It is interesting to compare the data obtained with the data of the authors (Chestnykh, Zamolodchikov, 2017), which were calculated for the European-Ural region of Russia, while a different calculation methods were used, when the data were distributed to latitudinal bands, thus, the entire territory of the European-Ural part was covered by three belts (northern, middle, and southern subzones of the taiga), for which we calculated the stocks of soil carbon under the dominant tree species. Despite the different calculation algorithms, the data on the average carbon content in the 0–100 cm layer are in good agreement. Thus, the magnitude of the absolute values of the differences in estimates for pine and spruce from the regions of the northern, middle, and southern subzones of the taiga and the data most relevant to these regions calculated by the methods of O.V. Chestnykh and D.G. Zamolodchikova (2017) averages 24% (14÷45). In the calculations taken for comparison, the mean values under the dominant tree species were calculated from the entire data array falling into the selected belt. In this work, these estimates are more detailed, since the profiles were distributed over biotopes, and the following calculations took into account the contribution of each biotope. Thus, we present weighted mean values for each forest region, not simple regional mean values.

For bogs, we register a natural increase in average stocks from the area of pre-tundra forests to the middle taiga area – from 505 t ha^{-1} to 679 t ha^{-1}. For biotopes not covered by forests, for example, for arable lands and hayfields, the carbon content in the 0–100 cm layer reaches its maximum values in the southern regions: the forest-steppe forest area (202 t ha^{-1} and 244 t ha^{-1}) and the North Caucasian forest region (217 t ha^{-1} and 183 t ha^{-1} for arable land and hayfields, respectively).

The samples used in Table 1 for the analysis of the geographical variability of C_{soil}, for a number of biotopes, show high variability. Even in the cases of the largest samples (25–50 soil profiles), the relative error of C_{soil} values ranges from 6% to 50%. Obviously, this is the result of inclusion of several soil types in the same biotope. For example, for the biotope of sparse forest-tundra in the area of pre-tundra forests, the relative error reaches 86%. The value is calculated based on 6 indicators for the Kola Peninsula, which describe 2 profiles of podzolic soils with mean values of 81 t ha^{-1}and 90 t ha^{-1}, 3 profiles with soddy soils with mean values of 83 t ha^{-1}, 93 t ha^{-1}, and 246 t ha^{-1}and the last profile of 6 – in peaty soils with a mean value of 600 t ha^{-1}.

Comparing the obtained mean values of soil carbon stocks with the estimates of other authors, we noted the following: the work of D.G. Shchepashchenko et al gives the data on the average reserves in the 0–100 cm layer for Russia; calculations are made using a soil map and a base of typical soil profiles (49 profiles), using a number of correction factors (Shchepashchenko et al., 2013). The estimates of the meter layer for the European part of Russia are in a good agreement. Although it is quite difficult to compare these data since this work does not contain any estimates for the soil carbon stocks under the dominant tree species, but only a general concept – forest. Nevertheless, in this category, the authors cite the average reserves for the northern taiga – 19.68 kg C m^{-2} whereas our estimates are somewhat lower – from 9.1 kg C m^{-2} under birch stands to 14.1 kg C m^{-2} under spruce stands. A good coincidence is observed for northern bogs – the authors' estimates of 40 kg C m^{-2} coincide with ours – 50 kg C m^{-2}.

For the forest category in the southern taiga, the authors give the figure of 14.6 kg C m^{-2}, which is covered by the range of the values we obtained: from 13.1 kg C m-^{2} for spruce stands to 19.9 kg C m^{-2} for birch stands; almost perfect coincidence is observed for the bogs in the southern taiga – 9.93 kg C m^{-2} according to data from the work of D.G. Shchepachenko et al. (2013) and 9.76 kg C m^{-2} according to our data. Our estimates of the average stocks of soil carbon are close to those given in this work, except for a number of cases with somewhat lower values.

The work of A.V. Pastukhov and D.A. Kaverin (2013) gives the data on the content of soil carbon in the main soil groups for the southern tundra and middle taiga of the Murmansk region for 0–30 cm and 0–100 cm soil layers. For the tundra, the estimates of soil carbon reserves in the 0–30 cm layer given by the authors are close to ours: 10.8 kg C m^{-2} versus 10.5 kg C m^{-2}, respectively. Not so complete agreement of the estimates is observed in the layer 0–100 cm – 28.7 kg C m^{-2} versus 16.7 kg C m^{-2} (our data), respectively. For the middle taiga, the authors give the figure of 8.2 kg C $m^{-2}$for 0–30 cm layer; for the 0–100 layer, this indicator is equal to 16.1 kg C m^{-2}, whereas our data are 9.2 kg C m^{-2} and 15.5 kg C m^{-2}, respectively. In general, the differences in estimates do not exceed the range of errors of the means. Table 2. shows the total soil carbon stocks for forest regions as a whole.

Table 2. Stocks (± SE)* of carbon in the soil layers of forest regions for the European-Ural part of Russia

Region	Area of 10^6 ha	Carbon stock of 10^9 t C			Number of profiles
		Depth of profiles, cm			
		0–30	0–50	0–100	
Tundra	0.24	0.026±0.018	0.033±0.027	0.041±0.038	60
Area of tundra forests and sparse taiga	23.38	3.47±0.98	5.29±1.71	6.12±2.04	53
North taiga area	35.09	4.94±2.01	7.20±3.07	9.53±4.30	57
Middle taiga area	31.91	2.92±0.93	3.62±1.03	4.93±1.37	37
South taiga area	17.79	2.09±1.80	2.33±2.1.99	2.57±2.13	34
Coniferous-deciduous forest area	23.01	1.02.±0.67	1.18±0.71	1.48±0.78	119
Forest-steppe area	4.98	0.27±0.18	0.36±.25	0.47±0.29	26
Steppe area	2.51	0.10±0.03	0.13±0.05	0.20±0.07	124
North Caucasian mountain area	2.23	0.14±0.06	0.18±0.08	0.25±0.10	117
North Ural area	12.46	2.54±0.38	4.12±0.49	5.81±0.61	17
Central Ural area	19.69	1.24±0.42	1.51±0.51	1.97±0.65	20
South Ural area	7.83	0.54±0.02	0.64±0.06	0.80±0.12	11
Total	181.13	19.30±7.5	26.60±9.95	34.17±12.51	675

*Note:***SE* – standard error

The mean values of carbon reserves obtained by us for a depth of 0–50 cm are close to the data obtained by E.A. Vaganov et al. for the soils of forest ecosystems of the Yenisey meridian (Vaganov et al., 2005). Thus, for forest tundra, the authors' indicator is 103 t ha^{-1}, whereas according to our data for tundra and sparse taiga these indicators should be 134 t $ha^{-1}$and 226 t ha^{-1}, respectively. For the northern taiga, the authors give an estimate of 118 t ha^{-1}, while according to our results this indicator should be 205 t ha^{-1}; for the middle taiga, the authors give an estimate of 107 t ha^{-1}, while according to our results this indicator should be 114 t ha^{-1}; for the southern taiga, the authors give an estimate of 134 t ha^{-1}, while according to our results this indicator should be 131 t ha^{-1}. In more northern areas, we registered greater differences in estimates, since the percentage of wetlands increasing the total reserves differs for the Siberian and European parts of the country.

The highest mean value of 466 t ha^{-1} is characteristic of the soils in the North Ural and north taiga; 272 t ha^{-1} is characteristic of the regions, where wetlands are taken into account. The minimum mean values of 64 t ha^{-1} were calculated for the coniferous-deciduous region and 80 t ha^{-1} for the steppe area, which is possibly due to either the aridity of the territories, or the plowing of the steppes, and the inclusion of areas with large mean values into the biotope "arable land".

Total soil carbon stocks of the forest regions in the European-Ural part was

$19.3*10^9$ C t for a depth of 0–30 cm, $26.6*10^9$ C t for a depth of 0–50, and $34.2*10^9$ C t for a depth of 0–100 cm. The total area of forest lands in the European part of Russia for these forest cover lands is estimated at $181.13*10^6$ ha. The maximum reserves are characteristic of the north taiga area, the minimum reserves are characteristic of the steppe area and the North Caucasian mountain area that reflects, on the one hand, the distribution of the areas of the corresponding plots, on the other hand, can be explained by the large amount of peat lands in the northern areas. The reserves of carbon in the soils of the tundra zone were estimated at $26*10^6$ C t for a depth of 0–30 cm, $33*10^6$ C t for a depth of 0–50 cm, and $41*10^6$ C t a depth of 0–100 cm.

Our results are incomparable with the data of other authors since our estimation approach is oriented towards the problem of estimating the carbon budget, its pools and fluxes in forest regions. At the same time, most of the estimates of soil C stocks are calculated using soil maps and can be compared with them only on the basis of data integrated at the regional level. Estimates of soil C stocks under dominant tree species and non-forest land categories are much less common than estimates of soil C stocks for different soil types. In the 0–100 cm layer, we register the convergence of the final C_{soil} estimates of different authors.

The work of D.V. Orlova et al. describes the reserves of organic carbon in soils and peats: for a meter thickness in the European part as a whole, they are $41.9*10^9$ C t (Orlov et al., 1996), whereas our calculations fit into the range of $34.2±12.5* 10^9$ C t of errors of the means.

When comparing our data with those of O.V. Chestnykh and D.G. Zamolodchikov (Chestnykh, Zamolodchikov, 2017), the other principles of calculation of which were mentioned above, we registered a good coincidence of both the data on the area of forest regions in the European part – $178.8*10^6$ ha and $181.13*10^6$ ha (this work), and of the data on the final stocks for different depths $–18.1*10^9$ C t and $19.3*10^9$ C t (this work) for a depth of 0–30 cm, $25.1*10^9$ and $26.6*10^9$ C t for a depth of 0–50 cm, $34.7*10^9$ C t and $34.2*10^9$ C t for a depth of 0–100 cm. Obviously, the reason for the differences in data is the result of analyzing soil data in terms of the representativeness of biotopes in the corresponding forest regions, while the work, with the results of which we compare our results, contains only the calculations of simple means of soil profiles by geographic bands.

The total reserves in the entire territory of the European-Ural part of Russia were estimated at $34.2±12.5*10^9$ C t for 0–100 cm depth, including the tundra region.

The gross reserves of C_{soil} in forest regions are hardly comparable, since they depend on the total areas of forest cover lands. Soil-carbon capacity (in t C ha^{-1}) of lands of different categories is more indicative in this case. Since these indices differ not so significantly for soils in forested and unforested lands (Table 3), it is advisable to analyze only the contribution of non-forest lands and lands covered with forest vegetation.

Table 3 shows the mean reserves of different categories of forest lands, calculated for the entire territory of the European-Ural part as a whole, without dividing them into forest regions. The smallest average stocks are typical for felling sites; higher average stocks are typical for pastures, hayfields and larch forests, whereas the highest average stocks are typical for bogs.

In general, for Russia, the ratio of carbon capacity in the 0–50 cm layer of non-forest land to forest land is 1.9. In the European part of the country, where there are a lot of bogs in the northern territories, this ratio rises to 3.0 (Chestnykh et al. 2004). Consequently, non-forest lands in the structure of forest cover lands act as the main accumulator of biological carbon in the entire biome of boreal forests. At the same time, the C_{soil} of the bogs determines the priorities of individual regions in the total carbon reserves of the forest cover lands, and not only in its non-forest lands.

Table 3. Average (±SE)* carbon stocks in soil of different categories for the entire European-Ural part of Russia

Category	Average carbon stock, t ha^{-1}			Number of profiles
	Depth of profiles, cm			
	0–30	0–50	0–100	
Pine	85.47±40.76	119.56±47.22	121.84±50.6	73
Spruce	88.04±56.61	110.32±73.3	140.51±90.99	108
Fir	74.2±49.43	96.13±63.12	124.66±67.59	12
Larch	136.5±0.02	155.25±0.06	186.49±0.21	4
Oak	34.24±9.71	44.9±12.67	65.56±16.06	43
Hornbeam	48.41±23.66	64.08±30.56	92.25±40.69	13
Beech	58.24±25.8	77.41±36.55	112.36±47.98	24
Linden	51.52±18.71	66.53±30.11	102.02±71.39	8
Birch	90.3±44.29	104.34±48.43	121.84±50.6	39
Aspen	55.34±5.61	65.95±4.85	79.71±3.53	5
Other hard-leafed forests	43.46±1.72	62.13±2.86	93.29±17.24	7
Other soft-leaved forests	58.49±19.51	75.32±27.58	95.36±35.06	17
Other shrubs	80.06	95.46	123.96	1
Felling sites	25.1±8.75	34.72±6.64	56.68±0.48	3
Bogs	257.06±20.86	417.6±70.26	539.2±114.8	18
Arable land	69.42±23.49	102.62±37.55	148.11±58.14	71
Pastures	77.62±22.68	110.4±30.47	156.84±39.37	46
Hayfields	85.06±19.85	111.07±25.84	145.6±33.48	102
Gardens	160.8	217.25	279.53	1
Sparse forests	117.58±96.67	143.19±122.48	175.44±156.03	80

Note: **SE* – standard error

This is clearly seen in Figure 1, which shows a map of the distribution of average stocks of soil carbon in the 0–50 cm layer over forest regions. It can be seen that the maximum mean values are observed in pre-tundra forests and northern taiga regions, as well as in the North Ural region. The minimum mean values are observed in the coniferous-deciduous area with a small share of non-forest lands. For the desert region, the data are absent at all, since they are not included in the database. Of interest are the data for the North Caucasus region with a total small area of 2.23 million ha, i.e. it is one of the smallest allotments, the mean values are significant reaching 112.07 t ha^{-1}; total reserves are equal to 250 10^6 t that is explained by a large number of arable lands in this region.

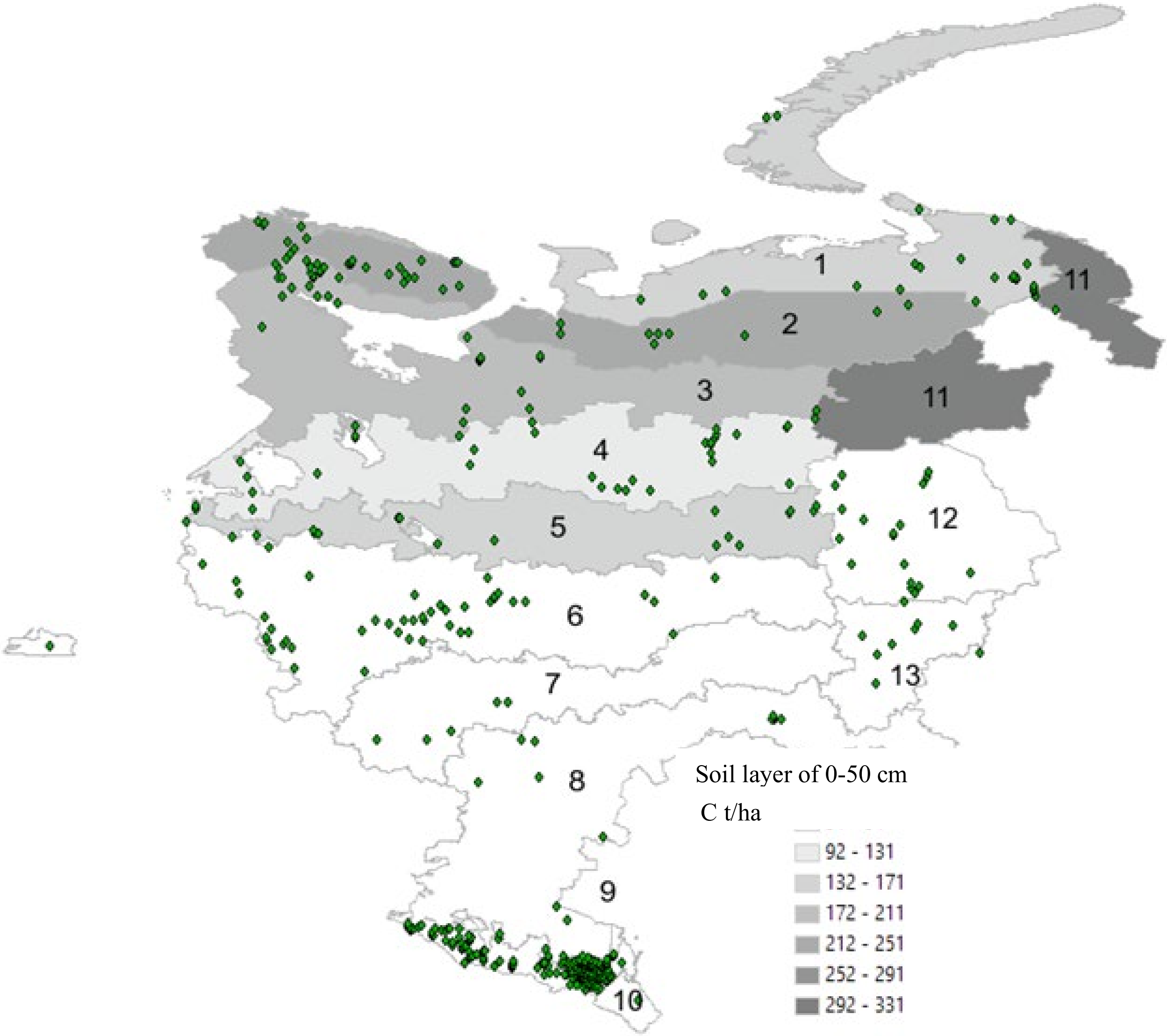

Figure 1. Average carbon reserves (t C ha^{-1}) in the 0–50 cm soil layer in the forest cover lands of the European-Ural part of the Russian Federation

The distribution of profiles from the database of biotopes of forest regions in the European-Ural part of Russia is uneven (diamonds in the figure). There are biotopes, for which data are not available for some forest regions. For example, there is no data on "bogs" in the middle Ural, southern taiga area, and the area of coniferous-deciduous forests; there are no profiles in the widely represented aspen forests of the southern taiga, the middle and southern Urals; there is a lack of data on the larch and birch categories from the North Ural forest region, etc. (the listed biotopes occupy an area of more than 800 thousand ha in the corresponding forest regions). To further fill the database of soil characteristics, it is necessary either to use the literature resources, or to take field measurements to fill in the missing information.

CONCLUSION

The estimation of soil carbon stocks in the territory of the European-Ural part of Russia is made using the topologies adopted in the classification of categories of forest cover lands in the State Forest Inventory (SFI). The attribution of each profile to the forest region and the category of land ("biotope") was established using the coordinates and descriptions of soil profiles from the available database (Chestnykh, Zamolodchikov, 2018). For each forest region of the European-Ural part of Russia, we obtained the shares of land cover variants (dominant species for forested lands and variants for unforested lands). The mean values of soil carbon for forest regions weighted over the areas of biotopes were obtained based on the representativeness of "biotopes" in forest regions. Thus, the average values of soil carbon were calculated by weighting the data on the proportions of the present category of land (biotope) in the corresponding forest area.

The final data are in good agreement with the estimates obtained earlier by other authors, although our results are hardly comparable with most published works due to the use of fundamentally different approaches to the spatial grouping of data. Namely, our data are aggregated according to biological "biotopic" criteria, while in most works by other authors the topological basis for aggregation consists in soil types themselves or soil maps.

One of the consequences of the work done was the identification of "holes" – biotopes, for which there is no soil data for some forest regions. It is desirable to perform appropriate work to obtain a more complete picture of the distribution of soil carbon in the forest cover lands.

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