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Growth and formation of Scots pine stands in Eastern Polissia of Ukraine

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Abstract

The purpose of the research is to study the current state, features of growth and formation of Scots pine (*Pinus sylvestris* L.) stands in Eastern Polissia of Ukraine.

The structure of pine stands by origin, age, the density of stocking, site indices, forest types and health condition was analysed. Features of the formation of stands were studied at the permanent sample plots. Visual assessment of health condition, as well as signs of pest and disease damage of trees, other defects and external signs that caused stem defects was carried out. The age structure of pine stands was not optimal: there was an excess of mature stands and a lack of young stands. The health condition of mixed pine stands was relatively better than that of pure pine stands. Mixed pine stands were characterised by high biological resistance and accumulated significant wood stock under regular sylvicultural maintenance. The dynamics of forestry and evaluation indicators of reference pine stands were evaluated and comparison of their growth with stocked pine stands was performed.

Key words

Pinus sylvestris, age structure, health condition, reference stands

Introduction

Forests are an important component of the biosphere and perform various useful functions. The forest fund of Eastern (left-bank) Polissia, located in the north-eastern part of Ukraine, is about 700,000 ha (6.7% of the forest area of Ukraine). The average forest cover within parts of the Kyiv, Chernihiv and Sumy regions is 25.7% (Zhezhkun 2021), which is slightly less than optimal (32%) (Tkach 2012). The biggest forest areas of the region are managed by State Forestry Enterprises (SFEs) of the State Forest Resources Agency of Ukraine (53.3%) and local self-government bodies (32%).

The vegetation cover in the region formed in the process of a long evolution. Forests with a predominance of Scots pine (*Pinus sylvestris* L.) are the dominant plant formation. The formation of existing pine stands is associated with sylvicultural measures. During the 20th century, pine forests were intensively diluted by selective felling, exploited by excessive clear final cuttings. During the Second World War, large volumes of valuable wood in the region were felled down and exported. In 1950–1960, deforestation in Ukraine exceeded by 2 times the volume of the annual allowable cut (Hensiruk 2002). The area of pine stands of SFEs of the Chernihiv region (in Polissia part) was steadily decreasing: in 1939,

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it was 196.5 thousand hectares, in 1946, 192.4 thousand hectares and in 1962, 181.2 thousand hectares. The proportion of mature and overmature pine stands was 4.6% in 1939, 0.8% in 1946 and 0.8% in 1962 (Zhezhkun 2021). The anthropogenic impact caused transformation of forests and changes in the growth and formation of stands.

Tkachuk (2004), Aleksiyuk and Lakida (2012) and Matushevich (2013) studied the growth and formation of pine stands in different regions of Ukraine. The intensity of tree growth and the success of stand formation are influenced by changes in weather and climatic conditions. In recent years, due to global climatic changes, a decrease in growth intensity, weakening and decline in pine stands are observed (Borodavka et al. 2016; Gilliam 2016; Meshkova and Borysenko 2018; Hlasny 2019; Klein 2020; Reyna et al. 2020; Zhezhkun and Porochniach 2020). Therefore, in modern conditions, the study of the processes of growth and formation of pine stands is relevant.

The purpose of the research is to study the current state, features of growth and formation of Scots pine (*P. sylvestris* L.) stands in Eastern Polissia of Ukraine.

Material and methods

The total area of Scots pine stands of SFEs and their distribution by origin, age, the density of stocking, site indices and forest types were evaluated in the study region on the basis of the materials of stand-wise forest inventory (as of 01.01.2012).

To determine the forestry and evaluation indicators of stands, permanent sample plots (PSP) were laid, according to the methodology found in Sample plots of forest inventory (2006). To determine the structure of stands, a growth class according to Kraft was estimated for each sample tree. According to the health condition of stands, the trees were divided into six categories: I – without signs of weakening, II – weakened, III – severely weakened, IV – drying up, V – recently died and VI – died over a year ago (Sanitary rules 1995). Based on the number of trees of each species, the average weighted Craft class and the average health condition index (HCI) were calculated. Forestry and evaluation indicators of stands at PSP are given in Table 1.

Table 1. Forestry and evaluation indicators of pine stands on permanent sample plots

No PSP	Species composition	Age [years]	Avg H [m]	Avg DBH [cm]	Density of stocking		Number [pcs ha^{-1}]		Stock [m^3·ha^{-1}]
					abs. [m^2· ha^{-1}]	relative	total	pine	
	Forest crops 8PiSy2QuRo	5	1.6	1.0	0.3	–	4,408	3680	1
6-Bat	Natural regener. 10PiSy	5	1.0	–	0.1	–	9,140	9140	1
3-Bat	6PiSy4BePe + QuRo, PoTr	9	2.9	2.7	4.4	0.59	6,979	5521	13
5-Bat	10PiSy + BePe, PoTr, QuRo	10	3.8	3.7	10.2	1.02	11,279	9000	28
4-Shst	8PiSy1QuRo1PiAb + BePe, QuRu, SaCa	15	10.0	9.0	15.1	0.90	5,680	1776	90
2-Slb	9PiSy1BePe + PoTr, SaCa	20	11.1	11.3	20.4	0.69	2,342	1773	126
1-Krp	10PiSy + BePe	20	8.0	9.0	10.8	0.48	2,647	1542	52
1-Uzr	10PiSy + RoPs, BePe, PoTr, QuRo, PyCo, SaCa	38	20.4	26.3	29.2	0.74	1,011	490	274
1-Slb	10PiSy	44	21.2	2.2	37.5	0.83	786	786	376
1-Khlm	9PiSy1QuRo + AcPl, BePe, PoTr, FrEx, CaBe	62	27.8	29.5	37.4	0.82	711	488	443
2-Vld	9PiSy1BePe + AcPl, QuRo, PiAb, MaSy, TiCo	80	30.8	38.2	48.7	1.08	773	353	625
18-Slb	10PiSy + QuRo, BePe, SaCa	101	28.4	32.7	38.2	0.78	422	316	534
2-Sb	I layer 10PiSy + BePe	103	32.0	41.5	46.0	0.92	341	335	645
	II layer 10TiCo	103	16.8	14.6	16.5	0.48	983	–	139

PiSy – *Pinus sylvestris*, QuRo – *Quercus robur*, BePe – *Betula pendula*, PoTr – *Populus tremula*, PiAb – *Picea abies*, SaCa – *Salix caprea*, RoPs – *Robinia pseudoacacia*, PyCo – *Pyrus communis*, AcPl – *Acer platanoides*, FrEx – *Fraxinus excelsior*, CaBe – *Carpinus betulus*, MaSy – *Malus sylvatica*, TiCo – *Tilia cordata*, QuRu – *Quercus rubra*.

The reference plots included stands that contained more than eight units of Scots pine (80% of the growing stock of the stand), with the density of stocking being at least 0.8, without foci of pests, diseases and damage by forest fires. The research materials were processed using mathematical and statistical methods, particularly, regression and correlation analysis, using a standard package of computer programs in Microsoft Excel.

Results

In Eastern Polissia of Ukraine, stands dominated by Scots pine as of 01.01.2012 occupied 290.5 thousand hectares, or 66.4% of the land covered with forest vegetation. The total growing stock of pine forests was 99,087.9 thousand m^3. Pine stands of V–VIII classes of age 51–80 years prevailed. Such an age structure with a large proportion of middle-aged and mature pine stands is a result of considerable volumes of logging and consequent reforestation in the 1930–1960s. The area of pine stands of VIII and VII age classes occupied 79.7 and 46.0 thousand hectares (27.4% and 15.8%), respectively. Young stands covered 45.1 thousand hectares or 15.5% of the area of pine stands, which is slightly less than that in optimal age structure (Bilous et al. 2020). The decrease in the area of young pine forests in recent decades is associated with a decrease in the volume of final felling and the transfer of pine forests to the objects of the nature reserve fund. The proportion of young pine stands of the first age class is 3.3% and of the second class is 5.2%. Almost all young pine stands are of artificial origin, so the experience of reproducing pine stands of natural origin needs to be restored. Pine stands older than 101 years cover 9.8 thousand hectares (3.4%). Consequently, the distribution of pine stand areas by age classes and groups is uneven. A similar trend was found for all pine stands in Polissya, Ukraine (Tkachuk 2004; Alexciyuk and Lakida 2012; Matushevich 2013). Due to the unbalanced age structure of pine forests, it is now difficult to ensure the principles of sustainable forestry.

Pine stands of Eastern Polissia belong mainly to the following forest types (according to the classification of Alekseev–Pogrebniak, used in Ukraine) (Ostapenko and Tkach 2002): fresh, relatively poor oak–pine type (62.3%); fresh, poor pine (13.6%); fresh, relatively fertile lime–oak–pine (7.3%); wet, relatively poor oak–pine (7.2%) and fresh, relatively fertile hornbeam–oak–pine type (4.6%). These forest types are most common in moraine-zander and alluvial-zander landscapes.

Pine stands grow mainly in fresh and wet, relatively poor and relatively fertile forest site conditions and have high productivity. High-productive pine stands with site index I and higher occupy 243.5 thousand hectares (83.8%). The proportion of low-productive pine forests (site index classes IV and below) is only 0.3%. Stands with medium and high density of stocking prevail, while the area of low density of stocking is 5.1 thousand hectares or 1.8%.

Artificial pine stands predominate (81.9%) in the region. Average evaluation indicators of pine stands in Eastern Polissia are as follows: average age 63 years, average density of stocking 0.77, site index IA.9 and growing stock 341.1 $m^3 \cdot ha^{-1}$.

The average stock of stands is an integral indicator of productivity. It depends on the forest type, age, species composition, the density of stocking and other components and characteristics of stands. The average stock of pine forests at SFEs varies from 294.8 to 391.4 $m^3 \cdot ha^{-1}$ (25% difference). The stock of pine stands of artificial origin created by sowing seeds is 35 m^3 ha^{-1} (6%) larger at maturity, compared to that of seedlings planted (Zhezhkun and Demianenko 2021).

Discussion

Forest stands are formed after the closure of young trees' crowns. In pine, young growth in wet, relatively poor oak–pine stand of natural origin (composition 5PiSy-3PoTr2BePe + QuRo, AlGl, PiAb; located at comp. 5, subcomp. 19 Krasnokhutirske forestry subunit of the SE 'Novgorod-Siverskyi Forestry', Chernihiv region), created after clear felling in 2012; the total canopy closure is 0.4. The total number of trees in the young stand is 11.5 thousand stems ha^{-1} from it, pine trees – 5.4 thousand stems $\cdot ha^{-1}$. The incidence of pine trees is 93% (with regular distribution). Under such conditions, the ground vegetation and undergrowth are restored and the microclimate of a new stand is formed (Maslakov 1984; Ostapenko and Tkach 2002). Natural regeneration of pine belongs to the age group of 4–8 years (average age 5 years), with an average height of 0.7 m. Except for the average height, the young stand meets the quality as-

sessment standards in all indicators for transferring to forest-covered land (Bilous et al. 2020).

In 5-year-old forest plantations (PSP 6-Bat) created at the clear-cuts in fresh, relatively poor oak–pine forest type (the mixing scheme is five rows of PiSy and two rows of QuRo), the average height (1.6 m) and density (3.7 thousand trees ha^{-1}) already meet the standards of transfer to forest-covered land (Bilous et al. 2020) for quality class 1 (see Tab. 1). English oak trees are inferior in average height to pine by 0.5 m and perform auxiliary functions in the formation of young stands. Pine trees of natural regeneration are somewhat inferior in average height to planted pine trees, but they have higher density.

Rows of distribution of Scots pine trees by diameter classes in young stands are marked by positive skewness and negative kurtosis (Fig. 1).

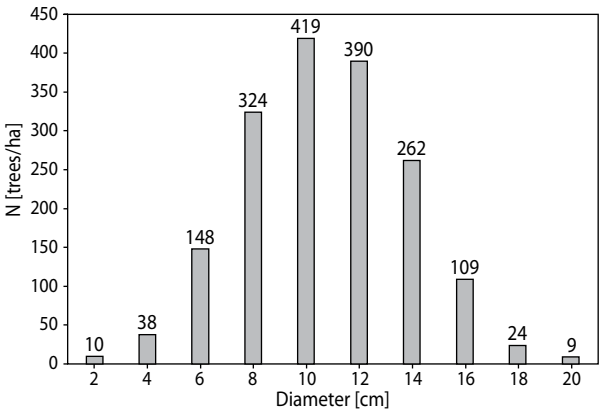

Figure 1. Distribution of Scots pine trees ha^{-1} by diameter classes on PSP 2-Slb in a 20-year-old pine forest in fresh, relatively poor oak-pine forest type ($DBH_{avg.}$ = 11.3 cm, skewness = 0.832, kurtosis = −0.125)

The proportion of thinner-than-average pine trees is more than 54%. At the same time, middle-aged and older stands are dominated by trees that are larger than the average diameter. In particular, at the PSP 18-Slb in a 101-year-old fresh, relatively poor hornbeam–oak–pine forest type, the distribution of pine trees by diameter classes is marked by positive skewness and kurtosis ($DBH_{avg.}$ = 38.7 cm, skewness = 0.002, kurtosis = 0.294).

In the process of canopy closing, trees differ in growth and development. Predominant, dominant and subdominant trees form the main part of the future stand, while suppressed and dying trees form the subordinate part of the canopy. In particular, in the 10-year-old pine forest (PPP 5-Bat), the proportion of Kraft class I pine trees is 13.7%, class II 35.1%, class III 40.4%, class IV 8.1% and class V 2.7%. In young stands and middle-aged stands, the proportion of trees of I–III Kraft classes is 76–89% (the average Kraft class is II.5–II.9), and in mature and older stands, it is 93–99% and I.7–II.0, respectively.

Introduction of *Betula pendula* to the composition of forest crops in the fresh, relatively poor forest site conditions (the mixing scheme is seven rows PiSy and three rows BePe) causes intense competition with pine when they grow together. On the PSP 3-Bat (see Tab. 1) at the age of 9, birch trees outstripped pine in height (the difference is 2.0 m) and shaded them. A significant share of birch in the stand (42% by growing stock) hindered the successful growth of pine trees, so the average value of their HCI was 1.66 (Tab. 2). A high density of young stands was formed due to the natural regeneration of Scots pine trees. In case of a decrease in the participation of birch in the composition of crops (the mixing scheme is four rows PiSy and one row BePe), its proportion in the 20-year-old pine forest at PSP 2-Slb does not exceed 15%.

In 15-year-old spruce–oak–pine crops (PSP 4-Shst; the mixing scheme is four rows PiSy and one row QuRo, PiAb), Scots pine trees grow in the upper canopy (average height is 10.0 m). Norway spruce trees have an average height of 6.5 m and English oak trees 3.7 m, and serve as an accompanying species for pine trees. Scots pine trees in mixed 62-year-old forest plantations (PSP 1-Khlm, the mixing scheme is seven rows PiSy and one row AcPl, FrPe; three rows QuRo and one row AcPl, FrPe) perform an edification function since their proportion is 92% of the stand stock (see Tab. 1). Only individual English oak trees reach the first layer. The average height of oak is 15.0 m; the oak and other species perform auxiliary functions in a highly productive stand.

Mixed pine stands are in a better health condition than pure stands and accumulate considerable wood reserves when maintained with care fellings. Trees of secondary species perform a soil-improving role, as they serve as a barrier for pests and diseases.

Pure Scots pine crops created in seed years have a high density of natural regeneration (PSP 5-Bat and 6-Bat). Natural pine forests are more resilient than for-

Table 2. Distribution of Scots pine trees by HCI

No PSP	Age [years]	Number of trees by HCI: in the numerator – trees, in the denominator – %							
		I	II	III	IV	V	VI	total	average
6-Bat	5	722 / 77.0	128 / 13.6	52 / 5.6	18 / 1.9	3 / 0.3	15 / 1.6	938 / 100.0	I.40
3-Bat	9	309 / 57.1	144 / 26.6	72 / 13.3	5 / 0.9	3 / 0.6	8 / 1.5	541 / 100.0	I.66
2-Slb	20	173 / 46.0	114 / 30.3	49 / 13.0	12 / 3.2	13 / 3.5	15 / 4.0	376 / 100.0	II.00
1-Krp	20	6 / 2.5	94 / 38.7	94 / 38.7	28 / 11.5	11 / 4.5	10 / 4.1	243 / 100.0	II.89
1-Uzr	38	104 / 55.6	32 / 17.1	30 / 16.0	3 / 1.6	1 / 0.5	17 / 9.1	187 / 100.0	II.02
1-Slb	44	89 / 47.3	67 / 35.6	12 / 6.4	9 / 4.8	–	11 / 5.9	188 / 100.0	I.92
1-Khlm	62	100 / 47.6	76 / 36.2	20 / 9.5	2 / 1.0	–	12 / 5.7	210 / 100.0	I.87
2-Vld	80	25 / 13.2	92 / 48.4	36 / 18.9	6 / 3.2	6 / 3.2	25 / 13.2	190 / 100.0	II.74
18-Slb	101	105 / 62.5	36 / 21.7	16 / 9.5	1 / 0.6	2 / 1.2	8 / 4.8	168 / 100.0	1.53
2-Sb	103	76 / 38.8	72 / 36.7	13 / 6.7	–	2 / 1.0	33 / 16.8	196 / 100.0	II.38

HCI = health condition index.

est plantations. Due to the high density of self-seeding of pine trees in fresh and wet site conditions, it is possible to leave cutting areas for natural regeneration in seed years and save money on creating forest plantations. In pure, 10-year-old pine plantations (PSP 5-Bat) with a high density of stocking, it is necessary to carry out care felling to regulate the competition between trees.

In high-stocked young pine stands, especially on old arable lands, root rot spreads (*Heterobasidion annosum* (Fr.) Bref.). The total area of pine stands damaged by this disease in Eastern Polissia is 31.7 thousand hectares or 10.9% of the area of pine stands.

In a 20-year-old pine stand of fresh oak and pine, with relatively poor forest type (PSP 1-Krp) infected with root rot, as a result of the formation of foci of drying trees, the density of stocking was 0.48. Only 2.5% of Scots pine trees were healthy without signs of weakening (see Table 4). The removal of birch trees in previous years (the mixing scheme is five rows PiSy and one row BePe) and the formation of pure pine stand led to a deterioration in its health condition (average HCI – II.9). The vast majority of Scots pine trees belong to the category of weakened and very weakened (77.4%). Dead trees constitute 4.5% in the current year and 4.1% in the previous years. The proportion of drying pine trees is 11.5%. After pine trees' mortality, up to 20-m-wide gaps in canopy were formed at the site. The spread of drying foci and disturbance of pine stands are the reasons for the assignment of clear sanitary felling.

The intensity of trees' mortality is relatively higher in the foci of the root rot than in the interfocal part and in middle-aged plantations, compared to stands of older age. In mature and overmature pine stands, the proportion of trees with signs of weakening increases. Even a small proportion of deciduous tree species (10%) in the composition of birch–pine stands reduces infection of pine trees with root rot, which is consistent with previous studies (Tkachuk 2004).

The creation of mixed forest crops and the introduction of soil-improving tree and bush species into their composition increase the biological stability of pine stands. In an artificial 38-year-old pine stand created at an old arable land (PSP 1-Uzr; scheme one row

PiSy and one row *Caragana arborescens* Lam. [placement 2.0 × 0.7 m]), high density of stocking and productivity are maintained, while some weakening of pine (HCI = II.02) is observed (see Tab. 1). The mortality over the past 5–7 years is 1.4% of the stock and is represented by thin-sized pine trees. For comparison, a pure, 44-year-old pine stand (PSP 1 – Slb) still retains a high density of stocking and productivity, but the proportion of weakened trees in it is higher than in the previous object. Therefore, preference should be given to creating resistant stands of mixed composition. Artificial pine stands with an admixture of *Tilia cordata* (PSP 2-Vld, 2-Sb) retain resistance to root rot damage and high productivity up to the maturity age, which is consistent with the report of Timofeev (1966).

In recent years, due to global climatic changes, forest health condition has deteriorated and weakening of stands and dieback are observed. Drying of pine stands (mainly by the group and curtain types) began in the region in 2015 as a result of the spread of bark beetles – *Ips acuminatus* (Gyll., 1827) and *Ips sexdentatus* (Boerner, 1776) (Coleoptera: Curculionidae: Scolytinae) (Zhezhkun and Porochniach 2020). Drying processes began with single and group mortality of pine trees in the walls of the forest, near clear-cuts, gaps, roads and other well-lit and warmed sites. The drying spread from west and southwest to east, covering all pine forests in the region by the end of 2017.

Analysis of *I. acuminatus* population indices for 2017–2018 showed the continuation of the initial phase of mass propagation (population concentration). Mild, relatively warm winters as well as dry and hot growing seasons contribute to intensive reproduction of bark beetles and increase the distribution area of pest populations. Therefore, it is effective to carry out selective sanitary felling of freshly colonised trees in drying foci in the autumn–winter period during insect dormancy (Meshkova and Borysenko 2018; Zhezhkun 2021). During 2017, the area of pine stands drying foci at SFEs of the Chernihiv region was 12.2 thousand hectares (5.9% of the area of pine forests). During this period, selective sanitary felling was carried out at an area of 8.0 thousand hectares and clear sanitary felling at an area of 80 hectares. In 2018, the total area of pine forests with new drying foci increased to 15.6 thousand hectares (by 28% compared to the previous year) and amounted to 7.6% of the area of pine stands. The proportion of entire pine drying was 13% of the total area (in 2017, this figure was 2%). During winter of 2018–2019, dead pine trees and those colonised by bark beetles were removed at an area of 10.7 hectares by means of selective sanitary felling and at an area of 240 hectares by clear sanitary cuttings. The rapid spread of pine mortality requires the implementation of a set of sylvicultural and protective measures. Over the past 2 years, the intensity of mortality of pine caused by bark beetles has slightly decreased; now, only single and group drying of trees prevail.

In the context of sustainable forestry of the region, the application of a system of sylvicultural measures will make it possible to form biotically stable, highly productive reference stands that perform high-quality useful functions. Based on the analysis of experimental data of sample plots in pine forests (fresh, relatively poor oak–pine forest type), forestry and evaluation indicators of reference stands were determined. Changes in average height, diameter, basal area, number of trees and stock, depending on age, are expressed by the corresponding approximation equations (Tab. 3).

Table 3. Equation of approximation of growth trends of reference pine stands of fresh, relatively poor oak-pine forest type

Evaluation indicator	Approximation equation	Reliability of the approximation
Average H [m]	$y = 10.556 \ln(x) - 18.72$	0.965
Average DBH [cm]	$y = 12.945 \ln(x) - 24.237$	0.970
Number of stems [ha^{-1}]	$y = 1260447x^{-1.272}$	0.899
Basal area [$m^2 \cdot ha^{-1}$]	$y = 14.467 \ln(x) - 23.063$	0.952
Stock [$m^3 \cdot ha^{-1}$]	$y = 0.0002x^3 - 0.0778x^2 + 12.72x - 78.68$	0.964

Artificial pine stands are usually formed with subsequent natural regeneration of combined origin (Tab. 4).

The dynamics of evaluation indicators of reference pine stands of fresh, relatively poor oak–pine forest type, in comparison with the data of yield tables (Bilous et al. 2020), indicate that up to 60 years of age, the average height is more than the IA line of the site index. However, the actual growing stock of stands at maturity age is lower than in the tabular data of stocked pine stands of the IA site index.

Table 4. Growth rate of reference pine stands of fresh, relatively poor oak-pine forest type of Eastern Polissia

Age [years]	Avg H [m]	Avg DBH [cm]	Basal area [$m^2 \cdot ha^{-1}$]	Number of stems [ha^{-1}]	Stock [$m^3 \cdot ha^{-1}$]	Stock change [$m^3 \cdot ha^{-1}$]	
						average	current
10	5.6	5.6	10.2	6738	41	4.1	–
20	12.9	14.5	20.3	2790	146	7.3	10.5
30	17.2	19.8	26.1	1666	238	7.9	9.2
40	20.2	23.5	30.3	1155	318	7.9	8.0
50	22.6	26.4	33.5	870	388	7.8	7.0
60	24.5	28.8	36.2	690	448	7.4	6.0
70	26.1	30.8	38.4	567	499	7.1	5.1
80	27.5	32.5	40.3	478	543	6.8	4.4
90	28.8	34.0	42.0	412	582	6.5	3.9
100	29.9	35.4	43.6	360	615	6.1	3.3
110	30.9	36.6	44.9	319	645	5.9	3.0
120	31.8	37.7	46.2	286	673	5.6	2.8

Conclusions

1. Pine stands cover an area of 290.5 thousand hectares, which is 66.4% of the forest-covered lands of Eastern Polissia and 6.7% of the forest area of Ukraine.
2. The age structure is dominated by middle-aged pine stands. The proportion of young and mature pine stands is slightly less than optimal.
3. Mixed pine stands have high biological resistance and accumulate considerable wood reserves in case of timely care felling. The health condition of mixed pine stands is relatively better than that of pure stands. In mature and overmature pine stands, the proportion of trees with signs of weakening increases.
4. The dynamics of evaluation indicators of reference pine stands of fresh, relatively poor oak–pine forest type, in comparison with the data of yield tables (Bilous et al. 2020), showed that up to 60 years, the average height is higher than in IA site index. However, the actual stock of mature stands is lower than the tabular data of stocked pine stands of the IA site index.
5. For the reproduction of sustainable pine stands of natural origin, it is necessary to apply sylviculture measures aimed at using natural regeneration of Scots pine and valuable accompanying tree species.

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