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Dynamics of final felling volumes in oak stands of the Forest-Steppe of Ukraine

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A forecast is presented for the volumes of final felling for a period of 110 years in operational (commercial) oak forests of the Forest-Steppe, and for a period of 130 years for other categories of forests included in the final felling calculation. For the calculations, data from the PA "Ukrderzhlisproekt" database as of January1, 2022 were used. Calculations were performed for the 1st and 2nd age, normal, and rational allowable cut for stands of both seed and coppice origin. It was found that the most justified approach is rational allowable cut, which provides for harvesting timber only in mature stands. To achieve an even level of harvesting and a more balanced age-class structure, it is proposed to switch to the normal allowable cut.

The calculation of the final felling volumes is carried out by turnover of management sections, taking into account the age of maturity. Under the baseline scenario, the total area of oak forests and their distribution by forest categories were assumed to remain unchanged. At the same time, it is proposed to gradually replace coppice oak stands with seed-origin ones.

When applying the rational allowable cut, a normal allowable cut with gradual leveling of age distribution can be achieved from the 3rd calculation periods. It is proposed to set the age of felling of seed-origin oak stands in operational forests of site class I and higher at the age of 131–140 years, and for coppice-origin oak stands of site class II and higher at the age of 91–100 years. This will contribute to improving the dimensional and qualitative structure of the stands, enhancing their ecological and protective functions, as well as accelerating the alignment of the age structure in oak forests.

Key words: *maturity age; Quercus robur* L.*; normal allowable cut; rational allowable cut; forest use forecast*.

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Introduction.

Long-term forecasting of forest use dynamics under different forest management scenarios is important for informed planning of forest resource use. Such forecasting is carried out using mathematical models with a defined objective function and a system of constraints. In forest resource assessment models, the main goal is not only to predict the production of wood raw materials, but also to assess the impact of different felling intensity rates. Growth models are selected based on stand composition, origin, forest site conditions and natural zone. In models that considered individual tree growth, parameters of increment and mortality are specified (Packalen et al., 2014). These models do not predict the total level of felling, rather, they show the distribution of areas and growing stock by age classes and stand types for a given volume of felling, and indicate whether the achieved harvesting level can be maintained for a long time. Among the most widely used simulation models are ATLAS and RFF-TSM, as well as IIASA model and its modification, EFISCEN, which was developed for large-scale scenario analysis of European forest resources and has been applied in Ukraine (Schelhaas et al., 2004). Simulation makes it possible to forecast forest resources use under various scenarios, taking into account forest management strategies, as well as changes in forest areas and growth rates, including those caused by climate change. The state of forests is presented as a matrix describing the distribution of forest areas by age and growing stock classes. The EFISCEN model provides results for assessing the dynamics of forest resources, carbon balance and provision of environmental services at the European level (Lerink et al., 2023).

Using the EFISCEN Space model (Schelhaas et al., 2018), stand dynamics were analysed based on the National Forest Inventory (NFI) data, applying species-specific growth models that predict tree growth as a function of tree diameter and stand basal area. Thinning is modeled as the removal of trees of a given species within defined diameter classes, while mortality is modeled using parameters derived from repeated NFI measurement. The stand-dynamics models are implemented in the form of fixed transition ratios (by tree species and diameter classes) obtained from successive NFI cycles.

To calculate the volume of final felling, the 1st and 2nd age, normal (even-flow) allowable cut, as well as rational allowable cut by area are usually determined. In Ukraine, given the existing deficit of mature forest stands, rational allowable cut is considered the most acceptable. At the same time, it must be supported by the available growing stock of mature and overmature stands for at least a five-year planning period, and during the next 5 years by stands that reach maturity within that interval. The methodology for calculating the rational allowable cut was first developed by the Ukrainian forester V.K. Poliakov (1972) and was later advanced in the works of S.M. Kashpor, O.A. Girs (2010), O.A. Girs (2011), R.V. Sodolinskiy et al. (2014) and others.

The calculation of the final felling volumes is carried out by working circles of management sections. The current age of maturity applied in Ukrainian forests are not sufficiently differentiated in terms of stand productivity or origin. It has been proposed to increase the maturity age for oak stands of seed origin (Girs et al., 2018). Considering the need for accelerated replacement of coppice stands with seed-origin stands and obtaining higher-quality timber of categories B and C in operational forests, it is recommended to set the maturity age of oak coppice stands of site class II and higher at 91–100 years (Tkach et al., 2021).

Rotation age for oak stands in Czech Republic is 100–180 years and in Slovak republic, it is 120–160 years. At the same time, the optimal rotation period of specific forest stands must be established in a differentiated manner, taking into account the economics of management and the diversity of ecosystems in accordance with the natural conditions (Hillayová et al., 2022).

According to the database “Forest fund”, as of January 1, 2022, stands dominated by common oak (*Quercus robur* L.) in the Forest-Steppe occupy more than 900 thousand hectares and perform important ecosystem functions, including sustainable use of timber stock, recreation, water balance regulation, climate protection and carbon storage (Ostrogović et al., 2019). When organizing forestry, determining the age of maturity and establishing the volume of forest use, it is necessary to take into account the balance between timber production, biodiversity and socio-cultural functions (Löf et al., 2016). Optimised forest-use planning for the Forest-Steppe as a whole enables a more even distribution of timber harvesting over time and makes it possible to increase the allowable cut by 15-20% (Girs, 2011).

The purpose of this study is to forecast the volumes of final felling in the Forest-Steppe over a full felling cycle, by economic sections of oak forests. For calculations under the baseline scenario, the total area of oak forests and their distribution across forest categories were assumed to remain unchanged.

Objects and methods.

The object of the research comprised all oak stands of the Forest-Steppe included in the operational management. Calculations based on the current "Methodology for determining the allowable cut" (Methodology ..., 2000) were performed for the oak operational forests of the Forest-Steppe, as well as other categories of forests included in the calculation of the final felling.

For the calculations, data from the PA "Ukrderzhlisproekt" database as of January 1, 2022 were used to compile the distribution of areas and growing stock of oak stands by age classes and quality by two economic parts: operational forests and forests with restricted forest use. For the convenience, the information on the distribution of area and growing stock by age classes was grouped by management sections and differentiated according to the maturity age for final felling, taking into account stand productivity and origin (seed and coppice). Using a software tool developed at the Department of Forest Mensuration and Forest Management of the National University of Life and Environmental Sciences of Ukraine, the following indicators were calculated for oak management sections: normal (even), 1st and 2nd age allowable cut, and rational allowable cut.

Results.

For the oak management sections of seed-origin in operational forests, normal (uniform) allowable cut in the first calculation period amounts to 2331.0 ha, 1st age – 2790.3 ha, 2nd age – 3275.3 ha, and rational allowable cut – 3147.1 ha. The rational allowable cut is calculated over 11 periods (Table 1).

Table 1. **Rational allowable cut for the oak management sections of the operational forests of the Forest-Steppe (seed origin)**

Age class	Area, ha	Accumulated area, ha	Calculation period	Allowable cut	Area of next period, ha
I	11157,3	256413,5	11	1115,8	5578,8
II	21638,3	245256,2	10	2339,1	17812,5
III	13134,1	223617,9	9	1147,7	7651,2
IV	10967,0	210483,8	8	1096,6	5483,1
V	11179,3	199516,8	7	1107,4	5590,1
VI	24573,8	188337,5	6	1787,6	12286,8
VII	46299,0	163763,7	5	4170,7	29420,0
VIII	33757,1	117464,7	4	3375,8	16879,0
IX	37181,9	83707,6	3	3905,5	22126,9
X	30110,1	46525,7	2	3011,0	15055,0
XI	16415,6	16415,6	1	3147,1	16415,6

The accumulated areas are calculated as follows: in the last row, the total area of all mature and overmature stands is recorded (S_{XI} = 16415.6 hectares), in the preceding row, the area of stands that will reach maturity within the next 10-year period is added – $S_{XI} + S_X$ = 46525.7 hectares. After 20 years, the accumulated area will amount to 83707.6 hectares, and after 100 years it will encompass the entire 256413.5 hectares of the working circle. In the second period of calculation, the “areas transition” is carried out taking into account the volumes of forest regeneration (31471 ha in age class I) and the remaining mature stands in age class XI (46525.7 – 31470.7 = 15055.0 ha). Age class I conventionally also includes unclosed forest crops. Subsequent calculations for the remaining periods over the entire felling cycle are performed in the same manner (Table 2).

Table 2. **Dynamics of the calculated allowable cut and the “area transition” for the oak management section of operational forests (seed origin)**

Calculation period	Area of forest stands per age classes, ha										
	I	II	III	IV	V	VI	VII	VIII	IX	X	≥ XI
1	11157,3	21638,3	13134,1	10967,0	11179,3	24573,8	46299,0	33757,1	37181,9	30110,1	16415,6
2	31470,7	11157,3	21638,3	13134,1	10967,0	11179,3	24573,8	46299,0	33757,1	37181,9	15055,0
3	30110,0	31470,7	11157,3	21638,3	13134,1	10967,0	11179,3	24573,8	46299,0	33757,1	22126,9

Table 2 (continued)

Calculation period	Area of forest stands per age classes, ha										
	I	II	III	IV	V	VI	VII	VIII	IX	X	≥ XI
4	39005,0	30110,0	31470,7	11157,3	21638,3	13134,1	10967,0	11179,3	24573,8	46299,0	16879,0
5	33758,0	39005,0	30110,0	31470,7	11157,3	21638,3	13134,1	10967,0	11179,3	24573,8	29420,0
6	41707,0	33758,0	39005,0	30110,0	31470,7	11157,3	21638,3	13134,1	10967,0	11179,3	12286,8
7	17876,0	41707,0	33758,0	39005,0	30110,0	31470,7	11157,3	21638,3	13134,1	10967,0	5590,1
8	11074,0	17876,0	41707,0	33758,0	39005,0	30110,0	31470,7	11157,3	21638,3	13134,1	5483,1
9	10966,0	11074,0	17876,0	41707,0	33758,0	39005,0	30110,0	31470,7	11157,3	21638,3	7651,2
10	11477,0	10966,0	11074,0	17876,0	41707,0	33758,0	39005,0	30110,0	31470,7	11157,3	17812,5
11	23391,0	11477,0	10966,0	11074,0	17876,0	41707,0	33758,0	39005,0	30110,0	31470,7	5578,8

In the oak management section of operational forests of seed origin, the rational allowable cut, due to the pronounced unevenness in the age-class distribution of stands, reaches its maximum (4,170.7 ha) in the fifth calculation period, followed by a substantial decrease to 1,115.8 ha. Therefore, to achieve an even level of timber harvesting and a more balanced age-class structure, it is proposed to proceed to the normal allowable cut starting from the third calculation period.

Calculations for the oak management section in coppice-origin stands are performed according to the same principle (Table 3).

Table 3. **Dynamics of the calculated allowable cut and the "area transition" for the oak management section of operational forests (coppice origin)**

Calculation period	Allowable cut, ha	Area of forest stands per age classes, ha										
		I	II	III	IV	V	VI	VII	VIII	IX	X	≥ XI
1	940,0	35,3	20,5	13,3	61	33,7	229,4	847,2	1702	3767,5	4864,1	6968,3
2	431,6	2400	35,3	20,5	13,3	61,0	33,7	229,4	847,2	1702	3767,5	2432,4
3	273,5	316	2400	35,3	20,5	13,3	61,0	33,7	229,4	847,2	1702	1883,9
4	127,6	735	316	2400	35,3	20,5	13,3	61,0	33,7	229,4	847,2	851,9
5	53,9	276	735	316	2400	35,3	20,5	13,3	61,0	33,7	229,4	424,1
6	13,1	39,0	276,0	735,0	316,0	2400,0	35,3	20,5	13,3	61,0	33,7	114,5
7	3,4	31,0	39,0	276,0	735,0	316,0	2400,0	35,3	20,5	13,3	61,0	17,2
8	5,1	14,0	31,0	39,0	276,0	735,0	316,0	2400,0	35,3	20,5	13,3	44,2
9	1,3	11,0	14,0	31,0	39,0	276,0	735,0	316,0	2400,0	35,3	20,5	6,5
10	3,2	3,0	9,0	14,0	31,0	39,0	276,0	735,0	316,0	2400,0	35,3	16,0
11	3,9	2,0	3,0	9,0	14,0	31,0	39,0	276,0	735,0	316,0	2400,0	19,3

In this case, the long-term objective is the gradual replacement of coppice stands with seed-origin stands. For these calculations, the rational allowable cut is applied. In the first calculation period, it amounts to 940.0 ha in operational forests.

Discussion.

Under the implementation of the proposed maturity ages (131–140 years for seed-origin oak stands of site class I and higher in operational forests), the decrease in the allowable cut during the first calculation period will amount to 30% due to the depletion of the operational stock. In the second period, this reduction is almost fully compensated. By area, the allowable cut reaches the normal level in the third period, while by growing stock the calculated allowable cut will exceed that obtained under the current maturity ages.

In forests with a restricted forest use regime for seed-origin oak stands of site class III and higher, the estimated rational allowable cut is 366.2 ha, normal allowable cut – 1,174.9 ha. From the fifth calculation period, it is possible to use normal allowable cut. and 316.4 ha for other forest categories included in the calculation of final felling.

In coppice-origin stands of site class II and higher, the estimated rational allowable cut is 316.5 ha, normal allowable cut - 365.4 ha. From the third calculation period, it is possible to use normal allowable cut. For other categories of forests included in the calculation of final felling, the corresponding values are 1174.4 ha, 418.7 ha, 838.9 ha and 366.2 ha, respectively.

With the introduction of the proposed maturity ages, it is expected that 16.8 thousand hectares of low-productivity oak forests of coppice origin will be harvested within a period of 40 years and subsequently replaced with seed-origin oak stands. An analysis of the estimated allowable cut showed that under the proposed maturity ages, it will increase by more than 1.5 times in the first 10 years compared to the current levels, and by 1.4 times over a 40-year period.

The proposed maturity age for coppice-origin oak stands in the Forest-Steppe within operational forests is 91–100 years for stands of site class II and higher, and 71–80 years for stands of site class III and lower, taking into account the dynamics of timber quality. This will contribute to improving the qualitative characteristics of the wood and will accelerate the alignment of the age structure of oak forests. Under the implementation of the proposed maturity ages, an improvement in the ecological and protective functions of the stands is also expected (Tkach et al., 2021). Similar conclusions were also made by O.A. Girs (2011), predicting the volume of wood resources exploitation in oak forests of coppice origin in Polissia and the Forest-Steppe of Ukraine.

The economic assessment of the value of oak wood stocks in Kharkiv and Chernihiv regions by natural zones confirms the general trend toward an increase in value at proposed maturity ages compared to current ones. Differentiation of maturity ages by stand origin and productivity (site classes) for oak stands significantly affected the distribution of stand areas and growing stocks, the commodity and assortment structure of wood, which would have a positive effect on the value of wood stocks (Torosov et al., 2020).

Conclusions.

1. For oak management section in the Forest-Steppe, the most appropriate is the use of rational and normal allowable cut, which allows for the gradual equalization of forest use and age structure. We propose calculating allowable cut based on aggregated management section, which will increase the use of forest resources.

2. For the oak management section of seed-origin in operational forests, normal (uniform) allowable cut in the first calculation period amounts to 2331.0 ha and rational allowable cut – 3147.1 ha. The rational allowable cut, due to the pronounced unevenness in the age-class distribution of stands, reaches its maximum (4170.7 ha) in the fifth calculation period, followed by a substantial decrease to 1115.8 ha. Therefore, to achieve an even level of timber harvesting and a more balanced age-class structure, it is proposed to transition to the normal allowable cut starting from the third calculation period.

3. Despite the temporary decrease in the allowable cut in the first calculation period for seed stands, the proposed increase in the age of maturity for oak stands in operational forests of site classes I and higher to the age of 131–140 years will contribute to strengthening the ecological and protective functions of forests and obtaining a better dimensional and qualitative structure of stands.

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Conflicts of Interest.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Динаміка обсягів рубок головного користування в дубових деревостанах Лісостепу України

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Наведено прогноз обсягів рубок головного рубання на 110 років в експлуатаційних дубових лісах Лісостепу та на 130 років – для інших категорій лісів, що входять до розрахунку рубок головного користування. Для розрахунків використовували інформацію з бази даних ВО "Укрдержліспроект" станом на 01.01.2022. Розрахунки проводили для 1-ї та 2-ї вікових, нормальної і раціональної розрахункової лісосіки для деревостанів як насінного, так і вегетативного походження. Встановлено, що найбільш виправданим підходом є раціональна розрахункова лісосіка, яка передбачає заготівлю деревини лише у стиглих деревостанах. Для досягнення рівномірного рівня рубок та збалансування вікової структури пропонується поступово переходити до нормальної розрахункової лісосіки.

Розрахунок обсягів рубок головного користування здійснено за господарськими секціями з урахуванням віку стиглості. За базовим сценарієм, загальна площа дубових лісів та їхній розподіл за категоріями лісів передбачалися незмінними. Водночас пропонується поступово замінювати паростеві дубові насадження насінними.

Для дубової господарської секції експлуатаційних лісів насінного походження нормальна розрахункова лісосіка в першому розрахунковому періоді становить 2331,0 га, 1-ша вікова – 2790,3 га, 2-га вікова – 3275,3 га, а раціональна розрахункова лісосіка – 3147,1 га. Раціональна розрахункова лісосіка через виражену нерівномірність у розподілі деревостанів за класами віку досягає свого максимуму (4170,7 га) у п'ятому розрахунковому періоді, після чого суттєво зменшується – до 1115,8 га. Тому, для досягнення рівномірного рівня заготівлі та більш збалансованої структури за віковими групами, пропонується перейти до нормальної розрахункової лісосіки, починаючи з третього розрахункового періоду.

У лісах з обмеженим режимом лісокористування для дубових насаджень насінного походження III класу бонітету та вище розрахункова раціональна розрахункова лісосіка становить 366,2 га, нормальна розрахункова лісосіка – 1174,9 га. З п'ятого розрахункового періоду можливе використання нормальної розрахункової лісосіки.

У дубовій господарській секції експлуатаційних лісів вегетативного походження II класу бонітету та вище раціональна розрахункова лісосіка становить 316,5 га, нормальна розрахункова лісосіка – 365,4 га. Починаючи з третього розрахункового періоду, можна використовувати нормальну розрахункову лісосіку з поступовим вирівнюванням вікового розподілу. Для інших категорій лісів, що включаються до розрахунку рубок головного користування, відповідні значення становлять 1174,4, 418,7, 838,9 та 366,2 га відповідно.

Пропонується встановити вік рубки дубових насаджень насінного походження в експлуатаційних лісах I класу бонітету і вище на рівні 131–140 років, а для дубових насаджень вегетативного походження II класу бонітету і вище – на рівні 91–100 років. Це сприятиме покращенню розмірної та якісної структури насаджень, підвищенню їхніх екологічних і захисних функцій, прискоренню вирівнювання вікової структури в дубових лісах.

Ключові слова: віки стиглості; *Quercus robur* L.; нормальна лісосіка; раціональна лісосіка; прогноз лісокористування.

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