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Territorial Assessment and Prioritization for Biodiversity Conservation Using the Example of the Center of European Russia

Ye. N. Bukvareva[a], *, A. A. Aleynikov[b], O. A. Klimanova[c], L. A. Titova[c], T. V. Sviridova[d], and A. V. Shcherbakov[e]

[a] *Biodiversity Conservation Center, Moscow, 117312 Russia*
[b] *Center for Forest Ecology and Productivity, Russian Academy of Sciences, Moscow, 117997 Russia*
[c] *Faculty of Geography, Moscow State University, Moscow, 119991 Russia*
[d] *Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow, 119071 Russia*
[e] *Faculty of Biology, Moscow State University, Moscow, 119991 Russia*
**e-mail: bukvareva@gmail.com*

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Abstract—For an adequate assessment and effective management of biodiversity and ecosystem services in the vast and extremely heterogeneous territory of Russia, a multilevel approach is required that integrates the tasks of biodiversity conservation on different hierarchical levels (diversity of ecosystems and species) and on different levels of territorial administration. Using the example of the Central Federal District of the Russian Federation, a preliminary methodology for prioritizing territories for biodiversity conservation at three levels of government (federal district, subjects of the Russian Federation, and municipal districts) is considered. To prioritize the territories, the rarity indicators of generalized ecosystem types within these territories and the value of territories for the conservation of “red-listed” animal and plant species are used. It is shown that the high-priority for biodiversity conservation purposes generalized types of ecosystems can be distinguished both on different territorial levels and in different territories within the same level. There is also a contradiction between the management tasks of preserving the diversity of species, requiring spacious habitats and the conservation of rare ecosystems that have a small area. These contradictions can be resolved through the development of environmental strategies for different levels of territorial administration.

Keywords: biodiversity, ecosystem functioning, ecosystem services, territorial level of management, forest district

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The UN Sustainable Development Goals sets the goal of conserving terrestrial ecosystems and biodiversity, as well as integrating their values into national and local territorial and economic planning (Mohieldin, Caballero, 2015). In Russia, the task has been set to formulate the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) (United..., 2021). Awareness of the value of ecosystems for the quality of life of the population is reflected in the documents on the implementation of the State Program of the Russian Federation “Comprehensive Development of Rural Territories” (Decree..., 2019), which involves projects to improve the quality of the natural environment within the framework of the activities of local governments. The approval of the Strategy for the Socioeconomic Development of the Russian Federation with Low Greenhouse Gas Emissions until 2050 (Order..., 2021) updates the work on assessing the quality and condition of forest ecosystems and the ecosystem services they provide. Formally, the tasks of preserving biodiversity are implemented within the framework of national projects of the Russian Federation and are taken into account at the level of constituent entities of the Federation and federal districts. In this regard, the task of integrating fundamental scientific data on the dependencies between biodiversity, ecosystem functioning (EF), and ecosystem services (ES) into planning systems for territorial development and biodiversity conservation becomes urgent.

Over the vast territory of Russia, adequate accounting of ecosystems, biodiversity, and ecosystem services for their management can be ensured only on the basis of a multilevel approach that takes into account the specifics of regions and different levels of territorial management (*Ekosistemnye uslugi*..., 2020).

The purpose of this article is to analyze the possibilities and problems of using a multilevel approach (taking into account both hierarchical levels of biodiversity and territorial levels of management) for prioritizing territories and ecosystems when making management decisions in the field of biodiversity conservation. The first part of the article provides a brief overview of current understanding of the links between biodiversity and EF/ES at different scales and under different conditions. Then, a preliminary methodology for the multilevel assessment of the importance of ecosystems and territories for biodiversity conservation, developed as part of the TEEB-Russia project, is presented, and the main results of its testing using the example of the Central Federal District of the Russian Federation are analyzed. The final part of the article discusses the main problems and issues that require solutions for the further development of a methodology for the multilevel assessment of territories for the purpose of preserving biodiversity.

1. BIODIVERSITY AS THE BASIS OF ECOSYSTEM FUNCTIONS AND ECOSYSTEM SERVICES

Biodiversity is now recognized as a necessary condition for human well-being and the achievement of sustainable development goals, and, in a more narrow scientific sense, as a key factor in ecosystem functioning, the weakening of which leads to the loss of vital ecosystem services (Cardinale et al., 2012; Tilman et al., 2014; *The IPBES*..., 2018; Van der Plas, 2019; Tebenkova et al., 2019; Lukina et al., 2020).

To ensure EF and ES, all hierarchical levels of biodiversity are important—genetic and phenotypic diversity in populations and species, diversity of species within communities and ecosystems, and diversity of ecosystems within landscapes and territories of various sizes (Bukvareva and Aleshchenko, 2013; Shin et al., 2019; Lukina et al., 2020; Arneth et al., 2020). The task of preserving intraspecific genetic diversity is important, first and foremost, in relation to rare and endangered species, as well as exploited commercial species. The conservation of forest genetic resources is considered as the basis for providing people with quality forest products, as well as for effectively providing essential ecosystem services by forests (Graudal et al., 2020). However, further in the article we consider only the diversity of species and types of ecosystems.

Modern understanding of the relationships between biodiversity and EF is based primarily on the results of hundreds of experiments in which EF indicators (productivity, biomass, carbon stocks, resource use efficiency, etc.) were measured in communities artificially composed of different numbers of species. The largest number of such experiments were carried out with herbaceous plants in small areas or in containers no more than a few square meters in size; experimental communities of aquatic, terrestrial, and soil invertebrates, algae, protozoa and bacteria were also used (Eisenhauer et al., 2019; Van der Plas, 2019). A relatively small number of experiments were carried out with artificial tree plantings on areas of several tens of square meters (Bruelheide et al., 2014; Verheyen et al., 2016). Experiments showed the predominance of the positive effect of species diversity on the volume and stability of EF. However, the practical application of this knowledge in real conditions requires a transition to spatially heterogeneous territories and scales relevant for management in the field of nature conservation and environmental management (Cardinale et al., 2012; Brose and Hillebrand, 2016; Isbell et al., 2017).

Combining the classic ecology thesis about the influence of external conditions on indicators of species diversity and EF with a modern understanding of how biodiversity affects EF forms the so-called “new paradigm” in the field of ideas about the interaction of biodiversity and EF (Loreau, 2010; Eisenhauer et al., 2019; Van der Plas, 2019). Special methods of statistical analysis (including *structural equation modeling* (SEM)) allow us to separate the impact of external conditions on biodiversity and EF from the impact of biodiversity on EF. Much less research has been carried out on ecosystems under real conditions than experimental work. However, it has been shown that in real conditions the influence of biodiversity on EF is comparable and sometimes exceeds the influence of abiotic factors (Duffy et al., 2017; Van der Plas, 2019). The nature of the relationships between biodiversity and EF (linear positive or negative, unimodal, U-shaped, etc.), as well as the degree of their statistical reliability, depend on natural conditions (climatic indicators, soil richness, moisture availability, etc.), the degree of anthropogenic disturbance (pollution, habitat disturbance, intensity of economic use, etc.), and the specifics of biocenoses and populations (interspecific interactions, trophic structure of populations, etc.). However, for herbaceous, forest, soil, freshwater and marine communities, a predominance of positive relationships between biodiversity and various EF indicators has been identified (Duffy et al., 2017; *The IPBES*..., 2018; Eisenhauer et al., 2019; Van der Plas, 2019).

For forest ecosystems, an analysis of more than 700000 plots in 13 ecoregions around the world has shown an overwhelming predominance of positive relationships between tree species richness and ecosystem productivity (Liang et al., 2016). However, as was shown for the United States (Watson et al., 2015), China (Baruffol et al., 2013; Chen et al., 2018), and European forests (Vila et al., 2013), in different forest types and in different conditions, the identified positive dependencies differ in detailed characteristics. Positive relationships have also been found in tropical forests (Cavanaugh et al., 2014; Poorter et al., 2015, 2017; Jucker et al., 2016b; Sullivan et al., 2017), although the frequency of their detection does not exceed the frequency of negative relationships or the absence of any dependencies (Van der Plas, 2019). A number of studies conducted in Canada (Paquette and Messier, 2011), China (Wu et al., 2015; Li et al., 2018; Liu et al., 2018), Europe (Jucker et al., 2016a; Ratcliffe et al., 2016), the United States (Potter and Woodall, 2014), and Japan (Mori, 2018a), showed that the positive effect of diversity on EF weakens and even becomes negative with an increase in resources available to organisms (climatic and bioclimatic indicators were used as indicators, as well as average forest productivity). In addition, the key importance of species diversity for ensuring the multifunctionality of forest ecosystems has been identified (Schuldt et al., 2018). The relationship between the number of woody plant species and EF may differ in forest ecosystems of different successional statuses (*Vostochnoevropeiskie*..., 2004; Smirnova et al., 2006; Lasky et al., 2014; Cai et al., 2016; Schuldt et al., 2018).

The nature and severity of the relationships between biodiversity and EF/ES are determined by the scale at which research is conducted. In this case, the total area under study, the size of the surveyed forest stands of different types, and the size of the minimum census plots are important (Chisholm et al., 2013; McBride et al., 2014; Poorter et al., 2015; Barnes et al., 2016).

At the level of ecosystems (communities) of one type, existing in relatively homogeneous natural conditions, the same cause-and-effect relationships between species diversity and EF/ES appear as in experiments. The predominance of positive relationships in this case suggests that the loss of species leads to a weakening of EF/ES. Declines in the number of species in any given ecosystem clearly indicate the need for specific biodiversity conservation measures to maintain EF/ES in that location.

At the landscape level[1] The nature of the influence of biodiversity on EF/ES varies depending on local conditions and characteristics of ecosystems. Various types of forests, swamps, meadows that make up the "landscape mosaic" of natural ecosystems are adapted to different environmental conditions and have different degrees of disturbance previous influences. The hypothesis of optimal biodiversity (Bukvareva and Aleshchenko, 2013) assumes that the maximum efficiency of EF is achieved with optimal diversity indicators, decreasing with any deviations from the optimum. Undisturbed natural communities adapted to favorable and relatively stable local environmental conditions have higher optimal indicators of species diversity and EF, while communities adapted to poor and unstable conditions have lower indicators of both. In such cases, lower indicators of species diversity (for example, characteristic of raised bogs) do not indicate a lower value of ecosystems, since it is precisely this level of diversity that ensures their most efficient and sustainable functioning in these conditions. However, when comparing ecosystems of the same type within the same landscape, a reduced level of biodiversity in a particular local ecosystem (for example, in a disturbed, drained raised bog or in forest areas subject to excessive recreational impact) is a dangerous indicator of its degradation and a likely decrease in EF/ES. Such damaged ecosystems are less valuable as ES suppliers and need to be restored.

In addition to species diversity, in each local ecosystem (α-diversity), the most important factor in the efficiency and stability of EF/ES at the landscape level is the diversity of ecosystems and the corresponding species β-diversity, which reflects the change in species composition in different local ecosystems. Different ecosystems produce different EF and ES, providing landscape multifunctionality. The asynchronous response of local ecosystems to disturbances and fluctuations in environmental conditions ensures the stability of landscape EF as a whole (Loreau et al., 2003; Olden, 2006). The positive influence of diversity of ecosystem types, successional stages, configuration of the landscape mosaic, and β-diversity on the multifunctionality and sustainability of EFs has been shown for experimental and real herbaceous ecosystems (Lamy et al., 2016; Grman et al., 2018; Hautier et al., 2018; Mori et al., 2018b) and in forest landscape models (Van der Plas et al., 2016).

At the regional level, which covers larger areas, the causal relationships between biodiversity and EF/ES may be different than at the level of a single ecosystem or landscape. On a regional scale, the variability of natural conditions and the degree of anthropogenic transformations increases, biomes can change, and the structural and functional type of ecosystems can radically change. This can be illustrated by the correlations between biodiversity indicators and EF/ES identified within the European territory of Russia within the framework of the TEEB-Russia 2 project (*Ekosistemnye uslugi*..., 2020). For example, based on data from the *Atlas of Breeding Birds of European Russia* (Kalyakin and Voltsit, 2020), different relationships between the number of bird species and the values of some ES in 50 × 50 km squares were identified at different spatial scales. Another example is the ES for ensuring the volume of runoff by terrestrial ecosystems (hereinafter referred to as *ecosystem flow*). The indicator of this ES is calculated as the difference between the observed runoff and the estimated runoff from the surface of bare solid soil (*Ekosistemnye uslugi*..., 2016, 2020). For the average values of the number of bird species and this ES in ecoregions, negative and unimodal dependencies were revealed (Fig. 1a). For indicator values in 50 km squares in European Russia, a negative dependence is generally observed (Fig. 1b). However, within the group of southern ecoregions (orange dots in Fig. 1b) the dependence is positive, and for the group of northern, forest, and mountain ecoregions (green dots in Fig. 1b) it is negative and more pronounced than for European Russia as a

[1] Here and below, the terms *landscape* and *region* are used as general concepts and reflect more the level of territorial planning rather than the hierarchy of geosystems.

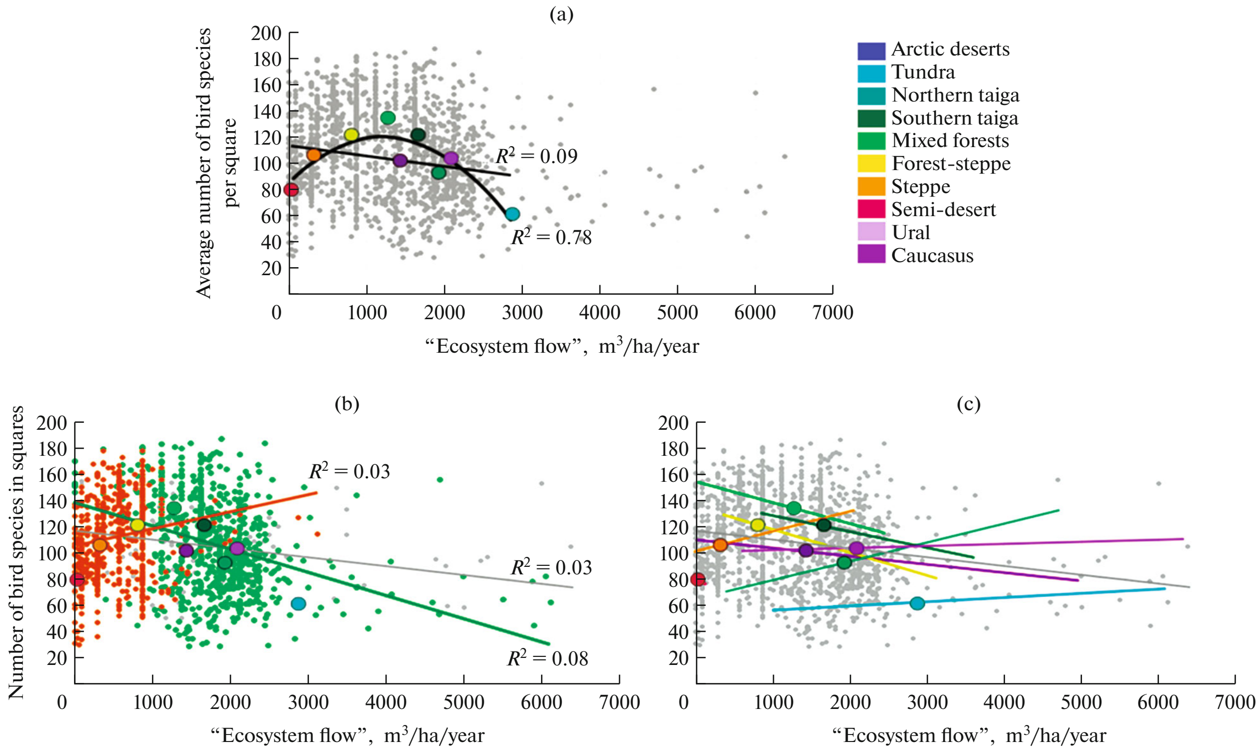

Fig. 1. Correlations between the number of bird species and the amount of ecosystem flow. (a) Dependencies between the average values of indicators per map cell in ecoregions. (b) Dependencies between the values in the map cells: gray line, dependence for the entire sample of 50-km squares in European Russia; green dots and line, values and dependence for 50-km squares of the group of northern, forest, and mountain ecoregions; orange dots and line, values and dependence for 50-km squares of the group of southern ecoregions. (c) Dependencies between values in map cells in individual ecoregions. Average indicator values and relationships for each ecoregion are shown in the colors indicated in the legend.

whole. These differences can be explained by the fact that, in the group of northern, forest, and mountain ecoregions, indicators of ecosystem flow and species richness change along the gradient of climatic conditions in the opposite way: the flow decreases from north to south and species richness, on the contrary, increases. In the group of southern ecoregions, changes in these indicators when moving from north to south are unidirectional: all indicators decrease when moving from forest steppes to semideserts. For individual ecoregions, these dependencies can be multidirectional or absent (Fig. 1c).

Based on the results of the TEEB-Russia 2 project (*Ekosistemnye uslugi*…, 2020), it was concluded that regionally differentiated approaches to organizing ecosystem accounting in Russia are necessary, taking into account differences in the dependencies between biodiversity and EF/ES at different spatial scales.

Thus, biodiversity conservation as a basis for EF/ES requires multiscale environmental policies (Isbell et al., 2017) based on a multidimensional research approach that must take into account the mutual influences of biodiversity and EF/ES and their mutual dependence on environmental conditions (Cardinale et al., 2009; Grace et al., 2016), as well as different hierarchical levels of biodiversity (we have already discussed the diversity of species and ecosystems above).

2. POSSIBLE APPROACHES TO THE MULTILEVEL ASSESSMENT AND PRIORITIZATION OF TERRITORIES FOR BIODIVERSITY CONSERVATION USING THE EXAMPLE OF THE CENTER OF EUROPEAN RUSSIA

In order to prepare for the beginning of the formation of ecosystem accounting in Russia, within the framework of the TEEB-Russia project, a preliminary methodology was developed for the multilevel assessment of the importance of[2] (significance) of territories and their prioritization for the conservation of ecosystem and species diversity at different levels of territorial management. To take into account natural zonality, forest areas were used, since their boundaries approximately coincide with the boundaries of municipalities. Accounting at the level of forest areas is also appropriate for developing measures for the conserva-

[2] In this article we deliberately use the term *importance* instead of the term *value,* emphasizing that we are not talking about a monetary valuation of ecosystems.

Table 1. Indices for the multilevel prioritization of ecosystem types and territories in order to preserve ecosystem diversity. The names of the value indices of ecosystem types are in italics and the value indices of territories are in bold

Index	Levels of problem solving	Formula for calculation
Regional E_{Ri}	Value of each ecosystem type for the region	$E_{Ri} = 100/S_{Ri}$, where S_{Ri} is the share of the area of each type of ecosystem in the total area of the region, %.
Forest District E_{Fi}	Value of each ecosystem type for a forested area	$E_{Fi} = 100/S_{Fi}$, where S_{Fi} is the share of the area of each ecosystem type within forest district, %.
Interlevel index: *forest district–regional* E_{FRi}	Value of each ecosystem type at two levels simultaneously	Average value between forest district and regional indices for each ecosystem type
Total forest area index $\mathbf{E_{FR}}$	Importance of the forest area for the region	Sum of indices of all types of ecosystems of a given forest district: $E_{FR} = \sum_{i=1}^{n} E_{FRi}$
Subjective E_{Si}	Value of each type of ecosystem for an individual subject of the Russian Federation	$E_{Si} = 100/S_{Si}$, where S_{Si} is the share of the area of each type of ecosystem in the total area of the constituent entity of the Russian Federation, %.
Cross-level indexes: *Subject–regional* E_{SRi} *Subject–forest-district* E_{SFi} *Subject–forestr-district–regional* E_{SFRi}	The value of each ecosystem type for two or three levels simultaneously	Calculated as average values between the corresponding indices for each ecosystem type
Total indices of a subject of the Russian Federation $\mathbf{E_{SFR}}$ $\mathbf{E_{SR}}$	The importance of a constituent entity of the Russian Federation for a large region	The sum of the ESFRi or ESRi indices for all types of ecosystems present in the territory of the subject: $E_{SR} = \sum_{i=1}^{n} E_{SRi}$; $E_{SFR} = \sum_{i=1}^{n} E_{SFRi}$
Municipal E_{Mi}	The value of each ecosystem type to the municipality	$E_{Mi} = 100/S_{Mi}$ where S_{Mi} is the share of the area of each type of ecosystem in the municipality, %
Cross-level indexes: *municipal subject* E_{MSi} *municipal–forest district* E_{MFi} *municipal–subject–forest-district* E_{MSFi} *municipal-subject–forest-district–regional* E_{MSFRi}	The value of each ecosystem type for two, three, or four levels simultaneously	Calculated as average values between the corresponding indices for each ecosystem type
Summary indices of the municipal district $\mathbf{E_{MS}}$ $\mathbf{E_{MF}}$ $\mathbf{E_{MSR}}$ $\mathbf{E_{MSFR}}$	The importance of the municipality for the conservation of ecosystem diversity, taking into account different levels of management	Sum of indices E_{MSi}, E_{MFi}, E_{MSFi}, or E_{MSFRi}, depending on the selected management levels, for all types of ecosystems represented on the territory of the municipality: $E_{MS} = \sum_{i=1}^{n} E_{MSi}$; $E_{MF} = \sum_{i=1}^{n} E_{MFi}$; E_{MSR}

* The coefficient for all types of ecosystems, the area of which is less than 1% of the area of the territorial unit, is taken equal to 100.

tion/restoration of biodiversity during forestry activities, for example, within the framework of voluntary forest certification.

The set of proposed indices includes intra- and interlevel indices for assessing types of ecosystems and territories (Table 1). Intralevel indices reflect the importance (significance) of ecosystems and territories within the corresponding territorial level (Central Federal District, forest area, subject, municipal area), and therefore can be used to develop measures for environmental protection and socioeconomic development of these territories. Interlevel indices can be applied if it is necessary to take into account the objectives of biodiversity conservation at several levels simultaneously.

The methodology was tested using publicly available state statistics and open digital cartographic materials using the example of the Central Federal District of the Russian Federation (due to the specifics of the urban environment, the territory of Moscow within its former borders was excluded from the analysis). The boundaries of forest areas are taken from the portal https://hcvf.ru/ru/maps/hcvf-russia. The calculation of the areas of generalized types of ecosystems was made on the basis of a specially created digital map of land (landscape) cover types, which integrates data from the GLAD ARD map of the University of Maryland (Potapov et al., 2020), a vegetation map of the Central Federal District (Ershov et al., 2015), and maps of preserved areas of steppe ecosystems according to the Improving the System and Mechanisms for Managing Protected Areas in the Steppe Biome of Russia project and the Conservation of Russian Steppes portal (http://savesteppe.org/ru/steppe-project). The map highlighted arable land, built-up areas, water bodies, and eight types of terrestrial ecosystems: dark coniferous, light coniferous, deciduous, mixed, and wetland forests, as well as swamps, steppe areas, and areas with nonsteppe herbaceous vegetation. The last type included unplowed areas without woody vegetation, not related to steppes. It is obvious that the identified types are not ecosystems in the strict scientific sense. However, more detailed digital maps of ecosystems for the Central Federal District are currently not publicly available, so at the first stage of testing the methodology, we considered it possible to consider them generalized types of terrestrial ecosystems.

The tasks of preserving species diversity were solved on the basis of data from the regional Red Lists on the number of red-listed species of birds and mammals in municipal areas. The Red Lists of the regions of the Central Federal District, published in the following years, were used: Belgorod (2005), Bryansk (2015), Vladimir (2010), Voronezh (2018), Ivanovsk (2017), Kaluga (2017), Kostroma (2009), Kursk (2002), Lipetsk (2014), Moscow (2018), Oryol (2007), Ryazan (2011), Smolensk (1997), Tambov (2012), Tver (2016), Tula (2013), and Yaroslavl (2015) oblasts. In addition, data on the number and conservation status of vascular plant species in eight oblasts (Vladimir, Voronezh, Moscow, Tula, Tambov, Ivanovo, Ryazan, and Lipetsk) according to the TEEB-Russia 2 project (*Ekosistemnye uslugi*..., 2020) were used.

2.1 Assessment and Prioritization of Ecosystem Types

To assess the importance (significance) of various types of ecosystems for the conservation of ecosystem diversity within a given territory, a criterion for the rarity of a given type of ecosystem is proposed. Ecosystems that have a smaller area within the analyzed territory are considered rare and have priority importance for the conservation of ecosystem diversity. This criterion is similar to the approach used when preserving species diversity. In the future, additional indicators of the rarity of ecosystems can also be developed, taking into account their occurrence and fragmentation.

Within the Central Federal District, the rounded values of ecosystem indices vary from 2 (for the most common types, which occupy 40–60% of the area within the study area) to 100 (for types that occupy no more than 1% of the area). The assessment of the importance (significance) of different types of ecosystems varies significantly at different spatial scales (Table 2). Thus, for preserving the diversity of ecosystems in the Central Federal District, steppes are the most important. However, to preserve the diversity of ecosystems within forest areas within the Central Federal District (assessed by the forest district index), steppes have not received the highest priority anywhere. Within all regions, except for the southern taiga, dark and light coniferous forests are a priority. The relatively small areas of these communities within the Central Federal District are explained by the long history of forest management (Evstigneev, 2009; Braslavskaya, 2020) and the current rate of logging and fires, which most often lead to the replacement of coniferous forests with deciduous ones (Uvsh et al., 2020). In the southern taiga forest region, the priority type of ecosystem was swamps, since the largest swamps within the Central Federal District are located in the area of mixed forests. It is worth emphasizing that forest district coefficients calculated within the Central Federal District do not fully reflect the situation in forest areas.

Within the constituent entities of the Russian Federation, the results of prioritization of ecosystem types are also different. In most regions, as well as in forested areas, coniferous forests turned out to be priority. However, in Kostroma and Kaluga oblasts, swamps received the highest rating and, in Tver oblast, swampy forests. In Lipetsk oblast, along with dark coniferous forests, priority was given to mixed forests, which did not receive the highest rating in any of the other regions. Within municipal districts, the priority

Table 2. Indices of importance (significance) of generalized types of ecosystems at different territorial levels. Indices for forest areas are calculated within the Central Federal District. Places of ecosystem type in the ranking of assessments within the corresponding territory are highlighted in color

Place	1	2	3	4	5	6	7	8

Territory	Dark coniferous forests	Light coniferous forests	Deciduous forests	Mixed forests	Swampy forests	Swamps	Herbaceous vegetation	Steppes
Ecosystem assessment **Central Federal District** by regional index								
Central Federal District	51	38	11	4	32	37	4	100
Ecosystem assessment of **forest areas** by forest district index								
South taiga area	23	21	7	2	32	48	6	-
Mixed forest area	37	30	10	3	26	27	3	-
Forest-steppe area	100	100	14	25	50	66	4	93
Area steppes	100	100	25	48	52	48	3	80
Ecosystem assessment of **forest areas** according to forest-regional index								
South taiga area	37	30	9	3	32	43	5	-
Mixed forest area	44	34	11	3	29	32	4	-
Forest-steppe area	76	69	12	14	41	51	4	96
Area steppes	76	69	18	26	42	43	4	90
Ecosystem assessment of **subjects of the Russian Federation** by intrasubject index								
Belgorod oblast	100	100	10	69	100	100	4	65
Bryansk oblast	100	19	10	4	38	30	3	-
Vladimir oblast	30	14	23	3	13	23	4	-
Voronezh oblast	100	100	17	57	33	46	4	100
Ivanovo oblast	26	31	15	3	21	25	3	-
Kaluga oblast	60	74	7	3	61	75	3	-
Kostroma oblast	23	16	7	2	31	55	7	-
Kursk oblast	100	100	10	49	86	53	4	100
Lipetsk oblast	100	69	13	100	39	80	4	-
Moscow oblast	20	45	16	3	28	36	4	-

Table 2. (Contd.)

Territory	Dark coniferous forests	Light coniferous forests	Deciduous forests	Mixed forests	Swampy forests	Swamps	Herbaceous vegetation	Steppes
Oryol oblast	100	100	10	28	100	100	3	–
Ryazan oblast	100	47	18	6	15	18	3	–
Smolensk oblast	100	92	9	2	48	44	3	–
Tambov oblast	100	63	74	11	30	48	4	–
Tver oblast	26	24	10	2	28	22	4	–
Tula oblast	100	100	7	27	100	100	2	–
Yaroslavl oblast	39	88	8	3	31	32	4	–
Ecosystem assessment of municipal districts of Ivanovo oblast by intramunicipal index								
Verkhnelandekhovo	19	30	47	2	20	36	4	–
Vichugsky	56	50	30	2	61	100	2	–
Gavrilovo-Posadsky	69	30	20	5	18	20	4	–
Zavolzhsky	23	65	5	3	100	100	4	–
Ivanovsky	27	9	78	3	35	38	4	–
Ilyinsky	44	77	12	3	17	19	2	–
Kineshemsky	17	95	4	3	88	100	4	–
Komsomol	72	57	11	3	20	20	3	–
Lezhnevsky	15	18	100	2	30	26	3	–
Lukhsky	20	28	25	2	24	30	3	–
Palekhsky	31	47	50	2	21	40	3	–
Pestyakovsky	42	21	100	3	6	8	4	–
Privolzhsky	49	100	11	4	100	47	2	–
Puchezhsky	11	85	32	4	100	100	3	–
Rodnikovsky	41	46	37	3	59	61	3	–
Savinsky	17	21	62	2	13	16	4	–
Teykovsky	27	28	15	2	26	19	4	–
Furmanovsky	66	29	9	3	59	50	3	–
Shuisky	16	24	100	3	29	27	3	–
Yuzhsky	38	18	31	3	6	8	5	–
Yurievetsky	21	100	13	4	100	100	3	-

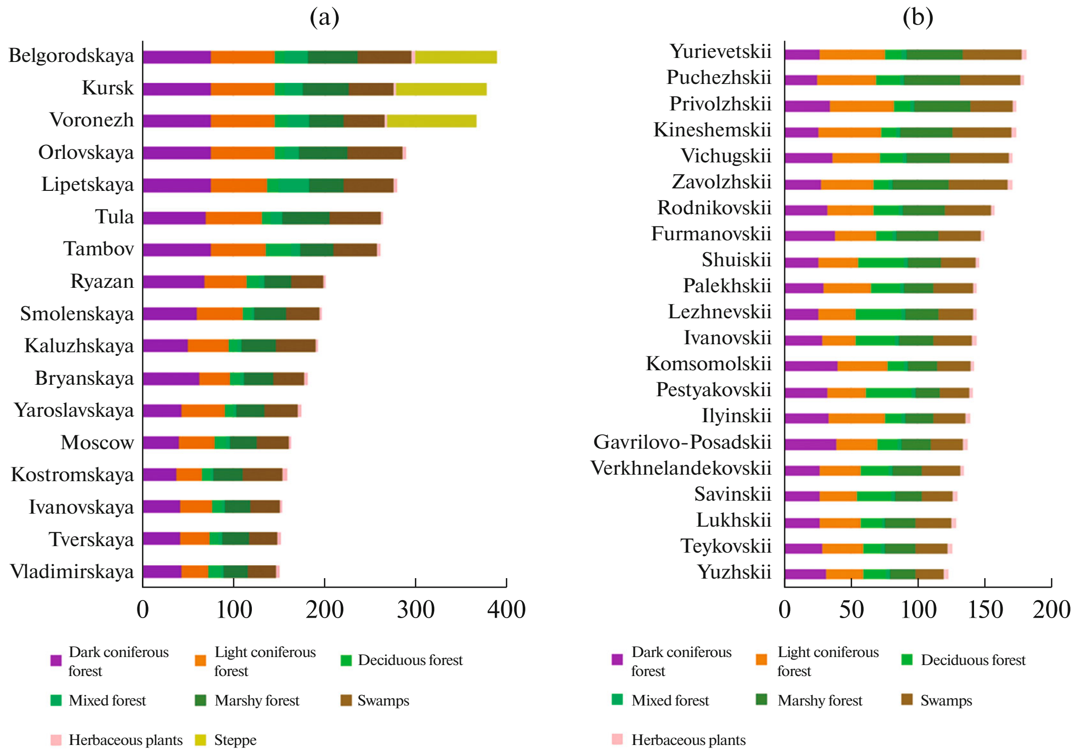

Fig. 2. Ranking of territories: (a) subjects of the Russian Federation within the Central Federal District according to the subject–forest-district–regional index; (b) municipal districts (using the example of Ivanovo oblast) according to the municipal–forest-district–subject index.

types of ecosystems also differ, and often they do not coincide with those in the corresponding constituent entities of Russia (an example for the municipal districts of Ivanovo oblast is shown in Table 2).

Obviously, the results of this preliminary assessment are largely determined by the accuracy of identifying ecosystems on the digital land cover map we used, and generalized types of ecosystems include both common and rare ecosystems. For example, deciduous forests, widely represented in most regions of the Central Federal District, contain both widespread derived small-leaved forests and rare broad-leaved forests. For a more accurate assessment, digital maps need to be updated, including using forest taxation materials.

The use of cross-level indices makes it possible to take into account the tasks of preserving the diversity of ecosystems simultaneously at two or more territorial levels. For example, when using the forest-regional index to assess the ecosystems of forest areas, the priority of steppes for the Central Federal District is better taken into account, and they become the main ones in the southern forest areas (Table 1). In general, when using interregional indices, differences between territories of the same level are smoothed out.

The indices we used are calculated based on the area of different types of ecosystems (Table 1). In the future, it is necessary to include in the assessment other indicators of the state of forest ecosystems that are important for the conservation of biodiversity—fragmentation and age. In addition, it is necessary to preserve not only the typological, but also the successional diversity of ecosystems. Since periodic anthropogenic disturbances, mainly fires and logging, return ecosystems to earlier successional stages, communities at later stages of succession should be considered important for conservation. The diversity of successional stages, formed naturally, is best preserved within large intact forest areas (IFL), where not only undisturbed ecosystems can be present, but also old-growth forests formed after disturbances of various types (Aleynikov, 2021). Nevertheless, to preserve forest ecosystems, priority should be given to natural forests of different ages, which in regions developed by humans can be considered a specific type of rare ecosystems that are on the verge of extinction.

One indicator of the importance of ecosystems for the conservation of biodiversity is their belonging to the categories of forests of high conservation value (primarily IFL) and water conservation/spawning protection forests, which often remain not only the last refugia of regional biodiversity, but also provide ecosystem connectivity. A special category are ecosystems unique to a particular region, which are identified by experts, as was done, for example, for the northwest of Russia (*Sokhranenie*..., 2011).

According to the criterion of rarity of ecosystems, the most important for the conservation of biodiver-

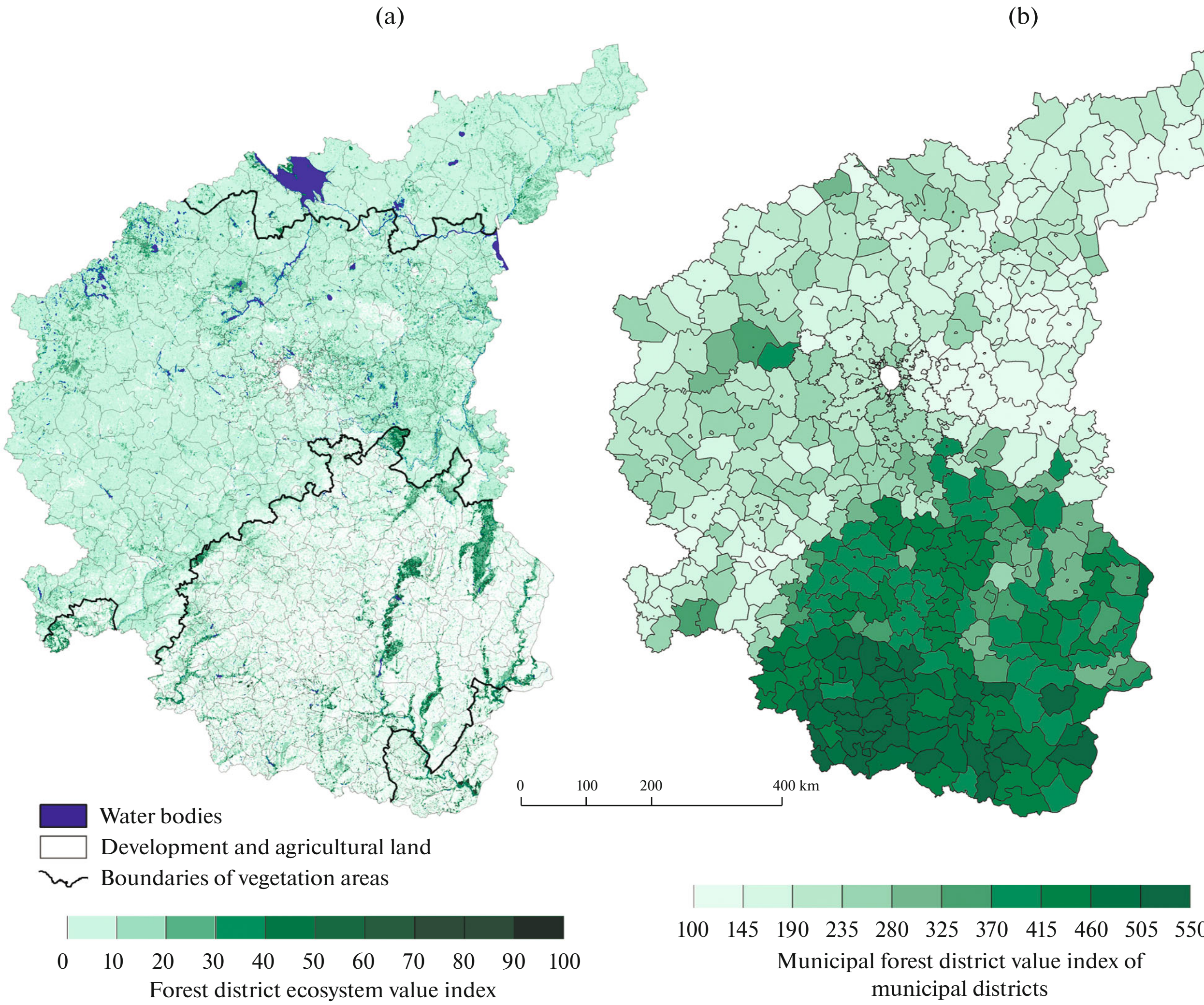

Fig. 3. Importance of ecosystem types for preserving their diversity in forested areas (a) and the importance of municipal areas for preserving the diversity of ecosystems simultaneously in municipalities and in forested areas (b).

sity are the areas most strongly transformed by humans (as shown below, for example, in Figs. 2a, 3b). A negative correlation was revealed between the indices of the importance of municipal territories for preserving the diversity of ecosystems and the share of the area of natural ecosystems in them (Pearson's correlation coefficient for intramunicipal indices is –0.764**). This negative correlation reflects the interrelationship between two aspects of anthropogenic threats to natural ecosystems: the threat of area loss and the threat of biodiversity loss. When using the criteria of low disturbance and age of ecosystems for assessment, the least transformed vast natural areas, most of which are located in the northern half of the Central Federal District, also receive a high rating.

2.2 Prioritization of Territories

Prioritization of territories for preserving the diversity of ecosystems is carried out on the basis of coefficients of their importance (significance), which are the sum of importance indices ecosystems within these territories (Table 1). Figure 2a shows the ranking of subjects of the Russian Federation according to their importance for preserving the diversity of ecosystems in the Central Federal District, in forest areas, and in the subjects themselves (according to the subject–forest-district–regional index; see Table 1). Figure 2b shows an example of ranking municipal districts according to their importance for preserving the diversity of ecosystems within a separate subject of the Russian Federation (Ivanovo oblast), taking into account the tasks of preserving the diversity of ecosystems in the forest region of mixed forests, as well as in the municipalities themselves (according to the municipal–forest-district–subject index).

Figure 3a shows an example of the spatial distribution of indices of the importance of ecosystems for the conservation of their diversity within individual forest areas (forest district index; see Table 1). Rare types of

Table 3. Values of the Pearson correlation coefficient for the relationship between the share of the number of species listed in the regional Red Lists that are noted in municipalities and the intramunicipal coefficient of importance of the territory for the conservation of ecosystem diversity

Oblast	Birds and mammals	Vascular plants
Vladimir ($n = 16$)	–0.504*	–0.400
Voronezh ($n = 33$)	–0.510**	–0.77
Moscow ($n = 39$)	–0.399*	–0.059
Tula ($n = 23$)	0.013	0.411
Tambov ($n = 23$)	–0.728**	–0.394
Ivanovo ($n = 21$)	–0.174	–0.219
Ryazan ($n = 25$)	–0.550*	–0.077
Lipetsk ($n = 18$)	–0.622**	–0.402
All municipalities of 8 oblasts ($n = 196$)	–0.427**	–0.209**
Average values for 8 areas ($n = 8$)	–0.484	–0.420

n is number of administrative districts and/or urban districts; ** $p < 0.01$; and * $p < 0.05$.

ecosystems (with a minimum area), isolated areas of which are concentrated in the southern regions of the Central Federal District, are of maximum importance. In the northern part of the Central Federal District, significant areas are occupied by ecosystems with a relatively large area and low indices. Figure 3b shows the importance of the territory of municipalities for preserving the diversity of ecosystems in forest areas and in the municipalities themselves (municipal forest district index, see Table 1). The assessment of the importance of municipalities increases from north to south, since more southern areas, as a rule, are more strongly transformed by humans and the threat of loss of ecosystem diversity in them is higher.

2.3 Using Species Diversity Indicators to Prioritize Territories

Currently in Russia there is no system for monitoring species diversity for the entire territory of the country. The best coverage of the territory (all of European Russia) is provided by data on the species richness of birds collected within the framework of the *Atlas of Breeding Birds of European Russia* project (Kalyakin and Voltsit, 2020). For the entire territory of the country, there is information from the regional Red Lists on registration points of rare species, indicating municipal areas (in some regional lists, the municipalities where the species were found are not indicated). The approaches of the compilers of regional Red Lists to the selection of species and the degree of knowledge of the constituent entities of the Russian Federation differ significantly. Therefore, it is possible to compare municipalities within a large region, including several constituent entities of the Russian Federation, not by the number of red-listed species noted there, but by the share of the total number of species in the regional Red List. Further assessments may also take into account the rarity category of species.

When testing the methodology, we used an indicator of the proportion of the number of Red List species recorded in individual municipalities from the total number of species listed in the regional Red List. Species of different rarity categories had the same "weight." The number of red-listed species of birds and mammals by municipality was determined according to the regional Red Lists; the number of vascular plants was determined by A.V. Shcherbakov based on literary and herbarium data within the framework of the Flora of the Oka Basin and Flora of the Central Black Earth Region projects.

Between the indices of the importance of municipalities for the conservation of ecosystem diversity and the total number of red-listed species of birds and mammals, either weak negative correlations or no dependence were identified. For vascular plants in none of the eight selected regions of the Central Federal District, negative correlations are statistically significant, and for Tula oblast there is a tendency towards a positive correlation (Table 3). This indicates that, in the eight regions of the Central Federal District being analyzed, the areas of rare ecosystems identified on the map are not sufficient for habitat of red-listed species of birds and mammals, but they are sufficient for vascular plants. It is also possible that more detailed surveys of territories may change the nature of these dependencies, especially in relation to small-sized and sedentary species.

The tasks of preserving the diversity of species and ecosystems are two key aspects of preserving biodiversity, and they are not interchangeable, but complementary. Because the amount of habitat needed to support the conservation of different species varies, indices for relatively large and widely moving species may conflict with indices that reflect the importance of ecosystem types based on their rarity. For smaller and less active species, this contradiction disappears, and it is precisely individual, small areas of rare types of ecosystems that turn out to be critically necessary for the conservation of red-listed species of plants and insects.

An additional indicator for future assessments of the importance of territories can be the share of the area within their boundaries of important bird territories (IBTs), which are identified according to unified qualitative and quantitative indicators of bird species diversity (Sviridova et al., 2016) and are of high value for preserving the diversity and quality of ecosystems (*Ekosistemnye uslugi*..., 2020).

3. OBJECTIVES AND PRIORITIES FOR BIODIVERSITY CONSERVATION AT DIFFERENT TERRITORIAL LEVELS: PROBLEMS AND ISSUES

The tasks and priorities for the protection of biodiversity objects of different hierarchical levels at different levels of territorial management should be different (Table 4). In some cases, apparent contradictions may arise between the priorities for the conservation of biodiversity at different levels, for example, as shown above, between the prioritization of ecosystem types based on their rarity and the desire to preserve vast intact tracts of natural systems (see Section 2.1) or the task of preserving species for survival which require large areas (see section 2.3). Similar contradictions between the objectives of conserving biodiversity and maintaining/enhancing ecosystem services (Sullivan et al., 2017) and the objectives of preserving species and ecosystem diversity (Bonn and Gaston, 2005) regularly arise in environmental practice. However, they can be addressed by optimizing conservation priorities and ecosystem management scenarios (Socolar et al., 2015; Law et al., 2016), including forest management (Trivino et al., 2016).

To apply the multilevel approach in practice, it is necessary to resolve a number of issues:

(i) develop methods for the spatial integration of the characteristics of natural systems and territorial levels of management, the boundaries of which do not coincide;

(ii) develop approaches to integrating the tasks of preserving the diversity of ecosystems and the diversity of species, taking into account the requirements of species for the size of habitats and the size of surviving rare types of ecosystems;

(iii) determine the sequence of prioritization of biodiversity objects at different territorial levels of management, which would make it possible to most adequately take into account the different scales of existing types of natural–territorial division, as well as the territorial sizes of biodiversity objects;

(iv) include in the assessment, in addition to the rarity indices of ecosystems determined by their area, a number of other indicators of the environmental value of ecosystems: age; degree of disturbance and fragmentation; the importance of habitats of rare, endangered, and key species; and the importance of individual ecosystems for the provision of ecosystem services.

The most important problem in Russia is still the lack of source data required for analysis, as well as difficulties in obtaining and using them, both objectively (different units of scale when collecting data on different groups of organisms or EF/ES, not always amenable to unification or interpolation) and subjectively (secrecy or difficulty in obtaining information, including the high cost of many data). In particular, to test the considered methodology, even for significantly generalized types of ecosystems, it was necessary to create our own digital map based on the integration of data from three different sources. Data from the federal Red List and from the vast majority of regional Red Lists have not yet been translated into a freely accessible electronic form (database); therefore, to assess the importance of territories for the conservation of red-listed species, labor-intensive work is required to search for data on the registration of species in municipalities in text of the Red Lists and entering them into electronic spreadsheets.

CONCLUSIONS

An analysis of the literature and recent reports from international projects indicates that today a scientific consensus has been reached in understanding biodiversity as a necessary structural basis for the provision of ecosystem functions and services. Biodiversity loss weakens and destabilizes EF/ES, which is a threat to human well-being. The key role of biodiversity in ensuring sustainable development should be included in the principles of developing ecosystem accounting and used to interpret its results when making decisions in the field of environmental management and conservation. For Russia, as a country with the world's largest arrays of natural ecosystems that provide ecosystem services of global importance, this task is of paramount importance. All hierarchical levels of biodiversity are important for the implementation of EF/ES—from intrapopulation diversity to ecosystem diversity. It is also necessary to take into account the specifics of the "work" of biodiversity at different spatial scales.

A preliminary multilevel methodology for prioritizing territories and ecosystems for the conservation of biodiversity at three levels of management (federal district, constituent entities of the Russian Federation, and municipal districts) developed within the framework of the TEEB-Russia project was tested using the example of the Central Federal District of the Russian Federation. Forest areas were used to take into account natural zonation. The prioritization of generalized types of ecosystems was based on the rarity criterion (an indicator of the share of the area of a given ecosystem type in the total area of the territory). Rarer types of ecosystems were considered priority objects

Table 4. Objectives and priority objects for the conservation of biodiversity of terrestrial ecosystems at different territorial levels. *Tasks and priority objects related to ecosystem diversity are in italics*

Territorial levels of organization of biodiversity/examples of objects	Compliance with the levels of state and departmental government, as well as local government	Challenges of preserving the diversity of species and ecosystems	Priority sites for biodiversity conservation
Local/individual ecosystem in similar local conditions	Departments within the municipality/forestry	(i) Preservation of species diversity typical for a given type of ecosystem (ii) Conservation of populations and habitats of species with minimum requirements for habitat size (small and sedentary species) (iii) Conservation of areas (parts) of habitats for species with medium and maximum requirements (large and migratory species)	Rare and endangered species (listed in the Red Lists of the Russian Federation and constituent entities of the Russian Federation, as well as locally endangered)
		Preservation of area, prevention of fragmentation of this ecosystem	–
Landscape/set of individual ecosystems	Municipality Forestry Subject of the Russian Federation	(i) Preservation of species diversity within a landscape or area—a collection of species characteristic of a combination of individual ecosystems (ii) Conservation of populations and habitats of species with moderate habitat size requirements (iii) Conservation of areas (parts) of habitats for species with maximum requirements (large and migratory species)	Rare and endangered species (federal Red Lists, regional Red Lists, and locally rare and endangered)
		(i) *Preservation of ecosystem diversity (“landscape mosaic”)* (ii) *Maintaining connectivity (preventing fragmentation) of natural ecosystems*	(i) *Rare and endangered ecosystems in this landscape* (ii) *Least disturbed ecosystems of all types with typical species diversity* (iii) *Ecosystems in late stages of succession (old growth forests)*
Regional/ecoregion, biome, natural area, major river basin	Group of subjects of the Russian Federation Federal District National level	(i) Conservation of regional and national species diversity (ii) Conservation of populations and habitats of species with maximum habitat size requirements	Species listed in the Red List of the Russian Federation
		Preservation of the diversity of the main types of zonal and intrazonal ecosystems	(i) *Rare and endangered ecosystem types (e.g., European steppes)* (ii) *Unique ecosystems and natural complexes* (iii) *Intact natural areas (including intact forest areas)*

for protection. The prioritization of territories at three scale levels (Central Federal District, constituent entities of the Russian Federation, and municipalities) was based on indices of the value of ecosystems within these territories and the importance of the territories for the conservation of red-listed species of animals and plants.

The approbation of the methodology showed that the priority types of ecosystems for the conservation of biodiversity differ both at different territorial levels (CFD, forest areas, constituent entities of the Russian Federation, and municipalities) and in different territories within the same level. For example, in most regions of the Central Federal District, as well as in forest areas, coniferous forests turned out to be a priority. However, in Kostroma and Kaluga oblasts, swamps received the highest rating, and, in Tver oblast, swampy forests received the highest rating. In Lipetsk oblast, along with dark coniferous forests, mixed forests turned out to be a priority. In different municipal districts, the priority types of ecosystems are also different, and often they do not coincide with those in the corresponding subjects of the federation. As was previously shown by the results of the TEEB-Russia project, the relationships between biodiversity and EF/ES may vary at different spatial scales, which reflects the specifics of biodiversity objects that have different spatial sizes and live and function in different natural and anthropogenic conditions.

The identified contradiction between the management tasks of preserving rare ecosystems and large undisturbed natural areas is resolved by developing regional environmental strategies that take into account the specifics of the southern regions of the Central Federal District, which have been heavily transformed by humans, and the less disturbed northern regions, as well as by using the criteria of low disturbance and age of ecosystems for prioritization.

A contradiction has also been identified between the management objectives of preserving the diversity of species that require extensive habitats and the conservation of rare ecosystems that have a small area. This contradiction manifested itself in the form of a negative correlation between the number of red-listed species of birds and mammals in municipalities and indices of the importance of municipalities for the conservation of ecosystem diversity. However, no statistically significant negative correlations were found for vascular plants. This indicates that the areas of individual areas of rare ecosystems are not sufficient for the habitat of red-listed species of birds and mammals, but they are sufficient for vascular plants.

Thus, the organization of ecosystem accounting in Russia within the framework of the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) requires the use of a multilevel approach, which should take into account the tasks of conserving biodiversity at different hierarchical levels, primarily the diversity of species and the diversity of ecosystems, as well as the specifics of conservation tasks biodiversity at different levels of territorial government. Thus, the differences we identified in the prioritization of ecosystem types at different territorial levels and within territories of the same level emphasize that, when making decisions, it is necessary to take into account both inter- and intralevel differences. Contradictions between management objectives for the conservation of different biodiversity objects (for example, large and widely moving animal species and rare types of ecosystems) can be resolved through the development of environmental strategies for different levels of territorial management by selecting priority biodiversity objects taking into account the requirements of species for habitat size and the size of surviving rare types of ecosystems.

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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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