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Carbon Fluxes from Soils of “Ladoga” Carbon Monitoring Site Leningrad Region, Russia

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Abstract: For the first time, data on the emission of climate-active gases from soils of different types of use of the south taiga sub-zone were obtained. Soils of the boreal belt are key elements of the global carbon cycle. They determine the sink and emission of climate-active gases. Soils near large cities are a major carbon sink, in the face of climate change, soils from sinks can become a source of carbon and contribute significantly to climate change on the planet. Studies of $\mathbf{F_{CO2}}$ and $\mathbf{F_{CH4}}$ fluxes were carried out on the territory of the monitoring site “Ladoga” located in the southern taiga subzone in soils of land not used in agriculture, former agriculture lands, and wetlands. During the chamber measurements, a portable gas analyzer GLA131-GGA (ABB, Canada) was used. The chamber was placed on the soil, after which the concentration of CO_2, CH_4 and H_2O in the mobile chamber was recorded. As a result of the study it was found that the lowest emission of carbon dioxide is characteristic of soils developing on the soils of wetland and is 0.64 $gCO_2/(m^2*year)$. Which is associated with a high degree of hydrophobicity of the territory and changes in the redox regime. The highest emission of carbon dioxide is registered in soils on the land not used in agriculture and is 4.16 $gCO_2/(m^2*year)$. This is due to the formation of predominantly labile forms of carbon in the soil, which can be relatively rapidly involved in the carbon cycle and affect the active emission of carbon from the soil. According to the data obtained on $\mathbf{F_{CH4}}$ emission from soils, it was found that soils of land not used in agriculture and former agriculture lands were net sinks, while soils of wetlands were characterized by CH_4 source, the emission was from 0.05 to 0.83 $gCH_4/(m^2*year)$. The results obtained indicate spatial heterogeneity and changes in the carbon cycle within the monitoring site “Ladoga”, which are due to the change of plant communities and habitat type. Monitoring the release of important greenhouse gases in close proximity to major urban areas is an important task in the face of predicted climate change and increasing rates of urbanization.

Keywords: CO_2; CH_4; carbon stocks; boreal belt; plaggen podzol

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1. Introduction

One of the causes of climate change on Earth is the increasing concentrations of thermodynamically active gases such as carbon dioxide (CO_2) and methane (CH_4) in the atmospheric air [1,2]. Atmospheric CO_2 content is controlled by gas exchange processes between different carbon reservoirs: the atmosphere, continental ecosystem, hydrosphere and lithosphere—and by some chemical reactions for which CO_2 is the end product. Such processes and reactions form the global biogeochemical carbon cycle, in which a range of carbon-containing gases, including CH_4 and carbon monoxide (CO), are involved in addition to CO_2 [1,3]. CH_4 is the second most important greenhouse gas, with a global warming potential 28 times greater than CO_2 [1]. The consequences of climate change have a significant and increasing impact on the socio-economic development of the country, living conditions and health of people, as well as on the state of economic facilities [4]. The boreal zone includes about 1/3 of the planet's forests and carbon stocks [5]. Boreal forests are thought to be a net carbon sink, but recent assessments indicate that this statement is only partially true [6]. Depending on the type of land use, boreal soils can be carbon neutral as well as acting as a carbon source [7]. This is due to increased temperature in the boreal ecosystem [8]. On the territory of Russia, climate warming is approximately 2.5 times more intense than the average for the globe [9]. According to the Report on Climate Peculiarities on the Territory of Russia for 2022 [10], it was found that the average annual air temperature (deviation from the average for 1991–2020) was +0.87 °C. Temperatures above the climatic norm were observed almost throughout the country. At the same time, the highest rate of increase in the mean annual temperature was observed in the Arctic zone +0.8 °C/10 years. There is a stable tendency for the Arctic ice cover to decrease: since the 1980s in the area of the Northern Sea Route, the decrease has amounted to 5–7 times. In the south of the European part of Russia in summer, against the background of rapid growth of average temperatures, moisture availability is decreasing and the risk of drought is increasing [10]. Based on modern scientific calculations using three-dimensional models of atmospheric and oceanic circulation, the main climate-influencing factor affecting trends in hydrometeorological parameters is the significant increase in thermodynamically active gases, particularly CO_2, in the atmosphere [11]. To accurately predict changes in the Earth's climate, it is essential to develop scenarios of variations in gas composition, considering both human-induced and natural factors. This includes projecting changes in carbon dioxide, methane, and other greenhouse gases. Therefore, both regular measurements of the content of these gases in the atmosphere and studies of their natural and anthropogenic sources and effluents are necessary to build reliable models of their circulation in nature [12]. The available model estimates of carbon emissions and stocks in the boreal zone require constant refinement, due to forest fires, which result in the loss of a significant amount of carbon, the construction of models only on a single sample of data, without annual repetition, the relatively young age of soils formed on glacial deposits, as well as the heterogeneity of topography [13–15]. Thus, the updating of data on stocks and emissions of climate-active gases is a necessary tool for improving existing models of carbon balance in the boreal zone [8].

In order to solve the tasks of monitoring of climatically active gases in Russia, an initiative has been launched to create a network of carbon monitoring site. The main task of carbon monitoring site [16], is to develop technologies and methods for determining the fluxes of climatically active gases, the main focus here is on studying the processes of sequestration and deposition of greenhouse gases by different types of natural environments and ecosystems [17,18]. Saint-Petersburg state University together with Voeikov Main Geophysical Observatory, with the support of the Government of the Leningrad Region, developed a project of the united carbon monitoring site "Ladoga", aimed at studying the potential of greenhouse gas uptake by the ecosystem of the southern taiga, characteristic of the North-West of Russia. Globally, wetlands accumulate one-third of soil organic matter and contribute up to 31% of annual CH_4 emissions [12,19]. The cold temperate humid zone, which is distributed in the east of Europe (Scandinavia, Russia) is the most active zone in terms of carbon stocks, accumulating up to 208 tC/ha, the largest carbon store after permafrost-affected soils, which contain up to 1173 tC/ha [20]. The territory of North-West Russia is characterized by the largest increase in average annual temperature in Russia, which may lead to transformation of ecosystems and soil organic matter, which will result in increased emission of climate-active gases [10]. A characteristic feature of Northwest Russia is a long history of farming, dating back several centuries [21]. The Ladoga carbon monitoring site contains former agricultural territories that were removed from agricultural use about 40 years ago and are affected by self-overgrowth [22]. The area of fallow land requires detailed study, as there is high uncertainty in estimating the emission of climate-active gases from areas that were used for agriculture. Annually, due to human activities in agriculture, around 17 billion tons of CO_2-equivalent are released into the atmosphere, accounting for approximately 31% of all human-induced greenhouse gas emissions. In addition to this, agriculture contributes significantly to soil and water pollution as well as impacting the planet's climate through chemical use. At present in Russia from 30 to 40 million hectares of arable land, which is converted into fallow land and transformed under the influence of natural and anthropogenic processes of soil formation, forest overgrowth, sodding, grass sowing, waterlogging, etc., is taken out of circulation and not used [22]. The territory of North-West Russia (Leningrad, Pskov and Novgorod regions) is a region with a direct connection to the history of surface development in glacial and post-glacial times. As a result, the Russian Plain's territory has maintained a range of landforms and glacial sediments that have been minimally altered by weathering. This factor contributes to the diversity of soil cover and influences agricultural development in the northern regions of Russia [21,22]. Data on climate-sensitive gas emissions will help to refine general estimates of the contribution of fallow lands to carbon storage [23]. Soils formed in relative proximity to large cities are subjected to significant anthropogenic impact due to the emission of climate-active gases as a result of fossil fuel combustion [24]. With the increasing rate of urbanization, soils near large cities can become carbon sinks, carbon sources, and contribute significantly to climate change on the planet, so the study and identification of soils capable of more efficient and long-term carbon sequestration is an urgent task aimed at mitigating climate change [25]. To the date, knowledge on climate-active gas emissions from areas of different types of use near large cities is very limited due to the high level of heterogeneity of soil formation conditions and their change as a result of anthropogenic use [26]. St. Petersburg and the Leningrad Region can be considered as a united ecological and climatic center for interdisciplinary research in the field of carbon neutrality and sustainable development, including a comprehensive study of sources and sinks of climate-active gases and analyzing the potential for the development of carbon farms—a new type of sequestration carbon industry enterprises—in the study area. The implementation of carbon monitoring site and farms at the scale of the Russian Federation is expected to support the advancement of carbon farming. This sustainable business model offers economic advantages through the implementation of enhanced land management practices, which promote carbon sequestration in biomass, organic matter and soils. These practices aim to increase carbon sequestration while decreasing carbon emissions into the atmosphere based on ecological principles that are beneficial for biodiversity and natural capital as a whole. The aim of the work is to study the fluxes of carbon dioxide and methane from soils formed in different types of landscapes of the Ladoga monitoring site.

2. Materials and Methods

2.1. The Study Area

The territory of the Ladoga carbon monitoring site is located in the southern part of the Vsevolozhsky District of the Leningrad Region (Figure 1). According to soil-geographical zoning [27], the study area belongs to the southern part of the Vyborgsky-Priozersky district of entic podzol soils.

The relief of the upland is eskers. In the central part of the upland the eskers form a hilly esker plateau. In the border part, the upland is often replaced by a stepped abrasion ledge. Further the relief is changed by waterlogged sandy terraces and plains. The majority of the area consists of flat, marshy terrains. There is a substantial variation in altitude, ranging from 32.5 to 77.5 m above sea level. Soil-forming rocks are presented by medium-grained loamy sands and sands, with thin interlayers of loamy material and fluvioglacial sands and loamy sands. Eskers landscapes are well drained (except for closed lakes of thermokarst origin), on well-warmed slopes there is a moisture deficit in summer. Plain landscapes are waterlogged by eutrophic type. The study site is located in the southern taiga zone. The flat rocky slopes and flat relief areas in the inter-kame depressions were previously used for agriculture. The forests here are secondary, post-agricultural, post-felling, lightened-deciduous with a significant admixture of non-moral and synanthropic species. The study area has the following climatic characteristics: temperate-cool climate with frequent change of marine and continental features, average annual temperature is +4.5 °C, average annual precipitation is 550–800 mm, more than half of days with precipitation, snow cover thickness exceeds 50 cm. The excess of precipitation over evaporation causes leaching type of water regime and development of podzol formation process on sandy materials and waterlogging conditions in relief depressions.

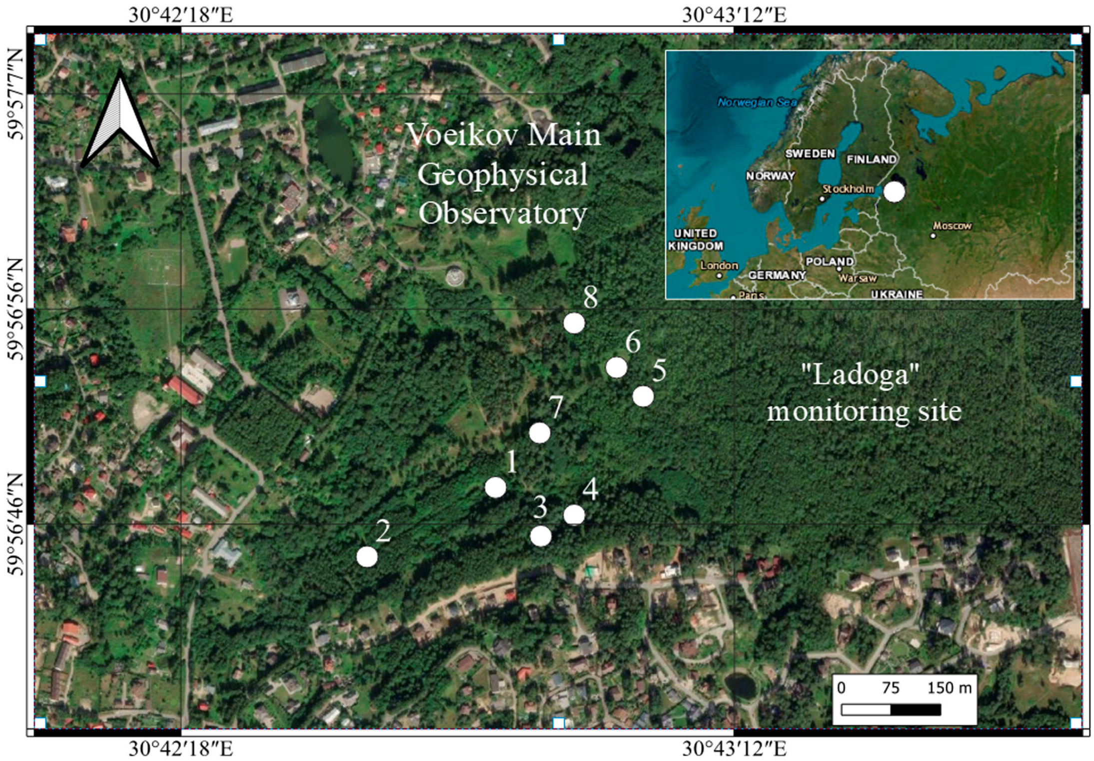

Figure 1. The "Ladoga" carbon monitoring site. The soil ID correspond to Table 1.

Table 1. Description of monitoring sites.

№	The Description of Monitoring Plot	Plant Communities	Soil Name *
1	Former agricultural land. Flat relief. Densely covered with forest litter. Vegetation is represented by shrubs, young trees.	Cereal birch	Plaggic Stagnic Podzol (arenic) on water-glacial sediments
2	Former agricultural land. Flat relief. Herbaceous cover, single trees present.	Fallow fern-ruderal-grass meadow	Plaggic Stagnic Podzol (arenic) on water-glacial sediments
3	Former agricultural land. Flat relief. Densely covered with forest litter.	Fallow fern-ruderal-grass meadow	Plaggic Gleyic Podzol (arenic) on water-glacial sediments
4	Land which are not used for agriculture. Esker slope. Represented by young trees, shrubs.	Birch-pine forest	Post-pyrogenic Umbrisol (arenic) on water-glacial sediments
5	Wetland. Depression of relief. Grass cover, individual trees.	Lowland moist-grass swamp	Folic Histosol on water-glacial sediments
6	Former agricultural land. Flat relief. Densely covered with forest litter.	Fallow fern-ruderal-grass meadow	Plaggic Stagnic Podzol (arenic) on water-glacial sediments
7	Land which are not used for agriculture. Top of the esker upland. Vegetation is represented by shrubs, young trees.	Birch-pine forest	Entic Stagnic Podzol on water-glacial sediments
8	Wetland. Depression of relief. Grass cover, individual trees.	Lowland moist-grass swamp	Folic Histosol on water-glacial sediments

* WRB FAO [28].

2.2. Strategy of Measurements

An experiment to estimate methane (CH_4) and carbon dioxide (CO_2) fluxes from the soil surface (vegetation was not removed) using a portable camera was conducted at the proposed Ladoga monitoring site. Measurements were taken on 9 November 2023 between ~9.00 and ~12.00 UTC. This study can be regarded as a so-called "reconnaissance study", necessary for optimal planning of a long-term experiment involving installation of stationary camera systems at the Ladoga carbon monitoring site. For this purpose, we conducted a one-day campaign to measure CO_2 and CH_4 fluxes using a portable camera for a number of the most promising measurement sites. Camera measurements of climatically active gas emissions were conducted at 8 monitoring sites (Figure 2).

Forest on fallow land (№1)   Forest on fallow land (№3)   Wetland forest (№5)   Forest edge on fallow land (№6)

Figure 2. Monitoring sites used to analyze emissions of climate-active gases.

A description of the sites is provided in Table 1.

For sites № 1, 3, 4, 5, 6 two flux measurements were taken at dispersed, representative points on the site. One measurement was taken for № 7, 2, and 8. The absence of additional (second) measurements at sites № 7, 2, and 8 is due to technical problems encountered during field measurements. Measurements at the site were made during cloudy weather, with light winds (1 m/s) of southerly directions. No precipitation was observed. The air temperature and atmospheric pressure during the period of field measurements varied from 5.7 °C (09 UTC) to 5.9 °C (12 UTC) and from 1007.7 hPa (09 UTC) to 1008.1 hPa (12 UTC), respectively.

2.3. Ecosystem Carbon Flux Measurement

Manual chamber method. The chamber was placed on the soil, after which the concentration of CO_2, CH_4 and H_2O in the mobile chamber was recorded. In the course of measurements, the air in the chamber and the gas analyzer circulated in a closed cycle—from the chamber to the gas analyzer, then back from the gas analyzer to the chamber. The closed loop is an idealized approximation for our case, since it is not possible to completely avoid air exchange with the atmosphere during mobile measurements with this design of the portable chamber (without digging into the soil). In order to ensure more uniform air mixing inside the chamber, the return air outlet from the gas analyzer was made through a perforated teflon tube running along the perimeter of the chamber. The total volume of the system, including the internal volumes of the gas analyzers in this arrangement was V = 7950 mL = 0.00795 m^3. The inner diameter of the chamber was d = 0.28 m. During the chamber measurements we used a portable gas analyzer GLA131-

GGA (ABB, Brampton, ON, Canada) to record concentrations of CO_2, CH_4 and H_2O in the air. Random uncertainty of measured values of gas concentrations (1σ), for accumulation time of 1 s and 10 s is: for CH_4: 0.9 ppb and 0.3 ppb; for CO_2 0.35 ppm and 0.12 ppm; for H_2O 200 ppm and 60 ppm. Experience with camera-based flux observations shows that, for example, for CO_2, 60–120 s of closed-camera measurements are usually sufficient. Longer recording times may be required to estimate the flux from soil of other small gas constituents. The specified duration of chamber measurements prevents a significant increase in CO_2 concentration in the chamber at typical rates of change such as 0.5 ppmv/s. It has been shown that the dead zone duration (equilibration processes in the chamber, this period is not used in flux estimation) can vary from about 10 to 60 s [29].

The fluxes of $\mathbf{F_{CO2}}$ and $\mathbf{F_{CH4}}$ were defined as the change in concentration Δq over the chamber measurement time Δt:

$$F = V \cdot \Delta q \ / \ (\Delta t \cdot S) \tag{1}$$

where q—concentration of target gas in dry air in kg/m^3; t—time in seconds; V—total volume of the system in m^3; S—inner square of the chamber in m^2.

When preparing for chamber measurements at the Ladoga carbon monitoring site and determining CO_2 and CH_4 fluxes, we utilized contemporary techniques for chamber measurements as described in the "Theory of Soil Gas Flux Measurement" section on the LI-COR website [29].

2.4. Policy Recommendation

The establishment of the "Ladoga" carbon monitoring site in the Leningrad Region is a long-term project of priority importance for climate and environmental security of the region, prepared by Saint Petersburg State University and Voeikov Main Geophysical Observatory with the assistance of the Government of the Leningrad Region. This project aims to research and assess the sequestration carbon potential of Leningrad Region ecosystems, harmonized with international regulations. This could lead to determining the carbon emissions produced by businesses, helping them reduce financial strain related to implementing a cross-border carbon tax. Russia's boreal forest plays a crucial role in carbon sequestration because a significant amount of carbon is stored in biomass and soil. To reduce carbon emissions in Russia's boreal forest, it is recommended to implement the following policy measures:

1. Implement strict regulations and monitoring systems to prevent illegal logging and ensure sustainable forest management practices.
2. Invest in research and technology to improve forest inventory methods, such as remote sensing of forest inventories, to accurately estimate the amount, distribution, and uncertainty of carbon sequestration in the boreal forest.
3. Promote afforestation and reforestation projects in degraded areas of the boreal forest to increase carbon sequestration capacity.
4. Encourage the conservation and restoration of peatlands in the boreal forest, as they are significant carbon sinks.

3. Results and Discussion

The studied area of the "Ladoga" carbon monitoring site is characterized by a large set of biotopes, this is due to the variety of different landforms, as well as former agriculture activities. Most of the studied soil are characterized by carbon dioxide emission and methane absorption, while both carbon dioxide and methane emission occur in soil of wetlands (Figure 3, Table 2).

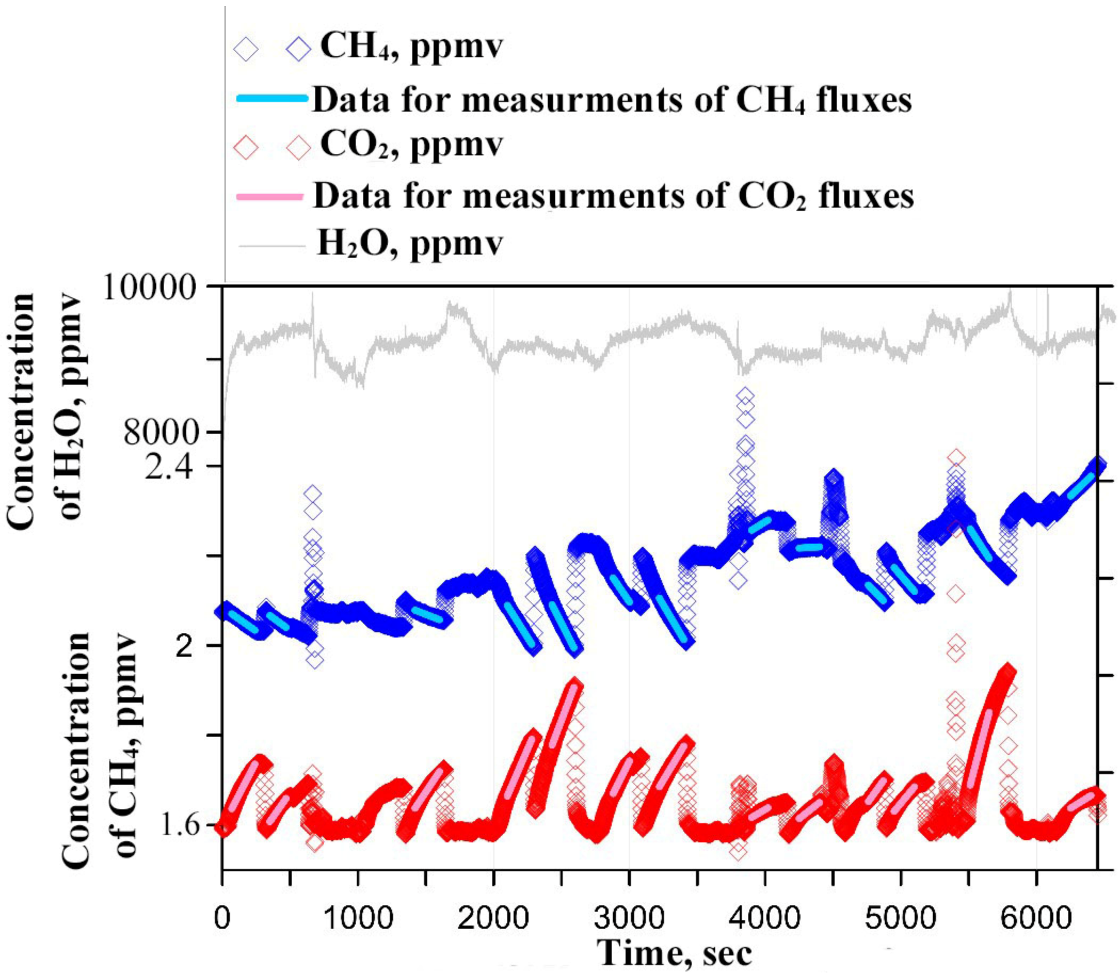

Figure 3. Results of chamber measurements carried out on 11 September 2023 on the territory of the Ladoga monitoring site.

Table 2. Results of a field experiment on 11 September 2023 to determine fluxes using a soil chamber.

№	Duration of the Period Used to Calculate F_{CH4} and F_{CO2}, s (Gas Analyzer Counts: Start and End of Measurements, s)	F_{CH4}, CH_4 g/(m^2·Year); $F_{CH4\text{-}C}$, CH_4-C g/(m^2·Year)	F_{CO2}, CO_2 g/(m^2·Year); $F_{CO2\text{-}C}$, CO_2-C g/(m^2·Year)
1	170 (70–240 s)	−0.61; −0.45	2090; 570
	120 (350–470 s)	−0.63; −0.47	1540; 420
2	180 (1420–1600 s)	−0.33; −0.25	1620; 440
3	180 (2100–2280 s)	−1.36; −1.02	2500; 690
	160 (2430–2590 s)	−1.69; −1.27	2870; 780
4	120 (2880–3000 s)	−1.26; −0.95	2160; 590
	180 (3220–3400 s)	−1.45; −1.08	1810; 490
5	120 (3900–4020 s)	0.53; 0.40	640; 170
	150 (4250–4400 s)	0.05; 0.04	860; 230
6	110 (4760–4870 s)	−0.89; −0.67	1510; 410
	150 (4950–5100 s)	−1.01; −0.75	1310; 360
7	140 (5510–5650 s)	−1.33; −0.99	4160; 1130
8	150 (6250–6400 s)	0.83; 0.62	680; 180

The values of $\mathbf{F_{CO2}}$ and $\mathbf{F_{CH4}}$ and $\mathbf{F_{CO2\text{-}C}}$ and $\mathbf{F_{CH4\text{-}C}}$ fluxes obtained during the field experiment are supported by the literature data published in [30,31]. The boreal belt is of the greatest importance for the global carbon balance, as the greatest amount of carbon in soils is stored here [32]. It was found that the highest level of carbon dioxide emission is observed in the soils of land which is not used for agriculture (4160 $gCO_2/(m^2*year)$). According to the study conducted in subtropics in China [33], it was found that the highest emission corresponds to soils formed under forests—533 $gCO_2/(m^2*year)$, while the maximum was reached in paddy soils—901 $gCO_2/(m^2*year)$. The results we obtained from natural soils are much higher than in forest soils of subtropical China, this may be due to the formation of a thick upper organomineral horizon of soils in humid conditions, in which active processes of humification and mineralization of organic carbon occur [34]. However, our values are confirmed by the study of Yi et al. [35], which measured CO_2 emission from undisturbed soils of Dinghushan Biosphere Reserve, subtropical China, and found that depending on the type of forest ecosystems (evergreen, coniferous and broad-leaved mixed forest) and humidity, there was a significant increase in $\mathbf{F_{CO2}}$ emission, up to 4129, 3710 and 3761 $gCO_2/(m^2*year)$, respectively. Relatively low carbon dioxide emission is observed from the soils of former agriculture land (from 1310 to 2880 $gCO_2/(m^2*year)$). This is due to the qualitative composition of soil organic matter of fallow lands, which has a relatively high level of stabilization compared to the organic matter of natural soils. With the transition of soils to fallow state, in the first 30–40 years the formation of aromatic structural fragments in humic acids is noted, it is connected with the change of plant communities, increase of biodiversity and changes in the composition and quality of humification precursors. Humic acids of natural soils is characterized by the predominance of aliphatic structural fragments, it is less mature and can be subjected to microbial degradation [36]. This is confirmed by a study by Yuste et al. [37], which found that CO_2 emission is influenced by the qualitative composition of organic matter, soil organic matter content, microbial population, and seasonal variations in temperature and precipitation. Among the soils of former agriculture lands, we can note the highest carbon dioxide emission from former soils densely covered with forest litter (2880 $gCO_2/(m^2*year)$), in areas dominated by grass vegetation, the values of carbon dioxide emission fluxes were relatively low (1310 $gCO_2/(m^2*year)$). The obtained data are confirmed by Lou et al. [38], in the studied arable soils in the subtropics of China, the emission level varied from 1410 to 2840 $gCO_2/(m^2*year)$ depending on the composition of soil-forming rocks, the highest emission was observed on red soils formed on granite deposits and the lowest on soils on clay. Sushko [39], noted that the forest-steppe zone is characterized by the lowest CO_2 emission for soils of former agricultural soils, the highest emission was observed in natural soils. The lowest emission level was observed in the soil of wetland (640 $gCO_2/(m^2*year)$), as active methane emission occurs here among all the studied soils. According to different studies on CO_2 emission from agricultural soils, a high variability of results can be observed, which is related to climatic peculiarities, lithological composition of soil-forming rocks and to the types of agricultural products, but the level of CO_2 emission from agricultural soils is on average lower than that of natural soils [40–42].

The boreal zone is one of the most vulnerable natural zones to climate change, due to the relatively high content of soil organic carbon and the annual increase in temperature [10]. According to Hicks Pries et al. [43], it was found that an increase in soil temperature by 4 °C, can lead to an increase in CO_2 emission of 34–37%, in the framework of the experiment, in temperate zone soils, an increase in CO_2 emission from 1100 to 1450 gC m^{-2} $year^{-1}$ was observed. This is due to the transformation of decadal-aged light fraction of organic carbon in soil, organic matter that is not enclosed in aggregates or does not have a complex molecular structure determine the CO_2 emission from soil [43]. Soils near major urban areas are likely to be more vulnerable to climate change due to the impact of urbanization on forested regions surrounding large cities, resulting in a soil carbon loss [44].

$\mathbf{F_{CH4}}$ fluxes from soils of wetlands ranged from 0.05 to 0.83 $gCH_4/(m^2*year)$. This is due to the activity of anaerobic microorganisms under conditions of increased hydromorphism of the territory. All soils, except soil of wetlands, are sink of methane from the atmosphere. Wanyama et al. [45] found that forest soils act as a net sink for methane in African tropical forests, as well as agricultural soils used to grow tea and eucalyptus. The main factor affecting the uptake was the change of dry and wet periods, so during dry periods methane uptake increased and during wet periods methane uptake decreased.

Anthropogenic impact on soil has a negative effect on methane uptake, it is associated with overcompaction, disturbance of hydrological regime, as well as tillage. Natural soils are greater methane sinks compared to anthropogenically transformed soils [46], which is also confirmed in our study. An important factor influencing carbon dioxide fluxes is the quality of wood and plant residues, so in a study by Gitarskiy et al. [47], it was found that soils of old-growth spruce forests have more active CO_2 emissions compared to younger spruce forests. Therefore, studying the fluxes of climatically active gases in soil of former agricultural land, where successional change of plant communities is actively taking place, is most relevant for estimating the carbon balance of forest ecosystems. This was also established by Wang et al. [12], who monitored the emission of climate-active gases for many years in soils on the Tibetan plateau, where, as a result of the change of plant communities, as well as the change of vegetation and non-vegetation periods, the periods of net absorption and net emission were changed. Thus, during the vegetation period, all studied biotopes (mesophytic meadow, wet meadow, and bog) were CO_2 sinks, and during the non-vegetation period they were CO_2 sources. In the works of Kurganova et al. [48,49] it found that components of the carbon balance and ecosystem runoff potential are determined by weather conditions (temperature and precipitation) of the current and previous year of the study, as well as by the type of ecosystem, so that extreme droughts reduced the emission activity of summer CO_2 fluxes by 44–47%.

The Ladoga carbon monitoring site is located in close proximity to one of the largest cities in Russia, which may also influence the level of climate-active gas emissions. Guo et al. [50], noted that urbanization and population increase leads to additional carbon dioxide emissions. The area adjacent to large cities is an important element of the global carbon cycle, which can act as both a source and sink of carbon. Current study confirms the results of Guo et al. [50], wetlands are less of a source of carbon dioxide, while they can even act as a sink.

4. Conclusions

As a result of a study of climate-active gas emissions from soils at the Ladoga carbon monitoring site, it was found that all soils were a source of $\mathbf{F_{CO2}}$ during the study period. Former agriculture soils showed relatively low level of $\mathbf{F_{CO2}}$ emission compared to soils which are not used for agriculture, the lowest level of $\mathbf{F_{CO2}}$ emission was observed in soils of wetlands. The obtained values of $\mathbf{F_{CO2}}$ emission from soils of different types of use show the importance of continuing measurements of $\mathbf{F_{CO2}}$ fluxes from soils located near a large urbanized zone for the purpose of further monitoring of climate-active gases under the conditions of predicted climate change. According to the emission of $\mathbf{F_{CH4}}$ from former agriculture soils and soils which are not in use for agriculture it was observed that the soils were net sinks, whereas soils developing in wetlands were a source of $\mathbf{F_{CH4}}$. Agricultural use of soils has a key impact on soil uptake of methane from the atmosphere, which is reflected in a decrease in methane uptake, and these spatial changes are associated with soil transformation as a result of land self-overgrowth. This study provides an initial assessment of climate-active gas emissions from soils of different types of use, and is necessary for a better understanding of how soil transformation in close proximity to a large urbanized area will affect the carbon balance in an urbanized ecosystem. The data obtained make an important contribution to the monitoring of soils at different stages of successional changes of plant communities as a result of transition to fallow state and can be used for comparison and parameterization of carbon balance models to obtain reliable predictions of carbon emission and sequestration by soils of forest, fallow and wetlands ecosystems in the boreal belt of the Earth.

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