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Growth and productivity of larch stands in conditions of urbanized environment, in European Russia

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Abstract

Urban forests have great ecological value as facilities for maintaining a favorable environment for the life of citizens. The development of industrial production, increased traffic flows lead to air pollution of cities, which contributes to a decrease in the productivity of stands, an increase in the decline, a decrease in growth. The aim of the work is to analyze the growth and productivity of larch stands under different anthropogenic influences and develop recommendations for increasing their stability and durability. The materials for the study were data from the repeated measurements of permanent inventory plots at the Experimental Forest District of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy and forest areas of the Moscow Region. The growth of stands of mean height in the permanent inventory plots doesn't correspond to the scale of site class determination: first, the forest site index is upgraded, and then it is declined. The results of the analysis of growth and productivity of larch stands have shown that these trees can be recommended for use in urban landscaping, as they demonstrate high resistance to adverse effects. Mixed pine-larch stands are the most promising for urban landscaping.

Keywords: Larch stands, urbanized environment, growth, productivity

Introduction

At the present stage of development of urbanized territories, the full utilization of various useful functions of green plantations forming the basis of city ecological nets, has become of particular urgency. Growing stock production is not the main function for recreational forests, the most important are their sanitary-hygienic, aesthetic, oxygen-producing and other useful functions (Liepa 1980). Achieving the optimal combination of useful functions is possible in the case of learning the dynamics of the production process of urbanized forest plantations and increasing their longevity and environmental sustainability.

Population growth and its migration to cities contribute to an increase of urbanized areas and anthropogenic transformation of natural landscapes. In the period from 1950 to 2014, the world population increased from 2.53 to 7.24 billion, with the proportion of people living in cities – from 29.6% to 53.6% (United Nations… 2015). According to the Federal State Statistics Service in 2017, 74.3% of Russia's population lived in urban areas. The area of the city of Moscow is 0.01% of the area of Russia, and 8.5% of the population of the country lives there. So the issue of maintaining a favorable state of the environment for the life of citizens is especially acute.

Analysis of the growth processes of stands is possible only in case of regular observations. Such materials have been accumulated in the Experimental Forest District of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy for 150 years of repeated inventory of permanent inventory plots. The aim of the work is to analyze the growth and productivity of larch stands under different anthropogenic influences and develop recommendations for increasing their stability and durability.

Materials and methods

The materials for the study were data from the inventory of permanent trial plots at the Experimental Forest District of the RSAU-MTAA located in the north-west of the city of Moscow. According to the results of the forest inventory in 2009, the area of the Experimental Forest District is 248.7 ha, including 233.4 ha (93.8%) of the forest-covered land. The most valuable stands of larch grow on an area of 34.8 ha with a total stand volume of 11900 m^3.

The first permanent inventory plots were laid in 1862 in the process of arrangement of the Petrovsky Forest District by Alfons R. Vargas de Bedemar. Later on, the studies were continued by professors Mitrofan K. Tursky, Nikolai S. Nesterov, Vladimir P. Timofeev. From the beginning of the XX century regular measurements were taken with an interval of 5–15 years on the permanent inventory plots of the Experimental Forest District. The data for counting on 16 permanent inventory plots, including 13 permanent inventory plots in pure larch plantations and 3 in mixed plantations of Scots pine and larch are used in this work.

To compare the results obtained on the permanent inventory plots of the Experimental Forest District, with the growth and productivity of the plantation forests under conditions with less anthropogenic impact, the forest measurements data on the permanent inventory plots of the Moscow region (Schelkovo Training and Experimental Forestry, Poretsky Forest District, Vinogradovsky forestry) have been used.

Larch stands on permanent inventory plots grow on sod-podzolic soils. In the ground cover of the permanent inventory plots of the Forest Experimental District, the predominant species are *Aegopodium podagraria*, *Lamium galeobdolon*, *Impatiens parviflora* and *Oxalis acetosella*. According to the system of forest types Vladimir N. Sukachov (1972) permanent inventory plots belong to the indigenous type of forest complex pine.

The alignment of the dependence of the mean heights on age was carried out using the growth function of Mitcherlich:

$$H = a_0(1 - \exp(-a_1 A))^{a_2} ,$$

where H – mean heights, m; A – age, year; a – model parameters.

Comparing the growth of stands of mean height on permanent inventory plots with the mean lines of the forest site classes was based on the aligned and enlarged scale of distribution of seed and coppice plantings according to the Michael M. Orlov forest site classes (Shvidenko et al. 2006) was based.

The growing stock of stands was calculated by multiplying the sum of the basal area by the form height. Dependence of the form height (HF) on the mean height (H) of the stands was obtained from regional tables for larch plantations of the European part of Russia (Shvidenko et al. 2006):

$$HF = 0{,}5608 + 0{,}4564H .$$

Oxygen production by stands was estimated according to the increment of net primary production (NPP) of phytomass of absolutely dry matter. It has been noted by many authors (Liepa 1980, Liepa et al. 1997, Voroncov et al. 1971) that when 1 ton of absolutely dry organic matter is formed, 1393–1423 kg of oxygen is released. The amount of oxygen released by the stand over the entire period of its existence was calculated through the total NPP. Taking into account that in urban forests only dead trees are harvested, and roots, falling branches and needles are left on the ground, and their further natural decomposition take place with the absorption of atmospheric oxygen, then the positive oxygen effect at the local level is manifested through the NPP of the trunks.

Results

The analysis of the growth series shows that in the stands of larch growth at a mean height doesn't correspond to lines from the scale of forest site index (Figure 1). In nature, there is a large number of different forms of growth curves, which are a combination of genetic features of trees and environmental conditions (Kuzmichev 1977, Donis et al. 2012). Initially, there is a gradual increase in the site classes (up to I^b–I^c class), and then there is a decrease (to I–II class). The age of the maximum of the dependence curve of the forest site index on age varies. For example, on a permanent inventory plot of 11/T, the inflection point has not been reached by the age of 140 years, and on a permanent inventory plot of 5/C the inflection point corresponds to the age of 65 years. The discrepancy between the growth trajectories of the stands and the lines of the dependence of the average height on age in the scale of forest site classes is noted in the works of many authors (Kuzmichev 2013, Khlyustov et al. 2016). But at the same time, the scale of forest site class determination is considered to be generally accepted and the most widespread classification system for the conditions of places of growing stands.

Growing stock increment is one of the main criteria for assessing the impact of natural and anthropogen-

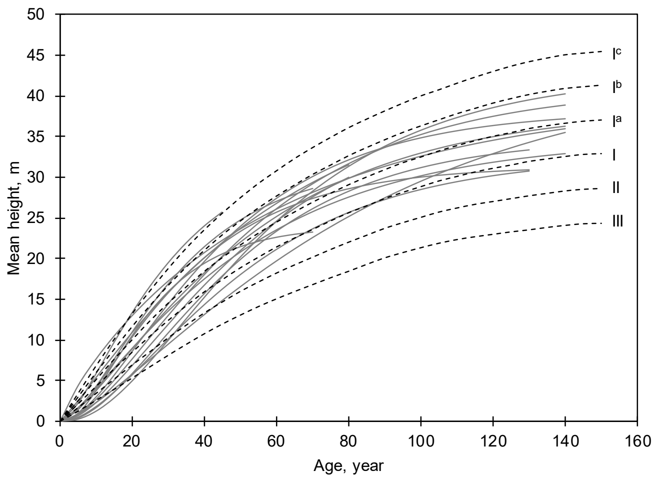

Figure 1. Growth of larch plantations of mean height

Gray line – plantations, black dotted line – scale of forest site classes.

ic factors on forest stands (Liepa 1980). In the stands of larch on permanent inventory plots, one maximum of the curve of the dependence of the growing stock current increment on age is formed. The average age of the maximum is 41±4 years, and the maximum growing stock increment is 10.7±0.8 m³·ha⁻¹. The average correlation between the year of creation of plantation forests and the age of the onset of the maximum of the growing current increment stock (r = –0.545) was revealed. The weak connection was revealed between the year of forest cultures creation and the magnitude of the growing stock increment (r = –0.360). Thus, in the stands created in the 1930–1970's, aging is faster than in the stands created in the 1870s and 1890s. The effect of the initial planting density on the maximum value of the growing stock increment and the age of its onset was not revealed (range of initial stocking densities varied from 700 to 4500 trees per hectare).

The change in the growing stock with age in larch stands is influenced by both internal factors – the planting density, and external ones – the level of anthropogenic impact (Figure 2). The stands of larch in the Moscow city are durable. In 130–140 summer, pure stands of *Larix sibirica* or *Larix decidua*, the process of stock accumulation is observed. Mixed plantings of *Larix sibirica* and *Larix deciduas* are less durable in comparison with them. For example, on the permanent inventory plot 5/R_2 at the age of 130 years, the growing stock was 965 $m^3 \cdot ha^{-1}$, and at the age of 140 years – 1030 $m^3 \cdot ha^{-1}$ (Figure 2).

The larch plantations in the Experimental Forest District are not inferior to the productivity of larch of local origin in the plantings of the Vinogradovsky forestry of the Moscow Region (Table 1). Since the density of planting in the Vinogradovsky forestry forest cultures is much higher than in the Experimental Forest District, here the first maximum of the curve of the dependence of the growing stock increment on age is formed by the age of 20–35. It is possible that in the future, after stabilization of the population size by intensive mortality, another wave of growth will occur, which will lead to the formation of the second maximum of the growing stock increment curve.

In mixed pine-larch stands with the understory of broadleaf species, the growing stock increment of the larch generation is formed somewhat differently than in pure plantings (Figure 3). For example, in the stand of pine and larch on the permanent inventory plot of 13/Z, the maximum of the curve of the growing stock current increment of the larch generation has not been achieved by the age of 140 years. As it was mentioned earlier, in the pure stands of larch the average age of the maximum of the curve of the growing stock increment is 41±4 years. At the same time, two maxima were formed in the curve of the growing stock current increment of the pine generation in 20 years (10.4 $m^3 \cdot ha^{-1}$) and 120 years (0.2 $m^3 \cdot ha^{-1}$).

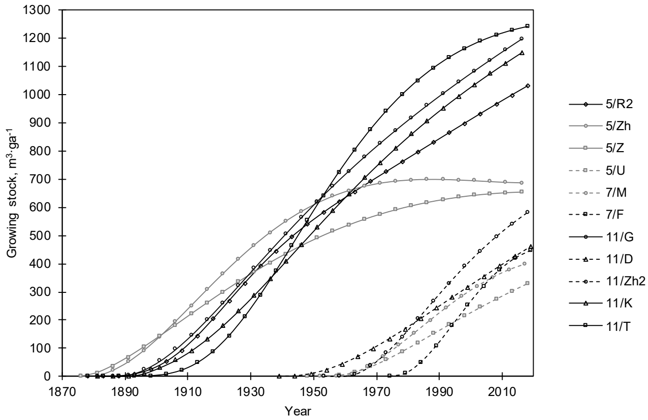

Figure 2. Dynamics of larch growing stock on permanent inventory plots

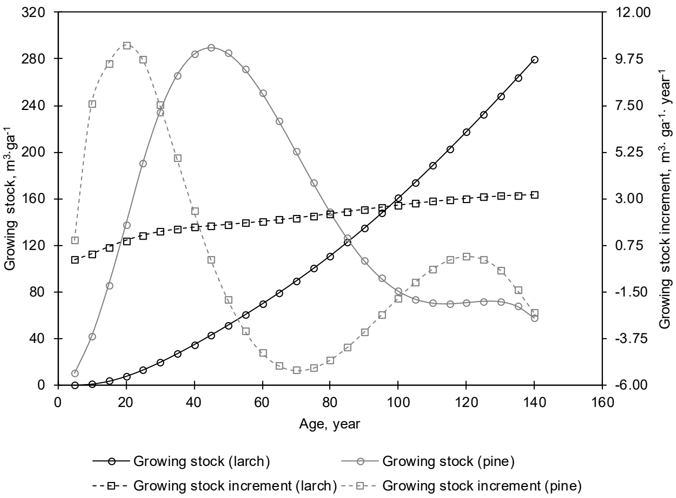

Figure 3. Dynamics of growing stock and growing stock current increment in mixed stands of plantation forests of pine and larch (permanent inventory plot 13/Z)

Table 1. Productivity of larch stands of Vinogradovsky forestry of Moscow Region

Age, years	Area №7 (*Larix sibirica*)		Area №8 (*Larix sibirica*)		Area №18 (*Larix decidua*)		Area №24 (*Larix decidua*)		Area №36 (*Larix sibirica*)		Area №37 (*Larix decidua*)	
	M	Z	M	Z	M	Z	M	Z	M	Z	M	Z
10	33	9,8	40	10,3	33	10,3	44	11,5	20	8,9	73	16,5
15	100	15,7	106	15,2	104	17,3	120	18,7	89	17,8	173	22,4
20	190	18,5	192	17,5	206	21,6	231	24,5	198	23,0	297	25,8
25	284	17,9	281	17,4	321	22,6	365	28,2	319	22,9	431	26,5
30	369	15,2	365	15,8	432	20,8	513	30,0	426	18,5	562	25,2
35	436	11,6	439	13,5	529	17,4	665	30,0	504	12,2	683	22,8
40	485	7,7	500	10,8	606	13,3	813	28,8	548	5,5	790	19,8
45	513	3,8	547	7,7	662	9,0	953	26,6	560	-0,2	881	16,6
50	522	0,1	577	4,5	696	5,1	1079	23,7	546	-4,6	956	13,3
55	514	-2,4	592	2,2	712	1,6	1190	20,6	514	-7,6	1015	10,3
60	498	-3,0	599	1,6	713	-1,1	1285	17,6	470	-9,4	1059	7,7

Comment: M – stand volume, $m^3 \cdot ha^{-1}$; Z – growing stock current increment, $m^3 \cdot ha^{-1} \cdot yr^{-1}$.

Pine is characterized by a higher growth rate than larch. As a result, the destruction of the pine generation begins much earlier. On a permanent inventory plot 13/Z, up to 80 years, the pine generation exceeds the larch stock in terms of stock. The maximum reserve of a pine generation was reached at the age of 45 years (289 $m^3 \cdot ha^{-1}$), followed by its destruction. After 80 years, the larch generation is characterized by maximum productivity. For example, at the age of 100 years the growing stock of pine was 80 $m^3 \cdot ha^{-1}$, and the reserve of larch – 160 $m^3 \cdot ha^{-1}$.

Similar results were obtained when analyzing the dynamics of productivity of mixed pine-larch stands of the Vinogradovsky forestry of the Moscow Region and the stands of Karl F. Tyurmer in the Poretsky Forest District. It should be noted that mixed pine-larch stands with a understory of broad-leaved species in urban conditions are promising, as pine compensates for low larch productivity in youth, and by the time of complete destruction of the pine generation, larch has formed maximally productive stands. Maple and linden in the second layer under the openwork crowns of the first layer trees improve protective, sanitary, hygienic and recreational functions of the plantings.

The estimates of oxygen productivity of larch stands obtained in the work are conditional, since at present there are many uncertainties in the determination of both the phytomass of the growing part of the stands and the NPP. One can single out the following reasons, leading to the uncertainty: a large number of field research methods, each having different accuracy; the use of heterogeneous and unbalanced samples in modeling; the use of incorrectly specified models to describe the dependence of phytomass or NPP on predictors, and others. In addition, in our case it is impossible to estimate the influence of the complex of anthropogenic factors on the phytomass and NPP of forest stands.

An analysis of the dynamics of oxygen production showed that the maximum amount of oxygen produced by pure larch stands on permanent inventory plots corresponds to the age from 50 to 70 years (15–20 $tons \cdot ha^{-1}$). From 40 to 50% of the released oxygen is formed due to the increase of the organic matter in trunks wood.

Conclusions

1. Materials of long-term observations on permanent inventory plots of the Experimental Forest District show that the scale of forest site classes doesn't reflect the whole variety of possible growth trajectories of larch stands. The growth of the mean height is influenced by the genetic features of trees and the conditions of the urban environment. With the increase in age, first, the class of forest site classes increases toward maximum productivity, and then it decreases.

2. The results of the analysis of growth and productivity of larch stands of different planting density demonstrate their high resistance to the conditions of the urbanized environment, which allows them to be recommended for use in urban greening. One of the significant factors that can limit the use of larch in green planting is the strong windiness of large trees.

3. Mixed pine-larch stands with a second layer of broad-leaved species, which improve the environment forming, protective, sanitary-hygienic and recreational functions are promising in urban conditions. Pine compensates for low larch productivity in youth, and by the time of complete destruction of pine generation larch forms the most productive stands.

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