Assessment of protective forest plantations on gray forest and sod-podzolic soils of the Predkamye region of the Republic of Tatarstan

Aigul Mukhametshina, *Haris* Musin, *Nail* Mirsiyapov, *Salavat* Usmanov* and I*ldar* Khalilov

Kazan state agricultural university, 65, Karl Marks St., Kazan, 420015, Russia

Abstract. Protective forest plantations increase soil fertility and fulfil an important role of soil protection from erosion. Much attention is paid to protective afforestation in the Republic of Tatarstan. In the region, in 2022, protective forest plantations were established on the area of 1801 hectares, of which ravine-beam forests make up 1763 hectares, including 645 hectares with terracing and 38 hectares of field protection strips. Protective forest plantations were created in Aznakaevsky municipal district on the area of 600 ha and in settlements of 114 ha of "compensatory" reforestation and afforestation. The article presents the results of the survey of existing protective forest plantations in the Predkamya zone of the Republic of Tatarstan on sod-podzolic and grey forest soils. The area is characterised by strong washing away, erosion and gully formation, where the area of washed away soils is 66%, erosion-hazardous lands amount to 15.5%. A sanitary condition of plantations, productivity and carbon deposition were assessed. According to silvicultural and taxation indicators, the average age of the surveyed stands is 48 years; the completeness ranges from 0.5 to 0.9, bonitet ranges from I to II. In terms of the sanitary condition, trees of the 1st and 2nd categories predominate; in some areas forest management measures are required. Under the canopy of the plantations, there is a natural regeneration of petiole oak, which is an indigenous species of the Pre-Kama region of the Republic of Tatarstan. On all surveyed sample areas, the largest amount of carbon stock is concentrated on PP7, PP8 and PP19: 786.96, 833.7 and 828.09 tonnes, respectively. These are mixed stands of pine and birch.

1 Introduction

Establishment of protective forest plantations provides multifunctional and long-term protection of soils from erosion. Under the influence of soil and wind erosion, unprotected soils lose fertility and are withdrawn from agricultural turnover. Due to the created plantations, species diversity is enriched, and ecological conditions of agricultural lands are improved [20, 3]. They have a lasting effect on the indicators and properties of washed away soils, restoring the lost fertility [12]. Forest strips on agricultural lands form a framework of erosion protection, and the efficiency of the complex as a whole depends to a great extent on their location in the relief [1, 2, 22]. In the presence of an interconnected system of forest ameliorative plantations, crop yields increase by 8–18%. On average, the impact of 1 ha of forest plantations extends to 10–12 ha of adjacent fields. According to A.I. Petelko, the scientifically justified need for forest plantations in the country is 14 million ha, but there are only 3.2 million ha [13]. The strategy for the development of protective afforestation in the Russian Federation until 2025 has been developed. It is aimed at creating a complete system of ameliorative protective forest plantations as a mandatory component of national and other programmes to preserve the environment, improve the efficiency of fertility, ensure environmental and food security of the country, reduce the level of discomfort in places of work and human habitation [8]. To date, agricultural science has developed and implemented the principles of adaptive-landscape farming. The most important principle is the application of a set of anti-degradation measures: organisational and economic, forest-reclamation, agrotechnical, meadow-reclamation, hydrotechnical, and others. The framework of adaptive-landscape farming is a system of protective forest plantations [5, 6, 7, 17].

The role of planted forests in carbon storage is exceptional. Forests located on agricultural land are of great importance for the absorption of greenhouse gases. According to Ivanov A.Y., Durmanov N.D. (2021), 1 ha of forests on the lands of the forest fund can absorb, on average, about 1 tonne of greenhouse gases per year. Protective and anti-erosion forests on agricultural lands increase this indicator 7 times up to about 7 tonnes per year. At the same time, according to various estimates, from 40 to 90 million hectares of agricultural land in Russia are overgrown with forests, which are not yet accounted for in the national statistics of greenhouse gas absorption because they do not belong to managed

* Corresponding author: salusmanov7@yandex.ru

forests [4]. This is approximately 26 million tonnes of carbon accumulation annually [9, 19]. It is considered a promising direction to increase soil productivity of these lands through carbon farming, application of modern methods of biotechnology and breeding.

For the effective functioning of existing forest plantations, it is necessary to assess their current state and to develop measures to maintain them. In this regard, it is relevant to conduct research in the Predkamye zone of the Republic of Tatarstan.

The aim of the work is to assess the condition of protective forest plantations on grey forest and sod-podzolic soils in the Predkamya zone of the Republic of Tatarstan.

2 Objects and methods of research

Protective forest plantations in the Predkamya zone of the Republic of Tatarstan were chosen as the object of research. Sample areas were laid in accordance with OST 56-69-83 "Sample forest inventory areas. Laying method" [11]. Glasometer and instrumental measurements (an altimeter, a full-meter, a measuring fork) were performed on each sample area. When carrying out the works, we were guided by the rules of sanitary safety in forests. They were approved by the Decree of the Government of the Russian Federation of 20 May 2017, No. 607; Order of the Ministry of Natural Resources of Russia of 16.09.2016, No. 480 "On approval of the order of forest pathological surveys and the form of the act of forest pathological survey" [15, 16]. A total of 20 sampling areas (hereinafter referred to as PAs) in the Predkamya zone of the Republic of Tatarstan were investigated. Tree counting was carried out at the PPs by thickness gradation (2 cm), and each tree was assigned to a category of condition [11]. During the research, 2000 trees were measured and surveyed. On a 100-metre long trial area, trees were assessed according to the following indicators. The number of trees was counted; a trunk diameter was measured with a measuring fork at a breast height of 1.3 m; a height was determined with a Danilin altimeter, and natural vegetation was visually described. Plots of different ages were selected for these purposes.

3 Analysis and discussion of the results

Preservation and rational use of lands are the main conditions for ensuring stable development of the agro-industrial complex and economy of the Republic of Tatarstan. Over the last decade, the area of agricultural land subject to erosion has increased. A high degree of agricultural land ploughing is observed in Arsk and Baltasinsk districts: 85–86%. On average, this indicator for the region is 77.0%. The greatest increase is observed in the zone of Predvolzhye (34.7%) and Predkamye (30.6%).

In the most pronounced form, the effect of water erosion is manifested in the processes of gully formation. The number of active gully tops is about 20 thousand, and their length is 27.4 thousand km. Over the last 40 years, the length of ravines has increased by more than 10 thousand kilometres.

In March 1997, the Cabinet of Ministers of the Republic of Tatarstan adopted Resolution No. 216 and approved the Comprehensive Programme of Soil Fertility Improvement and Erosion Protection in the Republic of Tatarstan for 1997–2005. It provides for a set of anti-erosion measures. In accordance with the programme, 7.8 thousand ha of protective plantations were planted [14]. To date, most of the forest belts are gradually dying off, subject to diseases and in a neglected state. There is a need to carry out a set of forestry measures to preserve and renew the systems of field protective forest belts [10, 21].

Special attention is paid to protective afforestation in the region in order to prevent water and wind erosion of soil, to increase the productivity of agricultural land, to protect settlements, enterprises and other objects from unfavourable natural phenomena and man-made impacts. According to the data of the Ministry of Forestry of RT, in 2022, protective forest plantations were established on the area of 1801 hectares, of which ravine-beam forests make up 1763 hectares, including 645 hectares with terracing, and field protection strips occupy 38 hectares. Protective forest plantations were created in the Aznakaevsky municipal district within the framework of climate projects on an area of 600 ha and in settlements of 114 ha of "compensatory" reforestation and afforestation. The volumes of protective afforestation for the last five years are shown in Fig. 1.

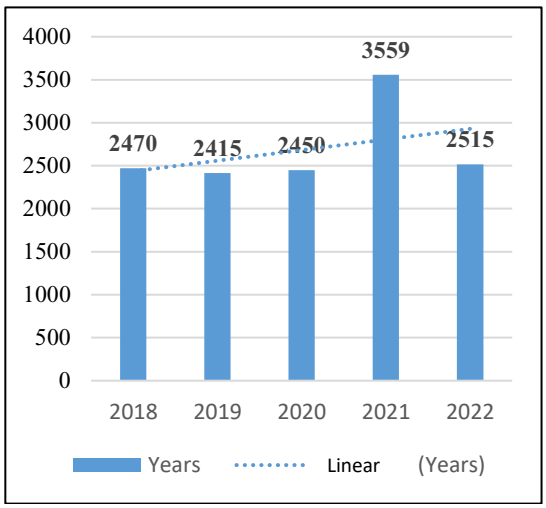

Fig. 1. Protective afforestation over the last 5 years

For the study, sample areas were established in the protective forest plantations in the Predkamya zone of the Republic of Tatarstan (Sabinsky, Arsky, Atninsky municipal districts). Territorially, the study area is located in the catchment area of the Volga slope rivers flowing parallel to each other from north-east to south-west: Ashit, Kazanka and Meshi. The area is characterised by strong washout, erosion and gully formation, where the area of washed out soils is 66%, erosion-prone lands are 15.5%. In this zone, light grey forest soils and sod-podzol soils are most widespread on

watershed plateaus and upper parts of slopes. There are also grey and dark grey forest and sod soils.

The results of the survey and the silvicultural and taxonomic characterisation of the plantations at the PP are given below (Table 1).

Table 1. Characteristics of plantations on grey forest and sod-podzolic soils

No. n/a	Composition of plantations	Breed	Age, years	Height, m	Diameter, cm	Bonnitet	Completeness	Area, ha
1	2	3	4	5	6	7	8	9
PP1	7E3Lz	European spruce, Siberian larch	30	8 10	12 14	1a	0.8	3.5
PP2	7B3E.	Hanging birch, European spruce	30	16 6	18 10	1a	0.8	5.8
PP3	10C	Common pine	54	20	22	1	0.6	4.5
PP4	8B1C 1E	Hanging birch	60	22	26	1a	0.6	5
PP5	10T	Poplar white	50	24	32	II	0.6	3.0
PP6	10Б	Hanging birch	65	23	32	1	0.6	5.3
PP7	9C1B	Pine Common birch Birch overhanging	50 15	22 10	24 18	1	0.7	7.2
PP8	9C1B	Pine Common birch Birch overhanging	50 15	22 10	32 16	1	0.5	7.0
PP9	10Б	Hanging birch	50	22	28	1a	0.6	
PP10	10Б	Hanging birch	60	20	22	1a	0.6	4.0
PP11	6C4E	European spruce Common pine	35	10 12	8 10	1	0.9	8.0
PP12	10Б	Hanging birch	80	24	36	1a	0.6	2.7
PP13	8E1B1 C	European spruce Hanging birch Common pine	40	10	12	1	0.8	2.65
PP14.	10E	European spruce	40	11	12	1	0.8	8.5
PP15.	10Б	Hanging birch	60	22	36	1a	0.6	2.2
PP16	10Б	Hanging birch	60	22	32	1a	0.6	7.3
PP17	10Os.	Poplar trembling	60	21	28	II	0.6	1.9
PP18	10Б	Hanging birch	60	21	28	1a	0.6	2.2
PP19.	5B5S	Hanging birch Common pine	60	21 24	32 28	1a	0.7	7.2
PP20	8T2B	Poplar Hanging birch	50	22 23	32 28	II	0.6	2.9

PP-1 is a mixed composition roadside forest belt representing a mix in row 8Ex4Ltsx8Ex4Lts, 5 rows. A row spacing width is 2.5 m, in a row of 1.3 m. A plantation composition is 7E3Lts. Taxation parameters are an average diameter of spruce (hereafter Cf. d) Cf. of d = 12 cm, an average height (hereafter Cf. h) is Cf. h = 8 m, a larch is Cf. d = 14, Cf. h = 10 m. The introduced larch forms a clump, where the forest environment under the canopy is formed more rapidly due to needle fall. It is located at a distance of 25 m from the road. In terms of the sanitary condition, trees of the 1st category predominate (90%) being without signs of damage. At this site, weakened trees account for 10%; there are minor mechanical damages.

PP-2 is a mixed composition roadside forest belt of 6-row YehBhEhEhEhBhB, a row spacing width is 2 m, in a row of 1.3 m. A composition of plantations is 5E5B. Taxation indices of birch are Cf. d =18, Cf. h =16 m, spruce is Cf. d =10, Cf. h =6 m. The forest belt is located at a distance of 25 m from the road. The slow-growing species European spruce lags behind the birch. In this forest belt, the trees of the 1st category predominate (95 %), "weakened" trees of the 2nd category are 5.0 %.

PP-3 is a clean composition roadside forest belt of 5 rows; a row spacing width is 2 m, in a row of 1.3 m. A composition of plantations is 10C. Taxation parameters are Cf. d =22, Cf. h =20 m. The forest belt is located at a distance of 30 m from the road. On the site, there are self-seeded pine trees of different ages (3–8 years old). In order to form a stable multi-age plantation, it is advisable to carry out measures to promote natural regeneration or mineralised strips. Weakened pine trees (2nd category) account for 35.0 %. In our opinion, the deterioration of the condition of plantations is due to their close proximity to the roadway.

PP-4 is a mixed composition roadside forest belt of old-growth 6-row. A row spacing width is 3 m, in a row of 1.5 m. Taxation parameters are Cf. d = 26, Cf. h = 22 m. A composition of plantations is 8B1C1E + shrub Acacia yellow. BxExBxBxSxBxBxB is reconstructed. Trees of the 1st category "without signs of weakening" predominate (95%).

PP 5 is a pure field-protective forest belt representing an 8-row old-growth; the row spacing is 3 m wide, 1.5 m in a row. A composition of plantations is 10T. Cf. d = 32, Cf. h =24 m. A forest litter thickness is up to 25 cm. A forest environment has been formed. Natural regeneration is due to aspen, sharp-leaved maple, small-leaved linden, birch, oak, oak, poplar of shoot origin. The predominant category of trees is "without signs of weakening" (65%), and category 3 is "severely weakened" (35.0%). Sanitary cuttings with removal of faulted trees are required.

PP 6 is a 6-row pure field protection forest belt. A width of row spacing is 3 m, in the row of 1.5 m. A composition is 10B. Taxation parameters are Cf. d = 32, Cf. h = 26 m. Forest environment is formed; characteristic forest plants are present. The condition of plantations is satisfactory, single adult silkworms were found. Clutches were not found. Natural regeneration is due to birch, oak, oak, oak, maple. Trees of the 1st category "without signs of weakening" are 70.0%, and 30.0% of the 2nd category are "weakened". Sanitary cuttings with removal of faunal trees and promotion of natural regeneration are required.

PP 7 is a mixed composition field protective forest belt. A width of row spacing is 3 m, in the row of 1.5 m. A composition of plantations is 8C2B. Taxation indices of common pine are Cf. d = 24, Cf. h = 22 m. Birch is lagging behind in growth. Taxation indices of birch are Cf. d = 18, Cf. h = 10 m. The condition of the stands is satisfactory; trees of the 1st category "without signs of

weakening" predominate (80%). Natural regeneration is carried out by birch and oak. It is necessary to carry out measures to promote natural regeneration.

Fig. 2. PP 7

Fig. 3. PP 8

PP 8 is a mixed composition field-protective forest belt. A width of row spacing is 3 m, in the row of 1.5 m. A composition of plantations is 8С2В. Taxation indices of common pine are Cf. d = 32, Cf. h = 22 m. The birch lags behind in growth. Taxation parameters of birch are Cf. d = 10, Cf. h = 16 m. The condition of the stands is satisfactory; trees of the 1st category "without signs of weakening" predominate (75.0%). The natural regeneration of the forest is represented by common pine, birch, oak (Fig. 3). It is necessary to carry out measures to promote natural regeneration.

PP 9 is a clear-cut field-protective forest belt. A width of row spacing is 3 m, in a row of 3 m. A composition of plantations is 10Б. Taxation indices of common pine are Cf. d = 22, Cf. h = 28 m. The condition of stands is satisfactory, trees of the 1st category "without signs of weakening" prevail (85.0%). There is the self-seeding of common pine, birch, oak. It is necessary to take measures to promote natural regeneration.

PP 10 is a pure field-protective forest belt, with the row spacing of 3 m in width, 1.5 m in a row. A composition of plantations is 10Б. Taxation indices of birch are Cf. d = 22, Cf. h = 20 m. The condition of the stands is satisfactory; "weakened" trees of the 2nd category predominate (92.0%). Ovipositors of gypsy moths were found on almost all counted trees. Fruiting bodies of the true moth were also found on trees of the 5th and 6th categories. The natural regeneration of trees is due to oyster maple, petiole oak and small-leaved linden. Measures to promote natural regeneration are required.

Fig. 4. PP 10

Fig.5. PP 12

PP 11 is a mixed composition roadside forest belt, with row spacing 2 m wide, in a row of 1 m. A composition is 6С4Е. Taxation parameters of European spruce are Cf. d = 8, Cf. h = 10 m. Taxation indices of common pine are Cf. d = 10, Cf. h = 12 m. The condition of the stands is satisfactory. Damage is localised along the road: yellowed needles, pine trees are drying out. There are trees of 5th and 6th categories. Natural regeneration is at the expense of birch. LNP is not formed; litter is in the form of fallen needles.

PP 12 is a pure composition of a field protective forest belt, with row spacing 3 m wide, in the row of 1.5 m. A composition is 10В. Taxation indices of birch are Cd. d = 36, Cd. h = 24 m. The condition of plantations is satisfactory; trees of the 2nd "weakened" category prevail (75.0%). The forest environment is formed. Oviposition of gypsy moths is found on almost all counted trees. Fruiting bodies of the true moth were also found on trees of the 5th and 6th categories. Natural regeneration takes place due to maple, linden, birch. Forest management measures with preservation of natural regeneration are required.

PP 13 is a mixed composition field protective forest belt. A width of row spacing is 3 m, in the row of 1.5 m. A composition is 8E1B1C. Taxation parameters are Cf. d=12, Cf. h=10 m. The condition of plantations is satisfactory; trees of the 1st category are predominantly without signs of weakening (85.0%).

PP 14 is a clean composition of frontage protective forest plantations. A row spacing width is 3 m, in the row of 1.5 m. A composition is 10E. Taxation indices of European spruce are Cf. d = 12, Cf. h = 11 m. There is intraspecific competition, no silvicultural measures (thinning). An insignificant number of trees damaged by bark beetle-typograph is up to 5.0%, it is of natural character.

PP 15 is a pure composition field protective forest belt. A width of row spacing is 3 m, in the row of 2 m. A composition is 10B. Taxation parameters of birch are Cd. d = 36, Cd. h = 22 m. Category 1 trees predominate (85.0%) without signs of weakening.

PP 16 is a clean composition of the forest fringe. A width of row spacing is 3 m, in the row of 2 m. A composition is 10 B. Taxation parameters of birch are Cf. d = 32, Cf. h = 22 m. The age is 60 years. Trees of the 1st category prevail without signs of weakening (74.0%). Single trees of category 6 are old deadwood.

PP 17 is a pure composition of a field-protective forest belt. A row spacing width is 3 m, in a row of 1.5 m. A composition of plantations is 10 Os. Taxation parameters of aspen are Cf. d = 28, Cf. h = 21 m. The age is 60 years. Trees of the 2nd "weakened" category predominate (85.0%). Trees of category 6 are old deadwood; sanitary felling is necessary.

PP18 is a clear field protective forest belt. A width of row spacing is 3 m, in the row of 2.0 m. A composition of plantations is 10Б. Taxation parameters of birch are Cf. d = 28, Cf. h = 21 m. The age is 60 years. Trees of the 1st category without signs of weakening prevail (85.0%).

PP19 is a mixed composition field-protective forest belt. A width of row spacing is 3 m, in the row of 1.5 m. A composition is 5B5C. Taxation parameters of birch are Cf. d = 32, Cf. h = 21 m. The age is 60 years. Taxation parameters of common pine are Cf. d = 28, Cf. h = 24 m. Category 1 trees without signs of weakening prevail (80.0%).

PP 20 is a mixed composition field-protective forest belt. A width of row spacing is 3 m, in the row of 1.5 m. A composition of plantations is 8T2B. Taxation parameters of poplar are Cf. d = 32, Cf. h = 22 m. The age is 60 years. Taxation parameters of birch are Cf. d = 28, Cf. h = 23 m. Trees of the 2nd "weakened" category predominate (85.0%). Trees of the 5th and 6th categories are present in insignificant quantities. It is necessary to carry out forest management measures.

Table 2. Volume of deposited carbon in forest plantations

Tree species	Area, ha	Total stock, m^3	Total phytomass, tonnes	Carbon stock, tonnes
1	2	3	4	5
Trial area 1				
Spruce	3.5	171.5	77.17	38.59
Larch		80.5	53.13	26.57
Total		252.0	130.3	65.16
Trial square 2				
Spruce	5.8	214.6	96.57	48.29
Birch		545.2	354.38	177.19
Total		759.8	450.95	225.48
Trial area 3				
Pine	4.5	832.5	416.2	208.1
Trial area 4				
Birch	5.0	700.0	455.0	227.5
Pine		70.0	35.0	17.5
Spruce		45.0	20.25	10.13
Total		815	510.25	255.13
Trial square 5				
Poplar	3.0	705.0	317.2	158.6
Trial square 6				
Birch	5.3	869.2	564.98	282.49
Trial square 7				
Pine	7.2	1180.8	590.4	295.2
Birch		302.4	196.56	98.28
Total		1483,2	786.96	393.48
Trial square 8				
Pine	7.0	1358.0	679	339.5
Birch		238.0	154.7	77.35
Total		1596	833.7	416.85
Trial square 9				
Birch	1.0	147.0	95.55	47.77
Trial area 10				
Birch	4.0	496.0	322.4	161.2
Trial square 11				
Spruce	8.0	360	162.0	81.0
Pine		480.0	240	120.0
Total		992	470.4	235.2
Trial area 12				
Birch	2.7	523.8	340.47	170.23
Trial square 13				
Spruce	2.65	108.6	48.9	24.4
Birch		18.6	12.6	6.0
Pine		10.2	5.1	2.5
Total		137.4	66.6	32.9
Trial square 14				
Spruce	8.5	459.3	206.7	103.3
Trial area 15				
Birch	2.2	378.4	245.96	122.98
Trial square 16				
Birch	7.3	1116.9	725.98	362.99
Trial square 17				
Poplar	1.9	362.9	181.45	90.73
Trial square 18				
Birch	2.2	345.4	224.51	112.26
Trial square 19				
Birch	7.2	733.6	476.84	238.42
Pine		702.5	351.25	175.63
Total		1436.1	828.09	414.05
Trial area 20				
Poplar	2.9	426.3	191.83	95.92
Birch		118,9	77.28	38.64
Total		545.2	269.11	134.56

Table 3. Annual volumes of average stemwood growth and carbon sequestration in sample plots

Tree species	Increase by stock		Phytomass growth		Carbon sequestration	
	m^3/year	m^3 /ha*year	tonnes per year	tonnes/ha*year	tonnes per year	tonnes/ha*year
Trial area 1						
Spruce	5.72	1.63	2.57	0.73	1.29	0.37
Larch	2.68	0.77	1.77	0.51	0.89	0.25
Trial square 2						
Spruce	7.15	1.23	3.22	0.56	1.61	0.28
Birch	18.17	3.13	11.81	2.04	5.91	1.02
Trial area 3						
Pine	15.4	3.4	7.7	1.7	3.85	0.85
Trial area 4						
Birch	11.66	2.33	7.58	1.52	3.79	0.76
Pine	1.16	0.23	0.58	0.12	0.29	0.06
Spruce	0.75	0.15	0.34	0.07	0.17	0.03
Trial square 5						
Poplar	14.1	4.7	6.34	2.1	3.17	1.05
Trial square 6						
Birch	13.37	2.52	8.69	1.64	4.35	0.82
Trial square 7						
Pine	23.6	3.3	11.8	1.6	5.9	0.8
Birch	20.16	2.8	13.10	1.82	6.55	0.91
Trial square 8						
Pine	27.16	3.39	13.58	1.94	6.79	0.97
Birch	9.2	1.31	10.31	1.47	5.16	0.74
Trial square 9						
Birch	2.94	2.94	1.91	1.91	0.96	0.96
Trial area 10						
Birch	8.26	2.07	5.37	1.34	2.69	0.67
Trial square 11						
Spruce	10.2	1.2	4.6	0.81	0.6	0.3
Pine	19.2	2.4	9.60	1.20	4.80	0.60
Trial area 12						
Birch	6.55	2.43	4.26	1.58	2.13	0.79
Trial square 13						
Spruce	2.7	1.0	1.2	0.5	0.6	0.2
Birch	0.5	0.2	0.3	0.1	0.2	0.1
Pine	0.3	0.1	0.1	0.0	0.1	0.0
Trial square 14						
Spruce	11.5	1.4	5.2	2.0	2.6	1.0
Trial area 15						
Birch	6.31	2.86	4.10	1.86	2.05	0.93
Trial square 16						
Birch	18.62	2.55	12.10	1.66	6.05	0.83
Trial square 17						
Aspen	6.05	3.18	3.02	1.59	1.51	0.80
Trial square 18						
Birch	5.76	2.62	3.74	1.70	1.87	0.85
Trial square 19						
Birch	12.23	1.69	7.95	1.10	3.97	0.55
Pine	11.71	1.63	5.85	0.81	2.93	0.41
Trial area 20						
Poplar	8.5	2.9	3.8	1.3	1.90	0.65
Birch	1.98	0.68	1.29	0.44	0.64	0.22

Carbon stocks and rates of carbon storage in forest ecosystems depend on forest productivity, their condition, species composition, age and commodity structure. The annual change in stem wood stock was assessed to calculate the mass of carbon to be deposited in the living phytomass of forests. The obtained growth data were used to calculate phytomass fractions and the amount of carbon deposited per year [18]. In all surveyed sample plots, the largest amount of carbon stock was concentrated in PP7, PP8 and PP19: 786.96, 833.7 and 828.09 tonnes, respectively. These are mixed stands of pine and birch (Table 2).

According to literature data, a promising species in carbon sequestration is poplar (Populus) in northern and continental climates. This species is common in part of Russia and is found in many Russian cities. It has a relatively high carbon sequestration potential of 1.8–6.35 t CO_2-eq/ha/year, a high growth rate of 1.524–3.6 m/year, a short productive cycle of 10–15 years [22]. Out of all the 20 surveyed sites, two of them have PP5 and PP20 poplar in their composition. According to the silvicultural and taxonomic characteristics, the plantations were classified as a II class of bonitet. At these sites, it is necessary to carry out sanitary cuttings. The volume of carbon deposition in these areas was 3.17 and 1.90 tonnes/ha per year.

Conclusions

The surveyed protective forest plantations on sod-podzolic and grey forest soils are in a satisfactory condition.

According to silvicultural and taxation indicators, the average age of the surveyed stands is 48 years; the completeness is within the range from 0.5 to 0.9, and the bonitet is within the range from I to II.

In terms of the sanitary condition, trees of the 1st and 2nd categories prevail; in some areas, forest management measures are required.

Under the canopy of plantations, there is a natural regeneration of petiole oak, which is a native species of the Pre-Kama region of the Republic of Tatarstan, as well as birch, pine, and oak maple.

Established protective forest plantations fulfil their functions, i.e. reduce erosion and increase soil fertility.

In areas with viable undergrowth, it is advisable to carry out measures to promote natural regeneration and conservation. Preservation of undergrowth promotes further formation of stable mixed, mixed-aged, complex in structure, protective forest plantations.

The largest volume of deposition was detected in mixed stands of birch and pine, poplar.

References

1. A.T. Barabanov, A.I. Petelko, A.V. Kulik, A.V. Vypova, New technology of placement of flow-regulating forest strips on slope lands, Izv. NV AUK **2(54)** (2019)
2. A.T. Barabanov, *Erosion-hydrological assessment of interaction between natural and anthropogenic factors in the formation of surface runoff of melt water and adaptive-landscape farming* (FSC Agroecol. RAS, Volgograd, 2017), 188 p.

3. V.I. Erusalimsky, V.A. Rozhkov, Multifunctional role of protective forest plantations, Bull. of Soil Inst. Pochv. inst. **88** (2017)
4. A.Y. Ivanov, M.P. Orlov, K.V. Piksendeev, Y.E. Rovnov et al., *Battle for the climate: carbon farming as Russia's stake*, Expert report, ed. by A.Y. Ivanov, N.D. Durmanov (Izd. dom Higher School of Econ., Moscow, 2021), 120 p. ISBN 978-5-7598-2519-7 (in reg.), ISBN 978-5-7598-2281-3 (e-book).
5. K.N. Kulik, Development of agroforestry science in Russia, Izv. NV AUC **3(35)** (2014)
6. K.N. Kulik, A.T. Barabanov, A.S. Manaenkov, Forecast of the development of protective afforestation in Russia until 2020, Probl. of Forecast **4** (2015)
7. K.N. Kulik, Protective afforestation in the Russian Federation: problems and development strategy until 2020, Theor. and appl. probl. of agroindustry complex **1** (2009)
8. K.N. Kulik, Strategy for the development of protective afforestation in the Russian Federation until 2025, Bull. of Agricult. Design **3**, 5–11 (2015)
9. P.I. Lakida, Carbon stocks in the phytomass of forest phytocenoses of the National Park "Pripyat-Stokhod", Problems of forestry and silviculture, In: *Collection of scientific papers of IL NAS of Belarus*, Iss. 77 (Inst. of Forestry of the National Acad. of Sci. of Belarus, Gomel, 2017), pp. 99–107.
10. A.R. Mukhametshina, G.A. Petrova, H.G. Musin, I.R. Taziev, Analysis of the state of agroforest landscapes of the Republic of Tatarstan and ways of their restoration, *Innovative technologies in agroindustrial complex in the conditions of digital transformation*, Proc. of the Int. Sci. and Pract. Conf. (Volgograd, 09–11 February 2022) (Volgograd State Agrar. Univ., Volgograd, 2022), Vol. I, pp. 421–426, EDN JSIVAC
11. OST 56-69-83 *Sample forest inventory areas. Method of laying*
12. A.I. Petelko, Restoration of fertility of washed away soils, Prirodoobustroystvo **1** (2017)
13. A.I. Petelko, N.E. Novikov, Protective afforestation, Vest. AIC Stavropolya **3(15)**, 175–178 (2014)
14. *On the Comprehensive Programme of Soil Fertility Improvement and Protection against Erosion in the Republic of Tatarstan for 1997–2005*, Resolution of the Cabinet of Ministers of the Republic of Tatarstan of 12 March 1997, no. 216
15. Resolution of the Government of the Russian Federation, of 20 May 2017, no. 607
16. *On approval of the procedure for conducting forest pathological surveys and the form of the act of forest pathological survey*, Order of the Ministry of Natural Resources and Environment of Russia, dated 16.09.2016, no. 480
17. P.N. Proezdov, D.A. Mashtakov, A.V. Panfilov, Theoretical substantiation of adaptive-landscape systems of farming and agroforestry in the steppe and dry-steppe zones of the Volga region, Niva Povolzhye **2(43)** (2017)
18. E.M. Romanov, T.V. Nureeva, T.F. Miftakhov, A.S. Puryaev, Ecological and raw material role of forests of the Republic of Tatarstan, Bull. of Volga Reg. State Technol. Univ., Ser.: Forest, Ecology, Nature Manag. **2**, 5–18 (2015)
19. V.G. Sergienko, Impact of expected climate change on the carbon balance and ecosystem productivity in the forest sector of the Russian Federation, Proc. of the St. Petersburg Res. Inst. of Forestry **1**, 74–90 (2018)
20. D.K. Suchkov, Role and economic efficiency of protective forest plantations in the restoration and transformation of landscapes, Sci. and Agron. J. **1(102)**, 20–23 (2018)
21. G.A. Petrova, A.R. Mukhametshina, H.G. Musin, R.H. Mukhametshina, H.G. Musin, R.H. Gafiyatov, Analysis of the Aspen Growth (Populus tremula L.) obtained by in Vitro in the Republic of Tatarstan, BIO Web Conf. **37** (2021)
22. S.T. Zhang, J.Z. Zhang, Y. Liu, Y.C. Liu, Effects of farmland vegetation row direction on overland flow hydraulic characteristics, Hydrol. Res.. **49(6)**, 1991–2001 (2018)