The assessment of the feasibility of using the state forest inventory data to implement the national commitments under the Paris Agreement

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Abstract. The authors have considered the feasibility of using the measurements of quality and quantity forest parameters on the State Forest Inventory (SFI) permanent sample plots (PSP) for estimating carbon stocks in forests in the preparation of the reports on the implementation of the national commitments under the Paris Agreement. The strengths and weaknesses of the SFI methods for estimating carbon stocks are revealed. The analytic assessment is demonstrated through the example of Khabarovsk Territory in which the SFI was completed in 2018. It is experimentally confirmed that significantly more accurate SFI data on the average growing stock volume, in combination with improved methods for estimating carbon assessment parameters, can increase the estimates of carbon stocks in the forest biomass approximately by +30%.

1. Introduction

The Decree of the Government of the Russian Federation No 1228 as of September 21, 2019 [1] that ratified the Paris Agreement emphasizes the importance of maintaining, increasing and estimating, to the most extent, the capacity of forests and other ecosystems to absorb carbon. For the purposes of the Paris Agreement, the issue of unbiased evaluation of the Russian forest CO₂ sink is more critical than ever before. The national reporting on the data relating to carbon stocks, removals, emissions and budget is currently based on the statistic information derived from the State Forest Register (SFR). In most countries featured by developed forest sector, the reports on their commitments under international climate agreement are based on the national forest inventory data (NFI) to be collected through estimating the quality and quantity forest parameters on the permanent sample plots (PSP). In Russia, the State Forest Inventory (SFI) represents a new type of forest inventory operations carried out from 2007 pursuant to the Forest Code of the Russian Federation [2, article 90]. By the time of the implementation of the Paris Agreement (after the year 2020), it is scheduled to complete the establishment of the SFI PSP in Russian forests. We can expect that these inventory data will be much in demand and, in compliance with international practice, taken as a basis for estimating carbon balance parameters for the national reports on the Land Use, Land Use Change and Forestry (LULUCF) sector under the international climate agreement. This will make it possible to align the greenhouse gas inventory data received in Russia and other countries which are using NFI data in their LULUCF sector. The opinion of many researchers [3, 4] regarding poor accuracy and irrelevance of merchantable growing stock data (that are taken as a basis of Russian greenhouse gas inventory) will...
be discarded. This opinion is still correct, because of the standard error of growing stock volume estimation (by conducting forest inventory operations) ranging from ±15 to ±30% and acceptable systematic errors reaching the value of ±10% [5]. In 2018, the forest inventory and planning materials that accounted for 58% of Russia’s forest area were received more than 20 years ago [5].

Generally, the future replacement of SFR data with SFI parameters regarded as a source for preparing international climate agreement reports, should be substantiated and experimentally assessed.

The aim of this research is to consider and discuss a possibility of using the data from SFI PSP measurements for estimating carbon balance forest parameters through the example of the region in which the SFI was completed.

The VNIILM research team developed and presented to the scientific community the Procedure for Estimating СО₂ Removals by the Forests of the Russian Federation [6]. This Procedure is based on the methodology for national greenhouse gas inventory, as recommended by the Intergovernmental Panel on Climate Change (IPCC) [7], and applies the SFR data. The State Forest Inventory (SFI) covers the forests referred to Forest Fund lands and lands of other categories. Such an approach is compliant with VNIILM methodology, as set forth in [5, 8, 9], for estimating carbon stocks, removals, emissions and budget for all categories of forest lands. It is our belief that all parameters required for international climate agreement reports should be estimated for all forests of the Russian Federation rather than only for the managed forests. Reserved forests were not referred to the category of managed forests by preparing the First National Report on Greenhouse Gas Inventory in 2006 [10], and are still not considered managed forests in the 2019 National GHG Inventory [11]. The area covered by Russia’s reserved forests amounts to some 200 million ha. Their removal from the category of managed forests and ignoring in the subsequent calculations has no grounds in the current forest legislation [2]. The SFI permanent sample plots are established in forests belonged to different categories, including reserved forests. Therefore, the use of the present-day source data, collected by a uniform method, for estimating the carbon balance parameters is compatible with the IPCC conception [7] thus encouraging us to explore the possibility to apply the said source data in the national climate agreement reports.

The forests of the Khabarovsk territory, in which the SFI was completed in 2018, were selected for testing. Some 40% of forests in the Khabarovsk Territory can be classified as reserved forests.

2. Methods and Materials
The SFI operations are conducted according to the Guidelines for Carrying out the State Forest Inventory [12], based on field measurements of forest indicators on permanent sample plots (PSP). The number of permanent sample plots can be determined by forest regions with an established accuracy of estimation of the total standing volume (standard error = ±2%). Following the establishment of the calculated number of permanent sample plots and the measurement data processing, a number of standard variables will be estimated (including average growing stock volume) which make it possible to assess the quality and quantity forest parameters. The outcomes will be summarized and presented according to a form approved by Rosleskhoz named Analytic Survey of Forest Health and Quantity and Quality Forest Indicators by the subjects of the Russian Federation and the forest regions. In our research we have used the data from the analytical review for Khabarovsk Territory prepared by Federal State Budgetary Institution Roslesinforg in 2019 [13]. All told, there were 2212 permanent sample plots on which field measurements were carried out in the Khabarovsk Territory. The actual error in calculating the total growing stock volume is about ±2.3%. The total growing stock volume by wood species and age groups is the major reference parameter used for estimating the carbon stocks in forest biomass. The comparison between the SFR data and SFI data, which are essential for the subsequent estimation of carbon assessment parameters, is presented in table 1.
Table 1. SFI quality and quantity parameters [13] vs. SFR data for Khabarovsk Territory as of January 1, 2018.

| Parameters                                      | SFI            | SFR            |
|------------------------------------------------|----------------|----------------|
| Forest land area, thous. ha                     | 59356.0        | 57918.0        |
| Stocked forest land area, thous. ha             | 50999.6        | 50952.9        |
| Total growing stock volume, thous. m³          | 5 308222.6     | 5 056090.0     |
| Average growing stock volume, m³/ha             | 126.2          | 98.9           |

*Under SFI, the average growing stock was calculated for stocked forest land only.*

The deviation of SFI data from SFR data was equal to +0.1% for stocked forest land, +2.4% for forest land, and +21.4% for average growing stock. The difference in total growing stock estimates is small (+4.7%) [13].

Based on the knowledge of some taxation specifications of growing stock and the data on mortality and litter fall on permanent sample plots, the State Forest Inventory provides for the assessment of total and average stocks of carbon in the biomass carbon pools including (1) total of above- and below-ground biomass; (2) woody detritus (dead wood either standing, or lying on the ground, and stumps) [12]. Out of a total of five carbon pools recommended by IPCC for preparing national greenhouse gas inventory [7], the three pools are estimated. The estimations of carbon stocks in litter and soil are not available. Inasmuch as the field operations include estimation of the forest litter depth and other soil parameters on permanent sample plots, the mentioned methodical gaps are expected to be filled in the time following.

The carbon stock in the living biomass pool will be calculated by using the following equation and conversion factors (see [12]):

\[
C = v \times D \times k_1 \times k_2 \times k_3
\]

where, \(v\) – average growing stock volume, m³ ha⁻¹; \(D\) – basic wood density, tones d.m. m⁻³ merchantable volume; \(k_f\)–value that corresponds to biomass expansion factor BEF for conversion of merchantable volume to aboveground tree biomass[7], dimensionless \(k_2\) – factor that corresponds to (1+R), where R is a ratio of living below-ground biomass (roots) to living above-ground biomass, dimensionless \(k_3\) – carbon fraction of dry matter (default=0.5), tones C (tonned. m⁻³)⁻¹ [7].

For the conditions of the test area (Khabarovsk Territory), the average wood density D was taken to be equal to 0.45 for all wood species. The dimensionless factors (\(k_f\) and \(k_3\)) are listed in the table 2.

Table 2. Dimensionless factors for conversion of merchantable growing stock volume to aboveground and below-ground tree biomass, according to SFI procedure [12], for the test area.

| Forest vegetation zone | Wood species group       | Factor |
|------------------------|--------------------------|--------|
|                        |                          | \(k_f\) | \(k_2\) |
| Boreal forests         | Coniferous/deciduous     | 1.35   | 1.2    |

The analysis of SFI PSP data quoted in [13] and the methods for calculating carbon stocks makes it possible to specify the research tasks to go with comparative study as follows:

1) Comparison of the carbon stock calculated by using the procedures described in [6] and SFR data, with the biomass carbon stock derived from SFI survey, for Khabarovsk Territory.

2) Comparison of potential carbon stock in the living biomass calculated based on the VNIILM procedure [6] by using SFI PSP data and SFR data, respectively.

3) Comparison of the biomass carbon stock derived from the National Report on Greenhouse Gas Inventory for Khabarovsk Territory [11], with the SFI biomass carbon stock calculated based on the VNIILM procedure[6] and SFI PSP measurements.
3. Results and Discussion

3.1. Comparison of the carbon stock calculated by using the VNIILM procedure and SFR data, with the biomass carbon stock derived from SFI survey

Equation (1) used in SFI for estimating the carbon stock in the living biomass pool, generally conforms to IPCC guidelines [7]. However, as indicated by the values of aggregate carbon stocks in the living biomass [13], the corresponding calculations are maximally simplified. As a matter of fact, despite significant variation of wood density of different wood species from 0.59 to 0.30 tonnes d. m. m$^{-3}$ [14, 15], the average wood density $D=0.45$ is used in calculations for all wood species. The dimensionless factors $k_1$ and $k_2$ are taken by default from [7]. The dimensionless factor $k_1$ heavily depends on the wood species and their age, as well as on a specific forest vegetation zone. The VNIILM procedure [6] involves the use of the biomass conversion and expansion factors for the expansion of the merchantable growing stock volume to the living biomass, by taking account of the basic wood density ($\text{BCEF}=\text{BEF} \times D$). The biomass conversion and expansion factor $\text{BCEF}$ varies according to species, age groups and the belonging to specific taxonomic units of the forest vegetation zones. This is the common approach which is developed and supported by competent researchers [16, 17]. The bottom line is that the biomass conversion and expansion factor for expansion of the merchantable growing stock volume to the living biomass, used in the VNIILM procedure, will exceed the similar factor used in the SFI procedure ($\text{BCEF} = D \times k_1$) by an average of +21% for any wood species. The difference in the values of the dimensionless factor $k_1$ in the said procedures is small (approximately 2%) and, therefore, can be neglected. The expansion of the merchantable growing stock volume to the living biomass, by using either procedure will be calculated by the same equations from IPCC guidelines [7]. The differences in concluding estimates are equally accounted for by differences in the estimates of the merchantable growing stock volume (by an average of +21%) and differences in the estimates of the biomass conversion and expansion factor for expansion of merchantable growing stock volume to the living biomass with account taken of wood density (by an average of +21%). As a result, despite the larger values of the average merchantable growing stock volume, according to SFI, the concluding difference in the estimates of total carbon stock in the living biomass pool amounts to 22% (figure 1). This is indicative of the incorrectness of the factor for expansion of the merchantable growing stock volume to the living biomass as used in the SFI procedure, resulting in the underestimation of the total carbon stock in the forest biomass.

![Figure 1. Comparison of the average carbon stock values for the forest biomass pools, calculated according to the SFI procedure/PSP measurements and the VNIILM procedure/SFR data.](image-url)
3.2. Comparison of potential carbon stock in the living biomass calculated based on the VNIILM procedure by using SFI PSP data and SFR data

The simplified calculation of carbon balance parameters by using equation (1), according to the SFI procedure, will reduce to nothing the more accurate estimation of merchantable growing stock volume through the measurements on permanent sample plots (table 3). In order to demonstrate the advantage of the more accurate estimation of growing stock volume and to bridge diversities of both procedures, we calculated the carbon stocks for stocked forest land according to the VNIILM procedure [6], based on the values of average growing stock volume on SFIPSP [13], and compared the results with SFR-based calculations. The area of stocked forest land remained unchanged in both estimations. The comparison results are shown in table 3.

Table 3. Comparison of carbon stocks in biomass pools, calculated according to the VNIILM procedure [6], by using the values of the average growing stock volume taken from SFI PSP measurements and those based on SFR data.

| Data   | Growing stock volume, m³·ha⁻¹ | Living biomass, million tonnes C | Total | Dead organic matter, million tonnesC | Stocked forest land, million ha | Average stock of carbon in biomass, tonnesC·ha⁻¹ |
|--------|-------------------------------|---------------------------------|-------|-------------------------------------|-------------------------------|-----------------------------------------|
| SFI    | 126.2                         | 2510.1                          | 3106.3| 630.4                               | 51.0                          | 67.7                                    |
| SFR    | 98.9                          | 1725.6                          | 2152.3| 493.2                               | 51.0                          | 57.1±9.3                                |

*The calculations were made for stocked forest land

As it follows from table 3, the total carbon stock in the living biomass (3106.3 million tonnes C) that was calculated by using SFI data and the conversion and expansion factors, differentiated by species groups and age groups with account taken of wood density [6], exceeded by far the total carbon stock in the living biomass that was calculated by using SFR data (2 152.3 million tonnes C). Therefore, the advantage of using more accurate estimations of the average merchantable growing stock volume and the correct values of conversion and expansion factors, will make it possible to increase the estimates of carbon stocks in the forest biomass approximately by +30%.

3.3 Comparison of the biomass carbon stock derived from the National Report on Greenhouse Gas Inventory for Khabarovsk Territory with the biomass carbon stock calculated based on the VNIILM procedure and SFI PSP measurements

Finally, we will compare the total carbon stock in the forests of Khabarovsk Territory, derived from the National Report on Greenhouse Gas Inventory [11] by using SFR data, with the total carbon stock calculated according to the VNIILM procedure[6] based on SFI PSP measurements[13]. For the sake of correctness of comparison, we will use the average carbon stock values in the biomass pools (below- and aboveground living biomass and dead wood) per unit area, by virtue of the fact that Rosgidromet (Federal Service for Hydrometeorology and Environmental Monitoring) calculations of carbon stocks were made only for managed forests, by neglecting reserved forests[11]. It will be recalled that reserved forests account for 40% of all the forests in the Khabarovsk Territory. It should be noted that forest carbon stock assessments by Roshydromet procedure and VNIILM procedure based on the same SFR data gives similar results.

The comparison of average biomass carbon stock in the forests of Khabarovsk Territory, derived from the 2019 National Report on Greenhouse Gas Inventory [11], by using SFR data, with the average biomass carbon stock calculated according to the VNIILM procedure based on SFI data (table 3), is shown in figure 2. The difference between the two compared estimates was found to be about +17-18%.
Figure 2. Comparison of the average carbon stock in the forest biomass, derived from the 2019 National Report on Greenhouse Gas Inventory [10], with that calculated by using the VNIILM procedure and SFI data.

Thus, a more accurate calculation of average carbon stock in living biomass with SFI measurements at the PSP gives 17-18% gain for stocked forest areas.

4. Conclusion

The State Forest Inventory makes it possible to create qualitatively new information on the Russian forests. The first cycle of inventory operations is scheduled to be completed in 2020. The collected information must be used in reports on Russia’s implementation of the international forest-related agreements, first of all, the FAO Global Forest Resources Assessment and the United Nations Framework Convention on Climate Change. From this perspective, the SFI procedure for estimating carbon balance parameters needs to be refined. Such a refined procedure should also provide for estimating carbon stocks in the pools of forest litter and soils, which are now left out of the calculations, despite the relevant data for the said pools are collected on SFI permanent sample plots. Given the applied procedure for estimating the carbon stock conforming, basically, to IPCC guidelines and equations, we need to look at improving the conversion and expansion factors for expansion of growing stock volume to biomass, in particular, through differentiation among those factors depending on wood species and age.

The above analysis and experimental estimates show conclusively that the use of more accurate data on the SFI average growing stock volumes, in combination with an improved procedure for estimating carbon balance parameters, can increase the estimates of carbon stocks in the forest biomass approximately by +30%.

The essential condition for using the SFI PSP data in the correct calculation of carbon balance parameters to be applied in the international reports will be making use of the source data derived from direct measurements on SFI PSP rather than summary data from analytical surveys featured by considerable defects. In order to make calculations by proving methods, it is necessary to initially estimate the merchantable growing stock volume classified at least by age classes and wood species.

The analytical surveys with the results of the SFI first cycle are lacking the most important indicator of forest productivity, namely, the net increment of merchantable growing stock. This parameter can be determined during the SFI second cycle, by repeated measurements on the permanent sample plots. This done, the annual removals of carbon in the forests will be calculated.

By the time of the implementation of the Paris Agreement, the SFI PSP data (subject to completion of the SFI first cycle) will be used, as a source material, for preparing the reports on implementation of the national commitments under the said agreement. The use of the SFI PSP data will make the carbon parameters comparable with those in national greenhouse gas inventory reports of other countries with boreal forests.
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