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The structure of Scots pine and Black locust forests in the Northern Steppe of Ukraine

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ABSTRACT: The article describes the distribution of areas of Scots pine (*Pinus sylvestris* Linnaeus) and Black locust (*Robinia pseudoacacia* Linnaeus) stands within the Northern Steppe of Ukraine based on forest biometry data. The total area of Scots pine stands is 21,472.9 ha, of Black locust it is 17,683.7 ha, which corresponds to 24.6 and 26.9% of the total forest-covered area. Scots pine is partly naturally, partly artificially regenerated. Black locust stands are man-made forests only. Both species form mainly pure stands within the study area. Mean age of Scots pine is around 60 years with a mean wood stock of 292 $m^3 \cdot ha^{-1}$. The dominant Black locust stands are overmature ones with a mean age of 43 years and a mean stock of 149 $m^3 \cdot ha^{-1}$. Generally, for both species, an increase in mean wood stock was observed, reaching its maximum at 71 to 75 (Scots pine) and 81–85 (Black locust) years of age. It has been demonstrated that the largest area of Black locust stands is represented by relatively rich soil conditions (54.3%), whereas in Scots pine stands there are relatively poor soils (56.5%).

Keywords: forest fund; wood stock; indexes of forest biometrics; forest-forming species; age structure; functional categories of forest

It is a well-known fact that forests have a dominant role in the biosphere stability, especially in conditions of global climate changes (Bonan 1992; Perry 1994; Breymayer et al. 1998; Korb et al. 2013; Lakyda et al. 2013; Shvidenko et al. 2014). That accounts for a particular interest of the world scientific community in monitoring the condition of forest ecosystems (Hammond 1992; Davis et al. 2001; de Vries et al. 2001; FAO 2001; Brydges 2004; Clarke et al. 2011).

Forest management based on sustainable development requires up-to-date and objective information on the current condition of forests (Tinker 1996; Girs et al. 2005). One of the topical issues of forest science is a definition of the role of forests to create a primary product (Lakyda 1996, 2002; Gold et al. 2006). In this issue it is very necessary to analyse the current condition of the main tree species (Belgard 1971; Hensiruk 1992, 2002; Furdychko et al. 2006).

Ukraine may be considered to be the motherland of steppe forestry (Belgard 1971; Furdychko 2003; Sviridenko et al. 2004; Hladun 2005). The Northern Steppe of Ukraine is a sparsely forested and wood-deficient region with a highly-developed industrial sector. That is why the forest is there one of the primary values for ecological and social spheres (Medvedev 2001). Forests of the above-mentioned zone mostly fulfil ecological functions. Compared to the other forest zones, forests in this region have their own peculiarities and require a differentiated approach of forest management.

According to some researchers, the optimal forest coverage of this zone should reach 10.0% in order to achieve a stable condition of the Steppe and to satisfy economic needs for forest resources (Tkach, Meshkova 2008). However, taking into consideration the present value of 5.2%, it seems possible only with the creation of man-made forests (Lokhmatov 1999; Furdychko et al. 2006) to achieve the recommended percentage values for forest cover. While creating artificial forests, special attention is paid to fast-growing and eurybiontic tree species (Sydelnyk 1975, 1977a; Lokhmatov 1999).

Current stands in the Steppe are composed of both native and introduced species, among which Scots pine and Black locust have shown the biggest distribution and ecological value of the limiting abiotic factor (Lovinska 2014; Sytnyk et al. 2015).

There is a lack of recent studies on the stratification of such tree species as Scots pine (*Pinus sylvestris* Linnaeus) and Black locust (*Robinia pseudoacacia*

Linnaeus) while there is a lot of older studies (Belgard 1971; Sydelnyk, Travleyev 1972; Sydelnyk 1977b). However, effective forest management is impossible without an up-to-date base.

Forest production is based on the principles of the multi-purpose use of forest resources, demands trustworthy regulatory and informative data that allow specifying the instruments for its implementation.

The aim of the present work is to investigate the stratification of Scots pine and Black locust stands in the Northern Steppe of Ukraine based on the forest regulation database.

MATERIAL AND METHODS

As to the object of the survey, it was Scots pine and Black locust stands of the Steppe within the Dnipropetrovsk region of Ukraine. The survey was conducted in forest plantations with Scots pine and Black locust within the responsibility of Dnipropetrovsk Administration of Forest and Hunting Management in 2009–2015. The total sample size for Scots pine was 5,158 small plots with a total area of 21,472.9 ha, and for Black locust it was 4,739 small plots with a total area of 17,683.7 ha.

Forest inventory data for State Enterprises of the State Agency of Forest Resources of Ukraine (http://dklg.kmu.gov.ua/forest/control/uk/index, accessed January 1, 2011) were analysed for the Dnipropetrovsk region. Database of Production Association "Ukrderzhlisproekt" (http://www.lisproekt.gov.ua/) was analysed for the State Forest Enterprises which are located in the Northern Steppe (Gulchak 2006; Gulchak et al. 2011).

The technique involves establishing temporary sample plots, where the research data is collected through felling and fraction-wise processing of model trees.

Diameter and height were measured using an optical height meter (PM-5/1520 model; Suunto Instrument Co., Helsinki, Finland). Exponential rise/decay and distributions are adopted in this study to fit the diameter frequency distribution and relationship between diameter and height. In order to verify the distribution of diameter frequency the relationship between diameter and height should be considered.

The analysis of age structure and mean wood stock in Scots pine and Black locust stands was conducted on the basis of database in forest inventory materials with mathematical statistics – proposed correlation coefficients and calculated regression models. The data were analysed using MS Excel (14.0, 2010) and Statgraph (5.0, 2010). The models demonstrate the dependence of mean wood stock, average diameters and heights on the age of investigated species.

The size of sampling units ranged from 0.25 to 0.5 ha. Work on the sampling units was performed in the following order:

(*i*) completion of the tree list;
(*ii*) determination of the mean diameter of stands using an average cross-sectional area according to the tally sheet, and dividing the sum of basal areas by the total number of trees within the forest stand;
(*iii*) selection of three mean-sized and -shaped sample trees at each level of diameter;
(*iv*) measurement of the sample tree diameter (mm);
(*v*) measurement of the sample tree height (to the nearest 0.1 m);
(*vi*) cutting of sample trees;
(*vii*) determination of the sample tree volume by Eq. 1:

$$V_{\text{aver}} = g_{\text{aver}} \times h_{\text{aver}} \times f_{\text{aver}} \tag{1}$$

where:
V_{aver} – volume of the mean sample tree,
g_{aver} – cross-sectional area of the mean sample tree,
h_{aver} – mean height of the mean sample tree,
f_{aver} – form factor of the mean sample tree.

(*viii*) determination of stock in the sampling unit according to Eq. 2:

$$M = V_{\text{aver}} \times N \tag{2}$$

where:
M – wood stock,
V_{aver} – volume of the mean sample tree,
N – number of trees within the stand.

Values of the wood stock obtained on the sampling unit ($M_{\text{sampl.un}}$) for investigated tree species were converted per 1 ha according to Eq. 3:

$$M = M_{\text{sampl.un}} \times F_{\text{conv}} \tag{3}$$

where:
M – wood stock,
F_{conv} – conversion factor (1 ha/$S_{\text{sampl.un}}$),
$S_{\text{sampl.un}}$ – area of the sampling unit.

According to forest management data, the respective areas of Black locust and Scots pine stands within a particular age class, as well as the total wood stock of these species within these areas were found. The average wood stock (M_{aver}) was calculated by Eq. 4:

$$M_{\text{aver}} = M_{\text{total age cl}}/S_{\text{stand age cl}} \tag{4}$$

where:
$M_{\text{total age cl}}$ – total wood stock in the same age class of stands,
$S_{\text{stand age cl}}$ – area of the stand of a given age class.

Table 1. Age structure of Scots pine and Black locust stands within the Dnipropetrovsk Administration of Forest and Hunting Management

	Tree species	Total	Age group				
			young	middle-aged	immature	mature	overmature
Area (ha)	Scots pine	21,472.9	7,037.1	12,576.8	1,344.6	528	6.4
	Black locust	17,683.7	370.2	1,414.6	486.3	2,626.6	12,786.0
Wood stock (thousand m^3)	Scots pine	4,571.0	768.2	3,353.8	341.8	106.1	1.2
	Black locust	2,625.2	6.41	45.8	34.9	346.4	2,191.6
Mean stock ($m^3 \cdot ha^{-1}$)	Scots pine	213	92	292	273	223	225
	Black locust	148	17	32	72	132	171

RESULTS

In the Northern Steppe the total area of Scots pine stands is 21,472.9 ha, that of Black locust is 17,683.7 ha, which accounts for 24.6 and 20.3% of the whole forest-covered area, respectively. By origin, Scots pine stands are divided into naturally and artificially regenerated (planted) forests; natural stands cover an area of 3,693.8 ha (17.2%), whereas planted forests of this species cover 17,779.1 ha, which corresponds to 82.8%. All Black locust stands are man-made forests.

The functional categories of the analysed species are as follows:

(*i*) forests intended for environmental protection, scientific, historical and cultural purposes – 1,831.1 ha (18.8%) are taken as Black locust forest stands, 1,538.1 ha (15.8%) – as Scots pine stands;

(*ii*) recreational-therapeutic forests – 7,173.5 ha (22.9%) are taken as Black locust stands; 9,732.7 ha (31.1%) – as Scots pine stands;

(*iii*) erosion protection forests – 8,679.1 ha (35.2%) are taken as Black locust stands, 4,916.8 ha (20.0%) – as Scots pine stands.

Scots pine and Black locust mainly grow in pure stands, 81.9 and 82.5% respectively. In mixed plantations of the analysed forest stands the companion species are *Quercus robur* Linnaeus, *Fraxinus lanceolata* Marshall, *Populus alba* Linnaeus, *Populus nigra* Linnaeus and *Populus deltoides* Bartram ex Marshall.

The age structure analysis showed an unequal distribution of areas (Table 1, Fig. 1). The age structure of both species comprises the following age groups: (*i*) young – 1–2, (*ii*) middle-aged – 3–5, (*iii*) maturing – 6, (*iv*) mature – 7, (*v*) overmature – 8 and more.

Considerable asymmetry in age groups was found for Scots pine: middle-aged stands – 58.5%, and young ones that occupied 32.8% area (Table 1).

Black locust shows a low percentage of young stands, namely plantations aged under 10 years (2.1% from the total area of Black locust stands), maturing 2.7%, middle-aged and mature stands 8.0 and 14.9%, respectively. The mean age of the plantations is 43 years. Dominant stands are the overmature ones, which make up for 72.3% from the total area of Black locust. As for the total wood stock, the classification is as follows: (*i*) young – 0.2%, (*ii*) maturing – 1.3%, (*iii*) middle-aged – 1.7%, (*iv*) mature stands – 13.2%. The forest stands composed of overmature Black locust have the highest total stock, constituting 83.6%.

Based on the data for stand age distribution and stock calculations we define forest management options. An age class for Black locust as a fast-growing species spans 5 years and 10 years for Scots pine.

The age class and total wood stock distribution of Scots pine and Black locust stands are shown in Fig. 2.

The largest Scots pine areas are found in age classes 3–7, in Black locust in age classes 8–11. In both investigated species the largest areas are occupied by stands at the age of 50 years. As can be seen from the graphs, the total stock changes directly proportionally to the areas occupied by the specimens of a certain age class, for both Scots pine and Black locust.

Changes in total wood stock according to the age are shown in Fig. 2. With ageing, for both Scots

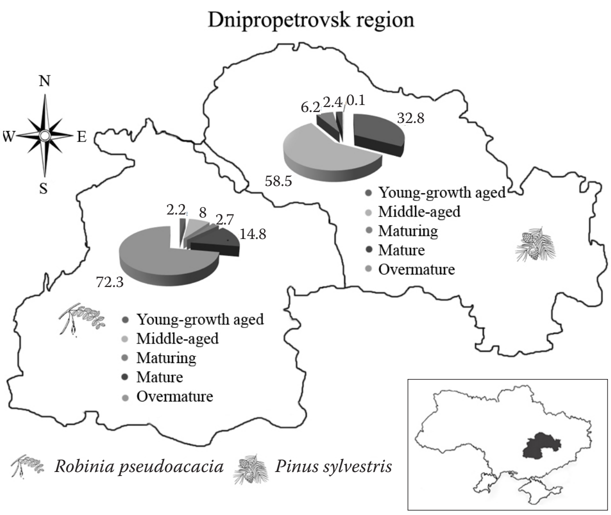

Fig. 1. Age structure of Scots pine and Black locust stands within the Dnipropetrovsk region

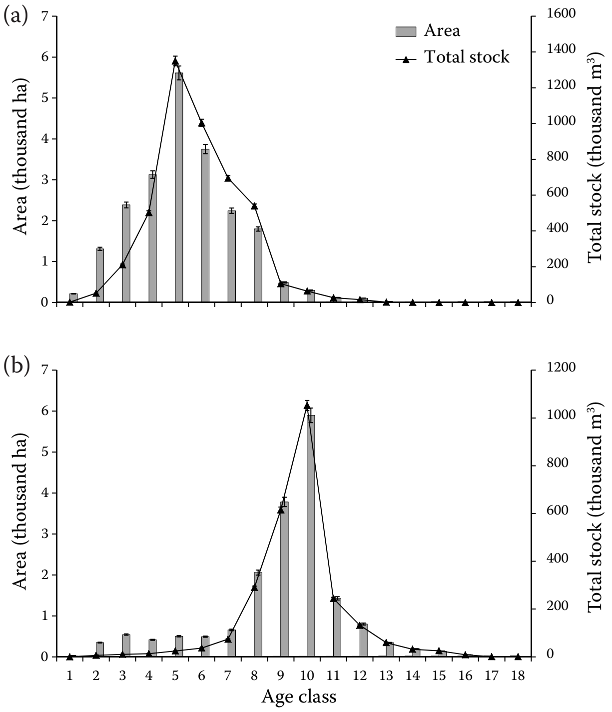

Fig. 2. Area and total wood stock distribution for Scots pine (a) and Black locust (b) stands according to age class

pine and Black locust specimens an increase in total wood stock has been observed, which reaches its maximum in the 5th (Scots pine) and 10th (Black locust) age classes. From these age classes on there is no positive trend of total wood stock increase for either of the analysed species. The maximum mean wood stock (342 $m^3 \cdot ha^{-1}$) was established for Scots pine in the age range of 71–75 years, for Black locust (218 $m^3 \cdot ha^{-1}$) in the age range of 81–85 years.

Proposed regression models allow easily and quickly calculating the parameters of dependent variables. In addition, they have the high value of approximate empiric dates (Fig. 3a).

Here are shown the models that demonstrate the dependence of mean wood stock on age for the investigated species.

For Black locust:
$y = -0.0433x^2 + 6.49x - 53.9$ ($R^2 = 0.93$)

For Scots pine:
$y = -0.0766x^2 + 11.0x - 102.5$ ($R^2 = 0.93$)

where:
y – mean wood stock ($m^3 \cdot ha^{-1}$),
x – age of stand (years) (from 5 to 90 years for Black locust and from 5 to 100 years for Scots pine).

Investigating the stratum structure of Scots pine and Black locust stands in the Northern Steppe it is of great importance to take into account the classification of trees according to their diameter and height. A comparative analysis of these biometric characteristics is presented in Figs 3b, c. While analysing the given material, we have discovered the dependence of tree diameter values on the tree age. However, the variability of diameter values tends to rise with an increase of average diameter values, for both pine and locust.

The models that demonstrate the dependence of average diameters on age for the investigated species are presented below.

For Scots pine:
$y = 0.403x + 0.336$ ($R^2 = 0.99$)

For Black locust:
$y = -0.0039x^2 + 0.646x - 1.69$ ($R^2 = 0.98$)

where:
y – average diameter (cm),
x – age of stand (from 5 to 100 years for Scots pine and from 5 to 90 years for Black locust).

Below are shown the models that demonstrate the dependence of average heights on age for the investigated species.

For Black locust:
$y = -0.0031x^2 + 0.536x - 1.05$ ($R^2 = 0.98$)

Table 2. Mathematic statistics for the parameters of Black locust stands

Characteristic	Correlation coefficient	Regression model
Mean wood stock (y) – diameter (x)	0.96 ($P \leq 0.00001$)	$y = -25.5 + 8.63x$ (R^2 adjusted for df = 91.5%)
Mean wood stock (y) – height (x)	0.97 ($P \leq 0.00001$)	$y = -28.4 + 10.2x$ (R^2 adjusted for df = 92.9%)
Height (y) – diameter (x)	0.99 ($P \leq 0.00001$)	$y = 0.321 + 0.841x$ (R^2 adjusted for df = 98.0%)

Table 3. Mathematic statistics for the parameters of Scots pine stands

Characteristic	Correlation coefficient	Regression model
Mean wood stock (y) – diameter (x)	0.80 ($P \leq 0.00001$)	$y = 50.9 + 6.63x$ (R^2 adjusted for df = 61.7%)
Mean wood stock (y) – height (x)	0.93 ($P \leq 0.00001$)	$y = -3.74 + 12.3x$ (R^2 adjusted for df = 85.7%)
Height (y) – diameter (x)	0.96 ($P \leq 0.00001$)	$y = 2.92 + 0.602x$ (R^2 adjusted for df = 92.0%)

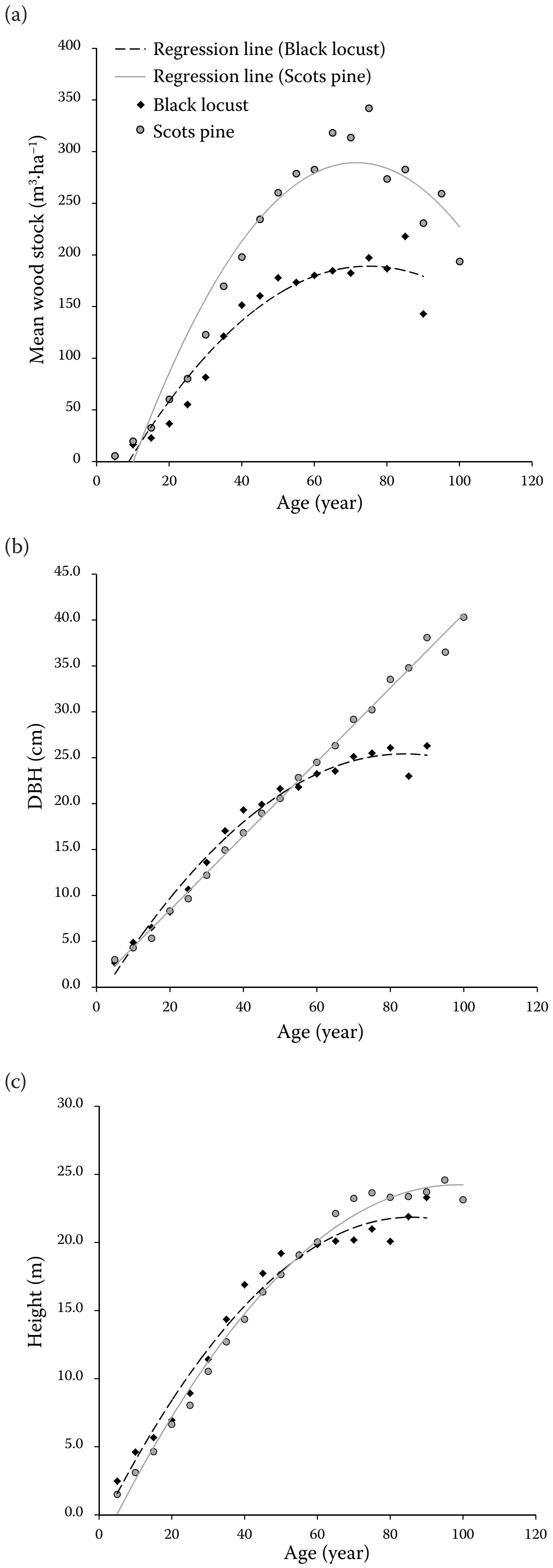

Fig. 3. Mean wood stock (a), average diameters (b), average heights (c) of Scots pine and Black locust stands according to age

For Scots pine:

$y = -0.0028x^2 + 0.544x - 2.58$ ($R^2 = 0.99$)

where:

y – tree height (m),

x – age of stand (from 5 to 90 years for Black locust and from 5 to 100 years for Scots pine).

For Scots pine the age with maximum productivity has these biometric parameters: diameters range from 24 to 40 cm (SD = 3.88) and height ranges from 16 to 30 m (SD = 2.72). For the other investigated species – Black locust the diameter range is lower – from 22 to 24 cm (SD = 3.54) and height 21–23 m (SD = 1.43).

Correlation coefficients and regression model were calculated that reflect interdependent investigated biometric indexes. For Black locust stands the results are presented in Table 2.

The R^2 statistic indicates that the model as fitted explains 91.5, 92.9 and 98.0% of the variability of dependent variables, respectively. The correlation coefficient equals 0.96, 0.97 and 0.99, indicating a relatively strong relationship between the variables. These regression models have the high degree of approximation.

In the investigated area Scots pine has the age range from 5 to 110. For Scots pine stands correlation coefficients and regression model were calculated that reflect interdependent investigated biometric indexes. The results are presented in Table 3.

The R^2 statistic indicates that the model as fitted explains 61.7, 85.7 and 92.0% of the variability of dependent variables, respectively. The correlation coefficient equals 0.80, 0.93 and 0.96, indicating a relatively strong relationship between the variables. These regression models (except the model that relates mean wood stock with diameter) have the high degree of approximation.

DISCUSSION

The forestry sector of the Northern Steppe of Ukraine has significant impacts and provides many benefits, especially in the environmental and social sphere. In view of tolerance to the abiotic factors, such trees as Scots pine and Black locust are the main forest-forming species of the forest ecosystem in this zone and take up half of the area covered by forest plantations (Pogrebnyak 1955).

Dynamics of changes in such forest-forming species has multidirectional behaviour (Gulchak et al. 2011; Lovinska, Sytnyk 2014). Thus, in the period from 1991 to 2015, the share of pine forests in the region had a tendency to decline, while the amount of Black locust stands increased significantly. This is due to a high phytomelioration potential of Black locust and large areas of lands affected by human activity that necessitate remediation (Masyuk 2008). That is why Black locust plantations are the part of forests of defensive functional categories, because the challenge of erosion protection can be solved by stands of this species (Ditsch et al. 1997). Scots pine is the main species to create public recreation sites, and therefore the prevalence of this species is shown in the functional category of recreational and health-improving forests. It should be emphasized that the percentage of forests with the nature conservation status is very low, and the study area is characterized by the lowest percentage of nature conservation objects in the steppe zone. Issues of the nature conservation status can be of interest during further surveys of these stands.

Forest age is the most important indicator of the services provided by forest ecosystems and the primary target for macro-scale management (Zeide 1978). Most forest stands reach their economic maturity prior to biological maturity. The size of the gap varies with tree species, site productivity, climate conditions, and the nature of the wood product. However, in general, the length of the harvest cycle could be increased at some cost to create carbon sinks (Kindermann et al. 2006).

Age structure of the surveyed arboreal species under conditions of the region is unbalanced and environmentally unsound, first of all related to the biological characteristics of the trees. Black locust is a fast-growing species, and due to this fact the major part of the area with this species has entered an overmature phase and requires thinning.

At the age of ca. 40–50 years, both surveyed species have maximal values of wood stock. As previously confirmed by the experimental data (Sytnyk et al. 2015), plantations composed of Black locust experience the active die-off process in trees older than such age.

It is related to the top drying and affection of plants by stem rot. That is why the issues of age changes with the reduction of rotation cutting in Black locust stands could be debatable. In its turn, it will increase the proportion of wood materials, which is quite a crucial issue for Ukraine during energy crisis in general and particularly within the Steppe zone.

Regression equations are a simple mechanism to implement age-specific rates in wood stock assessment, mean diameter and mean height for the main forest-forming species – Scots pine and Black locust.

The models are based on overall characteristic of growth process with maximum effects for Scots pine as well as for Black locust in 75 years.

Thus, the dependence of wood stock is evaluated in relation to age and implementations of regression equations show the high coefficient of determination. Nevertheless, further work is needed to explore estimation properties of wood stock from age class. The estimation of wood stock within the assessment model when age is fixed in each age class would be of particular interest.

Similarly to age, the regression equations were modelled for biometric characteristics such as diameter and height of trees.

Ageing is associated with an increase in size and eco-physiological studies have shown that size-related changes occur in functional processes in trees (Mencuccini et al. 2005). In conditions of the Steppe zone, different drought sensitivity (the relative impact of precipitation and temperature on radial growth of trees) was related to tree age (Belgard 1971).

Results from the regression analyses suggested that diameter and height are important factors in regulating the growth of forest-forming species. For both investigated species the assessment models provide a flexible modelling approach to estimating diameter and height at a given age and variability in the period of growth (class age), particularly from younger ages to 60 years of age. It was shown that for the investigated species, after 60 years of age Scots pine has a more strong dependence between diameter, height and age of trees with the high coefficient of determination compared to Black locust.

But as with most assessment approaches, the indices of these biometric characteristics depending on the age will not often be sufficient to fully estimate the overall condition of forest ecosystem. Nevertheless, regression equations are the mechanisms for incorporating dynamic values of wood stock into the general assessments.

The present composition of forest species represented by Scots pine and Black locust is well adapted to the severe soil and climatic conditions in the surveyed area of the Dnipropetrovsk region. In general, it is possible to evaluate the condition of investigated forest stands as satisfactory. With account of their climate-regulating, water and soil protection roles, the activity of creating new forests should be expanded on the lands out of agricultural use, or on the sites disturbed by mining activity that allow to solve the remediation challenge.

CONCLUSIONS

The most widespread in forests of the Northern Steppe in Ukraine are such tree species as Scots pine and Black locust. The age structure of these species is very irregular. For Scots pine middle-aged stands are typical, for Black locust – overmature stands with a very small share of young stands. A regression model was suggested as the most appropriate to determine the dependence of biometric parameters (mean wood stock, diameter and height distribution) on age.

More information about the current condition of the main tree species of the forest, describing age structure and biometric characteristics of different forest types composed of drought resistant species (inherent Steppe zone) is necessary to give a better picture of the role of forests in the carbon cycle for this region.

For the practice of forest management, in this research the models are proposed which demonstrate the dependence of wood stock on the age of dominant species in the Northern Steppe – Scots pine and Black locust. In general, based on the acquired data, we can predict the variability of the wood stock of stands in the investigated area and this suggests a possibility of further biomass study.

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