

Potential for carbon sequestration and the actual forest structure: the case of Krasnodar Krai in Russia

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Abstract

This work aims to analyze the age structure of forests in Krasnodar Krai in order to estimate their carbon sequestration potential. The research was conducted during 2015–2020 in 14 forested districts of Krasnodar Krai in the Russian Federation. A database of 96,000 sample plots was used. Aspen occupied the maximum area (20% of trees), while much smaller areas were occupied by linden, birch, pine, and oak ($p \geq 0.05$ with aspen). Spruce occupied three times smaller areas compared to aspen ($p \leq 0.05$), while maple, elm, ash, and alder had ten times smaller areas ($p \leq 0.01$). Among deciduous species by age, mature and overmature stands predominate, while in conifers a young growth prevails (44% – for pines). All pine forests belong to the 1st quality class (91%), for birch and aspen, it is 75–80% of trees ($p \leq 0.05$ with the frequency for pine), for spruce – 52% ($p \leq 0.05$), and for oak – 10% ($p \leq 0.01$). Different tree species make different contributions to carbon sequestration – from 0.3 tons per 1 ha (*Alnus glutinosa*) to 1.7 tons per ha (*Fraxinus excelsior*). Taking into account the areas occupied in the forest by different tree species, their contribution will also be different – from 0.5 thousand tons/1 year (*F. excelsior*) to 290 thousand tons per 1 year (*Populus tremula*). The total increase in wood stocks and carbon sequestration is mainly due to six forest tree species. The results obtained can be used to assess the potential for carbon sequestration in temperate forests, taking into account their different age structure and tree species composition.

Key words: carbon sequestration; forest plantations; tree species; trunk wood volume; wood increment

Editor: Ivan Barka

1. Introduction

The primary role of forests globally is to produce oxygen and store carbon dioxide (Pukkala 2020). The most important is carbon sequestration, taking into account the large-scale climate change observed in recent decades. Oxygen production is known to be associated with the ability of forests to absorb carbon dioxide as a result of photosynthetic processes (Akujärvi et al. 2019). Global warming is caused by the release of greenhouse gases into the atmosphere. Most climatologists are concerned about the escalating greenhouse effect as average air and water temperatures continue to rise (Seidl et al. 2014). Carbon dioxide content has increased by one quarter over half a century alone (Ampoorter et al. 2020). Pho-

tosynthesis is known to be the primary extraction factor for carbon dioxide from the atmosphere (Lindner et al. 2010). Forests play an important role in extraction as one of the main types of terrestrial vegetation (Palma 2017).

Carbon dioxide sequestration indicators are associated with the stand stock increment and the standstock itself (Trinh et al. 2020). It is known that the taxonomic characteristics of forest stands are directly associated with indicators of other forest ecological characteristics (Asylbaev et al. 2018; Kadiogullari et al. 2018). Currently, there are known models illustrating the ecological efficiency of forest plantations, which are based on a comprehensive demonstration of ecological utility (Schwaiger et al. 2019). Here, the relative ecological utility factor of each parameter is associated with a multivariability

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of them. Each calculated coefficient is associated with a percentage mapping of environmental parameters used as benchmarks. Dependence in the coefficient values is manifested in the following factors: the region in which the forests grow, the tree species, stand density, and age characteristics (Knoke et al. 2017). On the other hand, carbon dioxide sequestration is an interconnected determinant (Orazio et al. 2017). Sequestration has very close relationships, in particular with the release of oxygen, and biologically active substances, with the values of the growing stock and its increment, with the function of dust retention, finally, with the indicators of ecological efficiency (Milad et al. 2011).

The ecological maturity of forests is expressed by average increment, maturity age, and the total productivity parameter of forest stands (Daigneault et al. 2010). If average growth is related to the reproductive process of forest stocks, then the consistent use of forests for a particular area depends on it. The second parameter is more relevant to the evaluation criteria because it takes into account not only the stock of stands but also the rates of decay. The latter, in turn, plays an environmental role and is also responsible for carbon sequestration (Bugalho et al. 2016). The ecological and economic maturity of the forest is determined by the age of the forest stands, which have the maximum possibility of continuous use (Gamfeldt et al. 2013).

Forests remain of high value to humans. First and foremost, forestry is a source of wood used for many purposes, from construction to fuel. For example, every third person on the planet (approximately 2.5 billion people) still uses wood to prepare food (Daigneault et al. 2010). At the same time, forest area is steadily shrinking and agriculture is the major contributor to deforestation. It is commonly known that 80% of deforestation is caused by agricultural needs. Regions with initially small forested areas are the most affected (Clark et al. 2016).

Along with humans, forests play a critical role for animals, including invertebrates. Trees provide a permanent food source for vertebrates and invertebrates, and many animals also nest in trees, i.e., they are their habitat. Different species of trees are attracted to animals, including invertebrates, to various degrees, but species like common oak (*Quercus robur* L.) can act as consortia (Stukalyuk et al. 2020).

Due to uneven forest cover and the level of industrial development, different countries have different contributions to the level of carbon dioxide deposition by forests. Forests in Belarus, for example, absorb twice as much carbon dioxide as it is produced by transport and industry (Zamolodchikov et al. 2003). In other countries, including developed countries like China, Germany, and the United States, the situation is quite the contrary. The amount of carbon dioxide emissions may be much higher than the amount absorbed by forests. Thus, for 100% of emissions, forests absorb 8–15% of carbon dioxide (Clark et al. 2016). A proportion of the

European Union's forests are protected by the state such that protected areas account for 7% of the total forest area in EU and strictly protected areas for 3% (Economic Commission for Europe 2020). Their role in the absorption of carbon dioxide emitted by industry is enormous because they absorb about 10% of total CO₂ emissions. The European Union's forests are protected by a long-term management program based on EU environmental law, as well as supported by the concept of sustainable development. Part of this strategy involves increasing the number of national parks and nature reserves, as well as reforestation, afforestation and efficient forestry. All these trends and data are reflected in the proceedings of the IUCN World Parks Congress, the most recent being held in 2020 (IUCN World Parks Congress 2020).

CO₂ emissions in Russia are 1532 million tons per year (4th place in the world). The forests of the Russian Federation absorb 500 million tons of carbon annually, the total carbon stock in the country's forests is estimated at 223 billion tons. Of these, most of the carbon stocks are concentrated in the boreal forests (taiga), due to the slower rate of biological cycling (Konovalov 2010). Thus, the coniferous tree species dominating the taiga are the main ones in terms of carbon accumulation potential.

Krasnodar Krai (Russia) is considered a unique forest region. About one-third of the Russian oak forests are concentrated here, mainly in the foothills of the Caucasus, as well as along the Black Sea coast. Pine, birch, larch, pear, and aspen occur extensively in the highlands. Krasnodar has relatively little forest cover, up to 20 % of the total land or around 2 million hectares (Filipchuk & Moiseev 2004). This is due not only to the large area of agricultural land but also to the location on the border and steppe. The study of major ecological and economic indicators of forest maturity in the Krasnodar Krai remains relevant, as there are few such studies.

In this article, the authors focused on the actual forest structure in the territory of Krasnodar from the viewpoint of carbon sequestration potential. The authors suggest that such forest species as pine, larch, and birch can contribute to the resource role of rapidly growing forests.

This paper aims to study the age structure, species composition, and carbon sequestration potential of forests in Krasnodar Krai, Russia. The study sets the following tasks: a) to analyze the structure of forests in Krasnodar Krai; b) to identify what mass of carbon can be stored by forests; c) to establish indicators of trunk timber phytomass of regional forests; d) to determine what species are promising for cultivating fast-growing forests under the conditions of Krasnodar Krai.

The data collected allow analyzing the age structure of forests from the temperate climate zone in order to establish their carbon sequestration potential. This study also focuses on the tree species composition in the studied forests of Krasnodar Krai to show their variable parameters in wood increment, which defines their different capacity for carbon sequestration.

2. Materials and methods

2.1. Research design

The study was conducted in the period between 2015 and 2020 in 14 forested districts of Krasnodar Krai (see Fig. 1A). Data collection was done once a year every year, i.e., at the same sites for 6 years.

As can be seen from Fig. 1B, 1C, most deciduous and coniferous forests are concentrated in southern Krasnodar Krai, in the mountains and foothills of the Caucasus Chain. The northern part is occupied by steppes and forested steppe zones.

The selection of the data proceeded as follows. First, the database on taxonomic and silvicultural indicators of forest stands at the level of forest units was used. Data were collected during the entire study period. The database included taxonomic and forestry parameters collected from 96,000 sample plots (quadrats) in 14 forest units in the territory of Krasnodar. The other stages are described in the Methods section.

2.2. Methods

Carbon stocks and biomasses of dead wood and roots were calculated in accordance with the methodology proposed by the Ministry of Natural Resources and Ecology of the Russian Federation (Order of June 30, 2017 No. 20-r). This methodology suggests regular (annual or with

the interval of 5 to 10 years) accounting of the stand, seedlings and undergrowth of woody species, which appeared as a result of natural renewal. The stand includes trees with a trunk diameter at breast height of more than 8 cm. The undergrowth refers to younger trees with a diameter at breast height of less than 8 cm. A standard way to account for the stand, seedlings and undergrowth is as follows: an area to up 5 ha is divided into 30 quadrats for the accounting purposes. If the selected area is larger (5 to 10 ha or over 10 ha), then the number of quadrats will be higher, 50 to 100 quadrats, respectively. Their size varies depending on what is the focus of the research (undergrowth, 100 m²; stand, 400 m²). Attention is paid to these parameters: species, height, and diameter at breast height (1.3 m above the ground). No regard is given to spontaneous seedlings aged 1 to 2 years. The amount of carbon stored in the growing stand (carbon stock) is calculated for each tree species using the following formula:

$$C_{biomass} = 0.5 \sum (a(d_i^2 h_i)^b) \quad [1]$$

where, $C_{biomass}$ is the carbon content in the growing stock biomass (oven-dry weight, kg); 0.5 is the coefficient of conversion used to convert biomass into carbon units; d_i represents diameter at breast height, cm; h_i represents tree height, m; a and b are coefficients in the allometric equation for different fractions and wood species.

Carbon content in the undergrowth biomass was measured using this formula [2]:

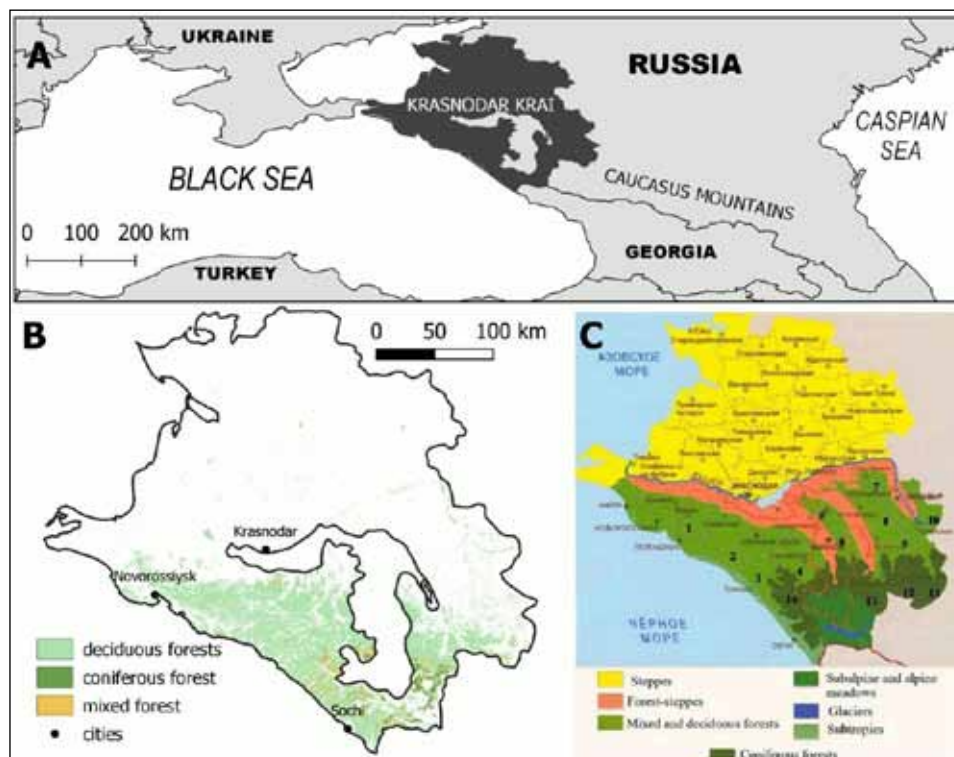


Fig 1. A – the position of the Krasnodar Krai Territory; B – the forest cover of the Krasnodar Territory; C – Map of natural zones in Krasnodar Krai of the Russian Federation (based on Oko Kubani (n.d.). 1 – 14 – forest districts in which research data were collected.

$$C_{agbm} = 0.5 \sum (ah_i^b) \quad [2]$$

where, C_{agbm} is the carbon content in the above ground biomass of the undergrowth, kg; 0.5 is the coefficient of conversion used to convert biomass into carbon units; h_i represents tree/shrub height, m; a and b are coefficients in the allometric equation for the above ground biomass.

To estimate carbon stocks in the underground biomass of trees, one can exploit the ratio of above ground biomass to below ground biomass, which is taken equal to 0.39 (with above ground biomass of less than 75 t/ha) or 0.24 (with above ground biomass of more than 75 t/ha) (Ministry of Natural Resources of Russia 2017). No regard was given to wood residues. The abundance index for each species was calculated by dividing the number of trees within a quadrat by the area of that quadrat.

The area not covered by forest was not taken into account in calculations.

Based on the known indicators of wood growth, it becomes possible to calculate the carbon deposition for the normalized curve using the formula:

$$Q_c = 0.5 \cdot P \quad [3]$$

P – annual wood growth per 1 ha. Then the carbon deposition is converted to carbon dioxide

$$Q_{CO_2} = 3.67 \cdot Q_c \quad [4]$$

The methodology is described in more detail by Fadeev and Zhgulyova (2009).

When calculating deposited carbon, the authors did not use the data on timber harvested and removed from the forests in Krasnodar Krai, since timber harvested in this region does not exceed 0.05% of the total volume, which is within the statistical error. The bulk of timber is imported to the Krasnodar Territory from more wooded regions of Russia, so the use of local forests as sources of firewood and commercial timber is minimal (Chabak 2012).

2.2. Statistical analysis

The arithmetic parameters were determined for value of growing stock. Some of the parameters are given in per-

centage (%): zones occupied by the main forest species, growing stocks, planting zones by age (mature, over-mature, etc.). Carbon sequestration rates are reported in million tonnes (mt). Differences between the characteristics of tree species were established by applying the Student t-test, $\alpha = 0.05$.

3. Results

The main forest-forming species of Krasnodar Krai include aspen (*Populus tremula*), small-leaved linden (*Tilia cordata*), birch (*Betula pendula*), pine (*Pinus sylvestris*), common oak (*Quercus robur*), spruce (*Picea abies*) and others (Fig. 2A).

When analyzing stock distribution, linden trees prevailed (Fig. 2B), while pine, aspen, and birch were nearly equal in volume ($p \geq 0.05$), oak was almost half their volume ($p \leq 0.05$), spruce – almost quarter ($p \leq 0.01$), and other tree species showed 1% each (Fig. 2B).

The differences between the area occupied by woody species and the growing stock are related to the uneven age composition of particular tree species.

For example, among deciduous tree species, such as aspen and birch, the middle-aged groups predominate (Fig. 3). Thus, the share of trees classified as young is 45%, whereas middle-aged trees account for nearly half of the area (45%, Fig. 3). This is because the calculated area of planned harvest was not used to the full extent in different years (a real harvest did not reach the level of planned harvesting), accounting for 99% in 1991 and only 20% in 2006. As a result, the accumulation of trees belonging to the age group of mature and overmature trees increased the mean age of deciduous trees. For conifers, particularly pine, the opposite is the case. Thus, the share of trees classified as young is 44%, whereas that of middle-aged trees is 36%. The youngest by age composition are birch forests (Fig. 3), which are about 0.5 times younger than pines and deciduous trees ($p \leq 0.05$). In birch forests, the majority of trees are young trees (approximately 80%, Fig. 3), while mature age groups make up a small number of trees (2%) ($p \leq 0.05$). In spruce forests, the majority of trees are young trees (approximately 80%, Fig. 3), while

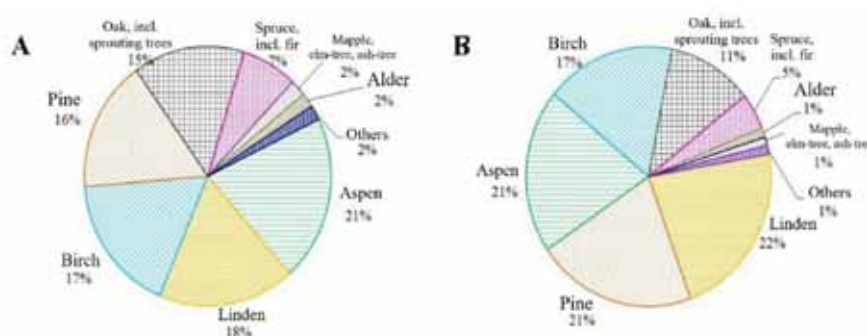


Fig. 2. Areas occupied by the main forest-forming tree species in forests of Krasnodar Krai (A) and indicators of their stock (B).

mature and over-mature age groups make up a small number of trees (2%).

Young oaks represent one-third of the trees (27%); 30% are mature, middle-aged trees account for 15% and over-mature trees represent 10%.

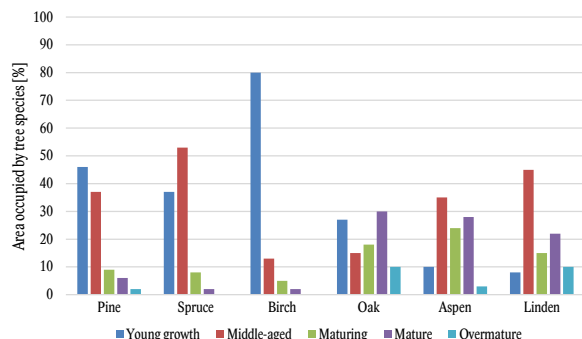


Fig. 3. Distribution of different tree species (in %) by age group and average age: pine 49 years, spruce 52 years, birch 27 years, oak 35 years, aspen 46 years, linden 63 years.

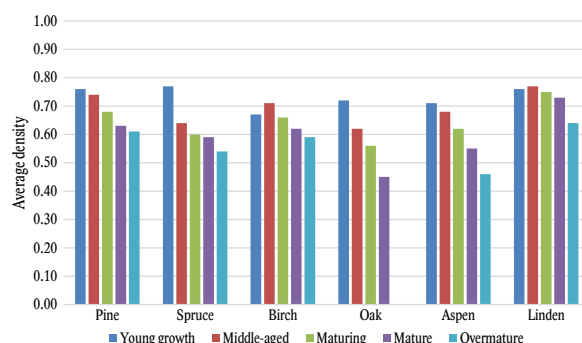


Fig. 4. Average density values with respect to the age group of the most common tree species in Krasnodar Krai.

It was found that for the most common tree species with an increasing age group, there is a decrease in the mean abundance index (Fig. 4). This indicator varies between species: pine, 0.76 to 0.61; spruce, 0.74 to 0.57, oak, 0.45 to 0.72 (in mature and overmature forests);

linden, 0.76 to 0.64; birch and aspen, 0.46 to 0.71 (Fig. 3).

An analysis of the distribution by quality class showed that forests of Krasnodar Krai are mostly very productive (Fig. 5).

In particular, nearly all pine forests belong to the first quality class (91%), of which 34% belong to classes Ib and Ia (Fig. 5). Birch and aspen, belonging to the 1st quality class, account for 75–80% of cases ($p \leq 0.05$ with the frequency of belonging to the 1st quality class of in pine). Birch has an average class I, 2, whereas aspen has a class I, 1. In the spruce forest, 58% of the stands belonged to the 1st quality class ($p \leq 0.05$ with the frequency of belonging to the 1st quality class of the pine), while in the oak forest this index was less than 10% ($p \leq 0.01$), and the bulk of the stands belonged to the 3rd quality class (Fig. 5).

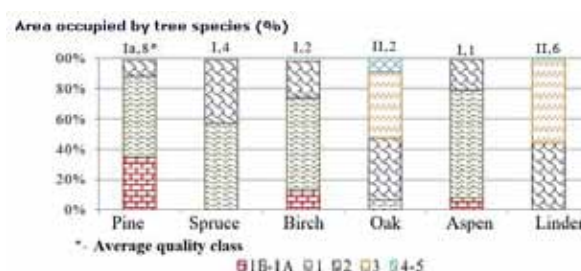


Fig. 5. Quality class distribution indices and average quality class values for the most common tree species in Krasnodar Krai.

The role of forests in Krasnodar Krai in carbon sequestration was determined by calculating indicators that characterize the raw material and ecological functions of forest plantations (Table 1).

As shown in Table 1, the majority (approximately 92%) of phytomass originate from the main forest species. Specifically, linden represents 22% of the phytomass, aspen 20%, pine, and birch 18% each ($p \geq 0.05$ between these species). The minimum biomass in t/ha are in oak, amounting to 12%, which is 1.5 times less than in pine and birch ($p \leq 0.05$). Other species have smaller biomass in t/ha, less than 1 % ($p \leq 0.01$ with other species).

Table 1. Indicators of the area occupied by woody species, their total wood stock, phytomass, and carbon stock for the forests of Krasnodar Krai.

Name of the tree species	Area occupied by woody species	Indicators of the total wood stock	Indicators of total phytomass	Carbon stock indicators
	[thousands of hectares]	[mln. m ³]	[mln. tons]	
<i>Pinus sylvestris</i>	190.0	40.0	18.0	9.0
<i>Picea abies</i>	83.0	8.0	4.0	2.0
<i>Abies alba</i>	1.0	0.3	0.1	0.05
<i>Larix decidua</i>	5.0	1.0	0.5	0.25
<i>Quercus robur</i> , high class	103.0	12.0	7.0	4.0
<i>Quercus robur</i> , low class	66.0	9.0	5.0	3.0
<i>Fraxinus excelsior</i>	1.0	0.03	0.02	0.01
<i>Acer platanoides</i>	20.0	2.0	1.0	0.5
<i>Ulmus</i> sp.	4.0	0.30	0.2	0.1
<i>Betula pendula</i>	201.0	32.0	18.0	9.0
<i>Populus tremula</i>	240.0	39.0	20.0	10.0
<i>Alnus glutinosa</i>	21.0	2.0	1.0	0.5
<i>Tilia cordata</i>	206.0	42.0	22.0	11.0
<i>Populus nigra</i>	3.0	0.5	0.2	0.1
<i>Salix fragilis</i>	13.0	1.0	0.4	0.2

*Values are expressed in round numbers here and in Table 2.

To calculate the carbon content of live wood biomass, we calculated the annual growth of wood stocks for the main forest species in the Krasnodar Krai (Table 2).

The database that included all the forests of the Krasnodar Krai was used for this purpose. For each tree species, the annual increment of the forest was calculated by multiplying the growth by the area occupied by each species.

According to the data in Table 2, it can be seen that only four tree species that make up the forest are responsible for total wood stock growth. The maximum growth rate of larch is approximately 5 m³ per ha per annum. Similar figures can be observed for ash and representatives of poplars. An increment in aspen and pine is on average less by 1 m³ per ha per year ($p \leq 0.05$); birch, linden, fir, and willow have an increment rate of 3.0–4.0 m³ per ha per year, much higher than alder ($p \leq 0.05$). Minimum growth rates for wood are expressed as elm, oak, maple, and alder – no more than 3 m³ per hectare per year ($p \leq 0.05$).

Maximum biomass growth values per hectare were recorded for larch, aspen, ash, and pine, while minimum values were noted for alder. Total growth indicators are highest in 6 tree species, namely, spruce, oak, pine, lime, birch, and aspen. In general, these species account for most of the total growth – up to 95%. That means that the 6 tree species mentioned above also represent the maximum amount of deposited carbon.

3. Discussion

The origin of forests in Krasnodar Krai is affected by intensive forest management and noticeable depletion of mature forests in recent decades. The total stock of timber in the forest fund is 225.77 million m³, including mature and overmature, 108.78 million m³. The volume of timber harvested during unauthorized felling in 2011 decreased by 2,155 m³, or 21%, compared to 2010 (10,378 m³). The volume of illegally harvested timber in 2020 was 8.222 thousand m³ (Chabak 2012). In the

future, due to the unequal distribution of tree species in terms of age, negative trends in forest management may be seen. Thus, in our case, and some similar studies in other regions, there is a buildup of woody resinous species such as trembling aspen (Tupek et al. 2019). The latter is known to be sensitive to degrading processes. In particular, drought plays an important role in reducing the marketable qualities of aspen wood as a result of the injury that develops the rot. Similar processes occur in linden-dominated woodlands, primarily due to wood-destroying fungi (Raymer et al. 2011). It follows from the data obtained that the share of conifers (especially spruce) in Krasnodar Krai may decrease in the next 20 to 30 years, and the share of soft-leaved species with wood of low quality may increase. The primary cause of spruce decline is the beetle-type pest (e. g., Pukkala 2011). For birch, the primary cause of desiccation is the development of bacterial rot, which is caused by bacterial dropsy. It frequently occurs after dry years. Due to the uneven distribution in age groups, as well as the spread of pests and diseases over large areas of forests, selective cutting of mature and overmature forests is used as an alternative preventive method (Kadiogulları et al. 2018).

The large proportion of mature and over-mature oaks may be related to severe frosts that were observed in this region in the late 1970s of the last century. Moreover, the oaks of this area are characterized by gradual desiccation, which is manifested by the death of the trees.

Due to the uneven age distribution of different tree species in the forests of Krasnodar Krai, it is necessary to use selective cuttings with respect to mature and overmature forests. Thus, thinning and selective cutting accounted for approximately half (49%) of all forest management activities in 2018.

From the 1940s to the 2000s, forest areas in Krasnodar Krai increased sixfold, mainly at the expense of forest crops. The greatest contribution to the increase in forest areas was made between 1950 and 1990 (Filipchuk & Moiseev 2004).

The data obtained allow stating that the forest plantations of Krasnodar Krai are highly productive. Growing

Table 2. Annual increments and deposited carbon in forest plantations of Krasnodar Krai.

Type of forest	Name of the tree species	Increment indicators of wood stock by volume	Increment indicators of wood per unit area	Indicators of phytomass increment		Indicators of deposited carbon volume	
		[thousand m ³ per year]	[m ³ per ha per year]	thousand tons per year]	[tons per ha per year]	[thousand tons per] year	[tons per ha per year]
Coniferous	<i>Pinus sylvestris</i>	815.0	4.3	372.0	2.0	186.0	1.0
	<i>Picea abies</i>	310.0	3.8	141.0	1.7	71.0	0.8
	<i>Abies alba</i>	4.0	3.0	1.6	1.1	0.8	0.6
	<i>Larix decidua</i>	28.0	5.1	14.0	2.6	7.0	1.3
Deciduous	<i>Quercus robur</i> high class quality	241.0	2.3	140.0	1.4	70.0	0.7
	<i>Quercus robur</i> low class	155.0	2.3	93.0	1.4	47.0	0.7
	<i>Fraxinus excelsior</i>	2.0	5.6	1.0	3.4	0.5	1.7
	<i>Acer platanoides</i>	52.0	2.6	32.0	1.6	16.0	0.8
	<i>Ulmus</i> sp.	8.0	2.1	5.0	1.2	2.3	0.6
	<i>Betula pendula</i>	706.0	3.5	393.0	2.0	197.0	1.0
	<i>Populus tremula</i>	1109.0	4.6	581.0	2.4	290.0	1.2
	<i>Alnus glutinosa</i>	28.0	1.3	14.0	0.7	7.0	0.3
	<i>Tilia cordata</i>	669.0	3.2	355.0	1.70	178.0	0.9
	<i>Populus nigra</i>	15.0	5.1	7.5	2.5	4.0	1.3
	<i>Salix fragilis</i>	51.0	4.0	26.0	2.0	13.0	1.0

conditions in this zone are favorable for 14 tree species. According to calculations, about 500 billion tons of carbon are deposited in the global terrestrial biomass, of which about 35 billion tons are deposited in the wood of forests growing in the Russian Federation (Filipchuk & Moiseev 2004).

Low-quality class stands are known to be not capable of sequestering significant amounts of carbon (Couture & Reynaud 2011; Forsell & Korosuo 2016). Furthermore, these stands have a low economic value (Felton et al. 2020). Thus, we should expect a maximum yield from forest plantations in terms of carbon sequestration and economic importance at the age of maturity. At the same time, forest sanitation of mature and overmature stands is necessary to limit the spread of fungal and bacterial diseases, as well as outbreaks of mass reproduction of xylophagous insects and other pests (Jucker et al. 2014).

4. Conclusions

Despite the low afforestation of the Krasnodar area, forests are important both ecologically and economically. The estimated total mass of carbon deposited in forests of Krasnodar Krai is 49 million tons, phytomass amounts to about 99 million tons, and total comprises 190 million m³. Calculations showed that forestry plantations annually sequester at least 1,090 thousand tons of carbon, with an increase in the volume indicators of timber by 4 million m³ per year. Studies have shown that the most promising tree species in terms of crop productivity and durability are birch, pine, larch and aspen plantations. Plantations of these species increase the resources and ecological potential of forests, and they are vital to the formation of fast-growing forests. Besides, these tree species have the potential to afforest rugged terrain exposed to erosion - ravine systems, ravines, and slopes. Such measures aimed at increasing forest cover are temporarily capable of sequestering at least 25 million tonnes of carbon. A key factor that determines the level of carbon sequestration in Krasnodar Krai is the further development of technologies for accelerated cultivation of the most promising tree species, as well as improvement of the forest management efficiency.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors would like to sincerely thank three anonymous reviewers for their insightful and helpful comments.

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