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Scots pine stands in the Left-Bank Forest-Steppe of Ukraine

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Abstract

The article presents the results of the research on the features of *Pinus sylvestris* L. condition and productivity in forest stands of the Left-Bank Forest-Steppe of Ukraine (in Kharkiv and Sumy regions) for 2006–2021. The study was carried out using the 'Forests of Ukraine' Database as of 01.01.2017, and the results of field research at 30 temporary sample plots (TSP), 3 permanent sample plots (PSP) (in 2006–2018), and 13 monitoring plots (2009–2021). Generally accepted methods and new standards were used.

The dynamics of forestry and evaluation indicators of Scots pine stands at sample plots were analyzed and compared with high-productive Scots pine stands. The characteristics of natural regeneration are given. It was revealed that the age structure of pine stands is not optimal: there is an excess of middle-aged stand areas.

Changes in the structure and development of managed Scots pine stands with respect to changing environmental conditions were observed for 2009–2021. Studied forest stands showed a tendency for negative changes in stand structural characteristics related to regeneration and growth.

Drought mainly in combination with even medium anthropogenic impact can further worsen the health status of Scots pine stands in lowland areas of the Left-Bank Forest-Steppe of Ukraine. Thus, the formulation of forest management measures to mitigate the impact of these stress factors is needed.

Key words

Pinus sylvestris, age structure, health condition, productivity, natural regeneration

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Introduction

In Ukraine, the area of forests and their composition vary greatly from one natural zone to another. The Forest-Steppe zone covers a large area of Ukraine and is characterized by alternating forest and agrarian landscapes, with climatic conditions that are borderline for temperate forests. In this natural zone Scots pine (*Pinus sylvestris* L.) and English oak (*Quercus robur* L.) prevail in the forests.

In the Left-Bank Forest-Steppe of Ukraine, Scots pine is one of the main target tree species for forest management, it covers an area of more than 180 thousand ha. This species is frost- and drought-resistant, quite unpretentious and can grow even on poor soils. In the region, man-made pure even-aged Scots pine stands dominate (Tarnopilska 2012; Yarotsky et al. 2016).

In recent years, the health condition of Scots pine forests has been deteriorating in Ukraine, and large areas of pine mortality after bark beetle damage were registered during 2015–2019 (Meshkova 2021). According to the climate forecast (Shvidenko et al. 2018), climatic conditions in the coming decades are expected to become unfavorable for pine forests, which in addition to bark beetles are also damaged by fires.

In many countries, the important data source on forests at the national level is National Forest Inventory (NFI) (Tomppo et al. 2010). In Ukraine, the NFI was launched in 2021 and it is undergoing, so its results are not available now. Traditionally in Ukraine, the main data source on forests is the 'Forests of Ukraine' Database. It is formed on the basis of periodic and continuous forest surveys (stand-wise forest inventory) conducted by the State Specialized Forest Inventory and Management Planning Enterprise "Ukrderzhlisproekt" and it contains respective data at the level of subcompartments. The stand-wise forest inventory data are used to develop forest management plans for each forestry enterprise, and also for generalizing forest data at regional and country levels. Another important source of up-to-date information about forest health is forest monitoring.

Previously, the structure and productivity of Scots pine stands on the base of 'Forests of Ukraine' Database as of 2011 and the monitoring database as of 2015 were studied (Yarotsky et al. 2016). Parameters of the main components of forest ecosystems, phytomass, and dead wood were assessed (Yarotsky et al. 2019). Currently, the 'Forests of Ukraine' Database has been updated as of 01.01.2017. Several studies were focused on the origin, age and stand composition, regeneration and growth of Scots pine stands taking into account climate change and anthropogenic impact in different forest site conditions (Matuszkiewicz et al. 2013; Vacek et al. 2016; Lovynska et al. 2017; Stefańska-Krzaczek et al. 2019; Zhezhkun 2021). The research on the formation of stands of natural origin and the possibility of their use in forestry, namely the causes of ecological replacement of pine due to natural regeneration was also conducted in the region. The dependence of natural regeneration on the pine stand structure, weather conditions, frequency of fruiting, competition with grasses, and damage by rodents has been revealed (Saltykov 2014).

The aim of our research was to study the Scots pine stands in the Left-bank Forest-Steppe of Ukraine; to reveal the features of their structure and the dynamics of forestry and evaluation indicators, and health condition at the Left-Bank Forest-Steppe of Ukraine (Kharkiv and Sumy regions) during last decade.

Material and methods

To study the climate features and trends, the climate data from the website ClimateCharts.net (Zepner et al. 2020) for 6 locations (3 in Kharkiv region and 3 in Sumy region) were grouped for several periods: 1960–1990 (baseline climate), 1990–2020 (current climate), particularly 2000–2010 and 2010–2020. The last two periods were used to identify the trend of climate indicators over the past decades. The following indicators were evaluated: mean annual temperature (*Ty*), annual precipitation (*Py*), and several indicators according to D. Vorobiev (*Tpos* – a sum of average monthly air temperatures for months with above-zero temperatures, *Ppos* – precipitation for this period, *W* – climate humidity index) (Vorobiev 1961; Buksha et al. 2021).

The climate classification was developed by D.Vorobiev (1961) as a component of forest typology classification used in Ukraine. Climate humidity was modeled using Vorobiev's method (Vorobiev 1961), according to which the climate type is a function of heat and moisture availability at the territory. Climate humidity index (W) was evaluated using the formula:

$$W = \frac{Ppos}{Tpos} - 0.0286 \times Tpos$$

Suitable for forest conditions are in 2–6 classes of climate humidity index (fresh climate and above).

Several data sources on forests were used for the study: the ‘Forests of Ukraine’ Database as of 2017 for Kharkiv region (for forest enterprises located in the Forest-Steppe zone), temporary sample plots, and repeated observations at intensive monitoring plots (in Kharkiv and Sumy regions).

Field research was conducted in forestry enterprises of Kharkiv and Sumy regions located in the Forest-Steppe zone, as well as in National Nature Park (NNP) “Slobozhansky” (Fig. 1).

The analysis covered the data obtained at 30 temporary sample plots (TSP), the data from 3 permanent sample plots in Kharkiv region (polygonal, 0.25 ha, observations during 2006–2018) (Nazarenko and Pasternak 2016), as well as the data from 23 TSP in Kharkiv region and 7 TSP in Sumy region laid in 2016–2020 in the main types of forests site conditions (TFSC) (Tab. 1).

More than half (52.6%) of the sample plots are laid in the stands of the I site class in fresh relatively poor site conditions. Sample plots cover stands aged 48 to 120 years with an average diameter at breast height (DBH) of 20.7–40.8 cm and an average height of 16.5–31.5 m.

At almost all sample plots (27), the stand composition is pure Scots pine or with a slight admixture of English oak, and silver birch (*Betula pendula* Roth.). In relatively fertile forest site conditions (C_2) Scots elm (*Ulmus glabra* Huds.) and small-leaved lime (*Tilia cordata* Mill.) are also present (less than 10%).

Table 1. The distribution of the number of temporary sample plots by types of forest site conditions and site classes

Site class	TFSC					Total
	A_1	A_2	B_2	C_2	C_3	
Ia		–	8	3	1	12
I		5	10	1	–	16
II	1	1	–	–	–	2
Total	1	6	18	4	1	30

Sample plots were laid in accordance with the generally accepted methods in forest mensuration, in particular, SOU 02.02-37-476: 2006 “Sample plots of forest inventory. Method of laying”. Field-Map technology was used during the fieldwork at monitoring plots and temporary sample plots, for tree mapping and data input (Forest mensuration 2008; https://www.fieldmap.cz/).

The observations in the intensive monitoring plots being conducted jointly with the staff of the Ukrainian Research Institute of Forestry and Forest Melioration (URIFFM) in 2011–2021 were also included in analysis. Monitoring plots were circular with an area of 0.1 ha. At the intensive monitoring plots, indicators of the main components of forest ecosystems (tree stand, undergrowth, ground vegetation) were evaluated. For each

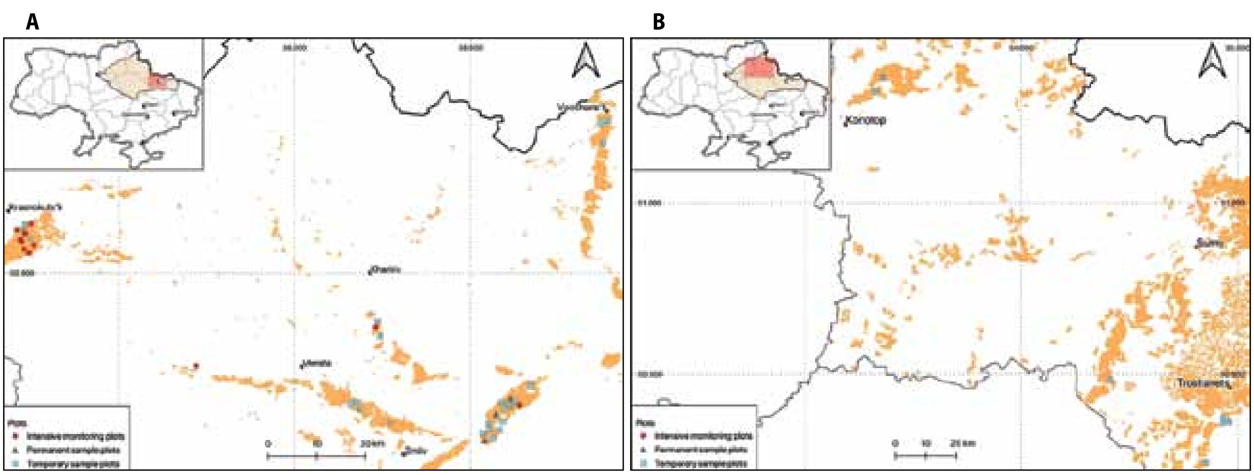

Figure 1. Temporary, permanent sample plots and intensive monitoring plots at the maps of Kharkiv (A) and Sumy (B) regions

tree with DBH ≥ 7 cm, its status (living, dead, fallen), diameter, health condition and damage were recorded, heights were measured for model trees (Pasternak et al. 2020). Observations at the permanent plots (2006, 2012 and 2018) and monitoring plots (2011–2021 – per 4–5 years) were repeated.

The analysis of forest evaluation indicators (age, stand composition, diameter, height, the relative density of stocking, site class, and growing stock) was conducted by generalizing data from the 'Forests of Ukraine' Database, as well as data from monitoring plots and temporary sample plots considering Scots pine stands distribution by forest site condition. For forest evaluation data processing, we used Forest inventory handbook and recommendations for forest inventory (Bilous et al. 2021; Myronuk et al. 2020).

The health condition of pine trees at monitoring plots was assessed by using the health condition index (HCI), and the share of damaged and dead trees. The health condition index for forest stands was defined as the average weighted by the number of trees (Sanitary Forests Regulations in Ukraine 2016). HCI includes six classes of tree health condition: 1 – healthy, 2 – weakened, 3 – severely weakened, 4 – dying, 5 – recently died trees, 6 – dead trees over a year ago. Data were generalized for monitoring plots.

The analysis of the state of undergrowth was carried out by a selective method at the circular sampling subplots with an area of 10 square meters. At each subplot, the distribution of undergrowth by age, height groups, and viability categories was evaluated.

Analysis of the normality of the distribution of indicators was performed using the Shapiro-Wilk test. Average values are given with standard errors. The conclusion on the significance of differences between average values was made based on T-Test: two samples assuming unequal variances (in MS Excel) at a = 0.05.

Table 2. Dynamic of climate indicators for two 30 years periods

Point	*Ty*, ºC			*Py*, mm			*Ppos*, mm			*W*	
	1960-–1990	1990-–2020	Δ*T*	1960-–1990	1990-–2020	Δ*P*	1960-–1990	1990-–2020	Δ*Ppos*	1960-–1990	1990-–2020
Zmiiv	7.7	8.8	1.1	519	520	1	367	402	35	0.29	0.09
Merefa	7.7	8.8	1.1	519	520	1	367	402	35	0.29	0.09
Krasnokutsk	7.3	8.4	1.1	559	555	–4	398	435	37	0.80	0.60
Trostyanets'	7.0	8.2	1.2	587	580	–7	423	461	38	1.21	1.02
Sumy	7.1	8.2	1.1	588	580	–8	426	461	35	1.23	1.02
Konotop	7.1	8.3	1.2	598	589	–9	433	466	33	1.32	1.04

* Ty – mean year temperature, °C; Py – annual precipitation, mm; Ppos – annual precipitation for months with above-zero temperatures, mm; W – hydrothermal Vorobiov index (the formula is in the text): significant difference is shown in gray.

Table 3. Dynamic of climate indicators in 2000–2010 and 2010–2020

Point	*Ty*, ºC			*Py*, mm			*Ppos*, mm			*W*	
	2000-–2010	2010-–2020	Δ*T*	2000-–2010	2010-–2020	Δ*P*	2000-–2010	2010-–2020	Δ*Ppos*	2000-–2010	2010-–2020
Zmiiv	9.2	9.5	0.4	521	511	–10	398	378	–20	–0.15	–0.49
Merefa	8.8	9.5	0.7	536	511	–25	417	378	–39	0.17	–0.49
Krasnokutsk	8.4	9.1	0.7	571	544	–27	451	410	–41	0.68	–0.02
Trostyanets'	8.1	8.8	0.6	598	563	–35	477	432	–45	1.10	0.35
Sumy	8.1	8.8	0.6	598	563	–35	477	432	–45	1.10	0.35
Konotop	8.3	8.9	0.7	605	564	–41	480	428	–52	1.12	0.30

* Significant difference is in gray.

Results

The average annual temperature in the region of study during the previous climatic period (1960–1990) was 7.3±0.5°C, and in the current climate (1991–2020) it reached 8.4±0.5°C, the temperature growth is significant ($p < 0.05$) and makes 1.1°C (Tab. 2). For recent decades, the average annual temperature increased by 0.7°C ($p < 0.05$), from 8.4±0.5°C in 2000–2010 to 9.1±0.5°C in 2010–2020 (Tab. 3). The annual precipitation at the basic climate was 565±17 mm, in the current climate this value is 557±11 mm (the difference is not significant ($p > 0.05$). During the last decades, we can observe a trend to decrease in annal precipitation from 573±16 mm to 543±23 mm ($p > 0.05$).

Climate humidity index according to Vorobiev (Vorobiev 1961) for the region was 0.9±0.2 (Class 2 – fresh climate) in the basic climate, and 0.5±0.1 in the current climate (Class 1 – dry climate) (the change is significant ($p < 0.05$). During the last decade, the hydrothermal coefficient W has significantly decreased from 0.6±0.2 to 0.1±0.2 ($p < 0.05$). Therefore, climate becomes drier even in the northern part of the region (in Sumy region) with wetter conditions.

In the Ukrainian forest site condition type classification scheme, there are four classes distinguished by soil fertility (Ostapenko and Tkach 2002; Bondar et al. 2020). These classes are the following: poor (A), relatively poor (B), relatively fertile (C), and fertile (D). The second variable for forest site condition type differentiation is soil moisture. Six classes are distinguished by this parameter. These classes are the following: 0 – very dry, 1 – dry, 2 – moist, 3 – damp, 4 – wet, 5 – swampy. A combination of soil fertility and moisture classes forms a forest site condition type, which is indicated by two characters e.g. A_1 or C_2.

An area of pine forest stands of the Forest-Steppe part of Kharkiv region is distributed according to the types of forest site conditions as follows: B_2 – 64.1%, C_2 – 15.6%, A_2 – 12.1%. The share of other TFSCs is less than 3%.

Analysis of the forest types of pine stands on the basis of the 'Forests of Ukraine' Database (stand-wise forest inventory) showed that the most common forest type in the Kharkiv region is fresh relatively poor oak-pine (B_2-oP), which occupies 64.1% of the total forest area (Fig. 2).

Pine stands in the studied region are mostly of man-made origin; they cover a wide range of ages, from 10 to 170 years. As shown in Figure 3, the predominant is VII class of age (61–70 years), it occupies an area of 24.4%, by the age of maturity the area decreases, and the share of overmature stands is insignificant. Due to active reforestation, the area of young stands (below 40 years old) has been increasing in recent years, their share is 22.6%.

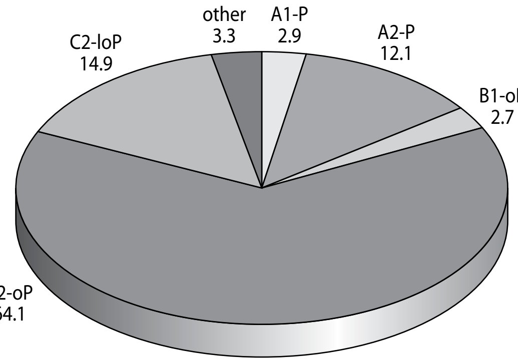

Figure 2. Distribution of the area of Scots pine stands in the forest-steppe part of Kharkiv region by forest types

To describe the state of pine stands by the 'Forests of Ukraine' Database, the average mensuration indicators were assessed (Tab. 4) for the main forest types (5 in total), and the underrepresented types (less than 1% each) were combined into a category – other forest types. The stands belonging to the high (I-Ia) site classes (for B_2-oP and C_2-loP) are mainly represented by the middle-aged group. Thus, Scots pine stands are productive and have the potential for growth in the Kharkiv region.

At the same time, the growing stock depends on the site classes and TFSC (Tab. 5). The most productive is a fresh relatively fertile forest site – C_2 (360±2 m^3ha^{-1}) and the least productive is dry poor (infertile) forest site A_1 (300±4 m^3ha^{-1}) (the difference is significant ($p < 0.05$).

The data of field studies of the stand distribution by productivity, reflect the representation of areas in different age classes, have high variability, and show the greatest growing stock in the fresh relatively poor (B_2) and fresh relatively fertile (C_2) TFSC.

The distribution of pine stands area by site classes (Fig. 4), shows a small area of low-yielding stands and the predominance of stands of the first site class (51.6%).

The distribution of pine stands by the relative density of stocking shows the predominance of stands with

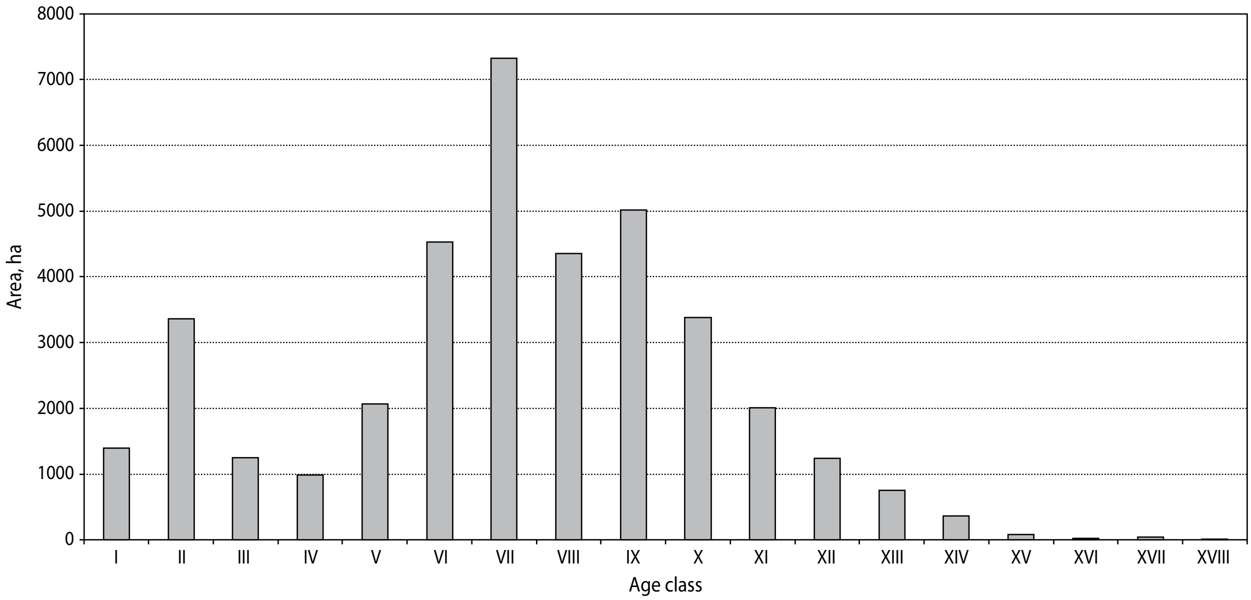

Figure 3. Distribution of area of Scots pine stands by 10-year age classes in the forest-steppe part of Kharkiv region

Table 4. Mean mensuration indicators and standard errors of Scots pine stands in the forest-steppe part of Kharkiv region in 2017 (according to the 'Forests of Ukraine' Database)

Forest type	N of plots	Mean mensuration indicators					
		age, years	diameter, cm	height, m	growing stock, m^3 ha^{-1}	relative density of stocking	site class
A_1-P	637	60±1	20.8±0.3	16.7±0.2	300±4	0.74±0.01	I.9
A_2-P	1842	66±1	24.1±0.2	19.0±0.2	325±3	0.72±0.01	I.5
B_1-oP	509	69±1	23.9±0.4	18.5±0.3	310±5	0.73±0.01	I.7
B_2-oP	8824	66±1	25.7±0.1	20.0±0.1	340±2	0.72±0.01	I.0
C_2-loP	1992	70±1	29.1±0.1	22.1±0.1	360±2	0.70±0.01	Ia.6
Other	597	51±1	25.4±0.4	18.9±0.3	310±5	0.76±0.01	I.2
Total	14401	66±1	25.8±0.1	20.0±0.1	338±1	0.72±0.01	I.1

Table 5. Productivity of Scots pine stands in the Forest-Steppe depending on forest site conditions and site class (average growing stock m^3 ha^{-1}) (according to 'Forests of Ukraine' Database)

Site class	Types of forest site conditions							On the average, m^3 ha^{-1}
	A_1	A_2	B_1	B_2	C_1	C_2	D_2	
Ib	364±61	379±25	363±0	412±6	350±36	422±7	281±0	415±4
Ia	352±12	410±5	374±17	405±2	275±23	338±4	374±24	383±2
I	340±5	374±3	356±7	302±2	229±10	365±4	330±10	319±1
II	280±5	256±2	287±6	320±4	201±11	299±6	309±11	309±6
III	170±6	237±8	230±7	215±6	78±6	195±13	191±8	207±3
IV	136±10	148±16	124±20	102±10	54±7	38±6	–	94±5
Total	300±4	325±3	310±5	340±2	208±2	348±2	312±2	338±1

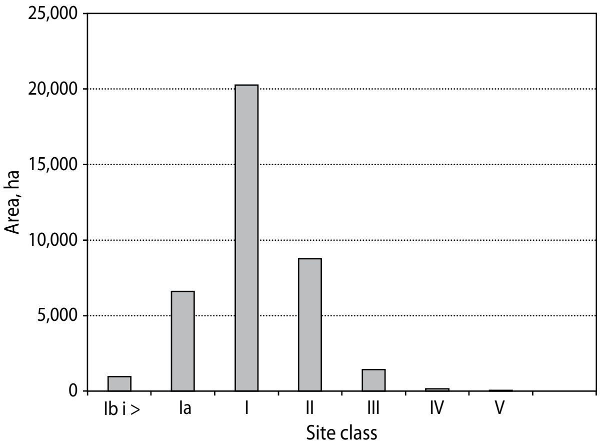

Figure 4. Distribution of Scots pine stand area by site classes in the forest-steppe part of Kharkiv region

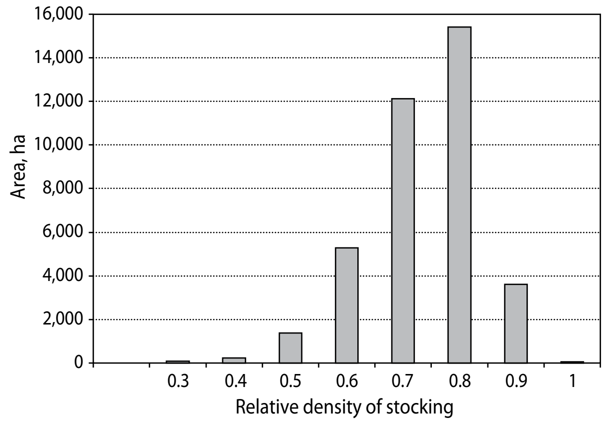

Figure 5. Distribution of Scots pine stands area in the forest-steppe part of Kharkiv region by relative density of stocking

a value of 0.8 and relatively small areas of low-density stands, (Fig. 5) which indicates the proper forest management by enterprises of the Kharkiv region.

According to the analysis of the ‘Forests of Ukraine’ Database for the Forest-Steppe part of Sumy region, pine stands dominated in the I site class – 42.9% and the stands of the Ia site class are in second place – 31.5%. The average site class is Ia,8. Pine stands with a medium relative density of stocking (44.9%) prevail, the average value of the relative density of stocking is 0.7.

Pine forest stands of the Forest-Steppe part of Sumy region are distributed by the types of forest site conditions as follows: B_2 – 45.4%, C_2 – 35.0%, A_2 – 6.6%. The share of other TFSCs is less than 3%. Therefore, most of the territory has fresh and rich site conditions, which is favorable for the normal growth and development of pine stands.

The pine stands of the VIII class of age (71–80 years) are predominant and occupy an area of 23.2%. By the age of maturity, the area of Scots pine stands decreases, and the share of overmatured stands is insignificant. The maximum growing stock is 371 m^3ha^{-1} in the IX age class.

Intensive monitoring plots were laid in the SE “Zhovtneve FE”, “Skrypaivske Educational and Research FE”, and NNP “Slobozhansky” in Kharkiv region. A repeated survey of mensuration and health indicators allowed us to trace the dynamics of pine stands’ growth (Tab. 6).

Table 6. Dynamics of Scots pine stands indicators in the intensive monitoring and permanent sample plots

Forest enterprise	Latitude/ longitude	TFSC	Year	Age, years	M, m^3ha^{-1}	P	G, m^2ha^{-1}	Site class	Mc, m^3ha^{-1}
1	2	3	4	5	6	7	8	9	10
SE “Zhovtneve FE”	N 49.90097° E 36.23000°	B_2	2011	60	410	0.69	34.1	Ia	1.1
		B_2	2015	64	428	0.70	34.5	Ia	1.3
		B_2	2019	68	441	0.69	35.0	Ia	4.6
SE “Zhovtneve FE”	N 49.83047° E 35.72024°	B_2	2011	55	397	0.73	35.4	Ia	0.0
		B_2	2015	59	432	0.77	37.9	Ia	6.6
		B_2	2019	63	453	0.79	39.2	Ia	27.0
NNP “Slobozhansky”	N 50.07916° E 35.21080°	B_2	2014	40	286	0.63	29.0	Ia	0.4
		B_2	2018	44	318	0.68	32.1	Ia	1.1

1	2	3	4	5	6	7	8	9	10
SE “Skrypaivske SRFE”	N 49.75801° E 36.63940°	B_2	2013	93	442	0.70	36.1	I	4.5
		B_2	2017	97	425	0.70	35.0	I	46.4
		B_2	2021	101	423	0.65	33.8	I	58.0
NNP “Slobozhansky”	N 50.07299° E 35.23105°	B_2	2016	85	371	0.61	30.4	I	5.9
		B_2	2020	89	392	0.63	31.9	I	7.9
NNP “Slobozhansky”	N 50.08953° E 35.25167°	B_2	2016	70	405	0.82	38.8	I	3.0
		B_2	2021	75	442	0.85	41.6	I	4.4
NNP “Slobozhansky”	N 50.07164° E 35.23530°	B_2	2016	120	529	0.88	44.2	II	16.5
		B_2	2020	124	543	0.88	44.5	II	16.3
NNP “Slobozhansky”	N 50.05740° E 35.22488°	B_2	2016	80	338	0.65	30.6	I	15.5
		B_2	2020	84	360	0.64	31.6	I	19.2
NNP “Slobozhansky”	N 50.06153° E 35.22173°	B_2	2016	110	565	0.90	46.0	II	0.4
		B_2	2020	114	596	0.91	46.5	II	0.0
NNP “Slobozhansky”	N 50.06005° E 35.21920°	A_{1-2}	2016	48	113	0.33	13.7	II	0.0
		A_{1-2}	2020	52	125	0.32	13.9	I	1.7
NNP “Slobozhansky”	N 50.03659° E 35.24382°	C_2	2016	60	470	0.80	39.6	Ia	9.2
		C_2	2021	65	502	0.82	41.2	Ia	16.3
NNP “Slobozhansky”	N 50.05129° E 35.25843°	C_2	2016	100	607	0.89	46.8	Ia	36.5
		C_2	2021	105	625	0.87	47.2	Ia	34.1
NNP “Slobozhansky”	N 50.04390° E 35.23067°	C_2	2016	95	405	0.75	35.3	I	27.4
		C_2	2021	100	411	0.74	35.7	I	45.0
SE “Skrypaivske SRFE”	N 49.27504° E 36.54960°	A_2	2012	75	468	0,9	44,2	I	1.8
		A_2	2018	81	449	0,85	41,9	II	5.2
SE “Skrypaivske SRFE”	N 49.87952° E 36.62420°	B_2	2012	55	503	0,92	45,5	Ia	15.7
		B_2	2018	61	501	0,85	42,9	Ia	21.3
SE “Skrypaivske SRFE”	N 49.67125° E 36.58750°	C_2	2012	50	432	0,89	42,8	Ia	7.4
		C_2	2018	56	467	0,91	44,8	Ia	9.5

P – relative density of stocking, Mc – stock of dead trees.

Data from intensive monitoring plots indicate that stands have a high productivity (site class Ia-I). The stands vary in age, ranging from 40 to 101 years. The relative density of stocking also varies, ranging from 0.32 to 0.91. As stands age, there is an increase in the stock of dead wood. The largest increment over the 4-year period was 50 m³ha^{-1} in Slobozhansky NNP where stands are younger and have active growth. In Zhovtneve FE, productivity was lower. In Skrypaivske SRFE, the growing stock decreased by 19 m³ha^{-1} due mortality of pine caused by the change in the microclimate resulting from clear-cutting in the neighboring area.

The health condition of the stands at the monitoring plots without considering dead trees is mostly good (Tab. 7). On most plots, deterioration of pine health condition is observed (increase of health condition index, share of damaged and dead trees). In some plots, the health condition index without considering dead trees and the proportion of damaged trees has decreased due to the mortality of damaged trees.

The deterioration of the health condition of stands as estimated by the health condition index of living trees was recorded at 13 sites, with significant changes at 6 of them ($p<0.05$). The health condition index of all trees decreased at 14 sites, with significant changes at 5 of them ($p<0.05$). Only a few plots showed a trend toward an improvement in health condition, with 3 sites showing improvement based on the health condition index of living trees and 2 sites based on the health condition index of all trees.

On average, during the last monitoring cycle the proportion of damaged trees increased by 2.8%, and the

Table 7. Health condition dynamic at monitoring and permanent sample plots

Forest enterprise	Latitude/ longitude	Year	Health condition index		Part of damaged trees, %	Part of dead trees, %
			without dead trees	with dead trees		
SE “Zhovtneve FE”	N 49.90097° E 36.23000°	2011	1.12±0.06	1.18±0.08	60.6	1.5
		2015	1.19±0.06	1.28±0.09	58.5	1.9
		2019	1.16±0.05	1.33±0.11	39.1	4.5
SE “Zhovtneve FE”	N 49.83047° E 35.72024°	2011	1.02±0.02	1.02±0.02	15.7	0.0
		2015	1.14±0.05	1.27±0.09	12.8	3.4
		2019	1.16±0.04	1.39±0.11	10.6	5.6
NNP “Slobozhansky”	N 50.07916° E 35.21080°	2014	1.04±0.02	1.07±0.04	1.7	0.9
		2018	1.04±0.02	1.11±0.05	1.8	1.7
SE “Skrypaivske SRFE”	N 49.75801° E 36.63940°	2013	1.13±0.04	1.19±0.07	9.5	1.6
		2017	1.14±0.05	1.57±0.15	8.6	10.8
		2021	1.42±0.09	2.08±0.21	5.8	15.6
NNP “Slobozhansky”	N 50.07299° E 35.23105°	2016	1.04±0.03	1.21±0.12	4.4	4.3
		2020	1.24±0.08	1.32±0.11	11.1	2.1
NNP “Slobozhansky”	N 50.08953° E 35.25167°	2016	1.02±0.02	1.07±0.05	1.2	1.2
		2021	1.08±0.03	1.13±0.06	6.3	1.2
NNP “Slobozhansky”	N 50.07164° E 35.23530°	2016	1.03±0.03	1.14±0.12	5.9	2.9
		2020	1.30±0.10	1.44±0.15	17.6	3.0
NNP “Slobozhansky”	N 50.05740° E 35.22488°	2016	1.22±0.07	1.81±0.21	6.0	13.8
		2020	1.17±0.06	1.80±0.22	0.0	14.3
NNP “Slobozhansky”	N 50.06153° E 35.22173°	2016	1.31±0.07	1.44±0.12	7.7	3.7
		2020	1.26±0.06	1.26±0.06	13.0	0.0
NNP “Slobozhansky”	N 50.06005° E 35.21920°	2016	1.09±0.05	1.09±0.05	0.0	0.0
		2020	1.69±0.12	1.90±0.21	27.6	6.5
NNP “Slobozhansky”	N 50.03659° E 35.24382°	2016	1.10±0.03	1.42±0.11	2.0	7.5
		2021	1.14±0.04	1.66±0.15	4.3	11.4
NNP “Slobozhansky”	N 50.05129° E 35.25843°	2016	1.04±0.02	1.52±0.18	1.8	11.1
		2021	1.13±0.04	1.67±0.20	10.7	11.1
NNP “Slobozhansky”	N 50.04390° E 35.23067°	2016	1.07±0.04	1.58±0.20	10.9	11.5
		2021	1.11±0.04	1.82±0.22	17.4	16.4
SE “Skrypaivske SRFE”	N 49.27504° E 36.54960°	2012	1.07±0.02	1.22±0.05	6.8	0.4
		2018	1.19±0.04	1.25±0.06	7.2	1.4
SE “Skrypaivske SRFE”	N 49.87952° E 36.62420°	2012	1.11±0.03	1.32±0.07	7.4	5.2
		2018	1.24±0.06	1.51±0.11	8.1	6.7
SE “Skrypaivske SRFE”	N 49.67125° E 36.58750°	2012	1.12±0.03	1.26±0.06	6.5	3.6
		2018	1.14±0.04	1.32±0.07	6.8	4.4

proportion of dead trees by 1.4%. Among the types of damage, resin flow (29.5%), fire damage (22.1%), insect damage to foliage (13.7%), rot damage (11.6%), and dieback of tops (10.5%) prevail.

Based on our observations on monitoring plots natural regeneration is mainly represented by Scots pine with groups of 4–8 years old plants. The majority of younger trees are damaged by insects, which gnaw at the young needles and tops, resulting in the tree eventually drying up or slowing down development. The spatial placement of undergrowth is very important and is influenced not only by forest site conditions but also by the relative density of stocking of the stand. We have recorded that in areas with a density of 0.8 and more undergrowth amount is significantly lower (500 plants·ha^{-1}) than in areas with a density of 0.6 and less, especially in the gaps of the stand (2500 plants·ha^{-1}). This is due to the lighting regime, in the gaps of the stand, the so-called "windows", the growth of pine seedlings is better. The most productive undergrowth is usually found in groups near the edge of the gap, in conditions of partial shading. Under the canopy of the mother stand, the amount of undergrowth is less, and it is not as productive. In large gaps, cereal vegetation grows quite rapidly, which negatively affects the growth and development of natural regeneration.

The largest number of productive undergrowth of Scots pine reached 2500 plants·ha^{-1} and 2.7 m in height under fresh relatively fertile forest site conditions. Additionally, there was undergrowth of the most productive age group, including such species as common oak – 1000 plants·ha^{-1}, silver birch – 500 plants·ha^{-1}, and small-leaved lime – 400 plants·ha^{-1}. However, during the observation period, the number of undergrowth decreased on average by 30% due to unfavorable lighting and moisture conditions, the growth of ground vegetation, and damage to seedlings.

Discussion

The climate of the Left Bank Forest-Steppe is moderately continental (Lipinskyi et al. 2003). During last decades the climate in the region is changing, especially the temperature regime, as it was shown by our current study as well as by other researchers (Koval 2017; Koval et al. 2017; Nazarenko and Pasternak 2016), which makes conditions less favorable for forests (Buksha et al. 2021), especially for Scots pine.

Obtained data allowed us to conclude that temperature growth is higher in the northern part of the study region. Dynamics of hydrothermal coefficient W values according to Vorobiev showed that during the past 30 years climate during vegetation became significantly dryer in Sumy region, and in the past 10 years it became significantly dryer in both regions – Kharkiv and Sumy. The observed trends are consistent with the broader scientific consensus that the Earth's climate is changing due to human activities (IPCC 2022). The observed trend to decrease in the annual amount of precipitation during the last decade in combination with significant temperature growth led to changes in climate conditions, and the climate of the region became dryer. This implies an increased risk of droughts. Droughts in combination with even medium anthropogenic impact can further worsen the health condition of pine stands in the Left-Bank Forest-Steppe of Ukraine. Thus, the development of forest management measures able to mitigate the impact of these stress factors is needed.

The typological structure of Scots pine forests of the Left Bank Forest-Steppe of Ukraine (within Kharkiv and Sumy regions) is quite diverse. There are 26 forest types, among which fresh relatively poor oak-pine type is dominant.

Forests of the forest-steppe part of Kharkiv and Sumy regions are located mainly in the valleys of the rivers Siverskyi Donets, Vorskla, and Psel. Pine and pine-oak forests occupy the sandy terraces of rivers (Bondar et al. 2020). Pine forests are represented mainly by high-yielding stands (site classes – Ia-II) (Tkach et al. 2018). The most common forest types are fresh relatively poor oak-pine (B_2-oP), fresh poor pine (A_2-P), and fresh relatively fertile linden-oak-pine (C_2-loP) ones (Bondar et al. 2020). The typological structure of the pine forest of Sumy region (Chigrinets et al. 2012) as of 01.01.2011 is represented by relatively poor (52.5%) and relatively fertile trophotopes (39.5%), and fresh hygrotopes (92.8%). Our results are similar to the results of other studies, based on the previous years' 'Forests of Ukraine' Database.

The studied Scots pine stands are characterized by an uneven age structure with a predominance of VII-VIII age classes. In terms of height, diameter, and growing stock per 1 ha, modal pines are inferior to pines from the tables of I.V. Turkevich (Nazarenko and Pasternak 2016).

Scots pine forests of the Left-Bank Forest-Steppe of Ukraine are represented mainly by pure stands. In the comparison of stocks, the TFSC C_2 and B_2 with the largest average stock per 1 ha (348 and 340 m^3 respectively) turned out to be more productive. In general, in the study area, the average site class is I, which indicates the high productivity of stands. The pine stands in the study region are more productive than in the Northern Steppe but slightly less productive than in Eastern Polissya (Lovynska et al. 2017; Zhezhkun 2021). This is mainly due to the different ratios of areas with different forest site conditions in these natural zones (Ostapenko and Tkach 2008; Buksha et al. 2021). According to Chigrinets et al. (2012), the increase in the share of relatively fertile, wet and damp forest site conditions is observed northward. In the Northern Steppe, the share of dry forest site conditions is 41% (Lovynska et al. 2017), while in the Left Bank Forest-Steppe (Kharkiv and Sumy region) – 5.2%.

In the Sumy region, pine stands are more productive in terms of site classes due to more fertile and slightly wetter site conditions, but have a lower relative density of stocking compared to Kharkiv region.

In the intensive monitoring plots, the most intensive growth of the stock was observed at the sample plot in the NPP "Slobozhansky", 50 m^3ha^{-1} during the 4-year period. Also, with age, the increment increases less actively, by the age of maturity the tree gains the largest possible diameter, and then there is natural mortality and a decrease in total stock per hectare. During the last decade, climatic indicators have changed significantly, which affects the growth and condition of forest stands.

Since 2015 there have been numerous facts of deterioration of health and dieback of pine forests in significant areas in different regions of Ukraine, including the Forest-Steppe (Meshkova, 2021). Scientists attribute these processes in particular to the outbreaks of bark beetles, which are indirectly related to climate change. In the context of climate change and increased anthropogenic impact, forest stands become more vulnerable and less resistant to biotic damage; they reduce productivity and decline (Buksha et al. 2017; Shvidenko et al. 2018; Vacek et al. 2016).

Natural regeneration in pine stands is mainly represented by Scots pine, with a slight admixture of English oak, silver birch, and small-leaved lime. The natural regeneration is located mainly in canopy gaps with more light availability. During the observation period, the number of undergrowth decreased on average by 30% due to unfavorable lighting and moisture conditions, the development of above-ground vegetation, and damage to seedlings. The observed amounts of pine natural regeneration are not sufficient for reforestation (as according to the standard should be 6 thous. seedlings per hectare (Rules of main cutting 2009)). Traditionally at the Left-Bank forest steppe of Ukraine artificial reforestation of Scots pine is used (Garmash 2019). So in the studied region, reforestation methods to increase the part of natural regeneration should be implemented.

Natural regeneration should be used primarily to preserve the biodiversity of valuable stands from both economic and forestry points of view. Focusing exclusively on the planting of forest stands will significantly deplete biodiversity, which may reduce the resilience of future forests. Therefore, natural regeneration should be used more widely, especially in forests with limited forest management.

Conclusions

The climate in the Left-Bank Forest-Steppe of Ukraine became warmer and dryer, especially during the last decade, which implies an increased risk of droughts.

Scots pine forests in the region are diverse, growing in different forest site conditions, mainly of artificial origin, and middle-aged, have high productivity and average density of stocking. Pine forests in relatively poor and fresh forest site conditions prevail. For 2009–2021, changes in the structure and development of managed Scots pine stands with respect to changing environmental conditions were revealed. The health condition of Scots pine stands has the trend to deterioration over the last decade. The amount of natural regeneration is not sufficient to form forest stands with the dominance of Scots pine.

Drought mainly in combination with even medium anthropogenic impact can further worsen the health status of pine stands in lowland areas of the Left-Bank

Forest-Steppe of Ukraine. Thus, the development of forest management measures able to mitigate the impact of these stress factors is needed.

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