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Growth and bioproductivity of urban forests

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Approved by

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Contents

Abstract

This paper provides information about the background, process and results of growth modeling, yield and bioproductivity of artificial (planted) pine stands in urban forests in the city of Kyiv . This topic is exceptionally important to ecological functions of urban forest ecosystems around Kyiv, like any other urban forests, in terms of maintaining sustainability of the internal environment of cities, improving the environmental situation and reducing harmful effects of industry, transport, etc. A characteristic feature of urban forests is a substantial anthropogenic pressure on forest ecosystems, which is much higher compared to production forests. As a rule, reference information, growth models, etc. for urban forests are either weak or completely absent. This work is designed to eliminate some of such shortcomings and problems for forests around the biggest city in Ukraine. As a major result of the study, models of growth and biological productivity (dynamics of live biomass, Net Primary Production have been developed. We show specific features of growth and functioning of urban forests and therefore a need for the development of a special reference and normative base for inventory and management of this category of forests.

Acknowledgments

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Bioproductivity of urban forests

Ivan Lakyda

Introduction

Under conditions of transition in Ukrainian forestry, towards principles of sustainable development, cognition of ecological, economical and social characteristics of the studied objects becomes more and more important. Urban forests are defined as those that are located in urban settlements, intended for recreational, cultural and sporting activities, as well as to maintain favorable environmental conditions (Rosleshoz, 2007). In addition, forests are renewable resources and, therefore, their role as such is expected rise significantly in the near future. The importance of urban forests is difficult to overestimate, firstly, as they play an ecological role, acting as a factor determining quality of life of urban population in the broadest sense. The geographical location of urban forests in the city of Kyiv is shown on Figure 1.

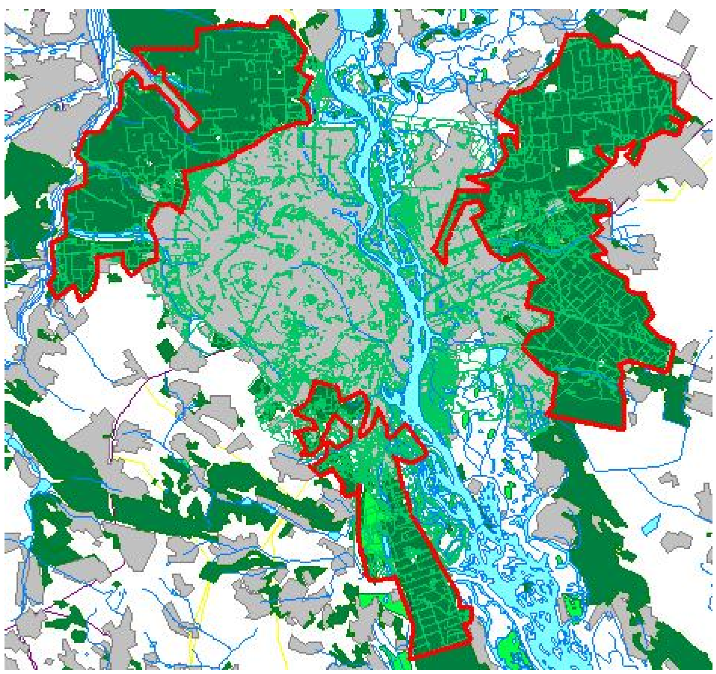

Figure 1. Geographical location of urban forests in Kyiv, managed by the Communal enterprise “Kyivzelenbud”

The main purpose of this work is to study biological productivity and associated ecological functions of urban forests in the city of Kyiv. This research topic is exceptionally important to ecological functions of forest ecosystems in the urban forests of Kyiv, as any other urban forest in terms of maintaining sustainability of the internal environment of cities, improving the environmental situation and reducing harmful effects of various anthropogenic factors.

Taking into consideration that most forested areas in Ukraine are planted pine stands, which occupy over 33% of area covered with forest or 3,130 thousand hectares (Gordiyenko et al., 2002) and within urban forests in Kyiv pine plantations dominate with a percentage of over 80%, developing informational provisions and support for their functions associated with bioproductivity is an important prerequisite for sustainable forest management in urban forests. It should be noted that at present this problem is far from being solved.

The overall objective of this study is to improve our understanding of regularities of growth, yield and dynamics of biological productivity of planted pine urban forests in the city of Kyiv. The aim is to develop corresponding models for the above category of forests. We studied pine stands of artificial origin, which are located in three forest-park economies of communal enterprise “Kyivzelenbud” – “Darnytske”, “Koncha-Zaspa” and “Svyatoshynske” (Figure 1) The total area of the stands specified is 14,619 hectares, growing stock volume – 5.2 million m^3, number of stands – 6648.

To gain a better understanding of processes of bioproductivity in urban forests in Kyiv it is worthwhile to show their silvicultural and mensurational characteristics. Distribution of areas and growing stocks of forested areas by groups of major forest forming tree species is presented in Table 1.

Table 1

Distribution of area and growing stock of forested areas by groups of major forest forming tree species

Year of inventory	Area, ha/Growing stock, $m^3 \cdot 10^3$/Stock percentage			
	total	by groups of forest forming tree species		
		coniferous	hardwood broadleaves	softwood broadleaves
2009	31119.7	25902.3	3286.7	1930.7
	11296.2	9969.4	933.3	393.5
	100	88.2	8.3	3.5

As illustrated in Table 1, coniferous forests dominate both in terms of area of stands and their growing stock. The latter is about 88% of total growing stock of urban forests in Kyiv. Hardwood and softwood broadleaves comprise about 12% of the total growing stock (Figure 2).

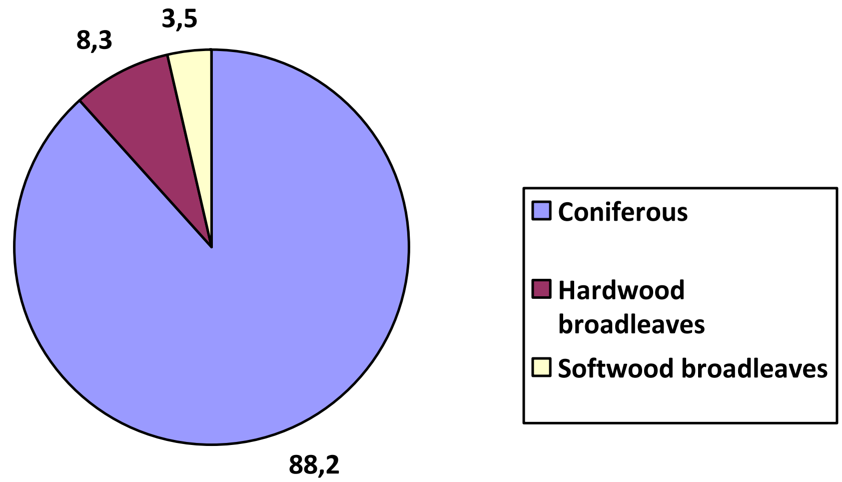

Figure 2. Distribution of growing stock of forested areas by groups of dominant forest forming tree species, %

Distribution of area and growing stock of forested areas by dominant tree species is provided in Table 2.

Table 2

Stock percentage of the main forest forming tree species within groups of forest forming tree species in urban forests of Kyiv city, %

Year of inventory	Coniferous			Hardwood broadleaves			Softwood broadleaves			
	pine	spruce	other	oak	beech	other	birch	aspen	alder	other
2009	99.8	0.2	0.0	80.5	0.6	18.9	43.7	2.9	40.8	12.6

According to Table 2, it becomes apparent that the dominant species in urban forests of Kyiv are Scots pine (*Pinus silvestris*) and Pedunculate oak (*Quercus robur*) in the coniferous and hardwood broadleaved group of forest forming tree species, respectively. Amongst the softwood broadleaved group of forest forming tree species, Black alder (*Alnus glutinosa*) and Silver birch (*Betula pendula*) are the dominant ones. According to Tables 1 and 2, the predominant tree species both in terms of area and growing stock is Scots pine. Among other tree species, the maximal growing stock per unit area has White poplar (*Populus alba*). Significant stock percentages of other hardwood and softwood broadleaves are explained largely by aims and direction of forest management in urban forests.

Distribution of growing stock of urban forests in Kyiv by age groups (young, mid-aged, immature, mature and overmature) and by groups of forest forming tree species is presented in Table 3.

Table 3

Distribution of growing stock of urban forests in Kyiv by age groups, %

Year of inventory	Coniferous				Hardwood broadleaves				Softwood broadleaves			
	young	mid-aged	immature	mature and overmature	young	mid-aged	immature	mature and overmature	young	mid-aged	immature	mature and overmature
2009	0.5	75.8	9.8	13.9	0.9	67.4	9.7	22.0	2.1	40.9	16.0	41.0

As shown in Table 3, the dominant age group in all the groups of forest forming tree species is mid-aged, and the smallest share is occupied by a group of young stands. There are several reasons for this phenomenon. The main one is the way in which urban forests are managed. Due to the forest management manual, clear cuts (in form of forest renovative cuttings) are practically prohibited in these forests. The areas available for afforestation are very limited in the region due to urbanization.

These phenomena indirectly reflect an increase of mean age of the studied forests, and their aging. As of 01.01.2009, the mean age of urban forests in Kyiv was equal to 83 years, at the same time mean age of a group of coniferous tree species was 83 years, hardwood broadleaves – 104 years, softwood broadleaves – 55 years. These values indicate that the mean age of stands is nearing their maturity age. Clearly, it is possible to state that older stands have higher aesthetic value, but it should also be noted that such a situation cannot last for a long period of time; aging planted forests are even-aged that will require their replacement due to inability to carry out their ecological functions.

Site index class of a forest stand indicates its level of productivity. Table 4 contains average site index classes of the studied forest stands.

Table 4

Average site index classes of urban forests in Kyiv by groups of forest forming tree species

Year of inventory	Mean site index class after M.M. Orlov		
	coniferouss	hardwood broadleaves	softwood broadleaves
2009	I^a,4	I,6	I,3

As it follows from Table 4, the mean site index classes of urban forests in Kyiv are rather high. Distribution of areas of stands of main forest forming tree species by site index classes as of 01.01.2009 is presented in Table 5.

Table 5

Distribution of areas of stands of main forest forming tree species by site index classes as of 01.01.2009, ha

Tree species	Site index class after M.M. Orlov									TOTAL
	I^d	I^c	I^b	I^a	I	II	III	IV	V	
Scots pine	1.1	165.3	4082.5	9217.0	9396.9	2635.8	308.9	30.1	3.4	25841.0
Norway spruce	1.0	8.1	23.9	11.2	4.3	1.1	–	–	–	49.6
Pedunculate oak	–	–	5.3	132.7	646.0	1570.4	215.6	12.1	8.4	2590.5
European beech	–	–	12.8	1.5	0.3	–	–	–	–	14.6
Silver birch	12.4	31.8	121.2	215.0	430.8	142.2	22.2	0.5	–	976.1
Aspen	–	–	0.8	10.0	25.3	2.8	3.8	–	–	42.7
Black alder	–	–	–	21.4	291.9	317.2	33.9	0.8	–	665.2
TOTAL	14.5	205.2	4246.5	9608.8	10795.5	4669.5	584.4	43.5	12.0	30180.0

Data presented in Table 5 show that stands of II – I^b site index classes are the prevailing ones. The most significant areas occupied by major dominant species belong to SI classes I and Ia in stands covered by Scots pine, SI class I and II in oak stands, SI class I in Silver birch stands and SI class II in Black alder forests.

Average growing stock on 1 ha of forested area is another biometric index, describing forest stand productivity. The average growing stock equals 360 $m^3 \cdot ha^{-1}$ for the studied forests in total; 380 $m^3 \cdot ha^{-1}$ for coniferous stands; 285 $m^3 \cdot ha^{-1}$ for hardwood broadleaved species; and 205 $m^3 \cdot ha^{-1}$ for softwood tree species. The corresponding average growing stock per 1 ha for all forests of State agency of forest resources in Ukraine is smaller, 229, 262, 214, and 167 $m^3 \cdot ha^{-1}$ respectively.

To summarize, it is necessary to identify the following prerequisites for the selection of pine stands of artificial origin of urban forests in Kyiv as the objective of this research:

- Important ecological, economic and social role of pine stands in the urban forests of Kyiv.
- Peculiarities of pine stands in the urban forests of Kyiv, due to their functions and anthropogenic load.
- Lack of information supporting functions linked with bioproductivity in urban forests compared with production forests.

Materials, Method and Results

Modeling growth and productivity of forests is a fundamental step of forest mensurational studies, its results have scientific value and are often important for practical forestry. Models of growth and productivity of forest plantations are the foundation based on which one can quantify ecological functions of forest stands, such as their bioproductivity in terms of its components, and can plan related management regimes.

Choice of the classification base is an important step in designing the study. We used site index classes as a major indicator for classification of the forests under study by level of productivity.

The subject of this study is presented by planted pine forests situated in the green zone in Kyiv. These plantations cover an area of 15,864.8 hectares, their growing stock is 5.4 million m^3.

The initial dataset used in this study derived from constructing queries to the forest inventory database “Stand-wise mensurational characteristics of forests of Ukraine”, which was developed and is being operated by the Ukrainian state forest inventory production association “Ukrderzhlisproekt”.

In order to answer the question of how to group research material for future modeling dynamics of main mensurational indices, it was decided to use cluster analysis.

When determining clusters, the following concepts were used:

- association or connection rule – defines methods for combination of clusters;
- measure of linkage distance – allows calculating distance matrices using a chosen method.

In order to perform the analysis, a matrix of distances is calculated for a certain measure, then, depending on the selected rule (method) of association, objects are assigned to different clusters and a tree structure is formed. We used Ward’s method as an association rule. This method applies analysis of variance techniques in order to assess the distance between clusters. The method minimizes the sum of squares for any two clusters that can be formed at each step (StatSoft, 1995). The applied association rule requires calculating linkage distances between elements using “Square of Euclidean distance” for correct operating. The linkage distance is calculated as a square of basic geometric distance in multidimensional space (StatSoft, 1995; Shmoylova, 2005).

Clusters were formed for the following mensurational indices: average height, average diameter and age of individual stands. Figure 3 presents the tree structure for cluster objects of average height in the first stage.

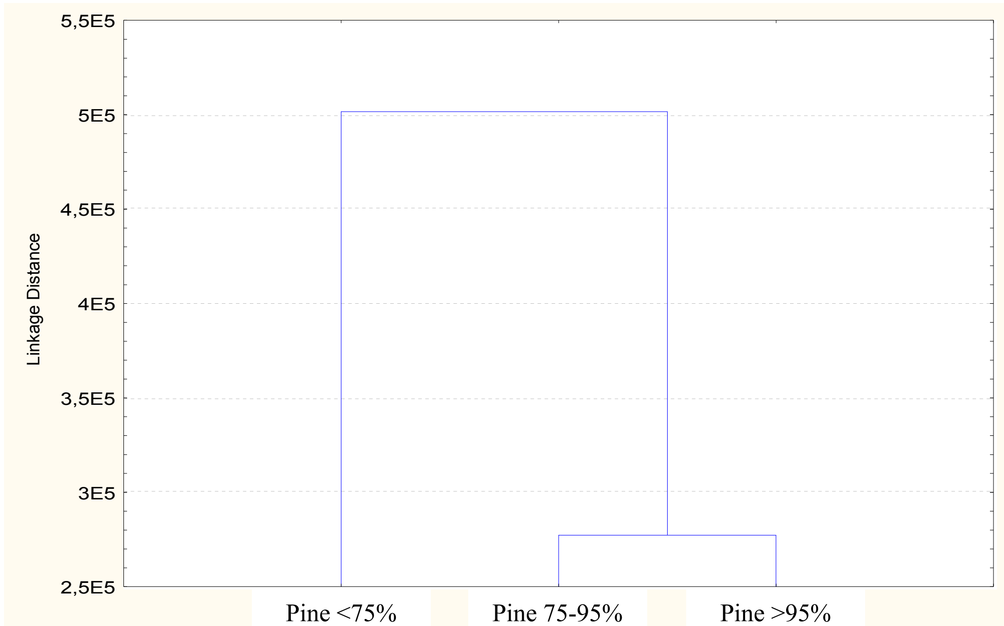

Figure 3. Tree structure for cluster objects of average height in the first stage

When analyzing Figure 3, it can be concluded that it is worthwhile to join clusters of pure pine stands with conventionally pure stands, i.e. having shares of 80 to 90 percent pine by growing stock volume. Figure 4 shows the tree structure for cluster objects of average diameter in the first stage.

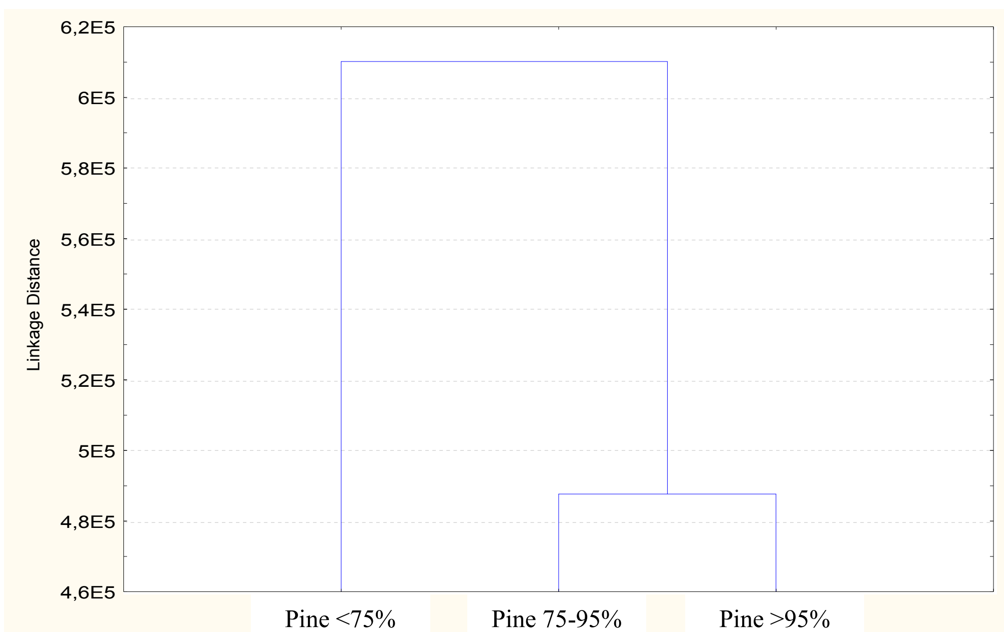

Figure 4. Tree structure for cluster objects of average diameter in the first stage

When analyzing Figure 4 it can be stated that it is worthwhile to join clusters of pure pine stands with stands that have 75 to 95 percent of pine species in their composition.

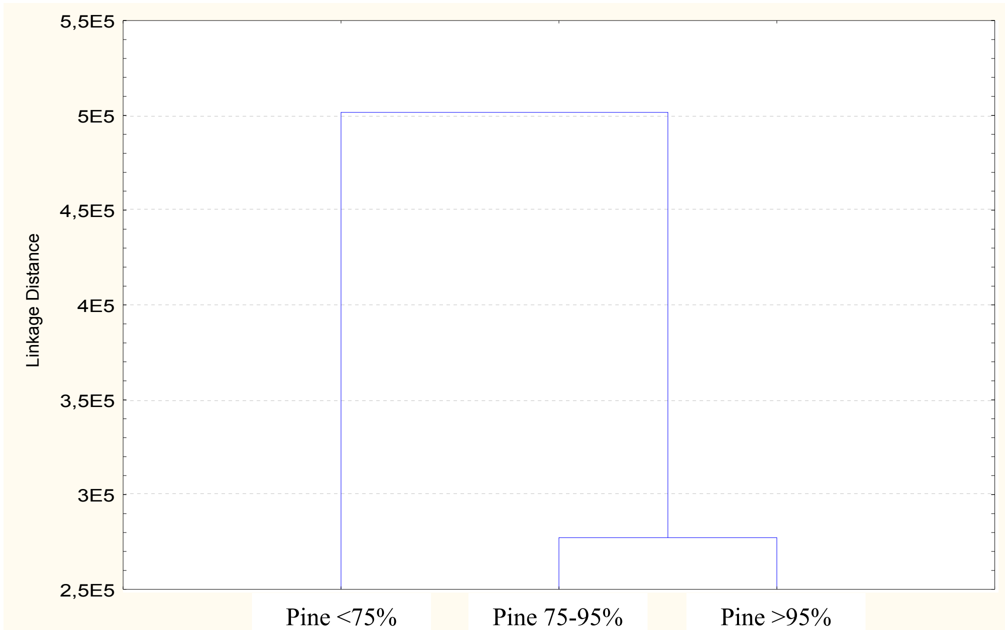

Figure 5. Tree structure for cluster objects of age in the first stage

Based on the cluster analysis conducted we conclude that the feasibility of joining clusters of pure pine stands of artificial origin with ones that have 75 to 95 percent of pine species in their composition. Hereafter, this group will be called pure pine stands in urban forests of Kyiv. The total area of the mentioned stands equals to 14,619 hectares and have a growing stock of – 5.2 million m^3.

The next step was to choose a model of height growth dynamics for the studied stands. As a basis, we applied the model of dynamics of relative heights and dynamic site index class scale for optimal pine stands of artificial origin in the Ukrainian Polissya region (Strochynsky et al., 1992), reduced to a base age of 120 years (Strochynsky, 1999; Terentyev, 2008). The main basis for this decision was that at the age of 120 years intervals between classes of site index class scale (after M.M. Orlov) are equal to 4 meters. The chosen model of dynamics of relative height has the following general view:

$$H \big/ H_{120}^{баз} = \frac{1.239 \cdot \left[1 - \exp\left(-0.0158 \cdot A \cdot \left(1 - \exp\left(-0.112 \cdot A\right)\right)\right)\right]^{1.012}}{1.028 + \frac{2.866}{A + 6.15}}, \qquad (1)$$

where A – age of a stand,

H – average height of a stand,

$H_{120}^{баз}$ – average height of a stand at base age of 120 years.

An example of the differences between site index class scale after M.M. Orlov and the applied dynamic site index class scale are depicted in Figure 6 for I^b site index class.

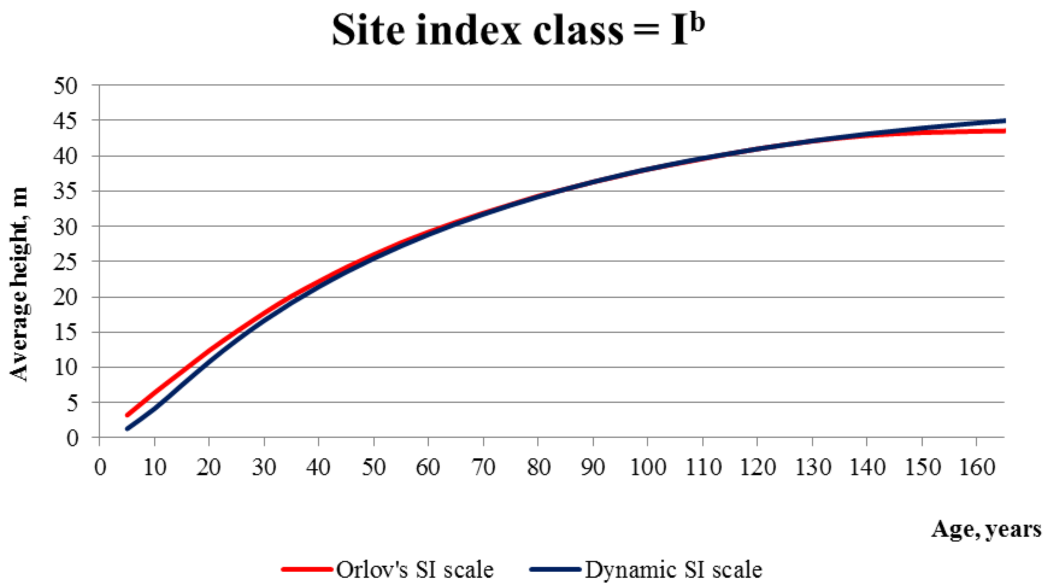

Figure 6. Differences between site index class scale after M.M. Orlov and dynamic site index class scale for optimal pine stands of artificial origin in the Ukrainian Polissya region

As we can see from Figure 6, the average height of trees, which are assigned to a particular site index class using the dynamic scale is somewhat lower at a younger age and slightly higher at an older age than it is indicated by Orlov's site index class scale.

Experimental data were divided by site index classes using the dynamic scale. Since the vast majority of stands belong to I^b - IV site index classes, the modeling of growth was performed for these site index classes. The parameters for stands of I^d, I^c, V and V^a site index classes were estimated using model regularities for the nearest site index classes.

The Bertalanffy's growth function was selected as a basis for modeling of average diameter, basal area and form height.

$$y = a_0 \cdot (1 - \exp(-a_1 \cdot x))^{a_2}, \tag{2}$$

where y – dependent variable,

x – independent variable,

a_0, a_1 i a_2 – regression coefficients.

As a result of modeling of dynamics for the above biometric indicators of stands, the following mathematical models were developed

a) model of dynamics for average diameter of the studied stands

$$D = 1.01236 \cdot a_0 \cdot (1 - \exp(-a_1 \cdot A))^{a_2}, \tag{3}$$

where $a_0 = 0.54415+5.54676 \cdot SI-0.04538 \cdot SI^2+0.767 \cdot 10^{-3} \cdot SI^3$,

$a_1 = 0.012474+0.391 \cdot 10^{-3} \cdot SI-0.00381 \cdot SI^{0,5}-0.24 \cdot 10^{-7} \cdot SI^3$,

$a_2 = 2.373+0.00914 \cdot SI-1.1869 \cdot SI^{0,1}-0.1 \cdot 10^{-5} \cdot SI^3$,

A –stand age, year,

D – average stand diameter, cm

SI – site index class code.

A systematic error of the model equals zero, standard deviation is 0.8735, and estimation error of mean value is 0.000432.

b) model of dynamics for basal area of the studied stands

$$G = 0.99032 \cdot a_0 \cdot (1-\exp(-0.083367 \cdot A))^{2.39778}, \tag{4}$$

where $a_0 = -9.6535+2.27548 \cdot SI-0.02587 \cdot SI^2-0.47 \cdot 10^{-4} \cdot SI^3$,

G – stand basal area, m^2ha^{-1},

A –stand age, year

SI – site index class code.

A systematic error of the model equals zero, standard deviation is 0.7014, and estimation error of mean value is 0.000257.

c) model of dynamics for form height of studied stands

$$HF=1.00833 \cdot (-5.7852+0.89165 \cdot SI-0.00915 \cdot SI^2) \cdot (1-EXP(-0.02819 \cdot A))^{1.4812}, \tag{5}$$

where *HF* – form height,

A –stand age, year

SI – site index class code.

A systematic error of the model equals zero, standard deviation is 0.1831, and estimation error of mean value is 0.000257.

The developed models accurately describe the experimental data and have no systematic errors. A graphic interpretation of the mathematical models is presented in Figures 7, 8 and 9.

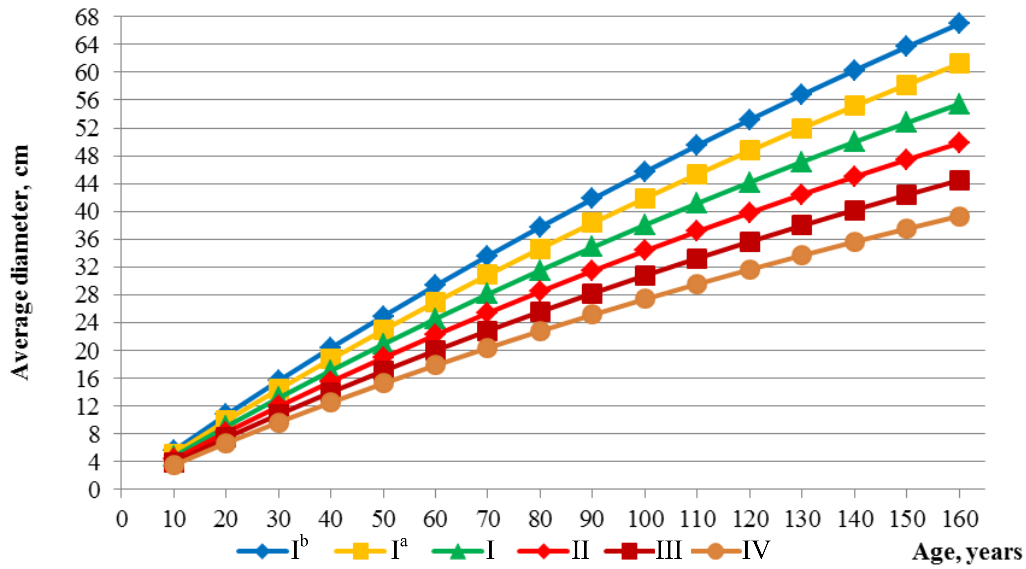

Figure 7. Graphic interpretation of the model of dynamics of average diameter

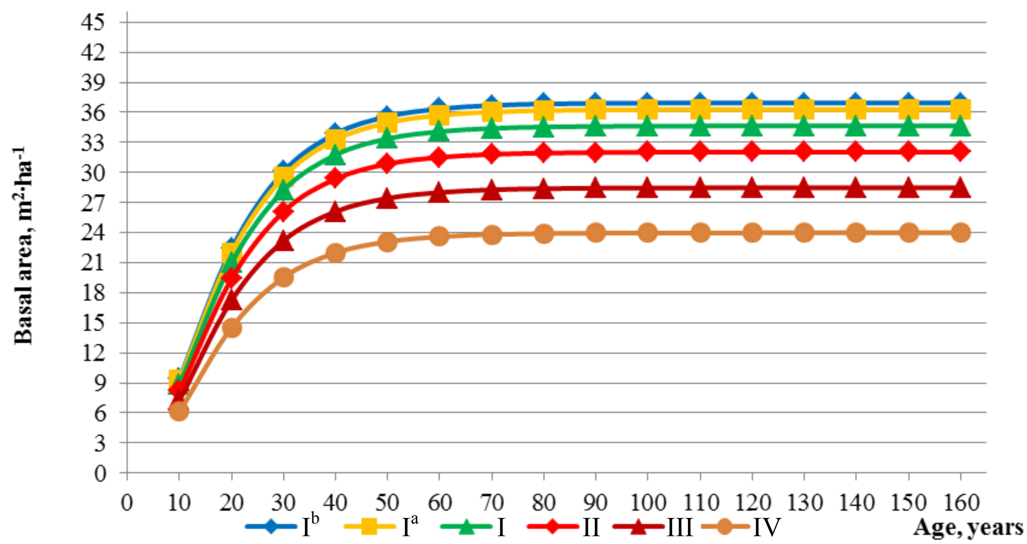

Figure 8. Graphic interpretation of the model of dynamics of basal area

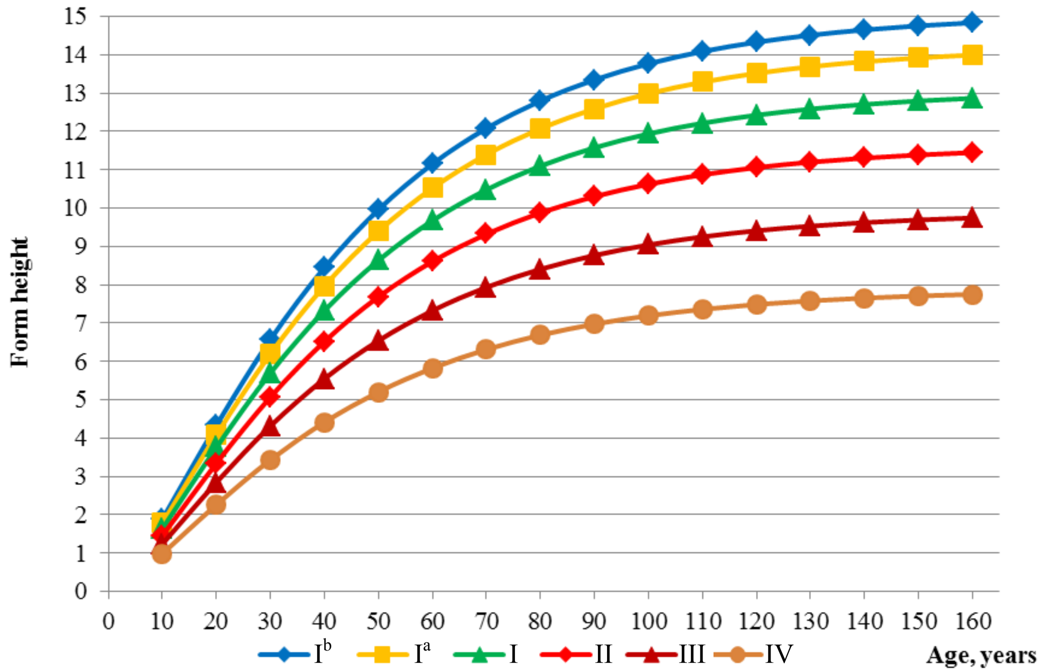

Figure 9. Graphic interpretation of the model of dynamics of form height

Some studies indicated that inventory based growing stock volume of stands has a bias (e.g., -7% for the study's region, U-Te-Tint, 1971). This bias impacts form factors when calculating these based on the models above, causing some underestimation of their values for all site index classes. In order to eliminate this bias it was decided to use a generic model of dynamics of form factor for optimal pine stands of artificial origin in the Ukrainian Polissya region (Strochynskyy et al., 1992), which has the following general view:

$$F=(A^{0.0841}\cdot D^{-0.202}\cdot H^{0.296}\cdot EXP(7.62-5.504/H+13.76/H^{2}))/1000, \tag{6}$$

where *F* – form factor,

A – stand age, year

D – average stand diameter, cm,

H – average stand height. m2.

The rest of mensurational parameters which are required for development of yield tables were calculated in the following way:

- Growing stock:

$$M = G\cdot H\cdot F, \tag{7}$$

- Number of stems per 1 ha:

$$N = 40000\cdot G/\pi/D^{2}, \tag{8}$$

- Current annual increment:

$$CAI = (M_{A}-M_{A-10})/10, \tag{9}$$

- Mean annual increment:

$$MAI = M_A/A. \tag{10}$$

Since the original dataset did not contain information about the removed part of the stands models of dynamics for reduction rates of the removed part by diameter and average height of optimal pine stands of artificial origin in the Ukrainian Polissya region were used in order to develop yield tables for the studied forests. The mentioned models have been developed based on measurements on permanent sample plots and could be presented in the following form:

a) model of dynamics for reduction rate of removed part by average height:

$$R^H = 0.640+0.178 \cdot A^{0.112}, \tag{11}$$

б) model of dynamics for reduction rate of removed part by diameter:

$$R^D = 0.695+0.173 \cdot 10^{-3} \cdot A^{1.462}. \tag{12}$$

where R^H and R^D are ratio of average height and diameter of removed part to corresponding values of the remaining part, respectively.

Graphic interpretation of these mathematic expressions is presented in Figure 10.

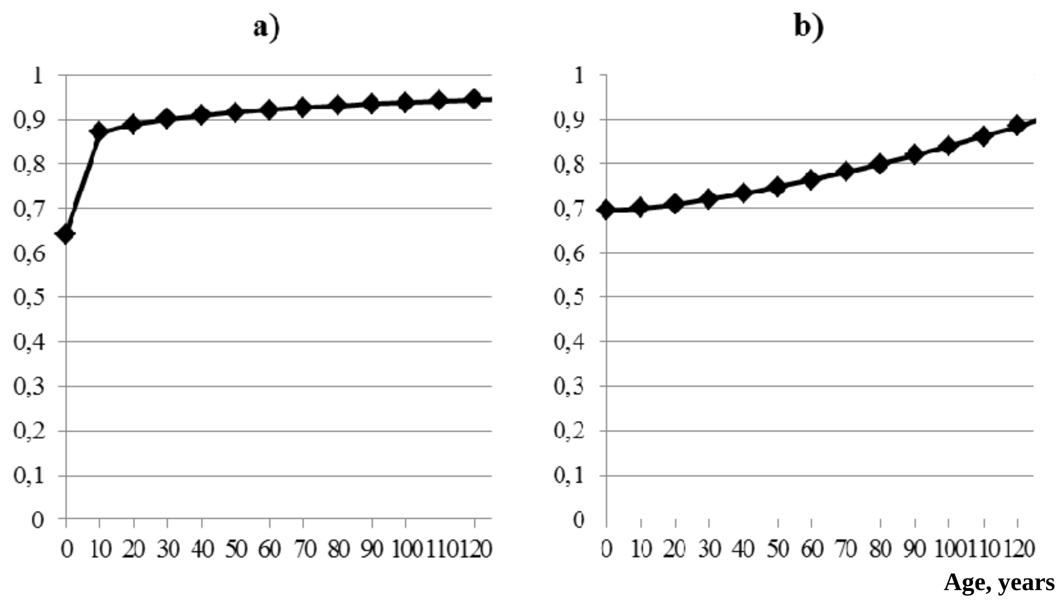

Figure 10. Graphic interpretation of models for reduction rate of removed part by average height (a) and diameter (b)

Based on these models, parameters of the removed part of a stand were calculated. The next step was to produce yield tables based on the above developed models. One of the important mensurational indices, shown in the tables above, is the total productivity of forest stands, defining as a total amount of stem wood which is produced by a stand during its lifespan. Its dynamics is illustrated in Figure 11.

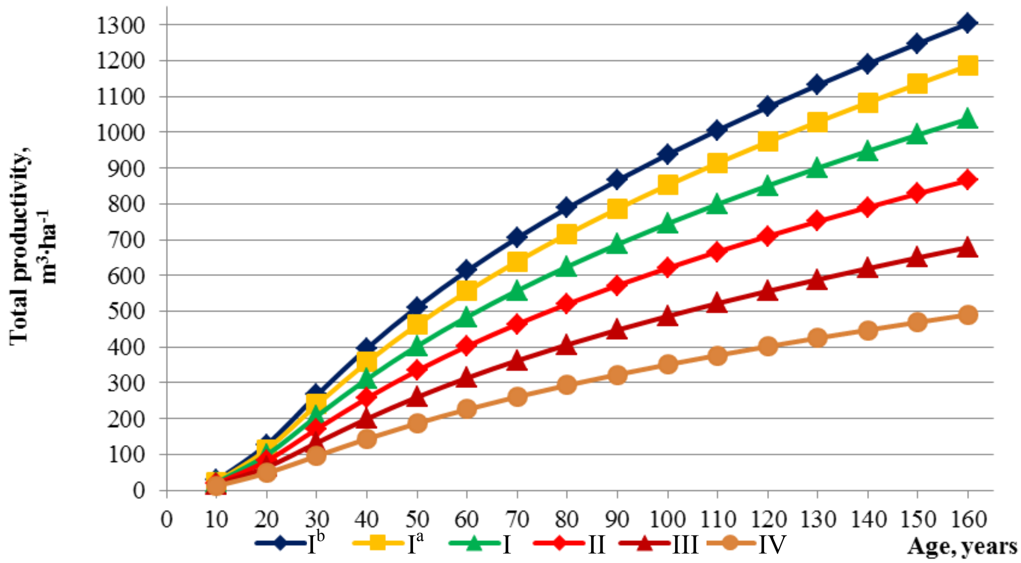

Figure 11. Dynamics of total productivity for modal pine stands of artificial origin in urban forests of Kyiv city

The developed yield tables are provided in Appendix 1.

In the second stage of this study, in order to develop tables of biological productivity, a recently suggested new method of assessing biological productivity of forests was applied (Shvidenko et al., 2007) The method is based on modeling of dynamics of total production of live biomass and has no biases in opposite to methods which are based on destructive measurements of NPP in forest ecosystems. However, reliability of the method depends on quality of live biomass models. Because this study is a first attempt of assessment of NPP by the above method in Ukraine, we used two available systems of models of live biomass applied to the developed growth models:

- local system of models for forests in Ukraine (Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008);
- regional system of models for forests in the European part of Northern Eurasia (Shvidenko et al., 2007).

The first of these two bioproductivity models systems is more general, developed for a geographically larger area. It should be noted that the data set used by the author for the system of local bioproductivity models is a subset of the data set on which the regional system of models was developed. However, it does not allow to comment on the similarity of these systems. The local system gives slightly worse results than the regional one, primarily because models for evaluation of some fractions of live biomass in it are based on a limited amount of data and cover a narrow age range. The difference between the results of these two bioproductivity models systems could be rather large. Thus, it seems relevant to consider both systems and provide a comparison of the results.

When applying both systems, amount of stand live biomass is estimated as a sum of its fractions (stem wood over bark, branches, needles, roots, understorey, undergrowth and green forest floor). The calculation of live biomass fractions of undergrowth and understorey, as well as green forest floor was carried out using the same models (Shvidenko, Lakyda, McCallum et al., 2008), so the results of both systems of models for these fractions have no differences. The comparison of the results of the two systems of models is carried out graphically. A comparison of the live biomass dynamics of a stem is shown in Figure 12.

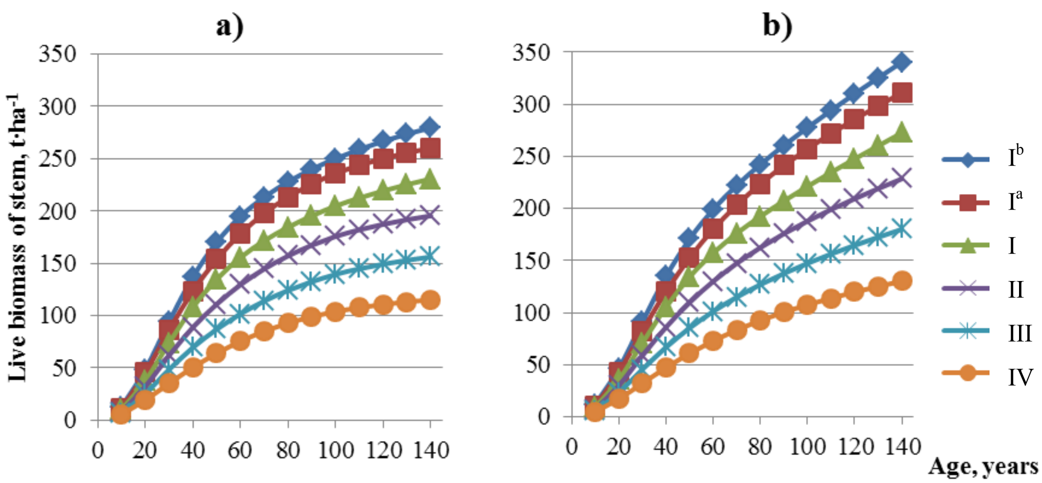

Figure 12. Dynamics of live biomass of a stem (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

As it is shown in Figure 12 the local system predicts higher amounts of stem live biomass than the regional. The difference between the results of the two systems of models increases for higher site index classes. A comparison of dynamics for live biomass of branches is shown in Figure 13.

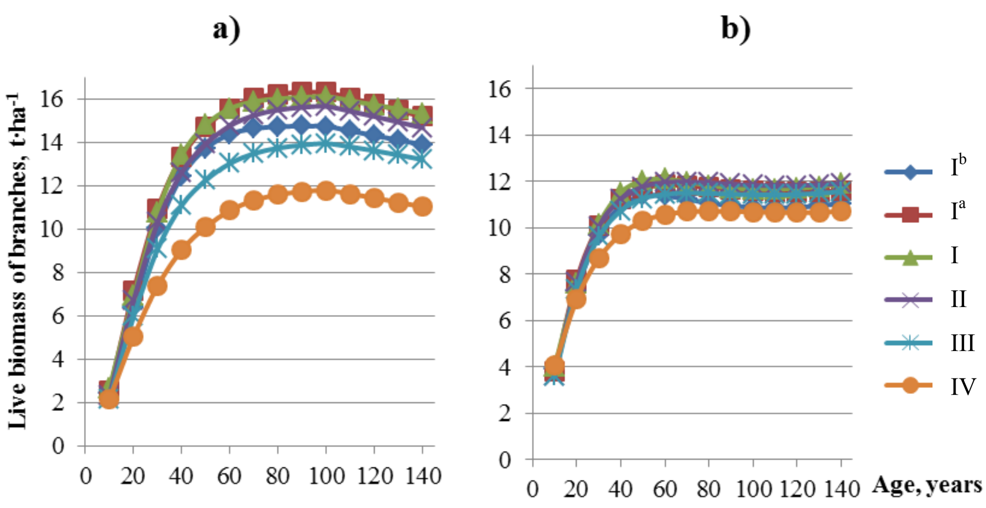

Figure 13. Dynamics of live biomass of branches (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

Figure 13 shows that the regional system of models overestimates live biomass of branches regarding the local system, and the discrepancy between the predicted values of live biomass of branches is about 15%. Minimum values are achieved in site index class IV, and maximum – in the I^a, I and II site index classes for regional and local system of models respectively. A comparison of the dynamics for live biomass of needles is shown in Figure 14.

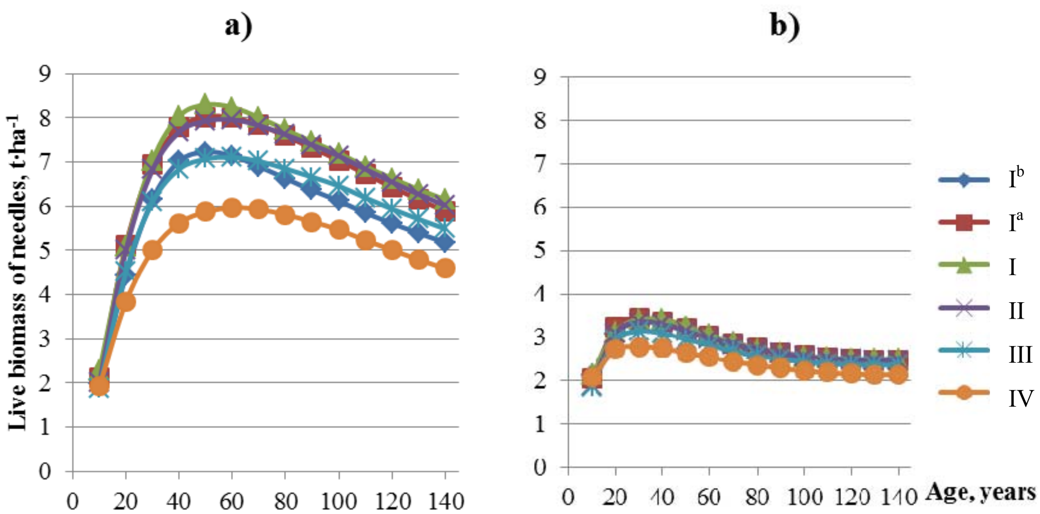

Figure 14. Dynamics of live biomass of needles (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

When comparing results of local and regional systems of models for predicting dynamics of live biomass fraction of needles, it has to be mentioned that, for the fraction of branches, the regional system of models calculates higher values than the local. The difference in this case is around 50%. The minimum value is observed in site index class IV, and the maximum – in I, II, and Ia site index classes for regional and local systems of models, respectively. A comparison of dynamics for phytomass of roots is shown in Figure 15.

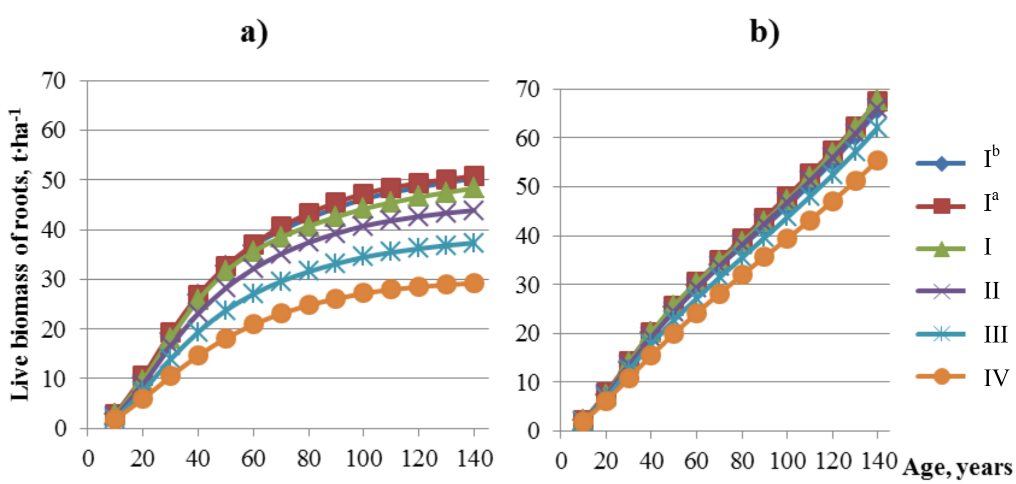

Figure 15. Dynamics of live biomass of roots (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

We can conclude that the regional system of models underestimates fraction of roots relatively to the local system. The discrepancy between the predicted values of the two systems is 35%. The minimum values correspond to site index class IV, and maximum – to site index class I^a. It should be noted that difference increases when age increases. A comparison of dynamics for total live biomass of the stands under the study is shown in Figure 16.

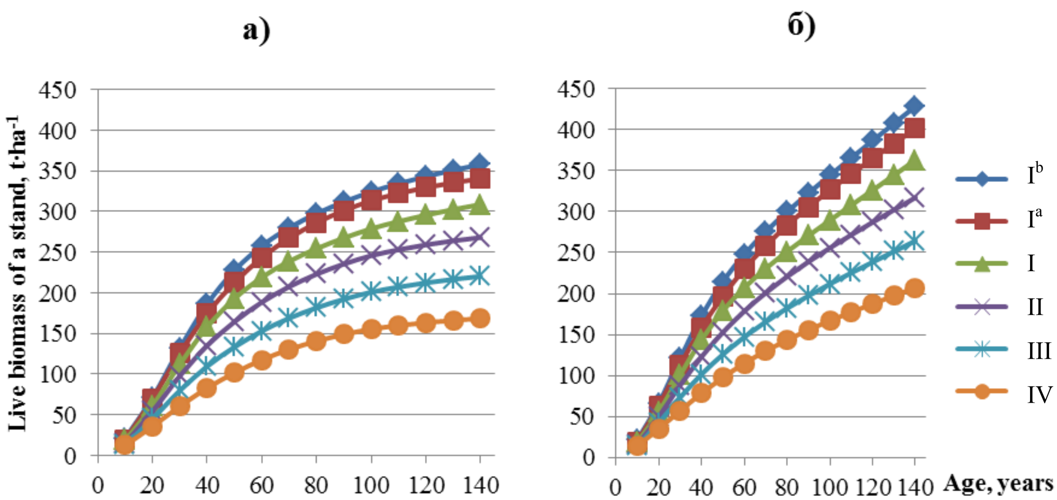

Figure 16. Dynamics of live biomass of a stand (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

Figure 16 shows that the local system of models overestimates live biomass of a stand relatively to the regional system of models by a value of 15%. Minimum and maximum values are recorded for site index classes IV and I^b, respectively. A comparison of the dynamics of total live biomass productivity is shown in Figure 17.

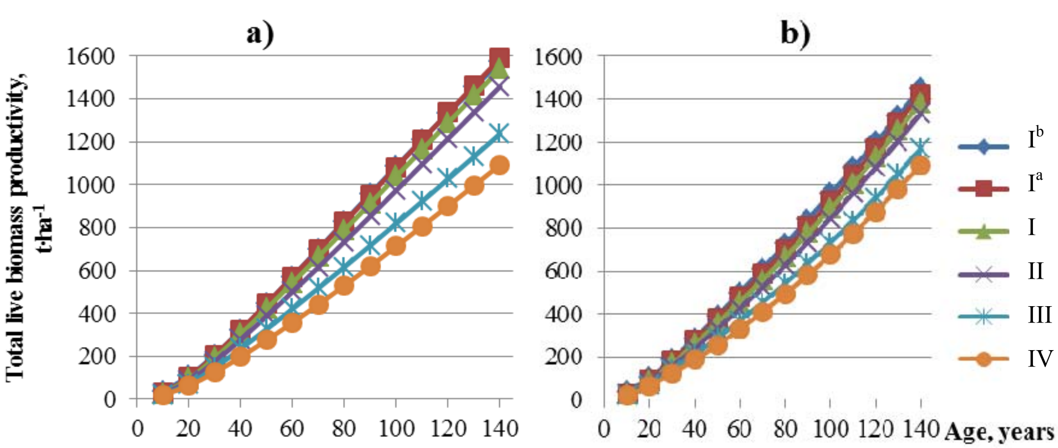

Figure 17. Dynamics of total live biomass productivity (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

As it is shown from the above comparisons the regional system of models predicts higher values of total biomass production than the local. The discrepancy does not exceed 10%, while minimum values are quite close together. The difference increases as site productivity increases. The maximum value for the regional model is achieved in site index classes I^a and I^b, and for the local model – in site index class I^b. A comparison of the dynamics for current annual increment of live biomass by present stock is shown in Figure 18.

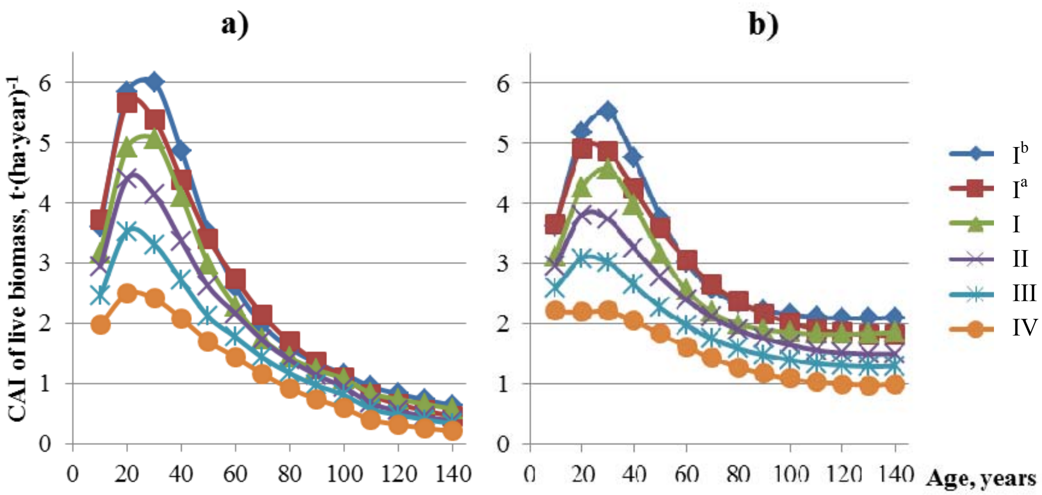

Figure 18. Current annual increment of live biomass by present stock (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

The curves depicting current annual increment of live biomass (Figure 18) have a similar shape, maximum is reached at a young age, after which values decrease with increasing age. This corresponds to the nature of current annual increment. The regional model overestimates the value of the parameter, relatively to the local model. The minimum value corresponds to site index class IV, and maximum to site index classes I^b and I^a. A comparison of the dynamics for net primary production is presented in Figure 19.

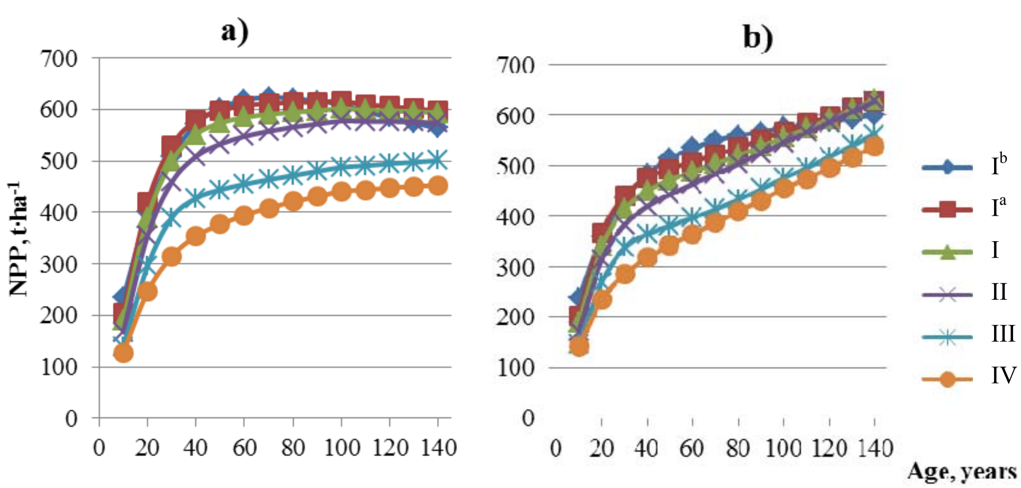

Figure 19. Dynamics of net primary production (a – after Shvidenko et al., 2007, b – after Lakyda, 1997; Shvidenko, Lakyda, McCallum et al., 2008)

When comparing the dynamics of net primary production, it should be noted that the local system of models gives higher values relatively to the regional system in older age. Minimum values are reached in site index class IV, and maximum correspond to site index classes I^a and I^b. In older age, the local system of models predicts further growth of NPP for all site index classes, and regional - only for site index classes III and IV. The forecast by the regional system looks more like the one corresponding to the nature of change of forest NPP with age.

The following reasons for the illustrated differences can be pointed out:

- availability of data that were used by the authors for developing their systems of models. This factor is especially notable when considering the dynamics of live biomass fractions of needles and roots. Live biomass of roots is correctly described by mathematical expression of the local system of models only to the age of 80 years. Clearly, empirical data for older age were missing, so the results for this period appear less adequate to objective reality. Live biomass of needles throughout the period to 140 years is low compared with actual data from sample plots in similar forest growing conditions (Usoltsev, 2001).
- impact of geographical factors. The peculiarity of the regional system of bioproductivity models is the impact of geographical conditions of a large region for which it was designed. Thus, the models for evaluation of green forest floor, understorey and undergrowth works in the same way for site index classes IV in dry, damp and wet conditions, which does not fully meet the conditions of the Ukrainian Polissya region.
- mathematical expressions used in modeling the dynamics of live biomass fractions in the regional system of models describe the experimental data more accurately compared to expressions used for developing the local system (Shvidenko, Lakyda, McCallum et al., 2008).

The main conclusion from the results above is a need to improve the local system of live biomass models in order to correct these deficiencies, which, despite not being critical ones, significantly complicate correct interpretation of the results. First of all, it should be set to expand on the initial dataset in order to better describe a considerable age gap and draw attention to the kind of mathematical expressions used to describe age dynamics for biological productivity of forest plantations. These measures may significantly improve the system of models for biological productivity of forests in Ukraine.

Conclusion

This study illustrated that urban forests which are basically destined for recreation and environment protection have distinctive features of growth and productivity and, consequently, require development of special models for assessing their biospheric services (e.g., impacts of forests on major biogeochemical cycles) and implementation of appropriate regimes of forest management. The approach used demonstrated its ability to satisfactorily reach the planned objectives. We showed that results of forest inventory of studied forests in combination with a number of empirical models could be used as initial information for development of guidelines and standards for sustainable forest management.

Developed models of growth and yields and dynamics of bioproductivity for modal pine stands of artificial origin for urban forests around Kyiv have a rather high accuracy and satisfactorily describe current functioning of the studied forests. The models are a basis for further quantitative assessment of ecological functions of studied forest ecosystems.

However, reliability of the modeling systems also substantially depends on consistency of all empirical models needed for the assessment of major indicators of biological productivity. Our analysis showed that there are some gaps in available sets of models which are used for assessing dynamics of live biomass of forest ecosystems in the region. For this reason, we tried to organize the entire process of modeling as a self-educated system which would be able to use new information and new knowledge for further improvements of developed models.

This study covers a major part of urban forests in the region. In the future it is planned to develop similar sets of models for natural pine stands, as well as for birch stands, which are dominant species amongst softwood broadleaves in urban forests of Kyiv. This will enable to characterize growth, development and productivity of urban forests in Kyiv more comprehensively, as well as performance of ecological functions associated with their biological productivity. From other side, this study supposes to be used as part of a modeling system of assessment growth and productivity of forests under global change which is under development now for the entire country.

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Appendix 1

Yield tables for modal pine stands of artificial origin of urban forests of Kyiv city

Site index class I^b

A, years	Stand								Removed part					Total productivity, $m^3 \cdot ha^{-1}$	Total increment, $m^3 \cdot (ha \cdot year)^{-1}$		A, years
	H, m	D, cm	n	G, $m^2 \cdot ha^{-1}$	F	M, $m^3 \cdot ha^{-1}$	Annual increment, $m^3 \cdot (ha \cdot year)^{-1}$		H, m	D, cm	n	m, $m^3 \cdot ha^{-1}$	M, $m^3 \cdot ha^{-1}$		mean	current	
							mean	current									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	3.9	5.7	3706	9.3	-	26	2.6	2.6	3.4	4.0	1318	4	4	27	2.7	2.7	5
20	10.3	10.9	2389	22.2	0.542	124	6.2	9.8	9.1	7.7	876	20	24	128	6.4	10.1	15
30	15.9	15.8	1513	29.8	0.512	242	8.1	1.8	14.3	11.4	508	38	62	266	8.9	13.8	25
40	20.4	20.6	1005	33.5	0.488	334	8.4	9.2	18.6	15.1	300	49	111	396	9.9	13.0	35
50	24.3	25.2	705	35.3	0.468	401	8.0	6.6	22.2	18.9	185	54	165	511	10.2	11.5	45
60	27.5	29.7	520	36.0	0.453	449	7.5	4.8	25.3	22.7	120	56	220	613	10.2	10.2	55
70	30.2	34.0	400	36.3	0.441	484	6.9	3.6	28.0	26.6	82	56	276	705	10.1	9.2	65
80	32.6	38.2	318	36.5	0.431	512	6.4	2.8	30.3	30.6	58	55	332	788	9.9	8.4	75
90	34.6	42.3	260	36.5	0.422	534	5.9	2.2	32.3	34.7	42	55	387	866	9.6	7.7	85
100	36.3	46.3	218	36.6	0.415	551	5.5	1.8	34.1	38.9	32	54	440	938	9.4	7.2	95
110	37.8	50.1	186	36.6	0.409	565	5.1	1.4	35.6	43.2	25	53	493	1006	9.1	6.8	105
120	39.1	53,8	161	36.6	0.404	577	4.8	1.2	36.9	47.6	20	52	545	1070	8.9	6.4	115
130	40.1	57.5	141	36.6	0.399	586	4.5	0.9	38.0	52.2	16	52	597	1132	8.7	6.2	125
140	41.1	61.0	125	36.6	0.395	594	4.2	0.8	39.0	56.9	13	51	648	1191	8.5	5.9	135
150	41.9	64.5	112	36.6	0.392	600	4.0	0.6	39.9	61.7	11	50	698	1248	8.3	5.7	145
160	42.6	67.8	101	36.6	0.389	606	3.8	0.5	40.6	66.7	-	-	-	1304	8.1	5.6	155

Site index class I[a]

A, years	Stand								Removed part					Total productivity, $m^3 \cdot ha^{-1}$	Total increment, $m^3 \cdot (ha \cdot year)^{-1}$		A, years
	H, m	D, cm	n	G, $m^2 \cdot ha^{-1}$	F	M, $m^3 \cdot ha^{-1}$	Annual increment, $m^3 \cdot (ha \cdot year)^{-1}$		H, m	D, cm	n	m, $m^3 \cdot ha^{-1}$	M, $m^3 \cdot ha^{-1}$		mean	current	
							mean	current									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	3.5	5.2	4269	9.2	-	22	2.2	2.2	3.1	3.7	1509	3	3	23	2.3	23	5
20	9.2	10.0	2760	21.8	0.552	111	5.5	8.9	8.2	7.1	1008	18	21	114	5.7	9.1	15
30	14.2	14.6	1752	29.3	0.523	218	7.3	10.7	12.8	10.5	587	34	55	239	8.0	12.5	25
40	18.3	19.0	1165	33.0	0.500	302	7.6	8.5	16.7	13.9	347	44	99	358	8.9	11.9	35
50	21.8	23.2	819	34.6	0.482	363	7.3	6.1	19.9	17.4	214	49	148	462	9.2	10.5	45
60	24.7	27.3	604	35.4	0.467	408	6.8	4.4	22.7	20.8	139	50	198	555	9.3	9.3	55
70	27.1	31.3	465	35.7	0.455	441	6.3	3.3	25.1	24.4	95	51	249	639	9.1	8.4	65
80	29.2	35.1	371	35.8	0.445	467	5.8	2.6	27.2	28.1	67	50	299	715	8.9	7.6	75
90	31.0	38.8	303	35.9	0.437	487	5.4	2.0	29.0	31.8	49	50	349	786	8.7	7.1	85
100	32.6	42.4	254	35.9	0.430	503	5.0	1.6	30.6	35.6	37	49	398	852	8.5	6.6	95
110	33.9	45.9	217	35.9	0.424	516	4.7	1.3	31.9	39.6	29	48	446	914	8.3	6.2	105
120	35.1	49.3	188	35.9	0.418	527	4.4	1.1	33.1	43.6	23	47	493	973	8.1	5.9	115
130	36.0	52.6	165	35.9	0.414	536	4.1	0.9	34.1	47.8	18	47	540	1029	7.9	5.6	125
140	36.9	55.8	147	35.9	0.410	543	3.9	0.7	35.0	52.1	15	46	586	1083	7.7	5.4	135
150	37.6	59.0	132	35.9	0.407	549	3.7	0.6	35.8	56.5	13	46	632	1135	7.6	5.2	145
160	38.2	62.0	119	35.9	0.404	554	3.5	0.5	36.4	61.0	-	-	-	1186	7.4	5.1	155

Site index class I

A, years	Stand								Removed part					Total productivity, $m^3 \cdot ha^{-1}$	Total increment, $m^3 \cdot (ha \cdot year)^{-1}$		A, years
	H, m	D, cm	n	G, $m^2 \cdot ha^{-1}$	F	M, $m^3 \cdot ha^{-1}$	Annual increment, $m^3 \cdot (ha \cdot year)^{-1}$		H, m	D, cm	n	m, $m^3 \cdot ha^{-1}$	M, $m^3 \cdot ha^{-1}$		mean	current	
							mean	current									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	3.1	4.8	4844	8.7	-	20	2.0	2.0	2.7	3.4	1697	3	3	21	2.1	2.1	5
20	8.2	9.2	3147	20.8	0.564	96	4.8	7.6	7.3	6.5	1144	16	19	99	4.9	7.8	15
30	12.6	13.3	2003	28.0	0.535	189	6.3	9.3	11.4	9.6	668	29	48	207	6.9	10.8	25
40	16.2	17.3	1336	31.5	0.514	263	6.6	7.4	14.8	12.7	395	38	86	311	7.8	10.4	35
50	19.3	21.2	940	33.1	0.497	317	6.3	5.4	17.7	15.8	245	42	128	403	8.1	9.2	45
60	21.8	24.9	696	33.8	0.483	356	5.9	3.9	20.1	19.0	159	44	172	484	8.1	8.2	55
70	24.0	28.4	536	34.1	0.471	386	5.5	3.0	22.3	22.2	109	44	216	558	8.0	7.3	65
80	25.9	31.9	428	34.2	0.461	409	5.1	2.3	24.1	25.5	77	44	260	625	7.8	6.7	75
90	27.5	35.3	351	34.3	0.453	427	4.7	1.8	25.7	28.9	57	43	303	687	7.6	6.2	85
100	28.9	38.5	294	34.3	0.446	442	4.4	1.5	27.1	32.4	43	43	346	745	7.4	5.8	95
110	30.0	41.7	251	34.3	0.440	454	4.1	1.2	28.3	35.9	33	42	388	799	73	5.4	105
120	31.1	44.7	218	34.3	0.435	463	3.9	1.0	29.3	39.6	26	41	429	851	7.1	5.2	115
130	31.9	47.7	192	34.3	0.430	471	3.6	0.8	30.2	43.3	21	41	470	900	6.9	4.9	125
140	32.7	50.6	171	34.3	0.426	478	3.4	0.7	31.0	47.2	17	40	510	947	6.8	4.7	135
150	33.3	53.4	153	34.3	0.423	483	3.2	0.5	31.7	51.1	14	40	550	993	6.6	4.6	145
160	33.8	56.1	139	34.3	0.420	488	3.0	0.4	32.3	55.2	-	-	-	1037	6.5	4.4	155

Site index class II

A, years	Stand								Removed part					Total productivity, $m^3 \cdot ha^{-1}$	Total increment, $m^3 \cdot (ha \cdot year)^{-1}$		A, years
	H, m	D, cm	n	G, $m^2 \cdot ha^{-1}$	F	M, $m^3 \cdot ha^{-1}$	Annual increment, $m^3 \cdot (ha \cdot year)^{-1}$ mean	Annual increment, $m^3 \cdot (ha \cdot year)^{-1}$ current	H, m	D, cm	n	m, $m^3 \cdot ha^{-1}$	M, $m^3 \cdot ha^{-1}$		mean	current	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	2.7	4.4	5378	8.1	-	17	1.7	1.7	2.4	3.1	1865	3	3	18	1.8	1.8	5
20	7.1	8.3	3514	19.2	0.579	79	4.0	6.2	6.3	5.9	1269	13	16	82	4.1	6.4	15
30	11.0	12.1	2245	25.8	0.548	155	5.2	7.6	9.9	8.7	744	24	40	171	5.7	8.9	25
40	14.2	15.7	1501	29.1	0.528	217	5.4	6.2	12.9	11.5	442	31	71	257	6.4	8.6	35
50	16.8	19.2	1059	30.6	0.512	263	5.3	4.5	15.4	14.3	274	35	106	334	6.7	7.7	45
60	19.0	22.5	785	31.2	0.499	296	4.9	3.3	17.5	17.2	179	36	142	402	6.7	6.8	55
70	20.9	25.7	606	31.5	0.488	322	4.6	2.5	19.4	20.1	122	37	179	464	6.6	6.2	65
80	22.6	28.8	484	31.6	0.478	341	4.3	2.0	21.0	23.1	87	36	215	520	6.5	5.6	75
90	24.0	31.8	398	31.7	0.470	357	4.0	1.6	22.4	26.1	64	36	251	572	6.4	5.2	85
100	25.2	34.8	334	31.7	0.464	370	3.7	1.3	23.6	29.2	48	35	286	621	6.2	4.9	95
110	26.2	37.6	286	31.7	0.458	380	3.5	1.0	24.6	32.4	37	35	321	666	6.1	4.6	105
120	27.1	40.3	249	31.7	0.453	389	3.2	0.8	25.5	35.7	30	34	355	710	5.9	4.3	115
130	27.8	43.0	219	31.7	0.448	395	3.0	0.7	26.3	39.0	24	34	389	751	5.8	4.1	125
140	28.4	45.5	195	31.7	0.444	401	2.9	0.6	27.0	42.5	20	33	423	790	5.6	4.0	135
150	29.0	48.0	175	31.7	0.441	406	2.7	0.5	27.6	46.0	16	33	456	829	5.5	3.8	145
160	29.5	50.4	159	31.7	0.438	410	2.6	0.4	28.1	49.6	-	-	-	866	5.4	3.7	155

Site index class III

A, years	Stand								Removed part					Total productivity, $m^3 \cdot ha^{-1}$	Total increment, $m^3 \cdot (ha \cdot year)^{-1}$		A, years
	H, m	D, cm	n	G, $m^2 \cdot ha^{-1}$	F	M, $m^3 \cdot ha^{-1}$	Annual increment, $m^3 \cdot (ha \cdot year)^{-1}$		H, m	D, cm	n	m, $m^3 \cdot ha^{-1}$	M, $m^3 \cdot ha^{-1}$		mean	current	
							mean	current									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	2.3	4.0	5805	7.2	-	15	1.5	1.5	2.0	2.8	1993	2	2	16	1.6	1.6	5
20	6.1	7.6	3812	17.1	0.600	62	3.1	4.7	5.4	5.4	1368	10	12	64	3.2	4.8	15
30	9.4	10.9	2444	23.0	0.561	121	4.0	5.8	8.4	7.9	805	19	31	133	4.4	6.8	25
40	12.1	14.2	1639	25.9	0.542	169	4.2	4.9	11.0	10.4	480	24	55	200	5.0	6.7	35
50	14.3	17.3	1159	27.2	0.528	205	4.1	3.6	13.1	12.9	298	27	82	260	5.2	6.0	45
60	16.2	20.3	861	27.7	0.515	232	3.9	2.7	14.9	15.5	195	28	110	314	5.2	5.4	55
70	17.8	23.1	666	28.0	0.505	252	3.6	2.0	16.5	18.1	133	28	138	362	5.2	4.9	65
80	19.2	25.9	533	28.1	0.496	268	3.4	1.6	17.9	20.7	95	28	167	407	5.1	4.4	75
90	20.4	28.6	439	28.2	0.489	281	3.1	1.3	19.1	23.4	70	28	195	448	5.0	4.1	85
100	21.4	31.2	369	28.2	0.482	291	2.9	1.0	20.1	26.2	53	28	222	486	4.9	3.8	95
110	22.3	33.7	317	28.2	0.477	300	2.7	0.8	21.0	29.0	41	27	249	522	4.7	3.6	105
120	23.1	36.1	276	28.2	0.472	307	2.6	0.7	21.8	31.9	33	27	276	556	4.6	3.4	115
130	23.7	38.4	243	28.2	0.468	312	2.4	0.6	22.4	34.9	26	26	303	589	4.5	3.2	125
140	24.2	40.7	217	28.2	0.464	317	2.3	0.5	23.0	38.0	22	26	329	620	4.4	3.1	135
150	24.7	42.9	195	28.2	0.461	321	2.1	0.4	23.5	41.1	18	26	355	650	4.3	3.0	145
160	25.1	45.0	177	28.2	0.458	324	2.0	0.3	24.0	44.3	-	-	-	679	4.2	2.9	155

Site index class IV

A, years	Stand								Removed part					Total productivity, $m^3 \cdot ha^{-1}$	Total increment, $m^3 \cdot (ha \cdot year)^{-1}$		A, years
	H, m	D, cm	n	G, $m^2 \cdot ha^{-1}$	F	M, $m^3 \cdot ha^{-1}$	Annual increment, $m^3 \cdot (ha \cdot year)^{-1}$		H, m	D, cm	n	m, $m^3 \cdot ha^{-1}$	M, $m^3 \cdot ha^{-1}$		mean	current	
							mean	current									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1.9	3.6	6053	6.1	-	11	1.1	1.1	1.7	2.5	2067	2	2	12	1.2	1.2	5
20	5.0	6.8	3987	14.4	0.637	46	2.3	3.5	4.5	4.8	1424	7	9	48	2.4	3.6	15
30	7.7	9.8	2563	19.3	0.577	86	2.9	4.0	7.0	7.1	840	13	23	96	3.2	4.8	25
40	10.0	12.7	1722	21.8	0.557	121	3.0	3.5	9.1	9.3	501	17	40	143	3.6	4.8	35
50	11.8	15.4	1221	22.9	0.543	147	2.9	2.6	10.8	11.5	312	19	59	187	3.7	4.3	45
60	13.4	18.1	909	23.4	0.532	167	2.8	2.0	12.4	13.8	204	20	79	226	3.8	3.9	55
70	14.7	20.6	705	23.6	0.523	182	2.6	1.5	13.7	16.1	139	20	99	261	3.7	3.5	65
80	15.9	23.1	566	23.7	0.515	194	2.4	1.2	14.8	18.5	99	20	120	293	3.7	3.2	75
90	16.9	25.4	466	23.7	0.508	203	2.3	1.0	15.8	20.9	73	20	140	323	3.6	3.0	85
100	17.7	27.7	393	23.7	0.502	211	2.1	0.8	16.6	23.3	55	20	159	351	3.5	2.8	95
110	18.4	29.9	338	23.7	0.497	217	2.0	0.6	17.4	25.8	43	19	179	377	3.4	2.6	105
120	19.1	32.0	295	23.7	0.492	223	1.9	0.5	18.0	28.3	34	19	198	402	3.3	2.5	115
130	19.6	34.1	260	23.7	0.488	227	1.7	0.4	18.5	31.0	28	19	217	425	3.3	2.4	125
140	20.0	36.1	233	23.7	0.485	231	1.6	0.4	19.0	33.6	23	19	236	448	3.2	2.3	135
150	20.4	38.0	210	23.7	0.482	234	1.6	0.3	19.4	36.4	19	18	254	469	3.1	2.2	145
160	20.8	39.8	191	23.7	0.479	236	1.5	0.2	19.8	39.2	-	-	-	490	3.1	2.1	155

Appendix 2

Tables for biological productivity of modal pine stands of artificial origin in urban forests of Kyiv

(after system of models by Shvidenko, Schepaschenko, Nilsson et al., 2007)

Site index class I^b, relative stocking 0.72

Age, years	Live biomass of a stand, $t \cdot ha^{-1}$									Total live biomass productivity, $t \cdot ha^{-1}$	Current annual increment of live biomass, $t \cdot (ha \cdot year)^{-1}$		Sequestered carbon, $t \cdot ha^{-1}$		Oxygen productivity, $t \cdot ha^{-1}$	
	stand						undergrowth and understorey	live soil cover	total		by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
	aboveground				roots	total										
	stem	branches	needles	total												
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	12.7	2.4	2.0	17.2	2.9	20.0	0.2	0.8	21.1	34.9	3.61	4.79	10.4	17.0	29.47	48.86
20	48.4	6.4	4.5	59.3	10.1	69.4	0.5	1.5	71.3	108.1	5.84	8.24	35.4	52.7	99.834	151.34
30	94.3	10.0	6.2	110.5	19.0	129.4	0.7	2.0	132.2	206.8	6.01	10.47	65.7	100.7	185.024	289.52
40	136.9	12.4	7.0	156.3	26.8	183.1	1.0	2.5	186.6	321.5	4.87	11.80	92.8	156.2	261.184	450.1
50	170.1	13.7	7.2	191.1	32.6	223.6	1.3	2.9	227.8	444.5	3.53	12.47	113.3	215.8	318.864	622.3
60	194.8	14.4	7.1	216.3	36.8	253.1	1.5	3.3	257.9	571.9	2.60	12.82	128.4	277.4	361.088	800.66
70	213.3	14.6	6.9	234.8	39.9	274.7	1.8	3.7	280.2	700.9	1.97	12.93	139.5	339.6	392.252	981.26
80	227.9	14.7	6.6	249.2	42.3	291.5	2.0	4.1	297.6	830.2	1.59	12.91	148.2	401.9	416.668	1162.28
90	239.9	14.7	6.4	261.0	44.4	305.3	2.3	4.5	312.0	958.7	1.34	12.83	155.4	463.7	436.856	1342.18
100	250.1	14.7	6.1	270.9	46.2	317.1	2.5	4.8	324.4	1086.2	1.16	12.72	161.6	524.9	454.188	1520.38
110	259.0	14.5	5.9	279.3	47.5	326.8	2.7	5.0	334.5	1211.3	0.95	12.45	166.6	584.9	468.342	1695.82
120	266.7	14.3	5.6	286.6	48.6	335.2	2.9	5.3	343.4	1334.4	0.83	12.24	171.0	643.7	480.69	1868.16
130	273.6	14.1	5.4	293.1	49.5	342.6	3.0	5.5	351.1	1455.3	0.73	12.03	174.9	701.5	491.54	2037.42
140	279.6	13.9	5.2	298.7	50.3	349.0	3.2	5.7	357.9	1574.3	0.64	11.84	178.3	758.2	501.088	2204.02

Site index class I[a], relative stocking 0.71

Age, years	Live biomass of a stand, t·ha⁻¹									Total live biomass productivity, t·ha⁻¹	Current annual increment of live biomass, t·(ha·year)⁻¹		Sequestered carbon, t·ha⁻¹		Oxygen productivity, t·ha⁻¹	
	stand						undergrowth and understorey	live soil cover	total							
	aboveground				roots	total										
	stem	branches	needles	total							by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	11.0	2.5	2.1	15.6	2.7	18.3	0.2	0.9	19.3	27.3	3.72	4.20	9.5	13.2	27.1	38.2
20	45.2	7.1	5.1	57.5	10.5	68.0	0.4	1.5	69.9	102.0	5.66	8.62	34.6	49.6	97.8	142.8
30	86.3	10.9	6.9	104.2	19.2	123.4	0.6	2.0	126.0	205.5	5.38	10.93	62.6	99.8	176.4	287.7
40	123.4	13.3	7.8	144.6	26.7	171.3	0.8	2.5	174.6	322.7	4.39	11.97	86.8	156.6	244.4	451.8
50	153.8	14.7	8.0	176.5	32.6	209.0	1.0	2.9	213.0	445.5	3.41	12.38	105.9	215.9	298.2	623.7
60	178.3	15.6	8.0	201.9	37.1	238.9	1.3	3.4	243.6	571.1	2.73	12.61	121.2	276.5	341.0	799.5
70	197.8	16.0	7.8	221.6	40.6	262.2	1.5	3.8	267.4	697.9	2.14	12.72	133.1	337.5	374.4	977.1
80	213.3	16.2	7.6	237.1	43.3	280.4	1.7	4.2	286.3	825.6	1.69	12.78	142.5	398.9	400.8	1155.8
90	225.8	16.3	7.3	249.4	45.5	294.8	1.9	4.6	301.3	953.7	1.36	12.82	150.0	460.4	421.8	1335.2
100	235.8	16.3	7.0	259.1	47.3	306.4	2.1	4.9	313.4	1082.2	1.10	12.86	156.0	522.0	438.7	1515.1
110	243.7	16.0	6.7	266.5	48.5	314.9	2.3	5.2	322.4	1209.9	0.81	12.76	160.5	583.1	451.3	1693.9
120	250.2	15.8	6.4	272.4	49.4	321.8	2.4	5.5	329.7	1337.1	0.66	12.69	164.1	643.9	461.5	1871.9
130	255.6	15.5	6.2	277.3	50.2	327.4	2.5	5.7	335.6	1463.4	0.55	12.61	167.1	704.2	469.9	2048.8
140	260.2	15.2	5.9	281.3	50.8	332.0	2.7	5.9	340.6	1589.0	0.46	12.53	169.6	764.2	476.8	2224.6

Site index class I, relative stocking 0.70

Age, years	Live biomass of a stand, $t \cdot ha^{-1}$									Total live biomass productivity, $t \cdot ha^{-1}$	Current annual increment of live biomass, $t \cdot (ha \cdot year)^{-1}$		Sequestered carbon, $t \cdot ha^{-1}$		Oxygen productivity, $t \cdot ha^{-1}$	
	stand						undergrowth and understorey	live soil cover	total							
	aboveground				roots	total										
	stem	branches	needles	total							by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	9.9	2.7	2.3	14.9	2.7	17.6	0.2	0.8	18.6	25.9	3.17	3.90	9.1	12.5	26.0	36.3
20	37.8	6.9	5.1	49.8	9.7	59.5	0.3	1.5	61.2	95.5	4.92	8.03	30.3	46.3	85.7	133.7
30	74.0	10.8	7.0	91.8	18.2	110.0	0.5	2.0	112.5	192.8	5.06	10.31	55.8	93.5	157.4	269.9
40	107.9	13.4	8.0	129.4	25.8	155.2	0.7	2.5	158.3	304.4	4.11	11.43	78.6	147.4	221.7	426.2
50	134.7	14.8	8.3	157.8	31.6	189.4	0.9	2.9	193.1	422.3	2.98	11.90	96.0	204.3	270.4	591.2
60	155.6	15.6	8.2	179.4	35.6	214.9	1.0	3.4	219.3	543.3	2.27	12.16	109.1	262.5	307.1	760.6
70	171.6	15.9	8.0	195.5	38.5	233.9	1.2	3.8	238.9	665.8	1.74	12.30	118.8	321.5	334.5	932.1
80	184.5	16.0	7.7	208.2	40.7	248.9	1.4	4.2	254.5	789.5	1.43	12.40	126.6	380.9	356.3	1105.3
90	195.3	16.1	7.5	218.9	42.5	261.4	1.6	4.6	267.6	914.1	1.23	12.49	133.1	440.6	374.7	1279.7
100	204.8	16.1	7.2	228.1	44.2	272.3	1.8	5.0	279.0	1039.7	1.08	12.58	138.8	500.7	390.7	1455.6
110	212.5	15.9	6.9	235.3	45.5	280.7	1.9	5.3	287.9	1165.0	0.84	12.53	143.3	560.6	403.1	1631.0
120	219.3	15.7	6.6	241.6	46.6	288.2	2.1	5.5	295.7	1290.3	0.74	12.51	147.2	620.5	414.0	1806.4
130	225.3	15.5	6.4	247.2	47.5	294.7	2.2	5.8	302.7	1415.1	0.66	12.48	150.6	680.1	423.7	1981.1
140	230.7	15.3	6.2	252.2	48.3	300.5	2.3	6.0	308.8	1539.8	0.58	12.45	153.7	739.5	432.3	2155.7

Site index class II, relative stocking 0.70

Age, years	Live biomass of a stand, $t \cdot ha^{-1}$									Total live biomass productivity, $t \cdot ha^{-1}$	Current annual increment of live biomass, $t \cdot (ha \cdot year)^{-1}$		Sequestered carbon, $t \cdot ha^{-1}$		Oxygen productivity, $t \cdot ha^{-1}$	
	stand						undergrowth and understorey	live soil cover	total		by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
	aboveground				roots	total										
	stem	branches	needles	total												
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	7.5	2.3	2.0	11.9	2.2	14.1	0.1	0.9	15.1	22.7	2.94	3.47	7.4	10.9	21.1	31.8
20	32.1	6.7	5.0	43.8	8.9	52.7	0.3	1.5	54.5	85.9	4.40	7.34	26.9	41.6	76.3	120.3
30	61.8	10.3	6.8	79.0	16.5	95.5	0.4	2.1	98.0	175.3	4.14	9.49	48.5	84.8	137.1	245.4
40	88.7	12.6	7.7	109.0	23.1	132.1	0.6	2.5	135.2	278.2	3.37	10.56	67.1	134.4	189.3	389.5
50	110.8	13.9	7.9	132.7	28.2	160.9	0.8	3.0	164.6	387.6	2.61	11.07	81.7	187.1	230.5	542.6
60	129.4	14.8	8.0	152.2	32.1	184.3	0.9	3.5	188.6	500.8	2.16	11.41	93.7	241.5	264.1	701.1
70	144.6	15.2	7.8	167.7	35.1	202.8	1.1	3.9	207.7	616.5	1.72	11.64	103.2	297.0	290.8	863.1
80	157.0	15.5	7.6	180.1	37.4	217.5	1.3	4.3	223.1	734.2	1.39	11.82	110.9	353.4	312.3	1027.9
90	167.2	15.6	7.4	190.2	39.2	229.4	1.4	4.7	235.6	853.4	1.14	11.97	117.1	410.5	329.8	1194.8
100	175.6	15.7	7.1	198.4	40.7	239.1	1.6	5.1	245.8	974.0	0.94	12.10	122.3	468.1	344.2	1363.6
110	182.0	15.4	6.8	204.2	41.8	246.0	1.7	5.4	253.2	1094.9	0.67	12.09	125.9	525.9	354.4	1532.9
120	187.3	15.2	6.6	209.0	42.7	251.6	1.8	5.7	259.2	1215.9	0.55	12.09	128.9	583.6	362.8	1702.3
130	191.7	14.9	6.3	212.9	43.3	256.2	1.9	6.0	264.1	1336.7	0.45	12.08	131.4	641.2	369.7	1871.4
140	195.4	14.7	6.0	216.1	43.9	260.0	2.0	6.2	268.2	1457.5	0.38	12.06	133.4	698.7	375.5	2040.5

Site index class III, relative stocking 0.67

Age, years	Live biomass of a stand, t·ha^{-1}									Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·(ha·year)$^{-1}$		Sequestered carbon, t·ha^{-1}		Oxygen productivity, t·ha^{-1}	
	stand						undergrowth and understorey	live soil cover	total		by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
	aboveground				roots	total										
	stem	branches	needles	total												
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	6.2	2.1	1.9	10.2	2.0	12.2	0.1	0.9	13.2	18.9	2.46	2.87	6.5	9.1	18.5	26.5
20	25.4	6.0	4.5	35.9	7.5	43.4	0.3	1.6	45.2	71.4	3.53	6.13	22.3	34.4	63.3	100.0
30	48.4	9.1	6.1	63.6	13.9	77.4	0.4	2.1	79.9	147.8	3.31	8.11	39.5	71.2	111.9	206.9
40	69.4	11.1	6.8	87.3	19.4	106.7	0.5	2.6	109.8	235.1	2.71	8.92	54.4	113.2	153.7	329.1
50	86.7	12.3	7.1	106.1	23.7	129.8	0.7	3.1	133.5	326.9	2.11	9.27	66.2	157.1	186.9	457.7
60	101.6	13.0	7.1	121.7	27.0	148.8	0.8	3.6	153.2	421.4	1.77	9.52	76.0	202.3	214.4	590.0
70	113.9	13.5	7.0	134.4	29.6	163.9	1.0	4.0	168.9	518.0	1.43	9.73	83.9	248.4	236.5	725.2
80	124.0	13.7	6.9	144.5	31.5	176.1	1.1	4.5	181.7	616.7	1.17	9.92	90.2	295.4	254.4	863.4
90	132.4	13.9	6.7	152.9	33.1	186.0	1.3	4.9	192.2	717.1	0.97	10.10	95.5	343.2	269.1	1003.9
100	139.4	13.9	6.5	159.8	34.4	194.2	1.4	5.3	201.0	819.5	0.81	10.29	99.8	391.8	281.4	1147.3
110	144.7	13.8	6.2	164.7	35.4	200.1	1.6	5.7	207.3	922.8	0.58	10.36	103.0	440.8	290.2	1291.9
120	149.1	13.6	5.9	168.7	36.2	204.9	1.7	6.0	212.5	1027.0	0.48	10.44	105.6	490.2	297.5	1437.8
130	152.9	13.4	5.7	172.0	36.8	208.8	1.8	6.2	216.8	1131.9	0.40	10.51	107.7	539.9	303.5	1584.7
140	156.1	13.2	5.5	174.8	37.3	212.1	1.9	6.5	220.4	1237.6	0.34	10.58	109.5	589.9	308.6	1732.6

Site index class IV, relative stocking 0.64

Age, years	Live biomass of a stand, t·ha^{-1}									Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·(ha·year)$^{-1}$		Sequestered carbon, t·ha^{-1}		Oxygen productivity, t·ha^{-1}	
	stand						undergrowth and understorey	live soil cover	total							
	aboveground				roots	total										
	stem	branches	needles	total							by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	5.6	2.2	1.9	9.7	1.9	11.5	0.1	1.0	12.6	19.0	1.97	2.66	6.1	9.1	17.6	26.6
20	19.1	5.0	3.8	28.0	5.9	33.9	0.3	1.7	35.9	63.3	2.49	5.13	17.6	30.3	50.2	88.6
30	35.1	7.4	5.0	47.5	10.5	57.9	0.4	2.3	60.6	125.2	2.41	6.58	29.9	60.0	84.9	175.3
40	50.4	9.0	5.6	65.0	14.6	79.7	0.5	2.9	83.0	197.2	2.08	7.41	41.1	94.4	116.2	276.1
50	63.7	10.1	5.9	79.7	18.1	97.8	0.7	3.3	101.8	274.9	1.70	7.91	50.4	131.5	142.5	384.9
60	75.3	10.9	6.0	92.1	20.9	113.0	0.8	3.9	117.7	356.9	1.44	8.31	58.3	170.5	164.7	499.7
70	84.9	11.3	5.9	102.1	23.1	125.2	1.0	4.4	130.5	442.1	1.16	8.62	64.7	211.1	182.6	618.9
80	92.6	11.6	5.8	110.0	24.8	134.8	1.1	4.9	140.7	530.2	0.92	8.88	69.8	252.8	197.0	742.3
90	98.9	11.7	5.7	116.2	26.1	142.3	1.2	5.3	148.9	620.6	0.74	9.11	73.8	295.7	208.4	868.8
100	103.9	11.8	5.5	121.1	27.2	148.3	1.4	5.8	155.4	713.2	0.59	9.32	77.1	339.5	217.6	998.5
110	107.6	11.6	5.2	124.4	27.9	152.4	1.5	6.1	159.9	806.9	0.40	9.41	79.3	383.8	223.9	1129.7
120	110.6	11.4	5.0	127.0	28.5	155.5	1.6	6.4	163.5	901.7	0.32	9.49	81.1	428.5	228.8	1262.4
130	113.0	11.2	4.8	129.1	28.9	157.9	1.7	6.7	166.3	997.0	0.26	9.56	82.5	473.4	232.8	1395.8
140	115.0	11.0	4.6	130.7	29.2	159.9	1.8	6.9	168.6	1093.0	0.21	9.62	83.6	518.7	236.0	1530.2

Appendix 3

Tables for biological productivity of modal pine stands of artificial origin in urban forests of Kyiv

(after system of models by Lakyda, 1997)

Site index class I^b, relative stocking 0.72

Age, years	Live biomass of a stand, $t \cdot ha^{-1}$									Total live biomass productivity, $t \cdot ha^{-1}$	Current annual increment of live biomass, $t \cdot (ha \cdot year)^{-1}$		Sequestered carbon, $t \cdot ha^{-1}$		Oxygen productivity, $t \cdot ha^{-1}$	
	stand						undergrowth and understorey	live soil cover	total							
	aboveground				roots	total										
	stem	branches	needles	total							by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	12.1	3.9	2.1	18.2	2.2	20.4	0.2	0.8	21.4	35.5	3.63	4.86	10.6	17.3	29.988	49.7
20	46.3	7.3	3.1	56.7	7.5	64.2	0.5	1.5	66.1	103.0	5.18	7.37	32.8	50.2	92.498	144.2
30	91.3	9.7	3.4	104.4	13.9	118.3	0.7	2.0	121.0	187.9	5.52	8.92	60.2	91.6	169.414	263.06
40	134.8	11.0	3.3	149.0	20.1	169.1	1.0	2.5	172.6	284.6	4.76	9.93	86.0	138.8	241.584	398.44
50	170.6	11.4	3.2	185.1	25.4	210.5	1.3	2.9	214.7	388.5	3.77	10.57	107.0	189.4	300.51	543.9
60	199.0	11.4	2.9	213.3	29.9	243.2	1.5	3.3	248.0	497.5	3.02	11.01	123.6	242.4	347.186	696.5
70	222.1	11.2	2.8	236.1	33.9	270.0	1.8	3.7	275.5	609.7	2.57	11.32	137.4	296.9	385.742	853.58
80	242.2	11.1	2.6	255.9	37.9	293.7	2.0	4.1	299.8	724.7	2.34	11.55	149.5	352.7	419.776	1014.58
90	260.4	11.0	2.5	273.9	41.9	315.8	2.3	4.5	322.5	841.4	2.22	11.74	160.8	409.2	451.486	1177.96
100	277.6	10.9	2.4	290.9	46.1	337.0	2.5	4.8	344.3	960.2	2.16	11.92	171.7	466.7	482.006	1344.28
110	294.0	10.9	2.4	307.3	50.5	357.8	2.7	5.0	365.6	1080.1	2.11	12.05	182.3	524.6	511.77	1512.14
120	309.9	10.9	2.4	323.2	55.2	378.4	2.9	5.3	386.6	1201.7	2.09	12.18	192.8	583.3	541.17	1682.38
130	325.4	11.0	2.4	338.7	60.3	399.0	3.0	5.5	407.5	1324.4	2.09	12.33	203.2	642.4	570.486	1854.16
140	340.5	11.1	2.4	353.9	65.7	419.6	3.2	5.7	428.5	1448.9	2.10	12.49	213.7	702.4	599.872	2028.46

Site index class I^a, relative stocking 0.71

Age, years	Live biomass of a stand, $t \cdot ha^{-1}$									Total live biomass productivity, $t \cdot ha^{-1}$	Current annual increment of live biomass, $t \cdot (ha \cdot year)^{-1}$		Sequestered carbon, $t \cdot ha^{-1}$		Oxygen productivity, $t \cdot ha^{-1}$	
	stand						undergrowth and understorey	live soil cover	total							
	aboveground				roots	total										
	stem	branches	needles	total							by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0
10	10.3	3.8	2.1	16.2	2.1	18.3	0.2	0.9	19.3	27.2	3.67	4.17	9.5	13.2	27.0	38.1
20	42.7	7.8	3.2	53.7	7.8	61.5	0.4	1.5	63.4	94.3	4.91	7.50	31.4	45.9	88.7	132.0
30	82.7	10.1	3.5	96.2	14.2	110.4	0.6	2.0	113.0	180.8	4.86	9.04	56.2	88.1	158.2	253.1
40	120.2	11.2	3.4	134.9	20.2	155.1	0.8	2.5	158.4	276.7	4.24	9.76	78.9	134.8	221.7	387.4
50	152.7	11.7	3.2	167.6	25.6	193.1	1.0	2.9	197.1	377.1	3.58	10.15	98.2	183.7	275.9	527.9
60	180.0	11.8	3.0	194.9	30.4	225.3	1.3	3.4	230.0	480.9	3.06	10.46	114.6	234.1	321.9	673.3
70	203.3	11.8	2.9	218.0	35.0	253.0	1.5	3.8	258.3	587.5	2.66	10.76	128.7	285.9	361.6	822.5
80	223.4	11.8	2.8	237.9	39.4	277.3	1.7	4.2	283.2	697.4	2.37	11.07	141.2	339.1	396.4	976.4
90	241.2	11.7	2.7	255.5	43.7	299.2	1.9	4.6	305.7	810.3	2.16	11.40	152.4	393.8	428.0	1134.4
100	257.2	11.6	2.6	271.4	48.1	319.5	2.1	4.9	326.5	926.8	2.02	11.74	162.8	450.1	457.1	1297.5
110	271.9	11.6	2.5	285.9	52.6	338.5	2.3	5.2	346.0	1046.4	1.91	12.06	172.5	507.8	484.4	1465.0
120	285.5	11.5	2.5	299.6	57.3	356.9	2.4	5.5	364.7	1169.3	1.85	12.38	181.9	567.2	510.6	1637.0
130	298.5	11.6	2.5	312.5	62.3	374.8	2.5	5.7	383.0	1295.4	1.82	12.72	191.0	628.1	536.3	1813.6
140	310.9	11.6	2.5	325.0	67.6	392.6	2.7	5.9	401.2	1425.1	1.81	13.06	200.1	690.7	561.6	1995.1

Site index class I, relative stocking 0.70

Age, years	Live biomass of a stand, t·ha^{-1}									Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·(ha·year)$^{-1}$		Sequestered carbon, t·ha^{-1}		Oxygen productivity, t·ha^{-1}	
	stand						undergrowth and understorey	live soil cover	total		by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
	aboveground				roots	total										
	stem	branches	needles	total												
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.0
10	9.3	4.0	2.2	15.5	2.2	17.7	0.2	0.8	18.7	25.8	3.13	3.88	9.2	12.5	26.1	36.1
20	35.7	7.6	3.1	46.4	7.4	53.8	0.3	1.5	55.6	88.3	4.26	6.98	27.5	42.9	77.8	123.6
30	70.9	10.1	3.4	84.5	13.9	98.4	0.5	2.0	100.9	169.2	4.57	8.49	50.1	82.4	141.2	236.9
40	105.4	11.5	3.4	120.3	20.2	140.6	0.7	2.5	143.7	260.0	3.98	9.27	71.5	126.6	201.2	364.0
50	134.3	12.0	3.3	149.5	25.7	175.3	0.9	2.9	179.0	355.8	3.17	9.71	89.2	173.2	250.6	498.1
60	157.3	12.1	3.1	172.4	30.4	202.8	1.0	3.4	207.2	455.6	2.56	10.07	103.2	221.6	290.1	637.8
70	176.1	12.0	2.9	190.9	34.6	225.6	1.2	3.8	230.6	558.5	2.19	10.40	114.9	271.5	322.8	781.9
80	192.4	11.8	2.7	206.9	38.7	245.6	1.4	4.2	251.3	665.1	2.00	10.75	125.2	323.1	351.8	931.1
90	207.2	11.7	2.6	221.6	42.9	264.5	1.6	4.6	270.7	775.1	1.90	11.13	134.9	376.4	378.9	1085.1
100	221.2	11.7	2.6	235.4	47.3	282.7	1.8	5.0	289.4	889.2	1.86	11.53	144.3	431.5	405.2	1244.9
110	234.6	11.7	2.5	248.8	51.9	300.6	1.9	5.3	307.8	1007.0	1.83	11.89	153.4	488.4	431.0	1409.8
120	247.5	11.7	2.5	261.7	56.8	318.5	2.1	5.5	326.1	1128.7	1.83	12.27	162.6	547.2	456.5	1580.2
130	260.1	11.8	2.5	274.4	62.1	336.5	2.2	5.8	344.4	1254.0	1.84	12.67	171.7	607.7	482.2	1755.6
140	272.5	11.9	2.5	286.9	67.7	354.6	2.3	6.0	362.9	1383.6	1.86	13.07	180.9	670.3	508.0	1937.0

Site index class II, relative stocking 0.70

Age, years	Live biomass of a stand, t·ha^{-1}									Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·(ha·year)$^{-1}$		Sequestered carbon, t·ha^{-1}		Oxygen productivity, t·ha^{-1}	
	stand						undergrowth and understorey	live soil cover	total							
	aboveground				roots	total										
	stem	branches	needles	total							by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.0
10	7.0	3.6	1.9	12.5	1.9	14.4	0.1	0.9	15.4	23.0	2.97	3.51	7.6	11.1	21.5	32.2
20	30.1	7.6	3.1	40.8	7.3	48.0	0.3	1.5	49.8	80.3	3.81	6.43	24.7	39.0	69.7	112.4
30	58.8	10.1	3.3	72.2	13.4	85.7	0.4	2.1	88.2	155.2	3.74	7.87	43.8	75.4	123.4	217.3
40	86.1	11.3	3.3	100.6	19.2	119.9	0.6	2.5	123.0	239.7	3.26	8.64	61.2	116.4	172.2	335.6
50	109.8	11.8	3.1	124.7	24.5	149.2	0.8	3.0	152.9	329.5	2.78	9.13	76.1	160.1	214.1	461.3
60	130.0	12.0	3.0	144.9	29.3	174.2	0.9	3.5	178.5	424.1	2.40	9.57	88.9	205.9	249.9	593.7
70	147.3	12.0	2.8	162.1	33.7	195.9	1.1	3.9	200.8	522.6	2.11	9.99	100.0	253.6	281.2	731.6
80	162.4	11.9	2.7	177.1	38.1	215.1	1.3	4.3	220.7	625.6	1.90	10.42	110.0	303.4	309.0	875.8
90	175.8	11.9	2.6	190.3	42.4	232.7	1.4	4.7	238.8	732.7	1.75	10.85	119.0	355.2	334.4	1025.8
100	187.9	11.8	2.6	202.3	46.7	249.0	1.6	5.1	255.7	844.5	1.65	11.31	127.4	409.2	358.0	1182.3
110	199.0	11.8	2.5	213.3	51.2	264.5	1.7	5.4	271.7	960.3	1.56	11.72	135.4	465.2	380.3	1344.4
120	209.3	11.8	2.5	223.6	55.9	279.5	1.8	5.7	287.0	1080.6	1.52	12.14	143.0	523.2	401.9	1512.8
130	219.1	11.9	2.5	233.4	60.9	294.3	1.9	6.0	302.1	1204.9	1.50	12.57	150.6	583.2	423.0	1686.9
140	228.4	11.9	2.5	242.8	66.1	308.9	2.0	6.2	317.1	1333.7	1.50	13.01	158.1	645.4	444.0	1867.2

Site index class III, relative stocking 0.67

Age, years	Live biomass of a stand, t·ha^{-1}									Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·(ha·year)$^{-1}$		Sequestered carbon, t·ha^{-1}		Oxygen productivity, t·ha^{-1}	
	stand						undergrowth and understorey	live soil cover	total							
	aboveground				roots	total										
	stem	branches	needles	total							by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.0
10	5.7	3.6	1.9	11.2	1.9	13.0	0.1	0.9	14.0	19.8	2.59	3.02	6.9	9.5	19.6	27.7
20	23.6	7.4	2.9	33.8	6.8	40.6	0.3	1.6	42.4	69.0	3.09	5.55	21.0	33.3	59.4	96.6
30	45.7	9.6	3.1	58.4	12.4	70.9	0.4	2.1	73.4	135.2	3.02	6.94	36.4	65.4	102.7	189.3
40	66.8	10.7	3.1	80.6	17.8	98.4	0.5	2.6	101.6	209.2	2.65	7.53	50.5	101.3	142.2	292.9
50	85.3	11.3	3.0	99.5	22.7	122.2	0.7	3.1	125.9	286.9	2.27	7.88	62.6	138.8	176.3	401.7
60	101.2	11.5	2.8	115.5	27.2	142.6	0.8	3.6	147.0	368.3	1.98	8.23	73.2	178.1	205.8	515.6
70	114.9	11.5	2.7	129.1	31.4	160.5	1.0	4.0	165.5	453.1	1.75	8.60	82.4	219.0	231.7	634.3
80	126.9	11.5	2.6	141.0	35.5	176.5	1.1	4.5	182.1	542.0	1.59	9.00	90.7	261.8	254.9	758.8
90	137.6	11.5	2.5	151.6	39.6	191.2	1.3	4.9	197.4	634.9	1.48	9.44	98.3	306.5	276.3	888.9
100	147.3	11.4	2.4	161.2	43.7	204.9	1.4	5.3	211.7	732.6	1.40	9.90	105.4	353.4	296.4	1025.6
110	156.3	11.4	2.4	170.1	48.0	218.1	1.6	5.7	225.3	834.5	1.34	10.33	112.2	402.4	315.4	1168.3
120	164.6	11.4	2.4	178.4	52.5	230.9	1.7	6.0	238.5	941.1	1.31	10.78	118.7	453.5	333.8	1317.5
130	172.5	11.5	2.4	186.3	57.2	243.5	1.8	6.2	251.4	1052.0	1.29	11.24	125.2	506.8	352.0	1472.8
140	180.0	11.6	2.4	193.9	62.1	256.1	1.9	6.5	264.4	1167.9	1.30	11.72	131.7	562.5	370.1	1635.1

Site index class IV, relative stocking 0.64

Age, years	Live biomass of a stand, t·ha^{-1}									Total live biomass productivity, t·ha^{-1}	Current annual increment of live biomass, t·(ha·year)$^{-1}$		Sequestered carbon, t·ha^{-1}		Oxygen productivity, t·ha^{-1}	
	stand						undergrowth and understorey	live soil cover	total		by current stock	by total productivity	by current stock	by total productivity	by current stock	by total productivity
	aboveground				roots	total										
	stem	branches	needles	total												
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	0.0
10	5.0	4.1	2.1	11.2	2.0	13.2	0.1	1.0	14.3	20.9	2.21	2.96	7.0	10.0	20.0	29.3
20	17.3	6.9	2.7	26.9	6.2	33.1	0.3	1.7	35.0	64.7	2.19	4.88	17.3	31.1	49.0	90.6
30	32.3	8.7	2.8	43.7	10.8	54.6	0.4	2.3	57.2	121.0	2.21	5.92	28.4	58.3	80.1	169.4
40	47.2	9.7	2.7	59.6	15.5	75.2	0.5	2.9	78.5	185.1	2.05	6.59	39.0	89.2	109.9	259.1
50	60.9	10.3	2.6	73.8	20.0	93.8	0.7	3.3	97.8	254.6	1.83	7.11	48.6	122.6	136.9	356.4
60	73.0	10.6	2.5	86.1	24.2	110.3	0.8	3.9	114.9	329.2	1.62	7.59	57.1	158.5	160.9	460.9
70	83.5	10.7	2.4	96.6	28.1	124.7	1.0	4.4	130.1	408.4	1.43	8.07	64.7	196.5	182.1	571.8
80	92.6	10.7	2.4	105.7	32.0	137.6	1.1	4.9	143.6	492.5	1.28	8.54	71.4	236.8	201.0	689.5
90	100.5	10.7	2.3	113.5	35.7	149.2	1.2	5.3	155.8	581.1	1.17	9.01	77.4	279.3	218.1	813.5
100	107.6	10.7	2.2	120.5	39.4	159.9	1.4	5.8	167.0	674.7	1.09	9.50	83.0	324.2	233.8	944.6
110	113.9	10.7	2.2	126.7	43.2	169.9	1.5	6.1	177.5	772.6	1.03	9.93	88.3	371.0	248.5	1081.6
120	119.7	10.7	2.2	132.5	47.1	179.6	1.6	6.4	187.6	875.0	1.00	10.36	93.3	420.1	262.6	1225.0
130	125.1	10.7	2.2	137.9	51.2	189.1	1.7	6.7	197.5	981.5	0.98	10.80	98.2	471.1	276.4	1374.1
140	130.3	10.7	2.2	143.1	55.5	198.6	1.8	6.9	207.3	1092.7	0.99	11.24	103.1	524.4	290.2	1529.8