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The productivity of oak stands in the Tsumanska Pushcha of Kivertsi National Natural Park

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Abstract

Today, the unique highly productive pine-oak and hornbeam-oak stands in Volynsk Polissia have been preserved in separate areas of the Tsumanska Pushcha Kivertsi National Nature Park (NNP) and need protection, regeneration and study of their condition and productivity at various stages of development. The objects of research were pine-oak and hornbeam-oak stands growing in different types of forests of the NNP. Forest management materials of the park for 2018 and typological analysis methodology were used for the study of the stands. The distribution of stands according to age classes and predominant species and stand density was carried. It was determined that productivity of stands with oak participation and forest typological potential in different types of forest is used by 82%–91%. In the wet and fresh hornbeam-oak-pine fairly fertile forest site type and wet hornbeam fairly fertile oak forest type the average actual volume of stands reaches the greatest value in the ninth age class (382, 350 and 309 m^3 ha^{-1}). From the tenth age class and older there is a decrease of the average actual stand stock. Mature and overmature pine-oak stands of a wet fairly fertile site type are characterised by low productivity. As a result of non-observance of the formation and improvement felling rules of forests, secondary stands were formed in the NNP. The share of secondary stands in the most widespread forest types is 66%–78%. Pine, red oak, birch and alder dominate in the secondary stands. Spruce, aspen, hornbeam, ash, linden, larch and acacia grow in small forest areas. Secondary stands of hornbeam fertile oak forest type are formed by middle-aged red oak and fir. In order to increase the productivity and stability of stands with the participation of English oak in the conditions of the NNP, it is necessary to transform secondary stands into primary stands. The study of the features of the formation of the primary stands based on the principles of close to nature forestry is a prospect for further research.

Key words

actual productivity, age class, primary tree stand, secondary tree stand, stand volume, type of forest

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Introduction

The Tsumanska Pushcha Kivertsi National Nature Park (NNP) was established on 22 February 2010 according to the Decree of the President of Ukraine No. 203/2010. Its total area is 33475.34 hectares of land for various purposes. The unique pine and oak forests make up the genetic fund of wildlife in Volyn Polissya, and the main task of the park is to preserve and restore them, ensuring the ecological balance in the region (Andrienko et al. 2004).

The territory of the NNP is the largest area of broadleaf forests on the Ukrainian plain. A significant area of the park is occupied by rather rich forest vegetation conditions, where oak and hornbeam-oak forests grow. They are the symbol of the Tsumanska Pushcha vegetation and the greatest ecological and scientific importance. Oak and hornbeam-oak forests had dominated the vegetation cover of the area before the intensive human use of forests began. In recent decades, in addition to oak (*Quercus robur* L.) and hornbeam (*Carpinus betulus* L.), birch (*Betula pendula* Roth) and alder (*Alnus glutinosa* (L.) Gaerth.) have been growing in large areas of the Tsumanska Pushcha forests. Aspen (*Populus tremula* L.), sharp-leaved maple (*Acer platanoides* L.), scots pine (*Pinus sylvestris* L.), and heart-leaved linden (*Tilia cordata* Mill.) intermix with the main tree species and form the secondary tree stands (Blazhko 2000, Andriienko et al. 2004).

The sustainability and productivity of oak stands are influenced by their geographical location within the range. The best conditions for the growth of oak stands in Ukraine are located in the central part of the oak forests area, and its territorial centre is in the Western forest-steppe region of Ukraine (Hensiruk 1992). In the conditions of Right-Bank Polissia of Ukraine, according to Ivanyuk (2021), the share of common oak in the mixed stands is 30%–90% of the stand. The age structure of oak stands in the Right-Bank Polissia is uneven. Dominant are the middle-aged stands, which make up 56.7%.

The state of the oak forests of the Kivertsi NNP is poorly investigated. Therefore, the study of the state of forests in protected areas is an integral part of the scientific tasks of the state nature reserve fund. To solve this problem, it is necessary to study their actual and potential productivity, types of stands and silvicultural efficiency of using soil and climatic conditions in specific forest types. Establishing investigation of the actual and potential productivity of stands in different forest types and stand age classes will allow to improve management in the plantations with oak participation and to develop measures to increase their productivity and sustainability.

The object of the study is the stands with oak participation growing in the Tsumanska Pushcha National Park. The subject of the study is the actual and potential productivity of stands, types of stands in the predominant pine-oak and oak forests of the park.

The aim of the study is to investigate the actual and potential productivity of pine-oak and oak stands in the dominant forest types of the National Park, as well as the forestry rationality of using soil and climatic conditions.

To achieve this goal, the following main objectives of the study were defined: to assess the current state and productivity of plantations with oak participation, to analyse the indicators of their use of forest vegetation potential and to find out changes in the primary stands.

Material and methods

To study the productivity of stands, we used the materials of the NNP forest management (2018) according to which oak stands are formed in the following forest types: wet hornbeam-oak-pine fairly fertile site type (68% of the total area), fresh hornbeam-oak-pine fairly fertile site type (17%), wet hornbeam fairly fertile oak forest type (13%), fresh hornbeam fairly fertile oak forest type (1.1%), wet hornbeam fertile oak forest type (0.04%) and fresh hornbeam fertile oak forest type (0.7%).

Forest stands based on similar natural features (mainly vegetation and growth conditions) were assigned to a certain type of forest. For this purpose, the forest typological classification scheme used in Ukraine (Pogrebnyak 1955) was used.

To assess the productivity of the stands, we used the methodology of typological analysis, which involves their distribution within age classes, determination of the maximum natural and actual productivity, as well as the distribution of stands by type and stand density in order to identify quantitative and qualitative changes in the

primary stands (Ostapenko and Gerushinskij 1975). Calculations of potential reserves of primary stands were carried out using regulatory and reference materials for forest stand inventory (Shvidenko et al. 1987).

Results

The results of the analysis of stand productivity of the predominant forest type of the Kivertsi NNP (a wet hornbeam-oak-pine fairly fertile site type) are presented in Table 1.

According to these data, the stands with oak participation achieve relatively high productivity. The average actual stock of stands in this forest type increases up to the ninth age class, reaching a maximum value of 382 m^3ha^{-1}. In the stands of the tenth age class, there is a decrease in their average volume to 315 m^3ha^{-1}. The average actual stock of mature and overmature stands aged 121–180 years ranges from 269 to 305 m^3ha^{-1}. The average actual volume of old oak stands (181 years and older) is 314 m^3ha^{-1}.

In a fresh hornbeam-oak-pine fairly fertile site type, the average actual stand volume reaches a maximum of 350 m^3ha^{-1} and is much lower than it is in wet conditions (Tab. 2).

In mature and overmature stands of fresh forest conditions, the average actual volume is 286–336 m^3ha^{-1} and 302–305 m^3ha^{-1}, respectively. In this forest type of fresh conditions the average actual increment of stands is much lower as well and is generally 3.1 m^3ha^{-1}. In wet conditions, it is 3.9 m^3ha^{-1} (Tab. 1).

In fresh forest conditions, the average actual increment reaches its highest value in stands of the seventh age class (5.0 m^3ha^{-1}), and in the wet conditions, the highest value is observed in the sixth age class stands (4.7 m^3ha^{-1}). A more intensive decrease in the average actual volume and increment of stands under fresh conditions is due not only to moisture but also to the unequal composition and structure of stands in different

Table 1. The actual and potential productivity of wet hornbeam-oak-pine fairly fertile site type stands

Group age, years	General area, ha	Actual volume on the whole square, thousand m^3	Average actual volume, m^3ha^{-1}	Average actual increment, m^3ha^{-1}	The existing typological standard		Potential volume, thousand m^3	The use of typological potential, %
					average increment, m^3ha^{-1}	volume, m^3ha^{-1}		
6–10	328.3	2.2	7	0.7	2.5	25	8.2	27
11–20	517.1	24.8	48	3.2	3.3	50	25.9	96
21–30	831.8	72.3	87	3.5	3.6	90	74.9	97
31–40	819.4	112.0	137	3.9	4.0	140	114.7	98
41–50	658.6	119.3	181	4.0	4.2	187	123.2	97
51–60	1,164.1	299.2	257	4.7	4.2	230	267.7	112
61–70	1,053.6	295.0	280	4.3	4.2	270	284.5	104
71–80	360.7	115.0	319	4.3	4.1	306	110.4	104
81–90	276.5	105.6	382	4.5	4.0	340	94.0	112
91–100	174.7	55.0	315	3.3	3.9	369	64.5	85
101–110	160.4	49.8	310	3.0	3.8	394	63.2	79
111–120	107.3	35.4	330	2.9	3.6	416	44.6	79
121–140	153.0	45.0	294	2.3	3.5	435	66.6	68
141–160	252.9	68.1	269	1.8	3.3	451	114.1	60
161–180	411.2	125.6	305	1.8	3.1	464	190.8	66
181– to >	233.9	73.4	314	1.7	2.9	462	108.1	68
Average	–	–	213	3.9	3.6	285	–	91
Total	7,503.5	1 597.7	–	–	–	–	1,755.4	–

Table 2. The actual and potential productivity of fresh hornbeam-oak-pine fairly fertile site type stands

Group age, years	General area, ha	Actual volume on the whole square, thousand m^3	Average actual volume, m^3ha^{-1}	Average actual increment, m^3ha^{-1}	The existing typological standard		Potential volume, thousand m^3	The use of typological potential, %
					average increment, m^3ha^{-1}	volume, m^3ha^{-1}		
1–10	45.0	0.2	4	0.4	2.5	25	1.1	18
11–20	70.3	2.2	31	2.1	3.3	50	3.5	63
21–30	64.4	4.4	68	2.7	3.6	90	5.8	76
31–40	59.4	9.4	158	4.5	4.0	140	8.3	113
41–50	91.1	16.9	186	4.1	4.2	187	17.0	99
51–60	112.1	27.6	246	4.5	4.2	230	25.8	107
61–70	95.7	30.9	323	5.0	4.2	270	25.8	120
71–80	55.6	18.3	329	4.4	4.1	306	17.0	108
81–90	57.1	20.0	350	4.1	4.0	340	19.4	103
91–100	11.9	4.1	345	3.6	3.9	369	4.4	93
101–120	37.2	12.5	336	3.1	3.8	394	14.7	85
121–140	14.0	4.0	286	2.2	3.6	416	5.8	69
141–160	93.1	28.4	305	2.0	3.3	435	40.5	70
161–180	278.8	84.3	302	1.8	3.2	464	129.4	65
181– to >	35.2	10.7	304	1.6	3.0	451	15.9	67
Average	–	–	238	3.1	3.7	278	–	82
Total	1,120.9	273.9	–	–	–	–	334.4	–

age classes, which is a consequence of intensive felling in previous years.

Within the NNP, the most intensive forestry was carried out in hornbeam-oak plantations, where the least productive stands are those which grow in the wet hornbeam fairly fertile oak site type. The average actual volume in these stands increases up to the ninth age class and amounts to only 309 m^3ha^{-1}, and in the tenth age class, it decreases to 253 m^3ha^{-1}. The average actual increment of stands reaches its maximum value (5.4 m^3ha^{-1}) at the age of 31–40 years, which can be explained by the presence of high-density stands in this forest type (Tab. 3).

The possibilities of forest site conditions in different types of forests are insufficiently used. For example, in the predominant forests types of fresh and wet fairly fertile site type, the degree of use of the typological potential by pine-oak stands is 82% and 91%, respectively (Tab. 1 and 2).

The hornbeam-oak stands of the wet fairly fertile site type use the forest vegetation potential by 90% (Tab. 3). Mature and overmature stands are characterised by the lowest indices of forest vegetation potential utilisation. In mature stands aged 121–160 years, it is 60–73%, and in overmature stands aged 161–200 years, it is 56–60%. The overmature hornbeam-oak stands of wet hornbeam fairly fertile oak forest type use potential forest conditions only by 56% and are characterised by the lowest productivity.

The oak stands of the park growing in other forest types in small areas are mainly middle-aged stands. The average actual volume of wet and fresh hornbeam and oak stands is 313 and 310 m^3ha^{-1} (Tab. 4).

The reason for the relatively high average actual stand volume in these forest types is the absence of young (up to 20 years old) and pole-stage stands (21–40 years old) and the presence of middle-aged secondary stands (Tab. 5).

Thus, the forest-type potential is not used equally in different forest conditions and age classes. In overdensed young and middle-aged stands, forest vegetation conditions are used the best. In such stands of certain

Table 3. The actual and potential productivity of wet hornbeam fairly fertile oak forest type stands

Group age, years	General area, ha	Actual volume on the whole square, thousand m^3	Average actual volume, m^3ha^{-1}	Average actual increment, m^3ha^{-1}	The existing typological standard		Potential volume, thousand m^3	The use of typological potential, %
					average increment, m^3ha^{-1}	volume, m^3ha^{-1}		
1–10	36.2	0.2	6	0.6	2.5	25	0.9	22
11–20	75.6	2.4	32	2.1	3.3	35	2.6	92
21–30	76.0	6.3	83	3.3	3.6	80	6.1	103
31–40	50.9	8.1	188	5.4	4.0	126	4.8	150
41–50	97.4	19.6	203	4.5	4.2	174	15.2	116
51–60	141.3	33.0	230	4.2	4.2	221	33.6	104
61–70	167.7	41.6	248	3.8	4.2	264	45.9	94
71–80	24.1	7.4	307	4.1	4.1	302	7.3	101
81–90	27.5	8.5	309	3.6	4.0	335	9.2	92
91–100	28.8	7.3	253	2.7	3.9	363	10.5	70
101–120	32.0	9.9	309	2.8	3.8	390	12.5	79
121–140	32.8	9.7	298	2.3	3.6	410	14.0	73
141–160	14.7	4.5	306	2.0	3.4	430	6.3	71
161–180	23.2	7.0	288	1.7	3.3	446	11.0	68
181– to >	20.8	5.4	257	1.4	3.2	462	9.6	56
Average	–	–	202	3.7	3.7	271	–	90
Total	849.0	171.2	–	–	–	–	189.5	–

Table 4. The results of a typological analysis of oak forests

Index type forest	Medium wood reserve, m^3ha^{-1}	Using typological potential, %	Breakdown of wood stand area by type and by completeness, ha/%						Total, ha/%
			indigenous			derivatives			
			1.0–0.8	0.7–0.5	≤0.4	1.0–0.8	0.7–0.5	≤0.4	
C_3-hoP	213	91	473.1 / 6	1270.6 / 17	39.1 / 0.5	2 893.4 / 39	2 792.9 / 37	34.4 / 0.5	7 503.5 / 100
C_2-hoP	301	82	253.0 / 5	775.0 / 16	28.6 / 0.5	2 043.0 / 43	1 694.1 / 35	24.9 / 0.5	4 818.6 / 100
C_3-hO	202	90	38.3 / 5	243.0 / 29	–	285.6 / 33	273.6 / 32	8.5 / 1	849.0 / 100
C_2-hO	231	90	2.2 / 2	25.9 / 28	1.6 / 2	3.2 / 3	61.9 / 65	–	94.8 / 100
D_3-hO	313	93	–	0.8 / 33	–	–	–	1.6 / 67	2.4 / 100
D_2-hO	310	118	–	1.8 / 4	–	–	43.3 / 96	–	45.1 / 100

Note: C_3-hoP, wet hornbeam-oak-pine fairly fertile site type; C_2-hoP, fresh hornbeam-oak-pine fairly fertile site type; C_3-hO, wet hornbeam fairly fertile oak forest type; C_2-hO, fresh hornbeam fairly fertile oak forest type; D_3-hO, wet hornbeam fertile oak forest type; D_2-hO, fresh fertile oak forest type; the numerator is the area in hectares; the denominator is the percentage.

Table 5. Distribution of stands with the participation of oak according to the dominant species

Types of stands	Distribution of stands by forest type, ha/%					
	C_3-hoP	C_2-hoP	C_3-hO	C_2-hO	D_3-hO	D_2-hO
Primary	1,780.0/24	1,055.1/22	281.3/33	29.7/31	0.8/33	1.8/4
Secondary	5,724.7/76	3,763.5/78	567.7/67	65.1/69	1.6/67	43.3/96
– spruce forests	126.7/2	45.6/1	1.6/0.2	13.7/14	1.6/67	5.9/13
– pine forests	1,794.7/24	3,230.9/67	31.5/4	5.2/6		
– oak woods	1,743.9/23	283.3/6	145.4/17	20.6/22		34.4/76
– birch forests	1,332.0/17	118.0/2	188.9/22	7.1/8		3.0/7
– alder forests	583.6/8	16.1/0.3	105.0/12	2.2/2		
– aspen forests	50.7/1	35.7/0.7	22.8/3	13.5/14		
– hornbeam forests	35.3/0,5	12.3/0.2	57.0/7	2.8/3		
– juniper forests	7.1/0.1	0.5/0.1	5.1/0,6			
– ash forests	29.1/0.6	2.4/0.1	5.5/0,6			
– poplar forests	0.6/0.4	0.9/0.1	4.6/0,5			
– maple forests	4.3/0.1	3.5/0.1				
– larch forests	4.2/0.1	12.6/0.3				
– acacia forests	11.3/0.2	1.7/0.1	0.3/0,1			
Total, ha/%.	7,503.5/100	4,818.6/100	849.0/100	94.8/100	2.4/100	45.1/100

age classes, the degree of utilisation of the typological potential exceeds 100%. The reason for the formation of stands of different productivity is obviously forest management deficiency made during forest restoration and untimely carried out the first tending felling. The decline in the mature stands volume can be explained by the intensive use of thinning and sanitation felling, which is also intensively carried out in stands of different ages. Frequent tending and sanitation felling in stands cause a decrease in stand productivity.

The division of forest stands by types and stand density showed that the derivative and high-density stands prevail in the NNP forests. The proportion of secondary stands in the most common forest types is 66–78%, the share of high-density stands is 33–43% and middle-density stands is 32–37% (Tab. 4). The stands of fresh hornbeam oak growing on the area of 41.5 ha are middle-density secondary oak and spruce forests (Tab. 4 and 5). Primary stands formed in the most common forest types on 22–34% of the area are predominantly middle-density stands (16–29%), while high-density stands grow only on 2–6% of the area.

The secondary stands of the park are formed by 13 tree species (Tab. 5). The largest number of them grows in the conditions of fairly fertile site type. The most widespread wet hornbeam-oak-pine fairly fertile site type is dominated by pine (*Pinus sylvestris* L.), oak (*Quercus robur* L.), red oak (*Quercus rubra*), birch (*Betula pendula* Roth) and alder (*Alnus glutinosa* (L.) Gaerth.) forests, which occupy 24, 23, 17 and 8% of their forest type area. In the fresh hornbeam-oak-pine fairly fertile site type, there are mainly pure pine (*Pinus sylvestris* L.) – 67%, oak (*Quercus robur* L.) – 6% and birch (*Betula pendula* Roth) – 2% forests. Smaller areas (0.1–2.0%) are occupied by spruce (*Picea abies* (L.) Karsten.), aspen (*Populus tremula* L.), hornbeam (*Carpinus betulus* L.), ash (*Fraxinus excelsior* L.), maple (*Acer platanoides* L.), lime (*Tilia cordata* Mill.), larch (*Larix decidua* Mill.) and acacia (*Robinia pseudoacacia* L.) forests. The wet hornbeam fairly fertile oak forest type is dominated by birch (*Betula pendula* Roth) – 22%, oak (*Quercus robur* L.) – 17% and alder (*Alnus glutinosa* (L.) Gaerth.) – 12% forests, and the fresh understory by oak (*Quercus robur* L.) – 22%, spruce (*Picea abies* (L.) Karsten.) – 14% and aspen – 14% forests. The secondary stands of the fresh fertile oak forest type are 76% formed by red oak (*Quercus rubra* L.) and English oak (*Quercus robur* L.) and 17% by spruce (*Picea*

abies (L.) Karsten.) forests. The smallest area in the park (2.4 ha) is occupied by a wet hornbeam fertile oak forest type, 67% of which is covered by secondary spruce forests (*Picea abies* (L.) Karsten.). The predominance of secondary high-density stands on the territory of the park, which leads to an increase in the actual productivity of plantations and the degree of use of the typological potential in certain age classes of the prevailing forest types, indicates a violation of the qualitative composition of forest stands.

Discussion

The productivity and growth of oak stands are significantly influenced by forest site conditions, soil trophicity and the level of moisture in the edftope. In the Right-Bank Polissia, plantations with an admixture of common oak are found in almost all edatopes, but the majority of their areas are confined to wet (62.1%) and fresh (21.1%) hygrotopes in the fairly fertile site type conditions (Ivaniuk 2021).

In recent decades, oak forests growing on the territory of Ukraine have been affected by adverse natural and anthropogenic factors. Their productivity and biological stability, as well as the area of natural forests within the oak range, are decreasing (Didenko and Vlasov 2006). According to S.A. Hensiruk and other authors (Hensiruk 1992; Hensiruk et al. 1998), the main reason for the degradation of oak forests is their intensive exploitation and insufficient attention to their natural renewal. These factors have led to the formation of plantations with a simplified structure and form, as well as to the intensive thinning of oak stands and appearance of secondary stands (Litopys pryrody… 2021; Mazepa and Novak 2005).

The anthropogenic impact on oak stands is enhanced by air and soil pollution caused by harmful emissions from industrial enterprises and motor transport. Oak trees growing in the zone affected by air pollution are mostly moderately or severely damaged. In terms of age, mature and overmature oak stands are the most damaged, and their productivity is the lowest (Mazepa and Novak 2005).

The analysis of literary sources on the study of the current state of oak plantations showed that their quality and age structure is disturbed. The areas of mature and overmature stands are decreasing, and the areas of secondary stands are increasing. Therefore, the formation of stable and productive oak forests, their protection and reproduction are important issues, which require further study. Determination the actual and potential productivity of stands in different forest types and age classes will make it possible to justify the choice of management direction and to develop silvicultural measures to increase oak stands productivity and sustainability.

The productivity of oak stands and their use of forest vegetation conditions in different regions of Ukraine has been studied by many researchers (Ivaniuk 2021; Mazepa and Novak 2005; Novak 2005; Matusiak 2019; Tkach et al. 2018; Rumiantsev and Kobets 2020; Musiienko et al. 2021; Lunachevskyi and Rumiantsev 2020). In Western Polissia, the current state of plantations with oak trees participation has been studied only by some scientists (Hensiruk et al. 1998; Ivaniuk 2021). It has been confirmed that in the NNP, as in other regions of Ukraine, there is a decrease in the productivity of pine-oak and oak stands, and mature and overmature stands are characterised by the lowest rates of the typological potential use (Ivaniuk 2021; Matusiak 2019; Tkach et al. 2018; Rumiantsev and Kobets 2020; Musiienko et al. 2021; Lunachevskyi and Rumiantsev 2020).

Conclusions

The pine-oak and oak forests of the Tsumanska Pushcha NNP are transformed due to the impact of a number of natural and anthropogenic factors. They have experienced a decline in productivity and replacement of primary stands by secondary ones. In the dominant forest types of the park including wet and fresh hornbeam-oak-pine fairly fertile site type and wet hornbeam fairly fertile oak forest, type the average actual volume of stands is 213, 301 and 202 m^3ha^{-1}, respectively, and the potential of forest vegetation conditions is used by 91, 82 and 90%. The greatest productivity in these forest types is achieved by stands in the ninth age class, and from the tenth age class onwards, the average actual volume decreases. The maximum value of the average actual volume of stands is reached at the age of 81–90 years in the wet fairly fertile site type conditions and amounts to 382 m^3ha^{-1}.

The hornbeam-oak stands of wet fairly fertile site type use the forest vegetation potential by 90%. The lowest rates of forest vegetation potential utilisation are characterised by mature and overmature stands. The overmature hornbeam-oak stands of the wet hornbeam fairly fertile oak forest type have the lowest productivity.

The forests of the NNP are dominated by secondary stands which are formed by thirteen tree species. The share of secondary stands in the most common forest types is 66%–78%. The predominant wet hornbeam-oak-pine fairly fertile site type includes pine, oak, birch and alder forests, which occupy 24, 23, 17 and 8% of the forest type area, respectively. Smaller areas (0.1%–2.0%) are occupied by spruce, aspen, hornbeam, ash, maple, larch and acacia forests.

Increasing the productivity and sustainability of stands in the conditions of the National Park is possible by the replacement of secondary stands into primary mixed forests with oak and pine participation. The formation of primary pine-oak and oak stands should be carried out depending on the types of forest by using conversion felling according to the selective forestry management system.

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