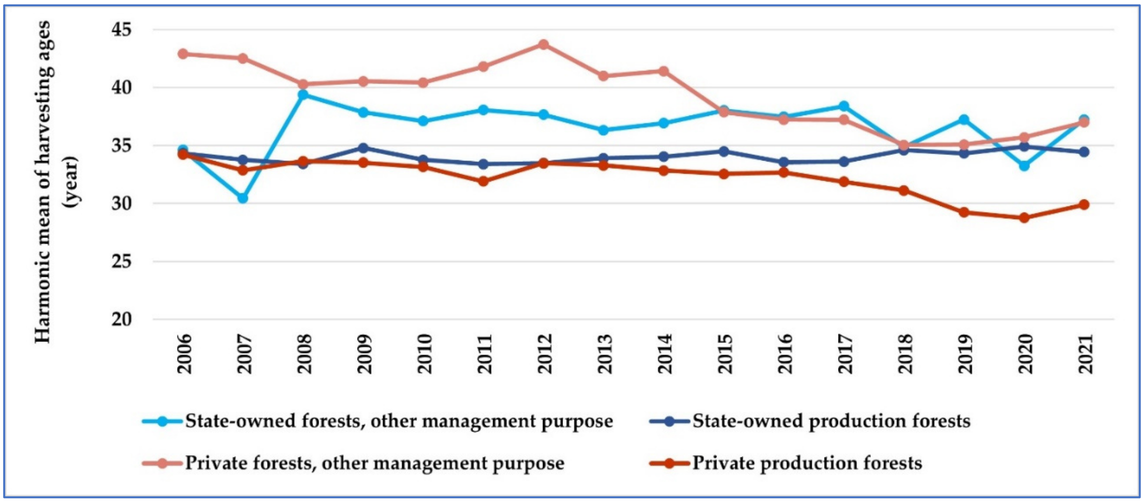

Figure 7. Harmonic mean of harvesting ages (weighted by the area under harvest) of black locust (*Robinia pseudoacacia*) stands in the period between 2006 and 2021 grouped by management purpose and ownership.

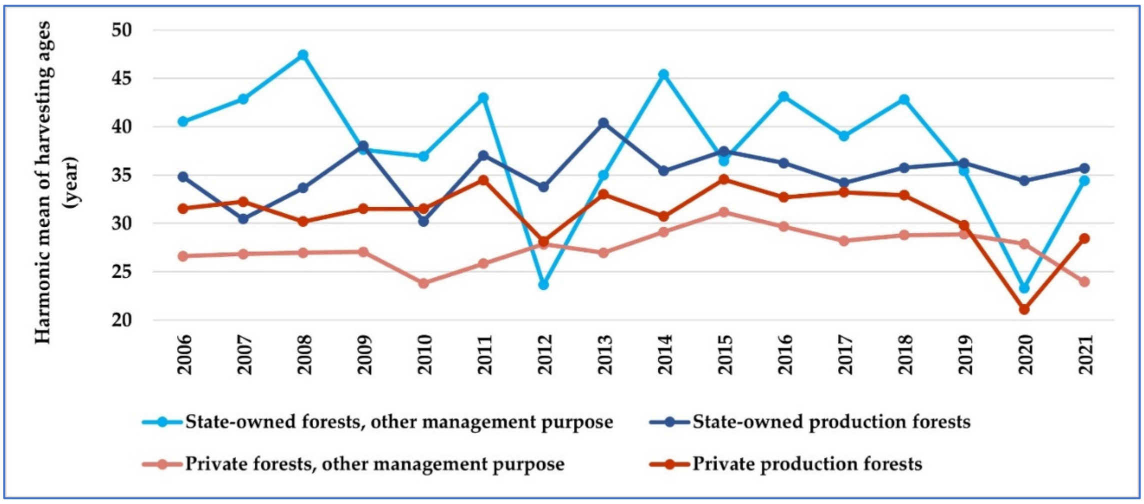

Figure 8. Harmonic mean of harvesting ages (weighted by the area under harvest) of indigenous poplar (*Populus*) stands in the period between 2006 and 2021 grouped by management purpose and ownership.

4. Discussion

Our results showed that in state-owned forests increasing trends in cutting ages were the characteristic tendency, while in private forests decreasing and also increasing trends could be observed depending on species and management purpose. In the case of indigenous species with long rotation periods such as pedunculate oak, sessile oak, Turkey oak and European beech, the actual harvesting ages had an increasing trend (or no change in some sub-groups) in the last fifteen years. This tendency might have been caused by increasing biodiversity concerns and nature conservation requirements in the EU and in national policies. The Hungarian National Forest Strategy [48] puts its main focus on sustainable forest management, biodiversity conservation and climate change mitigation objectives. This means that in the case of indigenous forest communities with high levels of naturalness, conservation efforts have an increasing importance and continuous forest cover is also among the desired objectives in the case of forest stands with outstanding nature conservation value. In state-owned forests, only an increasing trend (or no change) was observed in the harmonized cutting.

European beech and Norway spruce are the species most affected by the negative effects of climate change in Hungary. European beech populations in our country are living at or near their xeric (lower) distribution limits and a large part of low-elevation beech forests might disappear due to the warming temperatures in the second half of the century, while higher-elevation occurrences may remain stable [49]. Norway spruce is projected to almost vanish from low and mid-elevation areas in central, eastern, and southern Europe [19] and increasing damage to Norway spruce forests in Hungary has been observed in the last decades [50–52]. For this reason, these forests are continuously converted to forests with more stable species such as oaks mixed with hornbeam. These facts may affect the cutting age distribution of Norway spruce and beech, as on the one hand more salvage logging occurs, but on the other hand populations less affected by the aforementioned damages might not be harvested as there is no chance of their natural regeneration.

In the case of black locust, we observed a decreasing trend of harvesting ages in the private forests. In private forests with economic management purposes, a significant decrease in cutting ages was observed between the years 2016 and 2021. This significant decrease was most likely caused by the changes in the Forest Act which made it possible for private forest owners to harvest their forests before the prescribed cutting ages if the stand's naturalness was low. According to the new law, the cutting age specified for private tree plantations and cultivated forests is regarded only as a recommendation. While for private transitional forests with the primary purpose of timber production, harvesting can take place ten years before the prescribed cutting age in the case of fast-growing tree species, and twenty years before the prescribed cutting age in the case of slow-growing tree species. It seems that the new regulation had a short-term effect only in the case of fast-growing tree species with short rotation periods. Black locust is a non-native species which is primarily used for fuelwood production. Recent changes in energy prices and wood market trends caused increasing fuelwood demand and with the new regulation of cutting ages, this increased demand could be followed by supply from private production forests. According to recent economic analyses, black locust is still net profitable economically on the weakest sandy soils as a single agricultural plant (taking woody and other agricultural crops into account) if the rotation cycle is reduced to 20 years [53]. In contrast, the 30–35–40-year cutting age requirement makes the cultivation of black locust unprofitable under the same weak site conditions. Under good site conditions, it is worth increasing the cutting age, because extra-sized logs with optimal assortment-composition and value can be produced, and this compensates for a longer rotation period and a longer investment cycle.

In protected and Natura 2000 areas, the Nature Conservation Authority's requirement is to convert hybrid poplar stands to indigenous poplars. This is economically unprofitable, and these requirements may result in hybrid poplar stands being cut down later, especially in state-owned forests. On the other hand, on certain low quality site conditions, e.g., on medium and poor-quality sandy soils under the currently mandatory regeneration technology (stumping and complete soil preparation), it is unprofitable to harvest hybrid poplar stands as it does not generate enough income to cover the costs of harvesting and regeneration. This might cause increasing harvesting ages in hybrid poplar stands below this economic threshold. A solution to this problem would be to permit stump sprouting under weak site conditions on dry sandy soils, which would result in an economically much more affordable and more reliable regeneration.

We observed that the age distribution of the area to be harvested according to the prescribed cutting ages was less balanced than the age distribution of the area affected by actual harvesting events. According to Király [9], the distribution of the cutting age of real forest stands is a continuous, bell-shaped distribution, which contains small amounts of very early harvests (due to salvage logging and land use change) as well as extremely high cutting ages. The age distribution of the area affected by actual harvests showed this picture.

Overall, we can say that the Hungarian legislation is moving towards the separation of forest functions by ownership and naturalness. State-owned natural forests tend to have an increasing function in providing ecosystem services, protecting biodiversity and mitigating climate change through carbon sequestration and storage. This tendency is shown in the increasing trend of harvesting ages of the last fifteen years. On the other hand, private forests with a low level of naturalness and private tree plantations have other types of functions assigned to them. These forests have an overall economic purpose which can easily be supplemented with climate mitigation purposes through the enhanced and innovative use of wood as raw material, as a source of bioenergy and as a substitute of fossil-based products [19]. Wood used in long-lived products and built into buildings for tens of years or even for centuries can be one of the most effective means for carbon storage. Short rotation forests with low naturalness can be regarded as carbon pumps, the role of which is not the storage of carbon but its sequestration and channeling into the wood product carbon storage pool. If we look at the forest functions in this way, the decreasing trend of harvesting ages in private forest plantations and cultivated forests is a beneficial phenomenon that increases the efficiency of the carbon pump and provides raw material for an innovative, prosperous, and climate-friendly forest industry. With this separation of forest functions, private forest owners also gain more freedom in their management rights which may positively influence their entrepreneurial activities and empower them [37,54]. Eggers et al. [21] state that no single management regime performs best with respect to all economic and ecological indicators, which means that a mixture of management regimes is needed to balance conflicting objectives. The report of the European Forest Institute [19] emphasizes that to maximize the forest-based mitigation potential, different mitigation activities should be combined in an optimal way considering their interactions, synergies, co-benefits and trade-offs. The separation of forests by their functions is a good way of implementing this recommendation and can contribute to the successful achievement of climate goals set to 2050.

Our results are also a good starting point to actualize the projections made by the DAS forest model [55] and conduct new model runs considering the changes implied by the new Forest Act of 2017. In the framework of the ForestLab project (TKP2021-NKTA-43), we are planning to parametrize the DAS model for the changed legal circumstances and re-run the projections of forest standing volume, harvests, and carbon sequestration for the period of 2024–2050. We conclude that these new results are suitable for the parametrization of the DAS model.

5. Conclusions

In our study we examined the trend of the harmonized cutting ages in the period of 2006–2021 and we analyzed whether the effect of the new Forest Act of 2017 could be experienced in the harvesting events of the 2017–2021 period. We studied the trend of the cutting ages by tree species in the period 2006–2021 based on the data of the NFD and concluded that in the case of state-owned forests, the actual harvesting ages had an increasing trend (or no trend) in the last fifteen years. Indigenous species with long rotation periods also showed increasing trends in their effective rotation, while in the case of some species with short rotation periods and lower levels of naturalness, the cutting ages had a decreasing trend, especially since 2017. We concluded that the management of private black locust forest stands is moving towards the economically more profitable 20 years rotation cycle since the more permissive regulation of the new Forest Act of 2017. However, in the case of hybrid poplars, the legal environment is still imposing difficulties in the economically appropriate management, prescribing stumping and complete soil preparation as mandatory operations to be carried out before the regeneration of stands. The permission of stump sprouting under weak site conditions on dry sandy soils would result in more reliable regeneration and economically much more affordable cultivation.

The new Forest Act of 2017 can be regarded as an important step towards the separation of forest functions, which implies that the role of state-owned forests with high nature conservation values is to protect biodiversity, provide a broad range of ecosystem services and mitigate climate change through carbon storage in trees, dead wood and in the soil. Meanwhile, the role of forest plantations and private forests with lower level of naturalness is to provide timber which is a climate-friendly resource of the targeted circular bioeconomy, and which can contribute to climate change mitigation through long-term carbon storage in wood products, wooden buildings and through substitution of fossil products and fossil fuels.

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Data Availability Statement: All data that are necessary for the reconstruction of this study can be found in this paper and in the referenced sources.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Harmonic mean of harvesting ages (weighted by the area under harvest) of some examined tree species and tree species groups in the period between 2006 and 2021, grouped by management purpose and ownership. (In the table, 'NO' indicates that in the given year no harvest took place).

	Sessile Oak	Pedunculate Oak	European Hornbeam	Ash	Other Broadleaved Species	Hybrid Poplars	Willows	Alders	Lindens	Scots Pine	Black Pine	Norway Spruce
year	Private production forests											
2006	86	51	70	63	41	22	37	45	NO	35	39	31
2007	88	85	71	65	61	21	35	52	NO	37	32	33
2008	86	90	67	55	23	21	34	49	NO	34	26	40
2009	85	89	69	60	60	22	31	56	NO	40	36	33
2010	88	85	69	58	45	18	37	52	55	37	36	33
2011	87	98	70	75	40	19	34	53	67	40	42	33
2012	84	80	75	72	23	21	34	47	58	41	43	35
2013	89	85	73	54	51	21	34	40	66	39	46	36
2014	90	71	76	66	42	21	33	57	54	41	46	36
2015	86	92	80	54	28	21	36	56	68	42	42	36
2016	94	77	72	52	25	21	37	50	39	40	30	39
2017	55	83	71	40	65	21	39	56	74	40	42	39
2018	95	95	80	57	38	22	36	58	68	42	47	39
2019	93	97	72	49	49	21	36	52	64	43	42	38
2020	96	83	79	44	51	21	38	42	NO	45	46	39
2021	95	77	73	63	40	23	46	49	77	46	43	39
	Private forests, other management purpose											
2006	97	71	85	58	42	27	38	55	41	40	57	40
2007	92	87	87	76	34	27	32	60	61	49	51	39
2008	93	79	95	59	31	27	41	41	NO	63	44	37
2009	48	70	86	20	44	27	44	61	NO	71	52	42
2010	94	87	95	44	52	24	39	63	57	78	51	50
2011	94	97	79	43	54	26	45	56	70	52	59	37
2012	95	89	71	53	49	28	37	45	NO	60	60	47
2013	94	78	80	57	45	27	43	61	72	55	51	38
2014	98	99	84	57	41	29	41	62	73	48	42	39
2015	99	80	76	57	51	31	42	60	52	56	41	38
2016	91	99	83	52	53	30	40	70	74	59	44	41
2017	101	101	78	79	NO	28	43	60	NO	52	45	42
2018	73	90	85	53	42	29	47	61	105	51	48	44
2019	96	101	84	22	54	29	41	66	NO	50	52	42
2020	101	107	85	31	NO	28	40	67	NO	58	46	40
2021	103	95	88	57	59	24	55	60	NO	57	44	41

Table A1. *Cont.*

	Sessile Oak	Pedunculate Oak	European Hornbeam	Ash	Other Broadleaved Species	Hybrid Poplars	Willows	Alders	Lindens	Scots Pine	Black Pine	Norway Spruce
State-owned production forests												
2006	84	87	75	48	24	23	32	55	83	43	44	32
2007	89	92	78	69	53	24	30	52	75	44	33	35
2008	90	95	79	68	47	22	30	55	72	46	43	37
2009	92	94	79	56	50	22	31	55	65	45	44	35
2010	92	92	74	52	33	23	30	56	69	44	47	38
2011	93	95	79	68	53	24	31	54	66	46	48	40
2012	93	93	83	56	49	24	35	52	77	48	46	37
2013	92	95	76	70	53	23	35	54	73	46	50	37
2014	91	95	78	70	64	25	38	57	77	47	52	38
2015	87	97	73	47	49	25	35	61	78	49	50	37
2016	93	95	81	62	54	25	36	60	73	41	49	37
2017	95	78	88	73	47	26	35	59	83	46	53	40
2018	95	95	87	55	69	26	34	54	77	48	52	38
2019	86	95	86	70	63	26	42	55	88	48	54	40
2020	90	85	84	67	48	27	35	62	95	49	53	40
2021	94	92	83	66	72	27	39	60	82	50	54	41
State-owned forests, other management purpose												
2006	96	91	74	68	67	26	31	56	82	52	62	45
2007	91	81	81	74	55	26	33	55	89	53	49	48
2008	93	92	80	74	61	27	36	59	98	53	51	48
2009	96	94	83	67	65	26	33	61	87	58	65	46
2010	94	95	79	68	66	24	33	47	82	62	55	51
2011	96	95	78	66	61	27	35	58	79	58	52	47
2012	95	97	82	74	69	27	36	57	85	59	57	50
2013	95	94	82	65	65	28	35	58	95	55	57	43
2014	92	100	81	83	58	29	37	56	83	55	58	43
2015	99	96	87	62	65	28	35	59	94	55	57	45
2016	97	102	81	70	57	29	37	59	99	53	57	48
2017	99	99	89	75	64	29	38	58	90	58	59	46
2018	98	96	81	71	64	31	41	60	84	61	57	43
2019	97	102	90	78	70	31	42	62	100	57	60	45
2020	101	101	81	64	70	30	42	60	99	62	60	45
2021	101	104	84	60	70	33	42	51	93	59	57	44

Table A2. The trend of the harmonic means of harvesting ages (weighted by the area under harvest) of the examined tree species and tree species groups in the period between 2006 and 2021. ("I" means increasing trend, "D" means decreasing trend, while "x" means that no trend could be observed. The first number in brackets is the value of the determination coefficient R^2. The second number in brackets is the parameter 'a' of the trendline. The * indicates that there was a significant decrease in the harmonic mean of the cutting ages between 2016 and 2021).

Turkey Oak	Pedunculate Oak	Sessile Oak	European Beech	European Hornbeam	Black Locust	Ash	Other Broadleaved Species	Indigenous Poplars	Hybrid Poplars	Willows	Alders	Lindens	Scots Pine	Black Pine	Norway Spruce
Private production forests															
I (0.66; 0.53)	x (0.06; 0.59)	x (0.02; 0.31)	I (0.54; 0.48)	x (0.35; 0.51)	D * (0.71; −0.29)	x (0.24; −0.97)	x (0.00; 0.00)	x (0.12; −0.24)	x (0.12; 0.08)	x (0.37; 0.42)	x (0.00; 0.05)	x (0.15; 1.18)	I (0.79; 0.60)	x (0.32; 0.74)	I (0.53; 0.44)
Private forests, other management purpose															
x (0.26; 0.30)	I (0.51; 1.70)	x (0.08; 0.78)	x (0.00; −0.01)	x (0.04; −0.27)	D (0.71; −0.51)	x (0.03; −0.59)	x (0.40; 1.09)	x * (0.08; −0.32)	x (0.07; 0.11)	x (0.33; 0.61)	x (0.26; 0.79)	I (0.55; 3.28)	x (0.01; −0.16)	x (0.22; −0.59)	x (0.01; 0.06)
State−owned production forests															
I (0.67; 0.40)	x (0.02; −0.14)	x (0.1; 0.21)	x (0.00; −0.04)	x (0.41; 0.60)	x (0.15; 0.04)	x (0.09; 0.53)	x (0.42; 1.66)	x (0.08; 0.15)	I (0.85; 0.32)	I (0.62; 0.59)	x (0.40; 0.42)	x (0.37; 1.01)	x (0.36; 0.31)	I (0.72; 0.94)	I (0.65; 0.40)
State−owned forests, other management purpose															
I (0.56; 0.46)	I (0.65; 0.95)	I (0.59; 0.49)	x (0.01; 0.04)	x (0.34; 0.49)	x (0.01; 0.05)	x (0.02; −0.17)	x (0.18; 0.43)	x (0.14; −0.54)	I (0.82; 0.44)	I (0.83; 0.68)	x (0.06; 0.20)	x (0.21; 0.69)	x (0.25; 0.34)	x (0.07; 0.22)	x (0.22; −0.24)

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