State forest inventory data as a new information base for estimating carbon stocks and carbon removals by forests: the feasibility and prospects for use in national reporting under international agreements

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Abstract. The study considers the feasibility and prospects for using the data of the first forest inventory cycle for obtaining more objective and reliable assessments of carbon stocks and carbon removals by forests. The advantages of using the State Forest Inventory (SFI) data were demonstrated and quantitatively corroborated in specific contexts such as (1) the region of coniferous and broadleaved forests of the European-Ural part of Russia (EUPR) by field measurements at 9 105 permanent sample plots (PSP); (2) Republic of Karelia by measurements at 779 PSP; (3) 28 forest regions of Russia by measurements at 47,816 PSP. The following results were obtained: (1) In EUPR, the carbon stock values in the living biomass exceeded the corresponding data of the National Greenhouse Gas Inventory by more than 50%, and by more than 80% in the Republic of Karelia; (2) In 28 forest regions of Russia, the volumes of woody detritus were congruent with the corresponding values of the National Greenhouse Gas Inventory. However, the estimation error was about ±8%, thus being characterized by lower uncertainty due to using a representative sampling. Further research is needed for improving the calculation methods and making use of all the characteristics that are determined through SFI.

1. Introduction
The prevention of potential economic and social risks, following the adoption of the Paris Agreement [1, 2], and the fulfillment of Russia’s commitments for reducing global CO₂ emissions will necessitate the assessment of the actual contribution of the forest sector to the total carbon removal. Russia’s forests have significant carbon reserves that can be conserved and increased through efficient forest use, protection and regeneration. The assessment of such “ecological asset” is still debatable and calls for improving both research methods and informational background.

The anthropogenic emissions and greenhouse gas removals are accounted for in the National Greenhouse Gas Inventory of the Land Use, Land Use Change and Forestry (LULUCF) sector by using the methods which, albeit not prescriptive in nature, set standards in preparing the Russia’s National Reports [3]. The current methods for quantitative estimation of carbon stocks and removals, as well as CO₂ emissions, are based on the data of the national and institutional statistical reports on
the state of Russia’s forests. This refers to data derived from the State Account of the Forest Fund (SAFF) (before 2008) and the State Forest Register (SFR) (after 2008). The SFR data outlived their usefulness in view of the fact that the relevant forest inventory and planning materials that accounted for 53% of Russia’s forest area had been received more than 20 years ago [4].

The Strategy for the Development of the Forest Complex Until 2030 [5] calls for the development of the State Forest Inventory (SFI) as an instrument for the implementation of climate policy in the forest sector and the information support of management in the sphere of protection, conservation and regeneration of forests. In 2020 the first State Forest Inventory cycle was completed right across Russia, with field measurements carried out directly on permanent sample plots (PSP). A total of 69,100 PSP was established in the space of 13 years (2007-2020). In 2021 the obtained data are to be processed and generalized on a nationwide scale.

In many foreign countries (USA, Scandinavia, Canada, EU, etc.) the National Greenhouse Gas Inventory in LULUCF sector is prepared by making use of data derived from national forest inventories. However, it is a new source of information for Russia that cannot be used for preparing the National Greenhouse Gas Inventory Reports without carrying out preliminary research and development work that would make it possible to develop and test the relevant methods and algorithms and then calculate the quantitative parameters.

In earlier publications, we presented the first preliminary assessments of the replacement of existing information sources used for preparing the National Greenhouse Gas Inventory, by new information sources [6, 7]. So far, Russia has had no experience in using the SFI data in forest management practice and in preparing various reports including international reports. For this reason the new sources of information need analytical conceptualization, adequate empirical support for preliminary conclusions, and discussion. The SFI operations are carried out in Russian forests by using the same methods, thus making it possible to obtain uniform and comparable data [8]. The State Forest Inventory comprises both the Forest Fund land and land belonging to other categories. As compared to SFR data, this distinct advantage of SFI PSP data provides a means for evaluating the budget of carbon for all forest land categories irrespective of ownership. Based on SFI results, the analytic surveys on the state and qualitative and quantitative characteristics of forests were prepared by the subjects of the Russian Federation and forest regions. The data from the analytic surveys served as source data for experimental evaluation of the carbon budget in the present study.

The objective of this study is to explore the possibility of using SFI data for evaluating the carbon accumulated in living (above- and below-ground) biomass and woody detritus and analyze the prospects for using SFI data for preparing the National Inventory Reports under UNFCCC.

The results and discussion are presented for three case studies as follows: (1) The specific features of evaluating carbon stocks in the living biomass are considered, based on SFI data, for one of the forest regions in the European-Ural part of Russia (EUPR), and the Republic of Karelia; (2) The volume of woody detritus and the possibility of evaluating the carbon stocks within the woody detritus pool are considered for 28 forest regions of the Russian Federation.

2. Methods and Materials
The SFI PSP raw data comprises a long list of indicators that can be used for the quantitative evaluation of accumulated carbon and annual removal of carbon within the five carbon pools as recommended by IPCC Guideline [9], namely, the aboveground living biomass, below-ground living biomass, dead wood (woody detritus), litter, and soil. A total of 117 indicators will be measured or assessed at permanent sample plots, and can be classified into 8 groups:
1. Data relating to sample plots and forest site (47 indicators).
2. Data on trees and snags (18 indicators).
3. Data on stumps and downed wood logs (17 indicators).
4. Data on ground cover and soil (5 indicators).
5. Data on young growth, shrub layer, and live ground cover (4 indicators).
6. Reforestation data (12 indicators).
7. Biodiversity data (5 indicators).
8. Data on the shape and quality of tree stems (9 indicators).

The data from the first six groups are of immediate interest for evaluating carbon-related parameters. The application of the data of the fifth (young growth, shrub layer, and live ground cover) and the sixth (reforestation) groups of indicators calls for carrying out research as well. In this case the point at issue is estimating carbon stocks in the young growth, shrub layer, and live ground cover. The carbon stock may reach 5 to 10% of the total carbon accumulated in forests. No mention has been currently made of this carbon pool in the IPCC Guideline [9] but IPCC welcomes the extension of the list of carbon-related indicators and replenishment of the calculation methods. According to IIASA team [10], the total carbon stock accumulated in the young growth, shrub layer, and live ground cover of the Russian forests is estimated to be about 6% of the carbon stock accumulated in the living biomass.

When carrying out research based on permanent sample plots data, the carbon stock accumulated in the aboveground living biomass was calculated in full accordance with IPCC Guideline [9] by using the equation (see [11]) with conversion factors [12]:

\[
B_{AG} = \sum A_{ij} \times V_{ij} \times BCEF_{ij} \times CF
\]

where, \(B_{AG}\) – carbon stock in above ground living biomass, tonnes C; \(A_{ij}\) – area covered by stands of species \(i\) in the age group \(j\), ha; \(V_{ij}\) – average growing stock volume for stands of species \(i\) in the age group \(j\), m\(^3\) ha\(^{-1}\); \(BCEF_{ij}\) – biomass conversion and expansion factor for expansion of merchantable growing stock volume to aboveground biomass, by taking account of basic wood density, for stands of species \(i\) in the age group \(j\), tonnes d.m. m\(^3\); \(CF\) – carbon fraction of dry matter (=0.5 tonnes C (tonned. m.)\(^{-1}\) for coniferous and =0.47 tonnes C (tonned. m.)\(^{-1}\) for broadleaved species).

The carbon stock in below-ground living biomass can be calculated in full accordance with IPCC Guideline [9] by using the following algorithm and equation:

\[
B_{BG} = B_{AG} \times R
\]

where, \(B_{BG}\) – carbon stock in below-ground living biomass, tonnes C; \(B_{AG}\) – carbon stock in above ground living biomass, tonnes C; \(R\) – root-to-shoot ratio, dimensionless.

3. Results and Discussion

3.1. Estimation of carbon stock in above- and below-ground living biomass

The carbon stock of living biomass was estimated, based on SFI data, via examples of the region of coniferous and broadleaved forests of the European-Ural part of Russia (CBF EUPR) and one of the subjects of the Russian Federation (Republic of Karelia).

The said forest region comprised – wholly or partially - 23 subjects of the Russian Federation belonging to three (Northwest, Central, and Volga) Federal Districts. According to SFI, the total forest land area amounted to 28.9 million ha. The SFI operations were carried out from 2007 to 2013. During that period 9 105 PSP were established. The error in estimating the total growing stock in the forest region under study was established at \(\pm 1\%\) but actual error was only \(\pm 0.54\%\). Note: According to SFR data based on forest inventory and planning materials, the standard error of estimated growing stock was supposed to be \(\pm 15 - \pm 30\%\) while systematic errors should not exceed \(\pm 10\%\) [4].

According to SFI, the total forest land area in the Republic of Karelia amounted to 9.79 million ha. With relation to the division of the territory of the Russian Federation into forest vegetation zones, the Republic of Karelia has two forest regions, including Karelian Northern Taiga Region and Karelian Taiga Region [13], each of them occupying nearly 50% of the total forest land area. The SFI operations were carried out from 2007 to 2013. During that period 779 PSP were established. The actual error in estimating the total growing stock was \(\pm 5\%\).

In both case studies, the forest land areas were comparable. Upon the average, the total and average values of merchantable growing stock by using SFR data as compared to SFI data were
underestimated by nearly 50% in CBF EUPR and by more than 80% in the Republic of Karelia (table 1).

Table 1. Comparison of quantitative indicators by using SFI and SFR data for the forest region of coniferous and broadleaved forests of the EUPR, and the Republic of Karelia as of 2018.

| Indicator                                      | Forest region of coniferous and broadleaved forests in the EUPR | Republic of Karelia |
|------------------------------------------------|---------------------------------------------------------------|--------------------|
|                                                | SFI               | SFR           | SFI       | SFR      |
| Forest land, million ha                        | 28.9              | 28.6          | 9.78      | 9.78     |
| Total growing stock, million m³                | 7 371.8           | 4864.5        | 1843.24   | 1025.34  |
| Average growing stock, m³ ha⁻¹                 | 255.0             | 169.0         | 188.4     | 104.8    |

Table 2. Comparison of carbon stock in living biomass estimated by using SFI and SFR data for the forest region of coniferous and broadleaved forests of the EUPR, and the Republic of Karelia.

| Pilotarea/Data                                      | Forest region of coniferous and broadleaved forests in the EUPR | Republic of Karelia |
|-----------------------------------------------------|---------------------------------------------------------------|--------------------|
|                                                     | Total carbon stock, million tonnes C | Average carbon stock, tonnes C ha⁻¹ | Total carbon stock, million tonnes C | Average carbon stock, tonnes C ha⁻¹ |
| SFR                                                 | 1702.5                                                     | 59.4             | 345.3     | 36.4      |
| SFI                                                 | 2588.0                                                     | 89.5             | 645.4     | 66.0      |
| SFI/SFR discrepancy, %                               | 52                                                         | 51               | 86        | 81        |

The carbon stock in above- and below-ground living biomass were calculated by equations (1) and (2) (table 2). As a comparison, the expected values of similar indicators, derived from the recent National Greenhouse Gas Inventory Report [14], are presented in figure 1.

In the region of coniferous and broadleaved forests of the EUPR, the average carbon stock in above- and below-ground living biomass amounted to 59.4 tonnes C ha⁻¹ by using SFR data and 89.5 tonnes C ha⁻¹ by using SFI PSP data. The total carbon stock in living biomass was 1 702.5 and 2588.0 million tonnes C, respectively. The comparison of assessments presented in table 2 is indicative of underestimation of both total and average carbon stocks in living biomass by more than 50%.

In the Republic of Karelia, the SFI/SFR discrepancy in assessments of the average carbon stock in above- and below-ground living biomass was within the order of 81%. As a result of more accurate assessment of total merchantable growing stock by using SFI data and by taking account of all categories of forest land, the SFI/SFR discrepancy in assessments of the total carbon stock in living biomass was approximately 86%.
Figure 1. Comparison between estimated total and average carbon stocks in living biomass, derived from the 2020 National Greenhouse Gas Inventory Report [14], and the total and average carbon stocks in living biomass estimated by using SFI data, for (a) the region of coniferous and broadleaved forests of the EUPR and (b) the Republic of Karelia as of 2018.

3.2. Estimation of the total volume of woody detritus
The woody detritus carbon pool is the second largest carbon pool next to that of living biomass. It consists of snags, downed wood, stumps, dry branches, and dead roots of trees. The amount of carbon accumulated in the woody detritus will depend on (1) the volume of timber that became dead or damaged due to negative impacts or mortality in forest stands; (2) the time elapsed after negative impacts; (3) the rate of organic matter decomposition under specific climatic conditions; and (4) carrying out of forest health improvement measures.

When preparing the National GHG Inventory Report, the accepted method for estimating carbon accumulated in the woody detritus pool involves model calculations of the woody detritus volume based on the merchantable growing stock volume by using SFR data. The direct field measurements of SFI PSP parameters and the estimated characteristics of snags, downed wood, stumps and the rate of organic matter decomposition can be used in calculations of accumulated carbon.

In our previous article we reported on the results of estimating the woody detritus stock for 15 forest regions of the Russian Federation [6]. The present study extends the woody detritus assessment for 28 forest regions by using 47 816 SFI PSP (figure 2). The boundaries of forest regions on the map that were included in the assessment of woody detritus volume at the research are bright pink colour.
The average volume of snags was $12.8 \pm 1.8 \ m^3/ha$ in all the forest regions under study. The largest volumes of snags were found in Western and Eastern Siberia, as follows: $29.5 \pm 4.3 \ m^3/ha$ in the Lower Angara Taiga Region (region 25 in figure 2), $24.8 \pm 2.9 \ m^3/ha$ in the Middle Angara Taiga Region (region 26 in figure 2), and $18.5 \pm 1.1 \ m^3/ha$ in the West Siberian Southern Taiga Plain Region (region 21 in figure 2).

The average volume of downed wood amounted to $17.0 \pm 2.8 \ m^3/ha$ in all 28 forest regions. The largest volumes of downed wood were found in Eastern Siberia and South Siberian Mountain Zone, as follows: $40.8 \pm 2.4 \ m^3/ha$ in the Lower Angara Taiga Region (region 25 in figure 2), $36.5 \pm 2.4 \ m^3/ha$ in the Middle Angara Taiga Region (region 26 in figure 2), $27.3 \pm 1.4 \ m^3/ha$ in the Central Siberian Subboreal Forest Steppe Region (region 27 in figure 2), and $25.9 \pm 1.5 \ m^3/ha$ in the Altay-Sayan Mountain Taiga Region (region 28 in figure 2). The average volume of stumps in all regions was $1.1 \pm 0.2 \ m^3/ha$.

The net result is that the average volume of woody detritus was estimated to be $31.0 \pm 4.5 \ m^3/ha$. The largest volumes of woody detritus were found as follows: $72.6 \pm 0.2 \ m^3/ha$ in the Lower Angara Taiga Region (region 25 in figure 2), $63.4 \pm 0.2 \ m^3/ha$ in the Middle Angara Taiga Region (region 26 in figure 2), $45.1 \ pm 0.2 \ m^3/ha$ in the Central Siberian Subboreal Forest Steppe Region (region 27 in figure 2), and $44.4 \pm 0.3 \ m^3/ha$ in the Altay-Sayan Mountain Taiga Region (region 28 in figure 2).

The present research has covered 28 forest regions out of a total of 42. The volume of woody detritus to live wood volume ratio averaged 19.5%. This ratio is roughly equivalent to that derived from the National Greenhouse Gas Inventory while converting woody detritus volume to woody detritus mass [14]. However, the woody detritus volume was assessed both in our research and in the National Greenhouse Gas Inventory without regard to the rate of organic matter decomposition. This necessitates the subsequent refining of the method for estimating carbon accumulated by the woody detritus pool with allowance made to all estimated SFI PSP parameters. It is fair to assume that inclusion of the rate of organic matter decomposition should change the woody detritus carbon to growing stock carbon ratio. It is the SFI data, as distinct from the National Greenhouse Gas Inventory data (which disregard the uncertainty of the carbon stock assessment in the woody detritus), that make it possible to estimate the uncertainty. The error of estimates in this study was approximately $\pm 8\%$.

In order to evaluate the annual carbon removals by living biomass and other carbon pools, the annual basic wood increment should be used. This parameter has not been estimated in the first State Forest Inventory cycle. The precise and reliable values of the annual basic wood increment can be
obtained from the repeated PSP measurements in the second SFI cycle. The annual basic wood increment will be calculated as an annual average over a period between consecutive measurements. This parameter is expected to be assessed comprehensively for the entire Russia’s territory in ten years, i.e. by the year 2030. Nevertheless, the current annual growing stock increment can be calculated based on single measurements at PSP. The single measurements of model trees at permanent sample plots make it possible to develop yield tables/growth models for main forest forming species, proceeding from actual growing stock and forest productivity. There are several methods for drawing up yield tables, based on site classes, forest types, growth types, etc. [16, 17]. Their implementation will necessitate applied research.

4. Conclusion

The changeover to estimating qualitative and quantitative forest parameters by using permanent sample plots (SFI PSP) will open the way for Russia to develop an information base that would serve for unbiased and precise evaluation of carbon stocks and carbon removals by forests, thus reducing the uncertainty in estimates.

Using as an example of test regions, it was demonstrated that the actual SFI data collected at PSP, which allow estimating the merchantable growing stock volume with an accuracy of ±1-5%, will reduce the uncertainty of estimates, and improve and make consistent the Russia’s National Reports to UNFCCC with national reports of other countries. A more precise method of estimating carbon stocks in biomass pools in combination with actual SFI data makes it possible to increase the estimated carbon stock in forest biomass by no less than 35%.

Further improvement of methods and information base for carbon stock and carbon removal assessment in forest biomass will allow to scale up the nationally determined contribution to reduce the greenhouse gas emissions in the year 2030 not by 25-30%(when compared to the year 1990) but by much more.

References

[1] Decree of the Government of the Russian Federation On the Adoption of the Paris Agreement 2019 N 1228 Approved by 21/09/2019

[2] Presidential Decree On Reducing the Greenhouse Gas Emissions 2020 N 666 Approved by 04/11/2020

[3] On Approval of Methodological Guidelines for Quantitative Assessment of Greenhouse Gas Absorption An order of the Ministry of Natural Resources and Environment of the Russian Federation 2017 N 20-r (amended on N 3-r 20/01/2021).

[4] Filipchuk A N, Malysheva N V, Zolina T A and Yugov A N 2020 Russia's boreal forests: opportunities for climate change mitigation Forestry Information Electronic Weblog 1 pp 92–113 DOI 10.24419/LHI.2304-3083.2020.1.10 Available at: http://lhi.vniilm.ru

[5] Strategy for the Development of the Forest Complex of the Russian Federation up to 2030 Decree of the Government of the Russian Federation 2021 N 312-r Approved by 11/02/2021

[6] Malysheva N, Filipchuk A and Zolina T 2019 Assessment of coarse woody debris stock in Russia forests based on state forest inventory data IOP Conf. Ser.: Earth Environ. Sci.316 012033 DOI: 10.1088/1755-1315/316/1/012033

[7] Filipchuk A N and Malysheva N V 2020 The assessment of the feasibility of using the state forest inventory data to implement the national commitments under the Paris Agreement IOP Conf. Ser.: Earth Environ. Sci.574 012026 Available at: https://doi.org/10.1088/1755-1315/574/1/012026

[8] Methodological Recommendations on State Forest Inventory Order of Rosleskhoz2011 No472 Approved by 10/11/2011 (ed. 15/03/2018)

[9] 2006 IPCC Guidelines for National Greenhouse Gas Inventories2007vol 4 aAvailable at:http://www.ipcc-nggip.iges.or.jp/public/2006gl/russian/vol4.html

[10] Shvidenko A Z and Schepaschenko D G 2014 Carbon budget of Russian forests [in Russian –
Uglerodnyi byudzhet lesov Rossii] Siberian Forest Journal 1 pp 69–92
[11] Procedure for Estimating CO$_2$Removals in the Forests of the Russian Federation 2017 [in Russian – Metodika ucheta pogloshcheniya CO$_2$ v lesah Rossijskoj Federacii] (Pushkino: VNIILM) p 82
[12] Schepaschenko D, Moltchanova E, Shvidenko A, Dmitriev E, Martynenko O, See L and Kraxner F 2018 Improved estimates of biomass expansion factors for Russian forests Forests 9 312 doi:10.3390/f9060312
[13] Analytical Review on the State of Forests, Their Quantitative and Qualitative Characteristics in the Republic of Karelia and on the Implementation of the State Work Ensuring the Implementation of the State Forest Inventory, Including Remote Monitoring of Forest Use 2020 (Moscow: Roslesinforg) p 78
[14] The National Report of the Russian Federation on the Inventory of Anthropogenic Emissions and Sinks of Greenhouse Gases Not Controlled by the Montreal Protocol for the Years 1990–2018 2020 (Moscow: Rosgidromet) vol 1 p 471 Available at: https://unfccc.int/documents/226417
[15] An Order of the Ministry of Natural Resources and Environment of the Russian Federation On Approval of the List of Forest Site Productivity Zones of the Russian Federation and the List of Forest Regions of the Russian Federation 2014 No 367 adopted 18.08.2014 (amended on 19.02.2019 N 105)
[16] Zagreev V V 1982 Guidelines for the Preparation of a Nationally Uniform System of Unionized and Zoned Forest Inventory Handbooks[In Russian –Ukazaniya po poryadku podgotovki edinoj dlya strany sistemy obschchesoyuznogo i rajonirovannyh lesotaksacionnyh spravochnikov] (Moscow: VNIILM) p 15
[17] Zagreev V V et al 1992 Union-wide Standards for Forest Inventory [In Russian – Obshchesoyuznye normativy dlya taksacii lesov] (Moscow: Colos) p 495