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Geoinformation Analysis of Chernozem Diversity and Protection in Russia

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Abstract—The areal and typological representativeness of chernozem soil diversity throughout Russia and within federal-level specially protected natural areas (SPNAs) was assessed based on geoinformation analysis using a vector soil map of Russia at a scale 1 : 2500000 (the combined version of the Soil Map of the RSFSR and Soil Map of Crimea). All chernozem soils cover 123.5 million ha (7.4% of the country's soil cover), of which 86.4% are actually chernozems and 12.3, 0.8, and 0.5% are chernozem-meadow soils, meadow—chernozem-like soils, and chernozem complexes, respectively. Natural representatives of chernozems are found in 36 federal natural protected areas (15 nature reserves, 13 national parks, and eight wildlife sanctuaries), where 390.2 thousand ha (0.3% of the area of these soils in the country) are protected. The representativeness index of the network of federal natural protected areas with regard to the typological diversity of chernozems is 55%. The degree of territorial protection of individual varieties of chernozems has been determined with respect to the completeness of areal representativeness: satisfactory for eight map units (their areas cover 55.0 million ha, or 45% of the area of all chernozem soils in the country); insufficient for nine map units (46.0 million ha, or 37%). Representatives of 13 chernozem varieties are not protected in the network of federal natural protected areas (22.4 million ha, or 18% of the area of all chernozems). The most significant massifs of chernozems not represented in federal natural protected areas are in the Pre-Caucasus (Carbonate-micellar ordinary and southern chernozems, 9.8 million ha, or 7.9% of the area of all chernozems) and in the south of Western Siberia (Glossic and pocket leached chernozems, Glossic ordinary chernozems, and Glossic southern chernozems, 9.0 million ha, or 7.3% of the area of all chernozems). The preservation of these soils in a virgin state, at least as examples for comparison with anthropogenically transformed analogs, requires an inventory of all areas of their distribution and the assignment of conservation status.

Keywords: chernozem soils, soil diversity, representativeness of protected natural areas, geoinformation analysis, nature reserves, national parks, wildlife sanctuaries

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INTRODUCTION

Black soils are most fertile soils on Earth, and are actively used in agricultural production; although they occupy only 5.6% of the total land area, black soils feed not only the 223 million people living on these soils, but also the population of other countries through the import of products grown on these soils (FAO, 2020). Since there is no single concept of black soils in global soil science, the FAO Working Group (IUSS Working Group WRB) adopted criteria for attributing soils to the first and second categories of black soils during the creation of the Global Map of the Distribution of Black Soils (GBSmap). According to these criteria, black soils in the Russian Federation (RF) include not only Chernozems in terms of domestic classifications, but also dark grey forest soils ((Grey forest soils)/(Phaeozems)), dark chestnut and chestnut soils ((Chestnut soils)/(Kastanozems)), sod-carbonate soils ((Sod-carbonate soils)/(Rendzic/Mollic/Umbric Leptosols)), and some other soils: (Brown taiga soils)/(Dystric Cambisols); (Meadow chernozems)/(Gleyic Chernozems). The final Global Black Soil Distribution Map (GBSmap) is a digital map that shows areas where black soils of category 1 or 2 can be found with high probability (≥50%) (FAO, 2020). According to this map, about half of Earth's black soils are in Russia (326.8 million ha) and occupy slightly less than 20% of the country's area. Apparently, the large area and diversity of natural conditions in Russia determine the geographical potential of representativeness of all or almost all varieties of black soils on the planet.

The real situation differs from the probabilistic forecast; in addition, the characteristics of soils assigned to categories 1 and 2 of black soils also vary significantly. In the Russian Federation, only about 38% of the area of black soils shown on the map is occupied by chernozems proper in their classical definition given by V. V. Dokuchaev in his monograph on these soils *Russian Chernozem* (1883). Chernozems, including mountain ones, occupy about 7.2% of the land area; they stretch in a strip from west to east across the entire country and occupy vast areas in forest-steppe and steppe plain regions, as well as intermountain depressions and lowlands of southern mountain systems. In Russia, chernozems make up the bulk of the country's arable land fund; by the beginning of the 21st century, their proportion in the total arable land area was 52.6% (Romanenko et al., 1996). The load on chernozem regions currently continues to increase due to a decrease in the scale of agricultural production in regions with less favorable climate and soil conditions. Chernozem plowing is particularly high in the European part of the country; in some areas of Rostov oblast, it reaches 80%, while it should not exceed 60% according to different estimates (the optimal parameters are 40–45%) (Orlova, 2006; *Natsional'nyi atlas pochv*, 2011). Studies of the physicochemical regimes of virgin soils and the corresponding soils of agrocenoses have shown that agricultural use leads to the unification of soil properties in the direction of optimal indicators for agrocenoses and, accordingly, to a decrease in soil diversity. This is shown by a wide range of physicochemical characteristics: oxidation reduction potential, soil reaction, and activity of potassium, calcium, and nitrate ions in the liquid phase of soils (Snakin, Prisyazhnaya, 1997). Intensive agricultural use leads to an active transformation of soil cover, the development of water erosion and deflation, dehumification, and growth of salinization and alkalinization. The degree of plowing decreases towards the east; the number of pastures increases in this direction; degradation processes are often no less defined in these areas than on arable lands. In addition, modern climate trends, which are most clearly defined in climatically extreme regions (steppe areas) lead to an increase in climate aridity and an increase in the risk of atmospheric droughts (Gubarev et al., 2022; Alyabina et al., 2023). The discussion of the prospects for the development of a national system for monitoring carbon pools and greenhouse gas fluxes in terrestrial ecosystems of Russia has shown an urgent need to expand the network of observation sites in steppe ecosystems (*Rezolyutsiya* ..., 2023). Accordingly, the preservation of the diversity of natural chernozems is an important environmental and economic task.

The awareness of the globality of the ecological functions of soils in the cycles of elements and water, water and air quality, the conservation of genetic diversity, and, in particular, the maintenance of ecosystem productivity has made it possible to attract public attention to general issues of soil conservation (Sorenson et al., 1997). Attention has been drawn to the necessity of preserving areas of undisturbed ecosystems among anthropogenically transformed ecosystems, which should maintain the ecosystem functions of the territories and play the role of monitoring objects (Daily, 2001; Amundson et al., 2003; Arrouays et al., 2018). The need for monitoring natural soils is now recognized at the highest level. The *EU Soil Strategy for 2030* (2021) declares that natural representatives of the most fertile soils actively used in agricultural production disappear at a maximum rate; this primarily applies to chernozems.

The characteristics of chernozems significantly vary both globally and regionally; therefore, assessment of the level of degradation and monitoring of anthropogenic changes require test (reference) sites with natural soils typical for a certain region, which could serve as samples for background monitoring and comparison with anthropogenically transformed analogs. It is traditionally believed that the main mechanism for preserving the natural diversity of ecosystems, including soils, is its conservation within specially protected natural areas (SPNAs). Many studies (Asaad et al., 2016; Donald et al., 2019; Rodrigues, Cazalis, 2020) point to the imbalance of national networks of SPNAs, an extreme complexity of assessing their effectiveness, and the need to develop criteria for identifying key areas for preserving the natural diversity of areas.

The network of SPNAs of the Russian Federation is a system of minimally disturbed natural areas fully or partially withdrawn from economic use, which covers most of the country's natural zones. State nature reserves and national parks are the basis of the natural reserve fund; unlike SPNAs of other categories, their tasks are to preserve natural complexes in their natural state, carry out scientific research, and implement state environmental monitoring. The pronounced climate trends in recent decades, against the background of which natural disasters are becoming more frequent and intensive, and the necessity for monitoring changes in the biological cycles of matter and energy make the requirement for the representativeness of the SPNA system even more relevant.

In practical terms, it is most important to preserve areas with natural ecosystems and soils typical of large regions in SPNAs. It is especially important to focus on areas with minimally disturbed soil cover in steppe ecosystems, since it is grass ecosystems in which the proportion of soil is maximal in the sequestration and deposition of biophilic elements, in particular, carbon. Thus, it is known that the aboveground biomass in grass ecosystems is significantly, sometimes by many times, lower than the underground one both in terms of the mass of organic matter and in the annual increase in phytomass (Abatov, 2023), and the proportion of soils in the total carbon reserves of steppe ecosystems exceeds 90% (against 25–45% (including litter) in forest soils) (Chernova et al, 2020).

The most important direction for protecting the diversity of natural soils is to increase the representativeness of such soils in the system SPNAs; among them, state reserves provide the highest level of protection.

The purpose of this paper is to assess the current representativeness of the natural diversity of the country's chernozem soils in the network of federal SPNAs and consider the prospects for its increase by creating new federal SPNAs and raising the status of regional SPNAs.

The following tasks were set:

—to assess the areal and typological representativeness of all cartographic units of the legend of the Soil Map of Russia (SMR) that are included in the chernozem group (including meadow-chernozemic, chernozem-like, and chernozem complexes) in Russia and in state reserves, national parks, and federal-level wildlife sanctuaries;

—consider the possibility of increasing the representativeness of the federal system of SPAs with regard to the diversity of natural chernozem soils based on the existing regional SPNAs in the Ciscaucasia and southern part of Western Siberia.

MATERIALS AND METHODS

We carried out a geoinformational analysis of natural soil diversity and the representativeness of federal SPNAs (state reserves, national parks, and wildlife sanctuaries) with regard to chernozem soils in Russia. The paper examines the composition of the soil cover of federal level SPNAs based on the digital version of the Soil Map of the RSFSR at a scale of 1 : 2500 000 (1988), the largest-scale map of the currently existing soil maps, which was constructed in a single concept and with a single legend for the entire territory of Russia. In 2019, the map was supplemented with the Soil Map of Crimea (Urusevskaya et al., 2019) of the same scale, which was compiled according to the methodological principles and legend of the Soil Map of the RSFSR; at the same time, four new units (two soil varieties and two soil complexes) were added to the legend. The current version of the Soil Map of Russia is presented in the Information System "Soil and Geographical Database of Russia" (*Pochvennaya karta* ..., 2008).

The boundaries of SPNAs were digitized in accordance with the founding SPNA documents and information from the website Specially Protected Natural Areas of Russia (*Osobo okhranyaemye* ..., 2011) and plotted on the Soil Map.

The list of the studied soil types (units of the map legend) almost completely (except the "grey sands" unit) corresponds to the section of the map legend "Steppe Soils." The diversity of soils and the areas occupied by them were assessed based on the main (predominant in area) soil of each observation site on the SMR without taking into account the accompanying soils. Soil complexes were taken into account based on the soil with the largest area (the first soil in the complex name). Analysis of the diversity of soil complexes involved only their composition, not taking into account the genetic and geometric structure of the complexes.

The prospects for increasing the representativeness of the current system of federal-level SPNAs are assessed by comparing the areas of soils not represented in current federal SPNAs and the territories where it is planned to organize state reserves and national parks (*Kontseptsiya razvitiya* ..., 2011; Stishov, 2020; Chibilev, 2022). We additionally analyzed available data on the soils of regional SPNAs in the Cis-Caucasus and southern part of Western Siberia and considered the possibilities of preserving the last areas of natural soils and ecosystems within regional-level SPNAs in the chernozem regions most altered as a result of agricultural activity.

RESULTS AND DISCUSSION

The digital version of the SMR presents 259 cartographic units of the legend, identified as soils, nonsoil formations, and waters. The areal representativeness of soils was calculated taking into account only cartographic soil units (soils and soil complexes); accordingly, the proportion of the area covered by a certain cartographic unit is calculated with respect to the area of the soil cover, not taking into account internal waters and nonsoil formations (glaciers, rocky placers, and sands).

The composition of the soil cover of Russia was previously analyzed in (Prisyazhnaya et al., 2016; 2021). Soil units were combined into groups of genetically similar soils in accordance with the sections of the legend of the SMR. The "soils and soil complexes of steppes" group includes 31 soil units: 26 units of chernozem soils (99.2% of the total area of the steppe group), four units represented by complexes of chernozem soils (0.5%), and one unit represented by grey sandy soils (0.3%). As mentioned above, the "grey sands soil" unit was excluded from consideration.

Diversity of Chernozem Soils in Russia

We primarily assessed the distribution of 30 types of chernozem soils (units of the SMR legend). The names in accordance with the SMR legend (approximate translation into English) and in accordance with the World Reference Base (WRB) System (*World Reference* ..., 2022) are given in Table 1. Data on the size

Table 1. Representativeness of the diversity of chernozems in Russia (at the level of units of the SMR legend)

No.	Soil/soil complex	WRB, 2022	Area in Russia, thousand ha	Area in SPNAs, thousand ha
Chernozems and meadow–chernozem soils of steppe and forest-steppe, including:			123469.5	390.2
		Soils		
1	Podzolized chernozems	Greyzemic Phaeozems	8847.2	46.15
2	Leached chernozems	Chernic Phaeozems or Luvic Chernozems	24303.0	90.27
3	Typical chernozems	Haplic/Vermic Chernozems (Pachic)	8527.4	8.08
4	Ordinary chernozems	Haplic/Calcic Chernozems	17425.7	26.87
5	Southern chernozems	Calcic Chernozems	12653.9	20.86
6	**Carbonate-micellar podzolized chernozems (deep podzolized chernozems)*	Greyzemic Phaeozems (Pachic)	51.3	0
7	Carbonate-micellar leached chernozems (deep leached chernozems)	Chernic Phaeozems (Pachic) or Luvic Chernozems (Pachic)	760.8	1.70
8	Typical carbonate-micellar chernozems (deep typical chernozems)	Haplic/Vermic Chernozems (Pachic)	1023.6	0.44
9	*Southern and carbonate-micellar ordinary chernozems (deep carbonate chernozems)*	Calcic Chernozems (Pachic)	9752.4	0
10	*Glossic and pocket leached chernozems*	Tonguic Luvic Chernozems	4473.7	0
11	*Glossic ordinary chernozems*	Tonguic Calcic Chernozems	3136.4	0
12	*Glossic southern chernozems*	Tonguic Calcic Chernozems	1434.3	0
13	Meal-carbonated chernozems, including leached, typical, ordinary, and southern (washed) chernozems	Calcic Chernozems (Arenic)	2521.8	47.73
14	Deep effervescing and noncalcaric chernozems on light-textured rocks	Chernic Phaeozems (Arenic)	1776.4	8.53
15	Residually calcaric chernozems	Protocalcic Chernozems	3966.8	30.21
16	*Solodic chernozems*	Luvic Chernozems (Sodic)	204.8	0
17	Alkalized chernozems	Chernozems (Sodic)	2157.6	4.72
18	*Vertic chernozems*	Vertic Chernozems	334.0	0
19	Undifferentiated, mainly noncomplete chernozems	Chernozems	3066.4	4.12
20	Meadow-chernozemic soils	Gleyic Chernozems	6786.1	55.83
21	*Leached meadow-chernozemic soils*	Luvic Gleyic Chernozems	1162.8	0
22	*Calcaric meadow-chernozemic soils*	Gleyic Calcic Chernozems	83.7	0
23	*Solodic meadow-chernozemic soils*	Gleyic Chernozems (Sodic) or Chernic Planosols (Sodic)	412.6	0
24	Solonetzic and solonchak-like meadow-chernozemic soils	Gleyic Chernozems (Salic/Sodic)	6787.6	44.48
25	*Meadow chernozem-like soils*	Stagnic Chernic Phaeozems (Pachic)	953.3	0
26	Vertic alkalized chernozems	Vertic Chernozems (Sodic)	249.8	0.01
		Soil complexes		
27	Alkalized chernozems and solonetz	dominant: Chernozems (Sodic); codominant: Haplic Solonetz	40.0	0.13
28	*Meadow-chernozemic and meadow-solonetz soils*	dominant: Gleyic Chernozems; codominant: Gleyic Solonetz	46.1	0
29	*Solonetzic and solonchak-like meadow-chernozemic soils and meadow-solonetz*	dominant: Gleyic Chernozems (Salic/Sodic); codominant: Gleyic Solonetz	352.0	0
30	Vertic alkalized chernozems and meadow-solonetz	dominant: Vertic Chernozems (Sodic); codominant: Haplic Solonetz	177.9	0.09

* Soils/soil complexes not represented within federal-level SPNAs are shown in *italics*.

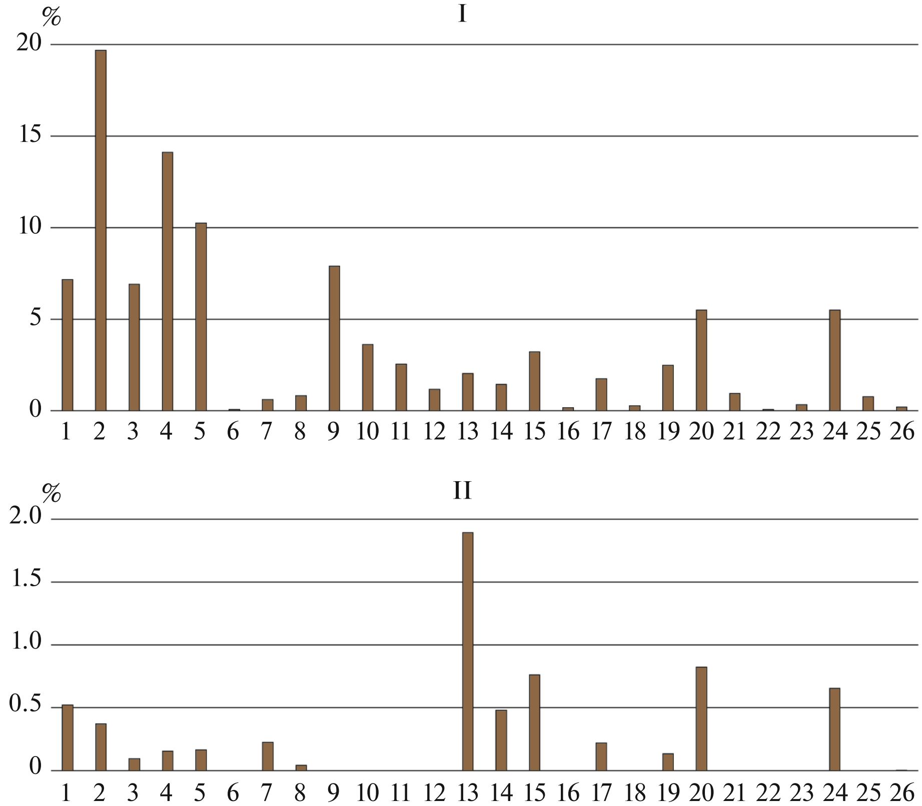

Fig. 1. Distribution of chernozems in Russia and their areal representativeness in federal SPNAs: (I) relative area of the cartographic unit in the country, % of total area of chernozem soils; (II) relative area of the cartographic unit in SPNAs, % of its total area. On the abscissa axis—number of the soil unit (see Table 1).

of soil areas within Russia and federal SNPAs are provided.

The occurrence of different chernozem soils in Russia and their representativeness in federal SPNAs are shown in Fig. 1. The largest areas in the country are leached chernozems (no. 2 in Table 1) (a fifth of the area of all chernozems). Also, vast areas are occupied by ordinary chernozems (no. 4) and southern chernozems (no. 5). The fourth most widespread type of chernozem soils in Russia is "southern and ordinary mycelial-carbonate chernozems (deep carbonate chernozems)"; their area exceeds 9.7 million ha, and this is the only widely represented and economically important soil in the steppe zone with virgin varieties absent in federal SPNAs.

According to our calculations, all chernozem soils of steppes and forest-steppes occupy 123.5 million ha (7.4% of the country's soil area), of which 86.4% are chernozems proper and 12.3, 0.8, and 0.5% are chernozem-meadow and chernozem-like soils and chernozem complexes, respectively. This areal estimate is about 38% of the probabilistic estimate of the area of chernozems in Russia according to the international criteria (FAO, 2020). It is these soils (excluding solonetzic, immature, and other nontypical representatives occupying small areas) that are traditionally considered by the domestic school of soil science as chernozems, and the zone of their distribution is often called "chernozem zone." When discussing the distribution, conservation, and diversity of chernozem soils, we mean these soils included in the "Steppe Soils" group of the SMR legend.

Territorial Protection of Chernozems

There are a significant number of protected areas in the chernozem zone; at the same time, the area of protected chernozem soils is only 0.4 million ha (0.3% of their total area in the country). The map (Fig. 2) shows the distribution of chernozems against the background of SMR polygons and the location of federal SPNAs where they are found.

In the steppe and forest-steppe regions, anthropogenic transformation affects mainly upland habitats, where natural ecosystems are almost completely replaced by anthropogenic ones. This explains the confinement of many protected areas to intrazonal or azonal positions: floodplains, gullies, wetlands, outcrops of bedrock, etc.; therefore, the presence of SPNAs in a region does not necessarily imply the preservation of natural soils typical for this region within the corresponding protected areas. In addition,

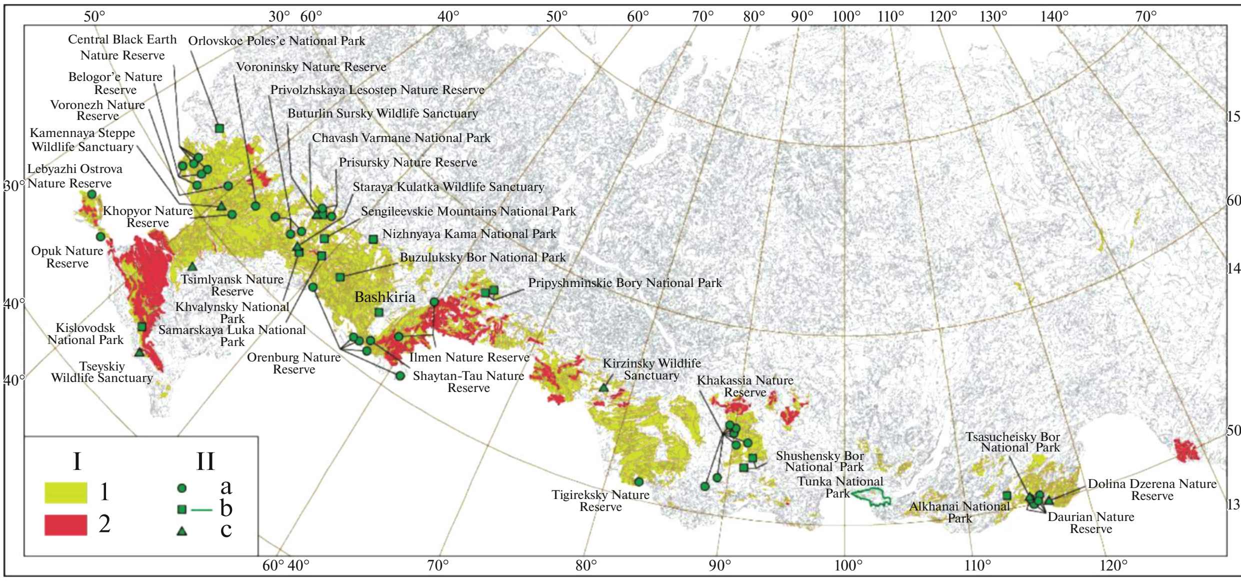

Fig. 2. Chernozem soils on the Soil Map of Russia. Their distribution and representativeness in federal SPNAs: (I) soil areas: (1) found in SPNAs, (2) not found in SPNAs. (II) federal SPNAs: (a) nature reserves, (b) national parks, (c) wildlife sanctuaries.

the main tasks and principles of creation and functioning of protected areas of different categories imply different levels of protection and study of natural complexes; therefore, the representativeness of chernozem soils was also assessed by SPNA categories.

At the federal level, chernozems are represented in 15 state nature reserves, 13 national parks, and eight wildlife sanctuaries, where 390.2 thousand ha is protected (Table 1) (this is only 0.3% of the total area of chernozems). According to our estimates, a total of 3% of the soil cover area is protected in federal SPN areas in Russia. For some groups of soils, this indicator reaches 7.6% (soils of mountainous areas) and 6.1% (Arctic and tundra soils).

Seventeen of the 30 studied varieties of chernozem soils are territorially protected; i.e., the representativeness of the network of federal SPNAs with regard to the typological diversity of these soils is 55%, which is significantly lower than the representativeness indicator for the general typological diversity of soils in Russia (69%). The preservation of the diversity of soil groups of taiga and coniferous broad-leaved (hydromorphic, floodplain, and marsh) forests in SPNAs reaches 80%.

The representativeness of different varieties of chernozem soils is uneven in federal SPNAs (Fig. 1II). The most fully represented soils are meal-carbonate chernozems (no. 13 in Table 1): 1.9% of the area of these soils is protected in the country; however, even this value does not reach 3%, the index of areal representativeness of the soil cover of Russia in federal SPNAs.

We assessed the completeness of territorial protection of individual chernozem soil units based on information about the area occupied by them on protected territories. The average values of the relative area (0.3%) were taken as a starting point. According to this estimate, the completeness of representativeness can be assessed as satisfactory only for eight chernozem soil units. They occupy 55.0 million ha (45% of the area of all chernozems). Territorial protection is insufficient for nine units; their area is 46.0 million ha (37% of the area of all chernozems); 13 cartographic units of chernozem soils are not represented in protected areas at all.

The territorial nature protection in Russia is based on a geographical network of nature reserves, which represent all natural zones. The fundamental difference of state nature reserves from all other categories of SPNAs, including national parks, is that they are completely withdrawn from economic use. Assessment of the contribution of different categories of federal SPNAs to the protection of the natural diversity of chernozems (Fig. 3) showed that 13 cartographic units were protected in the nature reserves (76% of the typological diversity of chernozems represented in all federal SPNAs). At the same time, the area of chernozem soils in the nature reserves is less than a quarter of the total area of chernozems in federal SPNAs. The area of national parks and wildlife sanctuaries is more than three times larger than the area of nature reserves; however, they increase the typological representativeness by only 13%.

Increase in the Representativeness of the SPNA System in Terms of the Diversity of Chernozems

Chernozems (13 units) not represented in federal SPNAs occupy 22.4 million ha, or 18% of the total

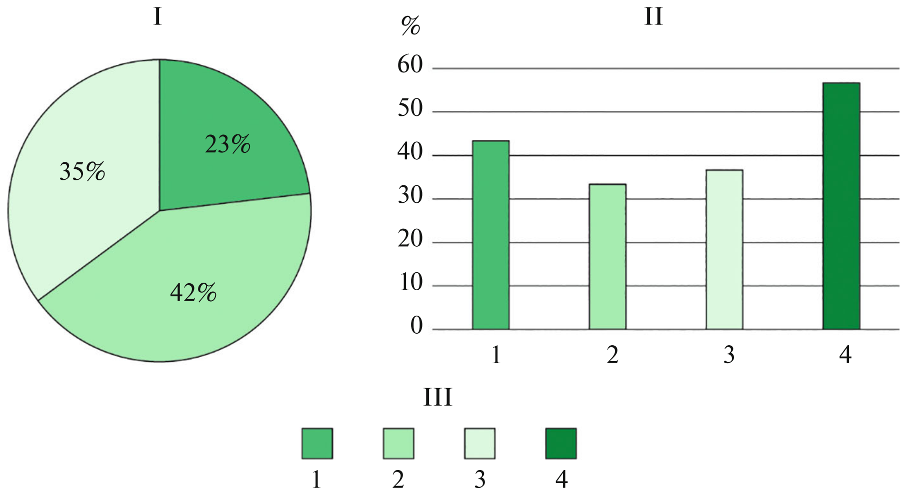

Fig. 3. Representativeness of the diversity of chernozems in federal SPNAs of different categories: (I) proportion of the area of chernozem soils in SPNAs of different categories, % of total area in SPNAs; (II) relative number of typological units of chernozem soils in SPNAs, % of their total number in the Russian Federation; (III) categories of SPNAs: (1) nature reserves, (2) national parks, (3) wildlife sanctuaries, (4) federal SPNAs of all categories.

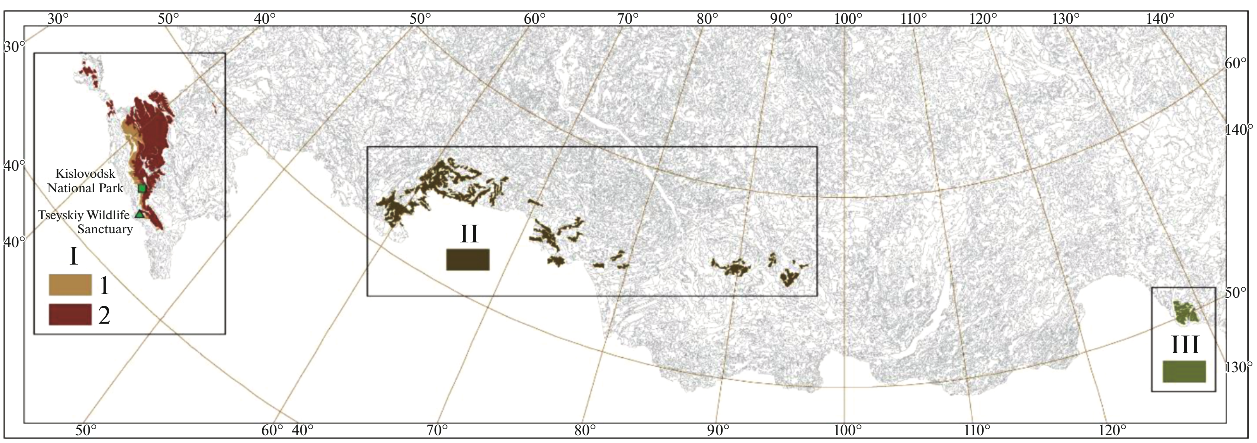

Fig. 4. Large chernozem massifs not represented in federal SPNAs: (I) mycelial-carbonate chernozems (nos. 6, 7, 8, and 9 in Table 1): (1) may be potentially found in SPAS, (2) not found in SPNAs; (II) Glossic chernozems (nos. 10, 11, and 12 in Table 1); (III) meadow chernozem-like soils of "Amur prairies" (no. 25 in Table 1).

chernozem area (Fig. 2). The largest areas of these soils are shown in Fig. 4.

Mycelial-carbonate chernozems. Soil areas belonging to four cartographic units of mycelial-carbonate chernozems (nos. 6, 7, 8, and 9 in Table 1) form a compact massif with a considerable area in the Ciscaucasia (Fig. 4I). They occupy 11.6 million ha in the country (9.4% of the area of all chernozems). Two soil units of these chernozems (nos. 6 and 9) are not protected at the federal level, and the other two (nos. 7 and 8) are insufficiently protected.

(1) Southern and ordinary mycelial-carbonate chernozems (deep carbonate chernozems) (no. 9): occupy the largest area (9.8 million ha, or 7.9% of the area of all chernozems). Their main massifs are distributed in Rostov oblast and in Krasnodar and Stavropol krai and extend in a narrow strip across the northern parts of Ciscaucasian republics: Karachay-Cherkessia, Kabardino-Balkaria, North Ossetia-Alania, Ingushetia, and Chechnya. Small areas are found in the Republic of Crimea.

The entire area of distribution of these soils has been significantly transformed by agricultural activities; natural complexes occur exclusively within protected areas. The only steppe SPNA of federal level in these soils is the Botanical Garden of the Southern Federal University, a small fragment of the Don steppe landscape with ordinary mycelial-carbonate chernozem typical for the region, which has been preserved in the center of the megalopolis. No significant areas with virgin soils and plant associations have been preserved in the area of distribution of these soils.

Although small isolated areas cannot fully perform standard natural functions, their refugium, resource conservation, and monitoring role is maximally manifested precisely in anthropogenically heavily transformed areas; therefore, an inventory of even small areas of undisturbed soils under natural vegetation is required here. In particular, it is logical to focus on regional SPNAs with minimally disturbed biogeocenoses; at the same time, it should be borne in mind that data on the soil cover of regional SPNAs are absent in most cases. Previously (Chernova, Prisyazhnaya, 2024a, 2024b), an attempt was made to select regional SPNAs with minimally disturbed biocenoses on southern or ordinary mycelial-carbonate chernozems. Analysis of available information showed that there were 66 regional SPNAs within these soils; among them, weakly disturbed representatives of these soils can be represented in eight SPNAs in Rostov oblast, two in Krasnodar krai, and six in Stavropol krai. Expeditionary studies in the Rostov oblast showed that small areas of southern and ordinary mycelial-carbonate chernozems were actually represented only in three regional SPNAs (Bezuglova et al., 2022). Soil studies of regional SPNAs in Krasnodar and Stavropol krai have not been carried out. In the southwest of the Stavropol Highland, a site (Uspenskaya steppe) has been proposed for nature reserve creation (Chibilev, 2018); here, steppe ecosystems have been preserved in an area of about 6 thousand ha; according to our estimates, natural differences can be found between southern and ordinary mycelial-carbonate chernozems here.

(2) Podzolized micellar-carbonate chernozems (deep podzolized chernozems) (no. 6) in a small massif (0.05 million ha) are in the Karachay-Cherkess Republic.

(3) Typical mycelial-carbonate chernozems (deep slightly leached chernozems) (no. 8) occupy 1.0 million ha (0.8% of the area of all chernozems). These soils are widespread in Krasnodar krai and the Kabardino-Balkarian Republic, as well as in small areas in the south of Stavropol krai. According to the map, the tiny area of these soils (0.04% of the area of the soil unit) is represented in the only SPNA, Kislovodsk National Park. The national park itself, a resort park in the city of Kislovodsk, occupies less than 1000 ha; therefore, undisturbed varieties of these soils are very unlikely to be found within its SPNA zone (several dozen hectares).

(4) Leached mycelial-carbonate chernozems (deep leached chernozems) (no. 7) occupy 0.8 million ha (0.6% of the area of all chernozems). They are located in small areas in Krasnodar krai and in the republics of the Ciscaucasia (Adygea, Karachay-Cherkessia, North Ossetia-Alania, and Chechnya). A small area of these chernozems is in the Tseyskiy Wildlife Sanctuary (0.2% of the total area of the unit).

Thus, it is relevant to increase in the representativeness of federal SPNAs for all four units of mycelial—carbonate chernozems in the Ciscaucasia. The creation of new large SPNAs with in these areas is hardly possible and it is necessary to preserve the last fragments of upland steppe ecosystems with undisturbed soil cover as objects of background monitoring in this extremely important agricultural region; therefore, it is obviously necessary to consider the possibility of increasing the conservation status of the most representative regional SPNAs.

Glossic and pocket-shaped glossic chernozems. Glossic and pocket-shaped Glossic chernozems are widespread in the south of Western Siberia (Fig. 5II); they occupy 9.0 million ha in the country (7.3% of the area of all chernozems). All the three units of these chernozems (nos. 10, 11, and 12 in Table 1) are not represented in the system of federal SPNAs.

(1) Glossic and pocket-shaped leached chernozems (no. 10): 4.5 million ha (3.6%). The main massifs are in the Chelyabinsk and Kurgan oblasts and in Krasnoyarsk krai. They occur in the Omsk, Kemerovo, and Tyumen oblasts.

(2) Ordinary Glossic chernozems (no. 11): 3.1 million ha (2.5%). Their main areas are in the Chelyabinsk and Omsk oblasts. They are also found in the Kurgan, Tyumen, Novosibirsk, and Orenburg oblasts, as well as in the Republic of Bashkortostan.

(3) Southern Glossic chernozems (no. 12): 1.4 million ha (1.2%). The main massif is in Orenburg oblast. They occupy small areas in the Omsk, Chelyabinsk, and Novosibirsk oblasts.

According to the “Action Plan for the Implementation of the Concept for the Development of the System of Federal SPNAs” for the Period until 2020 (*Kontseptsiya razvitiya* ..., 2011), four protected areas (nature reserves and national parks) should be created in the south of Western Siberia. None of them have been organized to date, although the necessity of creating some of them, e.g., the Barabinsky Nature Reserve, has been discussed since the middle of the last century. The implementation of these plans would significantly increase the territorial representativeness of SPNAs in terms of the representativeness of Siberian variants of chernozem soils. However, cartographic analysis (Chernova, Prisyazhnaya, 2024b) showed that the planned protected areas were outside the areas of all three cartographic units of Glossic chernozems. Analysis of the descriptions of natural complexes of regional SPNAs showed that some regional wildlife sanctuaries were located within the boundaries of the areas of these soils (12 wildlife sanctuaries in Chelyabinsk oblast, nine in Kurgan oblast, and four in Omsk oblast); however, almost all of them have a zoological profile. The identification of virgin areas on the territory of these wildlife sanctuaries requires special studies of soil cover.

Meadow-chernozem-like soils of "Amur prairies." Meadow-chernozem-like soils of "Amur prairies" are also not represented in federal protected areas (Fig. 5III) (no. 25 in Table 1). They are located in Amur oblast and occupy 1.0 million ha in the country (0.8% of the area of all chernozems). The genesis of these unique strong high-humus soils, the best arable soils in the Far East, is determined by a combination of specific conditions of their formation (monsoon climate, long-term deep seasonal freezing, etc.). It is reasonable to preserve the virgin varieties of such soils with the corresponding ecosystems as standards from both a scientific and practical point of view; however, there are even no regional SPNAs within their main area.

CONCLUSIONS

The diversity of chernozems was assessed by methods of geoinformation analysis using the vector Soil Map of Russia at a scale of 1 : 2 500 000 (the combined version of the Soil Map of the RSFSR and Soil Map of Crimea). According to the calculations, all chernozem soils occupy 123.5 million ha (7.2% of the land area, or 7.4% of the country's soil cover area), of which 86.4% are chernozems proper and 12.3, 0.8, and 0.5% are chernozem meadow and meadow chernozem-like soils and chernozem complexes, respectively.

The largest areas in the country are leached chernozems (one-fifth of the area of all chernozems). Ordinary chernozems and southern chernozems are also widespread.

At the federal level, natural representatives of chernozems are found in 36 federal SPNAs: 15 state nature reserves, 13 national parks, and eight wildlife sanctuaries, where 390.2 thousand ha (0.3% of the total area of chernozems) are protected, while only 3% of the soil cover is protected in federal SPNAs throughout Russia.

The representativeness of different units of chernozem soils is uneven in federal SPNAs. Meal-carbonated chernozems are most fully represented: the proportion of the area of the cartographic unit from its total area in SPNAs is 1.9%. However, even this indicator does not reach the value of the areal representativeness of the general soil cover in federal SPNAs throughout Russia.

According to the legend of the Soil Map of Russia, 30 cartographic units of chernozem soils are identified: 20 of them are chernozems proper, five are chernozem meadow soils, one is meadow chernozem-like soil of "Amur prairies," and four are chernozem complexes. Seventeen of them are territorially protected; i.e., the representativeness of the federal SNPA network in terms of the diversity of chernozem soils is 55%. This is significantly lower than the representativeness indicator in terms of soil diversity for Russia in general (69%).

The level of territorial protection of cartographic units of chernozem soils was estimated based on information about the area occupied by them within SPNAs. It was found that the completeness of representativeness could be assessed as satisfactory only for eight units. The areas of these soils occupy 55.0 million ha, or 45% of the area of all chernozems. Territorial protection is insufficient for nine chernozems; the total size of their areas is 46.0 million ha (37% of the area). The areas of the 13 units of chernozem soils not represented in the network of federal protected areas occupy 22.4 million ha, or 18% of the area of all chernozems.

Among the chernozems not represented in federal SPNAs, the largest area is occupied by the "carbonate-micellar ordinary and southern chernozems (deep carbonate chernozems)" unit (9.8 million ha, or 7.9% of the area of all chernozems). This is the only widely represented and economically important soil in the steppe zone with virgin varieties absent in federal SPNAs. Within the area of these chernozems, there are 66 regional protected areas; minimally altered varieties were described only in three of them, and the indicators of these varieties can be used as reference values for comparison with anthropogenically transformed analogs. Taking into account the number and size of unstudied soil areas with natural or minimally disturbed vegetation, the total area of undisturbed southern and ordinary mycelial-carbonate chernozems according to the most optimistic estimates cannot exceed several hundred hectares. Apparently, the only way to preserve them is to increase the conservation status of the most representative regional SPNAs.

The second largest massif of chernozems not represented in federal SPNAs is the area of the three Glossic chernozems (Glossic and pocket leached chernozems, Glossic ordinary chernozems, and Glossic southern chernozems). They are widespread in the south of Western Siberia and occupy 9.0 million ha in the country (7.3% of the area of all chernozems). It is shown that the implementation of plans to create the four new FPNAs in the southern part of Western Siberia will not significantly increase the representativeness of the system of protected areas in terms of the typological diversity of Glossic chernozems. Several regional wildlife sanctuaries are within their distribution (12 wildlife sanctuaries in Chelyabinsk oblast, nine in Kurgan oblast, and four in Omsk oblast); however, almost all of them have a zoological profile. There is no information about the soil cover of these SPNAs; therefore, special soil studies are required in this area for the inventory of even small areas of undisturbed soils.

A similar situation is developing for meadow chernozem-like soils of "Amur prairies," the best arable soils of the Far East; the preservation of their virgin representatives as standards is reasonable from both a scientific and practical point of view.

Our analysis revealed that many natural chernozems, including the most fertile and typical ones for large regions, are currently not represented in federal SPNAS. The most significant areas of such soils are in Ciscaucasia and in the south of Western Siberia; a smaller area of these soils is recorded in Amur oblast. Most of these territories have been transformed by economic activity, and it is highly necessary to create environmental and soil monitoring sites; however, the possibilities for creating new SPNAs are limited. Identification of even small areas of these natural soils, at least as samples for comparison with anthropogenically transformed analogs, requires special studies. An inventory of all areas of their distribution, as well as optimization of boundaries and an improvement of the conservation status of the most representative regional SPNAs, is required.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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