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To cite this article: A E Osipenko and S V Zalesov 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **316** 012047

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Evaluation of artificial reforestation efforts in the ribbon forest zone of Altai Krai

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Abstract. The ribbon forest zone of Altai Krai is located in the Kulunda Steppe and on the Priobskoye Plateau. The climate of this region is characterized by extreme aridity. Due to the harsh climate and the importance of the ribbon forests for the environmental sustainability of the region, artificial reforestation is an integral part of the regional forest management. Forest stands of artificial origin currently occupy a large area within the ribbon forest zone, as evidenced by forest inventory data. However, due to the fact that surveys are not conducted simultaneously on the whole territory of Altai Krai, and that they miss some of the forest management units, forest inventory data do not provide an up-to-date assessment of artificial reforestation efforts. Our project attempted to update the existing data of forest resource assessments and evaluate the results of artificial reforestation efforts in the ribbon forest zone of Altai Krai. This article presents data on the distribution of the artificially reforested area by predominant species and type of growing conditions, and the distribution of the growing stock of the artificially established stands by age and type of forest growing conditions.

1. Introduction

To improve the efficiency of use and restoration of forests, it is necessary to have the most recent information about the state of the forest area within which economic activities are conducted. It is particularly important to have the recent information on the state of protective forests, because they perform many social and ecological functions. In particular, the ribbon forests of Altai Krai provide soil-protective, soil-improving, hydrological, climate-regulating and social services. The ribbon forests are unique due to their intrazonal location: they grow at the junction of the Kulunda Steppe and the Priobsky Plateau. This territory has a continental climate. Annual mean temperature is +2.4 °C, maximum temperature of July is +40.7 °C, and minimum temperature of December is -48.7 °C; annual precipitation is 250-350 mm in the south-west and up to 450 mm in the north-east; the period with relative humidity below 30% occurs from May to September and lasts for 40 days on average [1]. Due to the extreme aridity of the territory, the restoration of the ribbon forests presents multiple challenges; in the last 100 years, much effort has been made to restore the ribbon forests using artificial means. The forest stands of artificial origin currently occupy a large area within the ribbon forest zone, as evidenced by forest inventory data. However, due to the fact that forest inventories are not conducted simultaneously on the whole territory, and that they miss some of the forest management units, forest inventory data do not give answers to the following questions (1) what area do the artificial forests occupy; and (2) how large is the growing stock of those forests. Our study attempted to answer these questions. The purpose of our study was to update forest inventory information and evaluate the results of artificial reforestation efforts in the ribbon forest zone of Altai Krai.



2. Methods and materials

Our study used the data of an electronic database containing characteristics of 31288 forest stands including 27673 artificially regenerated stands, 1878 open-canopy stands, and 1737 stands planted under the forest canopy. The database contains descriptions of the 15 forest management units of Altai Krai (the year of forest inventory is shown in brackets): Baevskoye (2009), Barnaulskoye (2011), Volchikhinskoye (2011), Znamenskoye (2001), Klyuchevskoye (2001), Kulundinskoye (2005), Lebyazhinskoye (2009), Novichikhinskoye (2006), Ozero-Kuznetsovskoye (2010), Pavlovskoye (2011), Pankrushikhinskoye (2005), Rakitovskoye (2009), Rebrikhinskoye (2013), Stepno-Mikhailovskoye (2004), and Shipunovskoye (2003). We identified six main types of forests where artificial reforestation had been carried out: dry pine forest on high hills (SBV), dry pine forest on gentle slopes (SBP), fresh pine forest (SVB), near-steppe pine forest (SPR), pine forest with grass cover (TRB), and meadows (RT). These forest types were grouped according to type of forest growing conditions [2]: A0 - SBV; A1 - SPB; A2 - SVB and SPR; A3 - TRB and RT.

Data analysis and updating were performed in Excel. For data approximation we used the Statistica program and the Mitscherlich function [3], which has the following form:

$$Y = a(1 - e^{-bx})^c$$

where, Y is the growing stock, m^3 / ha ; x is the average age of the forest stands, years; e is the Euler constant; a , b , c are the coefficients of the equation.

3. Results and discussion

One of the main indicators characterizing artificial reforestation is the species composition of artificially created forests. For the analysis of species composition, a table was compiled containing data on the artificial forests grouped by dominant species and type of growing conditions (Table 1). No entries of the forest stands planted under the forest canopy exist in this table. The area of the forest stands planted under the forest canopy is 7384 ha; of those 6968 ha are predominately occupied by pine (*Pinus sylvestris* L.), 338 ha, by birch (*Betula pendula* Roth), and 78 ha, by other tree species.

In the ribbon forest zone, pine is the dominant tree species. This species can tolerate severe drought, low air and soil humidity, as well as late spring frosts that are common in Altai Krai. Due to its flexible root system adapted to the structure and other characteristics of soil, pine can successfully grow on nutrient poor and dry sandy soils [4, 5]. All these qualities helped this species to get established in the ribbon forest zone and predetermined its widespread use in silviculture.

In addition to pine (*Pinus sylvestris* L.) stands, there are artificially created stands of Siberian larch (*Larix sibirica* Ledeb.), Siberian spruce (*Picea obovata* Ledeb.), and Siberian pine (*Pinus sibirica* Du Tour.). However, because these species have a high demand for soil moisture and nutrients [6], they grow in a very small area (mainly under A3 conditions), and they are not suitable for cultivation in the ribbon forests [7].

Under A3 conditions, birch is a natural competitor of pine. The dominance of birch indicates untimely thinning or lack thereof in some forests.

Populus balsamifera L., *Acer negundo* L., *Ulmus glabra* Huds., and *Ulmus laevis* Pall. are commonly used in protective forests of Altai Krai. Their dominance in some parts of the ribbon forest zone is explained by the fact that they were planted there to protect soil from erosion.

Among shrubs, *Salix acutifolia* Willd. has the widest distribution in artificial forests. This is explained by the fact that willow was used to consolidate sands and create more favourable conditions for the growth of pine [8].

Due to the fact that 94.5% of the artificial forests of the ribbon forest zone of Altai Krai are pine stands, the following assessment of the current state of artificial reforestation will be devoted to this tree species.

Table 1. Distribution of the area of the artificial forests by dominant species and type of forest growing conditions, ha.

Species	Type of forest growing conditions, ha.				Total
	A0	A1	A2	A3	
Softwood tree species					
<i>Pinus sylvestris</i> L.	91.3	68833.6	42024.4	4169.5	115118.8
<i>Larix sibirica</i> Ledeb.	-	0.2	39.2	302.8	342.2
<i>Picea obovata</i> Ledeb.	-	-	0.6	32.7	33.3
<i>Pinus sibirica</i> Du Tour.	-	-	-	1.4	1.4
Hardwood tree species					
<i>Betula pendula</i> Roth	-	-	13	3332.6	3345.6
<i>Ulmus glabra</i> Huds.	-	11.2	52.6	919.2	983
<i>Ulmus laevis</i> Pall.					
<i>Populus balsamifera</i> L.	-	7.6	132.5	529.5	669.6
<i>Acer negundo</i> L.	-	1.3	30.7	306.2	338.2
<i>Malus baccata</i> (L.) Borkh.	-	-	11.8	247.7	259.5
<i>Malus sylvestris</i> Mill.					
<i>Quercus robur</i> L.	-	-	0.1	0.2	0.3
Shrubs					
<i>Salix acutifolia</i> Willd.	1.9	211.2	285.7	50.5	549.3
<i>Hippophae rhamnoides</i> L.	-	-	22.6	21.7	44.3
<i>Ribes aureum</i> Pursh	-	3	21.8	8.3	33.1
<i>Ribes nigrum</i> L.					
<i>Elaeagnus angustifolia</i> L.		0.5	3.2	12.5	16.2
Total	93.2	69068.6	42638.2	9934.8	121734.8
Total, %	0.1	56.7	35.0	8.2	100

Figure 1 presents the distribution of the area of the artificial pine stands by age. The distribution by age is based on the year of the most recent forest inventory. We obtained the data on the number of forest stands established between 2011 and 2019 from the regulatory documents of the relevant forest management units (Figure 1).

The majority of the artificially created pine stands are 11 – 20 years old (Figure 1). A large number of the forest stands were established after 1997, when wildfires destroyed 67700 ha of the ribbon forests. Large-scale reforestation was also carried out 51 – 70 years ago. It was triggered by massive unauthorized loggings and wildfires in the early 1900s. The impetus for a large-scale reforestation was a special decree of the Council of Ministers of the USSR on the restoration of the ribbon forests of Altai and Kazakhstan adopted in 1947. Lack of equipment, planting material and qualified personnel were among the major challenges faced by reforestation during this period; however, the task was accomplished [9].

The area of the ribbon forests (that is, of the area covered by forest) is about 1.1 million ha [9]. According to our estimates, the artificially created pine stands occupy 12.0% of the total area of the ribbon forests, and the stands established under the forest canopy, 0.7% of that area. On the territory of the forest management units included in our study, another 11551 ha of pine forests are to be planted in 2019 – 2029. Most of these forest stands (93.6%) will be created in the south-west of the ribbon forest zone (Klyuchevskoye, Lake-Kuznetsovskoye, and Rakitovskoye forest management units).

There is a similar trend in the distribution of the existing pine stands of artificial origin: 78.4% of the artificial stands are located in the south-west, in the dry steppe zone [1] (Klyuchevskoye, Lake-Kuznetsovskoye, Rakitovskoye, Stepno-Mikhailovskoye, and part of Znamenskoye forest management units); 12.0%, in the arid steppe zone (Volchikhinskoye, Lebyazhinskoye, and part of Znamensky forest management units); and 9.6%, in the zone of moderately arid steppe (Bayevskoye, Barnaulskoye, Pavlovskoye, Kulundinskoye, Pankrushikhinskoye, Novichikhinskoye, Rebrikhinskoye and Shipunovskoye forest management units).

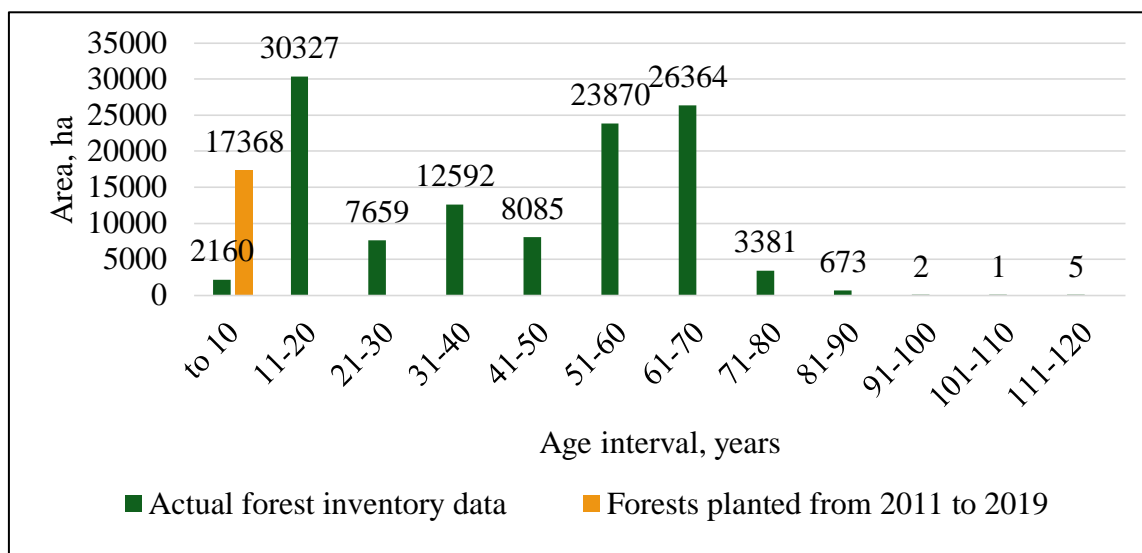


Figure 1. Distribution of the area of the extant artificial pine stands by age.

In order to update the data on the growing stock of the artificially created pine stands, we built growth curves (Figure 2). In Table 2, we present the coefficients of the equations describing the increase of the growing stock of the artificially created pine stands. To update the forest inventory data, we averaged the data on the growing stock of the artificial forest stands according to the yield curves (Figure 2); we then corrected (that is, enlarged) the growing stock of the stands according to the equations we built taking into account the year of the last forest inventory. According to our results, the current growing stock of the artificial pine stands of the ribbon forest zone is 13.6 million m^3 . Table 3 presents the distribution of the growing stock by age and type of forest growing conditions.

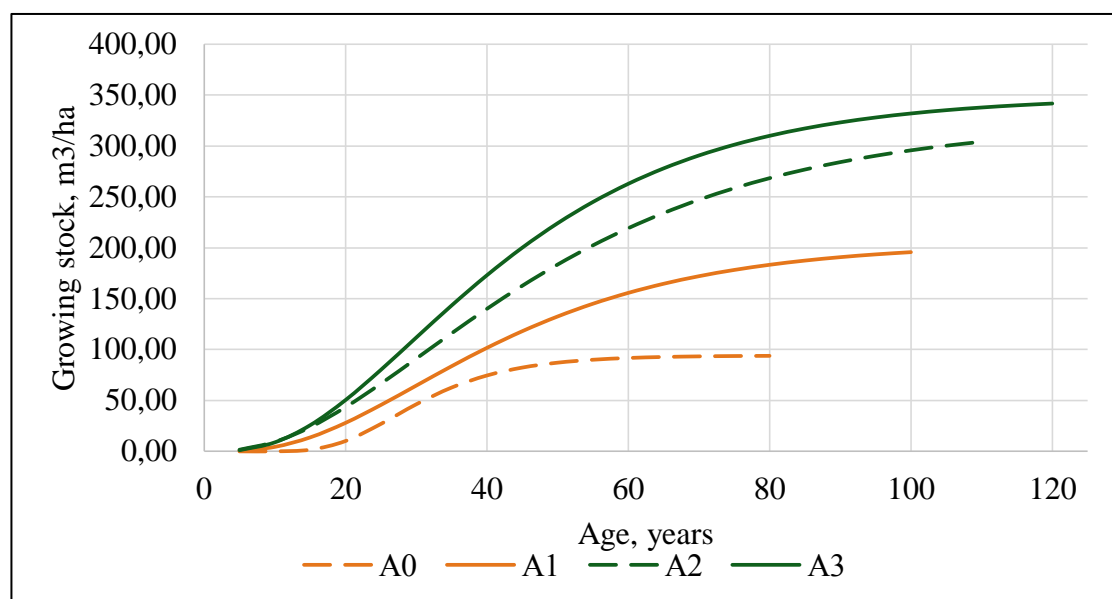


Figure 2. Accumulation of the growing stock of the artificial pine stands in various types of forest growing conditions (A0, A1, A2 and A3).

Table 2. Parameters of the equations describing accumulation of the growing stock of the artificial pine stands.

Type of forest growing conditions	Coefficient			R ²	Standard error, m ³ /ha
	a	b	c		
A0	94.1	0.1102	19.04	0.621	± 26,3
A1	204.9	0.0440	3.72	0.757	± 29,4
A2	325.5	0.0341	2.86	0.727	± 39,8
A3	349.2	0.0423	3.45	0.789	± 44,4

When building the yield curves, we did not take into account natural mortality and the volume of timber removed during thinnings, because the original data included descriptions of typical stands that are subject to natural mortality and thinning. Consequently, the resulting equations of the growing stock accumulation took into account the volume of the removed and dead wood.

The largest volume of the growing stock of the artificial pine stands has accumulated in the 51 – 70 year old pine forests growing in the A1 and A2 types of forest growing conditions. They account for 65.9% of the total growing stock.

The productivity of artificial stands decreases with the deterioration of the forest growing conditions. However, due to the fact that ribbon forests perform important environmental and social functions, artificial regeneration is particularly important in adverse forest growing conditions where natural reforestation may be delayed for many years or absent altogether [10, 11].

Table 3. The distribution of the growing stock of the artificial forest stands by age and type of forest growing conditions, m³/%.

Age interval, years	Type of forest growing conditions				Total
	A0	A1	A2	A3	
up to 10	-	<u>6987</u> 0.05	<u>4365</u> 0.03	<u>351</u> 0.00	<u>11703</u> 0.09
11-20	<u>17</u> 0.00	<u>340754</u> 2.51	<u>224111</u> 1.65	<u>25967</u> 0.19	<u>590849</u> 4.36
21-30	<u>233</u> 0.00	<u>165811</u> 1.22	<u>212815</u> 1.57	<u>28897</u> 0.21	<u>407756</u> 3.01
31-40	<u>2035</u> 0.02	<u>564649</u> 4.16	<u>602567</u> 4.44	<u>107026</u> 0.79	<u>1276277</u> 9.41
41-50	<u>402</u> 0.00	<u>559861</u> 4.13	<u>497932</u> 3.67	<u>94406</u> 0.70	<u>1152601</u> 8.50
51-60	<u>2051</u> 0.02	<u>1888474</u> 13.92	<u>2148189</u> 15.83	<u>186552</u> 1.38	<u>4225266</u> 31.15
61-70	<u>378</u> 0.00	<u>2554122</u> 18.83	<u>2360373</u> 17.40	<u>112015</u> 0.83	<u>5026888</u> 37.05
71-80	<u>1060</u> 0.01	<u>352053</u> 2.60	<u>347871</u> 2.56	<u>28013</u> 0.21	<u>728997</u> 5.37
81-90	-	<u>86595</u> 0.64	<u>51387</u> 0.38	<u>5372</u> 0.04	<u>143354</u> 1.06
91-100	-	-	<u>698</u> 0.01	-	<u>698</u> 0.01
101-110	-	-	<u>326</u> 0.00	-	<u>326</u> 0.00
111-120	-	-	-	<u>1692</u> 0.01	<u>1692</u> 0.01
Total	<u>6176</u> 0.05	<u>6519306</u> 48.05	<u>6450634</u> 47.55	<u>590291</u> 4.35	<u>13566407</u> 100

4. Conclusions

1. In the ribbon forest zone of Altai Krai, pine dominates 94.5% of the area of the artificial forest stands.
2. The largest forest areas were planted 51 – 70 and 11 – 20 years ago. Large-scale artificial reforestation was required after massive unauthorized loggings and wildfires at the beginning of the 20th century, as well as after the wildfires of 1997.
3. The largest area of the artificial pine stands (78.4%) is located in the south-west, in the dry steppe zone; in the zone of arid steppe, 12.0% of the artificial pine stands are located; and in the zone of moderately arid steppe, 9.6%.
4. According to our estimates, in the ribbon forest zone the artificial pine stands currently occupy an area of 132.5 thousand ha, and their growing stock is 13.6 million m³.
5. Productivity of the artificial pine forests depends on forest growing conditions. The highest productivity of the artificial forest stands has been observed under A3 conditions. However, A3 type of forest growing conditions occurs only in 3.6% of the area occupied by the artificial pine stands; as a result only 4.4% of the growing stock of the latter is concentrated in the area characterised by the highest productivity. The largest volume of the growing stock is concentrated in A1 and A2 types, 48.1 and 47.5%, respectively.
6. In the last 100 years, much effort has been made to restore the ribbon forests using artificial means. Artificial reforestation is particularly important in the south-west of the ribbon forest zone characterised by harsher climatic conditions.

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