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The role of planted forests in improving the productive capacity and ecological potential of Scots pine boreal forests in the Middle Volga Region

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Abstract

Background: Russia's boreal forests are a major source of timber as well as being a large terrestrial sink for carbon. Planted forests have played an important role in increasing the overall area of the Russian boreal forest. The total area of planted stands in republics and oblasts of the Middle Volga Region is about 3.2 million ha. Scots pine (*Pinus sylvestris* L.) is the most widespread species in planted forests of the Middle Volga Region. As a result of its mass planting since the 1950s, the proportion of pine forests increased from 21 to 29 %. In order to justify the continued use of artificial regeneration to re-establish forests after harvest, more information is required on the growth and yield of planted and natural Scots pine forests. Therefore, the main objective of this study was to quantify and compare the productivity of planted Scots pine forests with that of natural forests in the Middle Volga Region.

Methods: Data were obtained from seven representative forests in the republics and oblasts of the Middle Volga Region spanning the period between 1961 and 2007. The relationship between total standing volume and stand age was modelled for both planted and natural stands of Scots pine using the nonlinear Mitscherlich equation.

Results: Planted Scots pine forests generally have a higher relative stand density than natural forests, due to the presence of natural regeneration in planted stands. Mean annual volume increment of planted Scots pine forests was 5.6–9.2 m^3/ha, which is approximately 15 % greater than the volume increment of natural Scots pine forests.

Conclusions: Artificial stands are of high importance for maintenance of resource potential of Russian boreal forests. Mathematical and statistic calculations show benefits of planted Scots pine in comparison with natural pines in height, volume, density, productivity and growing stock increment. The achieved results suggest that wood can be obtained at an earlier age from planted forests thus preserving natural boreal forests.

Keywords: Scots pine, Planted forest, Natural forest, Restoration, Boreal forests

Background

Two thirds of all boreal forests globally grow in the territory of Russia (Olsson, 2009). In addition to providing a source of timber, they play a crucial role in sequestering carbon. The utility of boreal forests in effectively absorbing carbon dioxide provides an incentive to preserve and restore these valuable forest ecosystems in a sustainable manner. Planting is an important method of forest rehabilitation, and planted forests have a special importance in the Middle Volga Region, which is a region of active forest management.

The Middle Volga Region is located between 54° and 58° N and between 44° and 52° E and encompasses territories adjacent to the Volga Region in the European part of Russia (Fig. 1). These include the Republic of Mari El, the Chuvash Republic, the Republic of Tatarstan and the Nizhny Novgorod oblast.[1] The total area of the Middle Volga Region is more than 360,000 km^2, of which natural and planted forests cover about 36.5 %. Within this region, there are areas with different climatic zones as well as different soil and ecological conditions.

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Fig. 1 Location of the Middle Volga Region within the Russian Federation

The climate of the Middle Volga Region is classified as a warm summer subzone of the mid-latitude zone. It is moderately continental with warm summers, moderately cold winters and relative humidity between 50 and 70 %. The temperature is below freezing for a long period each year and snow cover is typical. Mean annual air temperature in the region varies from 1.1 to 3.0 °C. The average number of days per year when the temperature is above +10 °C is approximately 110–130. Forest species composition varies, but boreal forest with coniferous species (pines, spruces and larches) dominates. A quarter of Russian-planted forests are currently established in the Middle Volga Region, with Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) as the most widespread species. The Scots pine planted in The Middle Volga Region boreal forests accounts for 8 % in the Kirov Region to 32.5 % in the Chuvash Republic of the area of all pine forests (both planted and natural). Norway spruce is a less common species for planted forests but 60 % of Norway spruce forests are planted.

The forest communities of the Middle Volga Region are not high in biodiversity but are dominated by species that grow quickly and that naturally reproduce. The species composition of forests in the Middle Volga Region has changed since the 1950s mostly due to clearance of large areas of natural forest aimed at restoring the national economy after the Second World War. This issue affects spruce forests, in particular, as they grow in more fertile soils. Silver birch (*Betula pendula* Roth) is an early coloniser of bare ground so the forest area in this species increased from 17 % in 1942 to 23 % in 2007. The area of Scots pine plantations increased from 21 % in 1942 to 29 % in 2007 in four republics and oblasts of the Middle Volga Region (the Nizhny Novgorod oblast, the Republic of Mari El, the Chuvash Republic and the Republic of Tatarstan). Over a 65-year period, the overall proportion of coniferous forest remained the same due to reforestation work and timely planting of seedlings.

Cultivation of softwood trees is a long, complex and costly process in boreal and temperate zones. Dry periods in spring and summer, competition from hardwoods, susceptibility to diseases and pests attacks and forest fires are the main risks for cultivation of planted forests. Despite these risks, planted forests make an important contribution to the Russian boreal forest resource. The total area of forests in the Middle Volga Region increased 12–23-fold during the last 65 years, and it is important to note that planted forests have played an important role in this increase (Romanov, Eremin & Nureeva 2009). The area of planted forests has increased 6–7.5-fold during this period. Thus, it is possible to trace changes in forests over time. The Republic of Mari El is used as an example in Fig. 2 (Romanov, Eremin, Nureeva & Mamaev 2008; Romanov, Eremin & Nureeva 2013). The amount of un-forested land has reduced by a factor of 12.4 over the last 80 years. In the 40-year period from 1927 until 1966, there were only 70,000 ha of planted stands in the region but, in the following 40 years, the area of planted forests tripled. Most of the planted forests contain pines with smaller areas of other species, including Norway spruce, tillet (*Tilia cordata* Mill.), oak (*Quercus robur* L.), silver birch, aspen (*Populus tremuloides* Michx.) and Siberian fir (*Abies sibirica* Ledeb.) (Romanov, Eremin, Nureeva & Mamaev 2008).

Intensive forest management is one of characteristic features of the Middle Volga Region. Comparison of Russian forest management with forest management in Finland is provided in Table 1. There is an on-going need for timber, and consequently, there are a number of large wood processing enterprises in the Middle Volga

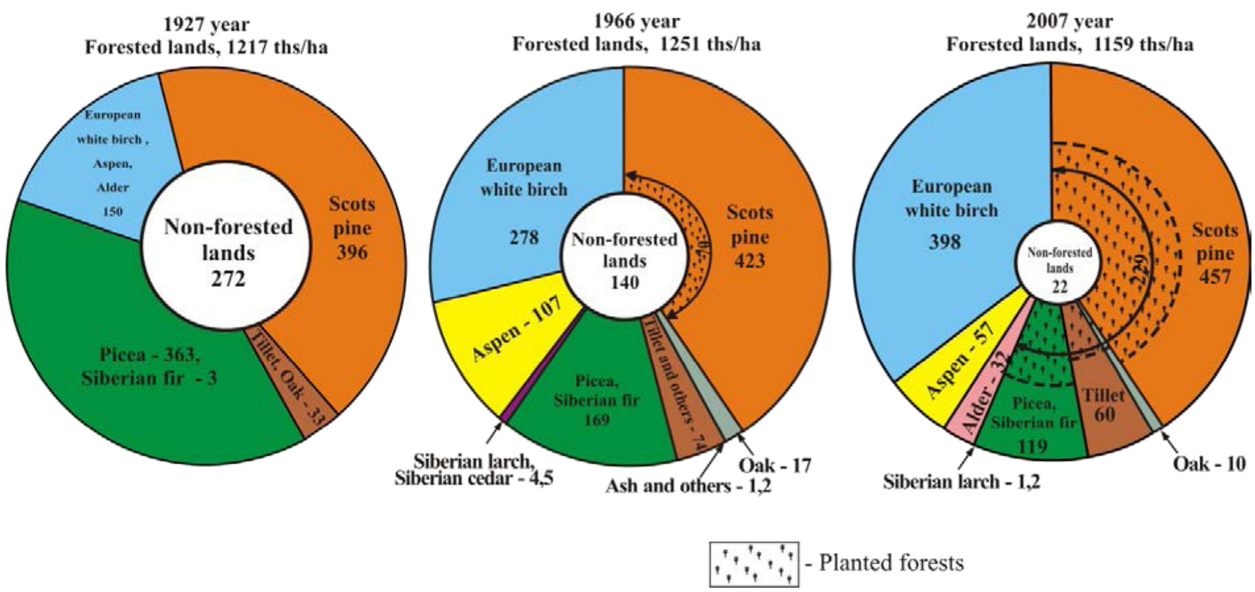

Fig. 2 Changes in the amount and composition of forests over an 80-year period in the Republic of Mari El (forest areas are given in 1000 per hectare data reproduced from (Romanov, Nureeva & Eremin 2013))

Region. There is considerable experience in artificial regeneration of non-forested areas in the Middle Volga Region, such that 25 % of Russian-planted forests are established in this region. The proportion of planted forests in different republics and oblasts of the Middle Volga Region varies from 8 to 32 %. It is important to note that the proportion of planted forests is lower in northern regions and greater in southern regions (Fig. 3). Like natural boreal forests, planted forests perform the functions of carbon storage and maintain carbon balance in the atmosphere.

The problem of choosing the most appropriate method of forest regeneration is still a focus for many researchers and experts. One group of authors (e.g. Sennov, 1999; Denisov 1984, Denisov et al. 2002, 2011; Demakov et al. 2008; Kalinin, 1996) highlight the advantages of natural methods of forest restoration in their papers. However, there is some evidence that accelerated forest restoration by means of planting is effective. Papers by Kotov (1990), Nezabudkin (1971), Pchelin (1999), Romanov, Eremin & Nureeva (2007, 2008a, 2008b, 2009, 2010, 2012), Eremin (2013), Kurbanov et al. (2011), Chernykh et al. (2009), Karaseva (2003, 2012), Nureeva et al. (2010), and Miftakhov (2011) provide information on productivity improvement of planted forests in the Middle Volga Region. Basic characteristics of forest growth conditions and the modes of forest management in pine forests are given in Table 2.

Active forest restoration by means of planting contributes to improvement in forest productivity as well as significantly increasing the total area of forests. According to the data of Romanov and his co-authors (2007, 2008a, 2008b, 2009, 2010, 2011, 2012), non-forested

Table 1 Comparison of the technologies for plantation establishment between the Middle Volga Region and Finland

Action	Middle Volga Region	Finland
Tillage	It is always carried out (scheme: ridge-forming → plough planting)	It is obligatory both in case of natural and artificial regeneration. With the exception of the land with the poorest and the driest soil.
Planting	Density of planting of seedlings with bare roots—no less than 5000–6000 trees/ha, density of planting of seedlings with container planting—2500–3000 trees/ha	Planting seedlings in containers—2000 trees/ha
Sowing	It is practically never used. It is sometimes used at the fire sites (dry and fresh sandy soil)	Number of seed beds per hectare for pine is 4000–5000
Planting material	Seedlings with bare roots are mainly used. Since 2000, seedlings in containers are used in the Nizhniy Novgorod oblast, since 2014—in the Republic of Mari El	Planting seedlings in containers (almost 100 %)

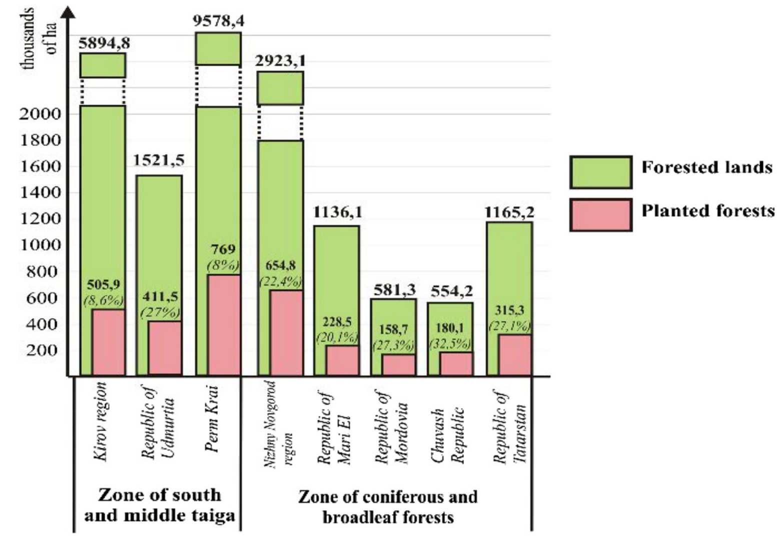

Fig. 3 Percentage of total forest land containing planted forests by republic or region within the Middle Volga Region (based on data from the (State Recording of Forest Fund for January 1, 2007) and reproduced from (Romanov, Nureeva & Eremin 2013); commas are used instead of decimal points)

areas (clearings, fire sites etc.) have considerably reduced in the republics and oblasts of the Middle Volga Region during the period 1940–2007. For example, the non-forested area of the Nizhny Novgorod oblast has reduced 5.2 times, the Chuvash republic—17.3 times, the Republic of Tatarstan—12.2 times and the Republic of Mari El—23.7 times. Accelerated forest growth will provide good-quality timber in a short time frame, which in turn will help to alleviate issues around resource supply for pulp-and-paper plants and woodworking enterprises as well as protecting high-value natural boreal forests from felling. However, little, if any, quantitative information is available that compares the growth and yield of planted Scots pine stands with that of natural stands in the Middle Volga Region. Therefore, the aim of the study reported here was to develop growth and yield functions for Scots pine in natural and planted stands to enable such comparisons to be made then use these to manage growth.

Methods

Stand information

Inventory data from seven forests (with a combined area of more than 185,000 ha) located in the republics and oblasts of the Middle Volga Region were obtained (Table 3). These data were collected as part of forest inventories conducted every 10 years by the state board of forest management. Forests were divided into natural and planted forests based on interpretation of forest survey data for the years 2002–2004.

Data collection and processing

Standing volume data from 17,448 sites[2] containing natural and planted Scots pine forests, ranging in age from 10 up to 70 years, were used to develop a mathematical model for stand growth. From these data, mean values of stock, growing stock increment and growth class in 10-year cycles were determined. Data for Scots pine growing under four different growth

Table 2 Modes of forest management in Scots pine forests with due account of forest growth conditions (soddy podzolic soil)

Forest growth conditions	Soil	Recommended methods of forest restoration	Number of thinning operations	Planting density of Scots pine (trees/ha)	Harvest age (years)
A_1—dry coniferous forest	Dry sand	Pine undergrowth conservation, bare soil with conservation of seed bearers (obligatory); planting and sowing in the furrows	3	8000	81–100
A_2—fresh coniferous forest	Fresh sand	Pine undergrowth conservation, bare soil with conservation of seed bearers (obligatory); planting in fire lines	3–4	5500–6000	81–100
B_2—fresh subor, i.e. mixed pine forests with birch	Fresh sandy loam (10–15 % loam)	Pine undergrowth conservation; pine planting in the furrows and in fire lines	3–4	4000–6000	81–100
C2—fresh suramen, i.e. mixed spruce and deciduous forest	Fresh clay loam (20–40 % loam)	Pine undergrowth conservation; pine planting in the furrows and in fire lines	3–4	4000	81–100

Table 3 Forest area by dominant species in the seven forests studied in the Middle Volga Region

Forest name	Location	Total forested area (ha)	Area of stands by dominant species (ha)						
			Scots pine	Norway spruce	Siberian fir	Common oak	Silver birch	Aspen	Other species
Scientific and Experimental	Republic of Mari El	7102.7	2773.5	341.7	1.8	0.9	3299	182.4	503.4
Kokshayskoe	Republic of Mari El	15432	8822.7	314.8	No data	664.7	3279.7	943.9	1400.6
Kuyarskoe	Republic of Mari El	16491	7272	279	0	0	7755	317	868
Kadadinskoe	Penza oblast	82138	42578	914	0	4136	15738	15309	3463
Agryzskoe	Republic of Tatarstan	42466	13860	5997	193	841	7854	6292	7429
Voskresenskoe	Nizhny Novgorod oblast	14208	10504	148	0	0	3349	123	84
Staroustinskoe	Nizhny Novgorod oblast	7230	4720	393	0	111	1606	396	3

The table provides the data obtained from the inventory of stands in the forest

conditions on soddy podzolic soil: dry and fresh lean sandy soil (A_1 and A_2, respectively); fresh sandy loam (10–15 % clay) soil (B_2); and fresh clay loam (20–40 % loam) soil (C_2) were used for the analysis (These growth conditions exist in all the forests studied), Table 2. The seven forest areas were chosen because pine forests are an important component of them, and those forests have large areas of planted pine forests. The forests were chosen in accordance with forest growth conditions which were common for the boreal forests. Mensuration characteristics (volume, growing stock increment) of the studied samples of Scots pine at these seven forest areas were determined using the standard Russian methods (Chernykh et al. 2006).

Determination of the main silvicultural indices for natural and planted stands and their comparative analysis was carried out using the methods of Romanov, Nureeva & Eremin (2009). The first step of this analysis was to select the plots to be included on the basis of the proportion of Scots pine. Next, tabular summaries of parameters such as forest growth conditions, age, density, productivity, provenance of plantations and the share of Scots pine in the plantations were made. Area-weighted mean values for the parameters (share of pine, density, productivity) of the plantations were calculated for every 10 years. The characteristics of the planted forests of interest are shown in Table 4 and were determined as follows. The number of trees per hectare plus their diameter and height are the input data for calculating standing volume. The original number of trees per hectare was calculated using information from the relevant planting plans and data on the distance between the trees within a row and between rows. (Planting pattern was defined by measurement of the distance between the rows and the distance between the densest planted trees in a row for all the stands. No fewer than 20 measurements were made between the rows and within the row. Actual number of planted trees should not and could not coincide with the number of planted trees by the planted pattern.) Tree diameter at breast height (1.3 m) was measured using a pair of tree callipers, and total tree height was measured using a height indicator. Standing volume was calculated using specially designed tables that were drew up by Moiseev in 1971 (Chernykh et al. 2006).

Tree age was determined by counting the annual rings from an increment core collected at the root collar from 3–5 mean trees chosen in each plot. The current stand density was obtained from the results of a test plot and recalculation of the obtained data per hectare. Mensuration practices are very similar in Russia and Finland (Table 5).

Absolute stand density was calculated as the sum of the total basal area per hectare. Relative stand density was calculated by dividing absolute stand density by the total basal area of the normal growing stock with a relative stand density of 1.0. Growing stock increment was determined by dividing the standing volume of a stand by the age of that stand.

Data analysis

The relationship between total standing volume and stand age was modelled using the nonlinear asymptotic Mitscherlich function as shown in Eq. 1:

$$\mathbf{Y} = \mathbf{K} * \{1 - \exp[-\mathbf{a} * \mathbf{A}]\}^{\mathbf{b}} \quad (1)$$

where **K** denotes the maximum growing stock, **A** denotes the 10-year age class and **a** and **b** define the form of the equation and show the growth rate of trees and their competitive stability or environmental resistance. Processing of the basic data from the seven sample areas was carried out using analysis of

Table 4 Mean stand characteristics of Scots pine in seven selected forests of the Middle Volga Region (some data reproduced from Romanov, Nureeva & Eremin 2013)

Forest name	Location	Age (years)	Planting density (trees/ha)	Relative stand density	Current stand density (trees/ha)	Diameter at breast height (cm)	Height (m)	Standing volume, (m^3/ha)	Mean annual increment (m^3 ha^{-1} $year^{-1}$)	Soil type
Scientific and Experimental	Republic of Mari El	58	13300	1.0	1245	19.0	20.4	324.0	5.6	Sandy
Kokshayskoe	Republic of Mari El	36	13300	1.0	3900	9.6	15.4	247.7	6.9	Sandy
Kuyarskoe	Republic of Mari El	36	10000	0.9	2160	11.9	12.8	210.5	5.8	Sandy
Kadadinskoe	Penzenskaya oblast	16	8000	1.0	5700	7.1	8.0	88.4	5.5	Light loam
Agryzskoe	Republic of Tatarstan	37	4250	1.0	935	21.6	20.0	322.0	8.7	Light loam
Voskresenskoe	Nizhny Novgorod oblast	41	4700	0.7	1095	16.0	15.0	160.0	3.9	Sandy
Staroustinskoe	Nizhny Novgorod oblast	33	4700	0.7	1600	12.0	11.0	110.0	3.3	Sandy

The table provides the data obtained from the sample plot

Table 5 Comparison of methods for calculating mean forest taxation indices of stands between Russia and Finland

Forest taxation indices	Unit of measurement	Methods used for calculation of mean forest taxation indices	
		Russia (on approval of forest management instruction, 2011)	Finland (Pykalainen and Kurttila 2009)
Basic unit for forest management		Site	Site
Area of stratum	ha	From 0.5	0.5–2.0
Mean diameter (d)[a]	cm	Empirical measurements of diameters at a height of 1.3 m. It is calculated as the quadratic average	Empirical measurements of diameters at the height 1,3 m
Mean height (h)	m	Empirical measurements of height of 3–5 mean trees with each class diameter	Empirical measurements of height of 3 mean trees
Relative density (p)		Total basal area per ha of stands relative to the total basal area of a normal stand ($p = 1$), derived from the yield table for the considered area	Not used
Sum of basal area in the stand	m^2/ha	Measured with Bitterlich's angle gauge	Measured with Bitterlich's angle gauge
Age of stand	years	Count of annual rings from an increment core collected at the root collar (3–5 mean trees are chosen)	Calculation of annual rings of mean trees
Number of trees	trees/ha	Use of the inventory data at a sample area	Use of the inventory data at a sample area
Stand composition	%	By the share of the tree species volume in the total stand volume	By the share of the tree species volume in the total stand volume
Stand volume	m^3/ha	Use of the tables; input data in the tables are the sum of basal area of trees in a stand and mean height	Use of the tables; input data in the tables are the sum of basal area of trees in a stand and mean height

[a]Maximum allowable measurement error is ±5 %

variance. Goodness of fit was assessed via the coefficient of determination (R^2).

Results and discussion

The calculated values of actual and standard stocks of planted or natural pine trees at the age of 100 years from seven forest areas with different soil types are shown in Table 6. In most cases, the productivity for 100-year-old trees (M_{100}) is higher for planted stands than for natural stands. The growth of stock also depends on soil quality. The data collected for the seven forests studied (which are for forests located in the zone of mixed coniferous-broad leaved forest of the Middle Volga Region) show the advantages of planted forest in terms of growth rate

Table 6 Estimates of model parameters and goodness of fit statistics for the relationship between growing stock and stand age for planted and natural Scots pine stands growing on different site types (data reproduced from Romanov, Nureeva & Eremin 2013)

Origin	Parameter	Actual stock				Standard stock			
		A_1	A_2	B_2	C_2	A_1	A_2	B_2	C_2
Planted	Number of forest sites	2206	3892	1423	9927	2206	3892	1423	9927
	K	216	311	400	318	409	520	593	573
	a	4.94	4.32	3.5	5.55	3.11	3.08	2.9	3.59
	b	3.5	3.34	2.53	3.23	2.47	2.56	2.21	2.41
	M_{100} [a], m^3	211	297	370	315	365	461	524	535
	R^2	0.844	0.907	0.922	0.878	0.907	0.953	0.953	0.954
Natural	Number of forest sites	736	4701	2717	2088	736	4701	2717	2088
	K	215	248	270	304	419	426	462	518
	a	5.75	9.14	8.96	4.3	3.41	5.4	4.68	3.23
	b	5.59	15.97	11.51	2.87	2.8	5.2	3.51	2.35
	M_{100}, m^3	211	248	248	292	382	416	447	471
	R^2	0.835	0.715	0.663	0.688	0.929	0.905	0.862	0.829

The actual stock is the true mean stock volume with relative density from 0.5 to 0.9. The standard stock is the calculated stock for plantations with relative density 1.0. The timber lands were chosen from the seven forests listed in Tables 3, 4, 7 and 8

[a]M_{100}—the productivity for 100-year-old stands. M_{100} (years) is a calculated for the plantations in the age of 100-year stock

and stock growth compared with natural forests. These data were combined and graphed in Fig. 4. The advantages of growing planted forests highlighted by these data are not widely known but can be used to improve the annual growth of trees to obtain more timber in shorter time periods.

The mean silvicultural characteristics of two age groups (<20 years and 21–50 years) of standing timber were studied in more detail through examination of Russian legal documents in force during different periods of forest regeneration (Tables 7 and 8). The two age groups differ in initial stand density: fewer than 5000 trees/ha for the stands less than 20 years old and 6000 trees/ha or even more for the stands 21–50 years old (Tables 7 and 8). Analysis of the proportion of Scots pine in the seven forests studied show that it is not always the main species in plantations under the age of 20 years in forest growth conditions A_2 (Table 7). The proportion of Scots pine was higher in planted than in natural stands for five of the seven forests studied (<20-year-old forests). In the case of the 21–50-year-old plantations, there was more Scots pine than other species in planted stands in all forests studied except for Voskresenskoe forest in the Nizhny Novgorod oblast. The proportion of planted Scots pine is higher than the proportion of natural Scots pine in pine forests with sandy soils (A_2). These sites are located in the Scientific and Experimental, Kuyarskoe and Kokshayskoe forests areas of Mari El Republic, Agryzskoe forestry of Tatarstan Republic, Kadadinskoe forestry of the Penza region and the Voskresenskoe and Staroustinskoe forests of the Nizhny Novgorod region.

Relative stand density of planted pines was higher than that of natural pines in six of seven forests studied. The Voskresenskoe forest was the only exception (Tables 7 and 8). Mean forest density in Kokshayskiy forest (up to 20 years old) and Voskresenskiy forest (21–50 years) is the same as in planted and natural forests. Planted pine forests generally have a higher relative stand density than natural forests due to a combination of high plant density and natural regeneration.

Mean quality class of planted pine stands was higher in two forests studied (Research and Experimental forest and Agryzskoe forest, age group—up to 20 years (Table 7)). For the age range of 21–50, mean quality class of planted pine forests is higher in three forests studied—Research and Experimental forest, Kuyarskoe forest and Agryzskoe forest (Table 8). In Kadadinskoe, Voskresenskoe and Staroustinskoe forests, this parameter is the same as in planted as in natural forests. Quality class of planted Scots pine is not always higher in comparison with natural stands, however. It can be explained by higher stocking density of plantations due to high density of planting. At the age range of 21–50 years, there is a higher proportion of Scots pine in all the studied planted forests, except Voskresenskoe forest. Mensuration characteristics are higher in Kuyarskiy and Kokshayskiy forests only (plantations up to 20 years). This phenomenon can be explained by the predominance of sandy soil in the area where Scots pine has no competitors. Calculated total volume per hectare for 15- and 35-year-old trees was higher in all the forests except for Voskresenskoe forest and Staroustinskoe forest. Scots pine standing volume is higher in all the forests except Scientific and Experimental forest (15 years old), Agryzskoe forest (15 years old) and Voskresenskoe forest (15 and 35 years old). Thus, mean volume of Scots pine stands in planted forests (35 years old) is higher than in natural forests by a factor of 2.7 in Scientific and Experimental forest, 1.25 in Kokshayskoe forest, 1.45 in Kuyarskoe forest, 1.11 in Kadadinskoe forest, 2.86 in Agryzskoe forest and 2.29 in Staroustinskoe forest. Some of the mensuration characteristics shown in the Voskresenskoe forest are due to a lack of tending,

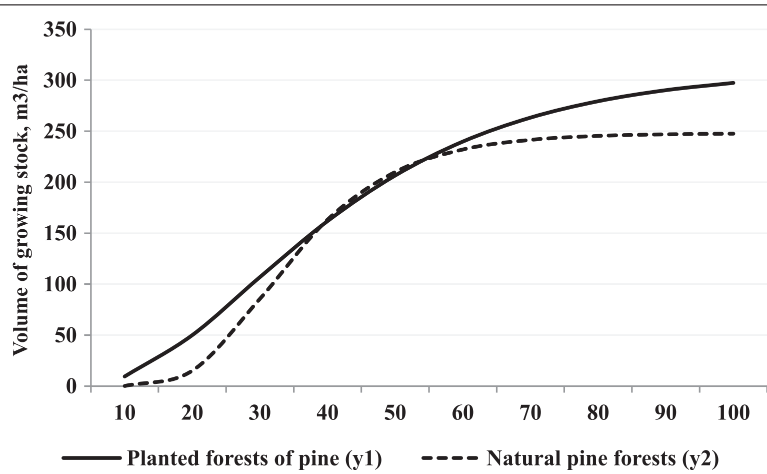

Fig. 4 The growing stock of wood in the natural and planted Scots Pine forests on the sandy soil

Table 7 Mean forest valuation characteristics for Scots pine plantations up to 20 years old growing in a sandy soil (A_2)

Forest name	Origin	Area (ha)	Mean values at mean age					Mean growing stock for 15-year-old stands (m^3/ha)	
			Growing stock (m^3/ha)	Age (years)	Proportion of Scots pine (%)	Relative density	Quality class	Total	Scots pine
Scientific and experimental	Natural	4.1	27.1	11.6	79	0.56	2.0	40.0	40.0
	Planted	153.6	59.0	15.3	71	0.74	1.5	51.6	26.6
Kokshayskoe	Natural	14.8	25.2	12.3	65	0.71	1.7	30.7	20.0
	Planted	120.8	34.7	13.4	76	0.71	1.8	38.8	29.5
Kuyarskoe	Natural	44.7	15.8	8.1	64	0.60	1.7	29.2	18.7
	Planted	83.6	34.2	14.2	80	0.80	2.0	36.1	28.9
Kadadinskoe	Natural	2.5	20.1	11.6	70	0.60	1.2	25.9	18.1
	Planted	35.7	45.0	19.3	64	0.65	1.8	35.0	22.4
Agryzskoe	Natural	4.1	27.1	11.6	79	0.56	2.0	40.0	40.0
	Planted	153.6	59.0	15.3	71	0.74	1.5	51.6	26.6
Voskresenskoe	Natural	40.8	24.5	11.6	72	0.60	2.5	31.7	22.8
	Planted	210.7	16.9	14.3	40	0.61	2.7	17.7	7.1
Staroustinskoe	Natural	3.2	11.3	12.5	96	0.76	2.0	13.6	13.0
	Planted	6.0	33.7	13.0	70	0.83	2.5	38.9	27.2

The mean square values of mensuration characteristics and age of the stands provided in the table are obtained from the forest inventory

which is caused by insufficient local workforce to manage the forests.

Despite the fact that mean quality class of planted Scots pine stands in most forests studied is lower than natural forests, their productive capacity and stock growth is higher. It is typical for young growth (<20 years) and also for older artificial stands, planted with higher starting density. Higher productivity of planted forests in comparison with natural stands is explained by the following factors: (1) use of the type of tillage, which contributes to improvement of soil agrophysical properties and intensification of planted forests growth; (2) regulation of density and spatial distribution of trees in order to reduce competition for light and nutrient during the first years of

Table 8 Forest valuation characteristics for 21–50-year-old Scots pine plantations growing in sandy soil (A2)

Forest name	Origin	Area (ha)	Mean values at given age					Mean growing stock for 35-year-old stands (m^3/ha)	
			Growing stock (m^3/ha)	Age (years)	Proportion of Scots pine (%)	Relative density	Quality class	Total	Scots pine
Scientific and experimental	Natural	23.4	38.5	32.9	73	0.63	3.6	41.0	29.9
	Planted	376.4	90.1	33.5	85	0.67	1.7	94.1	80.0
Kokshayskoe	Natural	611.7	117.3	31.7	79	0.67	1.4	129.5	102.3
	Planted	3022	137.7	34.7	92	0.75	1.5	138.9	127.8
Kuyarskoe	Natural	47.5	96.91	34.2	76	0.59	2.2	99.2	75.4
	Planted	1220.3	103.81	30.4	92	0.88	2.0	119.5	110.0
Kadadinskoe	Natural	15.5	196.1	44.3	89	0.72	1.4	154.9	137.9
	Planted	202.3	218.7	44.9	90	0.82	1.4	170.5	153.4
Agryzskoe	Natural	22.54	158.6	41.5	80	0.70	1.9	110.0	44.0
	Planted	998.5	157.4	34.8	87	0.80	1.5	138.9	126.0
Voskresenskoe	Natural	96.2	86.8	33.5	71	0.69	2.4	90.7	64.4
	Planted	2354.4	66.8	31.1	65	0.65	2.4	75.2	48.9
Staroustinskoe	Natural	5.8	189.7	45.0	20	0.60	2.0	147.5	29.5
	Planted	11.6	70.4	28.8	79	0.60	2.0	85.6	67.6

growth. Such conditions make it possible for planted trees to grow quickly in subsequent years; and (3) choice of optimum conditions of cultivation along with a decrease of intra-population and inter-species competition by implementing a number of agrotechnical and silvicultural measures.

Calculation of actual mean stand increment with the use of data from seven forests of republics and oblasts of the Middle Volga Region demonstrates the potential for accelerated growth of planted forest in comparison with natural forests. However, a lack of control over planted trees during the entire growing period sets them equal to natural stands. Even so, accelerated growth rates of planted forests have been obtained practice (data of artificial forest reproduction). Thus, growing stock increment of planted pine forests is 9–63 % higher than growing stock increment of natural pine forests (Table 9). In the future, a monitoring system should be implemented at the time of planting seedlings in un-forested areas and should be continued throughout the entire rotation for all the levels of management.

Stand increment of planted Scots pine forests may be improved by utilising productive land with favourable growth conditions. A particular feature planted Scots pine forests is a high starting density, which varies from 4300 to 13,300 trees/ha. Annual growing stock increment of planted Scots pine forests varies from 3.3 to 8.7 m^3 ha^{-1} $year^{-1}$ (Table 4).

A high stand density should favour canopy closure of the host species, reduction of stems with knots and more intensive height growth. Thus, expenditure on planted forest cultivation should include not only activities preceding planting of trees but also thinning. It is important to include into costs of planted forest cultivation both pre-planting cultivation and thinning. Thinning of 30–40-year-old plantations performs two tasks: (1) obtaining profit through the use of tree biomass in the pulp-and-paper industry, electricity sector and other spheres of industry; and (2) achieving additional growth of trees due to more light.

Planted forests are also of better timber and mensuration characteristics than natural forests. Thus, for example, the annual yield from planted forests yield is 5.6 to 9.2 m^3 per hectare, with higher yields leading to shorter rotations.

Conclusions

In conclusion, it is important to note that a long practice of planting forests in the Middle Volga Region (more than 100 years) may be a basis for development of standards in engineering and cultivation of planted forests. The Middle Volga Region may be an investment-attractive region for establishment of large timber complexes with complete production cycle as it is the region with high population density (in comparison with other parts of Russia), intensive wood consumption and vast forest plantations. Besides, intensive ways of forest restoration by means of establishment of plantations shall contribute to conservation of Russian natural boreal forests and improvement of ecology not only in Russia but throughout the northern hemisphere.

Endnotes

[1]Oblast and republic is a unit of federal division in Russia.

[2]The 17,448 sites are forest strata. A forest stratum is defined as an area of land that has similar soil conditions, and qualitative and quantitative characteristics of growing vegetation. Variability of growing vegetation in a forest stratum is within normative standards in which it is possible to carry out one and the same actions in protection, conservation and reproduction of forests in the territory of the forest stratum.

Table 9 The role of planted stands in increasing actual mean stock increment of Scots pine. (Source: state forest inventory materials of forests)

Forest name	Location	Mean annual increment of standing volume (m^3 ha^{-1} $year^{-1}$)							
		All stands				Stands <70 years old			
		Natural	Planted	Difference		Natural	Planted	Difference	
				Absolute	Percentage			Absolute	Percentage
Voskresenskoe	Nizhny Novgorod oblast	3.20	3.49	0.29	8.9	3.41	3.49	0.08	2.1
Staroustinskoe	Nizhny Novgorod oblast	3.42	5.59	2.17	63.3	4.53	5.62	1.08	23.9
Agryzskoe	Republic of Tatarstan	3.92	5.09	1.17	29.8	4.43	5.16	0.73	16.6
Scientific and experimental	Republic of Mari El	3.10	3.40	0.30	9.7	3.31	3.47	0.16	4.7
Kokshayskoe	Republic of Mari El	3.11	3.57	0.46	14.8	3.58	5.04	1.46	40.9
Kuyarskoe	Republic of Mari El	3.06	3.67	0.62	20.2	3.54	3.67	0.13	3.7
Kadadinskoe	Penzenskaya oblast	3.53	4.41	0.88	24.84	4.37	4.46	0.09	2.12

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Authors' contributions
The authors made equal contribution to preparation of the article. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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