Impact of forestry practices on carbon balance in forest steppes and steppes of European Russia

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Abstract. The paper assesses the impact of forestry practices on carbon balance in forest ecosystems the example of eleven regions fully or partly included in forest-steppe or steppe of European Russia (ER). Calculations made by the procedure «Regional evaluation carbon balance in forests», has shown, that yearly fires and other forest destruction causes harmed carbon stock by all pools of forest ecosystems the studied regions in amount of 2632,000 [tC year⁻¹] (87.3 % of total loss of carbon by forest ecosystems). Forestry practices such as salvage felling harm carbon stock of forest ecosystems in amount of 288 thousand [tC year⁻¹] (9.5 %). Improvement felling harmed it in amount of 108,000 [tC year⁻¹] (3.58 %). Only activities on forest restoration led to carbon stock accumulation in forest ecosystems in amount of 12 thousand [tC year⁻¹] (0.5 %) in the period 2007-2015. Total average annual carbon losses from forestry practices were equal up to 3,013,000 [tC year⁻¹] in studied forest ecosystems. Severe reduction of forest fires in 2016 led to a reduction in total carbon losses up to 397,000 [tC year⁻¹]. In general, during researching period the carbon balance has a positive value and was equal to 3,090,000 [tC year⁻¹] in the studied forest ecosystems in the period of 2007-2015, and rolled over to 5,706,000 [tC year⁻¹] in 2016.

1. Introduction
Forests in forest steppes and steppes perform important ecological functions as climate regulation, water protection, soil protection, land-improvement, and biota creation. Located in densely populated and low-forest areas they have a great impact on the human economic activity [1]. Forest fires, forest felling, harmful insects and diseases, as well as industrial pollution influence significant impact on the carbon balance [2]. Since tehre are practically no virgin forests providing active. Photosynthesis, maintaining the carbon cycle needs the introduction of new forestry practices [3].

The total carbon emissions from fires in Russian forests are estimated in an amount 35-93 million [tC year⁻¹] (tons of carbon per year), equivalent to atmospheric emission in an amount of 128 and 340 million [tCO₂ year⁻¹] [4]. Until the early 1990's there was cut down of wood up to 420 million [m³], 360 million [m³] of which were exported and 60 million [m³], in forests in Russia. The total amount of carbon in the phytomass of cuttings is about 170 million [tC year⁻¹][5].

Currently, there are no data on carbon stock and carbon emission in the forests of the forest-steppe and steppe zones of the European part of Russia (ER), especially under the influence of anthropogenic and abiotic factors [6]. Therefore, the aim of this research was to study the impact of forestry practices on carbon balance in forest steppes and steppes at European Russia in the context of current climate changes.
2. Methodology

In the collection, processing and analysis of the initial data, we used known typical forest management and taxation, forest management and mathematical and statistical methods of work.

Initial data pool included various sources of information as of: data collection of Intergovernmental Panel on Climate Change (IPCC), results of scientific research work in the field of application of forestry management systems in the management of the carbon cycle in connection with climatic changes in forest ecosystems of the forest-steppe region and the steppe region of the ER, statistical information on the status of forest fund of subjects at zone based area, main kinds of performed forestry practices, including information on improvement felling of forest vegetation, forest reproduction (non-natural and combined, felling of young forest) and forest planting, forest-protection activities in terms of different kinds of salvage felling, forest cleaning from littering, fire-safety measures (making of fire breaks and barriers, construction of roads, including fire-prevention purposes). The studied zone based area spans 11 regions located in European Russia, fully entering into the forest-steppe region (Belgorod, Kursk, Lipetsk, Tambov, Oryol and Penza regions), steppe region (Volgograd and Rostov regions), or partly - in both these areas (Voronezh, Samara and Saratov regions).

To estimate and forecast carbon stocks in forest ecosystems of the zone based area we used a methodology «Regional evaluation carbon balance in forests» (RECBF) [2]. Calculations are made on the basis of the State forest register data of 2017. All the main carbon pools of the forest ecosystems were measured in thousands of tC. The State forest register data reflect the area and growing stock by the predominant species and age groups, as well as the basic reference figures used in our study. We calculated the total accumulated carbon stock for all categories of forest lands of the region on the basis of these figures. For forested land, the amount of carbon stock in the standing biomass pool was calculated by multiplying the stem volume of predominant species with their respective conversion rates. The carbon stocks in the pools of deadwood, forest litter and soil were estimated on the basis of the State forest register data about the areas occupied by forest-forming species and the RECBF data about the loss of growing forest and carbon stock by age groups per unit area.

3. Results and discussion

Calculations showed that the largest carbon stock is in wooded lands - 535,776,000 [tC] (100%), including: in the Belgorod region 35554,000 [tC] (6,6%); in the Kursk region 33520,000 [tC] (6.3 %); in the Voronezh region 48272,000 [tC] (9.0 %); in the Lipetsk region 24277,000 [tC] (4.5 %); in the Oryol region 15097,000 [tC] (2.8 %); in the Tambov region 52286,000 [tC] (9.8 %); in the Penza region 122826,000 [tC] (22.9 %); in the Samara region 68768,000 [tC] (12.8 %); in the Saratov region 66963,000 [tC] (12.5 %); in the Volgograd region 45734,000 [tC] (8.5 %); in the Rostov region 22664,000 [tC] (4.2 %) (figure 1).

The carbon stock of forested land was not evenly distributed among the pools. The largest amount of carbon stock is concentrated in the soil pool – 243874,000 [tC] (45.5 %), followed by the standing biomass pool – 195864,000 [tC] (36.6 %), deadwood – 47436,000 [tC] (8.8 %), forest litter – 46493,000 [tC] (8.7 %), green cover – 2109,000 [tC] (0.4%) (figure 2).

All pools of coniferous forests account for 64403,000 [tC] (26.4 %), while pools of hard-wooded forests – for 84671,000 [tC] (34.7 %), soft-wooded forests – for 91098,000 [tC] (37.3 %). The smallest carbon stock is contained in the forest litter of coniferous forests where it amounts to 7565,000 [tC], and in the forest litter of soft-wooded forests – 7951 thousand [tC].

Non-wooded lands include 17581,000 [tC]. The largest amount of carbon falls in the wasteland – 5447,500 [tC] and in open forest plantation – 5396,000 [tC], the smallest – in forest nurseries and plantations – 424,000 [tC], and in natural open forests – 164,400 [tC]. The main carbon stocks of non-forest lands are concentrated in bogs – 39185,000 [tC].
During research, all factors of influence on the carbon cycle in managed forests were grouped into four categories. It has been found that yearly fires and other destruction causes of forest vegetation in the period of 2007-2015, which harmed carbon stock by all pools of forest ecosystems of the studied regions in the amount of 2632,000 [tC year⁻¹] (87.3 % of total carbon losses by forest ecosystems), are given as one of accounting variant of losses. For example, according to calculations, the carbon loss by the standing biomass is equal to 70.25 %, by the dead wood – 16.83 %, by the bedding – 2.83 %, by the soil – 10.03 % of the total losses for this category (table 1). Further, forest protection activities harm carbon stock by forest ecosystems in the amount of 288,000 [tC year⁻¹] (9.5 % of total carbon losses by forest ecosystems). In such case, standing biomass loses 0.202 million [tC year⁻¹], that is equal to 70.13 % of the total losses for this category, dead wood losses 17.01 %, bedding –2.8 %, soil – 9.7 % (table 1). Yearly improvement felling in forestry practices harms carbon stock in the volume of 108,000 [tC year⁻¹] (3.58 % of total carbon losses by forest ecosystems). Here, we observe also the largest loss of carbon in the pool of standing biomass – 76,000 [tC year⁻¹], that is equal to 70.37 % of the total losses for this category, dead wood loses 16.67 %, bedding – 2.8 %, soil – 10.18 % (table 1).
Finally, activities on forest restoration led to carbon stock accumulation in forest ecosystems [7] in the amount of 15,000 [tC year⁻¹]. In this category, we observed the greatest accumulation of carbon in standing biomass, it is equal to 0.012 million [tC year⁻¹] (80.0 % of the total accumulation for this category), dead wood – 13.3 %, soil – 6.67 % (table 1).

| Activity                           | Carbon losses, thousand [tC year⁻¹] | Total |
|------------------------------------|-------------------------------------|-------|
|                                    | standing biomass | deadwood | bedding | soil (0-30 cm) |       |
| Yearly fires and other destruction causes | -1849 | -443 | -75 | -264 | -2632 |
| Forest protection activities       | -202 | -49 | -8 | -28 | -288 |
| Yearly improvement felling         | -76 | -18 | -3 | -11 | -108 |
| Forest restoration                 | 12 | 2 | 0 | 1 | 15 |
| Total                              | -2116 | -508 | -86 | -303 | -3013 |

The total average carbon losses are equal to 3013,000 [tC year⁻¹] (table 1) in the period of 2007 to 2015. For example, standing phytomass loses 2116,000 [tC year⁻¹] on the average, that is equal to 70.22 % of total carbon losses by forest ecosystems, dead wood loses – 508,000 [tC year⁻¹] (16.86 %), bedding – 86,000 [tC year⁻¹] (2.85 %), soil – 303,000 [tC year⁻¹] (10.05 %).

Due to the effective implementation of fire prevention measures, the areas of forest fires is reduced in the forest fund of the studied regions of ER in recent years. Therefore, carbon losses have been significantly reduced, which were in 2016 according to calculations: by standing biomass – 11,750 [tC year⁻¹], dead wood – 2,820 [tC year⁻¹], bedding – 480 [tC year⁻¹], soil (0-30 cm) – 1,680 [tC year⁻¹]. In general, fire losses for all pools were lower compared to losses from other types of forestry practices (forest protection activities, improvement felling) – 16,720 [tC year⁻¹], and while their volumes are preserved at a stable level, the total value of carbon losses in the forest fund of studied zone based area at European Russia was equal to 397,720 [tC year⁻¹] in 2016.

Table 2 shows the stock and balance of organic carbon in forest ecosystems in the forest fund of the studied zone of European Russia. tC], including for Research has shown that 31.8 %, dead wood 7.6 %, soil 53.1 %. Carbon balance has a positive value and equal to 3,090,000 [tC year⁻¹] in forest ecosystems in the forest fund of the zone-based area at studied forest-steppe and steppe region of Russia. However, it has a negative value in some areas (Lipetsk region – 8,000 [tC year⁻¹], Tambov region – 202,000 [tC year⁻¹], Volgograd region – 25,000 [tC year⁻¹], Rostov region – 321,000 [tC year⁻¹]) due to the large areas of forest fires (table 2).

Carbon balance has positive value in 2016 in all regions of managed forests at zone based area due to the minimal areas of forest fires and was equal to by standing biomass – 4000,800 [tC year⁻¹], dead wood – 965,780 [tC year⁻¹], bedding – 169,120 [tC year⁻¹], soil (0-30 cm) – 570,820 [tC year⁻¹] and in total – 5706,520 [tC year⁻¹] (table 2).

In this research we evaluated the carbon stock in accordance with forest land categories of 11 studied subjects of ER. We also quantified the intensity of forest activities carried out on this territory and their impact on protective forests of forest-steppe and steppe region of Russia. Besides, we evaluated the carbon cycle dynamics and the balance of organic carbon in forest ecosystems of managed forests of the studied area.

Our research has shown that carbon balance in forest-steppe and steppe of ER depends largely on the amount of forest area affected by forest fires as well as on the nature and intensity of forestry activities.
All the studied forestry activities on the area can be divided into 2 main groups according to their influence on the carbon balance: 1 – those reducing the carbon stock and carbon sink and 2 – those that help raise carbon reserves.

### Table 2. Stock and balance of in forest ecosystems of managed forests at European Russia.

| Subject (region) | Stock Balance thousand [tC] | Carbon pool standing biomass | deadwood | bedding | soil (0-30 cm) | Total thousand [tC] |
|------------------|-----------------------------|------------------------------|----------|---------|---------------|-------------------|
| Belgorod         | 17275 3618 3204 13234       |                              |          |         |               | 37360             |
| Kursk            | 14963 3459 2633 15808       |                              |          |         |               | 36860             |
| Lipetsk          | 10147 2606 1618 14203       |                              |          |         |               | 28567             |
| Tambov           | 20511 5640 3160 33143       |                              |          |         |               | 62450             |
| Oryol            | 6669 1428 990 7005          |                              |          |         |               | 16091             |
| Penza            | 45287 11423 8069 66364      |                              |          |         |               | 131137            |
| Voronezh         | 19809 4796 4571 31661       |                              |          |         |               | 60826             |
| Saratov          | 21690 4737 8242 44007       |                              |          |         |               | 78670             |
| Samara           | 25240 5992 5428 39515       |                              |          |         |               | 76171             |
| Volgograd        | 12138 2523 6499 46889       |                              |          |         |               | 68049             |
| Rostov           | 6653 1433 3061 22544        |                              |          |         |               | 33686             |
| Total            | 200382 47655 47473 334372   |                              |          |         |               | 629868            |

Research has shown that the total stock of carbon at the studied object was equal to 629,868,000 [1]. The first group of activities, i.e. those that reduce the carbon stock and carbon sink, includes all kinds of improvement cuttings and forest protection measures such as sanitary clear cuttings and selective cuttings, removal of dead wood and other forestry practices. Our research confirmed the rather obvious fact that any kind of cuttings has a negative impact on the carbon balance in forest ecosystems. Therefore, in the mainly protective forests of the area all the cuttings should be carefully planned and implemented only when necessary. They should also help to improve either the forest’s productivity, as in the case of low-intensity fellings, or its health state.

It should be emphasized that unmanaged forest fires have the greatest negative impact on carbon stock. When a forest fire damages or destroys a particular forest area it almost instantly causes a huge carbon emission, therefore, halting or disrupting normal carbon dynamics dramatically in a relatively short period of time. Thus, the system of forest management should aim at the carbon stock conservation through timely, properly and fully implemented fire protection measures, which is also
confirmed by our research. The second group of forest activities that help to raise the organic carbon reserves includes reforestation.

4. Conclusion

The obtained data indicate that there is a positive carbon balance on the studied area of forest-steppe and steppe region of ER. However, in view of the climate changes [8] observed in the studied forests, such as rapid and extreme temperature fluctuations, increased number of droughts, hurricanes, tornadoes, floods and other adverse weather conditions, the system of forest management therefore should aim at the forest conservation through timely and adequate forestry practices and fire protection measures, minimizing the volume and intensity of cuttings, increasing the scale of reforestation, including the replacement of over-mature and declining forests, which are losing their environmental functions, by sustainable long-lasting and productive young stands of native forest-forming species. The implementation of these activities will help to stabilize the carbon cycle in the forests of the studied area and also to increase the carbon stock within a short-term time-frame.

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