E3S Web of Conferences **157**, 02028 (2020) https://doi.org/10.1051/e3sconf/202015702028
KTTI-2019

Methodology of estimation of forest-growing potential of soils and its approbation on the example of the Leningrad Region, Russian Federation

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Abstract. A progressive growth of anthropogenic soils and non-soil formations in the soil cover of the taiga forest zone and a general decrease in the ecological potential of soils necessitate the development of policies for the rational use of soil resources. The analysis of approaches to forest vegetation assessment of soils is carried out. The concepts of specific and resource potentials are introduced, and our own methodology for their assessment is developed. The methodology for calculating potentials was tested on the example of the Leningrad region, typical of the North-West of the European part of Russia and the North of the Russian Plain. Natural soil areas were calculated using a digital soil map. The analysis of changes in forest growing potential of soils is carried out from the beginning of intensive development of the territory to the modern period. These calculations can form the basis for assessing the potential contribution of the region to ensuring the reproduction of forest resources.

1 Introduction

Due to the increase in the scale and types of anthropogenic load, the soil cover of the forest zone is becoming more complicated, and the area occupied by anthropogenic transformed and anthropogenic soils, as well as technogenic non-soil formations (TSF), is increasing [1]. The progressive global warming and the growth of the scale of anthropogenic activity set the task of assessing the influence of these factors on the resource potential of soils and on ecosystems in general. According to the Food and Agriculture Organization of the United Nations (FAO), the total forest area of the planet decreased by 3% from 1990 to 2015 [2].

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There is growing interest in obtaining an informative idea of the changes that may occur in the forest zone, and the impact of these changes on forestry [3]. Updating knowledge about the forest-growing properties of soils and developing methods for calculating the forest-growing potential open up the prospects for its monitoring, which is necessary for the purposes of reforestation and rational use of soils. Forest-growing properties of soils are properties that ensure the functioning of forest biogeocenosis. Forest growing potential (FGPS) characterizes the natural ability of soils to provide one or another level of forest stand productivity. FGPS is characterized by specific (SFGPS) and resource (RFGPS) soil potentials. SFGPS is the soil potential in points, calculated per unit area, and RFGPS is the specific soil potential in points, referred to the area occupied by this soil.

The aim of the study is to develop a methodology for assessing FGPS and its testing on the example of the Leningrad Region, Russian Federation.

2 Materials and methods

The objects of study are the soil and soil cover of the taiga forest zone, typical of the North-West of the European part of Russia and the North of the Russian Plain. The Leningrad Region belongs to the taiga forest zone and two forest regions: the middle taiga and the south taiga. The forest area of the region is 60314 km2; coniferous stands prevail (Fig. 1) [4]. The main activities affecting the soil cover of forests include: logging (deforestation), land reclamation and fire prevention, agricultural use of forest land and recreation. Forest stands of the region have the following distribution by age groups and bonitet classes (Fig. 2) [4].

In terms of bonitet class III prevails (42%); second place (30%) is occupied by forests of class II and higher; the third position (12%) is occupied by forests belonging to class V. Significant differences in the distribution by age groups are not observed, but ripe and overripe stands (33% of the area of conifers) predominate.

The Leningrad region is characterized by genetic diversity of soils due to a variety of soil formation factors (topography, parent rocks, hydrogeological conditions [5-9]. The calculation of SFGPS consists of two stages. At the first stage (according to the criteria of the 1st order - a set of unfavorable properties and regimes that reduce the productivity of stands), all natural soils are divided into 5 groups (Table 1) according to habitat quality: very good (100 points), good (75-99), satisfactory (50- 74), bad (25-49) and very bad (0-24). As criteria, indicators of water regime, flowage, biological productivity and soil density are used.

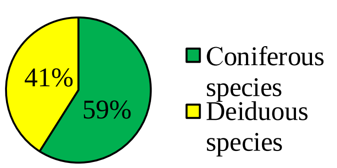

Fig. 1. The composition of the stands of the Leningrad region.

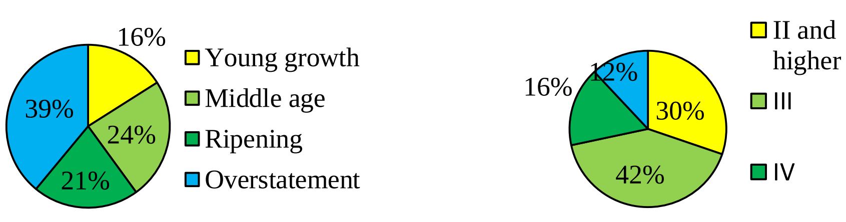

Fig. 2. Distribution of stands of the Leningrad region by age groups and bonitet classes.

Table 1. Signs of soils affecting SFGPS (1st order criteria)

Habitat quality groups	Criteria	Group score	Bonitet
Very good	None - the optimal values of the parameters of water, air and food regimes.	100	I, Ia
Good	Small deviations from the optimal parameters for: • acidity • availability of nutrients • availability of productive moisture • moisturizing	75-99	I-II
Satisfactory	• short age of nutrients • high or high acidity, • increased density, • deficiency of productive moisture, • water logging	50-74	II-III-IV
Bad	• low nutrient requirement • low flowrate • lack of productive moisture • high density • close occurrence of the gley horizon	25-49	IV
Very bad	• deficiency of oxygen and batteries • very low root layer thickness • very low moisture content or very strong waterlogging • very high or very low density	0-24	IV, Va

Table 2. Signs of soils affecting SFGPS (2nd order criteria)

# of parameter	Features	Parameter		Quality assessment	Lowering score
		Pine	Spruce		
1	Thickness of litter horizon, cm	> 5	> 5	Optimal	—
		2-5	2-5	Critical	- 1,25
		< 2	< 2	Negative	- 2,5
	Thickness of the humus horizon, cm	> 15	> 15	Optimal	—
		5-15	5-15	Critical	- 1,25
		< 5	< 5	Negative	- 2,5
	Thickness of the peat horizon, cm	< 20	< 20	Optimal	—
		20-30	20-30	Critical	- 1,25
		> 30	> 30	Negative	- 2,5
2	Humus type	Mull	Mull	Optimal	—
		Moder	Moder	Critical	- 1,25
		Mor	Mor	Negative	- 2,5
	Degree of peat mineralization	Mineralized	Mineralized	Optimal	—
		Medium mineralized	Med. miner.	Critical	- 1,25
		Not mineralized	Not mineralized	Negative	- 2,5

3	Humus content,%	> 3,5	> 3,5	Optimal	—
		2,0-3,4	2,0-3,4	Critical	- 1,25
		< 1,9	< 1,9	Negative	- 2,5
4	Cation exchange capacity, milliequivalent /100g of soil	> 30	> 30	Optimal	—
		10-29	10-29	Critical	- 1,25
		< 9	< 9	Negative	- 2,5
5	N content, mg/100g of soil	> 5	> 5	Optimal	—
		3-4	3-4	Critical	- 1,25
		< 2	< 2	Negative	- 2,5
	P content, mg/100g of soil	> 10	> 10	Optimal	—
		4-9	4-9	Critical	- 1,25
		< 3	< 3	Negative	- 2,5
	K content, mg/100g of soil	> 12	> 12	Optimal	—
		11-5	11-5	Critical	- 1,25
		< 4	< 4	Negative	- 2,5
6	Density of soil structure, g/cm^3 (for mineral horizons)	1-1,3	1-1,3	Optimal	—
		1,4-1,5	1,4-1,5	Critical	- 1,25
		> 1,6	> 1,6	Negative	- 2,5
7	Humidification mode / Groundwater level, cm	120-140	90-120	Optimal	—
		119-80	89-60	Critical	- 1,25
		< 79	< 79	Negative	- 2,5
8	Flowage (degree of gleying)	Not gleying	Not gleying	Optimal	—
		Gleying	Gleying	Critical	- 1,25
		Gley	Gley	Negative	- 2,5
9	The depth of the gley horizon, cm	> 30	> 70	Optimal	—
		20-30	30-70	Critical	- 1,25
		< 20	< 30	Negative	- 2,5
10	Acidity (pH_{H2O})	5.5-7.0	5.5-7.0	Optimal	—
		4.6-5.5	4.6-5.5	Critical	- 1,25
		< 4.5	< 4.5	Negative	- 2,5

The second stage is the ranking of soils by the quality of forest conditions within each group. For this, amendments are introduced to the base score of the group to adverse soil properties (criteria of the 2nd order). Based on a generalization of materials on the requirements of pine and spruce crops to soil conditions (Berezin L. B. [10], Zaitsev B. D., [11], Zelikov V. D. [12], Zonn S. V. [13, 14], Karpachevsky L.O. [10, 14, 15], Morozov G.F. [16], Remezov N.P., Pogrebnyak P.S. [17], Sukachev V.N. [18], Chertov O.G. [19, 20, 21] and others) 10 indicators were identified that most determined the forest-growing properties of soils (Table 2). They include: thickness of litter/humus horizon/peat, humus type/degree of peat mineralization, humus content, cation exchange capacity, content of nutrients (N, P, K), acidity, density of mineral horizons, groundwater level, flowage or gleying, depth of glue horizon. Each indicator is assigned a qualitative assessment. Three gradations are accepted: optimum, critical, negative. Each indicator of a qualitative assessment is assigned a lowering score. Negative - corresponds to 2.5 points, critical - 1.25 points. With an optimal estimate of the parameter, a lowering score is not administered. The value of SFGPS is determined by the difference between the group score and the sum of all points on the adverse soil properties.

Potentials are calculated for two main forest-forming species of the taiga forest zone - spruce and pine.

RFGPS is calculated by the absolute value of the area occupied by soils and the relative value occupied by soil differences in relation to the entire area of the study area:

RFGPS = (Sd·SFGPS)/10, where Sd - the proportion of the area of a particular soil to the total area of the region.

3 Results

Existing approaches to assessing the forest-growing properties of soils (Remezov N.P., Pogrebnyak P.S. [17], Sukachev V.N. [18]) are based on the typology of habitats, where the plant community and ground cover play the leading role. Zonn S.V. [13, 14], Karpachevsky L.O. [14, 15], Blagovidov N.L. [17] conduct a direct relationship between the influence of soil properties and the productivity (bonitet) of the stand. Chertov O.G. (in addition to the connection of soils with forest stand bonitet), pays great attention to the aspect of the water regime and the type of humus [23, 24]. The approach proposed by the authors of this study is based on a two-level assessment of soil properties, which to the greatest extent determines the productivity of the stand. Soil potentials were evaluated for two forest-forming species: pine and spruce. In the assessment, a digital soil map of the Leningrad Region, developed in the Dokuchaev Central Soil Science Museum (Fig. 3) [4].

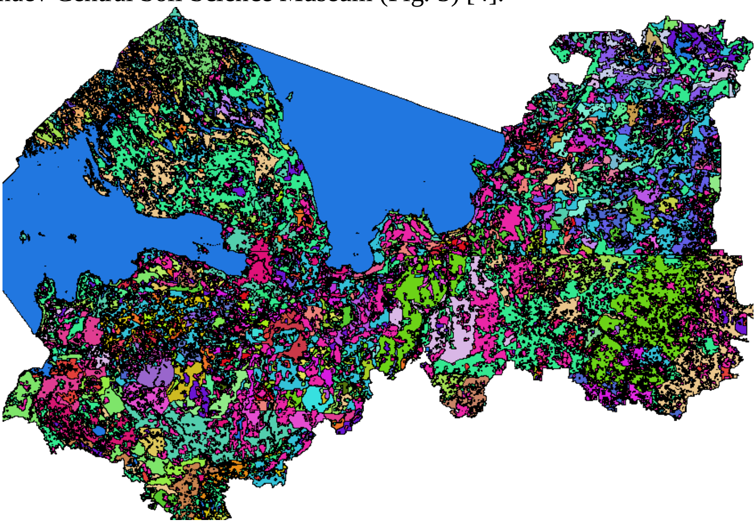

Fig. 3. Digital soil map of the Leningrad Region M 1: 200000.

RFGPS is calculated according to SFGPS and the fraction of the area occupied by each specific soil, relative to the entire area of the Leningrad region. All non-soil formations, territories with destroyed soil cover and located under highways were excluded from the calculation. Assessment of changes in the forest-growing potential of natural soils for the period from the beginning of intensive development of the territory to the present time was carried out on the basis of a comparison of RFGPS. The areas are calculated using a digital soil map and a map of the reconstruction of the soil cover of the Leningrad Region (Table 3). Calculations (Table 3) showed that the highest SFGPS score (99-100) was found in soils: Cambisols, Rendzic Leptosols and Umbric Albic Luvisols Calcaric. The group of good conditions includes soils with small deviations of properties from optimal values: Umbric Albic Luvisols and Umbric Entic Podzols (93 points). Soil: Lamellic Umbric Albic Luvisols (68 points), Umbric Albic Podzols (63 points), Gleyic Histic Albic Luvisols (60 points), Albic Luvisols (60 points), Haplic Entic Podzols and Rustic Entic Podzols (56- 61 points). The following soils have the lowest SFGPS scores (fifth group): Fluvisols (16 points), Fluvic Umbric Gleysols (13-14 points), Lithic Leptosols (13 points), Fibric Histosols (5 points).

Table 3. Specific and resource potentials of the main natural soils in points and change in resource potential from the beginning of intensive development of the territory to the modern period

Habitat quality groups	Soils	SFGPS		RFGPS		Change in RFGPS	
		Spruce	Pine	Spruce	Pine		
Very good	Haplic Cambisols	100		7		- 13	
	Cambisols	100		—		- 7	
	Umbric Albic Luvisols Calcaric	99		3		- 8	
	Rendzic Leptosols	99		1		- 4	
Good	Umbric Albic Luvisols	93		7		- 19	
	Umbric Entic Podzols	93		2		Not changed	
Satisfactory	Lamellic Umbric Albic Luvisols	68		3		- 6	
	Umbric Albic Podzols	63		5		- 9	
	Gleyic Histic Albic Luvisols	60		9		- 1	- 1
	Gleyic Umbric Albic Podzols	60		8		Not changed	
	Albic Luvisols	60		15		- 1	- 1
	Haplic Entic Podzols	61		1		Not changed	
	Rustic Entic Podzols	59	56	53	51	- 2	- 1
	Histic Umbric Gleysols	37	38	3		Not changed	
Bad	Rustic Albic Podzols	36	36	20		- 35	
	Gleyic Histic Albic Luvisols	35	34	0,5		- 0,5	
	Albic Podzols	33		5		- 2	
	Gleyic Albic Podzols	33	31	13		- 6	- 5
	Gleyic Histic Albic Podzols	33	30	9	8	- 1	
	Histic Gleysols	30		28		- 1	
Very bad	Fluvisols	16		0.2		- 6,8	
	Fluvic Umbric Gleysols	14	13	1		Not changed	
	Lithic Leptosols	13		1		- 1	
	Sapric Histosols	9		1		Not changed	
	Fibric Histosols	5		5		- 1,5	

The resource potential of soils differs significantly from the specific. Its scoring depends on the area occupied by the soil. The following soils have the highest resource potential score: Rustic Entic Podzols (53 and 51 points), Histic Gleysols (28 points), Rustic Albic Podzols (20 points) and Albic Luvisols (15 points). The lowest score of soil resource potential: Fluvisols and Gleyic Histic Albic Podzols have less than 1 point. According to the results of assessing changes in the forest-growing potential of natural soils for the period from the beginning of the development of the territory to the modern period, the soil resource potential did not change: Umbric Entic Podzols, Gleyic Umbric Albic Podzols, Haplic Entic Podzols, Histic Umbric Gleysols, Fluvic Umbric Gleysols, Sapric Histosols. The RFGPS score of the following soils decreased the most: Rustic Albic Podzols (-35 points), Umbric Albic Luvisols (-19 points), Haplic Cambisols (-13 points). The change in the specific potential of soils is mainly due to the drainage of waterlogged areas; Resource change is associated with the involvement of soils in agricultural use, the construction of cities, roads, overpasses and other human activities.

4 Conclusion

The developed methodology for assessing the forest growing potential of soils, which includes two stages, makes it possible to evaluate the forest growing potential of soils in points. Soils with the highest SFGPS score are: Cambisols, Rendzic Leptosols and Umbric Albic Luvisols Calcaric, the lowest scores are for the soils: Fluvisols, Fluvic Umbric Gleysols, Lithic Leptosols, Fibric Histosols. Soils that have the highest resource potential score: Rustic Entic Podzols, Histic Gleysols, Rustic Albic Podzols and Albic Luvisols. The lowest score of resource potential of soils: Fluvisols and Gleyic Histic Albic Podzols. According to the results of assessing changes in the forest-growing potential of natural soils over the period from the beginning of development of the territory to the modern period, the score of resource-growing potential of the following soils decreased to the greatest extent: Rustic Albic Podzols, Umbric Albic Luvisols, Haplic Cambisols. The technique has been tested for the conditions of the Leningrad region and can be recommended for use in other regions of the taiga forest zone.

5 Acknowledgments

This work was supported by the RFBR grant No. 19-04-01184.

References

1. E.Yu. Suhacheva, B.F. Aparin, Sbornik dokladov Tret'ej Vserossijskoj otkrytoj konferencii. Moskva – M.: Pochvennyj in-t im. V. V. Dokuchaeva, 1140-1154 (2019) (rus)
2. R. Keenan, G. Reams, F. Achard, J. de Freitas, A. Grainger, E. Lindquist, Forest Ecology and Management **352**, 9-20 (2015)
3. R. Annunzio, M. Sandkera, Y. Finegold, Z. Minc, Forest Ecology and Management **352**, 124-133 (2015)
4. *Lesnoj plan Leningradskoj oblasti* (Postanovlenie Gubernatora Leningradskoj oblasti, 2018) (rus)
5. V. Terleev, E. Petrovskaia, A. Nikonorov, V. Badenko, Y. Volkova, S. Pavlov, N. Semenova, K. Moiseev, A. Topaj, W. Mirschel, MATEC Web of Conferences **73**, 03001 (2016)
6. O. Degtyareva, G. Degtyarev, I. Togo, V. Terleev, A. Nikonorov, Y. Volkova, Procedia Engineering **165**, 1619-1628 (2016)
7. V.V. Terleev, W. Mirschel, V.L. Badenko, I.Yu. Guseva, Eurasian Soil Science **50(4)**, 445-455 (2017)
8. A. Nikonorov, V. Terleev, S. Pavlov, I. Togo, Y. Volkova, T. Makarova, V. Garmanov, D. Shishov, W. Mirschel, Procedia Engineering **165**, 1741-1747 (2016)
9. V. Terleev, E. Petrovskaia, N. Sokolova, A. Dashkina, I. Guseva, V. Badenko, Y. Volkova, O. Skvortsova, O. Nikonova, S. Pavlov, A. Nikonorov, V. Garmanov, W. Mirschel, MATEC Web of Conferences **53**, 01013 (2016)
10. L.B. Berezin, L.O. Karpachevskij, *Lesnoe pochvovedenie: ucheb. Posobie* (Omsk: Izd-vo FGOU VPO OmGAU, 2009) (rus)
11. B.D. Zajcev, *Pochvennye usloviya mestoproizrastaniya sosny i eli* (M.L: Sel'kolhozgiz, 1931) (rus)
12. V.D. Zelikov, *«Pochvy i bonitet nasazhdenij»* (Lesnaya promyshlennost', 1970) (rus)

13. S.V. Zonn, *Vliyanie lesa na pochvy* (M, Izd-vo akademii nauk SSSR, 1954) (rus)
14. S.V. Zonn, L.O. Karpachevskij, Pochvovedenie **9**, (1987) (rus)
15. L.O. Karpachevskij, *Les i lesnye pochvy* (M: «Lesn. Prom-st'», 1981) (rus)
16. G.F. Morozov, *Uchenie o lese* (Directmedia, 2016) (rus)
17. N.P. Remezov, P.S. Pogrebnyak, *Lesnoe pochvovedenie* (M: «Lesnaya promyshlennost'», 1965) (rus)
18. V.N. Sukachyov, *Rukovodstvo k issledovaniyu tipov lesa* (L: «Sel'hozgiz», 1930) (rus)
19. O.G. Chertov, M.A. Nadporozhskaya, Eurasian Soil Science **51**, 1142-1153 (2018)
20. O. Chertov, Applied Soil Ecology **123**, 420-423 (2018)
21. P.Y. Grabamik, V.N. Shanin, O.G. Chertov, V. Priputina, S.S. Bykhovets, B.S. Petropavlovskii, P.V. Frolov, E.V. Zubkova, M.P. Shashkov, G.G. Frolova, Russian Journal of Forest Science **6**, 488-500 (2019)
22. N.L. Blagovidov, V.G. Orfanitskaya, *Genezis i lesorastitel'naya harakteristika pochv Lisinskogo leskhoza* (Leningrad, 1954) (rus)
23. O.G. Chertov, *Izuchenie tipov mestoobitaniya lesa na Severo-Zapade SSSR - Metodich. ukazaniya. L* (Izd-vo Len NIILH, 1974) (rus)
24. O.G. Chertov, *Ekologiya lesnyh zemel' (pochvenno-ekologicheskoe issledovanie lesnyh mestoobitanij)* (Nauka, 1981) (rus)