Forestation potential in recultivation of disturbed lands for reduction of greenhouse gas emission

E A Kushnir\textsuperscript{1}, C O Grigoriyeva\textsuperscript{1}, E I Treshchevskaya\textsuperscript{3} and A V Konstantinov\textsuperscript{1,2}

\textsuperscript{1}Research Department for Forest Ecosystem Monitoring, Saint Petersburg Forestry Research Institute, 21 Institutsky Prospect, St. Petersburg 194021, Russian Federation
\textsuperscript{2}Dynamic Meteorology and Climatology, Voeikov Main Geophysical Observatory, 7 Karbyshev Street, St. Petersburg 194024, Russian Federation
\textsuperscript{3}Faculty of Forestry, Voronezh State University of Forestry and Technologies named after G. F. Morozov, 8 Timiryazeva Street, Voronezh 394087, Russian Federation

\textsuperscript{1}E-mail: e.kushnir@spb-niilh.ru

**Abstract.** Forestation during recultivation of disturbed lands may become an additional measure to expand the flow of greenhouse gases for the Russian Federation. The study of forestation potential on disturbed lands is based on analysis of public statistical data on the land distribution according to the grounds as well as data on the areas and growing stocks of forested lands for tree species and age classes in the Leningrad region. In order to establish an potential absorption capacity of recultivated lands, forest stands of the first and second age-classes were chosen as model (with pine, spruce and birch as dominating tree species). On the basis of model forest stands by the method of regional assessment of the forest carbon budget the feasible forestation potential for recultivation of disturbed lands for the areas of Leningrad region is established. Forestation in the stands of the first and second age-classes with dominating of spruce may increase the absorption capacity of the Leningrad region by 1.9 \%, stands with dominating of birch by 1.5 \% and stands with dominating of pine by 1.3 \% per year.

1. Introduction

In December 2015, at the 21st conference of the United Nations framework Convention on climate change (hereinafter UNFCCC), that was held in Paris, a bill addressing the future characteristics of international climate policy was signed, that has been knows as the Paris agreement. The agreement assumes that specific measures should be taken, aiming at reducing greenhouse gas emission in order to combat climate change. Development and implementation of such solutions are the sole responsibility of the very national governments [1, 2].

The Paris agreement recognizes and values the significance of preserving and increasing the carbon pools and greenhouse gas stocks referred to in the United Nations framework Convention panel on climate change, depending upon the constraints, imposed by the regional circumstances. According to the paragraph 1, of this agreement, “in order to achieve the long term global temperature goal, the Parties shall strive to reach as soon as possible a global peak in greenhouse gas emissions, and subsequently achieve rapid reductions in accordance with the best available scientific knowledge, in order to achieve a balance between anthropogenic emissions by sources and removals through
greenhouse gas pools in the second half of the current century”, implying the significant reduction in emission in all economic branches (energy, heavy - and mining industries), alongside with an increase in carbon sequestration through increased stock volume in the land-use economic sector. Article 5, paragraph 2, of the Paris agreement specifies the types of projects in the land-use sector that can be tailored to reduce emission from sources and serve as absorption pools of greenhouse gases – “activities related to reducing emissions from deforestation and forest degradation and the role of forest conservation, sustainable forest management and increasing carbon storage in forests” [1].

In case of ratification of the Paris agreement, the Russian Federation has to take measures to reduce greenhouse gas emission in such way that national interests of the country is met and the socio-economic development is not impaired. Having analysed of a variety of foreign and domestic experiences of studying the climate change problem, reforestation of previously deforested areas, forestation of damaged lands as well as lowering the current deforestation rate [2-4] turn out to be effective measures of removing excess CO$_2$ from the atmosphere and carbon retention.

Having been integrated in domestic practice, the term “forestation” corresponds with the term “afforestation”, mentioned in international climate agreements. According to part II, paragraph 3.1, PP. 24 of the intergovernmental panel on climate change (hereinafter IPCC) special report “land Use, land-use change and forestry” (hereinafter LULUCF), afforestation is defined as “forest establishment and planting on a land that has not had a forest for a specific period of time (e.g. 20-50 years or more) and has previously been in use for a different purpose” [5].

The effective implementation guidelines of LULUCF and the IPCC Programme on national greenhouse gas reservoirs [6] supplement the term “afforestation” with the criteria of “being a direct result of human activities to convert sites that have not been planted in for at least 50 years into forests by planting, seeding and (or) human - derived distribution of seeds of natural origins”.

Disturbed lands that have lost their economic value in the course of human activity impose a negative impact on the entire environment (disturbing of soil cover, hydrological regime, processes of erosion and deflation). Violation of land could be caused during development of mining excavations and peat, geological exploration, construction and other human activities. In the businesses, whose activities are associated with violation of lands, recultivation works are an integral component of technological processes [7]. Land recultivation measures aim at preventing further land degradation and (or) restoring its fertility by bringing the land into the suitable conditions for use for the intended purpose and permitted utilisation, by addressing the consequences of soil pollution, recultivation of the fertile soil layer and establishing protective forest stands [8]. According to item 7 of “guidelines of afforestation, project structure for afforestation, and its developmental sequence” approved by the order No 700 of the Ministry of natural resources and ecology of the Russian Federation on 28.12.2018 “about the rules of afforestation, project structure for afforestation, and its developmental sequence” [9] – afforestation on lands subject to recultivation, is implemented for the purpose of biological regeneration on these lands by creating of forest stands after completion of the technical stage of recultivation (planning, application of a fertile layer of soil, terracing of slopes of dumps and some other parts) according to the decree No 800 of the Government of the Russian Federation passed on 10.07.2018 “On recultivation and conservation of land” [8].

Table 1 presents an analysis of the prospects for forestation on disturbed lands from the perspective of a possible measure to increase carbon stocks and the legal status of disturbed lands.
Table 1. Use of recultivated lands for afforestation as measures to increase carbon flow.

| Measures to remove excess of CO₂ from the atmosphere and carbon retention | Disturbed lands | Russian regulatory acts for management of forestation |
|---|---|---|
| possible activities: afforestation (forestation); reforestation; reducing of deforestation | afforestation (forestation) | Resolution No 800 of the Government of the Russian Federation passed on 10.07.2018 ‘On land recultivation and conservation’ item 8(1) |
| Reducing emission sources / absorbing of greenhouse gases | Carbon sequestration | Land codex of the Russian Federation (article 13) Forest codex of the Russian Federation (article 21, 60.12, 60.14) Oder No 20-r of the Ministry of Natural Resources of Russian on 30.06.2017 ‘On approval of guidelines for the quantitative determination of the volume of greenhouse gas absorption’ |
| Carbon flows resulting from human activity | + | |

Table 1 shows that measures for recultivation of disturbed lands on the one hand are being reflected in the legal framework of the Russian Federation as mandatory regulations, and on the other hand they meet all the requirements of the carbon retention project. This opens up the doors to a whole new level of prospects for greenhouse gas emission reduction in the Russian Federation, as well as developing implementation mechanisms for projects aiming at increasing carbon pools in various sectors of the economy, including forestry.

Recently, interest in studying the carbon functions of post-technogenic ecosystems has increased. The prospect of afforestation on disturbed lands is proved by many modern international studies [10–15]. Soil organic carbon accumulation largely depends on vegetation cover. Vegetation age and tree type (deciduous, coniferous, and species) influence soil respiration [13]. The highest soil respiration rates were found for young spruce forest stands, when comparing 10-, 15-, 31- and 47-year-old stands [14]. Vegetation affects greenhouse gas emissions and positively correlates with net ecosystem production [15].

2. Materials and methods
To determine the potential of carbon sequestration in forest cultivation on disturbed lands, the following analysis was conducted: data on the distribution of disturbed lands provided by the State (National) report on the state and use of land in the Russian Federation in 2017. Methods and results of calculations of the carbon stock, sequestration, loss and budget of managed forests for the Russian Federation subjects given in section 6 “Land use, land-use change and forestry (LULUCF)” of the National report on the Cadastre of anthropogenic emissions by sources and absorption by pools of greenhouse gases that are not regulated by the Montreal Protocol for 1990-2017 and materials of the IPCC effective implementation guidelines LULUCF for the sector [5, 6, 7, 16, 17]. To calculate the expectable absorption of the territories with disturbed lands the technique for regional assessment of forest carbon budget (hereinafter ROBUL) was used [16, 18].

Woody plants, especially in the early stages of their life, are active sinks of CO₂. It is established that the most intensive process of atmospheric carbon absorption through phytomass growth occurs in forest stands under the age of 35 years [19]. Based on these features, for the purposes of our study, as a model, plantations of the first and second age classes (with predominant species – pine, spruce and
birch) were selected. In addition, it is assumed that there are no violations in the areas with disturbed lands that lead to greenhouse gas emissions, i.e. emissions are zero.

The potential of forestation in the recultivation of disturbed lands in order to reduce greenhouse gases emissions is considered by us on the materials of the Leningrad region. On the basis of data on the distribution of areas and growing stocks of forested land by species and age classes in the Leningrad region [20] according to the ROBUL method [16, 18] the calculation of carbon stocks in plantations of I and II age classes were conducted. Calculations of the carbon stock in young forest stands are given in table 2.

**Table 2.** Carbon stocks in forest stands of the first and second age-classes in the Leningrad region.

| Dominating tree species | Area, thousand ha | Growing stock, mln. m³ | Phyтомass | Carbon stock, thousand ton | total |
|-------------------------|-------------------|------------------------|-----------|---------------------------|-------|
| Forest stands of the first age-class |
| Pine                    | 54.69             | 1.174                  | 434.3     | 67.9                      | 404.7 | 3675.1 | 4582 |
| Spruce                  | 167.59            | 6.392                  | 2729.3    | 203.265                   | 1508.3| 12485.4| 16926.3 |
| Birch                   | 69.98             | 0.696                  | 327.1     | 13.0                      | 2053.3| 5304.5 | 7697.9 |
| Forest stands of the second age-class |
| Pine                    | 128.06            | 10.487                 | 3880.1    | 847.3                     | 404.7 | 9156.3 | 14288.4 |
| Spruce                  | 228.15            | 23.024                 | 9831.2    | 2108.9                    | 2486.8| 1826.7 | 16253.6 |
| Birch                   | 49.09             | 2.145                  | 1008.1    | 64.3                      | 391.8 | 3971.3 | 5435.5 |

Based on the data of table 2, the calculation of the carbon sequestration in the forests of the Leningrad region for forest stands of the first and the second age-classes was carried out. The estimated carbon stock values are shown in table 3.

The data obtained from table 3 allow us to calculate the potential carbon sequestration potential for the disturbed land area in the Leningrad region. The area of which on January 1, 2018 was 23.000 hectares [7]. Due to the specific state of disturbed lands resulting in the absence of soil, it is assumed for forest stands of I age class that the carbon budget in the litter and soil is zero. This assumption will make our forecast more close to the conditions of afforestation on disturbed lands. Calculations of possible carbon sequestration are given in table 4.
Table 3. Carbon sequestration by forest stands of the first and the second age-classes in the forests of Leningrad region.

| Dominating tree species | Carbon budget, thousand tons per year |  |
|-------------------------|---------------------------------------|---|
|                         | Phytomass | Dead wood | Litter | Soil | total |
| Forest stands of the first age-class |  |
| Pine                    | 52.3      | 10.7      | 22.4    | 189.2 | 274.6  |
| Spruce                  | 248.8     | 43.8      | 91.3    | 599.1 | 983.0  |
| Birch                   | 88.2      | 2.6       | 35.7    | 548.3 | 674.8  |
| Forest stands of the second age-class |  |
| Pine                    | 127.9     | 42.4      | 5.1     | 13.7  | 189.1  |
| Spruce                  | 280.5     | 113.0     | 10.8    | 24.5  | 428.8  |
| Birch                   | 54.6      | 7.8       | 3.2     | 18.6  | 84.2   |
| Total for the forest stands by pools | 852.3 | 220.3 | 168.5 | 1393.4 | 2634.5 |

Table 4. Possible carbon sequestration by forest stands of the first and the second age-classes at forestation of disturbed lands of the Leningrad region.

| Dominating tree species | Carbon budget, thousand tons per year |  |
|-------------------------|---------------------------------------|---|
|                         | Phytomass | Dead wood | Litter | Soil | total |
| Forest stands of the first age-class |  |
| Pine                    | 18.3      | 4.5       | -      | -    | 22.8   |
| Spruce                  | 34.1      | 6.0       | -      | -    | 40.1   |
| Birch                   | 29.0      | 0.9       | -      | -    | 29.9   |
| Forest stands of the second age-class |  |
| Pine                    | 23.0      | 7.6       | 0.9    | 2.5  | 34.0   |
| Spruce                  | 28.3      | 11.4      | 1.1    | 2.5  | 43.3   |
| Birch                   | 25.6      | 3.6       | 1.5    | 8.74 | 39.44  |
| Total for the first and second age-classes | 56.80 | 83.40 | 69.34 |

For the Leningrad region, where the forestation of all lands intended for recultivation, the following conclusion was made. In forest stands of first age class (up to 20 years for coniferous, up to 10 years for deciduous) with dominating of spruce it is possible to obtain the carbon sequestration up to 40.1 tons per year, birch - 29.9 tons per year, pine - 22.8 tons per year. In the II age class (up to 40 years for coniferous, up to 20 years for deciduous) in the spruce young stands it is possible to obtain the carbon sequestration volume up to 43.3 tons per year, for birch stands - 39.44 tons per year, for pine stands - 34.0 tons per year. Prior to the transferring of forest stands into the middle aged group the
total expectable emission is for young stands with dominating of spruce can be 83.40 tons of carbon per year, birch 69.34 tons of carbon per year and pine 56.80 tons of carbon per year.

During the organization and planning of measures on recultivation the potential of carbon sequestration can be strengthened by selection of method of planting and dominating tree species.

3. Discussion of results

The study demonstrates the positive effect of carbon accumulation during forestation on disturbed land areas.

To determine what possible effect the Leningrad region will receive from the implementation of such projects, we compare the calculated forecast data on disturbed lands with the data of carbon sequestration by various pools of managed forests on forest lands and calculated data for forest stands of the I and II age classes in managed forests of the Leningrad region. The results of a comparative analysis of carbon sequestration by different pools are shown in table 5.

| Forest stands | Phyto-mass | Dead wood | Litter | Soil | total | Percentage from all managed forests |
|---------------|------------|-----------|--------|------|-------|------------------------------------|
| Managed forests of the Leningrad region | 3319.9 | 763.6 | 91.5 | 286.5 | 4461.5 | 100 |
| Forest stands of the first and second age-classes of Leningrad region | 852.3 | 220.3 | 168.5 | 1393.4 | 2634.5 | 59 |
| Forestation on disturbed lands | | | | | | |
| With dominating of Pine | 41.3 | 12.1 | 0.9 | 2.5 | 56.80 | 1.3 |
| With dominating of Spruce | 62.4 | 17.4 | 1.1 | 2.5 | 83.40 | 1.9 |
| With dominating of Birch | 54.6 | 4.5 | 1.5 | 8.74 | 69.34 | 1.5 |

The forecast of forestation efficiency at recultivation of disturbed lands in order to reduce greenhouse gases emissions showed that absorption capacity of forest stands of I and II age classes of the Leningrad region will increase from 1.3 to 1.9 % per year.

4. Conclusion

An assessment of the potential for carbon accumulation in the implementation of forestation measures on lands needed in recultivation suggests that land recultivation can be an additional measure aimed at reducing greenhouse gas emissions. In total, the territory of the Russian Federation, on January 1, 2018, accounts for 1062.5 thousand hectares of disturbed land. The results of the study show a possible increase in the capacity of carbon sequestration due to forestation of disturbed lands (area of 23 thousand hectares) from 1.3 to 1.9 % per year for the territory of the Leningrad region. Forestation in young forests with dominating of spruce may increase absorption capacity by 1.9 %, birch – 1.5 %, pine 1.3 %. Forestation as recultivation of disturbed lands can be an additional measure taken to mitigate the effects of climate change. In the organization and planning of recultivation activities, the effect of carbon sequestration can be enhanced by selecting the planting method and the dominating
tree species. During designing a carbon project within the framework of forestation of disturbed land, economic factors should be taken into account. In phase of implementation of forestation project with dominating of spruce in the stands (which in the study showed the maximum absorption), significant costs may occur, since this breed is more demanding to the growing conditions.

Acknowledgements
This study was performed by a grant of Russian scientific Foundation that made it possible to conduct respective researches and analysis (project No. 16-17-00063).

References
[1] The IPCC 2015 *Paris climate agreement* Retrieved from: http://unfccc.int/resource/docs/2015/cop21/ru/09r.pdf
[2] WWF 2015 *Forest and climate* Retrieved from: https://wwf.ru/upload/iblock/a87/forest_climate_web_5.pdf
[3] Bass S. 2000 *Rural livelihoods and carbon management* (London: International Institute for Environment and Development)
[4] Smith J, Scherr S J 2002 *Forest Carbon and Local Livelihoods: assessment of opportunities and policy recommendation* (Jakarta: CIFOR)
[5] IPCC 2000 *IPCC Special report “Land Use, Land-Use Change and Forestry”* Retrieved from: https://archive.ipcc.ch/pdf/special-reports/spm/srl-ru.pdf
[6] IPCC 2003 *Effective Practice Guidance for Land Use, Land-Use Change and Forestry IPCC national greenhouse gas inventories program* Retrieved from: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_languages.html
[7] Federal service for state registration, cadastre and cartography 2018 *State (national) report on the state and use of land in the Russian Federation* Retrieved from: https://rosreestr.ru/site/activity/sostoyanie-zemel-rossii/gosudarstvennyy-natsionalnyy-doklad-o-sostoyanii-i-ispolzovanii-zemel-v-rossiyskoy-federatsii/
[8] Consultant Plus 2019 *Resolution of the Government of the Russian Federation of 10.07.2018 No. 800 On the recultivation and conservation of land* Retrieved from: http://www.consultant.ru/document/cons_doc_LAW_302235/
[9] Consultant Plus 2018 *The order of the Ministry of natural resources and ecology of the Russian Federation from 28.12.2018 No. 700 approving the rules On the Afforestation composition afforestation project, about its development,* Retrieved from: http://www.consultant.ru/cons/cgi/online.cgi?req=doc&base=LAW&n=322120&fld=134&ds=t=1000000001,0&rnd=0.583103822822824221#086413519717182492
[10] Rees F, Dagois R, Derrien D, Fiorelli J, Watteau F, Morel J L, Schwartz C, Simonnot M-O, Sere G 2019 *Geoderma* 337 641–648
[11] Miller A and Zegre N 2014 *Mountaintop removal mining and catchment hydrology* *Water* 6 472–499
[12] Lima A T, Mitchell K, O’Connell D W, Verhoenen J and Van Cappellen P 2016 The legacy of surface mining: Remediation, restoration, reclamation and rehabilitation *Environmental Science & Policy* 66 227–233
[13] Oertela C, Matschullata J, Zurbaa K, Zimmermann K and Erasmib S 2016 *Greenhouse gas emissions from soils* *Geochemistry* 76 327–352
[14] Peichl M, Arain A, Moore T, Brodeur J, Khomik M, Ullah S, Restrepo-Coupé N, McLaren J and Pejam M 2014 Carbon and greenhouse gas balances in an age sequence of temperate pine plantations *Biogeosciences* 11 5399–5410
[15] Dalal R C and Allen D E 2008 *Greenhouse gas fluxes from natural ecosystems* *Australian Journal of Botany* 56 396–407
[16] United Nations Climate Change 2019 *National Inventory Report on Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases not controlled by the Montreal
Protocol for 1990-2017 Retrieved from: https://unfccc.int/documents/194838 (Russian Federation. 2019 National Inventory Report)

[17] IPCC 2006 IPCC 2006 Guidelines for national greenhouse gas inventories. IPCC national greenhouse gas inventories program Retrieved from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/russian/pdf/0_Overview/V0_0_Cover.pdf

[18] Zamolodchikov D, Kareлина D, Gytarsky M and Blinov V 2017 Monitoring of gases in natural ecosystems (Saratov: Amirit) 279

[19] Ryaboshapko A, Revokatova A 2015 the Role of reforestation and new plantations in reducing the concentration of CO2 in the atmosphere Fundamental and applied climatology 2 81-92

[20] Committee on natural resources of the Leningrad region 2010 Forest plan of the Leningrad region Retrieved from: http://old.nature.lenobl.ru/programm/ wood/lesnoy_plan