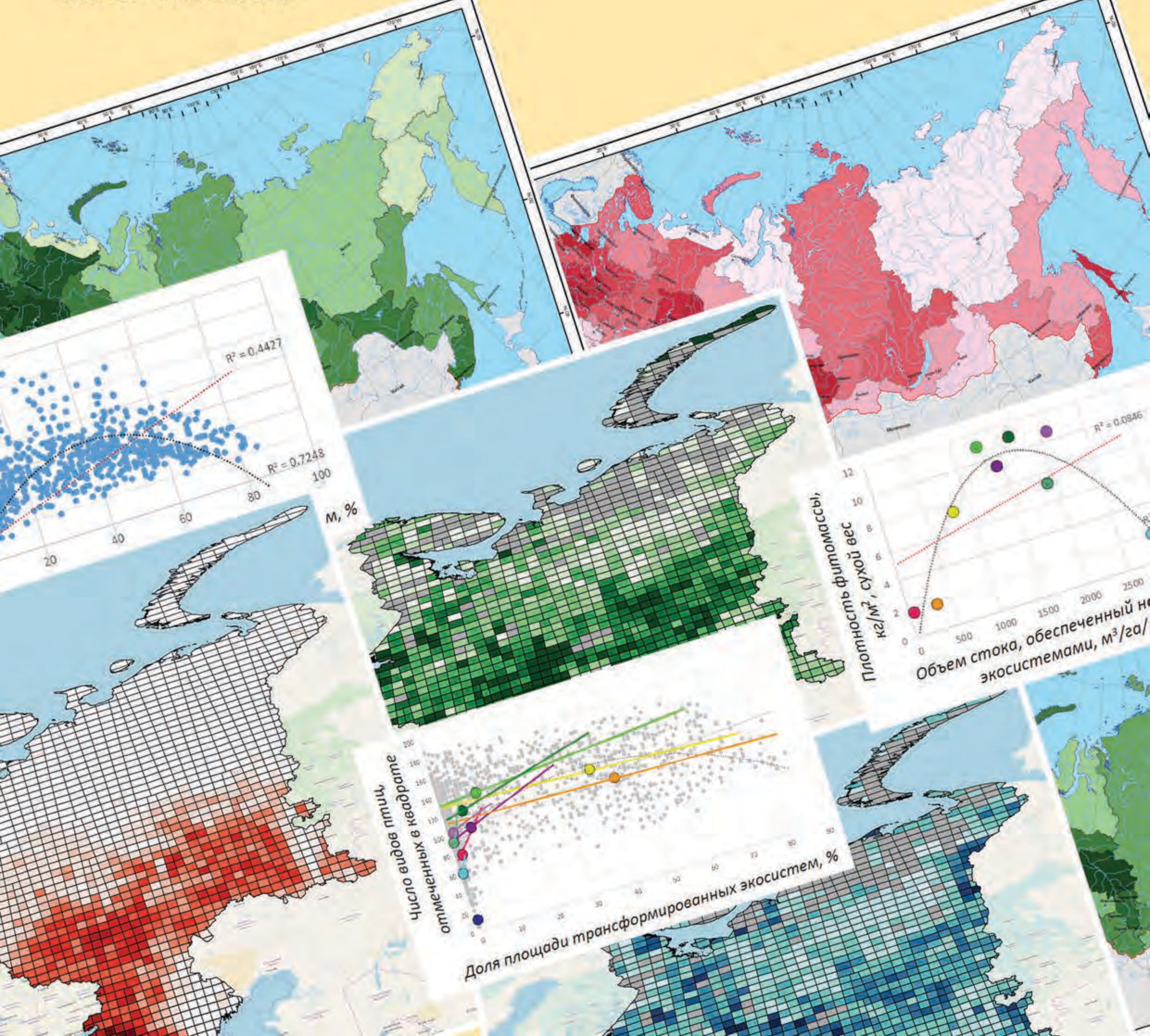
Ecosystem Services of Russia

Prototype of the National Report

Biodiversity and Ecosystem Services: Accounting Principles in Russia

TEEB-RUSSIA



TEEB-Russia

Biodiversity
Conservation
Center

Leibniz Institute of
Ecological Urban and
Regional Development

ECOSYSTEM SERVICES OF RUSSIA

PROTOTYPE OF THE NATIONAL REPORT

Volume 2
Biodiversity and Ecosystem Services: Accounting Principles in Russia

Edited by E. N. Bukvareva, T. V. Sviridova

Moscow – 2020

ISBN 978-5-93699-107-3

Report edited by E.N. Bukvareva, T.V. Sviridova

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The translation of the Russian text into English was done by KERN AG, Sprachendienste in Frankfurt am Main.

Recommended citation: Bukvareva, E.N., Sviridova, T.V. (Eds.). (2020). Ecosystem services of Russia: Prototype National Report. Vol. 2. Biodiversity and Ecosystem Services: Accounting Principles in Russia. English version of the report published originally in Russian in 2020. Moscow: BCC Press.

The book was prepared and published as part of the project "Assessment of biodiversity and ecosystem services in the Russian Federation – informing management principles and international processes". The project was commissioned by the German Federal Agency for Nature Conservation (BfN), the TEEB Russia projects were funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). They were supported by the Ministry of Natural Resources and Environment of the Russian Federation (MNR) with the active participation of experts from the Biodiversity Conservation Center (Moscow), Leibniz Institute of Ecological Urban and Regional Development (Dresden), Russian Academy of Sciences (A.N. Severtsov Institute of Ecology and Evolution, the Institute of Geography, Center for Forest Ecology and Productivity, and the Institute for Systems Analysis), Lomonosov Moscow State University (the faculties of Biology, Geography, Economics and Zoological Museum), the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, and limited liability company «NextGIS».

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Project website: http://teeb.biodiversity.ru/en

Contents

Introduction

TEEB (The Economics of Ecosystems and Biodiversity) is a global initiative focused on "making nature's values visible". Its principle objective is to capture, demonstrate and mainstream the values of biodiversity and ecosystem services into decision-making at all levels.[1] The TEEB-Russia project as a whole is aimed at developing approaches to assessing Russia's ecosystems and ecosystem services and is implemented by the Biodiversity Conservation Center (Moscow) in cooperation with the Leibniz Institute of Ecological Urban and Regional Development (Dresden) in accordance with decisions of the permanent Russian-German working group "Conservation of Nature and Biological Diversity". This report presents the main results of the second phase of the TEEB-Russia project (TEEB-Russia 2, 2018-2019).

The first project phase "TEEB-Russia – Ecosystem Services Evaluation in Russia: First Steps" (TEEB-Russia 1, 2013–2015) was the first national pilot assessment of Russia's ecosystem services (ES). Methodological approaches to the assessment of Russian ES at the national level in physical indicators for the subjects[2] of the Russian Federation were proposed, as well as approaches for comparing the regions of the Russian Federation in ES provisioning and use. The results of the TEEB-Russia 1 project are presented in Volume 1 of the Prototype of the National Report on Ecosystem Services of Russia (Bukvareva, Zamolodchikov, 2018), which was published in Russian[3] and English[4].

The second project phase TEEB-Russia 2 is aimed at further development of ecosystem accounting methodology in Russia through the integration of previously proposed ES indicators and indicators of ecosystem assets. Along with the ecosystems' area which indicates ecosystem extent, abiotic and biotic indicators of ecosystem condition are important for ecosystems' ability to provide ES. The key biotic characteristic of ecosystem assets is biological diversity. Therefore, one of the main tasks of TEEB-Russia 2 project was to analyse possibilities to integrate indicators of ES, ecosystems' area and biodiversity in the framework of ecosystem accounting. This task corresponds to the objectives of the Convention on Biological Diversity, cooperation within IPBES framework and is necessary for the development in Russia of Experimental Ecosystem Accounting within the framework of the System of Environmental-Economic Accounting (SEEA-EEA) (see further Section 6.3).

A preliminary assessment of Russia's ES, made in the TEEB-Russia 1 project, showed that they have decisive influence on the well-being of the population and the economy of the Russian regions. Thus, formation of ecosystem accounting in Russia is necessary for effective and sustainable nature management, including environmental impact assessment (EIA), long-term territorial planning in the regions of Russia, optimal development of the network of specially protected natural areas, attracting foreign investment in major economic projects in the country. The formation of a national ecosystem accounting system within the framework of UN standards is required to fulfill the UN Sustainable Development Goals 15 and 17[5].

Except for methodological information (Section 2), the present report includes four main informative sections. Section 3 describes indicators of ecosystems and biodiversity used in the study. Section 4 contains the results of a more detailed, after the first project phase, physical evaluation of selected ES within the European part of Russia. More detailed ES evaluation was needed to analyze the relationships between indicators of ES, ecosystems' area and biodiversity, the results of which are presented in Section 5. The concluding Section 6 considers a set of indicators proposed to start discussing the structure of ecosystem accounting in Russia. It also includes the results of the pilot economic assessment of ES in Russia and considers the main problems of integrating the value of ES and ecosystem assets into the system of national accounts of Russia.

[1] http://www.teebweb.org/

[2] Subjects of the Russian Federation are top-level constituent entities of the federal state.

[3] http://www.biodiversity.ru/programs/ecoservices/first-steps/Ecosystem-Services-Russia_V1_web.pdf

[4] http://www.biodiversity.ru/programs/ecoservices/first-steps/Ecosystem-Services-Russia_V1_eng_web.pdf

[5] Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development.

1. Key Messages

1. Ecosystem services (ES) of Russia have a decisive influence on the well-being of the country's population. Ecosystem assets providing ES should be considered as an important component not only of natural resources, but also of national wealth in general. For the population, ES provide favorable environmental conditions (e. g. clean air and water) and create conditions for people to relax in nature. For the economy, ES are important for the production of key biological resources (primarily wood and fish) and regulating ES of the purification of water and air, prevention of soil erosion, regulation of the water cycle, crop pollination which are necessary for business and the economic development of the regions of Russia. The conservation of ecosystems and the maintenance of their sustainable functioning in the regions of the country will significantly reduce the damage to the economy and human health from negative changes in the environment, as well as the cost of technological solutions necessary to deal with them. The ES of Russian ecosystems in the absorption and storage of carbon are important as key global factors in climate regulation.

Regulating ES make up the bulk of the total economic value of ES estimated in the TEEB-Russia project. Several key ES of this category in some regions of Russia can no longer cope with the task of maintaining favorable environmental conditions. Such ES include runoff volume assurance by terrestrial ecosystems, purifying water in natural reservoirs, and purifying air by suburban forests (TEEB-Russia 1 results).

Economic value of ES currently consumed by the population and economy of Russia is several percent compared to the country's gross domestic product. But in many regions, this cost significantly exceeds 10% of the gross regional product, which indicates the important contribution of ES to the well-being of these regions. The preliminary estimates obtained need to be clarified, but now they already show the scale of possible damage from the degradation of ecosystem assets and services, which may impede economic growth and cause a decrease in the living standards of the population in the regions of Russia (Section 6.2).

2. It is necessary to ensure macroeconomic accounting and statistical reflection of ecosystem assets and services. They should have appropriate quantitative characteristics within the framework of the system of national accounts. Macroeconomic and macroecological calculations should be based on the principles of the national accounting system standardized and accepted by most countries, and, first of all, on the international standard “System of Environmental-Economic Accounting – Central Framework (SEEA)” including the supporting recommendations “Experimental Ecosystem Accounting” (SEEA-EEA). In order to prepare Russia for the approval of ecosystem accounting as the UN international standard, it is necessary to begin phased, scientifically sound and practically meaningful development of this system based on standardized approaches but taking into account national and regional specifics of environmental conditions and the economy, as well as possible changes in the system of national accounts in Russia (Sections 6.2 and 6.3).

3. Physical indicators of ES and ecosystem assets have been proposed for SEEA-EEA at the national level for Russia (Section 6.1).

Indicators of ecosystem assets:

– area of ecosystems (fragmentation indicators are important at more detailed levels of management – local and, possibly, regional);

– indicators of ecosystem functioning – productivity and phytomass of ecosystems;

– indicators of biodiversity – species richness of plants and animals, including assessment of their protective status (inclusion in red lists).

Indicators of ecosystem services:

– ES provided by ecosystems (potential ES) for the accounting period;

– ES required by the population and economy of the regions of Russia for the accounting period;

– ES consumed by the population and economy of the regions of Russia during the accounting period;

– degree of use of ES and satisfaction of their needs (determined by the ratio of the provided, required and consumed ES).

4. A wide variety of natural and socio-economic conditions on the territory of Russia requires a regionally differentiated approach to the ecosystem accounting at the national level. The SEEA-EEA structure, sets of indicators of biodiversity, ecosystems and ES, approaches to the interpretation of indicators for decision-making should consider differences in the structure and functioning of ecosystems in regions with different environmental conditions and with varying degrees of anthropogenic transformation.

The average values of indicators of climatic conditions, ecosystem assets and ES, as well as the character of the relationships between them, are different in different ecoregions of the European part of Russia (Arctic deserts, tundra, northern taiga, southern taiga, mixed forests, forest-steppe, steppe, semi-desert, mountain forests and tundra of the Urals, mountain forests of the Caucasus). The strongest differences in the relationships between indicators were revealed between the group of northern, forest and mountain ecoregions (Arctic deserts, tundra, northern taiga, southern taiga, mixed forests, Urals, Caucasus) and the group of southern ecoregions (forest-steppe, steppe, semi-desert). In some cases, specific relationships between indicators have been identified for mountain ecoregions and for forest-steppe. In addition, significant differences were revealed by a group of relatively weakly transformed ecoregions (northern, forest, mountain ecoregions and semi-desert) and strongly transformed agricultural regions (forest-steppe, steppe) (Sections 5 and 6.1.3.2).

The revealed differences in the average values of indicators and the nature of the relationships between them reflect the fundamental differences in the structure and functioning of ecosystems of different types, which must be considered when assessing ecosystem assets and services.

In general, regions with more severe conditions (northern and arid) are characterized by lower levels of species diversity, phytomass, and ecosystem productivity. However, this does not mean that the ecosystem assets of these regions are less valuable for preserving biodiversity and performing ES, since the relatively low levels of biodiversity and phytomass in undisturbed ecosystems in these regions are their adaptation to physical and geographical conditions and provide the most effective and stable ecosystem functioning and regulating ES (Section 6.1.3).

Approaches to the economic valuation of ES and ecosystem assets and its interpretation for decision-making should also be regionally differentiated. The distribution of the value of ES and ecosystem assets across Russian regions is extremely uneven. In economically developed regions with a high population density, ecosystem assets are largely degraded due to human activities, and their value is low compared to the value of assets in the economy, but at the same time, demand for ES is high. In regions with low population density and weakly modified ecosystems, on the contrary, the value of ecosystem assets may exceed that for assets in the economy, but the demand for ES is relatively low. Obviously, the methods and interpretation of the economic valuation of ES and ecosystem assets in these cases should be different (Sections 6.2.2.4 and 6.2.3).

A regionally differentiated approach to the SEEA-EEA can be based on methods of physical-geographical and landscape zoning, which consider both the natural characteristics of the territories and the distribution of the population and economic activity on them (Section 6.4).

5. The managerial interpretation of the values of indicators of ES and ecosystem assets should take into account the nature of the revealed correlations between them, first of all, whether these correlations reflect causal relationships between indicators, or they are the result of simultaneous reaction of indicators to changes in other factors. Correlations between indicators of ES and ecosystem assets revealed in the TEEB-Russia 2 project at the national and subnational (for the European territory of Russia) scales in most cases do not reflect causal relationships, but the simultaneous reaction of indicators to changes in climatic conditions and degree of anthropogenic transformation of the territory, which in turn depends on climatic conditions. These correlations cannot be a direct basis for decision-making. Nevertheless, the obtained correlations are important for solving some tasks in the formation of SEEA-EEA: a) identifying the similarities and differences between the regions of Russia when developing a regionally differentiated approach to ecosystem accounting; b) identifying groups of indicators that change in a similar way in response to certain factors; c) identifying trade-off or synergy between ES, as well as ES bundles, i.e. groups of mutually reinforcing or supporting ES (Sections 5 and 6.1.3.2).

6. Biodiversity, phytomass, and ecosystem productivity are important indicators of the condition of ecosystem assets and the potential for delivering ES. Biodiversity is a crucial factor in ecosystem functioning and the provisioning ES. A decrease in the values of biodiversity indicators, at each point or on average in a region, indicates the degradation of ecosystem assets, which can undermine provisioning ES (Section 6.1.3.1).

The biodiversity indicators analyzed in the TEEB-Russia 2 project showed their potential applicability for assessing the condition of ecosystem assets: indicators of species diversity of birds (indices of species richness, conservation status and synanthropization) (Sections 3.2.3; 5; 6.1.3.2), indicators of species richness of higher plants (Sections 3.3; 5; 6.1.3.2). Now, the best coverage of the territory with biodiversity indicators has data on species richness of birds in the European part of Russia, collected within the project of the Zoological Museum of Lomonosov Moscow State University "Atlas of Breeding Birds of European part of Russia." For the formation of the correct system of biodiversity indicators within the framework of the SEEA-EEA, it is necessary to expand the collection of data on bird diversity in the Asian part of Russia as well, to include other groups of organisms (plants, insects and other animals) in the monitoring programs. Given the limited possibilities for detailed monitoring of biodiversity throughout the country in the near future, it is necessary to develop extrapolation methods for assessing biodiversity in cases of insufficient primary data. These methods can provide biodiversity assessments based on a combination of floristic and faunistic data available today, cartographic and remote sensing data, as well as expert estimates (Sections 3.2.3.8; 3.3.3.4; 6.1.3.2). To clarify the set of biodiversity indicators and approaches to their interpretation, focused studies at the regional and local levels are required.

7. The structure of SEEA-EEA, sets of indicators and approaches to their interpretation should consider the probability of a significant change in relationships between indicators at different scales and levels of management. The TEEB-Russia 2 project showed that correlations between the same indicators at different scales can change significantly up to a sign change (from positive to negative and vice versa). When moving from the nationwide or large region (European territory of Russia) to the scale of a group of ecoregions or individual ecoregions, positive correlations can change to negative, and vice versa. The absence of correlations on one scale does not mean the absence of a relationship between these parameters on another scale (Sections 3.2.3.7; 5; 6.1.3.2). Despite the fact that, at the national and subnational scales, correlations between indicators of ES and ecosystem assets cannot be a direct basis for decision-making (see conclusion 5), at the local level, one should expect manifestations of causal relationships, reflecting, in particular, the impact of biodiversity on ecosystem functioning and ES (Section 6.1.3.1). Thus, the estimates and conclusions made for one scale cannot be directly transferred to other scales.

When assessing ES, the scale and direction of their action must be considered. Thus, the value of ecosystem assets that provide locally operating ES that are spatially linked to farmland and cities is relatively low throughout the country, but at the local and regional scales these ES can be crucially important for the well-being of the population (Section 4.1.9).

2. Major Objectives, Scales of Analysis and Data Sources

2.1. The main objectives of the project

Experimental Ecosystem Accounting in the framework of the System of Environmental Economic Accounting (SEEA-EEA) is aimed at assessing the condition of components of two main blocks – ecosystem assets and ES they produce (System of Environmental Economic…, 2014 b). TEEB-Russia 2 project is aimed at development of ecosystem accounting methodology in Russia. In order to develop approaches to accounting for ES and ecosystem assets at the national level in Russia, the TEEB-Russia 2 project solved five main tasks (Tab. 2.1.1):

1) clarification of physical valuation of selected ES within the European territory of Russia (Section 4);

2) analysis of relationships between physical indicators of ecosystem assets and climatic conditions (Section 5.1.1);

3) analysis of relationships between physical indicators of ES and ecosystem assets (Section 5.1.2);

4) a preliminary analysis of the possibility of assessing biodiversity at the regional level using the example of the Central Federal Okrug of the Russian Federation (hereinafter RF) (Section 3.3.3);

5) a pilot economic valuation of ES and ecosystem assets of Russia and analysis of possible approaches to the SEEA-EEA development in Russia (Section 6).

Table 2.1.1. Main objectives, scales of analysis and data sources of the TEEB-Russia 2 project (ETR – European territory of Russia; FSSS – Federal State Statistics Service of RF).

Analyzed Indicators	*Minimal accounting units (grain)**	*Investigated objects (focus)**	*Total area (extent)**	*Data sources*
Task 1. Clarification of physical valuation of selected ES within the European territory of Russia				
Provided (potential) ES	50×50 km squares	–	–	Land Resources of Russia (Stolbovoi, McCallum, 2002) Vegetation map of Russia (Bartalev et al., 2011) Data base "Regions of Russia" FSSS Eurasia Land Cover Characteristics Data Base 2.0 Forest Register, 2014
Task 2. Analysis of relationships between physical indicators of ecosystem assets and climatic conditions				
Indicators of biodiversity and the state of ecosystems	50×50 km squares	Ecoregions	ETR	Atlas of Breeding Birds of European part of Russia- Land Resources of Russia (Stolbovoi, McCallum, 2002) Vegetation map of Russia (Bartalev et al., 2011)
	50×50 km squares	Subjects of RF	ETR	
	50×50 km squares	ETR	–	
	Subjects of RF	ETR	–	Morozova, 2011 Land Resources of Russia (Stolbovoi, McCallum, 2002) Vegetation map of Russia (Bartalev et al., 2011)
	subjects of RF	Whole Russia	–	Results of TEEB-Russia 1 project
Task 3. Analysis of relationships between physical indicators of ES and ecosystem assets				
Indicators of biodiversity, the state of ecosystems and ES	50×50 km squares	Subjects of RF	ETR	Atlas of Breeding Birds of European part of Russia- Land Resources of Russia (Stolbovoi, McCallum, 2002) Vegetation map of Russia (Bartalev et al., 2011) Results of TEEB-Russia 2 project (Section 4.1)
	50×50 km squares	ETR	–	
	Subjects of RF	ETR	–	
	subjects of RF	Whole Russia	–	Results of TEEB-Russia 1 project
Task 4. Preliminary analysis of the possibility of assessing biodiversity at the regional level				
Indicators of vascular plant diversity	Administrative districts	Subjects of RF	Central Federal Okrug	Materials of the projects "Flora of the Oka Basin" and "Flora of the Central Black Earth Region"
Task 5. Pilot economic valuation of ES and ecosystem assets of Russia				
Indicators of ES and ecosystem assets	Subjects of RF	ETR	–	Results of TEEB-Russia 2 project (Section 4.1)
	Subjects of RF	Whole Russia	–	Results of TEEB-Russia 1 project

**Spatial scales of analysis are described further in Section 2.2.*

To solve tasks 2 and 3 (see Section 5), the analytical part of the project includes indicators for the main blocks of the SEEA-EEA: ecosystem assets, ecosystem services, as well as the influence of external factors on them (Fig. 2.1.1). At this stage of research, climatic conditions (average annual temperature and average annual precipitation) and anthropogenic transformation of the territory were considered as external factors. The following indicators of ecosystem assets and ES were investigated as well as relationships between them (Fig. 2.1.1):

a) an indicator of the extent of ecosystem assets – the share of agricultural fields and urbanized zones in territorial units of assessment, i.e. indicator that is inverse to the area of natural ecosystems;

b) indicators of the condition of ecosystem assets – indicators of the ecosystem functioning (productivity and phytomass of ecosystems) and biodiversity (number of species of birds and vascular plants);

c) indicators of ES provided by ecosystems, i.e. potential ability of ecosystems to perform ES.

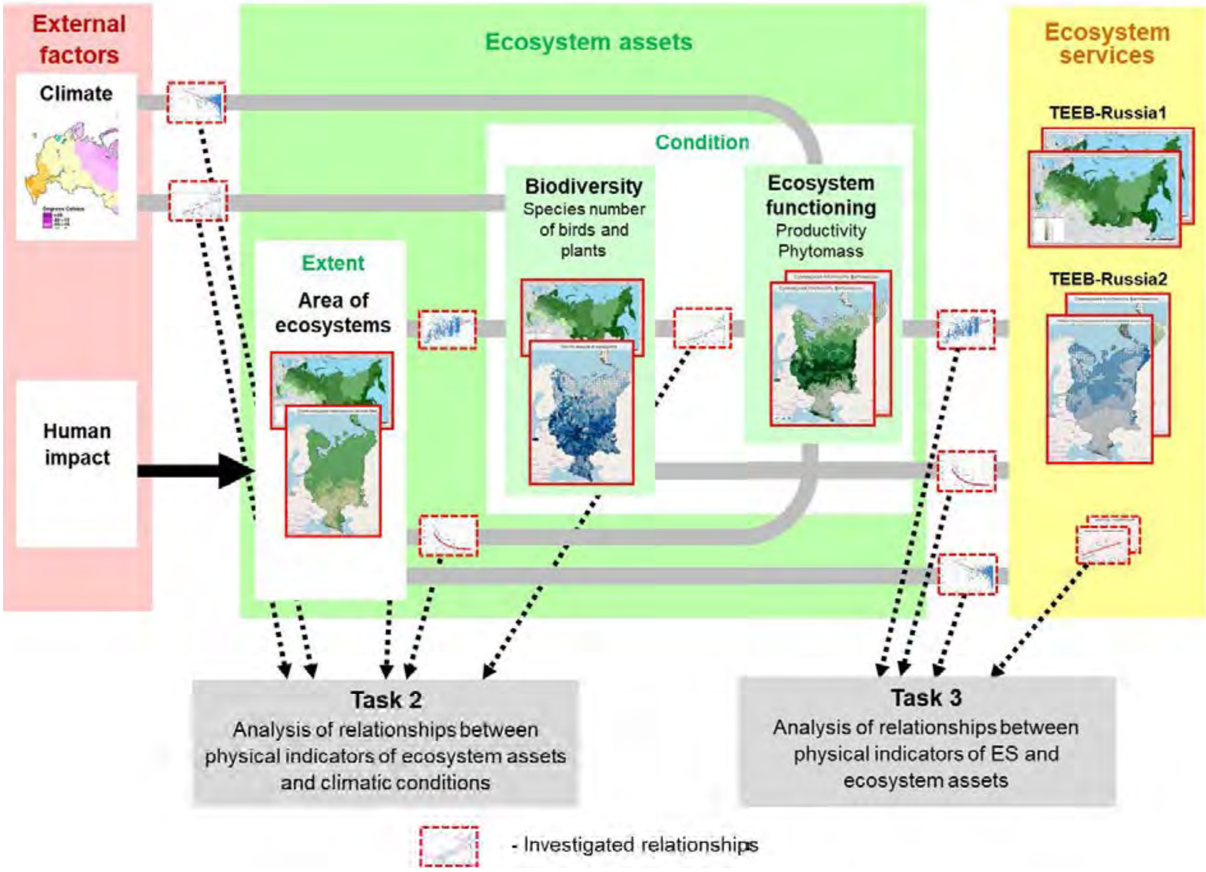


Figure 2.1.1. The main SEEA-EEA blocks reflected in the structure of the TEEB-Russia 2 project.

A pilot economic valuation (task 5) was carried out for the consumed ES and for ecosystem assets based on various valuation approaches (see Section 6).

Considering the approaches to the SEEA-EEA development in Russia, we should mention two groups of issues that have not yet been analyzed in the framework of the TEEB-Russia project, but which need to be included in further studies.

The first group is associated with freshwater ecosystems. Obviously, an assessment of their condition and ES they provide is inseparable from the adjacent terrestrial ecosystems. TEEB-Russia 1 and TEEB-Russia 2 projects made a preliminary assessment of ES of regulation and purification of runoff by terrestrial ecosystems and water purification in aquatic ecosystems (Bukvareva, Zamolodchikov, 2018; Section 4.1.4 of this report). However, an analysis of at least two other problems is necessary to determine further steps in the development of SEEA-EEA in relation to freshwater ecosystems. First, it is necessary to analyze the opportunities available to consider the role of freshwater biodiversity in providing ES of water purification. Currently, there are both a substantial theoretical basis for this (Ostroumov, 2004, 2016, 2017) and practical methods of hydrobiological monitoring. Secondly, in the TEEB-Russia project, we have not yet been able to evaluate the ES of production of freshwater ecosystems (primarily fish). Data on fish stocks and catch in freshwater bodies of Russia are collected by fisheries research institutes (now they are branches of the All-Russian Scientific Research Institute of Marine Fisheries and Oceanography). These institutes monitor the abundance, biomass, and age structure of commercial fish species for large freshwater bodies (lakes and reservoirs) and, based on these data, determine the total allowable catch. Thus, the data for the assessment of provided and consumed volumes of this ES are collected. But, unfortunately, these data are not publicly available, and it was not possible to use them in the framework of the TEEB-Russia project.

The second group of questions is related to the analysis of the dynamics of ecosystems and ES, which is necessary to identify current trends and predict future changes in ecosystem assets and ES. The most important indicator of ecosystem assets is the area of natural ecosystems and its decline directly indicates a reduction in ecosystem assets. Biodiversity is the structural basis for ecosystem functioning, which, in turn, determines the volume of ES provided (see Section 6.1.3.1). Therefore, a decrease in the indicators of biodiversity, phytomass, and ecosystem productivity in any location or on average in a region indicates dangerous degradation of ecosystems that can undermine the provision of ES. To understand the ongoing processes and predict future changes, both current trends in ecosystem assets and ES and their changes in the past are important. For example, a comparison of phytomass and productivity of climax ecosystems with the same indicators, adjusted for the current degree of disturbance of the territory, shows that a significant part of the phytomass and productivity of natural ecosystems in the European territory of Russia has been lost as a result of its anthropogenic transformation in historical time (see Section 5.1.9). This may indicate the likely loss of a significant amount of ES. An important source of data for analyzing the dynamics of ecosystem assets and ES is the accounting of commercial animal species, including fish and hunting resources (Danilkin, 2009; 2016). Data on accounts of commercial animals for different years are available in departmental reports of government services for managing hunting and fish resources of Russia. This body of information needs to be analyzed at the next stages of preparation for SEEA-EEA implementation in Russia.

2.2. Spatial scales of analysis and data sources

Estimates of ecosystem condition and ES obtained in the first and second phases of the project (TEEB-Russia 1, TEEB-Russia 2) are a single data set. Physical estimates of ES for the subjects of RF obtained in the TEEB-Russia 1 project were used in the TEEB-Russia 2 for comparisons with indicators of biodiversity (Section 5) and the economic valuation of ES and ecosystem assets (Section 6.2). Therefore, in this report, as in Volume 1 of the Prototype of the National Report on Ecosystem Services of Russia (Bukvareva, Zamolodchikov, 2018), the main units of assessment remain the subjects of RF within the borders of 2012. In the TEEB-Russia 2 project, an analysis of the relationships between indicators of ES, ecosystem assets and climatic conditions is supplemented by indicator values for a grid of 50 × 50 km squares used in the Atlas of Breeding Birds of European part of Russia[6].

The tasks of the project described above were solved based on the analysis of the following data arrays (table 2.1.1):

– estimates of ecosystem condition and ES obtained in the TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018);

– estimates of ecosystem condition and ES calculated in the TEEB-Russia 2 project on the base of different data including vegetation map of Russia (Bartalev at al., 2011) (Sections 3.1 and 4);

– digital maps from the data base Land Resources of Russia[7] (Stolbovoi, McCallum, 2002);

– data on bird diversity in the European part of Russia, obtained by the scientific and public project " Atlas of Breeding Birds of European part of Russia", curated by the Zoological Museum of Moscow State University M.V. Lomonosov (Section 3.2.3.1);

– data on the diversity of vascular plants in administrative districts of a number of regions of the Central Federal Okrug, obtained by the projects "Flora of the Oka Basin" and "Flora of the Central Black Earth Region" (Section 3.3.3).

Analysis of data on ecosystem condition, including biodiversity indicators, and physical estimates of ES was carried out at the following scales:

– ecoregions within the European Russia;

– subjects of RF throughout the country (according to the TEEB-Russia 1 project);

– subjects of RF within the European Russia;

– squares of 50 × 50 km within the European Russia.

A preliminary assessment of the possibilities of using data on the species richness of vascular plants in the administrative regions of several regions of the Central Federal Okrug was also made (Section 3.3.3).

The spatial scale of assessments of ecosystems and biodiversity affects the sensitivity and interpretation of indicators. It is known that relationships between biodiversity indicators and environmental parameters can be different at different scales. The so-called “grain-focus-extent” concept (see, for example, Scheiner et al., 2000) considers three main scale levels: primary accounting units (grain), the area of investigated object (focus) and the total area within which indicators of the investigated objects are compared (extent). Depending on research tasks, a certain territory can be considered both a “focus” and an “extent”. In this project, the relationships between indicators of ecosystem condition, biodiversity, and ES are analyzed at various scales (Tab. 2.1.1). All three scales are most fully used in the analysis of indicators of bird diversity (Sections 3.2.3 and 5.1).

A grid of 50 × 50 km was created by “cutting” parallels and meridians and consists of rectangular cells with an average area of about 2500 km^2. The grid of squares used in the project corresponds to that adopted in the project “Atlas of Breeding Birds of European part of Russia” (see Section 3.2.3.1).

For some tasks, it was necessary to reduce the influence of spatial differences in natural (primarily climatic) conditions on the analyzed indicators of ES and ecosystem assets within the vast territory of the European part of Russia. For this, all the squares were assigned to one or another ecoregion (Fig. 2.2.1), within the boundaries of which the natural conditions are relatively uniform. Ecoregions were identified based on the map provided by WWF (Olson et al., 2001) with the following amendments:

[6] http://zmmu.msu.ru/musei/struktura_muzeya/sektor-nauchno-obshhestvennykh-proektov/atlas-gnezdyashhikhsya-ptic-evropejskoj-rossii

[7] https://webarchive.iiasa.ac.at/Research/FOR/russia_cd/guide.htm

1) all types of zonal tundra (Kola Peninsula tundra, Northwest Russian – Novaya Zemlya tundra, Yamal-Gydan tundra) were considered as single ecoregion of tundra and all types of zonal mixed forests (Sarmatic mixed forest and Central European mixed forests) were considered as single ecoregions of mixed forests;

2) in the taiga zone, which also includes forest-tundra (Scandinavian and Russian taiga), the ecoregion of southern taiga was identified by drawing its northern border according to the vegetation map from the data base Land Resources of Russia[8] (Stolbovoi, McCallum, 2002) while the forest-tundra, middle and northern taiga remained in the ecoregion of northern taiga;

3) corrections were made to the contours of the ecoregions of steppe (Pontic steppe) and semi-desert (Caspian lowland desert) for several subjects of RF, where significant errors were found in borders of ecoregions.

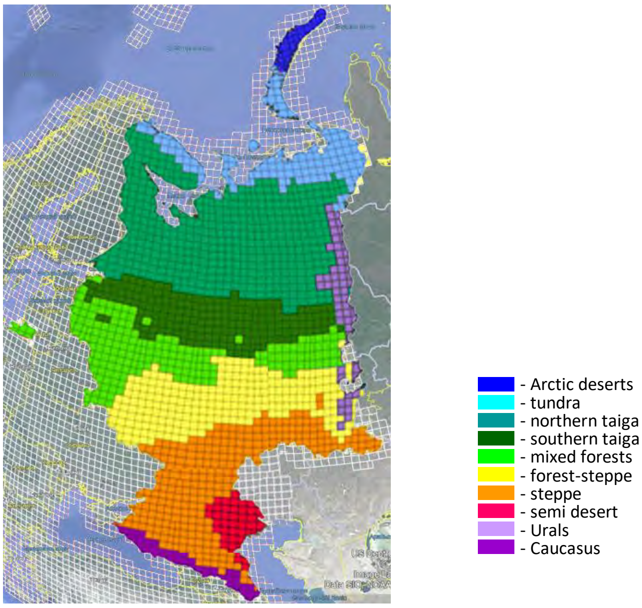


Figure 2.2.1. The distribution of the analyzed 50 × 50 km squares by ecoregions in the European part of Russia.

The 50-km squares located on the border of two ecoregions were attributed to the ecoregion, which occupied 60% or more of the square area. In rare cases, when more than two ecoregions fell into a square, the square was attributed to that ecoregion, whose share in the area was the largest. Squares, a significant part of which located in the seas or large waterbodies, were attributed to the ecoregion in which most of the land is located, even if its share in the square is below 60%.

Small sections of squares located on the border of the study area and dissected by the borders of the RF or subjects of RF, as well as small sections of coastal land and islands were excluded from the analysis if their area was less than 50% of the area of the smallest square in the grid. After that, 1654 squares remained in the full sample. In some cases, depending on the availability of actual data on the values of the analyzed indicators, the samples were smaller, which is indicated in the results of each analysis.

[8] https://webarchive.iiasa.ac.at/Research/FOR/russia_cd/veg.htm

2.3. Data processing and analysis methods

ArcGIS and NextGISQGIS were used to calculate values of indicators of ecosystem assets and ES, as well as to visualize the results.

Digital maps from the data base Land Resources of Russia (Stolbovoi, McCallum, 2002) were converted from vector to raster format and then analyzed using the same methods as raster layers of the Russian vegetation map (Bartalev et al., 2011). The method of zonal statistics and proximity analysis using ArcGIS were used to calculate values of indicators of ecosystem condition (Section 3.1) and ES (Sections 4.1.1–4.1.4, 4.1.6, 4.1.7) in 50 km squares and for subjects of RF. The average value of a parameter from the raster map within each contour (50 km square or a subjects of RF) was chosen as a function.

The values of indicators of the area of natural ecosystems and their fragmentation were calculated based on a vegetation map of Russia (Bartalev et al., 2011) after exclusion from the raster layer of roads and railways (see Section 3.1.2).

Calculation of the areas of different types of ecosystems in the buffer zones around cities (Sections 4.1.3, 4.1.7) and agricultural fields (Section 4.1.6) was done by overlaying three layers: a) buffer zones; b) ecosystem types; c) assessment units.

The number of bird species in 50-km squares was obtained from the Atlas of Breeding Birds of European part of Russia (see Section 3.2.3.1). The average values for indicators of bird species richness, Red Book indices and the degree of synanthropization for ecoregions and subjects of RF were obtained by averaging their values in individual squares within each ecoregion or subjects of RF.

The number of vascular plant species in administrative districts of selected regions of the Central Federal Okrug (CFO) of the RF was obtained from the projects "Flora of the Oka Basin" and "Flora of the Central Black Earth Region" (Section 3.3.2).

The structure of the analytical part of the TEEB-Russia 2 project is presented in Fig. 2.1.1. In accordance with it, correlations between indicators of climatic conditions, ecosystem assets and ES were investigated (Section 5). The values of indicators of climatic conditions, ecosystem assets and ES obtained in projects TEEB-Russia 1 and TEEB-Russia 2 were combined into three spreadsheets: a) for 50-km squares within the European territory of Russia; b) for the subjects of RF within the European territory of Russia; c) for the subjects of RF throughout the country. Further, these data were used to identify correlations between indicators.

Regression-correlation analysis were used for detection of dependencies between indicators. Pearson's correlation coefficient was used to identify correlations between quantitative indicators, and Spearman's rank correlation coefficient was used to identify correlations between indicators evaluated in points, as well as correlations between them and quantitative indicators. The statistical analysis performed at this stage should be considered preliminary. More detailed statistical analysis and correction of the obtained results is supposed to be done at the next stages of reserch, with the refinement of both the samples of data and the analysis methods, including multivariate analysis methods.

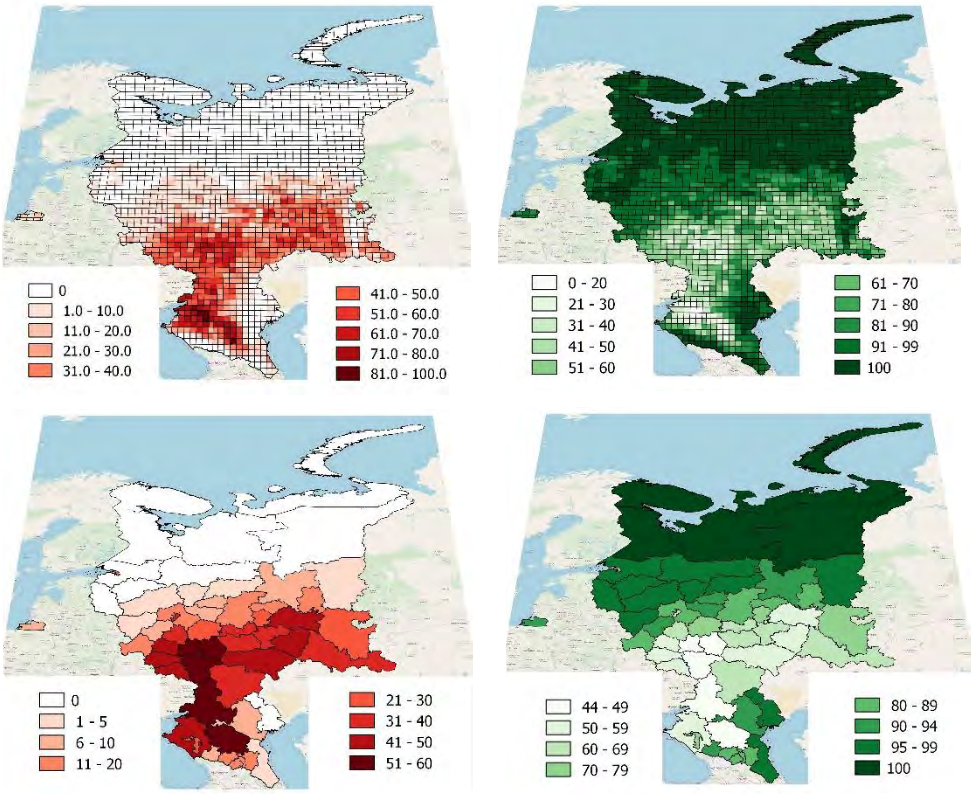
Specific methods for calculating indicator values of ecosystem assets and ES are indicated in the corresponding sections.

3. Ecosystem Asset Indicators

3.1. Indicators of the state of ecosystems

3.1.1. Degree of territory transformation

The degree of territory transformation was considered as an indicator of human disturbance of ecosystems. It was calculated as area share of fully transformed ecosystems (arable lands and urbanized zones, Fig. 3.1.1.1 a) according to the vegetation map of Russia (Bartalev et al., 2011) for subjects of RF and for 50-km squares within European Russia. In some cases, the inverse index – area share of natural ecosystems (all land cover classes except arable lands and urbanized zones) was also used (Fig. 3.1.1.1 b). The degree of territory transformation is almost entirely determined by area share of arable land area. Urbanized zones occupy a very small area overall. The exception is the square in which Moscow is located (Fig. 3.1.1.2).



a) б)

Figure 3.1.1.1. Indicators of the degree of territory transformation for 50-km squares (top row) and subjects of RF within European Russia (bottom row): a) area share of transformed ecosystems, %; b) share of natural ecosystems area, %.

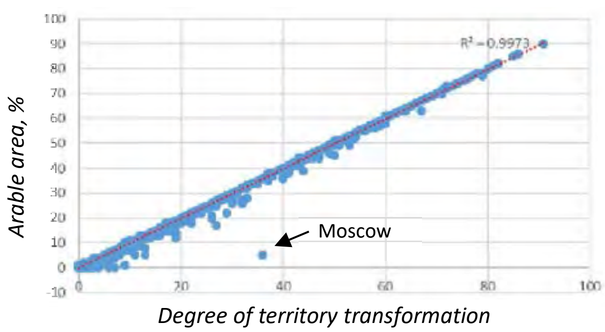


Figure 3.1.1.2. Relationship between share of arable area (%) and the degree of territory transformation.

3.1.2. Fragmentation of natural ecosystems

Two indicators of ecosystem fragmentation were calculated based on the vegetation map of Russia (Bartalev et al., 2011) for subjects of RF and 50-km squares in European Russia:

– the ratio of the perimeter to the area of plots of natural ecosystems (PAR);

– the average distance between plots of natural ecosystems (m) (DISTANCE).

All types of natural ecosystems (all land cover classes except arable lands and urbanized zones) were combined into one class. A raster layer of roads was imposed on the layer of ecosystems. According to the vegetation map resolution, a strip 250 m wide around the roads was included in the raster layer of roads. Four types of roads were considered[9]: national (federal) roads (red on the map), regional (orange) and provincial (yellow) roads, and railroads (Fig. 3.1.2.1). The discontinuities between natural ecosystems therefore consist of arable and urban areas, and roads. Figure 3.1.2.2 shows the results of the evaluation of the two indicators of fragmentation.

Figure 3.1.2.1. Four types of roads around the village of Kubinka (Moscow Oblast).

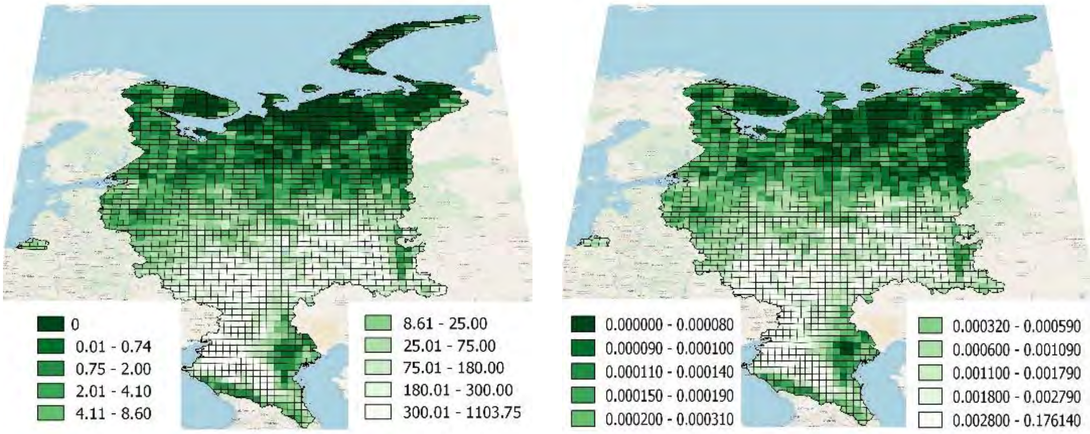


Figure 3.1.2.2. Indicators of natural ecosystem fragmentation: a) distance between natural ecosystem sites (DISTANCE); b) the ratio of their perimeter to their area (PAR).

9 Road map http://russianecoservices.nextgis.com/resource/5/display and legend for it http://m-d.me/img/ss/20180315-f3s-52kb.jpg

A strong positive relationship (*R > 0.9***, Fig. 3.1.2.3) between the degree of territory transformation and indicators of fragmentation of natural ecosystems was identified for subjects of RF and 50-km squares within European Russia. Obviously, on the scales studied, these three indicators reflect the same natural ecosystem transformation process, any of them may be used for further analysis. Subsequent analysis of relationships between biodiversity and ES, on the one hand, and the degree of natural ecosystem disturbance, on the other, were therefore performed only for the indicator of the degree of territory transformation (see Section 3.1.1).

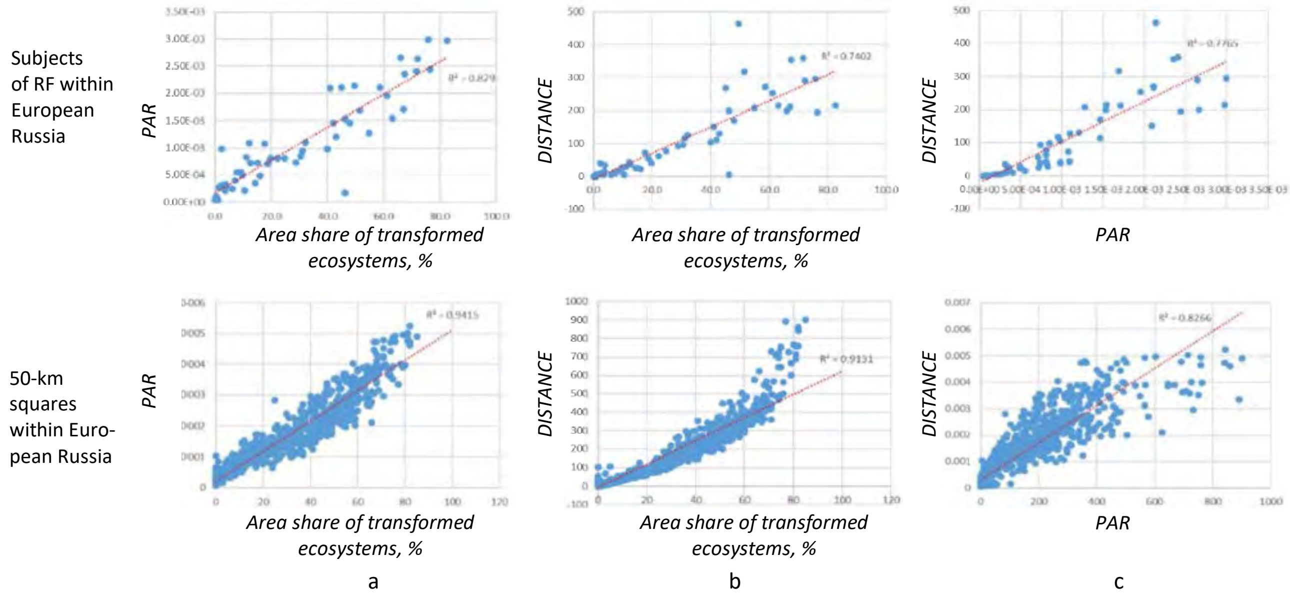


Figure 3.1.2.3. Correlations between indicators of natural ecosystem disturbance: a) PAR as a function of the degree of territory transformation; b) DISTANCE as a function of the degree of territory transformation; c) relationship between PAR and DISTANCE. Top row: relationships for subjects of RF within European Russia. Bottom row: relationships for 50-km squares within European Russia excluding incomplete border squares.

3.1.3. Phytomass and productivity

Indicators of the total phytomass density of ecosystems (hereinafter phytomass) and net primary production (hereinafter productivity) were calculated for 50-km squares and subjects of RF within European Russia (Fig. 3.1.3.1) based on data from the data base Land Resources of Russia[10] (Stolbovoi, McCallum, 2002). As follows from digital maps and their descriptions of this resource, mapped values reflect the characteristics of natural ecosystems that could be in a given territory in the absence of arable and urban areas, that is, without taking into account the current degree of territory transformation.

[10] https://webarchive.iiasa.ac.at/Research/FOR/russia_cd/veg_maps.htm#npp

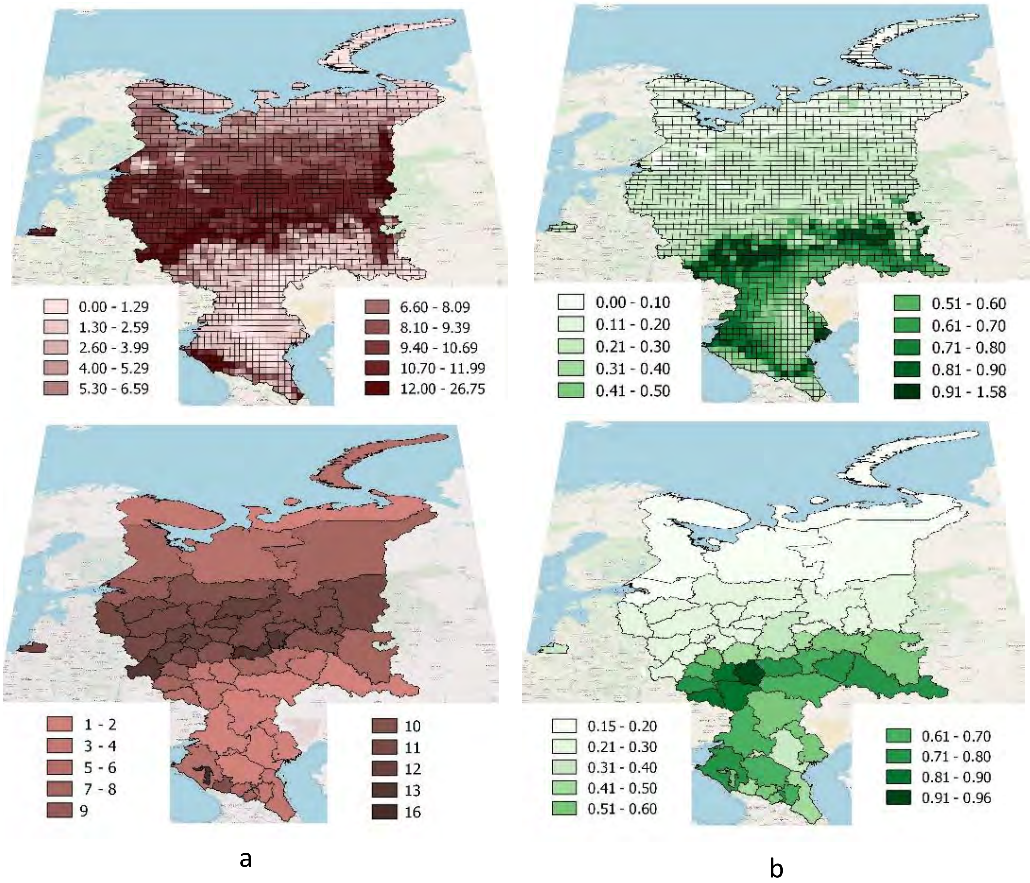


Figure 3.1.3.1. Total phytomass density, dry matter, kg/m^2(a) and net primary production, kgC/m^2/yr (b) for 50-km squares and subjects of RF within European Russia.

3.2. Indicators of bird diversity

3.2.1. Birds and Important Bird Areas as providers of ecosystem services

Biodiversity continues to decline worldwide. The intensive land use and the creation of artificial landscapes are leading to an increase in habitat fragmentation and the degradation of natural ecosystems. Birds are one of the vital components of ecosystems. At the same time, human economic activity started to play more often a defining role in the formation of the avifauna regions. The significant alteration of natural landscapes by people over time and in space often changes the significance of individual species of fauna, both in entire ecosystems (changes in species composition and abundance and sometimes even in reproduction and feeding ecology) and specifically for man. This likewise pertains to such a widespread group as birds. We know of examples when species that were abundant in the recent past (e.g., certain species and subspecies of Anseriformes) have ended up in the category of declining in numbers and protected on the global, national, or regional level, while numerically insignificant species have experienced rapid population growth in a short time period, and in a number of places their vital activities began to pose local "problems" for other fauna and man (e.g., the Common Cormorant, certain gulls and corvids).

In recent decades more and more bird species are joining the cohort experiencing a gradual population decline over a significant area of their range (State of the World's Birds…, 2018; Mischenko, 2017). As at early 2018 globally threatened species worldwide numbered 1469 (13%) of bird species, 222 of which are threatened with actual extinction in the near future (critically endangered species), unless urgent measures are taken to restore their population (State of the World's Birds…, 2018). In Russia there are 58 such species, the status of 7 of which is defined as critical, i.e., the species might disappear unless the current population declines are reversed. Europe is seeing population declines in 27.6% of breeding birds, and for another 22% trends are unknown; in only half of the species population is rising or fluctuating (BirdLife International, 2015 a). According to recent estimates, of 406 bird species (or 411 taxonomic units) that breed in European Russia a decline in population has been reported in 75 taxonomic units (73 species and 2 subspecies), including a substantial decline in 17 of them (Mischenko, 2017). This number may be larger, since population trends in more than a third of the species are unknown or opposite.

Some bird species have been classified as rare and protected globally for many decades, and their rarity has become a fact, while special efforts to preserve many of these species in some cases have halted the decline and stabilized their populations – albeit at an even lower level. The Spoon-Billed Sandpiper [Calidris (*Eurynorhynchus)* pygmeus], which nests in the tundra of north-eastern Russia, is a striking example of a species threatened with extinction globally because of the transformation and disappearance of its natural stopover sites during migration along the south-east Asian coast. However, international efforts are raising hopes for recovery of the population of this species and its preservation in nature (Syroechkovskiy, et al., 2018; Pain et al., 2018). The Spoon-Billed Sandpiper is an endemic breeding species in Russia with not a very extensive distribution range, but many bird species with extensive range are just as vulnerable. In literally just the last couple of decades the population of Yellow-breasted Bunting [Emberiza aureola] has declined catastrophically everywhere – both in Siberia, where it was more common, and in European Russia, where the species has almost stopped breeding in the last 5 years (Mischenko, 2018). The current situation with the Northern Lapwing [*Vanellus vanellus*] may be a cautionary example. This species would seem to be adapted to life in an environment substantially transformed by man, settling in large numbers on cultivated fields and meadows. The Northern Lapwing was considered a common species everywhere just recently. But, because of current changes in the processes for growing of agriculture crops, its population within the breeding range in Europe has contracted by 30–49% over 27 years; a decline has been reported also in the Asian part of its range (BirdLife International, 2018). At such rate of population decline, even a relatively numerous and widely distributed species might be at risk of extinction. In 2015 the Northern Lapwing was declared near threatened globally and vulnerable in Europe (BirdLife International, 2015 b). The rate of population reduction of the European Turtledove [Streptopelia turtur] is even more precipitous. In 1990 it was one of the most common birds, but its population decline by 30–49% in just 16 years, which places it among vulnerable species globally, not just in Europe (Belik, Mischenko, 2018; BirdLife International, 2017 a).

The Northern Lapwing and European Turtledove can certainly not be categorized as threatened as the Spoon-Billed Sandpiper. However, many species that are now threatened with extinction have started their way to rarity from an increase of the rate of drop in numbers on still extensive ranges. Analysis of the

148 most common bird species in 25 European countries has shown that, from 1980 through 2010, the population of 57 of them (39%) has fallen. Groups of farmland birds, the total population of which has fallen since 1980 by 300 million, is alarming (State of the World's Birds…, 2013). The monitoring of about 400 bird species for 40 years in North America reveals a similar gradual decline in 65 species of open habitats that inhabit primarily agricultural lands (BirdLife International, 2017b). This decline in bird population is a response to ongoing adverse changes in the use of agricultural lands (Donald et al., 2006). In this instance birds are the most visible "tip of the iceberg" of adverse changes in agricultural ecosystems. Current changes in technologies of agricultural crop growing are also leading to a simplification of food webs in soil invertebrate communities (Tsiafouli et al., 2015) and to weakness and even loss of the soil-protecting and anti-erosion properties of agricultural ecosystems (Trofimov, et al., 2016), and ultimately to a substantial disruption in the performance of this type of semi-natural ES with respect to providing people with a sustainable food supply, not only to a decline in biodiversity[11].

The current decline in the population of common bird species that inhabit almost all major types of habitats – agricultural lands, forests, and wetlands – is occurring in both temperate and tropical regions. The increasing scale of this population decline is signaling deeper environmental problems than just a decrease in the birds' numbers. The reasons for the decline in the population of the overwhelming majority of bird species and their disappearance in a particular geographic area are largely related to human economic activity and the transformation of natural ecosystems.

Birds play a substantial role in maintaining the balance of natural communities, providing certain ES. They are providers not only of provisioning ES – more utilitarian and the most comprehensible and acceptable to most people, e.g., as hunting resources or "suppliers" of down for clothing. Birds are often far more important providers of regulating and informational ES thanks to their role:

– in pest control (eliminating of rodents by birds of prey and of insect pests by insectivorous birds);

– as "clean-up crews" (many birds of prey perform important ES such as disposing of carrion, including stopping the spread of possible infectious diseases);

– in spreading the seeds of various plants (birds that eat berries and fruit);

– as plant pollinators (to some degree birds pollinate at least 50 species of the world's agricultural crops and medicinal plants).

Tracking the status of bird species that provide these and other ES can help to monitor the provision of these ES overall (BirdLife International, 2012 a; Morelli et al., 2017).

In the late 20th – early 21st centuries under the leading of BirdLife International, the global bird conservation association, a primary network of sites vital to preserving birds, or Important Bird Areas (IBAs), was identified in most countries based on scientifically validated criteria[12]. In Russia these areas are widely known as Key Ornithological Sites (Territories) of Russia (KOTR), which have international importance (completely equivalent to IBAs and included in this global network) and national or local status (they are part of the KOTR network within the Russian Federation (Sviridova et al, 2016). The monitoring of ES provided by Important Bird Areas on the international (IBAs, i.e., KOTRs of international importance) and national levels, may be the basis for tracking progress in the provision of ES in a particular region as a whole – already on the "supra-species" level (BirdLife International, 2012 a).

Since within the boundaries of KOTR/IBA, in comparison with the adjoining territory, the least deteriorated natural and natural-anthropogenic ecosystems prevail, it could be asserted that KOTRs/IBAs perform a significant portion of ES that natural ecosystems can provide, including climate regulation. In particular, it has been estimated that the global network of IBAs, which in 2013 numbered about 12,000 areas, stores about 60 gigatons of carbon in the surface and underground vegetation growing within them. This represents about 17% of carbon stores accumulated in the world's forests (State of the World's Birds…, 2013).

Understandably, the importance of each KOTR/IBA in maintaining the ecological balance may differ depending on their location, official (legal) and actual protection status of these areas, and the level of preservation of natural ecosystem patches within the KOTRs/IBAs. Some of such sites may be of the highest importance for maintaining ecosystem functions on the local level (e.g., small forest KOTRs or water bodies within a certain subject of RF), while others may be crucial to maintain and provide ecosystem services on

[11] see also http://www.ecogosdoklad.ru/2013/wwwAgrc1.aspx
[12] http://www.birdlife.org/worldwide/programme-additional-info/important-bird-and-biodiversity-areas-ibas

the national and global scale (e.g., large KOTRs/IBAs in the tundra or taiga zone, which are at the same time important wetlands).

BirdLife International initiated the creation of the Toolkit for Ecosystem Service Site-based Assessment, TESSA[13] which is intended for the development and testing of a standardized approach to assess and monitor the ES of particular sites (primarily an IBAs) by using the simplest instrumental method, which is low in cost and accessible to local specialists regardless of their training level, but it yields scientifically reliable results (Peh et al., 2014). It is planned that this method will be used by BirdLife International's partners and other concerned users to assess what part of an IBA is the most important for providing ES (benefits) for people and where within an IBA there are threats to the preservation of biodiversity or the provision of important ES by these sites. The goal of this methodological approach is to involve users and decision makers of all levels, from the local people to the national government, in the monitoring and protection of the natural environment in the interests of human welfare. One successful example of the use of this toolkit was demonstrated in Nepal (BirdLife International, 2008 a[14]). What distinguishes TESSA from many other existing ecosystem service assessment tools is the ability to use it on the local level – the assessment is carried out by taking direct field measurements of particular indicators within a limited site (e.g., an IBA/KOTR). Most other toolkits are still operated with vast territories and such indicators, application of which results in "coarse resolution" maps, the scale of which often prevents the use of a calculated ES assessment in practical decision making on management of territories on the local level[15].

Under the lead of BirdLife International in partnership with Conservation International, the International Union for Conservation of Nature and the UNEP World Conservation Monitoring Centre the Integrated Biodiversity Assessment Tool (IBAT) was developed to facilitate access to a whole dataset (represented on a global scale and on the national levels, such as: SPAs [specially protected areas] boundaries, biological information about indices of species and habitat diversity, and Key Biodiversity Areas (including IBAs) that might be useful in research and biodiversity conservation planning (IBAT for Research & Conservation[16]).

There are therefore global best practices for ES assessment, including for use by the business community, based on identified network of Important Bird Areas. In all, albeit in not very numerous, projects for ecological and economic assessment of IBAs that were to be converted for the needs of agriculture, mining industry, and other economic activities, it has been shown that the economic benefit of preserving an IBA (maintaining carbon and water balance of the area, developing its ecotourism component, etc.) is far higher or comparable to the anticipated economic gains from transforming habitats in IBAs for economic needs, especially when these services are considered and analyzed economically with a long-term (50 years or more) perspective rather than with a short-term one (a few years). Ultimately, in a number of cases after the assessment of ES of IBA, plans for cutting forests, draining lakes, and so on were canceled under the "pressure" of the received results (BirdLife International, 2008 b[17] and BirdLife International, 2012 b[18]). Mechanisms for assessing ES of IBA and putting them into economic and conservation practice have been tested primarily in countries in tropical and subtropical climate zones. This was largely governed by the orientation of the projects toward conservation of the forest ecosystems that are widespread in these zones and are the subject to extreme pressure from human economic activity, being at once as a "lungs of the planet", as well as by the significant role of wetlands in some of IBAs in providing the local population with potable water. In all cases, data on the bird species composition on IBAs were used as indicators of the condition of the environment and biodiversity during integrated ES assessment.

The practice of conducting economic work taking into account the assessment and conservation of biodiversity, including birds, both in IBAs/KOTRs and outside them, has become more common in recent years also among for-profit companies in Russia (subsoil users, manufacturers of any products…), which include a preliminary environmental assessment in their plans for development and further extraction of subsurface resources or infrastructure construction and subsequent monitoring of biodiversity in the area of future work. Examples of such approach in Russia, however, are still scarce and are being introduced into practice

[13] http://www.birdlife.org/worldwide/science/assessing-ecosystem-services-tessa),
[14] http://www.birdlife.org/datazone/sowb/casestudy/225
[15] http://www.birdlife.org/worldwide/science/Toolkit_for_Ecosystem_Service_Site-Based_Assessment/How_TESSA_is_different_from_other_tools
[16] https://www.ibat-alliance.org/; https://www.ibat-alliance.org/ibat-conservation/
[17] http://www.birdlife.org/datazone/sowb/casestudy/231
[18] http://www.birdlife.org/datazone/sowb/casestudy/507

primarily by large companies. At the same time, environmental assessment is usually considered as the conservation of "biodiversity for biodiversity's sake" (e.g., of the Red Book species – to prevent extinction) without consideration of its direct connection to preservation of human's environment per se and with the provision of any ES.

Nevertheless, for-profit companies are becoming increasingly aware of the need to conserve natural ecosystems, since they also both "depend on" and "impact" natural ecosystems and their services. Examples of up-and-running business projects that incorporate biodiversity preservation and monitoring are becoming more common. Birds serve as one of key groups for bioindication and environmental monitoring in almost all such projects. One of the first global examples of cooperation between large transnational companies and international NGOs to preserve avian biodiversity is the 10-year program by BirdLife International and the CEMEX group, a major producer of cement with a presence in more than 50 countries (BirdLife International, 2011[19]). One of the first independent Russian companies that has started to operate and provide complex environmental protection and industrial safety services to ensure environmentally friendly economic activities, including using birds as an indicator group, is FRECOM, whose customers include many oil and gas companies, energy and metallurgy companies, chemical enterprises, and the administrations of municipalities and subjects of RF, etc.[20]

In Russia, thanks to the long-term efforts of several conservation organizations under the Forest Stewardship Council (FSC), one example of indirect payments for ES is the voluntary Forest Certification System (FSC certification)[21], which include Key Ornithological Sites (Territories) of Russia[22]. Obtaining an FSC certificate gives to forestry companies an advantage on the forest products market, and the possession of this certificate means that the company made its products without impinging on the local dwellers' interests and without destroying/degrading the habitats of rare animal species and valuable nature areas. This positive experience should certainly be extended and refined in all regions of the Russian Federation, also in respect of KOTRs – including not only consideration of already known areas during conducting of forestry activities, but also further identification and disclosure of the value of KOTRs/IBAs in each region.

Thus, KOTRs/IBAs identified using uniform criteria developed based on quantitative assessment of birds' number are adequate indicators of biodiversity and natural ecosystem preservation and, at the same time, a convenient tool for protecting the natural habitat of birds and other wildlife. However, many IBAs that are important to protecting not only birds, but also other representatives of biodiversity, have either inadequate protection status or none at all. As a result, a considerable number of KOTRs/IBAs are entirely or partially under high anthropogenic pressure in the current time, and often there is a threat of decrease in the execution by these sites of their functions to conserve biodiversity, as well as to provide ES. At the end of the 2000s, SPAs existed in only half of Russia's IBAs (395 IBAs; 50.3%) and covered only 35.5% of their area; in many subjects of RF protected IBAs account for no more than 10% of their area, and the proportion of protected IBAs was lowest (about 20%) in the regions of Western Siberia (Sviridova et al., 2016). The planning and establishment of SPAs within existing IBAs is therefore an important point and a promising task of activity. The entire area of an IBA should be under some form of protection, which will ultimately foster the providing of many ES by those areas.

Birds are considered as good indicators of the environment conditions as a whole and of biodiversity in particular, since they usually belong to the top of the food chain, have large ranges and can move elsewhere when the environment becomes unsuitable for them.

Russia's bird fauna is fairly diverse and far surpass species of freshwater fish, amphibians, reptiles and mammals in number. Birds are characterized by mobility and, at the same time, by greater or lesser degree (in different species) of attachment to breeding areas (breeding site fidelity), migration stopover sites and wintering areas, which determine their prevalence under the specific conditions typical for each species. The importance of birds as indicators of the environment condition is attributable, among other things, to their large numbers and visibility, which makes it possible to record changes in their populations relatively easily and quickly. Thanks to these features, avian fauna is often more studied in many areas than other animal and

[19] http://www.birdlife.org/datazone/sowb/casestudy/228

[20] http://frecom.ru/

[21] Russian National FSC Standard. FSC-STD-RUS-V6-1-2012 Russia Natural and Plantations EN (https://ru.fsc.org/preview.russian-national-fsc-standard.a-911.pdf)

[22] http://hcvf.ru/ru/maps/hcvf-russia

plant groups. Finally, birds are a group of living organisms unmatched in their popularity, and bird experts can be found in many corners of the world, although there are fewer of them in Russia than in several other countries. These circumstances have long been used to organize and carry out monitoring of the status of both individual bird species and natural communities inhabited by particular bird species.

Requirements set for indicators usually includes the following:

– scientific validity and adequate ease of use: there must be a clear relationship between the indicator and the target object, the change of which is being tracked, and the resulting data must be integrable;

– sensitivity to changes in the "area of interest" where the use of the indicator is anticipated: the possibility of the early tracking or even prediction of ongoing changes;

– the reliability of data used as indicator;

– the possibility of regular replication (measurement) of the data that were selected as indicator;

– the existence of organizations that can continue to use the indicator in the long term, tracking and interpreting data obtained with it.

Birds meet many requirements usually set for indicators, assuming that the latter can be obtained both in the present and at any necessary time in the future. For example, in the international network Biodiversity Indicators Partnership[23], BirdLife International is positioned as an expert organization that provides biodiversity indicators based on data on birds and valuable for birds areas such as: Protected Area Coverage of Key Biodiversity Areas[24]; the Red List index in various versions of its calculation by bird data (Red List Index and disaggregations)[25]; Coverage by protected areas of sites important to mountain diversity[26]; Wild Bird Index (forest & farmland specialist birds)[27] and others. Figures of populations trends of 145 species of European birds and 380 North American bird species are used, in comparison with existing models, to calculate the Climatic Impact Indicator[28].

3.2.2. Review of existing bird databases

Monitoring, including monitoring considering the indicator role of birds in assessing ES, is not possible without databases, from which temporal and spatial slices of the status of particular species (their presence/absence, occurrence status, population, density in the environment, etc.) could be obtained. Lists of avifauna (global, regional, local) with birds' occurrence status are an example of a very simple database that can serve as a starting point for a rather limited range of monitoring tasks – for example, to track changes in the species composition of breeding fauna over a period of time, if the latter has been more or less accurately determined. The modern population monitoring is increasingly involved the collection of as much as possible amount of quantitative data, which must be comparable, i.e., gathered using a uniform methodology. However, the collection and subsequent processing of a significant amount of quantitative data, especially regularly, is challenging because of expenditures of time and money. When selecting methods for gathering of monitoring data and creating databases from them, one must therefore almost always find a compromise between the anticipated final results and the costs to collect and process source data.

The World Bird/Biodiversity Database (WBDB) is an example of a global database on birds and areas important to them. It was developed by BirdLife International[29] to gather information on the distribution of rare bird species and Important Bird Areas (IBA), but over two decades, the data that is compiled in it and the problems it solves have expanded. The WBDB is first and foremost a working tool for "internal" use in which BirdLife International's partner organizations share data essential for practical protection and analysis of the status of particular species, sites, the environment, and biodiversity as a whole. After processing and verification by experts, public information from this database is posted on the BirdLife International – Data Zone website[30]. Another example of a database on birds and areas important to them, with an emphasis on information mapping, is the online Critical Sites Network[31], which compiles information needed to manage the

[23] https://www.bipindicators.net/
[24] https://www.bipindicators.net/indicators/protected-area-coverage-of-key-biodiversity-areas
[25] https://www.bipindicators.net/indicators/red-list-index
[26] https://www.bipindicators.net/indicators/coverage-by-protected-areas-of-important-sites-for-mountain-biodiversity
[27] https://www.bipindicators.net/indicators/wild-bird-index
[28] https://www.bipindicators.net/indicators/climatic-impacts-on-european-and-american-birds
[29] http://www.birdlife.org/
[30] http://datazone.birdlife.org/home
[31] http://criticalsites.wetlands.org/en

preservation of 294 waterbird species and areas important to them in Africa and Western Eurasia from several independent databases. This tool was developed jointly by BirdLife International and Wetlands International[32], an international organization for wetland protection and restoration. Wetlands International also created an online database where current and retrospective population estimates for species, subspecies, and biogeographic populations of more than 800 waterfowl and other waterbird species[33] could be obtained. All these databases contain information on birds for the Russian Federation.

Since their establishment, mentioned above databases have been largely focused on solving applied conservation problems, although the information in them is also used to solve a number of scientific problems. The more effective development of bird protection activities often requires more extensive data about species composition, distribution, numbers, nesting density and other features of species presence not only on most valuable for bird areas, but in a region as a whole. Such information serves as the basis for a more accurate estimate of the current distribution and rarity of birds and for tracking trends of species number. This kind of information is collected, for example, in the eBird database[34] – one of the first online resources for gathering bird observations in the United States, which is currently broadening the collection and presentation of bird observations worldwide. In Europe, many projects for gathering alike information, e.g., the Atlas of European Breeding Birds[35], are carried out by the European Bird Census Council (EBCC)[36], whose work is largely focused on monitoring of bird population changes and developing biodiversity indicators for use in European countries (Vorishek, 2018). In many countries, particularly in Europe, these databases or software packages compatible with them are used to develop national databases.

Most of these bird databases are expanded and populated thanks not only to the participation of specialists – academics and programmers, but to information gathering by ornithologists and bird lovers. Specialists are primarily engaged in setting the objectives for creation of the databases (both for the purposes of some current short-term projects and for longer-term prospective objectives), developing the methodologies for monitoring and data acquisition, training amateurs to use these methodologies, processing the resulting data, preparing reports and publications, etc. Also important are efforts to engage new people in the work and maintain their interest in regular participation in database population: projects, training and other seminars, field trips, the publication of bulletins and periodicals, presentations of results obtained using information from the database, etc.

Most of these bird databases are developed and updated due to not only the participation of specialists – scientists and programmers, but also because information gathering by ornithologists and birdwatchers. Specialists are primarily engaged in setting the objectives of databases establishment (both for the purposes of some current short-term projects and for longer-term prospective objectives), developing the methodologies for monitoring and data collection, training amateurs to use these methodologies, processing the obtained data, preparing reports and publications, etc. Also important are efforts to engage new people in the work and maintain their interest in regular participation in updating database: projects, training and other seminars, field trips, the publication of bulletins and periodicals, presentations of results obtained using information from the database, etc.

Similar work on birds is also being done in the Russian Federation. So far, its scope is smaller than in western European countries, although this scope is required to cover the vast Russian territory, and with less regularity, which in most cases is determined by a shortage of financial resources. Current limitations on updating the existing Russian databases are also attributable to the fact that the country still lacks enough ornithologists – both specialists and amateurs – to cover this vast territory. Nevertheless, bird databases, it seems, are currently more representative in Russia than data banks for other fauna.

The spatial distribution of bird species diversity of bird and other groups within Russia has been analyzed more than once (e.g., analysis of the country's 487 landscape zones[37]), but not in direct relation with ES or the indicator role of these groups in evaluating the preservation of natural ecosystems. Researches on avifauna and zoogeographic zoning has been developing in Russia traditionally, and in particularly they were

32 https://www.wetlands.org/
33 http://wpe.wetlands.org/
34 http://ebird.org/ebird/eBirdReports?cmd=Start
35 http://s1.sovon.nl/ebcc/eoa/
36 http://www.ebcc.info/art-1/
37 http://www.sci.aha.ru/biodiv/npd/1_27.htm, http://www.sci.aha.ru/biodiv/npd/npd1_25.gif

based on a quantitative assessment of birds – extrapolation of some sampling counts to vast areas of habitats based on habitats' maps of different scales and accuracy. The results of this study represent a fairly valuable format of data on bird distribution within various zones of Russia – species composition, abundance, population density, etc. (e.g., Blinova, Ravkin, 2008; Ravkin, Ravkin, 2005; Vartapetov, Germogenov, 2011). But adequate abundance and distribution estimates for the majority of rare and sporadically distributed or colonially settled species is difficult or impossible. Indicators of bird abundance obtained with this extrapolation probably better reflect the actual situation in nature for widely distributed common species. Because such type of work is costly enough, this format and other similar formats for collecting and processing data, in which habitat maps are used to extrapolate data on bird numbers over vast areas, not often applied for operational development of specific conservation measures and indications, but this is possible and has been tested in a number of regions of the Russian Federation[38]. It is this approach that is usually used to determine the bird resources in a particular territory, including with a calculation of their cost and an economic estimate of the damage from economic activity as well as to develop principles for managing the populations of individual groups of birds (Krivenko et al., 2004; Krivenko, Vinogradov, 2008; Korepova, 2017; Rosenfeld, 2015; Rosenfeld, et al., 2017).

Information on species listed in national and regional Red Data Books is most often used to promptly solution of various conservation tasks and as indication on good quality of natural ecosystems. In addition to more comprehensively collected data on birds that are rare or declining in numbers, regular work is being done to estimate the population of game birds. This work is being done specifically by the Russian Ministry of Natural Resources – its Federal Center for the Development of Hunting (FCDH) division. Field counts are usually done as part of the activities of hunting enterprises using similar methodologies, presented in particular on the FCDH website[39]. This organization processes and analyzes count data received from hunters[40], which, however, have significant gaps[41].

Table 3.2.2.1 presents examples of currently available data sources on birds in Russia and areas important for bird conservation. The databases marked in the table with three asterisks are currently the most comprehensive in terms of coverage of territories and/or groups of bird species within Russia and, at the same time, have most open policy for using these data for purposes of nature conservation. Some important information on aspects of bird distribution, primarily on their migrations, can also be found in the database of the Ringing Center of Institute of Ecology and Evolution of the Russian Academy of Sciences[42]. Additional information on bird biology and ecology, which may be useful in developing conservation measures or setting biodiversity indicators are, among other places, contained in resources such as: "The Vertebrates of Russia" database, where Birds section contains profiles of 738 bird species of Russia[43]; "Birds of Russia" – the online version of published volumes in the "Birds of the USSR" / "Birds of Russia" series[44] and others.

A significant portion of mentioned above databases is devoted to information exclusively or primarily on birds. In some of them the information on bird distribution is a component of a more extensive database. Besides international and all-Russian databases, numerous regional databases have been created and expanded in recent years, often in the format of various kinds of cadasters, in which birds are almost always components. Regional databases usually contain a lot of actual (not outdated) information about state of birds in corresponding territory (subject of RF; municipality; SPAs; several subjects of RF combined on the basis of some common attribute, etc.). The content of some databases is limited to a certain geographical area (e.g., Arctic Birds; Breeding Birds of European Russia; Birds of Moscow and the Moscow Environs). Many databases emphasize one group of birds or topic (e.g., databases on game species; databases on Red Data Book species; databases of raptors; a database on Important Bird Areas; a database on the nesting of the White Stork, etc.). Regional and multi-regional sites for birdwatchers have expanded significantly in recent years. While they are not formally databases on bird distribution, they contain current information on bird

[38] e.g.., http://www.ecoexpertcenter.ru/imp_pics/inf_blok/Kadastr_present.pdf, https://www.casarca.ru/images/proekty/rar-eyanao/02Rozenfeld.pdf; https://www.casarca.ru/images/okhota/09_Rozenfeld_2015a.pdf

[39] http://www.ohotcontrol.ru/materials/methods/

[40] http://www.ohotcontrol.ru/resource/Resources_2008-2013/Resources_2008-2013.php

[41] See, for example, https://www.casarca.ru/okhota-na-guseobraznykh

[42] http://ringcenter.ru/

[43] http://www.sevin.ru/vertebrates/index.html?pre_birds.html

[44] http://www.egir.ru/

encounters in a particular geographic area (e.g., Birds of the Yaroslavl Area[45]; Birds of the Middle Volga[46]; Birds of Russia's Far East[47] and many others).

Unfortunately, some databases are still fully or partially presented in hard copies (both in published form and in manuscript) or are available in an electronic version, but only in text format (e.g., Nature Archives, the majority of Red Data Books). In the best case these text data are provided in the form of interactive web publications (e.g., Red Data Book of the Russian Federation (2001)[48]; Red Data Book of Moscow Oblast (2008)[49]; data on KOTRs of international importance (IBAs)[50]; database of birds of South-east Siberia[51]). Not all of currently existing data banks on birds of Russia or its regions contain sufficiently formalized data – e. g., datasheets in some format with a "breakdown" of their content by topic fields, which allow to get any set (queries) of data for analysis as quickly as possible.

Most databases on bird distribution in Russia are based and maintained primarily by non-governmental organizations. Government databases that contain information on birds include: Nature Archives of Strict Nature Reserves; species data in the Red Data Books of the RF and RF regions (subjects of RF); data on estimates of game species populations gathered by FCDH; databases of a number of research institutes (e.g., IPEE RAS, ISEA SB RAS, etc.).

Currently not all databases with information on bird distribution can provide complete or almost complete open access to all concerned parties. In some cases, this is determined by technical difficulties – the organization does not have resources to develop and maintain a full-function online version for data that it could provide in the open access. Many cadastral data are usually closed to public access and used internally by the organization that established the database and/or its affiliates, and the data can be used only on a contractual (both commercial and non-commercial) basis.

A main problem of most biodiversity databases established in the Russian Federation in the late 20th – early 21st century is a low degree of updating information in them or low replenishment with current data for "new" (previously uncovered) territories. The most common source of this problem, not the only one, but the main one, turns out to be the lack of sustainable funding channels to maintain a data bank. No less important is significant imbalance between the number of ornithologist and huge areas of the country. With rare exception, most databases were developed as part of short or long-term projects, at the end of which data collection and database replenishment ceased, either immediately or over time. In some cases, data banks continue to be maintained even without adequate funding, but the coverage of data and geographic areas is substantially lowered. As a result, the value of the information in the DB gradually declines because of its less completeness and the outdating. In particular, these "problem" databases, including those on birds, include many databases on the open access portal Biodat[52]; a number of other databases have similar problems.

The development of programs to support existing regional and all-Russian bird databases, including by the Russian Federation governmental entities, would certainly allow to have already in nearest years extensive and adequate information that can be used efficiently for bioindication of natural ecosystem preservation and assessment of ES on one or another territory. The gradual development of amateur ornithology in Russia sooner or later will make it possible to solve of the problem of the lack of personnel (birdwatchers) for gathering primary information about bird distribution, as has been demonstrated in many other countries in recent decades. The development of this direction in Russia is already engaged by a number of public (non-governmental) organizations dedicated on bird conservation and research.

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[45] http://yarbirds.ru/index.html
[46] http://volgabirds.ru/home/o-sajte
[47] http://fareastru.birds.watch/v2about.php?l=ru
[48] http://www.sevin.ru/redbook/
[49] http://kkmo2.verhovye.ru/index.html
[50] http://www.rbcu.ru/programs/92/
[51] http://bird.bsu.ru/basic/web/index.php
[52] http://biodat.ru/

Table 3.2.2.1. Examples of databases (DB) on bird distribution in the Russian Federation.

*****For the majority of databases, the reference to all of the Russian Federation (RF) or part of it pertains to the data gathering objectives set by the coordinators, but as at 2018 many databases are being in the stage of accumulating information (i.e., data for all of the RF may not yet be sufficiently complete for particular indicators).

*** Databases with the most comprehensive coverage of territories and/or groups of bird species within Russia and, simultaneously, most open policy for using these data.

III – HC (hard-copy texts: publications, manuscripts); **EL** (electronic texts; may be available (completely or partially) or not available on websites); **SS** (software shell) of a DB, from which one can select data, but an online version does not exist); **ONL** (fully or partially developed – not all data are output) online version of the DB; online data selection available).

IV – completely open (data are in a completely open online version with the option of creating and saving queries from them, or the needed data samples can be obtained on request from the coordinators: free for non-commercial use); **partially open** (data are accessible and may be used for non-commercial purposes, but prior agreement to the terms for acquiring and using them is required; in special cases data may be used on a fee basis); **restricted** (data are usually used internally by the developer (or copyrights holder); agreement on the possibility of their use by outside individuals and organizations is required in each specific case.

I	II	III	IV	V
Main content	*Coverage of the RF**	*Storage medium*	*Access to data*	*Primary organization that holds copyrights on the database DB URL and/or other contacts to communicate with DB administrators*
Key Ornithological Sites (Territories) of Russia (KOTR) ***				
Name, coordinates, area and rank of the KOTRs' importance. Information on the occurrence status and number of birds in the KOTR, primarily – rare and congregatory species; trends in population change (if known). Data on habitat (% of total KOTR area), land use (%), and threats (ranks) of the KOTR. Data on KOTRs of international importance (IBAs) are also presented in the Russian section of the World Bird/Biodiversity Database.	whole Russia,	SS, HC, EL, ONL	partially open	Russian Bird Conservation Union (coordinating center and regional branches) *http://www.rbcu.ru/programs/93/* (*IBAs in European Russia*) *http://www.rbcu.ru/programs/92/* (*IBAs in Western Siberia*) *http://www.rbcu.ru/programs/78/27222/ (IBAs boundaries in GIS format)*
Breeding birds of European Russia***				
Species composition, breeding status (*categories*) and number (*numerical score according log scale*) of birds for 50×50-km squares in European Russia, with the observation year (season) or period (e.g., 2011–2013); more precise expert estimates of number are given for some species (not on a log scale). Data for the RF are also fully represented in the European Bird Census Council database and are expected to be included in the Global Biodiversity Information Facility (GBIF).	whole European Russia	SS, EL, ONL	partially open	Zoological Museum of Lomonosov Moscow State University *http://zmmu.msu.ru/musei/podrazdeleniya/sektor-nauchno-obshhestven-nykhhttp://zmmu.msu.ru/musei/struktura_muzeya/sektor-nauchno-obshhestvennykh-proektov/atlas-gnezdyash-hikhsya-ptic-evropejskoj-rossii* *voltzit@zmmu.msu.ru* (O. V. Voltzit, adm.)
Birds observations database from Russia and neighboring regions ***				
Species composition and occurrence status of birds with dates and coordinates of encounters, types of habitats and a number of other features of bird presence at the observation point; the actual number of observed birds is given. Database combined with map. Data is also fully presented in the Global Biodiversity Information Facility (GBIF).	whole Russia,	ONL	completely open	Zoological Museum of Lomonosov Moscow State University *http://www.ru-birds.ru/*
Birds of Moscow and Moscow Region				
Species composition and occurrence status of birds with dates and coordinates of encounters, types of habitats and a number of other features of bird presence at the observation point; the actual number of observed birds is given.	Moscow region and, in part, adjacent regions	SS (main DB), HC, EL,	partially open	Zoological Museum of Lomonosov Moscow State University *http://www.birdsmoscow.net.ru/* *voltzit@zmmu.msu.ru* (O. V. Voltzit, adm.) *a-morkovin@ya.ru* (A. A. Morkovin, adm.)

Web-GIS Wildlife Monitoring (or Web-GIS "Faunistics") ***				
Bird encounters with dates and coordinates; the completeness of encounter information varies and is entered in text format; there is a library of observation photos. Database combined with map. The DB has regional and topic-specific section, which contain data not only on birds (sections of Web-GIS "Faunistics" platforms could be filled separately). The data are also full presented in the Global Biodiversity Information Facility (GBIF).	whole Russia,	ONL (main DB), SS,	partially open	Sibecocentre LLC *http://wildlifemonitoring.ru/ (web GIS)* *contacts:* *office-sibeco@ya.ru;* +7-923-150-12-79
Arctic Birds ***				
Data on bird distribution, presence, reproductive success and abundance at different points in the Arctic (circumpolar, but most data pertain to the RF). There is information on the abundance of a number of mammals (lemmings, Arctic foxes [Alopex lagopus], whose presence influences bird reproductive success. Database combined with map. Weather and climate maps for all breeding seasons are also provided.	Arctic regions of Russia	ONL	completely open	International Wader Study Group; Working Group on Waders of Northern Eurasia *http://www.arcticbirds.ru/* *http://www.arcticbirds.ru/*
The IUCN Red List of Threatened Species				
Information on all the world's bird species with an assessment of their rarity state, including species that are currently not categorized as rare (least concern species). The main IUCN Red List DB contains extensive data (both proprietary and links to outside resources) about all rare bird species that require conservation and restoration globally. Registered users have the ability to obtain the data they need in tabular form and in GIS format.	whole Russia,	ONL	open	International Union for Conservation of Nature and Nature Resources (IUCN) *http://www.iucnredlist.org/*
Red Data Book of the Russian Federation (RDB of RF) ***				
Data on rare bird species that require conservation and restoration on the national level. RDB of RF species profiles contain distribution maps, information on species rarity category, population and distribution, limiting factors and necessary conservation measures. A web publication has been created at the Institute of Ecology and Evolution of the Russian Academy of Sciences [IPEE] website to search for information about species in the RDB of RF (2001). A new edition of the RDB of RF is planned in the near future.	whole Russia,	HC, EL,	open	Ministry of Natural Resources and Environment of RF *http://www.mnr.gov.ru/docs/strategii_i_doktriny/* (*version of the online publication for downloading as an archive*) *The online version of the 2001 RF RD is available at the IPEE website*: *http://www.sevin.ru/redbook/*
Regional Red Data Books (RDB of subjects of RF)				
Data about rare bird species that require preservation and restoration on the level of a particular subject of RF. Species profiles contain distribution maps, species rarity category, information on population and distribution, limiting factors and necessary conservation measures. Online versions of RDB of subjects of RF profiles in many regions have been created in text and/or database format for easy access (including for maintaining RDB using GIS technologies).	territory of a subject of RF	HC, EL, SS, ONL	public (text format) partially open or restricted (DB for maintaining the RDB of subjects of RF)	Regional divisions of the Ministry of Natural Resources and Environment of the Russian Federation in the respective subjects of RF *The majority of regional Red Data Books or links to them are accessible in the "SPA of Russia" information analysis system: http://oopt.aari.ru/rbdata/900*

Nature Archives of RF reserves				
Birds are one of the basic components of monitoring to maintain annual Nature Archives of Strict Nature Reserves. The completeness of bird data depends on a reserve's research plans, the size of its ornithologist staff, etc. Most often data are gathered from different kinds of route (transect) censuses, but methodologies may vary (even within one reserve from year to year). Nature records are transferred (as report materials) to the Ministry of Natural Resources and Environment of RF.	within the reserve boundaries, sometimes more widely	HC, EL,	partially open	Administrations of Reserves Ministry of Natural Resources and Environment of RF *Archives of Ministry of Natural Resources and Environment of RF* *Many Nature Archives, especially in the recent years, are available for free download at the reserves' websites and elsewhere.*
Monitoring of game species by Federal Center for the Development of Hunting (FCDH)				
Data on the population (reserves) of game birds as a component of the DB for all game animals. Primary census data are provided by regional community (society) of hunting users. Then these data are consolidated for municipal districts, federation constituents, RF administrative districts (okrugs), and the entire RF. The approval of FCDH is required to obtain data.	whole Russia,	EL, SS,	restricted	FCDH of the Ministry of Natural Resources and Environment of RF *http://www.ohotcontrol.ru/* *http://www.ohotcontrol.ru/resource/Resources_2008-2013/Resources_2008-2013.php (consolidating data for the RF for several years)*
DB "Resources of waterfowl birds of Russia" of the Science Center "Biodiversity Protection" LLC				
Contains initial census data and resource assessments of waterfowl birds based on extrapolation of sample censuses to habitat maps of a particular natural zone (47) or a subject of RF. The database has a GIS component. The DB's primary purpose is for cadaster use. The DB software shell is universal and makes it possible to create cadasters for any set of species groups and geographic areas. Developed initially for waterfowl birds, the database currently contains information about different bird species for many areas of the RF. A series of integrated fauna cadasters have been developed on the basis of the Center's methodology and DB.	whole Russia,	SS,	restricted	Science Center "Biodiversity Protection" LLC of the RANS [Russian Academy of Natural Sciences] *http://www.ecoexpertcenter.ru/* *A consolidated DB of waterfowl birds in RF hosted by the IPEE RAS [Russian Academy of Sciences] as a component of hunting resources*: *http://www.sevin.ru/bioresrus/db_methodology.html*; *http://www.sevin.ru/biores/index.html*
The Northern Eurasia fauna population data bank of the RAS Siberian Division's Institute for Fauna Taxonomy and Ecology [RAS SD IFTE]				
The actual animal's counts, including birds, within Northern Eurasia (within the USSR's boundaries in 1990), primarily for the Western Siberian Plain and the Altai-Sayan Mountains. Birds are one of the major components of the DB. Census data are available primarily starting from 1960, but there are earlier data (from 1929). The bank is outfitted with a number of proprietary data processing programs. The bank's services are used by employees of 35 research organizations (including 17 Strict Nature Reserves).	a number of regions in Siberia and some regions in European Russian	SS,	partially open	Institute of Systematics and Ecology of Animals of Siberian Branch of Russian Academy of Sciences (ISEA SB RAS), Zoomonitoring Laboratory *http://eco.nsc.ru/data_bank.html*
Database of White Stork nests in Moscow Region				
The database was created as part of a project to count and monitor the nesting sites of the White Stork [Ciconia ciconia] in Moscow Region; it also has some information on adjacent areas. It contains data on known nests with their status (occupied/empty) and the number of nestlings and breeding success (if known) in different years. An example of a narrowly focused DB created within a more extensive program, Birds of Moscow and the Moscow Environs.	Moscow Region	ONL	open	Zoological Museum of Lomonosov Moscow State University *http://birdsmoscow.net.ru/monitoring-gnezd-belogo-aista.html* *http://birdsmoscow.net.ru/stork.html*

3.2.3. Indicators used in the project

3.2.3.1. Use of data from the Atlas of Breeding Birds of European part of Russia

In the frame of the program "Atlas of Breeding Birds of European part Russia" under the leading of the Zoological Museum of Lomonosov Moscow State University, in 2005–2018 a database was assembled, including 166,857 records on 414 bird species for 1,662 50 × 50 km squares, 55 of which are entirely or partially outside European Russia – along the eastern boundary of the Ural Mountains within West Siberia (for the data collection methodology used in the atlas see in Kalyakin, Voltzit, 2015). Biodiversity indicators based on data from the "Atlas of Breeding Birds of European part Russia" were developed for European Russia within RF constituents that are located entirely or partially west of the Urals. 20 species, mainly on the edge of their ranges, that were found in 2005–2018 within the ETR in 5 or less squares were excluded from the analysis[53]. In addition, 90 squares were excluded, which were least studied, and species lists in which are not representative. The final set of data used for this analysis includes 160,698 records in 1532 squares on 394 species of breeding birds registered within the administrative boundaries of European Russia in 2005–2018. The Russian Federation Red Data Book (2001) includes 53 of the 394 species, for which there are 5,931 records for analysis in 1272 squares.

To diminish the impact of regional variations in breeding bird lists on the values for biodiversity indicators, all 50 × 50 km squares were assigned to a particular ecoregion, within each of which the bird habitats and, accordingly, species lists are more similar (see Section 2.2 and Fig. 2.2.1).

Table 3.2.3.1.1 presents the distribution of breeding bird species in 10 ecoregions in European Russia. Indicators of bird species richness (table 3.2.3.2.1) and of conservation importance (table 3.2.3.3.1) were calculated for each of 50 × 50 km squares. In addition, such index as the synanthropization level of the bird population was considered (Section 3.2.3.6).

Table 3.2.3.1.1. Total number of breeding bird species registered in 2005–2018 in ecoregions of European Russia

Ecoregion	*Number of species*	
	Total	*Included into the RF Red Data Book*
Arctic deserts	23	1 (4.3%)
Tundra	204	11 (5.4%)
Northern taiga	263	15 (5.7%)
Southern taiga	241	18 (7.5%)
Ural montane forests and tundra	230	13 (5.7%)
Mixed forests	243	21 (8.7%)
Forest steppe	249	28 (11.2%)
Pontic steppe	292	47 (16.1%)
Caspian lowland semi-deserts (or Caspian lowland desert)	217	36 (16.6%)
Caucasus forests	235	33 (14%)

Data series for total set of squares or samples for ecoregions as well as mean values per square calculated for each ecoregion were used. Because bird habitats and spatial distributions in mountain are different from those on plains, the Ural montane forests and tundra (Urals for short) and Caucasus forests (Caucasus for short) ecoregions were classified as montane, the rest as plain.

A part of the analysis, including to develop and select indicators, where it was necessary to account for bird diversity most completely, was applied for entire available sample of squares (*n=1532*). Since land mass

[53] Northern Gannet (Morus bassanus), Canada Goose (Branta canadensis), Snow Goose (Anser caerulescens), Steller's Eider (Polysticta stelleri), Pacific Golden Plover (Pluvialis fulva), Greater Sand Plover (Charadrius leschenaultii), Grey Phalarope (Phalaropus fulicarius), Swinhoe`s Snipe (Gallinago megala), Snowy Owl (Nyctea scandiaca), Red-rumped Swallow (Cecropis daurica), Brown Shrike (Lanius cristatus), Red-tailed Shrike (Lanius phoenicuroides (inc. karelini) [isabellinus]), Asian Desert Warbler (Sylvia nana), Firecrest (Regulus ignicapilla), Rufous Scrub Robin (Erythropygia galactotes), Short-toed Treecreeper (Certhia brachydactyla), Shikra (Accipiter badius), Yellow-legged Gull (Larus michahellis), Red-throated Flycatcher (Ficedula albicilla), Long-tailed Rosefinch (Uragus sibiricus). Bird names are taken from Koblik, Arkhipov, 2014.

area within some squares was very small (squares on the borders of the RF, islands, etc.), it was impossible to do representative calculations of the values of other indicators (degree of transformation of the territory and phytomass, productivity, etc.) for them. A significant part of the subsequent analysis was therefore done for a set of data on 1452 squares, after excluding such incomplete squares from the sample to reduce possible errors. These 1452 squares were distributed among the ecoregions as follows: 16 squares in the Arctic desert, 68 in the tundra, 340 in the northern taiga, 179 in the southern taiga, 201 in mixed forests, 242 in the forest steppe, 270 in the steppe, 41 in the Caspian lowland semi-desert, 40 in the Caucasus forests and 55 in the Ural montane forests and tundra. The largest proportion of incomplete squares (*n=16*, 50%) was typical for the Arctic desert ecoregion because many squares there have only small islands and insignificant areas of coastal land. The proportions of incomplete squares in other ecoregions were: 16% in the tundra (because of extensive coastal belt), 2% in the northern taiga, 0.5% in the southern taiga, 5% in mixed forests, 1.6% in the forest steppe, 1.5% in the steppe, 18% in the Caspian lowland semi-deserts (because of extensive coastal belt), 11% in the Caucasus forests (because of squares along the RF border) and 12.7% in the Ural montane forests and tundra (because of squares along the eastern boundaries of administrative regions of European Russia). It should also be noted that areas within the Arctic desert, tundra, and extreme north-east of the norther taiga ecoregions were the least studied during data gathering. Accordingly, data for these ecoregions, especially the Arctic deserts and tundra, are less complete in the samples than for the remaining ecoregions.

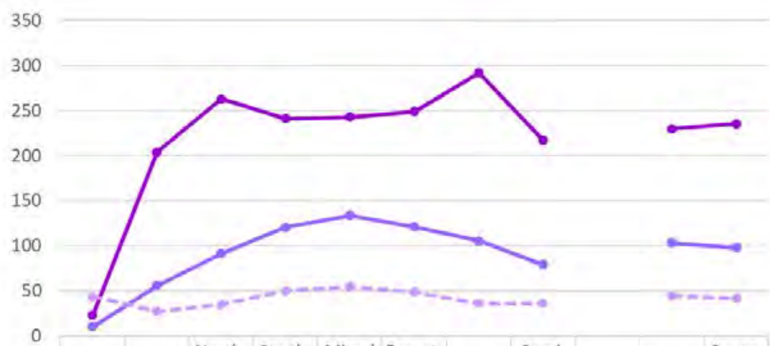
3.2.3.2. Indicators of bird species richness

Two indicators were calculated for testing to assess bird species richness (table 3.2.3.2.1).

Table 3.2.3.2.1. Indicators of bird species richness

No.	*Indicator*
1	**Number of bird species registered in a square**
2	**Share of registered in a square species of their total number in the ecoregion (%)**

The first indicator is the simplest, relatively easy to obtain, and often used in practice to estimate bird diversity. In eight lowland ecoregions, indicators of bird species richness are highest in forest, forest steppe and steppe regions, naturally decreasing in the north – in the tundra and Arctic deserts and in the south in the semi-desert zone. The largest total number of bird species in an ecoregion was registered in the steppes and northern taiga; somewhat less in other forest ecoregions and the forest steppe (table 3.2.3.1.1). The mean value of species number per square in an ecoregion (hereinafter mean species number per square) varies more uniformly and is almost entirely consistent with the well-known relationship between species richness and climate (see Section 5.1.4) and maximum in mixed forests (Fig. 3.2.3.2.1.).



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Cauca-sus
Total bird species number in ecoregions	23	204	263	241	243	249	292	217		230	235
Mean bird species number per 50-km square	10	56	92	121	134	121	106	79		103	98
Share of registered in a square species of their total number in the ecoregion	44	28	35	50	55	49	36	36		45	42

Fig. 3.2.3.2.1. Indicators of bird species richness in ecoregions within European Russia (total set of squares, n=1532).

The second indicator, "Share of registered in a square species of their total number in the ecoregion", was calculated to try to minimize the effect of latitudinal climate changes on bird species-richness in the squares to ascertain the effect of other natural and anthropogenic factors on bird distribution in European Russia. Obvious, these indices are interchangeable within each individual ecoregion, since the second indicator is obtained by dividing values of the first one by the same figure (total number of species in the ecoregion). The change in the mean for ecoregion values of index "Share of species of their total number in the ecoregion" turned out to be largely similar to the change in the mean species number per square, except the high value for this indicator in Arctic deserts, which reaches its maximum values in forest ecoregions and the forest steppe, and the absence of a decrease in the semi-desert ecoregion (Fig. 3.2.3.2.1). The high value of index in the Arctic desert ecoregion may be a result of statistical error because of the small number of squares and incomplete data for this ecoregion in the analyzed sample. Accordingly, the values for this index in the Arctic desert are unsuitable for practical use yet – both on the scale of European Russia and within this ecoregion.

A comparison of the mean for ecoregions values of the index "Share of species in a square of their number in the ecoregion" shows that it is almost independent on the total species number in an ecoregion (Fig. 3.2.3.2.2 a, b), which may be expected if species spatial distribution does not depend on the total species richness in an ecoregion. However, there is a significant positive correlation between mean values of index "Share of species in a square of their number in the ecoregion" and-mean species number per square, especially if the outlying value for the Arctic deserts is excluded from analysis (Tab. 3.2.3.7.3; Fig. 3.2.3.2.2 c, d). This correlation indicates differences in the features of the spatial distribution of bird population in different ecoregions, which is reflected by the index-"Share of species in a square of their number in the ecoregion".

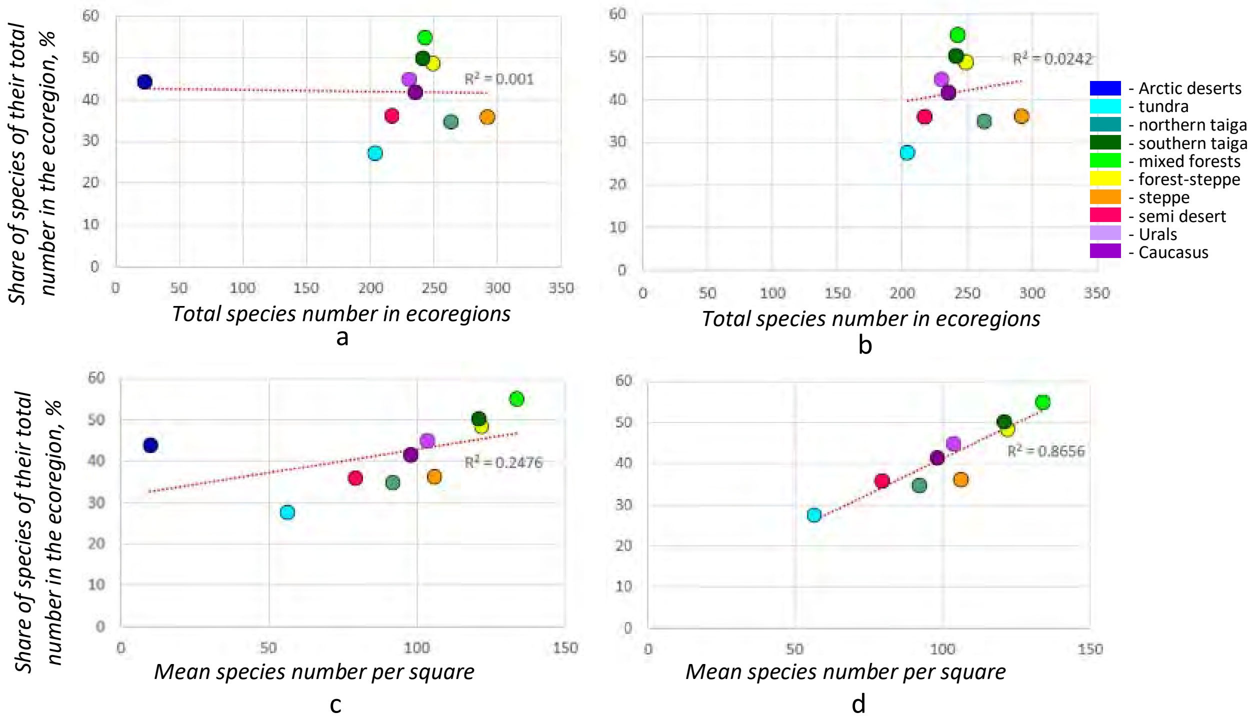
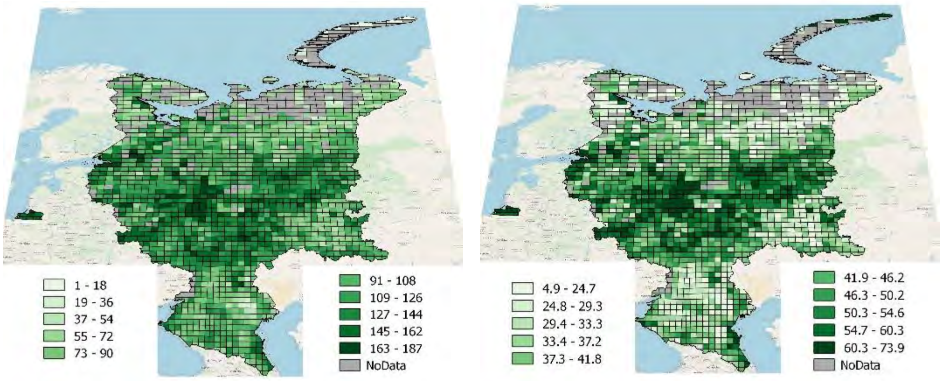


Fig. 3.2.3.2.2. Relationships between mean values of the index "Share of species of their total number in the ecoregion" and indicators of species richness in ecoregions: total number of species in ecoregions (a, b) and mean number of bird species per square (c, d). Graphs "a" and "c" are plotted for all ecoregions within European Russia; the Arctic desert ecoregion is excluded from graphs "b" and "d". Values pertaining to different ecoregions are shown in colors that correspond to the ecoregions map in Fig. 2.2.1.

The spatial distribution of the actual values of bird species richness indices in the 50-km squares is also similar (Fig. 3.2.3.2.3) and both indicators remain highly correlated (R_s=0.94, n=1452, p<0.0005). This fact is largely determined by the relatively small differences in values of the total number of breeding birds registered in a particular ecoregion, except Arctic deserts, and lower values in the tundra and Caspian lowland semi-desert (Tab. 3.2.3.1.1).



a b

Figure 3.2.3.2.3. The spatial distribution of bird species richness indicators in 50-km squares: a) bird species number per square; b) the index "Share of bird species in a square of their total number in the ecoregion".

As stated above, the index "Share of species of their total number in the ecoregion" was calculated to smooth out as much as possible the influence of zonal differences in breeding bird species richness during subsequent analysis of their diversity within European Russia. However, the marked positive correlation between mean for ecoregions values of index "Share of species of their total number in the ecoregion" and mean species number per square of the respective ecoregions, like the significant correlation in the actual values for these indices in the 50-km squares, shows that zonal aspect remains a significant factor in the distribution of bird species diversity when index "Share of species of their total number in the ecoregion" is used for analysis within entire European Russia. Therefore, because the use of this index does not eliminate the influence of latitudinal climate factors on bird distribution within European Russia, it cannot be used as the correct indicator for the impact of other factors, particularly anthropogenic, on bird distribution within entire European Russia.

At the same time, the index "Share of species of their total number in the ecoregion" could be used up to some degree to analyze the spatial distribution of birds within concrete ecoregions and be relevant to the development of a differentiated approach to preserving biodiversity within them. Thus, higher mean for ecoregion values of the index "Share of species of their total number in the ecoregion" indicate that the species pool typical for each ecoregion is, on average, more uniformly represented in each square of that ecoregion. The squares in which a higher share of species of their total number in the ecoregion is recorded better ensure the preservation of the total species richness of that ecoregion, but at the same time they become less unique in species composition, while the conservation of unique communities requires special attention.

Therefore, the patterns identified in materials on birds presented above provide a basis for developing different strategies for conservation of species diversity in regions with a small and large number of species. It is also obvious that correct consideration of zonal differences in bird distribution within European Russia requires a larger data set than just the number of species in the fauna of a particular region.

3.2.3.3. Indices of Red Book bird species

The indices presented in table 3.2.3.3.1 were calculated to develop indicators of the conservation importance of territories based on bird data. Items 3–8 are indices calculated for bird species listed in the Red Data Book of the Russian Federation (2001; RF Red Book for short); hereinafter – indices of Red Book bird species. Indices 3 and 4 are similar to the indicators described above for total species richness but pertain only to species listed in the RF Red Book (hereinafter – Red Book species). In addition, the "Overall index of the Red Book species" was calculated (item 8 in Tab. 3.2.3.3.1), which accounts not only the number or share of these species in squares, but also category of their rarity.

The "Overall index of the Red Book species" was obtained as follows:

1) A rank was assigned to each category of bird rarity according to the RF Red Book (2001): category 1 in the RF RB – 5 points; category 2 – 4 points; category 3 – 3 points; category 4 – 2 points; category 5 – 1 point. Presumably, the higher the score, the better the hypothetical preservation of natural habitats and the greater

the value of the square for preserving bird diversity; and vice versa – the lower the score, the more degraded habitats in the respective square.

2) Then, the sum of products of the number of species of each category registered in each square times the corresponding rank was calculated to yield the index value: *$(N_1 \times 5)+(N_2 \times 4)+\ldots(N_5 \times 1)$ ="Overall index of the Red Book species".*

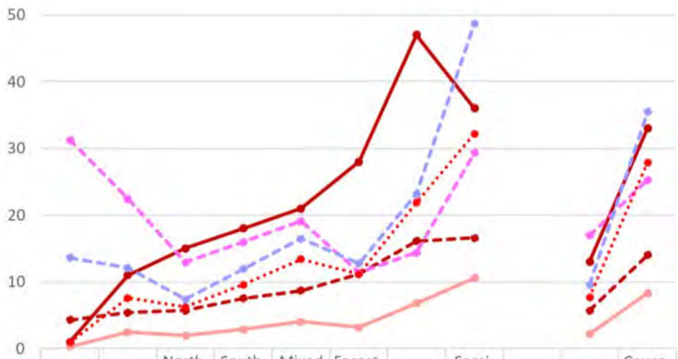
Table 3.2.3.3.1. Indicators of the conservation importance of territories calculated based on bird data. Indices in bold are those selected for testing as basic indicators; the rest are used as intermediate indices for calculating indicators.

No.	*Indicators*
3	**Number of species listed in the Red Data Book of RF registered in a square**
4	**Share of Red Book species in a square of the total number of RB species in the ecoregion (%)**
5	**Share of Red Book species in a square of the total number of all bird species in the ecoregion (%)**
6	**Share of Red Book species in a square of the total number of all bird species in the same square (%)**
7	Number of Red Book species in a square by Red Data Book categories (was used to calculate indicator 9)
8	**Overall index of the Red Book species (score)**
9	**Overall index of bird diversity (score based on sum of indicators 2, 4, 8 and 10)**
10	The proportion of Important Bird Areas in a square (%)

It should be noted that indices based on data about Red Book species do not always a priori indicate the best preservation of natural ecosystems, and a careful approach to their interpretation is required at different scales of assessment (see also Section 3.2.3.7).

The "Overall index of bird diversity" was also calculated (indicator 9 in table 3.2.3.3.1). It will be discussed below in Section 3.2.3.4.

Changes in the total number of Red Book species in ecoregions and mean values of various indices of Red Book bird species in ecoregions (Fig. 3.2.3.3.1) differ from the picture obtained for indices of total species richness (Fig. 3.2.3.2.1.). In plains ecoregions, the total number of Red Book species increases steadily from north to south, slightly decreasing only in the semi-desert ecoregion, while the index "Share of Red Book species of the total number of all species in the ecoregion" increases steadily (Fig. 3.2.3.3.1).



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert	Urals	Caucasus
Total number of RB species	1	11	15	18	21	28	47	36	13	33
Share of total number of RB species in an ecoregion of the total species number in this ecoregion	4.3	5.4	5.7	7.5	8.7	11.2	16.1	16.6	5.7	14.0
Mean number of RB species per 50-km square	0.3	2.5	1.9	2.9	4.0	3.2	6.8	10.6	2.2	8.3
Share of RB species in a square of the total number of RB species in the ecoregion	31.3	22.4	12.9	16.0	19.1	11.4	14.4	29.3	17.0	25.3
Share of RB species in a square of the total number of species in the ecoregion*10	13.6	12.1	7.4	11.9	16.5	12.8	23.2	48.7	9.6	35.5
Overall index of RB species	0.9	7.6	6.2	9.6	13.4	11.1	21.9	32.2	7.7	27.9

Figure 3.2.3.3.1. Changes of mean for ecoregions values of indices of Red Book bird species on north-south gradient (n=1532).

The mean number of Red Book species per square is relatively similar in forest ecoregions, in tundra and Urals (mostly because of small number of these species in these ecoregions and limited distribution range of many of them), but it increases substantially in the steppe, semi-desert and Caucasus forests (Fig. 3.2.3.3.1). In the majority of ecoregions the mean number of Red Book species in a 50-km square is just 2–4 species (with a maximum in some squares up to 9 species in the northern and up to 11 species in the southern taiga, and 14 species in the mixed forests), while the mean value in the steppe is 7 (with a maximum in some squares of 26 species), 11 in the semi-desert (with a maximum of 24 species), and eight species in the Caucasus forests (with a maximum of 21 species). The rather high number of Red Book species on average per square in the semi-desert, given the small number of these squares (n=41) compared to most other ecoregions, determines the higher mean values of indices of Red Book species obtained for this ecoregion.

Mean for ecoregions values of the index "Share of Red Book species of the total number of all species in the ecoregion" and the "Overall index of the Red Book species" generally also increase from north to south, but not as steadily as the actual number of Red Book species registered in the ecoregions (Fig. 3.2.3.3.1). The pattern of the changes in mean values of the "Overall index of the Red Book species" is more similar with the pattern of the number of Red Book species in an ecoregion than with changes of the index "Share of Red Book species of the total number of species in the ecoregion". Differences between the distribution of mean values of the "Overall index of the Red Book species", like of other indices of Red Book bird species (indices 3, 4, and 8 in Tab. 3.2.3.3.1), and the distribution of values of total number of species in the ecoregions result from the fact that both presence of Red Book species in a square and category of their rarity in the RF Red Book are taken into account. The decrease in the mean values of "Overall index of the Red Book species" in the northern taiga ecoregion may be governed by the high percentage of squares (33%) where not a single Red Book species is encountered, which is typical of it (Tab. 3.2.3.3.2), as well as by possible errors in the available material – less complete information on squares in this ecoregion because of the greatest inaccessibility of many areas within it, i.e., it may be that Red Book species in some squares have not been fully identified. The total number of registered Red Book species in the forest steppe is fairly high and similar with mixed forests ecoregion (Tab. 3.2.3.1.1), therefore, the lower mean values for the "Overall index of the Red Book species" there, as the others (Fig. 3.2.3.3.1), may arise for reasons such as:

– the greater number of bird species in this ecoregion belong to the lowest RF Red Book's categories, which may serve as an indicator;

– the greater number of squares where the number of Red Book species is zero or low, which could be both an indicator characteristics that emphasize the differences between these ecoregions and the errors of the applied methodology (but in the ecoregions under discussion the percentage of squares where there are no Red Book species differs slightly – 17% in mixed forests and 14% in the forest steppe).

The outlying high values of the index "Share of RB species of the total number of species in the ecoregion" in the Arctic deserts are attributable to the same reasons that were discussed in relation to the analogous indicator of total species richness (index 2 in Tab. 3.2.3.2.1.). But when Red Book species indices are considered similar, largely artificial, deviation in the mean of this index turns out to be typical for the tundra ecoregion as well (Fig. 3.2.3.3.1).

Changes in mean for ecoregions values of index "Share of Red Book species in a square of the total number of Red Book species in the ecoregion" differ more significantly from other indices shown on Fig. 3.2.3.3.1: there are greater differences in the values for this indicator between ecoregions and a more pronounced decrease in them in the forest steppe and steppe (Fig. 3.2.3.3.1). The reasons why maximum values for this index occur in the northern (Arctic tundra, tundra) and southern (semi-desert) ends of the latitudinal gradient are similar to those discussed above. In Arctic deserts, among other things, Red Book species have not been reported in two thirds of the surveyed squares (Tab. 3.2.3.3.2). As for steppe region, mean value of index "Share of Red Book species of the total number of Red Book species in the ecoregion" are decreasing there, in contrast to three other indices, which are increasing in comparison to plains forest ecoregions. It is determined by the combination in that ecoregion of such "initial" characteristics as the largest number of RB birds species that breed there (Tab. 3.2.3.1.1) set against their more even distribution – in only 3% of the squares rare birds were not registered (Tab. 3.2.3.3.2) as well as a higher mean number of RB species are noted in a square there (7 species). All three calculated indices of Red Book bird species are similar in value only in the forest steppe (indices 4, 5, and 8 in Tab. 3.2.3.3.1).

Table 3.2.3.3.2. Distribution of squares where no bird species listened in the Red Data Book of Russia have been reported by ecoregions.

Ecoregion	*Number of 50 × 50 km squares*	
	total	*where no RF Red Data Book species are encountered (%)*
Arctic deserts	32	22 (69%)
Tundra	81	6 (7%)
Northern taiga	350	117 (33%)
Southern taiga	180	32 (18%)
Mixed forests	212	35 (17%)
Forest steppe	246	34 (14%)
Pontic steppe	274	7 (3%)
Caspian lowland semi-deserts	50	0 (0%)
Ural montane forests and tundra	63	7 (11%)
Caucasus forests	45	0 (0%)

As regards changes of actual number of Red Book species in squares and of other indices that account data on Red Book bird species, on the European Russia scale they have even more pronounced local differences than does the distribution of total bird species richness (Fig. 3.2.3.3.2). And the final picture of the spatial distribution of values of conservation importance of the squares based on data on Red Book species largely depends on the indicator used (Fig. 3.2.3.3.2).

The values of the majority of calculated indices for Red Book species correlate highly both amongst themselves – e.g., the "Overall index of the Red Book species" with the index–"Share of Red Book species in a square of the total number of Red Book species in the corresponding ecoregion" (R_s*=0.87, n=1452, p<0.0005*) and the index "Share of Red Book species of the total number of species in the ecoregion" (R_s*=0.98, n=1452, p<0.0005*), and with the actual number of Red Book species in a square – e.g., the "Overall index of the Red Book species" (R_s*=0.995, n=1452, p<0.0001*) and the index-"Share of Red Book species in a square of the total number of Red Book species in the ecoregion" (R_s*=0.88, n=1452, p<0.0005*). The high correlation of Red Book indices give evidence that they are interchangeable on the scale of European Russia. When calculated the overall index of the Red Book species we anticipated to obtain a picture of the spatial distribution of the conservation importance of sites within European Russia that is more detailed than one just based on the number of Red Book species. But the high correlation of the mentioned above indices obtained on this scale of consideration for now proves rather that our assumptions were unjustified. In the same time, it is not impossible that the "Overall index of the Red Book species" will be more correct and popular index for analyzing the correlations of bird diversity with other indicators in the 50-km squares such as productivity, phytomass, anthropogenic transformation of the area, etc.

Both mean values of Red Book indices for ecoregions (Fig. 3.2.3.3.1) and their actual values in squares (Fig. 3.2.3.3.2) show pronounced regional features (see also Section 3.2.3.5). The actual values in the 50-km squares of almost all of analyzed Red Book indices correlate highly with indices of total species richness (except the index "Share of Red Book species in a square of the total number of species in the same square"), and in this case the correlations within ecoregions were stronger than for entire European Russia (the values of the correlation coefficients for the ecoregions are shown in Appendix; see also the example in Fig. 3.2.3.7.3 a).

At this stage of analysis it has been also preliminary shown that the mean for ecoregions' values of Red Book indices do not have significant correlations with species richness, and the index "Share of Red Book species in a square of the total number of all bird species in the ecoregion" is least related to them (see Tab. 3.2.3.7.3 below). It is possible that in the future it will make sense to analyze in more detail the opportunities for its use as the sole index for European Russia based on data about Red Book bird species. Although the index "Share of Red Book species in a square of the total number of RB species in the ecoregion" is logically easier to understand when it comes to preserving Red Book species since it clearly reflects the value of each square for preserving the Red Book species of the respective ecoregion.

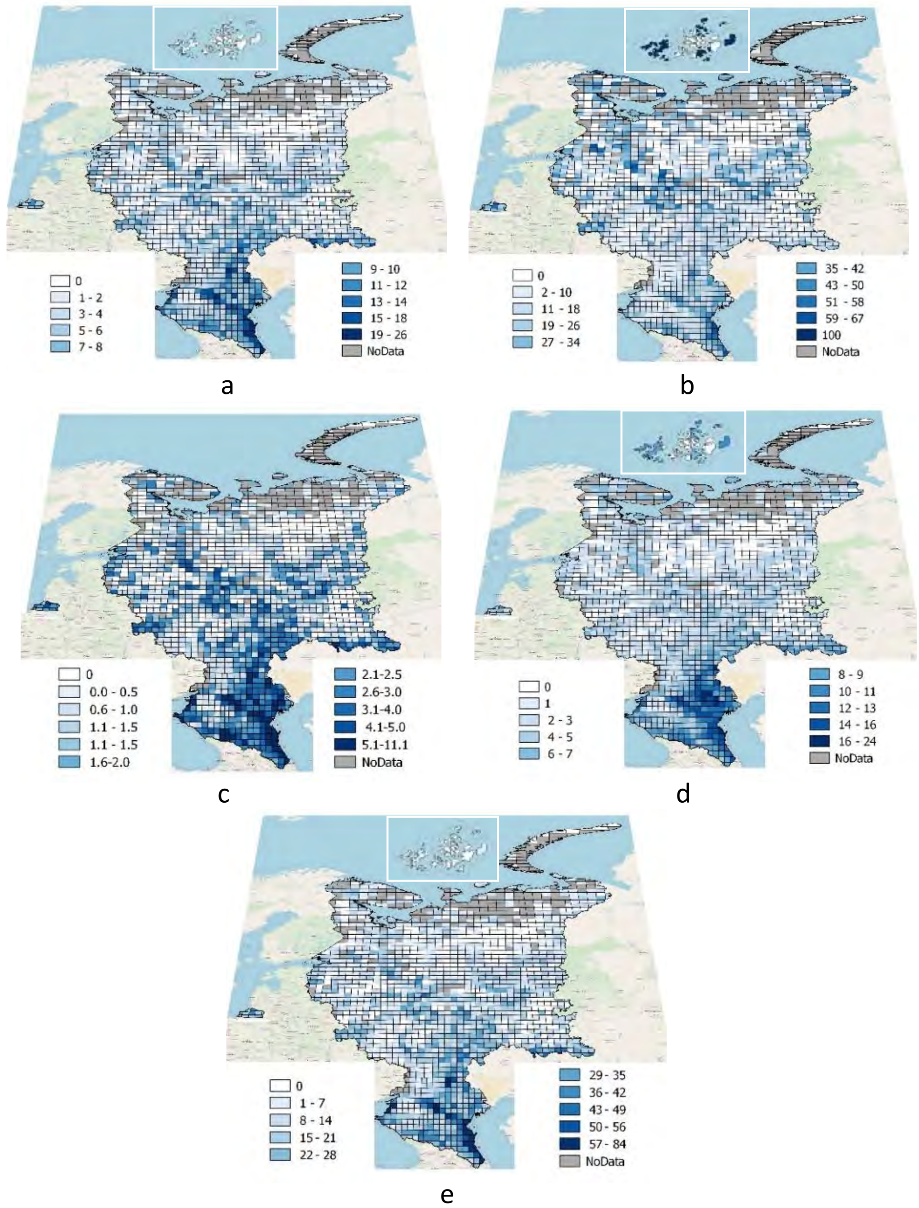


Figure 3.2.3.3.2. Spatial distribution of the Red Book bird species indices in European Russia on the scale of 50-km squares: a) number of Red Book species in a square; b) "Share of Red Book species in a square of the total number of Red Book species in the ecoregion"; c) "Share of Red Book species in a square of the total number of all bird species in the ecoregion"; d) "Share of Red Book species in a square of the total number of species in the same square"; e) "Overall *index of the Red Book species".*

3.2.3.4. Overall index of bird diversity

"Overall index of bird diversity" (indicator 9 in Tab. 3.2.3.3.1) accounts all of indices of bird species richness in a square and all indicators of its conservation importance, including the representation of Red Book species there and Key Ornithological Sites (Territories) of Russia, which have international importance (or Important Bird Area, KOTR/IBA – index 10 in Tab. 3.2.3.3.1; Cartographic Database…, 2014). The latter serve as refuges for the reproduction of many rare and common bird species and as centers for their resettlement into surrounding areas. Therefore, the "Overall index of bird diversity" reflects not so much the conservation importance of territories, as it is treated by us as a cumulative indicator of bird diversity in squares.

This index was calculated in the following way:

1 – percentage values of the number of species (total and Red Book species) in squares (indicators 2 and 4 in Tab. 3.2.3.2.1 and 3.2.3.3.1) were ranked on a 10-point scale: 1 point – species representation in a square ≤10%, 2 points – species representation 11%–20%, 3 points – 21%–30%… 10 points – 91%–100%;

2 – ranks from 1 to 10 were similarly assigned to the values of “Overall index of the Red Book species” (1 point – value of overall index ≤10; 2 points – index 11–20; ... 10 points overall index 91–100) and proportion of IBAs in the square (1 point – proportion of IBA area 0–10%; 2 points – 11%–20%;... 10 points – 91%–100%; squares without IBAs were assigned a value of zero);

3 – ranks obtained for four indicators were summarized for each square and final score treated as the “Overall index of the Red Book species”.

The higher this index, the more valuable the natural ecosystems in a square are for preserving bird diversity and vice versa (Fig. 3.2.3.4.1).

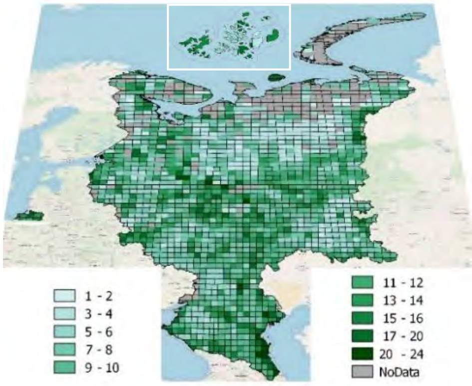


Figure 3.2.3.4.1. Distribution of values of the “Overall index of bird diversity” *within European Russia in 50-km squares.*

Since the calculation of the “Overall index of bird diversity” included all indicators of species richness and indices of Red Book species, it reliably correlates with all of them. But the correlation with indicators of total species richness is somewhat less pronounced than with indices of Red Book bird species (Tab. 3.2.3.4.1 and 3.2.3.7.2).

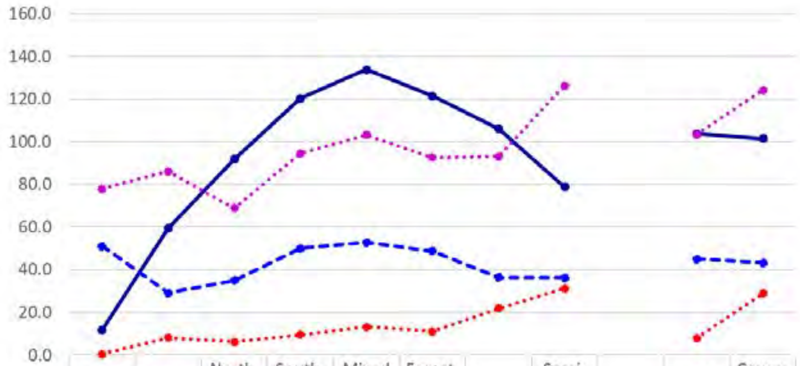
Table 3.2.3.4.1. Correlation (Rs) of the “Overall index of bird diversity” with other indices based on bird data.

Other indices	*Overall index of bird diversity*
Indices of species richness	
Number of bird species registered in a square	0.663**
Share of these species of their total number in the ecoregion	0.668**
Indices of Red Book species	
Number of species listed in the Red Data Book of RF registered in a square	0.839*
Share of Red Book species in a square of the total number of RB species in the ecoregion	0.872*
Share of Red Book species in a square of the total number of all bird species in the ecoregion	0.862*
Share of Red Book species in a square of the total number of all bird species in the same square	0.727**
Overall index of the Red Book species	0.846*

*n=1452, *p<0.05, ** p<0.0001*

In general, the mean for ecoregions values of the “Overall index of bird diversity” increase from north to south, often like the “Overall index of the Red Book species” (Fig. 3.2.3.4.2). The decrease of the mean in the northern taiga ecoregion is consistent with the decrease in most indices of Red Book bird species in this ecoregion (Fig. 3.2.3.3.1). Therefore, the values of indices of Red Book bird species have a greater impact on the “Overall index of bird diversity” than do indices of total bird species richness.

Within ecoregions, all relationships between the “Overall index of bird diversity” and values of bird species richness and the “Overall index of the Red Book species” are also positive (solid colored lines on Fig. 3.2.3.4.3). The absence of a relationship between mean for the ecoregion’s values of “Overall index of bird diversity” and mean values of species richness is noteworthy (Tab. 3.2.3.7.3 and 3.2.3.4.3 a). This may attest to the potential for using the “Overall index of bird diversity” to analyze bird distribution for the entire European Russia after some adjustment.



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert	Urals	Caucasus
Mean bird species number per 50-km square	11.8	59.4	91.9	120.4	133.7	121.4	106.0	78.8	103.8	101.5
Share of registered in a square species of their total number in the ecoregion	51.1	29.1	34.9	50.0	52.9	48.7	36.3	36.3	45.1	43.2
Overall index of the Red Book bird species	0.6	8.1	6.1	9.5	13.3	11.0	22.0	31.3	7.9	28.9
Overall index of bird diversity*10	78	86	69	95	103	93	93	126	103	124

Figure 3.2.3.4.2. Changes of the mean for ecoregions values of the "Overall index of bird diversity" and some other indices based on bird.

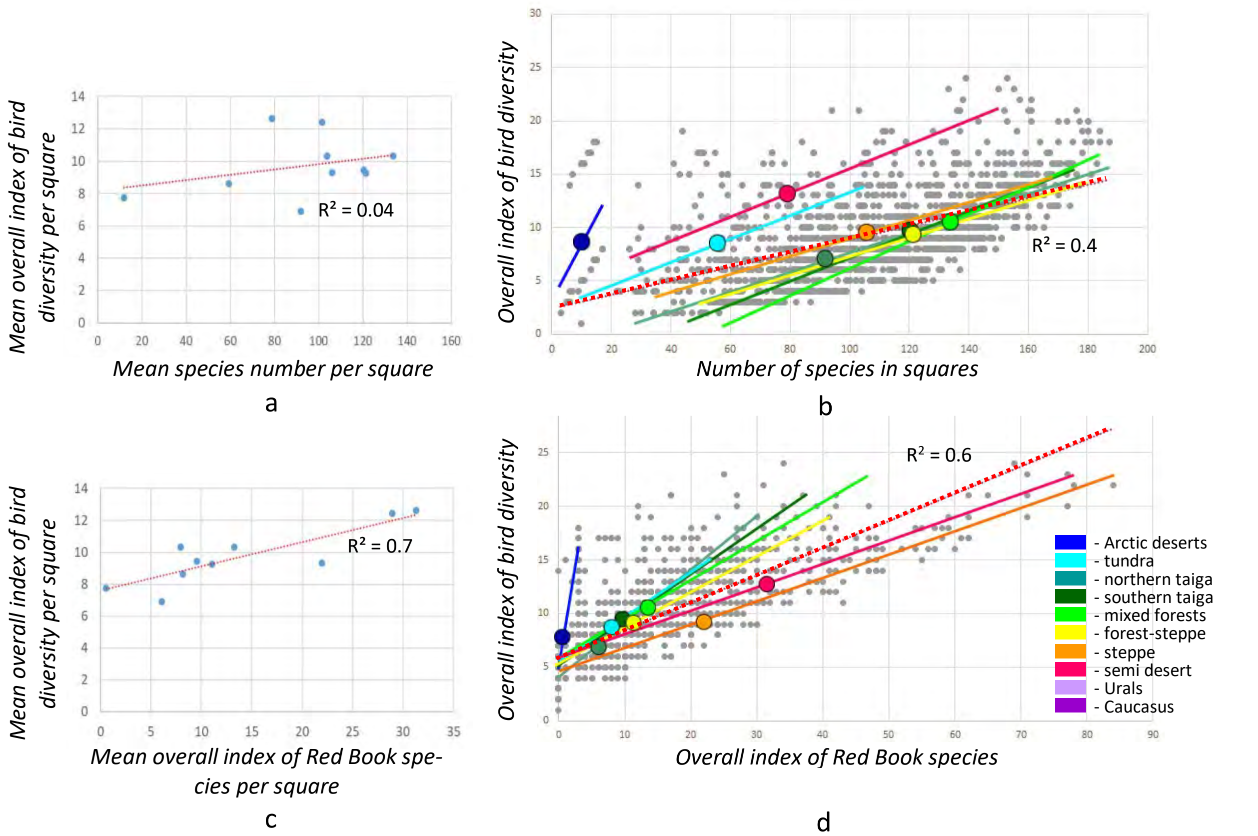


Figure 3.2.3.4.3. Relationships between the "Overall index of bird diversity" and the number of species in squares (a, b) and the "Overall index of the Red Book species" (c, d). Graphs a and c show the relationships between the mean for ecoregions values of indices; graphs "b" and "d" – between the actual values for the 50-km squares. The dotted lines on graphs "b" and "d" are trends for the whole European Russia; the coefficient of determination is shown for them. Mean values and trend lines pertaining to different ecoregions are shown in colors that correspond to the map in Fig. 2.2.1.

3.2.3.5. Regional aspects of the application of bird diversity indicators

Analysis of bird diversity indicators within ecoregions requires consideration of the specific characteristics of their geographic location and the completeness of data and the features of the spatial distribution of common and Red Book bird species within regions. Below are some examples of regional aspects and features of the applicability of the indices within individual ecoregions, including further analysis of the correlation of these indices with some indicators of ecosystem condition (see Section 5.1). For convenience, Table 3.2.3.5.1 once again consolidates some characteristics of the eight ecoregions except the two least-surveyed arctic regions.

Table 3.2.3.5.1. Description of selected ecoregions in European Russia in relation with analysis of data on the distribution of birds in them

	Number of 50 × 50 km squares			*Number of breeding species*	
Ecoregion	*total**	*most representative for detailed analysis (%)***	*where no RF Red Book species are encountered (%)****	*total*	*Included in the RF Red Book (%)*
Northern taiga	350	340 (98%)	117 (33%)	263	15 (5.7%)
Southern taiga	180	179 (99.5%)	32 (18%)	241	18 (7.5%)
Mixed forests	212	201 (95%)	35 (17%)	243	21 (8.7%)
Forest steppe	246	242 (98.4%)	34 (14%)	249	28 (11.2%)
Steppe	274	270 (98.5%)	7 (3%)	292	47 (16.1%)
Caspian lowland semi-deserts	50	41 (82%)	0 (0%)	217	36 (16.6%)
Ural montane forests and tundra	63	55 (87.3%)	7 (11%)	230	13 (5.7%)
Caucasus forests	45	40 (89%)	0 (0%)	235	33 (14%)

*Only squares for which data on breeding birds for 2005–2018 are available were considered; not surveyed during this period squares for which there are no data were excluded from consideration at the outset.
**Complete squares (incomplete squares are excluded)/
*** The number of squares from of the pool of all squares for which data are available (including incomplete squares).

As within entire European Russia (Tab. 3.2.3.4.1), on the scale of the 50-km squares, inside almost all ecoregions the "Overall index of bird diversity" shows the strongest links with indices of Red Book species; the relationship between total bird species richness remains in the majority of instances, but is less pronounced (see Appendix). The "Overall index of bird diversity" and indices of total bird species richness are least related in Ural montane forests and tundra ($R_s=0.40, n=55, p<0.005$), tundra ($R_s =0.54, n=68, p<0.0001$) and Arctic deserts ($R_s =0.69, n=16, p<0.005$) as well as in steppes ($R_s =0.67, n=270, p<0.0001$), while most related in mixed forests ($R_s=086, n=201, p<0.0001$), forest steppe ($R_s=0.82, n=242, p<0.0001$) and Caspian lowland semi-desert ($R_s=0.80, n=41, p<0.0001$).

Data within ecoregions like Ural montane forests and tundra must be analyzed carefully since they not only include various types of natural communities such as montane tundra and taiga forests, but also extend longitudinally over a great distance. The latter may cause on more substantial variations of bird species diversity in squares of this ecoregion. This longitudinal expanse is a significant difference between the Ural montane forests and tundra and ecoregions like Caucasus forests, which, in contrast, are oriented latitudinally and are relatively short in extent (Fig. 3.2.3.1.1). Further, a major biogeographic boundary runs along the Urals, defining the presence of a significant number of both European and Siberian species there. The Ural montane forests and tundra most likely cannot be treated as a uniform unit for analyzing the degree of disturbance of ecosystems. It is therefore noticeable that the indicator "Overall index of bird diversity" within the montane Caucasus shows a significantly more pronounced relationship with indices of total species richness ($R_s=0.75, n=40, p<0.0001$) than within the Ural montane forests and tundra ($R_s=0.40, n=55, p<0.005$).

A distinguishing feature of the Caucasus forests and Caspian lowland desert ecoregions might be relatively high percentage of Red Book species in them and, simultaneously, more even occurrence of these species in squares, in contrast of many other ecoregions. (Tab. 3.2.3.5.1, Fig. 3.2.3.3.2 a and Fig. 3.2.3.5.1). In particular, this determines a more pronounced correlation in these two regions of the "Overall index of bird diversity" and the indices of total species richness – "Number of bird species in a square" and "Share of species of their total number in the ecoregion" (Rs = 0.75, n = 40, p <0.0001 and Rs = 0.80, n = 41, p <0.0001), in comparison with the majority of other ecoregions (see Appendix). At the same time, an index such as “Share of Red Book species in a square of the total number of species in the same square” proves to be entirely different in the Caucasus forests and Caspian lowland semi-deserts, although the number of the most completely surveyed squares in these ecoregions (40 and 41, respectively) and the characteristics of the spatial distribution of RB species there are similar (Tab. 3.2.3.5.1). The index “Share of Red Book species in a square of the total number of species in the same square” is a simplest calculated indicator that accumulate effect of accounting of both the total species richness and the number of rare species in one square. For obvious reasons, in squares within most ecoregions it correlates less with the “Overall index of bird diversity” than do other indices which account of Red Book species. However, as stated above, only in the semi-desert ecoregion this index does not correlate with any other indicator, that is simultaneously associated with its quite different spatial distribution within squares of this ecoregion (Fig. 3.2.3.3.2 d and 3.2.3.5.1 f). The reasons for this are not clear at present, but it is obvious that this index “works” differently (or, to the contrary, stops “working”) in the conditions that exist in the Caspian lowland semi-desert.

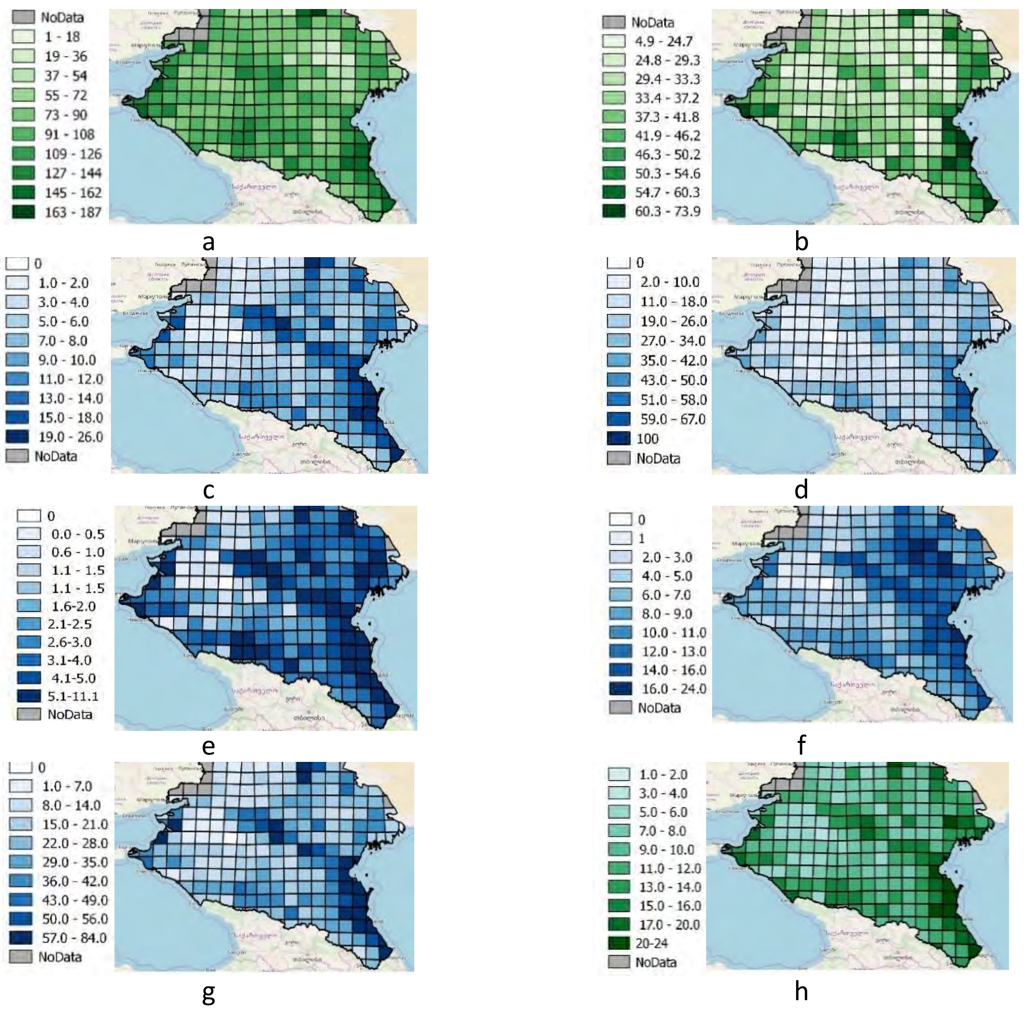


Figure 3.2.3.5.1. Spatial distribution of values of various indices in the ecoregions Caspian lowland semi-deserts and Caucasus forests: a) number of species registered in a square; b) “Share of registered in a square species of their total number in the ecoregion”; c) number of Red Book species registered in a square; d) “Share of Red Book species in a square of the total number of Red Book species in the ecoregion”; e) ‘Share of Red Book species in a square of the total number of all bird species in the ecoregion”; f) “Share of Red Book species in a square of the total number of species in the same square”; g) “Overall index of the Red Book species”; h) overall index of bird diversity.

In the ecoregions of the north and south taiga, mixed forests, forest steppes, and steppe, the values and distribution of indicators based on bird data may be influenced by features of these ecoregions such as: 1) the percentage and specifics of forest cover in squares of these ecoregions, which must be additionally calculated in one way or another to analyze bird distribution in them (except, probably, the steppe ecoregion); 2) the degree of patchiness of the landscape, which might influence bird distribution in all ecoregions, etc.

It is worth to emphasize here again the importance of the completeness and specifics of the data used for analysis. For example, only 1 species (Ivory Gull *[Pagophila eburnea]*) and 1 subspecies (Pale-bellied Brant Goose [*Branta bernicla hrota*]) of birds listed in the RF Red Book actually breed in the Arctic desert ecoregion. But we did not consider subspecies in this analysis. Further, the rather strict time constraint on data gathering for the "Atlas of Breeding Birds of European part of Russia" (2005–2018) together with both a small number of squares in this ecoregion and maximal lack of data for them (only 50%) because of incomplete observations and methodological errors (many squares with a small area of land) make these data unsuitable for a correct analysis, either on the European Russia scale or within this ecoregion. It should be also noted that the Arctic desert ecoregion is distinguished by a significant number of bird species that form offshore colonies. Because the condition and population of these species largely depend on fish stocks in the seas surrounding Arctic islands, sea birds cannot serve as indicators of the condition of terrestrial ecosystems.

3.2.3.6. Indicators of the synanthropization level of bird population

The assessment of the anthropogenic transformation of ecosystems using indicators based on bird data was tested by selecting of 12 species with more or less pronounced level of synanthropization (Tab. 3.2.3.6.1).Two of them (*Rock Pigeon and House Sparrow)* breed primarily in urban settlements; 5 species (*Barn Swallow, Eurasian Skylark, Common Starling, Rook and Eurasian Tree Sparrow*) in rural areas, and 5 species (*Common Swift, Common House-martin , White Wagtail , Eurasian Jackdaw and Hooded Crow)* are found in both urban and rural locales, primarily in landscapes transformed by man. Of these birds, Skylark corresponds least to the term of synanthropic species. However, it is very closely associated with agricultural fields and its population is highest there; for this reason, it was included in the list as a species that might potentially indicate the degree of plowing of the territory.

The majority of these species are easily recognized in the field, and their breeding range broadly encompasses European Russia, which satisfies the basic requirements for the selection of indicator species. However, species with wide ranges may serve as indicators only if there are data about their abundance, differences in which are usually used to get a bioindication picture. Data only about the number of species or theirs share of the total number of species at a particular site are not informative, because the majority of them are present over a most of the area. Thus, all or the majority (from 9 to 12) of the species mentioned in Table 3.2.3.5.1 are found in 54% of squares within European Russia (Fig. 3.2.3.6.1 a).

Therefore, we taken those squares from the "Atlas of breeding birds of Russia" database for which there is abundance estimates of 12 selected species. The final sample for these species totaled 13,293 records for 1404 squares; or 1349 squares, when incomplete border or littoral squares were excluded. The data-gathering methodology for the European Bird Breeding Atlas, including European Russia, calls for an estimate of the bird abundance in 50 × 50 km squares only on a logarithmic scale based on the number of nesting and territorial pairs and the number of vocalizing males according to the following gradations: <10, 11–100, 101–1000, 1001–10000, etc. (Kalyakin, Voltzit, 2015). This is more than a rough estimation, but at present for most of the squares in the European Russia there is either such assessment or it is absent. Each population category was assigned a rank from 1 to 6: 1 point – 1–10 nesting/territorial pairs of a species per square, 2 points – 11–100 pairs of the species, …., 6 points – >100,000 pairs. Then we calculated the summarized conditional score of the abundance of all species in each of the squares, averaged for the number of species reported in a particular square – "Synanthropization index based on the abundance of each bird species". This approach made it possible to obtain a more "variegated" picture of how indicator species represent the disturbance of natural ecosystems within European Russia (Fig. 3.2.3.6.1 b).

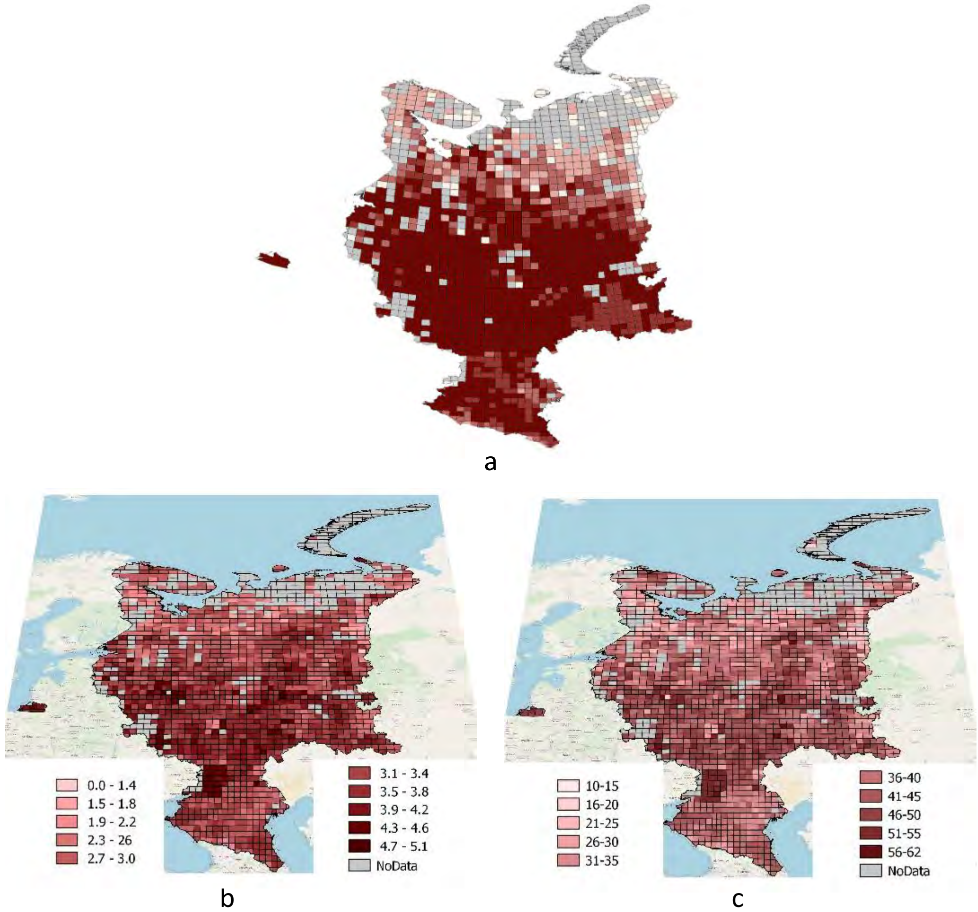


Figure 3.2.3.6.1. Indicators of the synanthropization level of bird population: a) number of synanthropic species per square: b) "Synanthropization index based on the abundance of each bird species"; c) "Synanthropization index based on the abundance and synanthropic "weight" of each bird species".

However, 11–100 pairs of Rock Pigeon or Hooded Crow and 11–100 pairs of Skylark or Barn Swallow are rather unbalanced indicators. As an example of one possible approach to a more detailed accounting of the contribution that indicator species make to the final index of synanthropization of bird population, we made an expert estimate of the total "weight" of each of these species to indicate the degree of natural ecosystem disturbance based on 5 values (columns I–V in Tab. 3.2.3.6.1):

I – the species inhabit in the breeding season primarily: towns (4 points); both towns and rural villages (3 points); primarily rural villages (2 points); and agricultural lands outside of villages (1 point);

II – the specie's main feeding strategy in the breeding season: omnivorous (4 points), consumes both plant and animal food, but mostly first one (3 points), feeds primarily on invertebrates (2 points), exclusively insectivorous species (1 point);

III – nest building sites: primarily on/in man-made structures (4 points); both in man-made structures and in natural conditions (3 points), on trees, both in towns/villages and beyond (2 points), outside towns/villages (1 point);

IV – uses human infrastructure for nesting (e.g., utility poles of power lines, bridges, road banks, etc.): often (4 points), occasionally (3 points), sometimes (2 points), never (1 point);

V – the species is mostly resident (in many regions it winters in towns/villages; 2 points) or is exclusively or mainly migratory (1 point).

Accordingly, the sum of all ranks in columns I–V is the total "weight" of the species for assessing the degree of natural ecosystem transformation (column VI in Tab. 3.2.3.6.1). It is assumed that the higher the total weight of a species with respect to the selected characteristics, the more its presence in particular territories is determined by the degree of disturbance of natural ecosystems there.

Table 3.2.3.6.1. Synanthropic bird species – indicators of natural ecosystem disturbance and the score for their conditional "weight" in reflecting of the degree of territory transformation by humans.

Species	I	II	III	IV	V	VI
Rock Pigeon *[Columba livia]*	4	3	4	2	2	**15**
Common Swift *[Apus apus]*	3	1	3	2	1	**10**
Barn Swallow *[Hirundo rustica]*	2	1	4	1	1	**9**
Common House-martin *[Delichon urbicum]*	3	1	4	3	1	**12**
Eurasian Skylark *[Alauda arvensis]*	1	2	1	1	1	**6**
White Wagtail *[Motacilla alba]*	3	2	3	4	1	**13**
Common Starling *[Sturnus vulgaris]*	3	2	3	4	1	**13**
Eurasian Jackdaw *[Corvus monedula]*	3	2	4	4	2	**15**
Rook *[Corvus frugilegus]*	2	2	2	2	1	**9**
Hooded Crow *[Corvus cornix (corone)]*	3	4	2	3	2	**14**
House Sparrow *[Passer domesticus]*	4	3	4	3	2	**16**
Eurasian Tree Sparrow *[Passer montanus]*	2	2	3	3	2	**12**

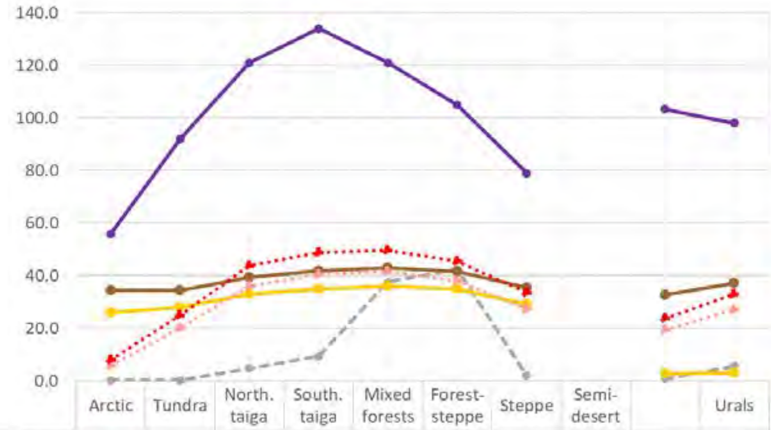
Then, taking into account the conditional score of the abundance of each species in each square obtained previously, we calculated the conditional summarized weight of indicator species in each square, averaged for the number of these species reported in each particular square – the "Synanthropization index based on the abundance and synanthropic "weight" of each bird species". This approach made it possible to obtain a more detailed picture of the differences in the distribution of species that are indicators of transformation of natural ecosystems within European Russia (Fig. 3.2.3.6.1 c).

Despite the partially different bird datasets that were used to calculate the "Synanthropization index based on the abundance of each bird species" and "Synanthropization index based on the abundance and synanthropic "weight" of each bird species", their actual values in the 50-km squares correlate highly ($R_s=0.97, n=1404, p<0.0001$). However, even with such high correlation of values of these indices, their spatial distribution within European Russia differs slightly (Fig. 3.2.3.6.1 b, c).

The mean for ecoregions values of the "Synanthropization index based on the abundance and synanthropic "weight" of species" increase from north to south, having the highest values in mixed forest, forest steppe, and steppe ecoregions. This is to some degree consistent with the features of change in mean for ecoregions values of the degree of territory transformation, although the amplitude of the increase of the latter in the forest steppe and steppe ecoregions is far higher than is typical for mean values of synanthropization indices. The change in mean for ecoregions values of synanthropization index is similar to the change in the mean number of species in squares (Fig. 3.2.3.6.2).

It is also noteworthy that figures of the "Summarized conditional score of the abundance of all synanthropic species in a square" and "Conditional summarized weight of synanthropic species in a square based also on the conditional score of the abundance of each of them in that square" (not averaged yet on the number of synanthropic species in a square), that did not consider by us as potential indicators of synanthropization and used as intermediate indices, have mean for the ecoregions values that change somewhat differently (Fig. 3.2.3.6.2). They increase more quickly (with a steeper gradient) in the northern taiga versus the tundra and in the southern taiga versus the northern taiga than averaged "Synanthropization index based on the abundance and synanthropic "weight" of each bird species", that we selected for testing; changes between other pairs of ecoregions are less pronounced and are like the changes in the synanthropization indicator values that we selected.

There is a positive relationship between the mean for ecoregions values of the "Synanthropization index based on the abundance and synanthropic "weight" of each bird species" and the degree of territory transformation, and there is also a unimodal relationship consisting of an ascending shoulder for intact ecoregions and a descending shoulder for the heavily disturbed forest steppe and steppe ecoregions (Fig. 3.2.3.6.3 a). The relationships between actual values of synanthropization indicators in squares and the degree of territory transformation are less pronounced within European Russia (Fig. 3.2.3.6.3 b) than for mean for ecoregions values. Probably, this is largely determined by differences in conditions within ecoregions.



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals
Area share of transformed ecosystems, %	0.1	0.1	4.7	9.3	37.6	42.4	2.0		0.7	5.5
Mean species number per square	56.0	92.0	121.0	134.0	121.0	105.0	79.0		103.4	98.1
Synanthropization index based on the abundance of each bird species"	26.0	28.0	33.0	35.0	36.0	35.0	29.0		2.6	3.0
Synanthropization index based on the abundance and synanthropic "weight" of each bird species	34.5	34.4	39.5	42.0	43.1	41.5	35.4		32.6	37.2
Summarized conditional score of the abundance of all synanthropic species in a square	5.8	20.0	35.9	40.4	41.6	38.1	27.5		19.3	27.2
Conditional summarized weight of synanthropic species in a square based also on the conditional score of the abundance of each of them in that square /10	8.0	25.0	43.7	48.7	49.6	45.5	33.5		23.9	33.1

Figure 3.2.3.6.2. Changes in mean for ecoregions values of synanthropization indices of the bird population and bird species number in squares, as well as the intermediate indices, which were used for synanthropization indicators calculating.

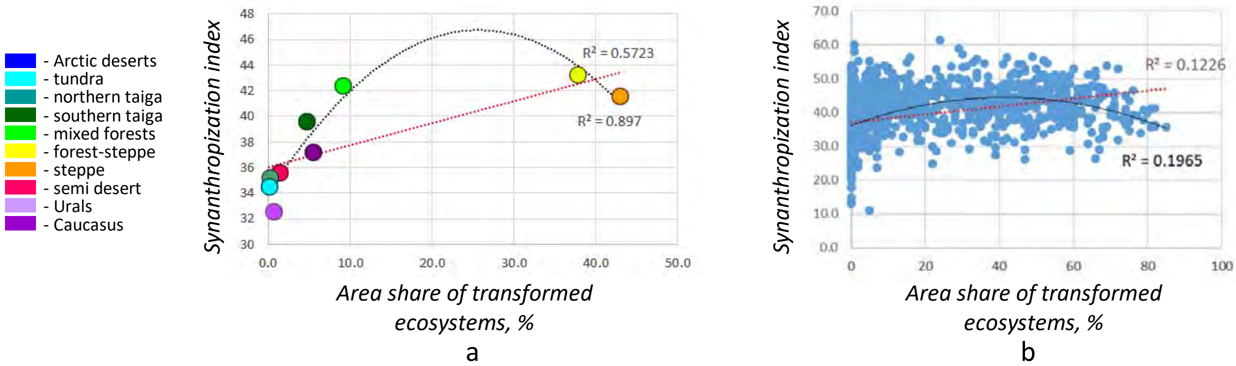


Figure 3.2.3.6.3. Relationships between "Synanthropization index based on the abundance and synanthropic "weight" of bird species" and the degree of territory transformation: a) relationship between mean values for ecoregions (mean values for different ecoregions are shown in the colors that correspond to the map on Fig. 2.2.1; b) relationship between values for 50-km squares.

Within European Russia, the "Synanthropization index based on the abundance of species" correlates with percentage of transformed ecosystems in squares with a somewhat stronger relationship (*R_s=0.55, n=1404, p<0.0001*) than does the "Synanthropization index based on the abundance and synanthropic "weight" of species" (*R_s=0.48, n=1404, p<0.0001*). The same relationships are demonstrated by values of "Summarized conditional score of the abundance of all synanthropic species in a square" (R_s=0.64, n=1404, p<0.0001) and "Conditional summarized weight of synanthropic species in each square based also on the conditional score of the abundance of each of them in a square" (*R_s=0.62, n=1404, p<0.0001*), which were not averaged for the number of species in a square. Moreover, correlations of these indices, which we initially treated as intermediate, and the degree of territory transformation is somewhat stronger than of the two averaged synanthropization indicators. It is possible that the averaging of these summarized conditional scores, given the number of species in each of the squares, was unnecessary for obtaining the final synanthropization indicators for the bird population.

An analysis of the correlations of the synanthropization indices and the summarized conditional scores used to calculate them was carried out on sample of 1349 squares, excluding all the incomplete squares with a small land area. Within many ecoregions no reliable correlation was found between the degree of natural ecosystem transformation and both of synanthropization indices: in the northern taiga ($R_s=0.1$, $n=319$, $p>0.059$), mixed forests ($R_s=0.02$, $n=182$, $p>0.76$), forest steppe ($R_s=0.1$, $n=224$, $p>0.093$), steppe ($R_s=0.07$, $n=267$, $p>0.24$), and Ural montane forests and tundra ($R_s=0.2$, $n=50$, $p>0.01$). In mixed forests and forest steppe there were likewise no reliable correlations with the “Summarized conditional score of the abundance of all synanthropic species in a square” ($R_s=0.05$, $n=182$, $p>0.5$ and $R_s=0.11$, $n=224$, $p>0.08$, respectively) and the “Summarized “weight” of synanthropic species based also on their abundance score in a square” ($R_s=0.04$, $n=182$, $p>0.56$ and $R_s=0.1$, $n=224$, $p>0.11$, respectively). Within the last two ecoregions, therefore, the proposed trial indicators of bird population synanthropization turn out to be unsuitable for assessing natural ecosystem transformation. As for the rest of ecoregions mentioned in this paragraph, then in the absence of correlation between the degree of territory transformation and synanthropization indices, this indicator does correlate with the “Summarized conditional score of the abundance of all synanthropic species in a square” and the “Summarized “weight” of synanthropic species based also on their abundance score in a square”. However, the values of correlation coefficients indicate only a weak dependence in the northern taiga ($R_s=0.12$ and $R_s=0.13$ at $n=319$ and $p<0.05$, respectively) and steppe ($R_s=0.14$, $n=267$, $p<0.05$), which may give evidence that these values are ill-suited for assessing the degree of transformation in these ecoregions as well. In the Ural montane forests and tundra ecoregion this relationship becomes stronger ($R_s=0.47$ and $R_s=0.48$ at $n=50$ and $p<0.005$, respectively).

A significant correlation between all four of the indicators under discussion with the degree of ecosystem transformation was revealed in the tundra, southern taiga, and Caspian lowland semi-deserts (Tab. 3.2.3.6.2). In all these ecoregions the relationship with the degree of territory transformation is also somewhat stronger, when the “Summarized conditional score of the abundance of synanthropic species in a square” and the “Summarized “weight” of synanthropic species based also on their abundance score in a square” are used. Ultimately, only in the Caucasus ecoregion was it possible to ascertain most strong relationship between the degree of territory transformation and all potential indicators of bird population synanthropization under discussion ($R_s=0.77$ and $R_s=0.78$ at $n=40$ and $p<0.0001$). A moderate analogous relationship was noted in the Caspian lowland desert and in the tundra (Tab. 3.2.3.6.2).

Table 3.2.3.6.2. The correlation (Rs) of the actual values of the degree of natural ecosystem transformation (%) with indexes of synanthropization of bird population in some ecoregions of European Russia.

Indicator	**Tundra** (n=55)	**Southern taiga** (n=173)	**Caspian lowland semi-deserts** (n=39)	**Caucasus forests** (n=40)
Summarized conditional score of the abundance of synanthropic species the square	0.436**	0.467***	0.467**	0.766***
Summarized “weight” of synanthropic species based also on their abundance score in a square	0.438**	0.456***	0.491**	0.782***
Synanthropization index based on the abundance of species, averaged for the number of species in a square	0.369*	0.420***	0.343*	0.642***
Synanthropization index based on the abundance and synanthropic “weight” of species, averaged for the number of species in a square	0.407**	0.406***	0.370*	0.638***

**p<0.05, **p<0.005, *** p<0.0001*

The relationships of both analyzed synanthropization indices on the degree of ecosystem transformation for squares in entire European Russia and for particular ecoregions are similar to those for bird species richness indices (see Section 5.1.6). It is also noteworthy that indices of synanthropization and bird species richness within European Russia are positively correlated (Tab. 3.2.3.7.2), therefore detection of similar relationships for them to be expected. However, these patterns appear in more flattened form for synanthropization indices. As for species richness indices, there is a unimodal relationship between calculated final synanthropization index and the degree of ecosystem transformation, consisting of an ascending shoulder for ecoregions with a high percentage of intact natural ecosystems and a descending one for severely disturbed ecosystems in the forest steppe and steppe ecoregions (Fig. 3.2.3.6.4 a). Within a group of ecoregions slightly transformed by humans there is a weak positive relationship between this synanthropization index and the degree of ecosystem transformation, which is absent in ecoregions severely transformed by humans – the forest steppe and steppe (Fig. 3.2.3.6.4 a). Within individual ecoregions the trend toward a positive correlation weakens as the degree of ecosystem transformation in them increases – the slope of the linear relationship decreases as the degree of transformation of the respective region increases (Fig. 3.2.3.6.4 b). As a preliminary hypothesis it can be assumed, that in ecoregions with greater representation by intact natural ecosystems, the tendency toward a positive relationship between indices of synanthropization and the degree of ecosystem transformation is explained by the fact that conditions for synanthropic birds improve within these ecoregions as the values of the latter increase. In ecoregions with highly transformed ecosystems, this relationship disappears because, on average, the "optimum" level of natural ecosystem transformation for the 12 selected species has already been reached there. However, because the relationships obtained in this analysis are very weak, further testing and verification are required in areas of a different scale, and also the methodology for calculating indicators of synanthropization of bird population must be refined.

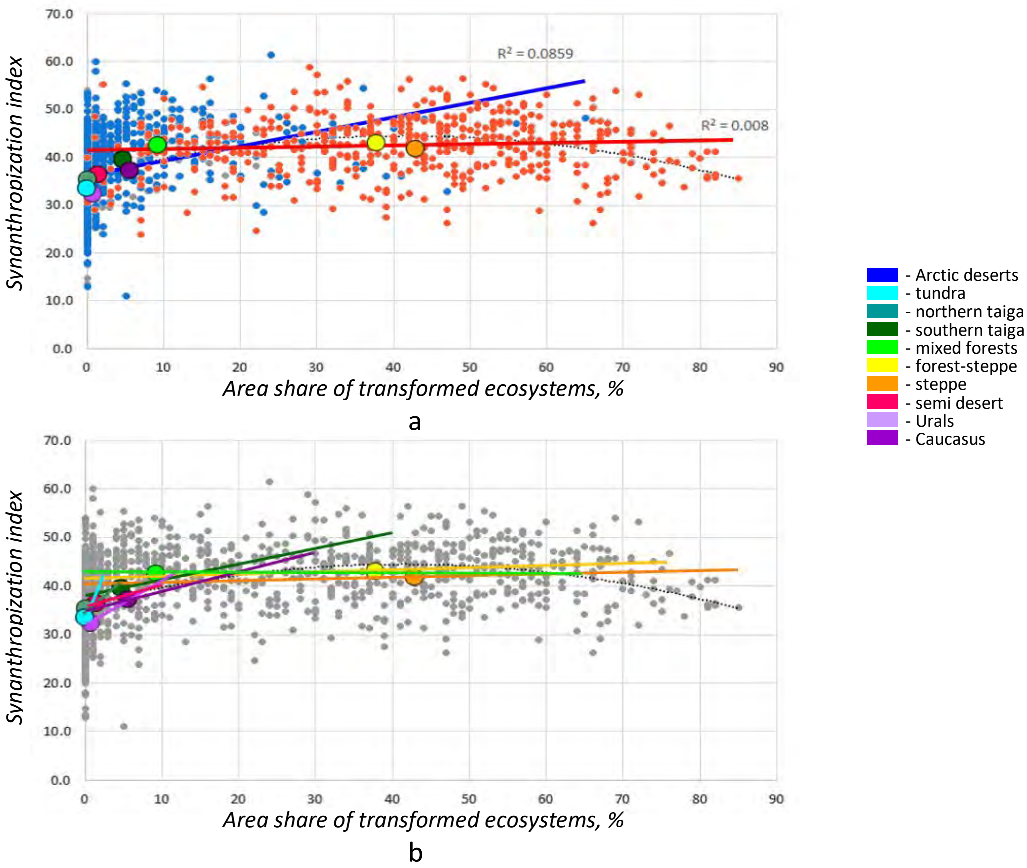


Figure 3.2.3.6.4. Relationship between "Synanthropization index based on the abundance and synanthropic "weight" of bird species" and the degree of territory transformation for 50-km squares: a) relationships within group of ecoregions slightly transformed by humans (blue) and group of ecoregions severely transformed by humans (red); b) relationships for individual ecoregions. Mean values and trend lines for individual ecoregions are shown in the colors that correspond to the map in Fig. 2.2.1.

The analysis of the proposed synanthropization indices allows us to draw the following preliminary conclusions:

1. As in the case of indicators of total bird species richness and Red Book species, the potential applicability of indicators of synanthropization level of bird population for assessing the degree of natural ecosystem transformation depends on the scale of the analyzed area.

2. Indicators of synanthropization level of bird population "reacted" unexpectedly best to the degree of natural ecosystem transformation in montane ecoregions, which requires further, more detailed analysis to find the reasons for such expression of the indicators in these units.

3. The detected correlations as well as their absence demonstrate insufficient effectiveness of the proposed final indicator for determining the degree of territory transformation, both on the scale of European Russia and on the level of large ecoregions. It is most likely that the pool of 12 species selected for analysis within the vast European Russia was too generalized and "superfluous", i.e., excluding some of species from it or using only 1 or 2 of them to calculate the same indicators as well as applying of those indicators on a more local level would allow to obtain a more accurate assessment of the degree of natural ecosystem transformation by using of bird data.

3.2.3.7. Effect of the scale of analysis on relationships between bird diversity indicators and their interpretation

It was already stated in the Section 2 that the scale selected for assessing ecosystem condition and biodiversity might significantly affect the sensitivity and interpretation of the indicators used. Bird diversity indicators were analyzed in three scales (Tab. 3.2.3.7.1).

Table 3.2.3.7.1. Scales for analysis of bird diversity indicators

	Minimal accounting plots	*Areas studied*	*Total area*
1	50 × 50-km squares	European Russia	–
2	50 × 50-km squares	Ecoregion	–
3*	50 × 50-km squares	Ecoregions (mean values)	European Russia
4*	50 × 50-km squares	Subjects of RF (mean values)	European Russia

** these scales were used to analyze relationships between bird diversity indicators and ecosystem condition indicators (5.2.2.1)*

When comparing 50-km squares within European Russia, all analyzed indices correlate generally positively with one another, except that there is no correlation between synanthropization indices and two indices of Red Book species (Tab. 3.2.3.7.2). Within most ecoregions, especially of forests zone, the correlations between species richness indices, indices of Red Book species, and the overall index of bird diversity are stronger than the same correlations for entire European Russia (for correlations of indices within individual ecoregions see Appendix). The correlation between indicators of the synanthropization level of bird population and other indices of bird diversity within European Russia is weak.

Within samples of squares for individual ecoregions the analyzed indicators of bird diversity significantly correlate in the overwhelming majority of cases (see Appendix). Significant dependencies are absent only in the following cases.

1 In each of indices "Number of bird species registered in a square" and "Share of species of their total number in the ecoregion" with all indicators of conservation importance in the Arctic desert ecoregion. At the same time, both these indices show a quite strong link to the "Overall index of bird diversity" (R_s*=0.69, n=16, p<0.005*), which is determined by already mentioned near total absence of Red Book species in this region.

2. In each of the indices "Number of bird species registered in a square" and "Share of species of their total number in the ecoregion" with the index "Share of Red Book species in a square of the total number of species in the same square" (R_s*=0.04, n=68, p=0.76*).

3. Between the index "Share of Red Book species in a square of the total number of species in the same square" in the semi-desert ecoregion and all other indices: "Overall index of bird diversity" (R_s*=0.082, n=41, p=0.6*), indicators of total bird species richness (R_s*=–0.14, n=41, p=0.37*), indicators of conservation importance (R_s*=0.28, n=41, p>0.07* – "Overall index of the Red Book species" and R_s*=0.78, n=41, p>0.05* – for the other indices).

Table 3.2.3.7.2. Correlation (Rs) of diversity indices based on bird data within European Russia.

	I	II	III	IV	V	VI	VII	VIII	IX
Number of bird species registered in a square **(I)**									
Share of species in a square of their total number in the ecoregion **(II)**	0.934*								
Number of Red Book species registered in a square **(III)**	0.515**	0.431**							
Share of Red Book species of the total number of Red Book species in the ecoregion **(IV)**	0.500*	0.497**	0.881**						
Share of Red Book species in a square of the total number of all bird species in the ecoregion **(V)**	0.500*	0.447**	0.988**	0.913*					
Share of Red Book species in a square of the total number of species in the same square **(VI)**	0.246*	0.177**	0.941**	0.841*	0.945*				
Overall index of the Red Book species **(VII)**	0.542*	0.460**	0.995**	0.875*	0.983*	0.924*			
Overall index of bird diversity **(VIII)**	0.663*	0.668**	0.839**	0.872*	0.862*	0.727**	0.846*		
Synanthropization index based on species' abundance **(IX)**	0.440**	0.382**	0.173**	0.007	0.151**	0.051	0.189**	0.159**	
Synanthropization index based on species' abundance and synanthropic "weight" **(X)**	0.382**	0.337**	0.135**	0.004	0.121**	0.030	0.150**	0.129**	0.968*

***p<0.0005, *p<0.0001; n=1452 for indices of species richness, indices of Red Book species, and the overall index of bird diversity; n=1351 for the correlation of synanthropization indices amongst themselves and with other indices.*

The correlations of the mean for ecoregions values are weaker within European Russia and, in many cases are absent (Tab. 3.2.3.7.3, the Arctic desert ecoregion was excluded from the analysis). There are no correlations between species richness indicators (I and II in Tab. 3.2.3.7.3) and Red Book indices (III–VII) on this level of analysis, while there are a tendency to some negative relationships between two Red Book indices (IV and VI) and species richness indicators (I and II), although they are statistically unreliable.

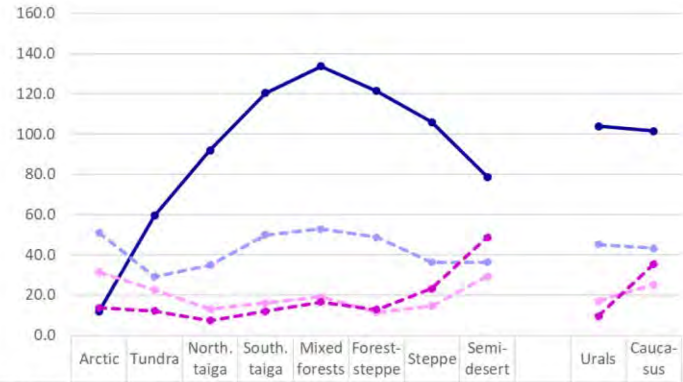
Table 3.2.3.7.3. Correlation (Rs) of mean for ecoregions values of diversity indices based on bird data within European Russia. Indices of Red Book species are highlighted in green, indices of synanthropization of bird population – in yellow. The Arctic desert ecoregion was excluded from the analysis.

	I	II	III	IV	V	VI	VII	VIII	IX
Mean number of bird species per square **(I)**	1.000								
Share of species in a square of their total number in the ecoregion **(II)**	.887**	1.000							
Mean number of RB species per square **(III)**	.083 *p=0.83*	.151 *p=0.70*	1.000						
Share of Red Book species of the total number of RB species in the ecoregion **(IV)**	–.483 *p=0.19*	–.151 *p=0.70*	.517	1.000					
Share of Red Book species in a square of the total number of all bird species in the ecoregion **(V)**	.033 *p=0.93*	.092 *p=0.80*	.996**	.544	1.000				
Share of Red Book species in a square of the total number of species in the same square **(VI)**	–.267 *p=0.49*	–.201 *p=0.60*	.900**	.683*	.929**	1.000			
Overall index of the Red Book species **(VII)**	.083 *p=0.83*	.151 *p=0.70*	1.000**	.517	.996**	.900**	1.000		
Overall index of bird diversity **(VIII)**	.033 *p=0.93*	.360 *p=0.34*	.667*	.700*	.644	.533	.667*	1.000	
Synanthropization index based on species' abundance **(IX)**	.798**	.595	.471	–.412	.435	.168	.471	–.008	1.000
Synanthropization index based on species' abundance and synanthropic "weight" **(X)**	.750*	.577	.500	–.283	.477	.267	.500	–.017	.966**

*** p<0.01; * p<0.05.*

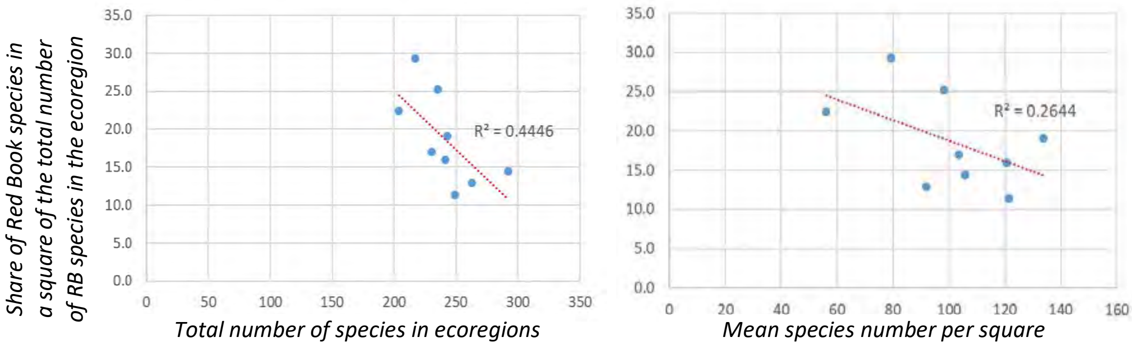
Relationships between the same indicators can therefore vary widely on different scales of analysis, up to and including a tendency to change sign. The relationships between Red Book indices and indices of bird species richness may be an example.

The graph of mean for ecoregions values of indices shows that changes in mean values of Red Book species indices in several cases are the opposite of those for species richness (Fig. 3.2.3.7.1). Indeed, there is a tendency toward negative relationships between mean values of "Share of Red Book species in a square of the total number of Red Book species in the ecoregion" and the mean indices of species richness (Tab. 3.2.3.7.3; Fig. 3.2.3.7.2).



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert	Urals	Caucasus
Mean bird species number per 50-km square	11.8	59.4	91.9	120.4	133.7	121.4	106.0	78.8	103.8	101.5
Share of registered in a square species of their total number in the ecoregion	51.1	29.1	34.9	50.0	52.9	48.7	36.3	36.3	45.1	43.2
Share of RB species in a square of the total number of RB species in the ecoregion	31.3	22.4	12.9	16.0	19.1	11.4	14.4	29.3	17.0	25.3
Share of RB species in a square of the total number of species in the ecoregion*10	13.6	12.1	7.4	11.9	16.5	12.8	23.2	48.7	9.6	35.5

Figure 3.2.3.7.1. Changes in mean for ecoregions values of indices of species richness and Red Book species.



a b

Figure 3.2.3.7.2. Relationship of mean values of the index "Share of Red Book species in a square of the total number of RB species in the ecoregion" with the-total-number of bird species in the ecoregion (a) and the mean for ecoregion value of number of species per square (b). Arctic desert ecoregion is excluded from analysis.

The picture changes, however, when actual values of indices in squares are compared. The relationship between the index "Share of Red Book species in a square of the total number of Red Book species in the ecoregion" and the number of total species in squares becomes positive (Fig. 3.2.3.7.3 a). Inside ecoregions there are positive relationships between these indicators – stronger than the relationship for the entire European Russia. The positive trend in entire European Russia results from these stronger intra-regional relationships, despite the negative trend for the means for ecoregions values.

It turns out that, in ecoregions with high species richness (total and mean per square), a smaller percentage of the Red Book species of the given ecoregion is preserved in each square compared with ecoregions with lower species richness, which seems strange. But within each ecoregion the opposite, logical clear, picture is revealed: in squares with a greater number of species there is also a greater proportion of the Red Book species of their total number in the ecoregion. This counter-intuitive negative relationship on the scale of comparing of mean for ecoregions values of indices within European Russia is explained by simultaneously increase from north to south not only of species richness and total number of Red Book species in ecoregions, but also of their share (%) of the total number of species in the ecoregion (Tab. 3.2.3.5.1; Fig. 3.2.3.3.1).

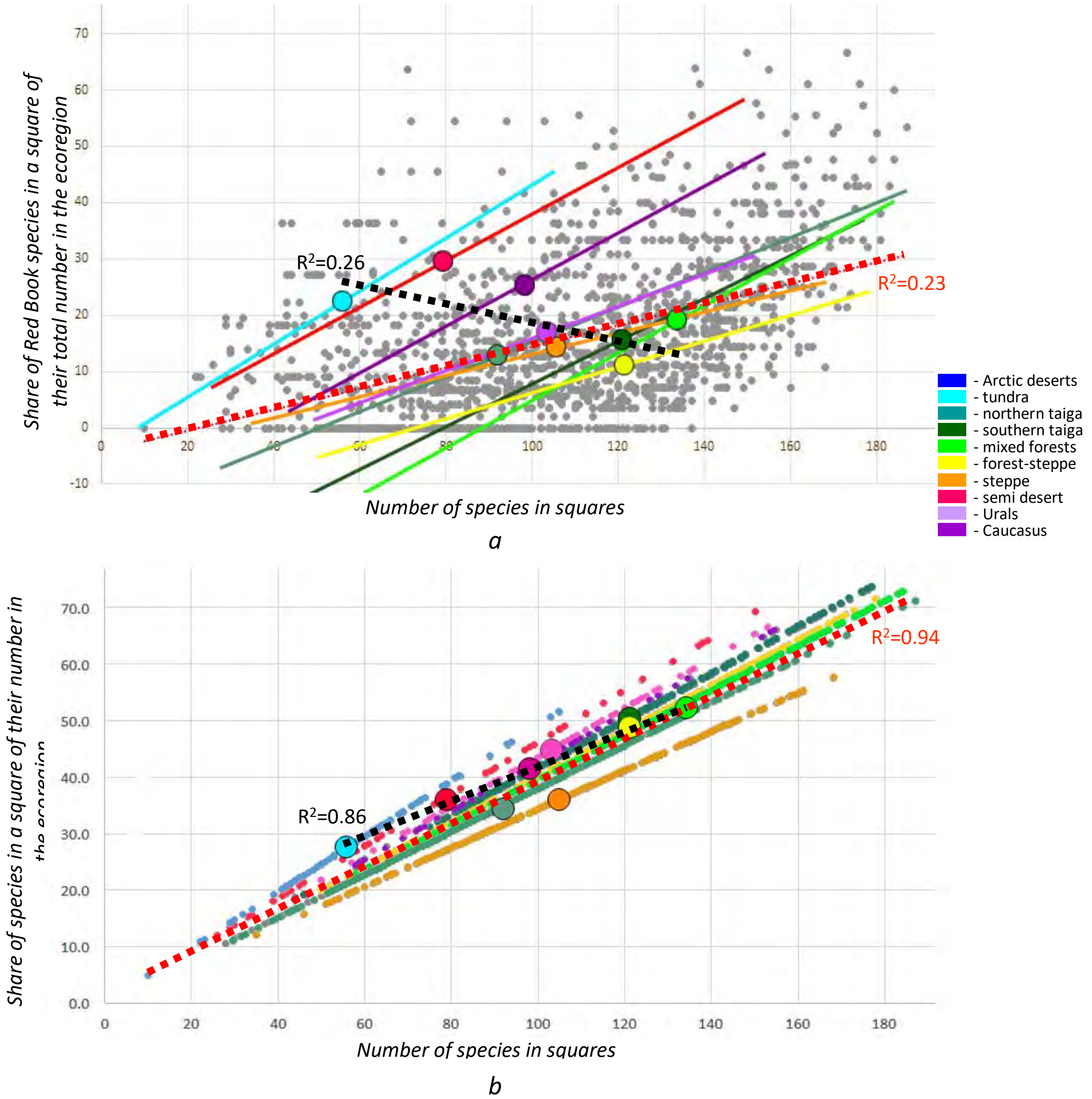


Figure 3.2.3.7.3. Relationship between the number of all bird species in a square and indices "Share of Red Book species in a square of their total number in the ecoregion" (a) and "Share of species in a square of their number in the ecoregion" (b). Relationships for actual values of indices in squares for entire European Russia are indicated by dotted red trend lines; relationships for mean values for ecoregions are indicated by dotted black trend lines. Mean values and trend lines pertaining to different ecoregions are shown in colors that correspond to the ecoregions map in Fig. 2.2.1. The graphs are plotted without accounting of the Arctic desert ecoregion.

The negative relationship of mean for ecoregion values between the index “Share of Red Book species of their total number in the ecoregion” and the total number of species in squares is in the contrary to the positive dependence identified for the analogous indicator calculated for all species (the index “Share of registered in a square species of their total number in the ecoregion”, Section 3.2.3.2, Fig. 3.2.3.7.3 b).

This example illustrates the need for a different interpretation of the correlations between the same indicators obtained at different scales of analysis.

Within ecoregions, the positive correlation between the total number of species in a square and the index “Share of Red Book species of their total number in the ecoregion” indicates that the squares most abundant in species, i.e., the most important for preserving an ecoregion’s total species richness, are simultaneously more valuable for preserving the pool of Red Book species. The situation is similar for the index “Share of species in a square of their number in the ecoregion”: within ecoregions squares with more species are more valuable for preserving the ecoregion’s total species diversity (see also Section 3.2.3.2).

However, the direct transfer of such interpretation to a comparison of ecoregions on the scale of entire European Russia will result in false conclusions. A negative relationship between mean for ecoregions values of index “Share of Red Book species of their total number in the ecoregion” (Fig. 3.2.3.7.2 b and 3.2.3.7.3 a) does not indicate that squares and ecoregions with high species richness are less valuable for preserving Red Book species in European Russia. Likewise, the positive relationship for the index “Share of species in a square of their total number in the ecoregion” (Fig. 3.2.3.7.3 b) does not mean that, on the scale of entire European Russia, ecoregions and squares with higher species diversity are more valuable to the preservation of this diversity, since the set of species in the northernmost ecoregions and in squares with a small number of species are different from those in the south, where species richness is generally higher due to more favorable climatic conditions. The latter case emphasizes the need to account zonal and regional specifics of natural conditions and biodiversity in decision making on conservation and environmental protection. The existence of positive or negative relationships between mean for ecoregions values of indices emphasizes the need to account for regional (zonal) features in the development of a strategy for monitoring ecosystems and biodiversity and for managing them.

Indices of Red Book species once again provide an example of their varying interpretation on different scales. In a comparison of 50-km squares within single ecoregion, the high values of these indices in a square most likely indicate on preserving of rare species habitats there and on good quality of preservation of natural ecosystems in general. However, on the level of more extensive and generalized assessments, the interpretation of these indicators may became the opposite: when comparing the total number of Red Book species in ecoregions and the average values of Red Book indices for ecoregions within European Russia, high values of these indicators in any ecoregion can generally reflect a greater disturbance of natural habitats which makes breeding birds in this region threatened.

3.2.3.8. Opportunities to use bird diversity indicators in SEEA-EEA

The scale of analysis of bird species diversity has a crucial impact on interpretation and, accordingly, practical application of bird diversity indicators. In particular, relationships between the same indicators may vary widely, up to and including a change of sign, when they are analyzed on different scales. Consequently, the assessments and conclusions based on a comparison of 50-km squares within ecoregions cannot be directly applied to the entire area of European Russia or the whole Russia. For example, the fact, confirmed by the positive relationships of species richness indicators and Red Book species indicators, that squares with more species, including Red Book species, are more valuable for preserving species diversity inside any ecoregion, cannot be extrapolated to the entire area of European Russia, since analysis within European Russia as a whole reveals both positive and negative correlations between these indices. Accordingly, squares with more species will not necessarily have a higher priority for the preservation of bird diversity throughout entire European Russia, in contrast to the ecoregion level.

The relationships between indices of species richness, Red Book species and the “Overall index of bird diversity” are stronger within many ecoregions than for entire European Russia, which demonstrate the possibility of using these indicators primarily to analyze bird distribution within ecoregions. It is also obvious that indices, the calculation method of which accounts the squares’ affiliation to a certain ecoregion, “work” almost identically within each ecoregion, therefore at this level of consideration it is enough to use one of them.

Strong correlations between the mean for ecoregions values of most indicators of bird diversity proposed at the current stage of research (primarily correlations with indicators of species richness) show that they are not free of impact of latitudinal and climatic factors on bird distribution within European Russia, which does not allow to use them as correct indicators on this scale. At the same time, the index “Share of RB species of the total number of species in the ecoregion” and the “Overall index of bird diversity” have almost no correlation with mean for ecoregions values of indicators of species richness. This finding shows the potential possibility for their refinement for use in assessing bird diversity within European Russia and at the national level.

The correlations revealed between mean for ecoregions values of indices point to the need to develop, on the national level, regionally differentiated approaches to monitoring, assessing, accounting for, and preserving species diversity, which take into account the principal differences in its species and spatial structure in different regions, including in regions with relatively high and relatively low levels of natural biodiversity.

The proposed indicators of the synanthropization level of bird population have shown a certain sensitivity to the degree of territory transformation, but they need significant correction. It is most likely that the set of 12 species selected for analysis within European Russia is too generalized and redundant. The exclusion of some species from it or the use of only one or two species to calculate the same indicators as well as application of these indicators on a more local level will allow to get more accurate estimation of the degree of natural ecosystem transformation by using of data on birds.

The patterns of spatial distribution of indicators values showed that a number of ecoregions (e.g., Ural montane forests and tundra or northern taiga) include subregions with very different conditions (e.g., forest tundra, the northern and middle taiga zones within the northern taiga ecoregion), which complicates the correct use of indicators of bird diversity even within these ecoregions. A geographic area must be zoned more precisely (see also Section 6.4) to assess the distribution of species diversity.

Developing an adequate and correct system of biodiversity indicators requires research on the regional and local levels. The greater detail of such studies can improve their quality both by increasing the homogeneity of the territorial units of assessment, and by considering the characteristics of a particular region in the development of indicators. For example, when analysis within an individual subject of RF or a small number of adjacent subjects, additional information for calculating indicators can be obtained from regional Red Data Books – the changes in species state could be monitored in more detail by theirs data, since regional Red Data Books are published more often than the national one.

The development of indicators requires the use of a larger bird data set, including data on species abundance and distribution density within units of the assessment as well as taxonomic (the number of systematic groups) and functional (the number or proportion of granivorous, insectivorous, raptors, and other species) characteristics of bird diversity. It is possible to use also other characteristic of species biology and ecology that could to some degree indicate their links with preserved or, to the contrary, disturbed natural habitats. An example of a possible approach to the development of such indicators is presented, in some degree, in the methodology of calculation of the index “Synanthropization level of bird population”.

The density characteristics of bird distribution (pairs/km^2, ind./km^2, etc.) certainly cannot be a “working” indicator on the scale of highly generalized types of ecosystems, and especially, ecoregions. However, analysis on a more local scale (within small by area subjects of RF or administrative entities of a lower level) requires more accurate information about habitat types used by different species as well as more accurate quantitative data about species distribution in them. Hence, to organize and conduct targeted data gathering on the distribution of certain habitat types and components of biodiversity.

It is also necessary to develop a generalized index of overall biodiversity, which would accumulate data not only on birds, but also about the distribution and abundance of other components of fauna, flora and ecosystems. All this requires the establishment, maintenance and regular updating of relevant databases at the federal, regional, municipal and other levels.

3.3. Indicators of plant diversity

Despite relatively low species richness, Russian flora has not been well studied. Even in Middle Russia (CFO and the west part of Volga Federal District) the density of herbarium collections (the number of herbarium sheets in public libraries per unit of area) is 1.5 lower than the world average and more than an order of magnitude lower than in most Western and Central European countries (Seregin, Shcherbakov, 2006). The situation in some regions is even worse: the density of herbarium sheets is an order of magnitude below the world average. The density of herbarium collections in most subjects of RF is appreciably lower than even in Middle Russia.

The project used data on the number of vascular plant species from three sources, discussed further in Sections 3.3.1, 3.3.2, and 3.3.3.

3.3.1. Number of vascular plant species per 100,000 km^2

The number of vascular plant species per 100,000 km^2 was determined for subjects of RF based on data from the National Atlas of Russia (2004–2008) in the TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018; Fig. 3.3.1).

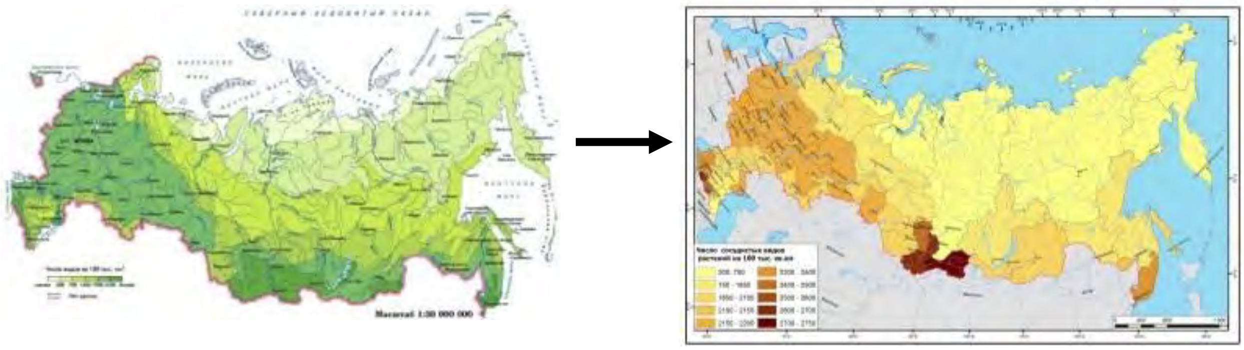


Figure 3.3.1. Number of vascular plant species of per 100,000 km^2 averaged for the area of subjects of RF.

3.3.2. Number of plant species in local flora

The mean number of plant species in local flora for subjects of RF within European Russia (Fig. 3.3.2) was determined by GIS methods (Section 2.3) based on data from O .V. Morozova (2011).

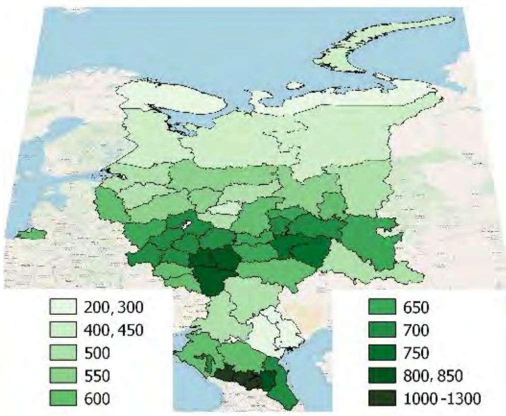


Figure 3.3.2. Mean number of plant species in local flora in subjects of RF within European Russia.

3.3.3. Plant species richness in administrative districts of the Central Federal Okrug of RF

A preliminary analysis of currently available data on vascular plant species richness was performed for administrative districts in eight oblasts of the Central Federal Okrug (CFO). Although relationships between indicators of biodiversity and ES were not analyzed on this scale in TEEB-Russia 1 and 2 projects, this analysis is necessary to understand possible prospects for future ecosystem assessment (Section 2.1).

3.3.3.1. Level of floristic study and primary sources of data on plant species diversity in European Russia

Because insufficient level of floristic study of Russian territory, analysis of plant species richness on a scale more detailed than at the level of subjects of RF was possible only for several subjects of RF of the CFO (Moscow city and Moscow Oblast were united in one region). The low density of herbarium data is not enough to use grid mapping, since available data is in most cases insufficient to fill 100 km^2 grid cells. Plant species composition has been mapped with this accuracy in only one subject of RF – Vladimir Oblast (The Flora of Vladimir Oblast..., 2012). Data for Moscow region and Kaluga, Orel, Ryazan and Tula oblasts are available on this scale only for aquatic and semi-aquatic plants (Shcherbakov, 2011). The scale with 2500 km^2 grid cells used in the "Atlas Florae Europaeae" project is, in contrast, too small and over-generalizes the information. Based on the density of herbarium data in Central Russia, the most adequate scale for analysis of plant species richness are 1000 km^2 cells. However, the creation of such a grid and its filling are too labor-intensive and could not be completed on time for TEEB-Russia 2 project. Therefore, administrative districts were selected as territorial units for floristic data analysis. The average area of administrative districts in most subjects of RF in the CFO is slightly greater than 1000 km^2. Administrative districts, as a rule, are the smallest units for making managerial and economic decisions, including in the field of environmental management.

The CFO includes 18 subjects of RF: 17 oblasts (Belgorod, Bryansk, Vladimir, Voronezh, Ivanovo, Kaluga, Kostroma, Kursk, Lipetsk, Moscow, Orel, Ryazan, Smolensk, Tambov, Tver, Tula and Yaroslavl) and the city of Moscow. Because they have been studied floristically to different degrees, only eight oblasts were included in our analysis (Tab. 3.3.3.1).

Table 3.3.3.1. Data sources for assessing floristic diversity in subjects of RF within the CFO (subjects included in this analysis are shown in bold).

Oblast	*Main floristic reports*	*Data on the status of protected species*	*Data on species' invasive activity*	*Density of herbarium data*, sheets/km^2*
Belgorod Oblast	*Elenevsky et al.*, 2004. The first published flora of this region is extremely incomplete (Kalinichenko et al., 2006). Currently in the framework of the "Flora of the Central Black Earth Region" project, N. M. Reshetnikova is completing data collection, but it was unavailable to us.			more than 2.2
Bryansk Oblast	*Bulokhov, Velichkin,* 1998. The book abounds with errors (Gubanov et al., 2002). There are 3 available published local flora. Manuscript lists are unavailable.			at least 0.5
Vladimir Oblast	*Seregin, 2012.* Currently it is the best regional flora of Russia. The study was done by grid mapping with cells a little smaller than 100 km^2. The appendix gives a list of species by administrative district.	Red Book of Vladimir Oblast, 2018.	Seregin, 2012.	
Voronezh Oblast	There is no main floristic list, but there are several detailed floristic lists for towns, reserves, refuges, and biostations. All information on herbarium collections was considered in materials of the "Flora of the Central Black Earth Region" project.	Red Book of Voronezh Oblast..., 2011.	*Grigorievskaya et al.,* 2004.	more than 1.6
Ivanovo Oblast	*Alyavdina, Vinogradova, 1972.* The list of flora is extremely incomplete and obsolete (Tikhomirov et al., 1998). As part of the "Oka Basin Flora" project, we used all herbarium data and obtained two published lists of local flora and more than 50 separate floristic descriptions for different districts of the region.	Red Book of Ivanovo Oblast..., 2011.	*Borisova, 2007.*	more than 1.1
Kaluga Oblast	*Reshetnikova et al. 2010.* Currently, as part of the "Oka Basin Flora" project, N. M. Reshetnikova is completing data gathering, but it was unavailable to us.			more than 0.9
Kostroma Oblast	*Belozerov, 2008.* The work reflects study of flora as of the mid-1960s (Kalinichenko et al., 2011). Manuscript lists are unavailable or non-existent.			0.2

Oblast	Main floristic reports	Data on the status of protected species	Data on species' invasive activity	Density of herbarium data*, sheets/km^2
Kursk Oblast	*Poluyanov, 2005.* Currently, as part of the "Flora of the Central Black Earth Region" project, N. I. Zolotukhin and A. V. Poluyanov are completing data gathering, but it was unavailable to us			more than 1.8
Lipetsk Oblast	*Aleksandrova et al., 1996.* At present as part of the "Flora of the Central Black Earth Region" project, we used all herbarium data and obtained several published lists of local flora from different parts of the oblast and monitoring data on the regional Red Data Book.	Red Book of Lipetsk Oblast..., 2014.	*Aleksandrova et al., 1996.*	more than 2.7
Moscow region**	*Shcherbakov, Lyubeznova, 2018.* A list of species distribution by districts was compiled within framework of the projects "Oka Basin Flora" and TEEB-Russia 2.	Red Book of Moscow Oblast..., 2018.	*Mayorov et al., 2012.*	
Orel Oblast	*Elenevsky, Radygina, 2005.* This source is extremely incomplete. As part of the projects "Oka Basin Flora" and "Flora of the Central Black Earth Region", L. K. Kiseleva completes data collection by the method of grid mapping for a new regional flora synopsis, but it was unavailable to us.			more than 1.5
Ryazan Oblast	*Kazakova, Shcherbakov, 2017.* A list was compiled as part of the "Oka Basin Flora" project.	Red Book of Ryazan Oblast..., 2011.	*Kazakova, 2004.*	
Smolensk Oblast	*Reshetnikova, 2004.* An unannotated list of species from published or herbarium materials (Kalinichenko et al., 2006). Relatively complete species lists are available for only a few districts.			at least 0.4
Tambov Oblast	*Sukhorukov et al. 2010.* As part of the projects "Oka Basin Flora" and "Flora of the Central Black Earth Region", we used all herbarium data and obtained more than 20 local species lists from the Oka basin, from the Voronino reserve, and from the surroundings of Michurinsk.	Red Book of Tambov Oblast..., 2002.	*Sukhorukov et al. 2010.*	more than 0.7
Tver Oblast	*Notov, 2005.* The flora synopsis was done well, but information on many administrative districts is extremely incomplete.			more than 0.7
Tula Oblast	*Sheremetieva, et al., 2008; Shcherbakov et al., 2017.* The latest list was compiled as part of the "Oka Basin Flora" project and expanded with data from more than 50 floristic descriptions from the Don basin provided by I. S. Sheremetieva.	Red Book of Tula Olast..., 2010.	*Sheremetieva et al. 2008.*	
Yaroslavl Oblast	*Belovashina et al. 1986.* Information regarding species distribution throughout the region is extremely incomplete and quite obsolete. There are lists of local flora for only 7 administrative districts. Work led by E. V. Garin on compiling a modern regional flora synopsis is in initial stage.			The declared density of 3.3 sheets/km^2 is overestimated by more than 6 times.

*According to data from A. P. Seregin and A. V. Shcherbakov (2006).

**Moscow Oblast and Moscow city.

3.3.3.2. Preliminary results of the analysis of plant species richness

Data on plant species number registered in administrative districts of eight selected oblasts of the CFO are shown on Fig. 3.3.3.2.1.

Significant number of non-native plant species was registered in most districts (Fig. 3.3.3.2.1 d). This fact points to the need to segregate non-native species in a separate category when assessing plant species diversity in Russia's central oblasts.

Subsequent analysis shows that the number of species of different categories registered in administrative districts is per se an insufficiently accurate indicator of the actual species diversity for several basic reasons:

– the dates of species registration vary, and some species were reported several decades ago and after that were no longer reported;

– although species at the first steps of the analysis were divided into three categories (native, red book and non-native) they differ widely in their importance to a general biodiversity assessment within these categories (red book species have different categories, non-native species have different spreading attributes);

– the degree of survey of districts is very uneven, therefore, the number of species recorded in districts may be the result of the incompleteness of their survey, and not reflect the actual species richness.

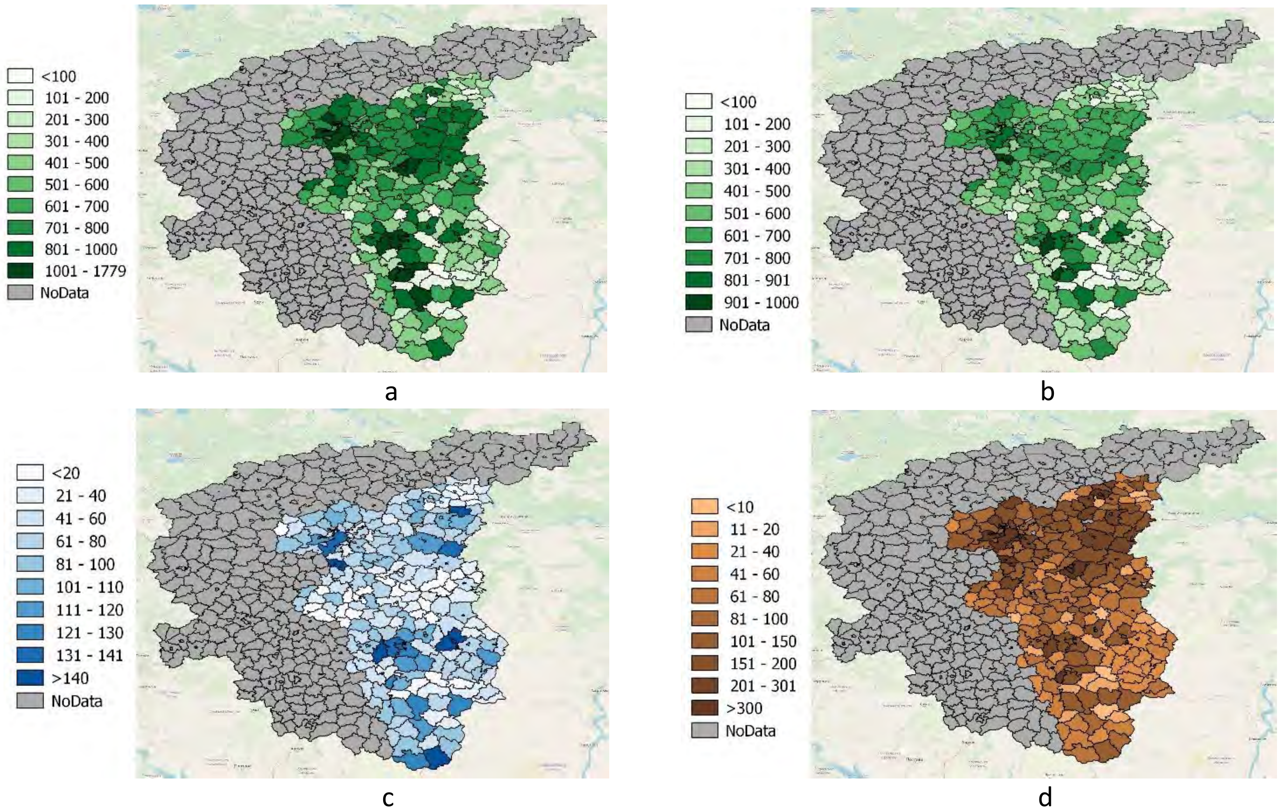


Fig. 3.3.3.2.1. Plant species number registered in administrative districts of eight oblasts of the CFO: a) total number of all species; b) number of native flora species; c) number of species included into regional Red Data Books or Red lists; d) number of non-native species.

To test possible approaches to solving these problems, the number of species reported in districts was adjusted based on a score for these three factors. The total score for a species was increased if it was registered relatively recently and/or has a more important conservation Red Book category. The total score for non-native species was decreased for the most aggressively spreading species. The final rank of plant species as well as administrative districts in their importance for preserving the total species richness within eight analyzed oblasts was determined based on the sum of adjusted scores. The importance of districts was ranked from 1 to 10: 1st rank goes to the most important district; 10th rank to the least important. Figure 3.3.3.2.2 a, b, c shows the results of the assessment for three basic species categories.

Further, by means of expert assessment, cases of possible overestimation or underestimation of obtained estimates of species number in administrative districts due to their insufficient survey were identified. For most districts in each of the selected eight oblasts estimated of plant species diversity were determined to be basically correct. Overall, the rank assigned to 28% of the districts was found to be either understated or overstated; for individual oblasts this figure varies from 18 to 40% (Tab. 3.3.3.2.1, Fig. 3.3.3.2.2 d).

Table 3.3.3.2.1. Quality of plant biodiversity estimates for selected subjects of RF.

Subject of RF	*Number of districts*				*Share of districts with inconsistent assessment, %*
	Total	*Assessment consistent with expert*	*Assessment understated*	*Assessment overstated*	
Vladimir Oblast	16	12	2	2	**25**
Voronezh Oblast	33	22	7	4	**33**
Ivanovo Oblast	21	16	4	1	**24**
Lipetsk Oblast	18	13	3	2	**28**
Moscow region	40	24	9	7	**40**
Ryazan Oblast	25	16	3	6	**36**
Tambov Oblast	33	27	4	2	**18**
Tula Oblast	33	26	4	3	**21**
All subjects of RF	**219**	**156**	**36**	**27**	**28**

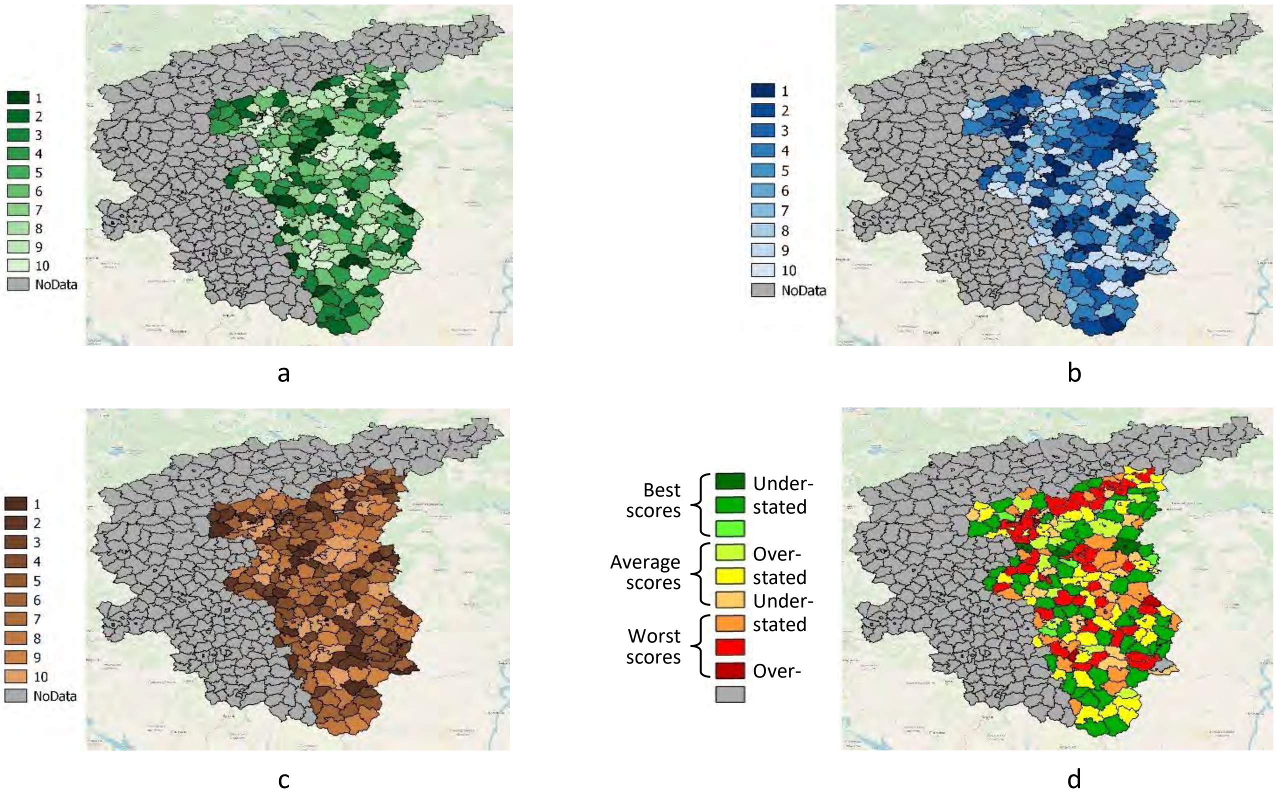


Figure 3.3.3.2.2. The scoring for plant species diversity for administrative districts of selected subjects of RF: a) district's rank based on the sum of all species divided by the number of native species; b) district's rank based on the number of Red Book species; c) district's rank based on the number of naturalized non-native species; d) district's final rank.

3.3.3.3. Basic reasons for inaccuracy and distortion of estimates of plant species richness

Incomplete and uneven study of the flora

Among the selected eight subjects of RF only the flora of Vladimir Oblast had been studied relatively completely and uniformly. The flora of Moscow region is well studied, but Zaraisky, Kashirsky, Pavlovo-Posadsky, Serebryano-Prudsky, and Shakhovskoy districts are still insufficiently floristically studied. The Lipetsk Oblast is well studied floristically, although even there the flora of two peripheral districts (Dolgorukovsky and Lev-Tolstovsky) is extremely incompletely studied. In the well-studied Ryazan Oblast, there is extremely sparse data on the floristically uninteresting Zakharovskiy, Pitelinsky, Putyatinsky, and Chuchkovsky districts. Flora of Tula Oblast is studied relatively uniformly, the amount of data is noticeably less than in four above regions. Although there are areas that have not been studied enough: Arsenevsky, Kamensky, and Uzlovsky. Data on the Voronezh and Tambov oblasts are mainly obtained from herbarium collections, and therefore, there is insufficient data for one-fourth of districts within these regions. Among selected eight subjects of RF, the situation is the worst in Ivanovo Oblast where more than half of districts have been floristically studied worse than Shakhovskoy district, which ranked last in this parameter in Moscow region. Nevertheless, even for the Vladimir Oblast, well studied floristically using grid mapping, estimates of plant diversity obtained by calculations and expert evaluation did not coincide for a quarter of districts (Tab. 3.3.3.2.1).

Some districts are rarely visited, since, according to known information, they have no botanically remarkable natural objects. This leads to a closed loop: districts are not visited because there is no information about interesting objects, which are not discovered because these districts are not subjects of special interest. Examples might include Ertilsky district in Voronezh Oblast, Lezhnevsky in Ivanovo Oblast, Lev Tolstoy in Lipetsk Oblast, Chuchkovo in Ryazan Oblast, Staroyuryevsky in Tambov Oblast, Arsenyevsky in Tula Oblast and Pavlovo-Posadsky in Moscow region.

Even within the same administrative district there are often areas that have been studied to different degrees. The flora of regional centers and large cities where there are higher educational institutions that train specialists in biology has been traditionally well studied compared with the average. Natural reserves, biological stations, nature study stations and certain other facilities can also be relatively well studied.

Different degree of knowledge of native, non-native flora and rare plant species in different districts

Registered number of non-native species in a district is determined not only by the degree of its economic development and anthropogenic transformation, but also by the scope and quality of special studies of the adventive component of its flora. All these factors vary significantly among subjects of RF. The number of non-native species identified in Moscow region exceeds the number of native flora species (Shcherbakov, Lyubeznova, 2018). Adventive and urban flora of Ivanovo Oblast have long been studied (Borisova, 2007). The adventive flora of Voronezh, Lipetsk, and Tula oblasts were objects of special studies, but only either as part of a separate project (Voronezh Oblast) or doctoral dissertations (Lipetsk – see Vyukova, 1985; Tula – see Khorun, 1998). The level of study of adventive flora of these oblasts should therefore be considered about average (375 species for Tula, about 400 for Lipetsk, and 435 for Voronezh). The adventive flora of Vladimir, Ryazan, and Tambov oblasts have not been studied specially, but have been described as part of general floristic research. More than 300 non-native plant species have been registered in each of these regions. In Ryazan and Tambov oblasts, the number of identified non-native species is slightly less than in other regions, but the assessment of their presence in administrative districts is much worse. In cases where adventitious flora has been specifically studied, and the level of examination of natural flora remains low, noticeable distortions may occur in assessing the quality of plant biodiversity in certain areas. Noticeable distortions in assessing the quality of plant diversity can occur in areas where non-native flora has been specifically studied, but the level of natural flora examination remains low.

The completeness of identification of non-native flora substantially depends on the duration of floristic surveys. With limited terms of work, it often does not reach a serious study of the adventive component of the flora. On the other hand, at long-existing scientific stations, including nature reserves, with a high level of natural flora detection, species richness begins to grow due to non-native species. For example, flora of the Prioksko-Terrasny and Voronezh reserves has been significantly "enriched" by non-native species discovered near towns, power lines, and roads and railways crossing these reserves (Alekseev et al., 2004; Golitsyn, 1961; Smirnov, 1958; Starodubtseva, 1999). The number of plant species has significantly increased due to non-native species at Lomonosov Moscow State University's Zvenigorod biology station (Barsukova, Pyatkovskaya, 1967; Alekseev et al., 2008).

Another source of possible distortions is the preferential search for rare plant species that is often typical in the studies of remote districts by infrequent excursions. Native species are described as a characteristic of the habitats of rare and protected species, and non-native species are occasionally reported. This is the situation in Melenkovsky district in Vladimir Oblast; Vorobyovsky and Kantemirovsky districts in Voronezh Oblast; Ilyinsky and Pestyakovsky districts in Ivanovo Oblast; Volovsky and Dolgorukovsky districts in Lipetsk Oblast; Ermishinsky and Kadomsky districts in Ryazan Oblast; Gavrilovsky district in Tambov Oblast; Arsenievsky and Kamensky districts in Tula Oblast, and Serebryano-Prudsky and Shakhovsky districts in Moscow region.

Different quality of regional Red Data Books and of Red Book species monitoring

Rare and protected species are an important criterion in assessing biodiversity. These species are usually indicators of the presence of remarkable or unique natural objects and the relatively good preservation of rare or endangered biotopes. However, the quality of the information contained in the Red Data Books may be unsatisfactory for several reasons:

– not all regions have enough specialists with the requisite biological qualifications;

– not all of these specialists have sufficient environmental protection experience to adequately assess the categories of Red Book species;

– among specialists working in regional Red Data Books, sometimes there are conflicts, up to the exclusion of colleagues to work on their preparation;

– not in all regions, specialists follow the "Guidelines for maintaining the Red Book of a subject of the Russian Federation" (2006), especially regarding update frequency and monitoring;

– monitoring is not properly organized in all regions;

– Red Data Books are often based on insufficient materials, which are sources of inaccuracies and errors. In other words, a Red Book should be created at the end of a competent floristic study of a region, and not precede it.

In view of these factors, regional Red Data Books can be grouped as follows:

– Red Data Books based on sufficient data, compiled by qualified specialists, and reinforced by systematic monitoring studies: the second edition of the Lipetsk Oblast Red Data Book (2014), the third edition of the Moscow Oblast Red Data Book (2018) and the second edition of the Ryazan Oblast Red Data Book (2011);

– Red Data Books based on sufficient data, but whose authors do not always have enough environmental protection experience, and regional monitoring is not always done systematically: the second edition of the Vladimir Oblast Red Data Book (2018) and the first edition of the Tula Oblast Red Data Book (2010);

– Red Data Books based on insufficient data, the qualifications of some authors raise doubts, regional monitoring is done irregularly or not at all: the first edition of the Voronezh Oblast Red Data Book (2011), Ivanovo Oblast Red Data Book (2011) and Tambov Oblast Red Data Book (2002).

The contribution of these regional Red Data Books to the assessment of regional plant biodiversity is therefore unequal, and these documents do not always adequately assess the significance of particular species for nature preservation in a region.

The vast area of administrative districts and heterogeneity of conditions within them

The analysis showed that the area of administrative district (about 1000 km^2), which we used as the minimum territorial unit, is too large to correctly assess the significance of the biodiversity of vascular plants. In many cases administrative districts include different complexes of plant communities, for which both a high and a relative low level of species diversity can be typical. For example, the Oka river divides Ryazan district in Ryazan Oblast into two parts approximately equal in area, the right bank of which has undergone significant anthropogenic transformation, while the left bank has little economic activity. In the Serpukhov district of the Moscow Oblast, on the one side, there is the oldest nature reserve in the region, which has exceptionally rich flora, and on the other, one of the largest industrial centers in the region (the city of Serpukhov). Similar examples are available in any of the eight subjects of RF examined.

Obtaining the most accurate assessments requires switching to a more detailed level that accounts for the geographic distribution of various types of plant communities. Accuracy significantly increases if cells of about 100 km^2 in area are used (Aleshchenko et al., 1995; Sheremetieva, 1999).

3.3.3.4. Possibilities of using and refining indicators of plant diversity

The plant species richness indicators used in TEEB-Russia 2 project demonstrated their potential applicability for assessing biodiversity on the level of administrative districts. Quantitative estimates of plant species richness and its “quality” for most districts are compatible with expert estimates, which were also based on complete lists of plants (Section 3.3.3.2). Therefore, further development of biodiversity indicators on this scale may be based on current floristic data and biodiversity indicators we have proposed.

However, at the administrative district level, estimates of vascular plant diversity cannot always be used as unambiguous indicators, since districts often includes different plant community complexes. Obtaining the most accurate assessments requires switching to a more detailed level that accounts for the geographic distribution of various types of plant communities.

To obtain adequate estimates of plant diversity, it is also necessary to adjust the possible shifts and distortions of the estimates of species richness due to the uneven knowledge of the flora within the CFO within subjects of RF and even within individual administrative districts; varying degrees of knowledge of native, non-native flora and rare plant species; heterogeneity of quality of regional Red Data Books.

The study of flora by grid mapping in the coming years in most regions of Russia is hardly possible due to the high labor costs and in some places due to the lack of specialists with proper qualifications. Therefore, it is necessary to develop extrapolation approaches to assessing plant diversity and the state of plant communities based on a combination of floristic data available today, cartographic and distance data, as well as expert estimates.

4. Ecosystem Services of Russia: Detailing after the TEEB-Russia 1

4.1. Refined ecosystem services estimate for European Russia

4.1.1. Wood production

Wood stock per unit of total area is used as an indicator of **provided volume** of ES of wood production and related ecosystem assets. This indicator was calculated for 50-km squares and subjects of RF within European Russia based on data from the State Forestry Register (Forest Register, 2014) on wood stocks in forest districts (Fig. 4.1.1). Vector maps of forest districts with information on wood stocks were converted to a bitmap. The zonal statistics method was used. 50-km squares and subjects of RF were used as zones.

The largest wood stocks are typical for the southern taiga ecoregion and subjects of RF located within this band (Leningrad, Novgorod, Tver, Moscow, Vologda, Kostroma, and Kirov oblasts and Perm krai).

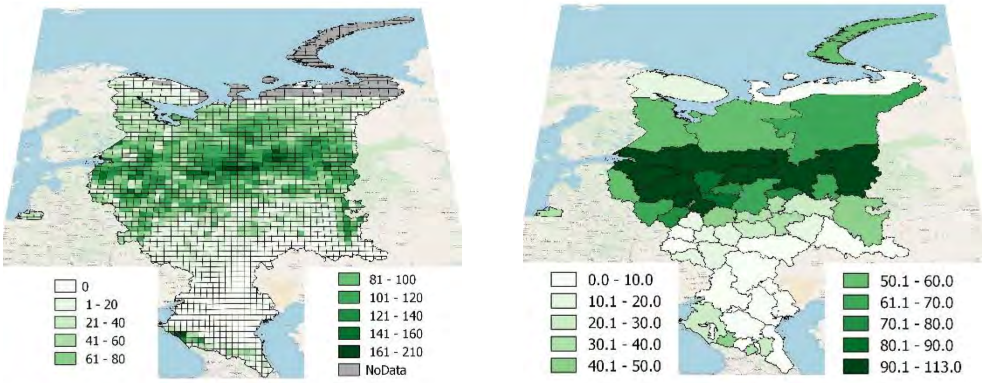


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Figure 4.1.1. Wood stock per unit of total area (m^3/m^2) within European Russia: a) for 50-km squares; b) for subjects of RF.

The State Forestry Register, until 2009 called the state forest inventory (SFI), establishes a procedure for gathering and presenting data about the condition and distribution of forests on the national level. The first forest inventory was completed in 1957, and in 1961 the first SFI was created. Later, up until 1998, the SFI was updated every 5 years. The major forest inventory methods were as follows: 1) ground data collection (so-called forest surveying); 2) remote sensing data analysis; 3) aerotaxation. By 1998 these methods accounted for 61, 24 and 15% of the data, respectively[54]. After 1998 data were updated every 2 years, but the level of data aggregation has grown: until 2008 data were provided on the level of forestry districts but, with the abolition of forestry districts, data came to be aggregated to the level of subjects of RF, which greatly reduces opportunities for regional analysis.

State Forestry Register data is public. Its content is defined by Russian Ministry of Natural Resources order № 301 "On approval of the scope and content of information about forests" (registered with the Russia Ministry of Justice on 27.07.2018 under № 51719). According to Russian Ministry of Natural Resources order № 464 dated 30.10.2013 "On approval of the list of data contained in the state forestry register" (registered with the Russian Ministry of Justice on 21.03.2014 under № 31683) State Forestry Register data are provided to any person in the form of extracts upon written request to the authorized governmental body. It is also possible to obtain data via the Internet, including a portal of state and municipal services.

However, currently, the State Forestry Register information system is not being used as a single software product[55]. Because of this, regions use irrelevant data on the forest fund to compile documents. Russia therefore has no unified system of forest resources accounting that would provide reliable information about their quantity, quality, and value.

[54] https://webarchive.iiasa.ac.at/Research/FOR/russia_cd/for_des.htm

[55] https://www.cnews.ru/news/top/2019-01-22_ais_dlya_rosleshoza_za_185_millionov_ne_vypolnyaet

4.1.2. Carbon storage

The total amount of carbon in soil (0–100 cm) and phytomass according to the database Land Resources of Russia (Stolbovoi, McCallum, 2002) was used as an indicator of **provided volume** of carbon storage ES and corresponding ecosystem assets. This indicator was calculated by summation of data from two digital maps: “Mean soil carbon density 0–100 cm” and “Total phytomass density”. The average values for 50-km squares and subjects of RF within European Russia were calculated by the obtained summary indicators (Fig. 4.1.2).

The figures show that the maximum carbon content is found in individual 50-km squares in the tundra zone and adjacent parts of the northern taiga. In the middle zone Meshchera[56] stands out. To the south is a vast area with a high carbon content in black-earth regions of the forest-steppe ecoregion. Among subjects of RF, the Murmansk Oblast and the Nenets Autonomous Okrug stand out in the north, and all the black-earth regions in the south, primarily Kursk, Belgorod, Voronezh, and Tambov oblasts.

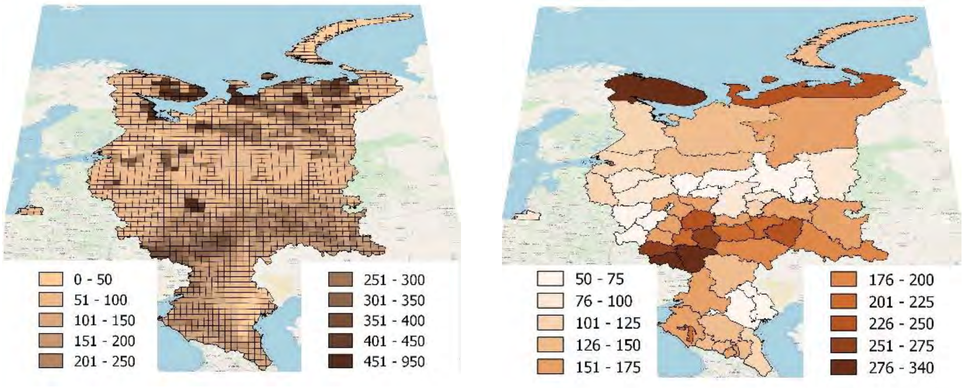

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Figure 4.1.2. Total carbon content in soil and phytomass, kgC/m^2: a) for 50-km squares; b) for subjects of RF.

4.1.3. Air purification by suburban forests

The ES of air purification by vegetation is most relevant in districts where there is marked atmospheric pollution from emissions by stationary and mobile sources. Because these geographic areas include first and foremost cities, most methods developed to assess the scale on which this function is carried out refer to urban and suburban forests.

Estimation options of this ES on the level of municipal districts and subjects of RF are limited, primarily by the availability and completeness of information on emission volumes and the composition of the pollutants. The most complete statistics for the European part of the Russian Federation are found in a database of indicators of municipalities[57], which contains records on emissions from stationary sources within urban districts included in subjects of RF. On the local (urban district or group of districts) level of estimates for calculating the volume of services, information on source localization, the distribution pattern of pollutant depending on the wind direction and weather, and territory relief is relevant. In calculating the service performed by suburban forests, we assumed that the generalized pollution source for them would be the area of the adjacent city, which is treated as space where pollutants are uniformly distributed, disregarding the sources’ specific localization.

Later, data for urban districts included in the subjects of RF were summarized, and the result was compared with similar data on stationary source emissions for the subjects from the Federal State Statistic Service database. Discrepancies were minimal, which confirmed that a large portion of purification services are performed in buffer zones of urban districts. This made it also possible to use these data in calculations for other categories of administrative geographic units – municipal districts and squares.

The concept of the buffer zone is the base concept for calculating air purification services by suburban forests. In TEEB-Russia 1 (Bukvareva, Zamolodchikov, 2018) air purification services were calculated for 5-km

[56] The boggy region in the southeast of the Moscow oblast and in adjacent regions (editor's note).
[57] https://www.gks.ru/dbscripts/munst/

suburban zone identical for all cities; in the new version of the calculations we took a differentiated approach to determining the size of this zone. Russian published literature is not in unity regarding the size of the suburban (or buffer) zone that performs environmental functions. Several works note that size of buffer zone depends on of the city's population and administrative status. In the first case, for cities with a population above 1 million people, the proposed buffer zone equals 60–80 km; with 500,000–1 million – 40 km; 250,000–500,000 – up to 20 km (Fomina, 2020). Values are similar in the second instance (Gorokhov, 1991) where small cities that do not even have the status of district center have the minimum – 7 km – buffer zone. In forestry literature, suburban forest zones are often divided into three belts: the first one – with a radius of 30 km – performs protective functions; the second and third ones – with a radius of 40 km and 60 km respectively – are primarily of recreational importance (Paramonov, Malenko, 2007). These approaches are logical for assessing suburban forests' recreational services, but the use of these criteria to account for air purification services is not justified. At present, in Russia's most populated cities (and therefore having the biggest buffer zones) atmospheric pollution from automotive transport predominates and, because of its distribution, can hardly be mitigated by the forests of suburban zones.

The designation of sanitary protection zones [SPZ] is intended to minimize the impact of industrial enterprise emissions to values set by health standards. Under the requirements of Russian legislation, the size of these zones is set at 50 to 1000 m depending on the hazard class of the enterprise (SanPiN 2.2.1/2.1.1.1200-03). In the case of thermal power enterprises, the SPZ grows in proportion to the capacity of the power units. In some studies, it is noted that a buffer of at least 10 km is required to remove chemical and metallurgical enterprise emissions from the air (Konstantinova, 1981). In foreign studies, buffers are most often designated on the basis of per-capital requirements for green space to ensure the population's physical health: 3 km, 15 km and 30 km depending on the prevailing type of urban land use, road spacing, development density, and natural conditions (Eum et al., 2015).

We assume that the role of suburban forests is crucial in removing gaseous emissions and dust that enter the atmosphere from tall, and medium-tall pollution sources, which are usually found at industrial and electric power generating enterprises. At the same time, given the height of tree crowns (up to 20–25 m), regarding, for example, dust particles we can only talk about the fact that dust settles on the leaves in this altitude range or falls on them from above, while the remaining dust particles are scattered or transported over longer distances..

Given that the emission volume is proportional to the pollutant concentration in the air, we assume that, the greater the volume of emissions comes from an urban area, the larger the buffer zone is needed to purify this volume. The range in emission values for a total of 137 cities in European part of Russia included in the study was from 318,400 to 200 tons. This indicator was used to divide the cities into 4 groups, and a buffer zone size was set for each one: pollution volume more than 100,000 tons – 15 km; 30,000–99,900 tons – 10 km; 9,100–29,900 tons – 5 km; 100–9,000 tons – 3 km.

It is known that, along with source parameters, weather conditions also affect the dispersal of pollutants and, consequently, indirectly affect the size of the buffer zone. Advection and convection processes are the most relevant for pollutant transfer on the local scale (several tens of kilometers) (Shtyreva, 2002). In this report, their differentiation across Russia is considered through an indicator of the potential for air pollution (PAP)[58] (Bezuglaya, et al. 2013). The main characteristics of the atmosphere that determine PAP are surface inversions, wind conditions, mixing layer height, the duration of fog and calm conditions, and a number of other factors (Bezuglaya, et al. 2013). In European Russia the PAP can be assigned values from 2.1 to 3, with researched cities assigned to four PAP classes: 1 – low (most conducive to pollutant dispersion); 2 – moderate; 3 – increased; 4 – high (least conducive). The PAP was used to introduce a correction for buffer zone size for cities located in the most and least conducive conditions (Tab. 4.1.3.1).

Buffer zones calculated by the method set forth above were delineated around cities on the map of Russian vegetation (Fig. 4.1.3.1).

[58] In general form, the PAP, expressed in relative units, is the ratio of the average level of pollutant concentration (with stable emission parameters) in a specific district (q_i) to the average level of concentration of the same pollution in a nominally clean district (q_0): PAP = q_i / q_0, where q_i is the actual pollutant concentration; q_0 is the pollutant concentration in a nominally clean district.

Table 4.1.3.1. Sizes of buffer zones in cities depending on the emission volume and PAP, km.

Emission group, '000 tons	1	2	3	4
PAP	more than 100	30–99.9	9.1–29.9	0.1–9.0
1	20	15	10	5
2	15	10	5	3
3	15	10	5	3
4	10	5	3	3

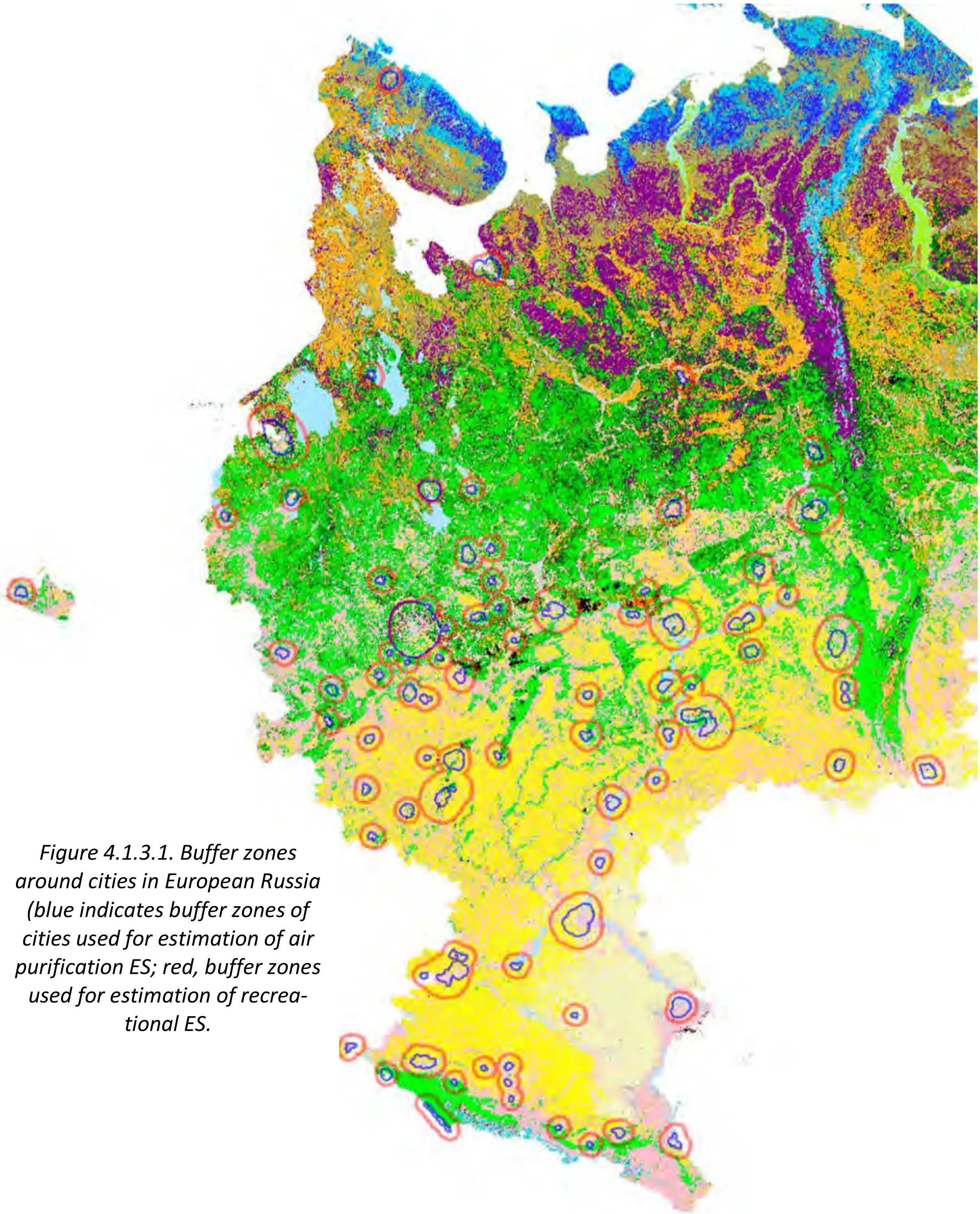

Figure 4.1.3.1. Buffer zones around cities in European Russia (blue indicates buffer zones of cities used for estimation of air purification ES; red, buffer zones used for estimation of recreational ES.

Provided volume of ES was estimated, same as in TEEB-1 Russia (Bukvareva, Zamolodchikov, 2018), as the maximum amount of pollution that vegetation can capture. We estimated it in several stages:

1. The area of dark coniferous, light coniferous, mixed, small-leaved and broad-leaved forests in the buffer zones of cities was determined. Urban areas were identified on the Russian vegetation map, based on the database of municipalities, all cities were selected from them, which were provided with data on the composition of emissions [59]. Even cities with a population below 100,000 were therefore included in the calculation. A combined 50-km buffer was plotted for Moscow[60] and nearby cities in Moscow Oblast; for Saint Petersburg, the buffer was 15 km (Fig. 4.1.3.2).

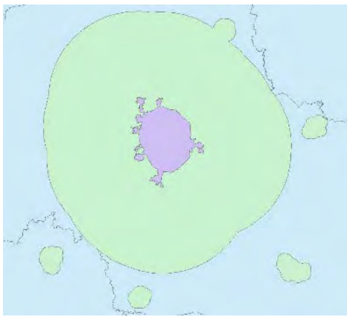

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Fig. 4.1.3.2. *Buffer zones of Moscow and nearby Moscow Oblast cities and for Saint Petersburg.*

2. The amount of toxic gases and dust that can be captured by suburban forests was determined. The calculation of absorbing capacity in TEEB-Russia 1 (Bukvareva, Zamolodchikov, 2018) was based on calculations of the absorbing capacity of forests in US cities which are mostly located in the subtropical zone (Nowak, 2006) Given that most of the cities in European Russia lie in the temperate zone, data for Canadian cities were selected for the project TEEB-Russia 2 (Nowak, 2018). To make correct use of the data, the Canadian cities were assigned to 5 groups depending on their localization within a forest zone: dark coniferous, light coniferous, broad-leaved, mixed and small-leaved forests. Average values for the absorption of gaseous emissions – NO_x, SO_2, CO and particulates ($PM_{2.5}$) by the vegetation in cities in each group were used in the calculation (Tab. 4.1.3.2).

Table 4.1.3.2. *Average values for the absorption of basic atmospheric pollutants by different types of forests (Nowak, 2006, 2018).*

Type of forest	*CO, t/ha/year*	*SO_2, t/ha/year*	*NO_x, t/ha/year*	*Total for gases, t/ha/year*	*$PM_{2.5}$, t/ha/year*	*Total*
Dark coniferous	0.0002	0.0022	0.0072	0.0096	0.0028	0.0124
Light coniferous	0.0002	0.0025	0.0078	0.0105	0.0085	0.019
Broad-leaved	0.0006	0.0033	0.0081	0.012	0.0051	0.0171
Mixed	0.0004	0.001	0.0055	0.0069	0.0067	0.0136
Small-leaved	0.0002	0.0007	0.0047	0.0056	0.0088	0.0144

Calculations were performed for 50 × 50-km squares and subjects of RF within European Russia separately for gases (all gases in total), dust, and total absorption of all pollutants (Tab. 4.1.3.3).

With this approach, the used average total index of air purification by forests for four pollutants turned out to be almost 10 times less than the preliminary values that we obtained in the TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018). Differences of the same order are observed in the works of D. Nowak for the USA and Canada, made in different years, which is probably due both to changes in the calculations by the iTree program and to the features of the cleansing ability of subtropical and boreal vegetation.

[59] https://www.gks.ru/dbscripts/munst/

[60] Moscow denotes the area within the city limits before 1 July 2012, and a buffer was plotted around "Old Moscow" according to emissions sizes.

Moreover D. Nowak's data are two orders of magnitude lower than those in domestic sources for dust-absorbing capacity (Nichiporovich, 1964, Kulagin, 1974). This difference is primarily explained by the term "dust" which is defined as particulates of different sizes up to 0.1 mm, while the works of D. Nowak consider only $PM_{2.5}$ or PM_{10} (i.e., particulates measuring 2.5 and 10 microns). Most domestic works estimate the absorbing capacity of forests far from major cities or of individual tree species. In cities, as well as in their buffer zones, the environmental situation, i.e., the chemical composition of the air basin, impacts the health and condition of trees and, consequently, their ability to absorb pollutants (Chernyshenko, 2018).

The results were stated per unit of area for 50-km squares within European Russia to compare them with indicators of other ES and the condition of ecosystems (Fig. 4.1.3.3). This figure shows that, because this service "works" only around cities, its distribution throughout European Russia is represented only by sporadic spots over a small part of the total area. The features of these services associated with cities are discussed in Section 4.1.9.

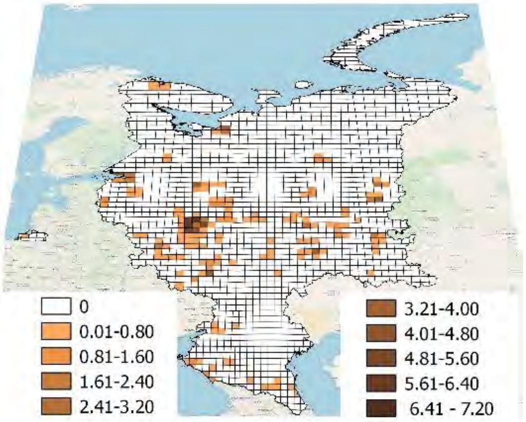


Figure 4.1.3.3. Absorption of dust and gases by suburban forests in 50-km squares, kg/ha.

Since this ES is concentrated around cities, its scope depends little on the total area of the subject of RF unlike most other ES that are performed by all ecosystems in the subject. We therefore analyzed the distribution of the ES on the level the subjects of RF on the basis of total indicators for the volume of ES provided and required for the subjects, not specific indicators per unit of their area, as for other ES. Fig. 4.1.3.4 shows the results for the subjects of RF.

The volume of ES provided by suburban forests to remove dust and gaseous emission from the air is the greatest in the Moscow region, since the largest buffer zone is formed around Moscow. The amount of potentially absorbed pollutants is also high in forested subjects of RF within European Russia: in Perm krai forests can absorb 1218 t/year of dust and 1484 t/year of gases; in Vologda Oblast, 738 t/year of dust and 1146 t/year of gases. The volume of ES provided is smallest in forestless subjects – Astrakhan and Vologda oblasts, the Republic of Kalmykia, and the Nenets autonomous okrug (Tab. 4.1.3.3; Fig. 4.1.3.4 a).

Required volume of ES (Tab. 4.1.3.3; Fig. 4.1.3.4 b) at this stage was defined based on data for municipalities as the total amount of emissions from stationary sources. Indicators of the volume of services necessary to remove dust and gaseous emissions form the air differ by four orders of magnitude in the subjects or RF. The maximum volume for dust emissions is in the Komi Republic (37,936 t/year), and minimum in Kalmykia (2 t/year). Gaseous emissions are highest in Vologda Oblast (293,554 t/year) and lowest in Kabardino-Balkaria (37 t/year). Note that the volume of services needed to remove dust emissions is an order of magnitude lower than one needed to remove gaseous emissions.

Table 4.1.3.3. Assessment of air purification services provided by suburban forests for subjects of RF in European part for dust, gas, and in total for all pollutants.

	Dust			*Gases (SO_2+NO_x+CO)*			*Dust and gases total*		
Subject of RF	*Emissions (t/year)*	*Absorbed (t/year)*	*Proportion absorbed (%)*	*Emissions (t/year)*	*Absorbed (t/year)*	*Percentage absorbed (%)*	*Emissions (t/year)*	*Absorbed (t/year)*	*Percentage absorbed (%)*
Republic of Adygea	256	21	8.2	560	49	8.8	816	70	8.6
Arkhangelsk Oblast	22060	667	3.0	60652	925	1.5	82712	1592	1.9
Astrakhan Oblast	1196	0	0.0	80632	0	0.0	81828	0	0.0
Republic of Bashkortostan	12012	270	2.3	124939	611	0.5	136951	880	0.6
Belgorod Oblast	17827	118	0.7	56344	205	0.4	74171	322	0.4
Bryansk Oblast	10037	60	0.6	10206	77	0.8	20243	138	0.7
Vladimir Oblast	701	208	29.6	5731	284	5.0	6432	492	7.6
Volgograd Oblast	3960	0	0.0	62716	0	0.0	66676	0	0.0
Vologda Oblast	19564	738	3.8	293554	1147	0.4	313118	1885	0.6
Voronezh Oblast	854	358	41.9	7328	600	8.2	8182	958	11.7
Republic of Dagestan	171	14	8.1	1386	32	2.3	1557	46	3.0
Ivanovo Oblast	164	51	30.9	4267	69	1.6	4431	120	2.7
Republic of Kabardino-Balkaria	21	18	84.8	37	42	113.2	58	60	102.9
Kaliningrad Oblast	1926	32	1.6	8627	56	0.6	10553	87	0.8
Kaluga Oblast	201	296	147.5	3501	518	14.8	3702	815	22.0
Republic of Karachay-Cherkessia	116	0	0.4	546	1	0.2	662	1	0.2
Kirov Oblast	9034	222	2.5	33831	298	0.9	42865	520	1.2
Kostroma Oblast	861	22	2.6	28275	42	0.2	29136	64	0.2
Krasnodar Krai	3409	320	9.4	35972	751	2.1	39381	1071	2.7
Kursk Oblast	3180	54	1.7	8741	101	1.2	11921	155	1.3
Lipetsk Oblast	20477	235	1.2	264806	354	0.1	285283	590	0.2
Marii El Republic	1177	26	2.2	5078	36	0.7	6255	62	1.0
Moscow and Moscow Oblast	7764	4169	53.7	114071	5829	5.1	121835	9998	8.2
Murmansk Oblast	9955	94	1.0	80823	275	0.3	90778	369	0.4
Nenetsk Autonomous Okrug	460	0	0.0	8411	0	0.0	8871	0	0.0
Nizhny Novgorod Oblast	1334	135	10.2	15852	207	1.3	17186	342	2.0
Novgorod Oblast	1727	241	13.9	12446	318	2.6	14173	559	3.9
Orenburg Oblast	9170	23	0.3	76315	53	0.1	85485	75	0.1
Oryol Oblast	314	12	3.8	3150	25	0.8	3464	36	1.1
Penza Oblast	764	102	13.4	5125	183	3.6	5889	285	4.8
Perm Krai	4259	1218	28.6	47768	1484	3.1	52027	2703	5.2
Pskov Oblast	244	117	48.0	1578	149	9.5	1822	266	14.6
Republic of Kalmykia	2	0	0.0	520	0	0.0	522	0	0.0
Republic of Karelia	1930	129	6.7	65715	203	0.3	67645	332	0.5
Komi Republic	37936	176	0.5	109326	232	0.2	147262	408	0.3
Republic of Mordovia	1263	17	1.3	4880	40	0.8	6143	56	0.9
Republic of North Ossetia – Alania	247	22	9.0	1637	52	3.2	1884	74	3.9
Rostov Oblast	28803	22	0.1	81481	52	0.1	110284	74	0.1
Ryazan Oblast	667	61	9.2	12195	81	0.7	12862	142	1.1
StP and Leningrad Oblast	2223	1148	51.6	44396	1666	3.8	46619	2814	6.0
Samara Oblast	6232	422	6.8	52191	792	1.5	58423	1214	2.1
Saratov Oblast	440	17	3.9	7174	41	0.6	7614	58	0.8
Smolensk Oblast	288	23	8.3	3381	43	1.3	3669	67	1.8
Stavropol Krai	1696	28	1.6	13961	65	0.5	15657	92	0.6
Tambov Oblast	720	22	3.2	4058	44	1.1	4778	67	1.4
Republic of Tatarstan	6268	505	8.1	105036	898	0.9	111304	1403	1.3
Tula Oblast	6674	105	1.6	63153	238	0.4	69827	343	0.5
Tver Oblast	1057	71	6.8	10109	97	1.0	11166	168	1.5
Udmurt Republic	2098	188	9.0	13043	265	2.0	15141	453	3.0
Ulyanovsk Oblast	1105	79	7.2	7586	146	1.9	8691	226	2.6
Chechen Republic	6291	21	0.3	619	48	7.8	6910	69	1.0
Chuvash Republic	959	27	2.8	5247	57	1.1	6206	84	1.4
Yaroslavl Oblast	2185	213	9.8	25091	381	1.5	27276	594	2.2

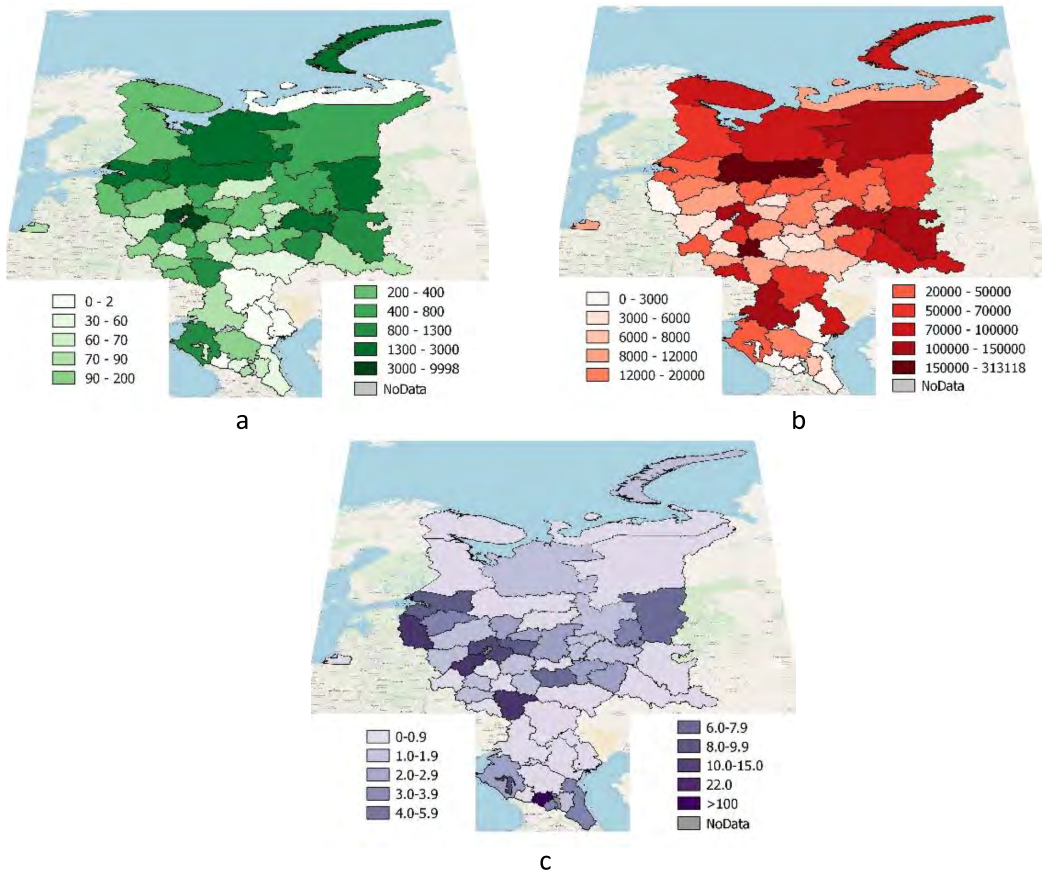


Figure 4.1.3.4. Estimates of suburban forests' air purification ES based on total indicators for all pollutants: a) provided ES – how much gas and dust suburban forests can absorb, t/year; b) required ES – gas and dust emissions, t/year; c) degree of satisfaction of the need for ES, share of absorbed pollutants, %.

Comparison of provided and consumed ES (Tab. 4.1.3.3; Fig. 4.1.3.4 c). The ratio between the volume of service provided and required shows the percentage of pollutants captured by suburban forests. This ratio varies from zero in forestless subjects (Nenets Autonomous District, Volgograd and Astrakhan oblasts, and Kalmykia) to 103% (in this case, provided ES exceeds consumed ES) in Kabardino-Balkaria. Suburban forests can capture only 10% of dust and gas in most of the subjects of RF. Except for Kabardino-Balkaria, this indicator is higher than 10% in only three subjects of RF (Pskov, Kaluga, and Voronezh oblasts). The obtained too high ratio between the required and the provided ES of dust absorption (as well as gaseous pollutants – see below), observed in Kabardino-Balkaria, apparently, can be explained by the specificity of the applied methodology – the forest area is large in this region in buffer zones of selected cities, and the volume of emissions is small. The highest indicators are typical for subjects where pollutant emissions are negligible, but there are suburban forests; the smallest indicators are for subjects in forestless zones or those with a large volume of emissions – among the latter are Lipetsk and Belgorod oblasts.

The situation is even less conducive for gaseous emissions. The highest ratios between the provided and required ES occur in Pskov Oblast (9.46%) and Adygea (8.83%). Suburban forests even in the most advantageous subjects can absorb no more than 1/10 of the gaseous emissions from stationary sources. In the most subjects, forests absorb less than 10% of emissions from gaseous sources.

The revealed ratio clearly demonstrates that, when this updated methodology is used, the volume of air purification ES by suburban forests turned out to be even less than that based on estimates performed under TEEB-Russia 1 (Bukvareva, Zamolodchikov, 2018). A possible reason for this is the more differentiated approach to determining the area of buffer zones and the use of new, even lower coefficients to describe the purifying capacity of vegetation. Given that stationary pollution sources are within city lines and may be protected by sanitary protection zones, it can be assumed that some of the gaseous substances and dust from them disperse and settle without reaching the buffer zone. On the contrary, some may be transferred outside it and contribute to the pollution of other regions.

It is also important that this low absorbing capacity of buffer zones is linked to the drastic reduction of forest vegetation areas within them first of all as a result of urbanization and rapid suburban development. In half of the considered subjects of RF forests represent less than 20% of urban buffer zones (Fig. 4.1.3.5), which significantly reduces their absorbing capacity. The highest indicators of forested area in buffer zones are reported in Leningrad, Perm, and Moscow oblasts, in the latter because the buffer zone is wider than in the other subjects. Therefore, it is possible to speak only hypothetically about the existence of a suburban green belt in cities in the considered subjects of RF.

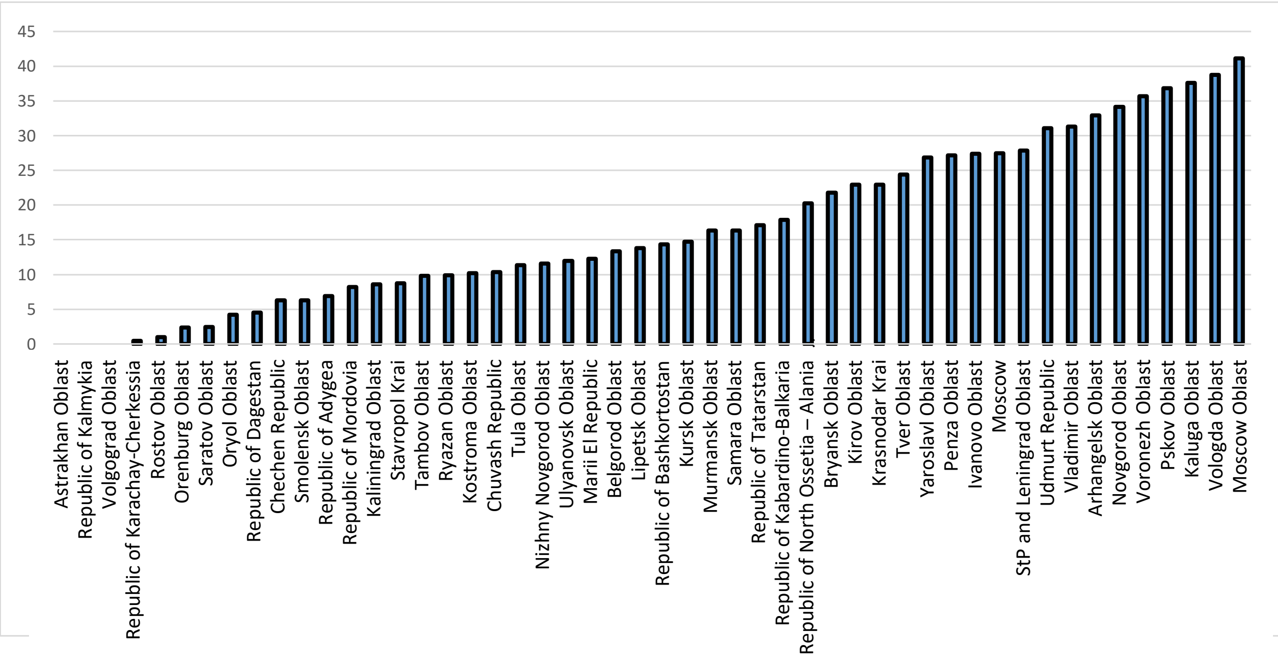


Figure 4.1.3.5. Percentage of forest vegetation in urban buffer zones in the subjects of RF, %.

4.1.4. Assurance of runoff volume by terrestrial ecosystems

The indicator of provided volume of ES of runoff volume assurance by terrestrial ecosystems was calculated for 50-km squares within European Russia by the methodology used in TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018The values for the indicator were determined by the following steps:

1) GIS tools were used to determine surface runoff as the difference between total runoff and underground runoff based on data of Land Resources of Russia (Stolbovoi, McCallum, 2002);
2) GIS tools were used to determine hypothetical runoff as the difference between average annual precipitation and average annual evapotranspiration based on data of Land Resources of Russia;
3) GIS tools were used to determine runoff provided by terrestrial ecosystems ("ecosystem runoff"): a) for geographic areas with excess moisture, i.e., those where values for hypothetical runoff are greater than zero, "ecosystem runoff" equals the difference between surface and hypothetical runoff; b) for geographic areas with normal or insufficient moisture, i.e., those where values for hypothetical runoff are equal to or less than zero, "ecosystem runoff" equals surface runoff.

The resulting estimates for 50-km squares and for subjects of RF within European Russia are shown in Fig. 4.1.4. The largest volumes of this ES are provided by ecosystems in northern and montane ecoregions, where total and surface runoff are high.

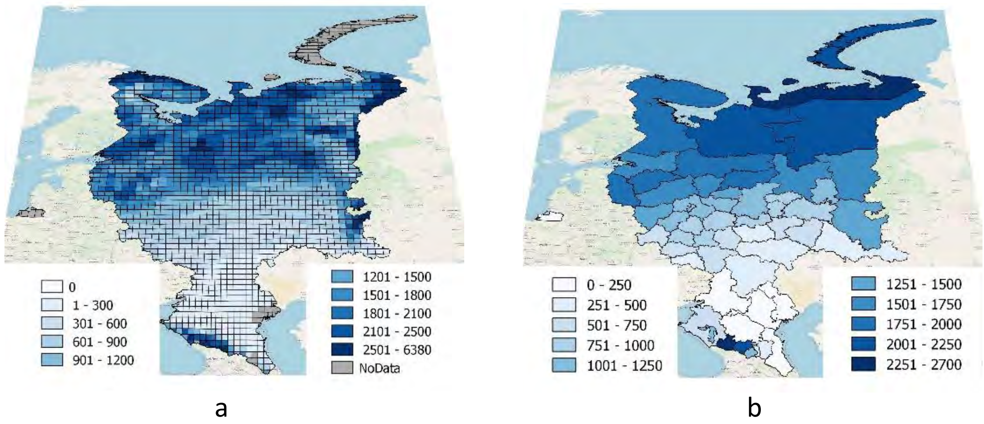


Figure 4.1.4. Runoff provided by the functioning of terrestrial ecosystems within European Russia, m^3/ha/year: a) for 50 km squares; b) for subjects of RF.

4.1.5. Prevention of soil water erosion

The ability of natural ecosystems to withstand soil water erosion, caused by both linear and planar flushing, is commonly considered as one of the critical regulating ES. This section presents approaches to estimation of **provided ES** on scales of 50 km squares and subjects of RF within European Russia, and administrative districts within CFO.

Current modeling practice is based on three interrelated indicators: potential erosion, current erosion, and avoided erosion. The calculation of any of these indicators involves the use of empirical, physically justified, or conceptual models. At the same time, In Russia the model for calculating soil washout has not been approved, and global practices have not been compared.

In Western Europe and North America, ecosystem supporting services – current and avoided erosion – are calculated using the classic empirical model: the well-known Wischmeier-Smith universal soil loss equation (USLE) (Wischmeier et al., 1971). This equation is a statistical compilation of observation data and accounts for the effect of precipitation, soil erodibility, the terrain's erosion potential, land use, and the intensity of soil protection activities. As modified by American RUSLE2 (Revised…, 2013), and German ABAG (Syrbe et al., 2017) models the equation in a modified form is as follows: $W=0.224 \times R \times K \times LS \times C \times P$, where

W is the average annual modulus of soil loss, t/ha;

R is the erosion factor of rainfall;

K is the soil erodibility factor;

LS is the relief factor, where L is the slope length factor and S is the slope degree factor;

C is the land use factor;

P is the soil protection activities factor.

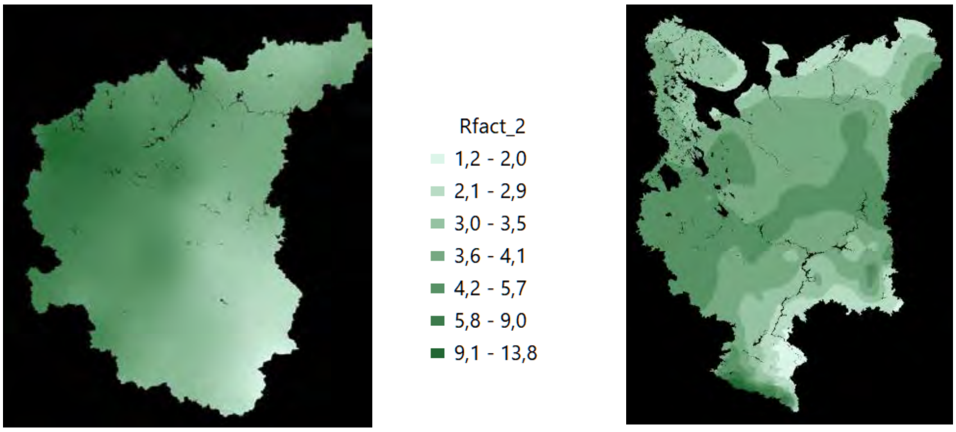
Coefficient 0.224 is a multiplier proposed in the RUSLE2 manual as "universal", because it is least dependent on regional differences in the intensity of erosive processes, though it takes different values usually on the local level. The change in this index is one of the reasons why results obtained by authors on different scales cannot be compared.

Because the model was proposed as a kind of not-to-scale tool, it underwent various modifications for use on different spatial levels and under different physical geography conditions. The nature of the source data and the grid of geographic units have a great influence on the feasibility and correctness of using an empirical model.

We modeled these parameters in two spatial scales and for two types of geographic units. For the Central Federal Okrug of RF (CFO) the assessment was performed using a grid of municipal districts; for European Russia, using a 50 × 50-km grid. CFO includes 17 oblasts with a complex administrative structure with the presence of urban areas that have the status of municipal districts. To obtain a matrix of relatively equal size, these areas were combined with surrounding municipal districts; the final matrix consists of 428 units (municipal districts and large city okrugs).

The assessment of the ecosystem service of avoiding soil erosion included the following major steps.

The erosion factor of rainfall (R) was calculated on the basis of the total rainfall depth for summer months (RWARM) with the formula of the Hessian Agency for Nature Conservation, Environment and Geology (HLUG, 2016)[61]: $R = r * RWARM_{So} - 1.48$, where "r" is a regional coefficient, usually set in Euro-American models to 0.141. In this calculation it was corrected based on published data (DIN 19708, 2005; Ermolaev et al., 2017). The final result was obtained in the ArcMAP 10.5 raster calculator (Fig. 4.1.5.1).

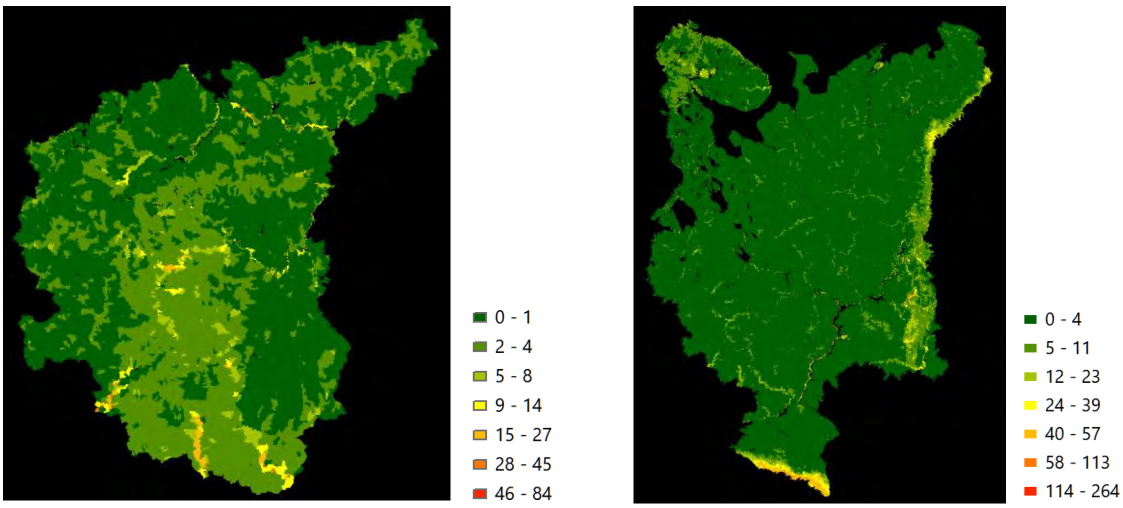


a b

Figure 4.1.5.1. Results of the calculation of R, erosion factor of rainfall: a) for the CFO; b) for European Russia.

The soil erodibility factor (K) was calculated using a map of European Russia soil types from tables of potential erodibility from HLUG (2016) and DIN 19708 (2005) documents. One of the key properties that defines soil erodibility is the content of clay, sand, silt, and coarse particles. The indicator varies from 0.05 to 0.80 for most soil types.

Relief factor (LS) is calculated using a digital model of the topography in all methodologies, while the specific approaches to calculation vary extremely widely. The classical model uses the simple multiplication of slope length by gradient in degrees (L × S). For the CFO we've used the Unit Stream Power Erosion and Deposition (Revised…, 2013) method, which is based on the determination of slope length and gradient within elementary watersheds. The calculation was done with the ArcMap program with a 90-m raster per pixel. A grid of 3rd order basins was used for European Russia (Ermolaev et al., 2017), and parameters for slope length and gradient were extracted from the digital terrain model and projected onto the basin grid with a "regional statistics" tool (Fig. 4.1.5.2).



a b

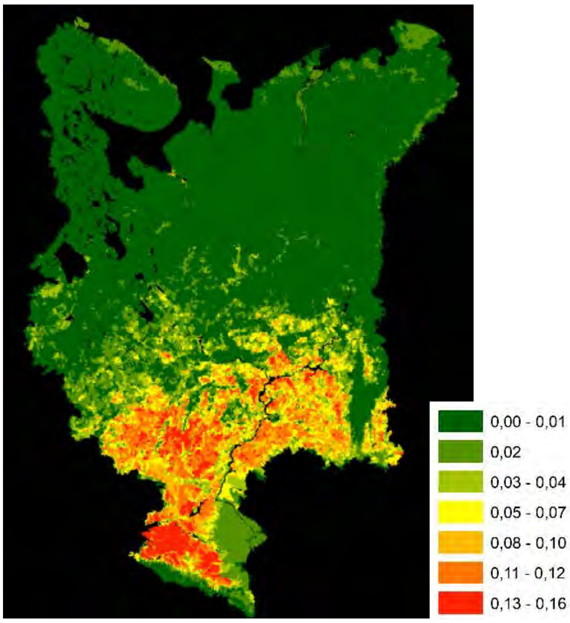
Figure 4.1.5.2. Results of the calculation of relief factor LS: a) for the CFO; b) for European Russia.

[61] https://www.hlnug.de/themen/boden/auswertung/bodenerosionsbewertung/bodenerosionsatlas/

Because of significant differences between montane and plain areas and amongst different types of plains (high, hilly, glaciolacustrine plains) LS relief factor varies fairly widely within limits from 1 to 264.

The land use factor (C), can be called the most complex one in the model we used. Here the differences in the nature of the source data are the highest. In large-scale models there is an opportunity to use data on crop rotation in individual fields; in small-scale models – only generalized types of landscape cover. Factor C was calculated separately for the CFO and European Russia.

The Russian Ministry of Agriculture and Russian Academy of Sciences Soil Science Institute are now working on digitizing all the country's farmland, but this work is far from finished. The C factor for European Russia was estimated using a Kazan Federal University database for river basins (this area has 50,386 basins of 3–4th order)[62], in which, in turn the area of forests, wetlands, meadows, and arable land was calculated on the basis of vegetation map of Russia (Bartalev et al., 2011). The urbanized area is taken from digital OSM maps. Figure 4.1.5.3.a shows the estimate of the C factor for European Russia.



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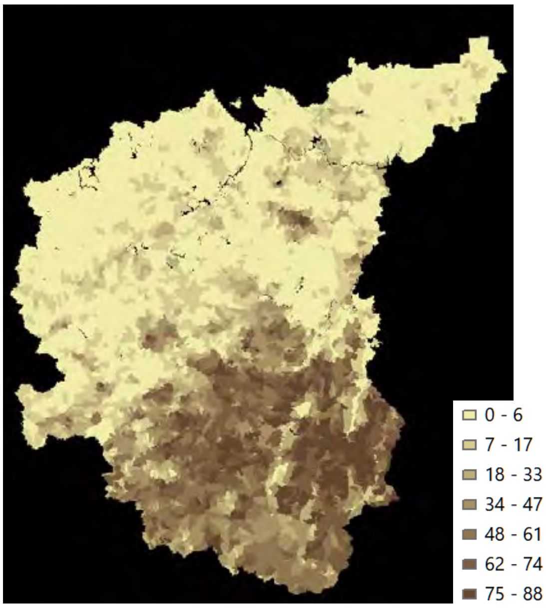

b

Figure 4.1.5.3. Estimate of land use factor C: a) C for European Russian; b) one of the layers used to estimate C for the CFO – share of arable land, %.

The vector layers *land use-polygon*, *vegetation*, *poi_polygon* from Open Street Map for 17 administrative oblasts were used to calculate the land use factor for the CFO. The result consisted of combined mosaics of the earth cover with different C values – forests, shrubbery, meadow and pastures, parks, quarries, urbanized areas, etc. Farmlands on the Open Street Map maps were digitized with differing degrees of completeness, and this parameter was therefore further corrected based on two other sources – plough disturbance of European Russia river basins (Ermolaev et al., 2017) and data from the RF Ministry of Agriculture GIS portal. Figure 4.1.5.3 b shows an example of one of the indicators used to estimate C-factor for the CFO.

Since C factor in the RUSLE2 model is a coefficient of soil loss and describes the protective effect of terrestrial vegetation and other cover versus a fallow field, its value is largely determined by the general level of plough disturbance (C for fields is 0.15) and forest cover (C for forests is 0.04).

The factor of soil protection activities (P) is also quite complicated on the medium (CFO) and small (European Russia) modeling scale. Soil protection structures usually include snow-holding and field-protecting forest belts, tree-shrubby remises (bio-groups among fields), belt (no more than a few hundred meters wide) and island (with a diameter of several hundred meters or less) forests, shrubbery and meadow, including in erosional forms (hollows, ravines, gullies) amidst fields. Obviously, an exact accounting of these elements is

[62] http://mapadmin.bassepr.kpfu.ru/

possible only within an individual farm; in the best case within a municipal district. Factor P was calculated separately for the CFO and European Russia.

The calculation for the CFO was done by first extracting plots of various types of vegetation (wood, forest, grassland, meadow, scrub, bush, heath, wetland) from polygon layers of Open Street Map (vegetation, surface, land use) being on a certain distance from field lines according to the area and length of the fields. The area of the forest belts and small-scale forests was analyzed first. The analysis revealed a median of about 3.6 ha for forest plantings, while many sites, e.g., island and small-scale forests in the upper reaches, were larger; as a result, the threshold maximum value was set at 6.8 ha. This figure was 2.0 ha for shrubbery. It is harder to estimate the maximum distance at which green infrastructure elements can have a soil-protecting effect. Various works have presented various data, and it is obvious that this soil-conserving effect is derived from a combination of many factors – the steepness and exposure of a slope, the mechanical structure of soils, the physical geographic district (CFO districts are found in four natural sub-zones – southern taiga, conifer-broadleaved forest, forest steppe, and steppe) and finally, the spatial structure of vegetation area and the height of the vegetation in those areas. Because it was impossible to account for all these circumstances in this model, a figure of 50 m was used. Figure 4.1.5.4 presents an example of isolating forest belts from the vegetation layer.

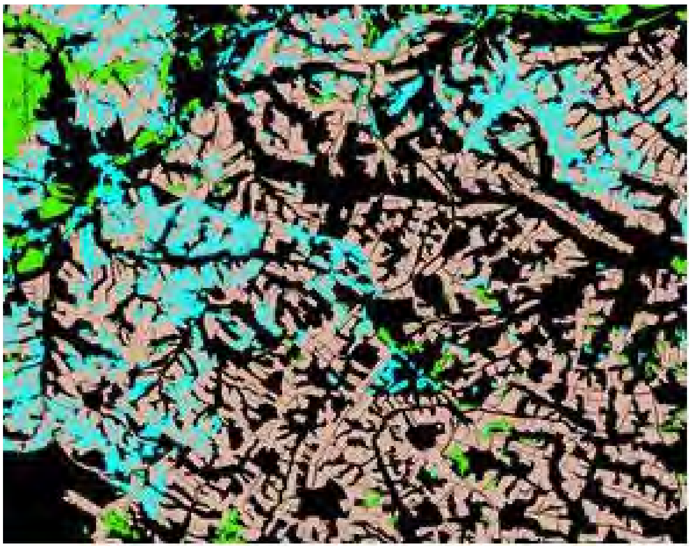

Figure 4.1.5.4. Example of isolating forest belts (turquoise) from the "vegetation" layer (green) based on threshold area and distance from farmlands (brown).

For European Russia, because of differences in the degree of digitization of the Open Street Map maps and the overall large amount of data, P factor was accounted for on the basis of the vegetation and land use layer from the Eurasia Land Cover Characteristics Data Base Version 2.0, which includes 17 classes after extraction of the class Cropland/Natural Vegetation Mosaic.

In the last step we calculated three parameters: potential erosion, actual erosion, and avoided erosion. **Potential erosion (W_{pot})** is essentially a function of the first three factors – rain erosion factor, soil erodibility, and relief factor: $W_{pot}=R \times K \times LS$. The land use factor C is set equal to the one for the surface of a fallow field. **Actual erosion (W_{act})** accounts for the current land use condition (i.e., it is calculated for observed values for C for all the types of land use and landscape cover) and the presence of erosive elements: $W_{act}=R \times K \times LS \times C \times P$. **Avoided erosion ($W_{avd}$)** is the difference between potential and actual erosion: $W_{avd} = W_{pot} - W_{act}$. Erosion indicators for CFO administrative districts, 50-km squares, and subjects within European Russia are shown on Figures 4.1.5.5, 4.1.5.6 and 1.4.5.7. The results obtained correspond to the values given for local models (Smirnova et al., 2012; Ermolaev, 2017). For example, for Belgorod Oblast according to data by Smirnova et al. (2012) actual erosion values average up to 2.5 t/ha; and peak erosion observed along erosion systems is more than 15 t/ha.

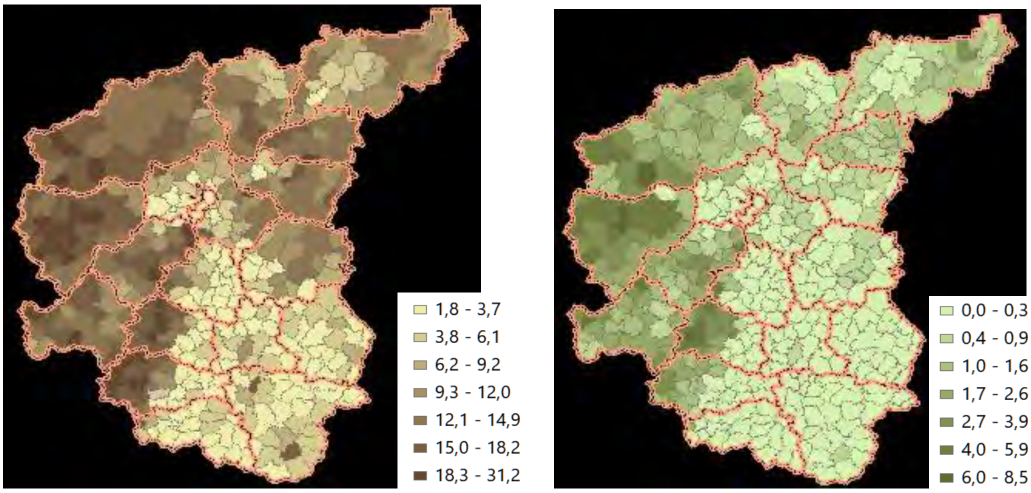

Figure 4.1.5.5. Assessments of erosion indicators for CFO districts: a) potential erosion, t/ha; b) avoided erosion, t/ha.

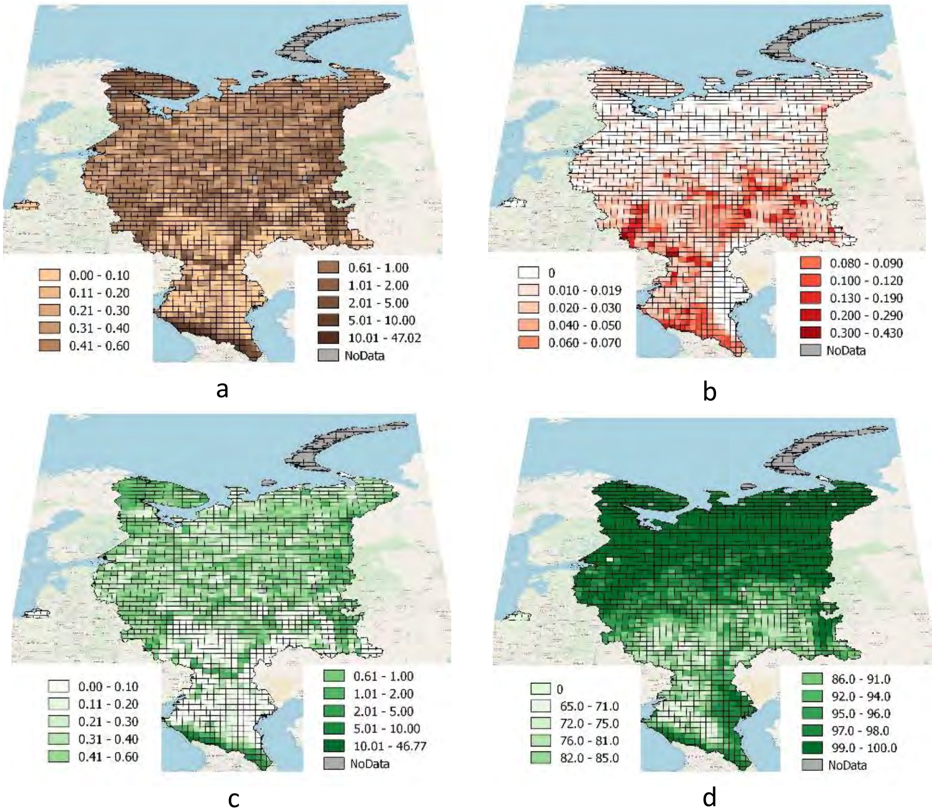

Figure 4.1.5.6. Erosion indicators for 50-km squares within European Russia: a) potential erosion, t/ha; b) actual erosion, t/ha; c) avoided erosion, t/ha; d) share of potential erosion prevented by ecosystems, %.

Obviously, the highest values for avoided erosion are confined to districts where potential erosion is high. This relationship is particularly strong on the scale of European Russia, which is clearly seen when maps "a" and "c" on Figures 4.1.5.6 and 4.1.5.7 are compared as well as in the graph 4.1.5.8 a. The correlation between these two indicators in European Russia, both for 50-km squares and for the subjects of Russia, is almost unequivocal ($R^2=0.999$). At the same time on the same scales there is no correlation between the amount of avoided erosion and key indicators of ecosystem condition such as the percentage of forest area and the percentage of transformed ecosystem area (the second indicator actually reflects the degree of plough-disturbance, see 3.1.1) in one or another territory.

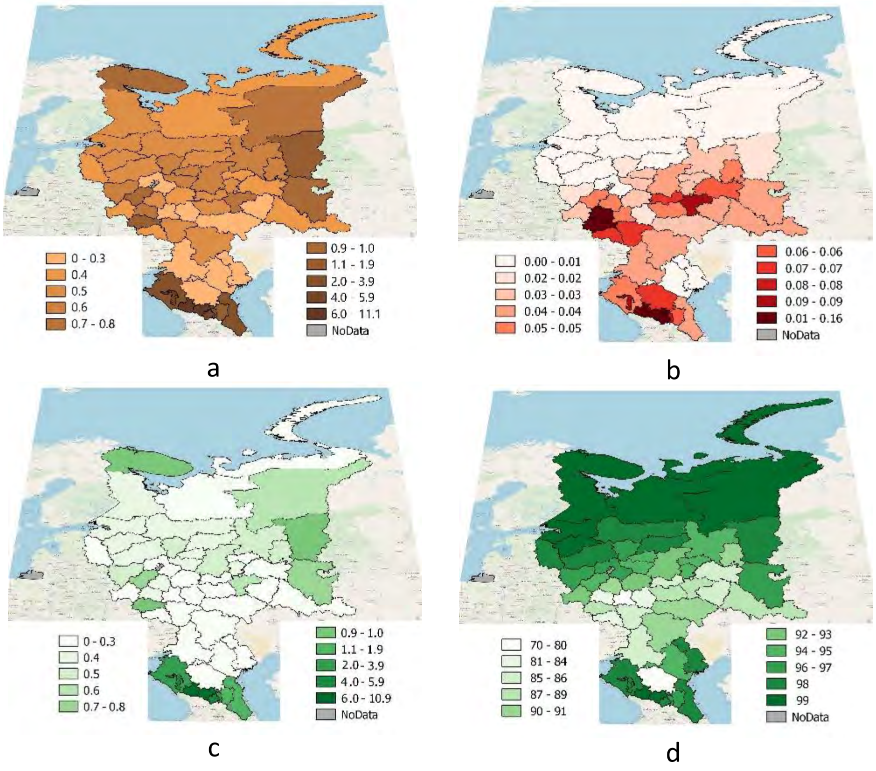

Figure 4.1.5.7. Erosion indicators for the subjects of RF within European Russia: a) potential erosion, t/ha; b) actual erosion, t/ha; c) avoided erosion, t/ha; d) share of potential erosion prevented by ecosystems, %.

If we move to a more detailed level of assessment, this correlation becomes far less unequivocal (Fig. 1.4.5.8 b), which indicates that the model on this scale is more sensitive to various factors that influence erosion processes. As noted above, when we modeled erosion on European Russia and CFO scales, we used different data and methods to calculate erosion indicators. They were more detailed for the CFO scale (e. g, consideration of the vegetation and land use mosaic, data on the degree of plough-disturbance), which obviously resulted in a more adequate representation of the actual processes on this scale of assessment.

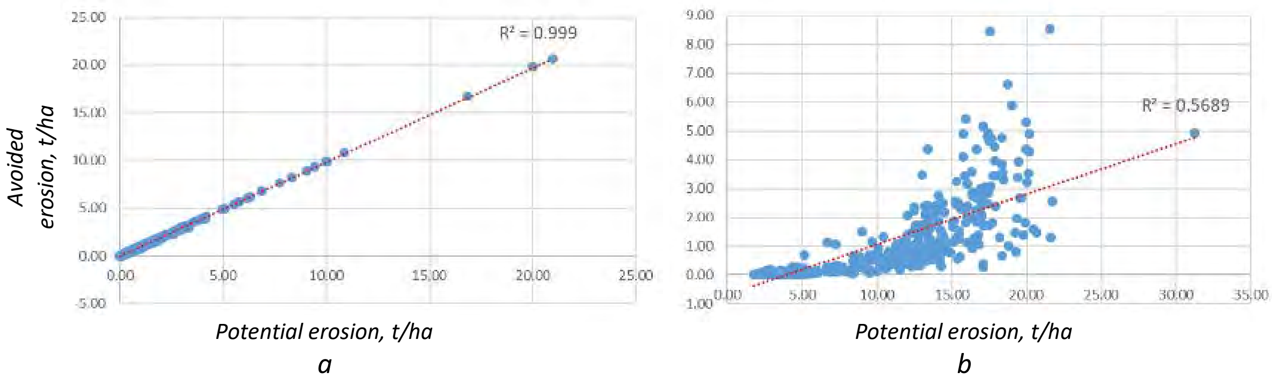

Figure 4.1.5.8. Correlations between the volume of avoided and potential erosion: a) for 50-km squares within European Russia (the analysis does not include incomplete squares, so the maximum value on the graph does not correspond to the maximum value in the legend of the corresponding map); b) for CFO administrative districts.

Despite all the limitations in assessing erosion indicators on the European Russia level, useful results can still be obtained. The use of relative indicators instead of absolute ones makes it possible to account to a larger degree for actual factors that affect the ecosystem service of erosion avoidance. Instead of the indicator for the volume of avoided erosion (t/ha), we can use the percentage of potential erosion avoided by natural vegetation, i.e., the percentage by which potential erosion was avoided thanks to ecosystem functioning. Unlike the indicator for the volume of avoided erosion, the relative indicator responds to the degree of ecosystem transformation (i.e., in fact the degree of plough-disturbance) and to the proportion of forest area. For 50-km squares there is a high negative correlation between the percentage of potential erosion avoided by ecosystems and the degree of ecosystem transformation (Fig. 4.1.5.9 a) and a noticeable positive correlation with the proportion of forest area (Fig. 4.1.5.9 b). Similar correlations are found for the subjects within European Russia.

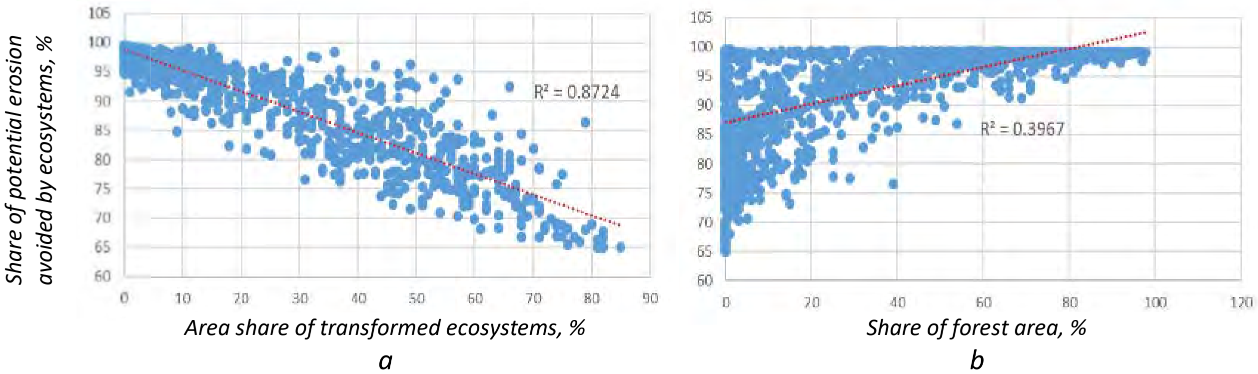

Figure 4.1.5.9. Correlations between the share of potential erosion avoided by ecosystems and indicators of ecosystem condition for 50-km squares within European Russia: a) correlation with the degree of territory transformation; b) correlation with the share of forest area in a square.

It is necessary to emphasize that in current assessment practice value of avoided erosion indicator depends on actual plough-disturbance. This approach understates the soil-preserving role of forests in “non-agricultural” regions, since farming is hardly the only cause of erosion processes. The felling of old growth taiga forests, especially on light loamy soils, including on dried peat bogs, may result in the rapid, almost catastrophic development of various forms of human-induced erosion (both linear – along the tracks left by wheeled vehicles and track bulldozers – and planar – on slopes) and the subsequent overloading of water intakes by human-induced sediments and the degradation of entire river systems.

Opportunities for improving ES assessment

The accuracy of the calculation of avoided erosion values is directly related to the scale of the assessment and the possibility of the most correct account for included factors. We will briefly consider the main opportunities of further refinement of the estimates obtained.

1. Although ES are often calculated within administrative units (that makes it possible to identify service donor regions and service consumer regions), the only correct grid of assessment units for a regulating service such as erosion avoidance is the river basin. Within water basins from watershed to valley bottom there is a regular transformation of the surface runoff, which is directly reflected in erosion intensity (Revised..., 2013). The GIS laboratory of Kazan Federal University is currently completing the mapping of 3rd order river basins (according to the Straler-Filosofov classification) for Russia. The parameters in this database include the indicator of potential erosion within water basins (Ermolaev, et al., 2017).

2. The lack of accurate data on the actual contours of farmlands is a serious problem affecting calculation accuracy. OSM (Open Street Maps) maps with “farmland” objects in the “land use” layer of different subjects of Russia are hard to compare because they differ in degree of digitization (the quality for Smolensk Oblast, for example, is high: all the fields there were digitized practically by one volunteer – well-known GIS master I. M. Bavshin). Final digitization, typology (by types of crops and crop rotation) and correction of condition (many fields are at different stages of vegetation) now being done by order from the Russian Ministry of Agriculture will certainly provide researchers with new data, since it will be possible to more accurately calculate LS and C factors thanks to more accurate accounting of actual land use.

3. Calculating the K factor of soil erodibility requires access to soil maps of Russian oblasts, which were made (depending on the size of the region) in the 1: 200000 and 1:300000 scales.

4. The accuracy of the calculation of LS factor is related to two circumstances. The first is the accuracy of the digital elevation model (DEM) underlying the calculation. All highly detailed DEM, which are today open source (accurate to more than 30 m per pixel) are digital relief models of with all objects on its surface. Obviously, the best results can be obtained based on the so-called "digital terrestrial models" (DTM), i.e., free of vegetation and artificial objects. But these models are available only on a commercial basis (the cost is about 10–11 euros per km^2).

The second is the need and possibility to account for a different set of factors on different scales. The existing method for calculating LS factor one way or another comes to estimating slope length and steepness. Obviously, the division of slopes into dispersing and concentrating (with different planned and profile curvature) is the first step in achieving more accurate models. The next step is to calculate the "topographic" LS within elementary catchment areas, since erosion energy at the estuary point of these elements essentially transitions to a "channel" process. Researchers are therefore proposing all new algorithms [9] implemented in geoinformation systems. The open source (non-commercial) SAGA GIS by O. Conrad proposed the relevant "LS Factor" tool.

It is also important in the RF to consider exposure, which also greatly affects erosion processes during the spring snowmelt (Buryak, 2014).

5. Further adjustments to the model may also involve including a large number of indicators in the assessment, particularly the following: loss of humus content as a % of initial one, degree of removal of soil layers A–B and the humus layer, the area of eroded soils and the gullied area. This approach combined with other calculations provides opportunities for further monetization of this kind of ES.

6. Relevant for the expansive area of Russia are zoning procedures, which are based on the intensity of slope erosion with developed river basins and identify non-hazardous (removal rate less than 2.5 t/ha/yr), slightly hazardous (2.5–10 t/ha/yr), moderately hazardous (10–15 t/ha/yr), and intensely (15–50 t/ha/yr) and extremely hazardous (more than 50 t/ha/yr) lands (Kuksina, Alekseevsky, 2016). Work on zoning individual large regions of the country, which will make it possible to adjust values of the variables in the Wischmeier-Smith formula, continues.

4.1.6. Pollination

As an ecosystem service, pollination is defined as support of crop yields by pollinator animals (Vallecillo et al., 2018). Only insects can provide this service in European Russia. The crop plants grown in European Russia include many that are insect-pollinated (entomophilous). In addition to fruit trees, they include many oilseed crops, vegetables, cucurbits, and beans. Obtaining fruit from them requires pollination by insects: besides specially bred honeybees and bumblebees, this can be done by wild insects from natural ecosystems.

Estimation of pollination ES must consider the variety of biological objects – both plants and animals.

On the one hand, different insect-pollinated crops depend to different degrees on insect pollinators, since many of them can produce a portion of the yield through self-pollination. Data regarding how much higher the yield from cross-pollination is, however, is not available for all crops grown in Russia. Moreover, the demand for pollinators may vary not only among species, but even among different varieties and may depend on the agrotechnologies used (Lopatin et al., 2008). Such data for the territory of Russia are currently not available, therefore, while estimating the required volume of pollination ES, we have not yet taken this indicator into account.

On the other hand, many insect species can pollinate plants, and they vary in pollen transfer efficiency. Current methods are based first and foremost on evaluating bee (the superfamily Apoideae of the order Hymenoptera) activity. In fact, these insects are traditionally considered the most efficient pollinators. It is the representatives of this superfamily – honeybees (*Apis mellifera*) and bumblebees (*Bombus* spp.) that are most often used for supplemental pollination of farm crops, including commercially. However, there are different ecological groups even within the superfamily Apoideae, and sometimes it is this functional diversity that is more important for assessing pollination than is species abundance (Blitzer et al., 2016). Even honeybees and bumblebees, which are phytogenetically close, can differ in activity level depending on temperature (Nielsen et al., 2017). Many other insects also participate in pollination, however, and recently their role is being acknowledged as more and more important (Rader et al., 2016). These are primarily syrphid flies (Syrphidae). It is possible, however, that the diptera from other families are even more important for pollinating crop plants (Orford et al., 2018). Currently, because of the "global decline in pollination" these insects are considered as an alternative to bees for pollinating crop plants. Moreover, there are data that wild pollinators increase the yield regardless of the abundance of honeybees (Garibaldi et al., 2013). Published results are though contradictory: some studies claim that "non-bees" can replace bees, and others say the opposite. The number of studies devoted to assessing the ES of pollination as applied to these insects is far smaller, and they are primarily devoted to the question of the bee replaceability.

An adequate assessment of the ecosystem service requires study of the abundance of insects in specific habitats and the dependence of their activity level on abiotic (primarily weather) conditions. Most works, especially in Russia, assess not abundance, but species richness (the number of species), as is usual in faunistic works. A rare exception might be the work of E. V. Chenikalova (2005) on the bees of the central Caucasus, which is focused directly on the pollination of farm crops, or the classic work of D. V. Panfilov (1968) on the geographic variability of the relative abundance of different bee groups in Eurasia.

The lack of data on insect abundance prevents the full use of available best practices with the respect to the needs of individual crops for pollinators obtained using artificially bred insects (Lopatin et al., 2008, Devyatov et al., 2013).

Methodologies for assessing the ES of pollination in geographically close regions have been developed in the most detail in Europe (Maes et al., 2012; Vallecillo et al., 2018). The volume provided is assessed based on expert opinions on the abundance of bees in different types of biotopes, their flight distances, and climate data on the number of days with a certain temperature. However, these methodologies provide no data on many types of ecosystems found in European Russia. The possibility of transferring results obtained in Western Europe to the same natural zones and ecosystems in Russia also requires separate study. Further, assessment of the volume provided in them includes an assessment of the total number of bees in a geographic area, including far from farmlands. But it is important to consider that, to use all these pollinators, there must be crop plants next to them, i.e., these ecosystems must be partially destroyed! For this reason, our methodology considers only natural ecosystems adjacent to existing farmlands. The required ES volume in the reports was calculated based on areas occupied by basic insect-pollinated crops and an estimate of their dependence on pollinators. However, these data are not available for all such crops and were obtained only for certain regions. It is necessary to say that in the final analysis European methodologies also assess the ecosystem service on a rather crude point scale, acknowledging that obtaining data for an exact quantification is unrealistic (Vallecio et al., 2018).

In this project the pollination service was assessed on the basis of three indicators: the volume provided by natural ecosystems (for 50-km squares and subjects of RF within its European part), the volume needed for agriculture, and the degree to which the need for this service is satisfied (for subjects of RF within its European part).

Provided ES volume (pollination potential) was estimates as follows. The vegetation map of Russia was used to calculate the area of different types of natural ecosystems in a band 920 m wide (4 pixels) of arable land and in all small bits within fields for spatial assessment units. Next, this area was multiplied by factors that represent the abundance of bees in these ecosystems: for all types of forests – 0.3; for meadows – 0.7; for steppes – 1; for tundra – 0,2; for coastal vegetation – 0.5; for wetlands and unvegetated areas – 0. The results were multiplied by the percentage of days in a year with a daytime temperature above 10 °C according to Interactive Agroatlas data (Afonin, et al., 2006) and then divided by the area of the assessment unit. The resulting assessments of pollination potential are presented in Table 4.1.6.1 and in Fig. 4.1.6.1.

Table 4.1.6.1. Indicators of the provided and required volumes of pollination ES in subjects of RF within European Russia

Subject of RF	*The provided volume (index of pollination potential)*	*The required volume (share of entomophilous crops area in a region, %)*
Arkhangelsk Oblast	0.1	0.0
Astrakhan Oblast	5.0	0.4
Belgorod Oblast	14.6	14.9
Bryansk Oblast	10.9	2.5
Vladimir Oblast	8.0	0.7
Volgograd Oblast	17.3	8.1
Vologda Oblast	1.7	0.1
Voronezh Oblast	11.5	12.3
Ivanovo Oblast	10.5	0.3
Ingush Republic	8.9	2.8
Republic of Kabardino-Balkaria	7.7	4.4
Kaliningrad Oblast	5.8	3.7
Kaluga Oblast	11.4	0.6
Republic of Karachay -Cherkessia	3.6	0.8
Kirov Oblast	5.7	0.3
Kostroma Oblast	4.5	0.0
Krasnodar Krai	9.1	10.0
Kursk Oblast	13.9	14.3
Leningrad Oblast	1.3	0.1
Lipetsk Oblast	10.3	15.1
Moscow Oblast	10.6	1.4
Murmansk Oblast	0.0	0.0
Nenetsk Autonomous Okrug	0.0	0.0
Nizhny Novgorod Oblast	8.2	1.3
Belgorod Oblast	1.6	0.1
Orenburg Oblast	14.3	8.9
Oryol Oblast	13.7	14.6
Penza Oblast	10.5	9.2
Perm Krai	3.3	0.1
Pskov Oblast	2.9	0.1
Republic of Adygea	11.0	9.2
Republic of Bashkortostan	8.4	3.3
Republic of Dagestan	7.0	1.2
Republic of Kalmykia	10.3	0.2
Republic of Karelia	0.1	0.0
Komi Republic	0.0	0.0
Republic of Marii El	6.3	1.0
Republic of Mordovia	9.7	2.9
Republic of North Ossetia-Alania	8.3	2.6
Republic of Tatarstan	9.3	5.2
Rostov Oblast	16.2	9.7
Ryazan Oblast	10.8	4.8
Samara Oblast	10.9	14.5
Saratov Oblast	13.3	15.1
Smolensk Oblast	7.5	0.6
Stavropol Krai	14.9	9.4
Tambov Oblast	8.2	16.2
Tver Oblast	5.2	0.1
Tula Oblast	14.2	8.1
Udmurt Republic	10.1	0.6
Ulyanovo Oblast	9.5	7.4
Chechen Republic	10.8	3.2
Chuvash Republic	11.2	1.7
Yaroslavl Oblast	8.0	0.2

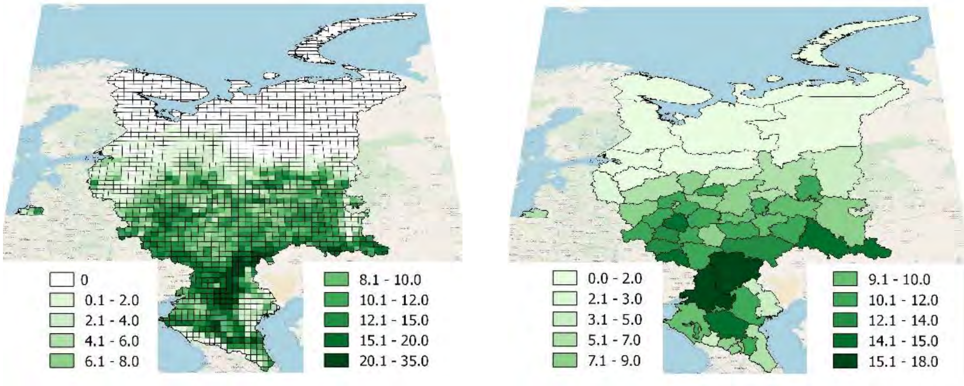

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Figure 4.1.6.1. Pollination index calculated for 50-km squares and subjects of RF within European Russia.

Pollination potential is significant in the forest steppe and steppe ecoregions and the highest in steppe regions (Volgograd and Rostov oblasts).

Later, pollination potential assessments must be updated by considering the ratio of the dimensions of the farm fields and the flying distance of the natural pollinators into the fields. A recent European report on the pollination ES (Vallecio et al., 2018) states that, at 1500 m from the edge of natural ecosystems, we might expect a 50% drop in pollinator population; at a distance of 5 km, the drop is already about 90%. In European Russia, the largest fields are in Krasnodar and Stavropol krais and in southern Rostov Oblast. Because some fields in these regions measure about 5 km from edge to center (Fig. 4.1.6.2), our pollination potential assessments might be reduced when updated. Fields in the rest of the area are far smaller and reach these large sizes only in some cases.

Required ES was estimated using 2016 data from the Federal State Statistics Service on the area of insect-pollinated crops in subjects of RF (Results..., 2018 a). The area of the following crops was included: fruits and berries, cucurbits, buckwheat, cotton, zucchini, pumpkin, tomatoes, cucumbers, green peas, coriander, safflower, sunflower, camelina, rape, other oilseeds, mustard, soy, bean, chickpea, lentil, broad beans, vetch, lupine, and pea. Figure 4.1.6.3 shows the total area of insect-pollinated crops and their area as a percentage of the subject's area. The latter figure was used as the index for the required ES volume.

The degree of satisfaction with the need for ES was estimated using the ratio of the scores for the provided (pollination potential) and required ES volumes. Obtained estimates of provided (pollination potential) and required ES (area of insect-pollinated crops as a percentage of the region's area) were converted to 4-point assessments (1 point – low, 2 – reduced, 3 – increased, 4 – high) by dividing all the values into four equal-sized groups, i.e., the 25% minimum values end up in the group with the minimum score which is 1, etc. (Fig.4.1.6.4). The degree of satisfaction with the need for ES was estimated by comparing the scores for provided and required ES according to the table 4.1.6.2. Figure 4.1.6.5 shows the result.

A visual comparison of maps for the provided and required volume of pollination ES already clearly shows a general tendency to increase from north to south. This result is to be expected – in that direction the climate becomes warmer and the diversity of flowering plants needed to support pollinators increases, as does area under cultivation, including those designated for insect-pollinated crops. The area with a low level of both a need for pollination and of the provided volume ends at about 55 degrees north latitude.

The map of the required ES volume is more distinctly divided into latitudinal zones than the map of provided volume – the high-level area begins at about 52 degrees north, i.e., in the Black Earth belt. The need again decreases (as well as the provided volume, but the geographic connection is less precise here) on the Caspian Sea coast – apparently this is primarily because of the more arid conditions.

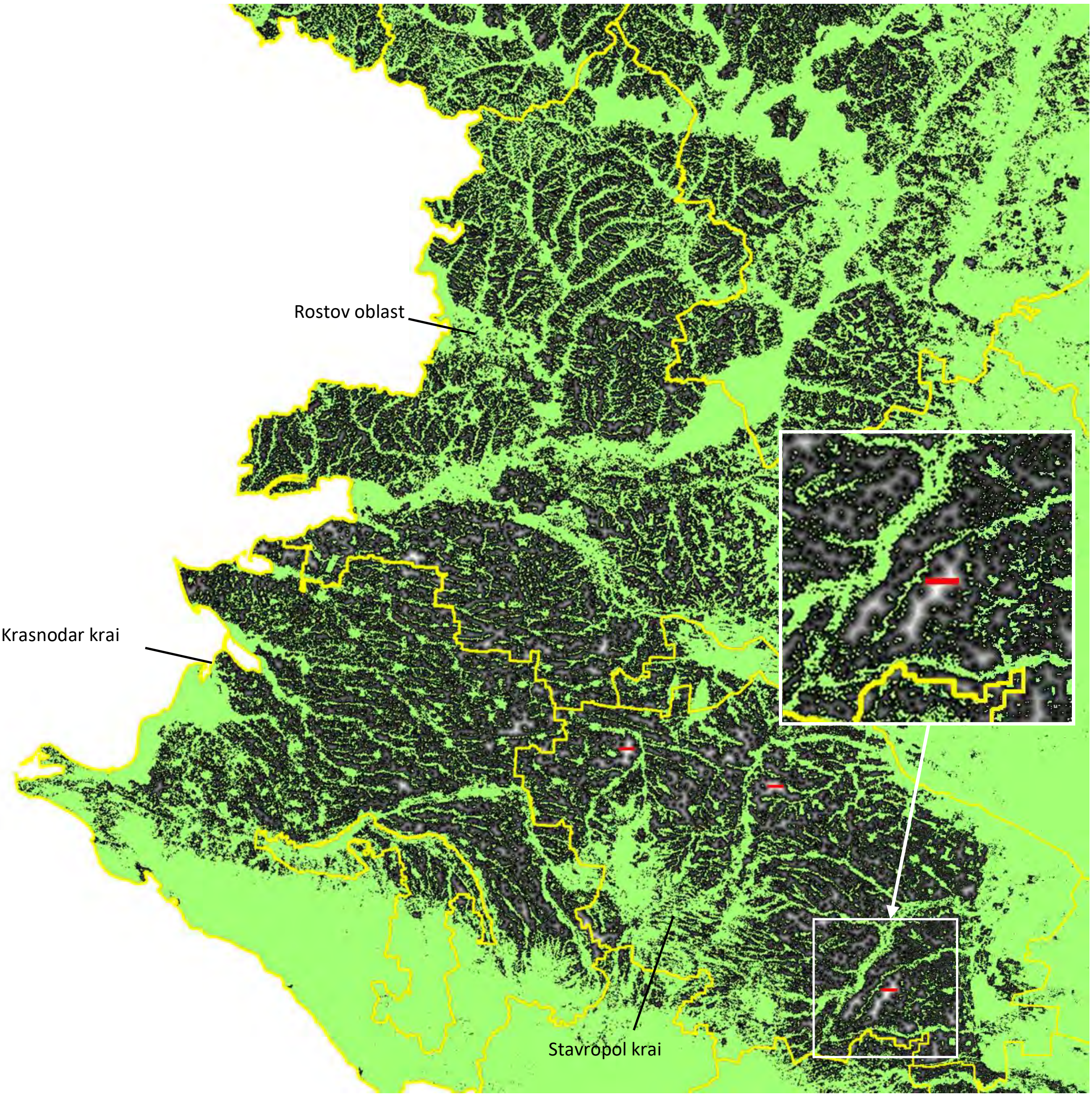

Figure 4.1.6.2. Section of the map with an estimate of field size. Green denotes all vegetation except arable land. The colors from black to white show the distance from the edge of the field – the lighter the farther; white is at a distance of 5 km. Red segments correspond to a distance of 10 km.

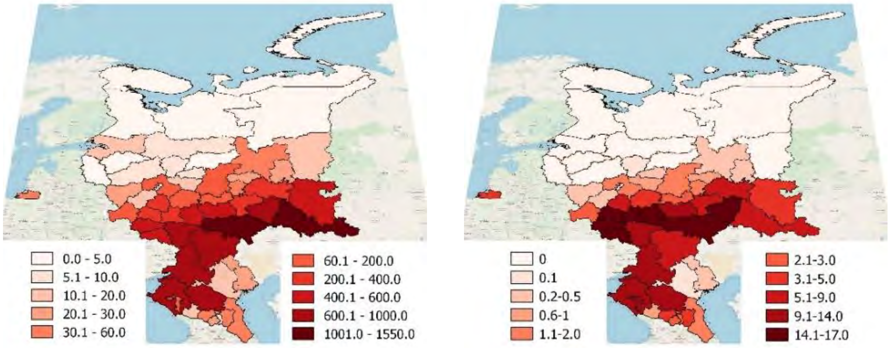

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Figure 4.1.6.3. Area of entomophilous crops in subjects of RF within European Russia: a) area, thousand ha; b) share of entomophilous crops area in subjects of RF, %.

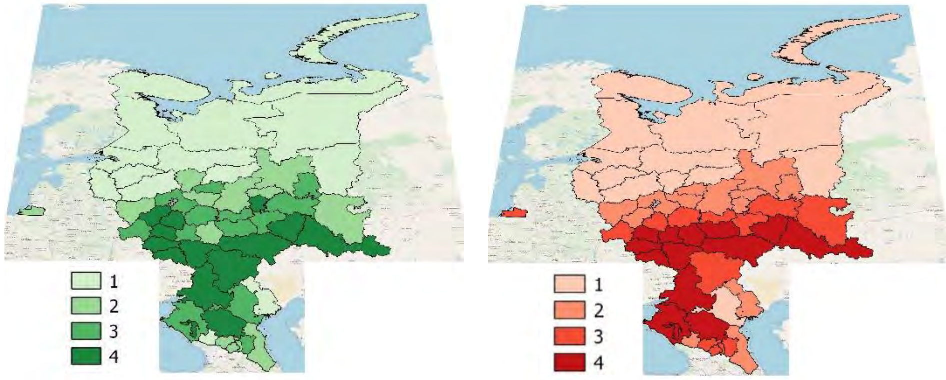

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Figure 4.1.6.4. Scores for the provided (a) and required (b) pollination ES.

Table 4.1.6.2. Assessment of the degree of satisfaction with the need for the pollination ES based on scores for provided and required ES.

Needed / **Pro-vided**	1 – Low	2 – Reduced	3 – Elevated	4 – High
1 – Low	Adequate (0)	Shortage (–1)	Shortage (–1)	Extreme shortage (–2)
2 – Reduced	Excess (1)	Adequate (0)	Shortage (–1)	Shortage (–1)
3 – Elevated	Excess (1)	Excess (1)	Adequate (0)	Shortage (–1)
4 – High	Extreme excess (2)	Excess (1)	Excess (1)	Adequate (0)

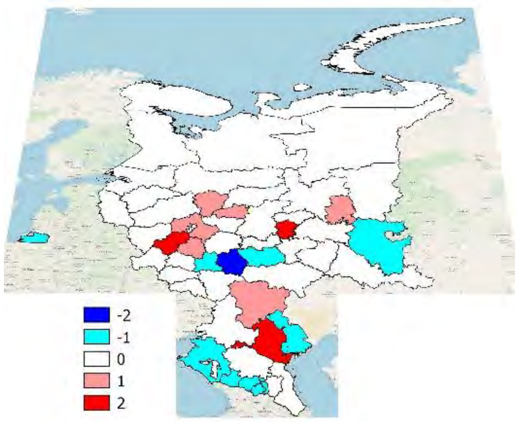


Figure 4.1.6.5. Score for the degree of satisfaction with the need for the pollination ES.

The map of the degree of satisfaction with the need for the pollination ES shows that, in most of subjects of RF in European Russia, the volume of ES is adequate or even excessive (white, pink, and red in Fig. 4.1.6.5). There is an extreme shortage of pollination in only one region – Tambov Oblast, an insufficient level in ten (mostly in the northern Caucasus), a surplus in six (mostly in central Russia), and a high excess there is in three subjects of RF(Kaluga Oblast, Kalmykia and Chuvashia). The extreme shortage of pollination in Tambov Oblast can be explained by the highest value of the required ES and the relatively low pollination potential (table 4.1.6.1). The latter is probably determined by the oblast's very high degree of plough disturbance (56% in European Russia along with Stavropol Krai). Including the factor of pollinators' flight distance into fields (see above) might reduce Tambov Oblast's potential even more, since its fields are large. The high excess of the service in Chuvashia can be explained by the high provided volume; the high excess in Kalmykia, by the low needed volume. The high excess in Kaluga Oblast results from the fact that it is on the border of regions with a reduced needed volume and high provided volume.

Analysis of cases of mismatch of the provided and required volumes of pollination ES suggests that the reason for its shortage or excess most often lies precisely in the shortage or excess of the provided volume. Differences in required ES volume between regions are less important. This result, together with latitudinal zoning, may be interpreted as an indication that both an excess and a shortage of provided volume are related primarily to the differing degrees to which little-disturbed biocenoses that support pollinators are preserved and possibly, to for the underestimating this factor in the distribution of cropland.

Overall, it is possible say that, on the studied scale, the pollination ES in European Russia is used quite effectively.

Threats to pollination ES

Pollination ES now suffers from a global decline of pollinators activity. Its causes are not entirely clear and require further study (Vanbergen et al., 2013), but the major causes apparently include habitat fragmentation and degradation and pesticide use. Regarding the first factor, the trend toward a decline in pollination potential in the most plough-disturbed European Russia regions shows that this threat must be considered in Russia's southern regions. Pesticides equally negatively affect not only insect pests, but also pollinating insects. In addition, the reduction of available habitats area and resources in them (primarily wild entomophilous plants) is causing a steady decline in insect population and diversity. Since most of efficient pollinators are insects with complete metamorphosis, maintaining their populations requires micro habitats suitable for the life not only of the imago, but also of larvae – often the environmental requirements of this phase of the life cycle are poorly studied. In addition to the area of natural biotopes, it is also necessary to consider their spatial location and geometric shape, since insects rarely fly more than one kilometer in search of food (Maes et al., 2012). It is therefore recommended that long stretches of natural habitats, or at least stretches with additional wild flowering plants, run along lands occupied by insect-pollinated farm crops (Blaauw, Isaacs, 2014; Chenikalova, 2005).

Recommendations for further pollination ES assessments

It seems that provided ES volume was assessed most accurately in our methodology. Available data make it possible to calculate it not only on the level of the subjects of RF, but also on a smaller scale. However, it makes sense to update data on the abundance of bees (and other pollinators, although this is an even more labor-consuming task) in different types of ecosystems and to evaluate their activity depending on natural conditions. Old data (more than a few decades old) is most likely no longer relevant, since they do not reflect the current state of pollinators populations, which could have been affected by climate change, habitat fragmentation, and pesticide use. In addition, the assessment of the provided volume should be supplemented by including in it the factor of the pollinators flight distance into the fields.

A more accurate assessment of required ES should consider, first and foremost, the different relationships between crops and pollinators. As already noted, many plants may set fruit by self-pollination, but the yield is usually lower than with cross-pollination, and it is possible to evaluate the relationship between yield and pollinators. The transfer of the results obtained under different geographic conditions (including peculiarities of farming) to European Russia may be inadequate, therefore additional research to compare the effect of self-pollination, real pollination, and artificial cross-pollination on yields in several climate zones is desirable, at least for the basic insect-pollinated crops and varieties used.

To more accurately assess required volume of pollination ES, it should be also considered the use of artificially bred honeybees and bumblebees (other insects far less), which might cover a significant portion of crop plant needs for pollinators in certain regions.

Finally, the assessment of consumed ES volume can be improved by obtaining data on how exactly areas occupied by insect-pollinated crops are arranged in the subjects of RF – how far they are from the nearest natural ecosystems and whether they have additional areas that support pollinator populations.

However, even after the improvements listed above, the assessment of pollination ES in the coming years will most likely remain scored, since quantitative estimation of pollinators abundance and the need for them, considering all local characteristics, is extremely laborious.

4.1.7. Creation of natural conditions for weekend recreation

To assess the provided volume of this ES, TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018) used a point score based on the cumulative account of the comfort of natural conditions and anthropogenic disturbance of the natural environment. At this stage in the research an attempt was made to calculate the volume of this service in quantitative indicators using approximate norms for the recreational capacity of various kinds of land cover.

Provided ES volume is calculated as the maximum allowable number of people who can visit nature areas for brief recreation for walking, picking mushroom and berry, camping, etc., during weekends (Saturday and Sunday) throughout the year. The area of suburban zones adjacent to a city was used as the potential weekend recreation area. Its size is proportional to the population in cities (Lappo, 1997): more than 1 million people – 50 km; 0.5–1 million people – 30 km; 0.1–0.5 million people – 25 km. Obviously, these sizes are approximate and generalized and may be used only for preliminary pilot studies, which is what this assessment is. Our assessment considers suburban zones around European Russia's cities with a population greater than 100,000 people (Fig. 4.1.3.1).

For the territorial units of assessment (50 km of squares and subjects of RF within European Russia), the area occupied by various types of ecosystems within the suburban zones was calculated from the vegetation map of Russia (Bartalev et al., 2011). These values amounted to the total area of ecosystems within 50 km of squares or subjects of Russia, which can be used for the weekend recreation. For all European Russia, the suburban zones we considered for weekend recreation include more than 10 million hectares of various types of forests and 14 million hectares of meadows. We used these figures to calculate the maximum allowable one-time recreational load on natural systems within the territorial assessment units.

The only methodology approved in the Russian Federation on the national level for calculating recreational loads on natural systems outside urban conditions (Temporary Methodology..., 1987) takes into account two conditions: kinds of recreation (excursions, prearranged tourism, self-organized tourism, routine mass recreation); type of forest and meadow communities (in fact – a type of ground cover). With the prevalence of a certain type of recreation in the same natural conditions, the degree of manifestation of recreational effects depends on the concentration of vacationers per unit area. For our purposes we used indicators for mass daily recreation (the minimum of the available standards) for consolidated types of ecosystems, the area of which was determined from the map of vegetation of Russia (Tab. 4.1.7.1). The authors of the standards point out that load norms may be adjusted depending on the age of the plantings, the length of roads and trails, the degree of atmospheric pollution, and other factors. We did not consider these additional factors in assessing provided volume.

Multiplication of allowable one-time loads (Tab. 4.1.7.1) by the area of the relevant types of ecosystems with the 50-km squares and subjects of RF results in an indicator of the one-time allowable load in the squares and in subjects of RF. According to the Temporary Methodology that we used (1987), the allowable load for recreation within a certain time period is calculated as the multiplication of the allowable one-time load by the percentage of time when this recreation is in progress. For weekend recreation this percentage equals 7/2 (the number of weekend days in a week). The multiplication of one-time allowable loads calculated for 50-km squares and subjects of RF by coefficient 7/2 therefore gave the desire figure for allowable weekend loads (Fig. 4.1.7.1). This figure shows that, just as in the case of the air purification provided by suburban forests (Section 4.1.3), this service "works" only around cities, and its distribution throughout European Russia is represented by occasional patches on a relatively small portion of the total are. The peculiarities of these services associated with cities are discussed in Section 4.1.9. Moscow region (Moscow and

Moscow Oblast together) stands out among other subjects, since it is there that the maximum buffer recreational area around cities is found (Tab. 4.1.7.2, Fig. 4.1.7.2.a).

Since this ES, like the ES of air purification by suburban forests, is concentrated around cities, its volumes depend little on the total area of subjects of RF. We therefore analyzed the distribution of the ES based on cumulative indicators for subjects of RF, not specific indicators per unit of their area, as for most other services. The provided volume of ES equals the cumulative number of people who might spend weekend recreation in suburban zones (Tab. 4.1.7.2; Fig. 4.1.7.2 a).

Table 4.1.7.1. One-time allowable recreational load for different types of ecosystems (Temporary Methodology..., 1987, with the authors' generalizations).

Ecosystem type	*One-time recreational load, people/ha*
Dark coniferous forests	0.7
Light coniferous forests	0.7
Deciduous forests	1.3
Mixed forests dominated by conifers	0.7
Mixed forests dominated by deciduous species	1.3
Meadow	2
Steppe	1.5
Wetland vegetation	0.1

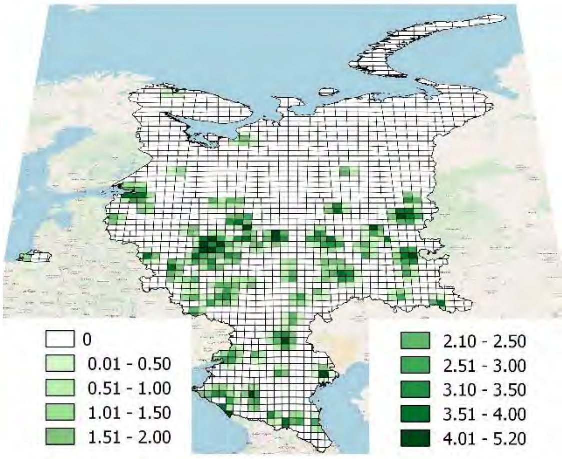


Figure 4.1.7.1. Provided ES of creating natural conditions for weekend recreation in 50-km squares within European Russia: allowable recreational load for the weekend, people/ha.

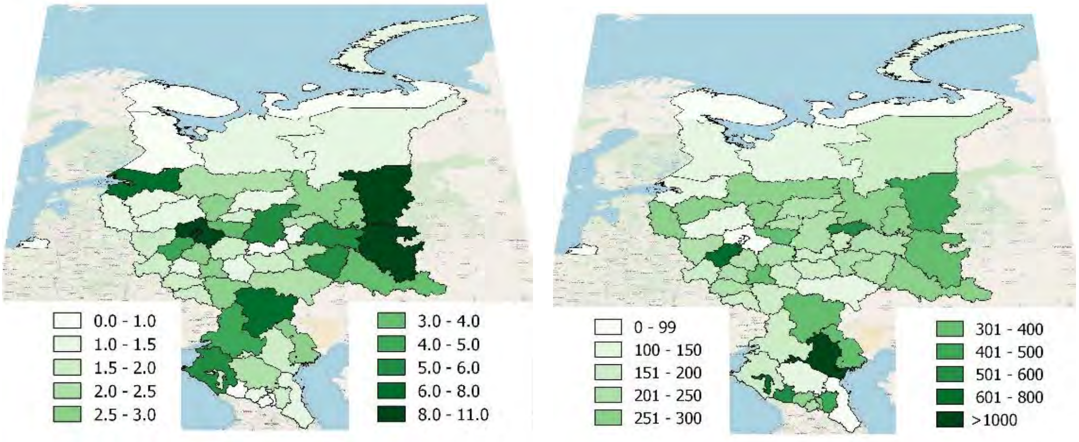
Leaders in the provided volume of recreational ES are Moscow region, Perm Krai, and the Republic of Bashkortostan, in which a significant part of the buffer zones of cities is represented by mixed forests with high rates of allowable one-time recreational load. The minimum values are typical for Murmansk Oblast and the Nenets Autonomous Okrug and for the Republic of Ingushetia and Kaliningrad Oblast, where buffer zones are not large.

Let us stress that these and similar results can be considered only the first approximate quantitative estimate. A more detailed calculation of the provided volume of this ecosystem service requires specification of the recreational capacity of various types of ecosystems, which should differ for parks, forest parks, and natural areas farther from the city. The methodology we used has no such breakdown, and the recreational capacity indicators obtained for parks and forest parts are unsuitable for natural areas far from the city. Also, it is necessary to consider the cadastral designation of the lands. Obviously, the value of the provided volume calculated in this way also includes the territories of departmental forestries, as well as the territories of bases and stationary recreation facilities, access to which is limited for recreation. The quality of recreational lands and the degree of their development for recreational use must also be considered. Finally, the calculation did not account for the fragmentation of suburban forest ranges. Note that, in most federation subjects developed areas account for no more than 2% of buffer zones, and only two areas clearly stand out regarding this indicator – Moscow and Saint Petersburg (about 25% in each).

Table 4.1.7.2. Indicators for ES of creating natural conditions for weekend recreation in subjects of RF within European Russia.

Subjects of RF	*Allowable loads, people/ha/year*	*Allowable loads, million people/year*	*Share of the urban population that can potentially enjoy recreation, %*
Arkhangelsk Oblast	0.03	1.2	124
Astrakhan Oblast	0.50	2.7	394
Belgorod Oblast	0.74	2.0	198
Bryansk Oblast	0.46	1.6	181
Vladimir Oblast	1.36	4.0	354
Volgograd Oblast	0.58	6.5	329
Vologda Oblast	0.17	2.5	297
Voronezh Oblast	0.57	3.0	199
Ivanovo Oblast	0.84	1.8	211
Ingush Republic	1.36	0.5	294
Republic of Kabardino-Balkaria	1.13	1.4	300
Kaliningrad Oblast	0.42	0.6	78
Kaluga Oblast	1.65	4.9	638
Republic of Karachay-Cherkessia	0.72	1.0	504
Kirov Oblast	0.22	2.6	267
Kostroma Oblast	0.19	1.1	242
Krasnodar Krai	0.73	5.5	199
Kursk Oblast	0.60	1.8	243
Leningrad Oblast and St. Petersburg	0.68	6.1	102
Lipetsk Oblast	1.11	2.7	357
Moscow Oblast and Moscow	2.24	10.9	63
Murmansk Oblast	0.02	0.3	35
Nenetsk Autonomous Okrug	0.00	0.0	0
Nizhny Novgorod Oblast	0.72	5.6	213
Belgorod Oblast	0.22	1.2	271
Orenburg Oblast	0.25	3.1	252
Oryol Oblast	0.44	1.1	211
Penza Oblast	0.41	1.8	194
Perm Krai	0.56	9.0	454
Pskov Oblast	0.25	1.4	288
Republic of Adygea	2.03	1.6	708
Republic of Bashkortostan	0.62	8.8	358
Republic of Dagestan	0.26	1.3	97
Republic of Kalmykia	0.25	1.7	1338
Republic of Karelia	0.04	0.7	138
Komi Republic	0.03	1.3	185
Republic of Marii El	1.02	2.4	544
Republic of Mordovia	0.32	0.8	164
Republic of North Ossetia-Alania	1.22	1.0	215
Republic of Tatarstan	0.86	5.9	206
Rostov Oblast	0.43	4.3	151
Ryazan Oblast	0.51	2.0	249
Samara Oblast	1.08	5.8	224
Saratov Oblast	0.24	2.5	132
Smolensk Oblast	0.33	1.6	229
Stavropol Krai	0.36	2.4	148
Tambov Oblast	0.32	1.1	171
Tver Oblast	0.14	1.2	116
Tula Oblast	1.11	2.9	232
Udmurt Republic	0.67	2.8	269
Ulyanovsk Oblast	0.56	2.1	220
Chechen Republic	1.18	1.9	420
Chuvash Republic	0.70	1.3	174
Yaroslavl Oblast	0.78	2.8	271

Required ES is determined by the number of people (both city dwellers and rural residents living in suburban areas) who want to spend weekends in nature. This indicator was not assessed, since sociological research accounting for the specifics of different cities would be needed to determine it. However, the percentage of the urban population[63] that can potentially enjoy recreation in suburban areas may serve as a preliminary assessment of the degree to which the need for the service is met (Tab. 4.1.7.2, Fig. 4.1.7.2 b).



a b

Figure 4.1.7.2. ES of creating natural conditions for weekend recreation in subjects of RF within European Russia: a) provided volume – number of people who can enjoy recreation in suburban areas, million; b) share of the urban population that can enjoy recreation in suburban areas, %.

Our results based on the Temporary Methodology (1987) show that the entire urban population can use suburban areas for recreation in almost all subjects of RF within European Russia. In only five regions (Nenets Autonomous Okrug, Murmansk, Moscow region, Kaliningrad Oblast, and the Republic of Dagestan) not all city dwellers can have a recreation in the nature. In most subjects of RF within its European part the provided ES volume is 2–3 times higher than the urban population.

Possible improvements in the ES estimation

1. Correction of estimates of acceptable forms and intensity of recreation. Existing norms are overstated and do not consider the specific features of different kinds of recreation, including those that appeared in the 2000s and substantially damaged ecosystems, e. g, riding quadrocycles. The recreational capacity of parks, forest parks, and nature areas far from the city must be differentiated. The high degree of generalization of values without detailed analysis of ecosystem sustainability data overstates the volume of recreational services that can be provided.

2. Introducing into the calculation indicators of the accessibility of recreational forests and other ecosystems (as was done in the calculation of aesthetic ES, see Section 4.1.8), which, according to our preliminary expert assessments, will lead to a reduction in the volume of ES available to the population in individual subjects of RF by no less than three quarters.

3. Consideration of the actual number (flow) of recreational ES users, which is related to the redistribution of the recreational load to city parks and artificially landscaped areas. This last item imposes increased requirements for amenities in urban green areas but provides additional opportunities for the protection of suburban forests.

4. Accounting for the really used (excluding cottages, closed recreational lands, etc.) recreational forests and other types of ecosystems.

[63] The urban population in RF constituents was taken from the Regions of Russia database of the Federal State Statistics Service.

4.1.8. Aesthetic value of ecosystems

Cultural (informational) services are the category of ES that is perhaps the most difficult to assess (Costanza et al., 2011). These ES are defined as intangible benefits for people, which are provided by ecosystems (Millennium Ecosystem Assessment, 2005; Verschuuren, 2006). Quantitative estimation of the impact of a birch grove on flow regulation or erosion avoidance is understandable, but how is it possible to assess this grove's contribution to the beauty of the locale or its significance to the local community, especially if the grove is considered a sacred, "holy" place? Most theoretical approaches and applied methods were developed as part of sociological, psychological, and aesthetic approaches that do not involve a quantitative, not to mention monetary, valuation (Chan et al., 2011; Daniel et al., 2012; Stephenson, 2008). Attempts to assess cultural ES based on planning approaches are closely linked to expert assessments (Bishop, Lange, 2005), while design assessments are susceptible to the subjective influence of style, fashion and taste in landscape architecture (de Groot et al., 2010, a, b).

The aesthetics of nature and the landscape is certainly a subjective concept, since its assessment is always "in the eyes of the beholder" (Meinig, 1979). Consideration of target groups of beholders therefore plays a significant role in the assessments of a landscape's aesthetic properties. At present polls and surveys and the reporting of aesthetic preferences in the media are given prominence (Richards, Tuncer, 2018).

Researches on the housing market have revealed a connection between the landscape's aesthetic qualities and the value of land and real estate and has shown the possibility of assessing aesthetic ES exhibited by nature and the landscape and perceived by people (Langemeyer et al., 2018). A 4-step sequence for the monetization of intangible ES has been proposed on this basis (Daniel at al., 2012). It assumes that, as assessment methods evolve, the degree to which ecosystem structures and functions are considered will increase (Tab. 4.1.8.1).

Table 4.1.8.1. Prospective phases in the monetization of intangible ES (according to Daniel et al., 2012, with changes)

Phases	Types of methods	Methods	Examples of targets of assessment
1) Qualitative descriptions	Studies of man-nature interaction	Observations of stakeholders, interviews, field descriptions, group discussions	Cultural relevance of sacred groves
2) Non-monetary quantification	Quantitative assessments of ES	Assessments of preferences, modeling of landscape aesthetics, choice experiment, estimates of the visitor population, psychometric and physiological scales	The value of inherited cultural landscapes
3) Indirect monetary valuations	General economic assessment of ES	Assessment of the population segment, estimate of the readiness to pay, choice experiment	Aesthetic aspects of different forest use models
4) Direct monetary valuations	Detailed economic assessment of ES	Estimate of the costs to "consume" services, travel cost method, hedonistic valuation method, etc.	Recreation and tourism in a national park, health benefits of recreation in a city park

Opportunities to estimate provided and consumed volume of aesthetic ES

Indicators of aesthetic ES potentially provided by a landscape – its "aesthetic potential" – might include its qualities that affect man's assessment of its beauty. Any quantitative assessments of these indicators imply the preliminary made decision of what to consider as a demanded service (Burkhard et al., 2014). Many studies have revealed differences in the aesthetic preferences of ethnic, national, age, gender, professional, and religious groups (Andrienko et al., 2009), but the level of consensus was ultimately quite significant, i.e. certain canonical standards of beauty surroundings prevail and find public expression, e.g., in geotagged photography services (Figueroa-Alfaro, Tang, 2015). A number of works published in the last 20–25 years have shown that the historical, traditional landscapes of the countryside are considered the most beautiful and prompt a feeling of a "small homeland" in almost any country – from the Mediterranean to Southeast Asia (Yang et al., 2014).

Modern media mapping services, geotagged photographs taken by many individual users available to the public can be a fine tool for assessing the importance of nature's aesthetic qualities (Casado-Arzuaga et al., 2014; Dunkel, 2015; Langemeyer et al., 2018; Plieninger et al., 2013; Tenerelli et al., 2017; van Zanten et al., 2016; Yoshimura, Hiura, 2017). The Google Earth application Panoramio (Casalegno, et al., 2013) and later

Flickr (Figueroa-Alfaro, Tang, 2015; Langemeyer et al., 2018) were among the first of these sources. In the simplest case, the total number of photographs tagged to a point is considered; in more complicated methodologies (Figueroa-Alfaro, Tang, 2015) images are analyzed to identify and classify groups of landscape elements. Special software was used to recognize common landscape elements: topogaphic mesoforms (peaks, buttresses, valleys, ravines, horizon lines), water bodies (lakes, bogs, rivers, seas), plant cover and agricultural elements (field patterns and mosaics in combination with forests and forest fringes), artificial structures in the landscape (buildings, terraces, fences). This approach makes it possible to assess the contribution of various elements to a landscape's aesthetic quality. Analysis of people's aesthetic preferences based on "big data" from media photography services made it possible to go beyond the discussion between supporters of cognitive and non-cognitive aesthetics (Carlson, 2008; Kaplan, 1982; Plieninger et al., 2013; Tenerelli et al., 2017) and solve a number of other important problems. It was shown that landscape elements that are aesthetically important in the eyes of professional experts are also appreciated by many ordinary users of the photo services. At the same time, it was confirmed that there are certain cultural differences among users that should be considered, especially in assessing potential services (Tengberg et al., 2012).

The existence of good viewpoints, making it possible to see objects outside the viewshed in which the observer is located has a strong influence on the volume of aesthetic services provided by landscapes. Because photographs contain objects in different planes (foreground, middle ground, background), some modern methodologies (Figueroa-Alfaro, Tang, 2015) try to consider objects at several distances.

A key step in developing quantitative approaches to assessing the aesthetic qualities of landscapes was the demonstration that the parameters of the landscape mosaic (the so-called land cover, i.e., the combination of the natural landscape cover with the pattern of land use) have a reliable connection with parameters of perception (Bishop, Lange, 2005). In other words, landscape metrics (e.g., the metrics modeled in the Fragstat program) such as diversity, dimensionality, congestion, the nature of the boundaries of patches, and others directly influence generalized assessments of the beauty of the countryside. People perceive a locale in which small and outlier forests alternate with farmlands as more beautiful.

Regarding the assessments of the volumes of landscape aesthetic services used, the key factor is there accessibility. Analysis of the connection of the distribution of the density of images on photo services to indicators of the landscape's aesthetic quality reveals localities in which the contemplation of natural beauty is extremely difficult because they are remote or inaccessible. These localities include most alpine landscapes and unique views lost among forests, wetlands, and tundra. The accessibility of a landscape is therefore an important parameter in assessing used aesthetic ES. Consumers observe many views on the medium and small-scale modeling level from vehicular roads or railroads (Langemeyer et al., 2018). On the large-scale level, e.g., during assessments within a national park, all viewpoints are concentrated along ecological hiking trails or at viewing platforms.

In addition to this spatial gap between the provision and consumption of aesthetic ES, there is also a time lag associated with the nostalgic undertone of aesthetic assessment that is typical of European, North American and Russian perception, when landscapes of past eras filled with signs of desolation have special charm (Kolbovskii, Medovikova, 2017).

The assessment of the volume of landscapes used aesthetic services reflects the number of people beholding it. We do not yet have other tools available to account for this indicator except to count geotagged photographs (made and uploaded to photo services by viewers) and subsequent mapping of "density fields" of these photos. Photo service data can also be used in assessing the volume of service provided, including if the photographs were used to identify landscape features that attracted attention or had a positive effect on the aesthetics of the scenery. In this case both the number of images and the parameters (total number) of features identified (elements of the mesorelief, plant cover, water bodies, etc.) are also an assessment.

Spatial scale and territorial units of assessment of aesthetic ES

The problem of selecting operating territorial units (OTU) for assessing aesthetic ES is determined by the fact that potential services are provided primarily by nature or by a traditional cultural landscape but are consumed largely by residents of large cities (Langemeyer et al., 2018). It is impossible to identify any standard OTUs that are equally appropriate for different types of environments (urban, rural) and landscapes (coastal, mountain, plain). Nevertheless, the development of geoinformation modeling has led to an understanding of viewable localities or viewsheds that can be observed from a particular geographic point (Kolbovskii, Medovikova, 2016). Viewsheds are in fact somewhat similar to river basins, especially if one assumes that a person is at the estuary point of that water basin. The concept of viewsheds makes it possible to solve the problem of OTUs, at least on the large and medium scales. On a plain, the observer's gaze may be limited not by topography, but by a forest wall, but it is possible to impose a layer of forest ranges on the digital terrain model (DTM) to obtain a comprehensive picture of the limits of visibility.

Additional difficulties arise on more generalized (small-scale) spatial levels and in a specific geographic environment, e.g., in mountains, since a viewer on a mountain slope sees objects both in his viewshed and in others, including extremely far off. This problem is solved by identifying visibility areas – around viewpoints and in the form of belts along linear routes (including vehicular roads and railroads). The dimensionality of the areas is determined experimentally as a function of the general ruggedness and relative altitude of the area for the most frequently encountered intervals, e.g., 300 m, 800 m, 6400 m and to the horizon (Tenerelli et al., 2017). Special tools for modeling visibility from a point to a specific object have been implemented in a number of programs, in particular in the ArcMAP package (Kolbovskii, Medovikova, 2017). When moving to analysis on an average and small scale, it becomes much more difficult to consider the relative position of the observer and the object of observation., In such case "abstract visibility" and the potential for localizing the viewer are usually used as individual properties.

Assessment of aesthetic ES in European Russia

As operational-territorial units of assessment we used 50-km squares within European Russia. This assessment scale makes it possible to model some properties and not others. For example, on this scale it is almost impossible to define visibility belts, since they will vary widely for plains and mountain regions. To increase overall accuracy, a number of parameters (e.g., topography) were initially assessed on the basis of viewsheds, and then the assessments were generalized on the basis of the 50-km grid.

Provided ES was assessed as the "objective" aesthetic properties of a landscape intrinsic to it regardless of a viewer's presence or absence. The following indicators were used to assess a landscape's aesthetic properties:

A) topographic features: the relative height above river; slope; topographic openness; number of landforms; and variety of landforms;

B) aesthetic properties related to the land use mosaic and vegetative cover (so-called landcover: landcover types variance, patch size coefficient of variance, and area weighted man patch fractal).

Topographic parameters were obtained using SAGA software based on the open-source ASTERGDEM2 DTM and were processed with a standard algorithm (Fig. 4.1.8.1):

1. plotting of a raw thematic raster (e.g., surface slope);
2. classification and normalization of the raster for the selected number of intervals (e.g., for a slope – 10 intervals identified by Natural Breaks method);
3. cleaning and generalization of the raster to eliminate noise using ArcMap tools: focal statistic and boundary clean;
4. extracting parameter values for a grid of viewsheds and derivation of the attribute raster of the viewsheds;
5. extraction of a parameter value with a zonal statistics tool (median average option) for the grid of 50 × 50 km squares

The Integral Relief Variety (*IRV*) assessment was done with the formula:

$$IRV = LndF\_V \times [(Har\_Varnce + Slope/100000) + Open\_\_Mean)],$$

where: *LndF_V* is relief variety, *Har_Varnce* is height range variety, *Slope* is slope variety, *Open__Mean* is the potential openness of the relief (Fig. 4.1.8.2).

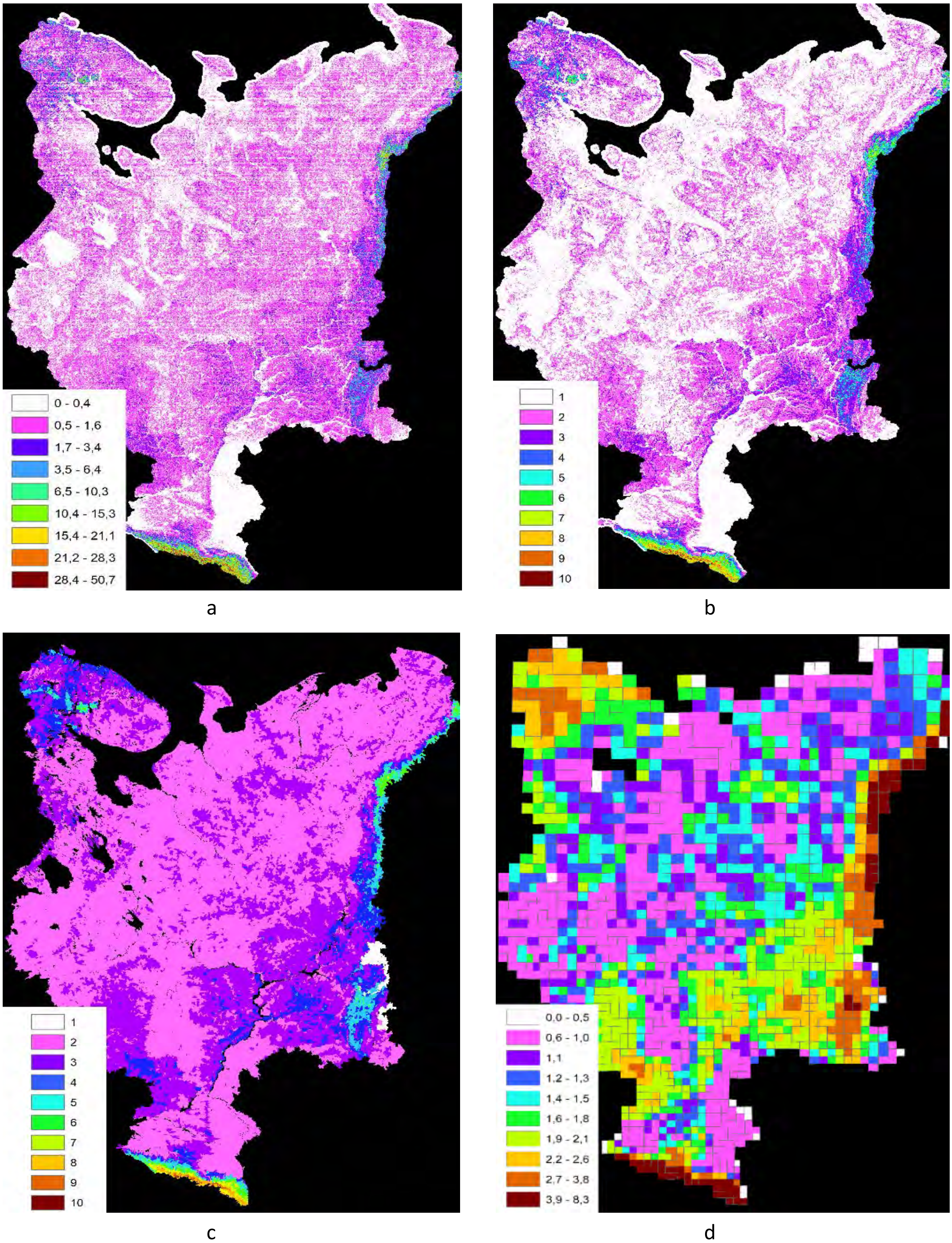


Figure 4.1.8.1. Basic stages in processing topographic parameters exemplified by a surface slope: a) raw raster – surface slope, degrees; b) raster after reclassification and noise elimination – surface slope, points; c) raster of viewsheds with median slope – surface slope, points; d) 50-km squares with extracted statistics – surface slope, points.

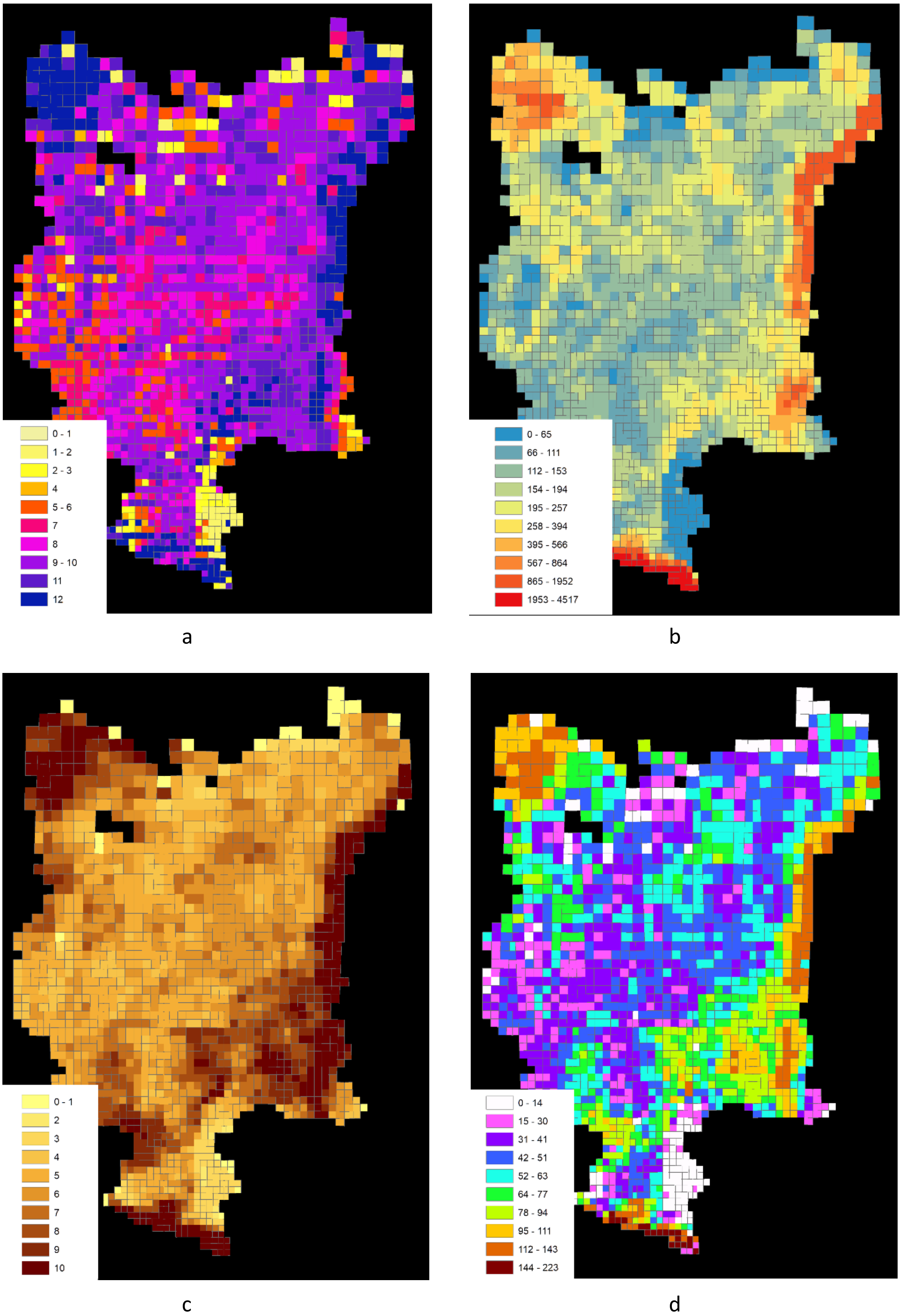


Figure 4.1.8.2. Assessment of integral relief variety: a) relief variety, points; b) relative height range variety, m; c) relief openness, points; d) integral relief variety, points.

Aesthetically relevant parameters of the cropping and plant cover mosaic were obtained by modeling in several steps.

1. The initial plant cover and land use raster, Eurasia Land Cover Characteristics Data Base Version 2.0, which includes 17 types was reclassified to 5 types of landscapes: open natural, open artificial, semi-open, closed, and mosaic landscapes (Tab. 4.1.8.2). On the scale of our assessment, the various classes of landscape cover form open, semi-open, semi-closed, and closed landscapes, the features of which must be correctly considered. For example, various kinds of vegetation perform different visual functions: large forests form the background of scenes and form the horizon line, groves and woody-shrubby groups form objects in the foreground, middle ground, and background. Farmlands and large water bodies form the bottom planes of visual scenes. An example of the reclassification of the original cover is shown in Fig. 4.1.8.3.

Table 4.1.8.2. Generalized groups of landscape cover used to assess the aesthetic quality of landscapes in European Russia

Initial land cover from the Eurasia Land Cover Characteristics Data Base (adapted by author for European Russia)	*Ind*	*Reclassified visual landscape types*
Water Bodies	1	Open
Evergreen Needleleaf Forest	5	Closed
Evergreen Broadleaf Forest	5	Closed
Deciduous Needleleaf Forest	5	Closed
Deciduous Broadleaf Forest	5	Closed
Mixed Forest	5	Closed
Closed Shrublands	4	Semi-closed
Open Shrublands	4	Semi-closed
Woody Savannas	4	Semi-closed
Savannas	3	Semi-open
Grasslands	3	Semi-open
Permanent Wetlands	3	Semi-open
Croplands	1	Open man-made
Urban and Built-Up	–	No data
Cropland/Natural Vegetation Mosaic	2	Semi-open man-made
Snow and Ice	1	Open
Barren or Sparsely Vegetated	2	Semi-open, of various genesis

2. In the ArcMAP 10.3 Patch Analysis package (using the capacities of a virtual Windows computer on Google) 18 various metrics were calculated, characterizing the dimensionality, form, and general fractality and fragmentation of the landscape mosaic (so-called Fragstsat metrics) for more than 2300 squares in the grid of 50 × 50 km operating territorial units). Analysis of published literature and expert experimental assessments (samples for areas with well-known aesthetic properties) resulted in the selection of three metrics that directly determine a landscape's aesthetic properties: Landcover Types Variance, Patch Size coefficient of variance, and Area Weighted Mean Patch Fractal.

Integral LCVF was assessed with the formula:

$$Integral\ LCVF = LndCvr\_V \times [(PSCoV / 1000) + AWMPFD)],$$

where *LndCvr_V* is the variety of types of land cover, *PSCoV* is the patch size coefficient, and *AWMPFD* – is the coefficient of land cover fractality.

3. At the final step, the integral estimates of the aesthetic quality of the relief (IRV; Fig. 4.1.8.2, d) were combined with the integral estimates obtained for land cover and land use mosaic (*Integral LCVF*). The resulting distribution of total assessments of landscape aesthetic quality reveals higher aesthetic qualities of territories with a rugged (usually mid-mountain) topography and pronounced mosaic patterns with a high degree of participation of half-open and half-closed natural types of vegetation (Fig. 4.1.8.5 a).

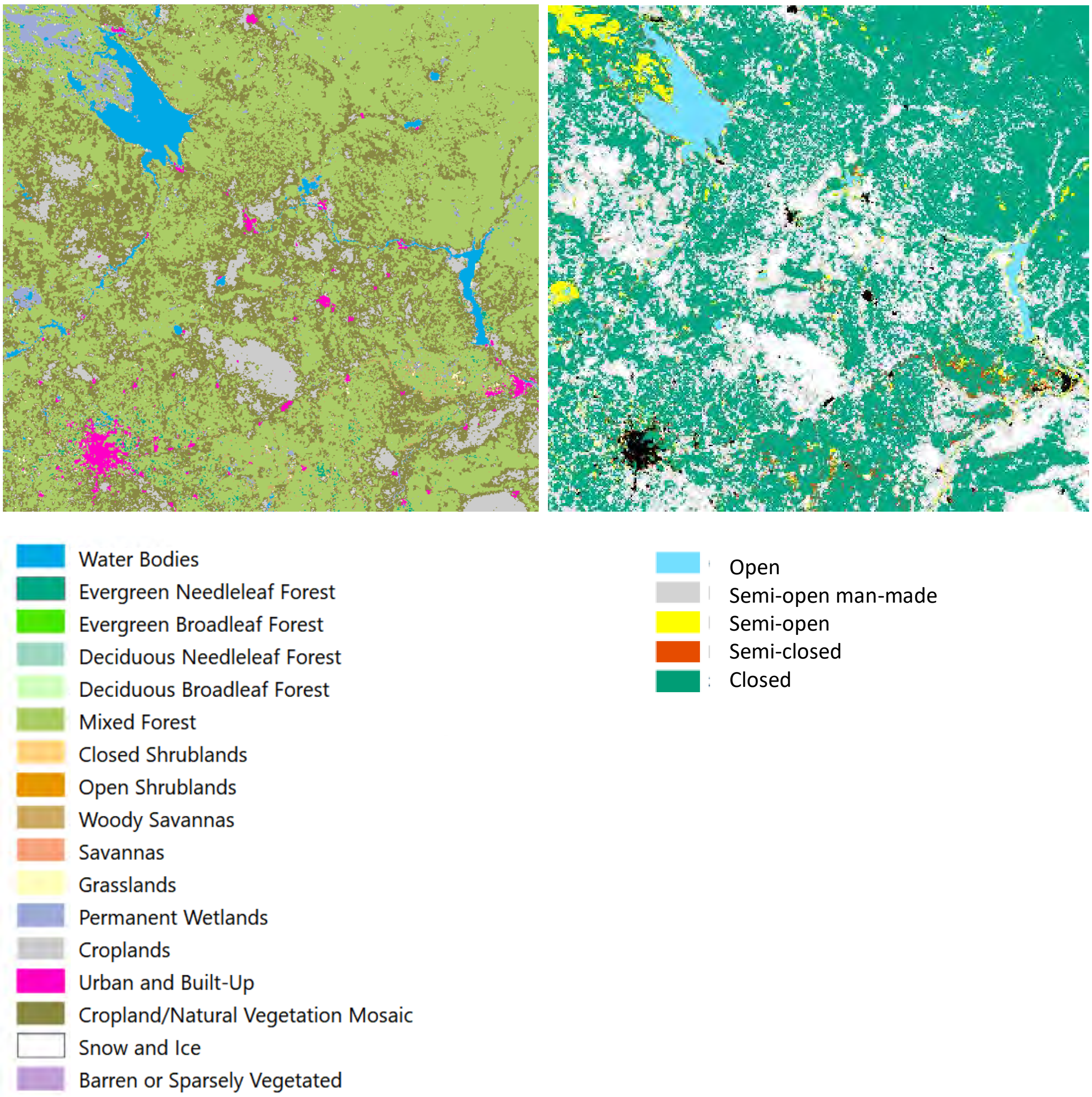


Figure 4.1.8.3. Example of the reclassification of an original map of plant cover and land use for the 5 landscape types used in assessment of aesthetic ES (on the right).

Consumed ES is defined as the sum of the cases of human observations of the landscape. It was impossible in this project to make a direct estimation of consumed ES based on an analysis of media photo services because the API codes of the relevant services in Russia are closed. Therefore, the parameter accessibility, i.e., the sum of factors that define the ability to view a landscape, was assessed as a necessary condition for use of the service (Burkhard et al., 2014). These factors were assessed using two grids – viewsheds with a median area of about 270 km^2 (Fig. 4.1.8.4) and 50-km squares. The accessibility of and possibility of viewing a landscape were assessed based on the following characteristics.

– the sum of viewpoints occupying a dominant position (on peaks and near-peak surfaces of positive topographic forms) within viewsheds;

– the sum of viewpoints at the intersection of roads with water bodies (rivers, lake and reservoir banks);

– the total length of the buffer zones of roads along water bodies;

– the total length of road segments that intersect prominent topographic mesoforms, with allowance for their relative value to the aesthetic properties of the landscape (Tab. 4.1.8.3, Fig. 4.1.8.5).

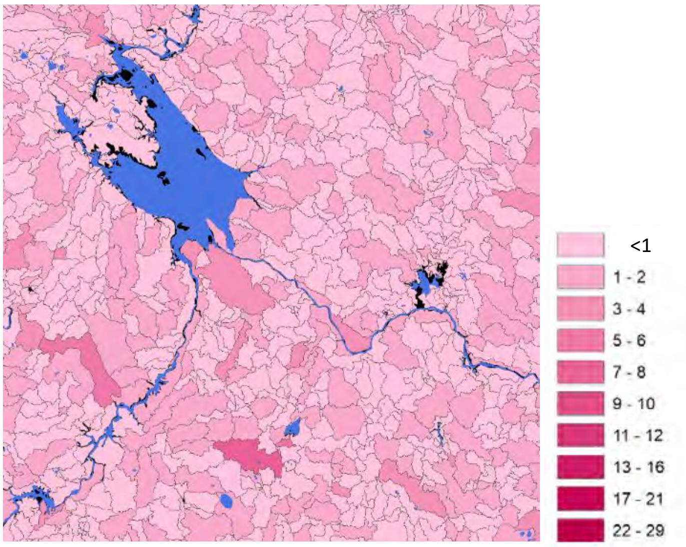


Figure 4.1.8.4. Fragment of a GIS layer showing the number of points of intersection of roads with prominent topographic forms within viewsheds.

Table 4.1.8.3. Relative value of topographic mesoforms for a landscape's aesthetic qualities

Topographic mesoforms (landforms)	*Score*
gorges	3
deep valleys	2
valleys	1
plateau or plain	0
ridges, hills	4
ridges, crests	5

An integrated assessment of the accessibility and observability (contemplation possibilities) of landscapes, generalized for squares of 50 × 50 km, revealed vast territories with a very low level of actual availability of places with high aesthetic potential (Fig. 4.1.8.5 b). Vast areas with high aesthetic quality indicators in the northern part of the European Russia and the Urals (Fig. 4.1.8.5 a) are practically inaccessible to observers. As can be seen from Fig. 4.1.8.6, there is no correlation between the indicators of the volume of aesthetic services provided (integral index of the aesthetic quality of landscapes, Fig. 4.1.8.5 a) and the possibility of their use (integrated index of landscape accessibility and observability, Fig. 4.1.8.5 b). The most beautiful areas with the highest indicators of aesthetic quality are inaccessible to people ("1" in Fig. 4.1.8.6), the most accessible areas have an average level of aesthetic quality and they are very few ("2" in Fig. 4.1.8.6), the bulk of the squares have medium and low indicators of aesthetic quality and inaccessible to observers ("3" in Fig. 4.1.8.6).

A final combination of assessments of the provided volume of aesthetic services and the possibility of their use can be obtained in different ways. If one assumes that the possibility of observation of the landscape is a key factor in perception, then the resulting assessment might be the product of the integral index of landscape aesthetic quality times the integral index of accessibility (Fig. 4.1.8.5 c). Obviously, in this case the final consolidating assessment largely replicates the spatial distribution of the index of landscape accessibility and observability.

Since we did not have the opportunity to verify the assessment through media photo services, we did a random calculation of the number of uploaded photos of nature for individual squares in the north, center, and south of European Russia, which showed that:

– the number of photographs decreases noticeably with the distance from cities, and the larger the town, the more prominent this pattern;

– European Russia is characterized by the presence of vast inaccessible territories that are impossible to be viewed by observers, which makes the amount of aesthetic ES used there negligible – a prominent mountainous and rugged topography increases areas of visibility, which increases the possibility of the use of their ES, despite the physical inaccessibility of certain peaks and mountain ranges.

It is interesting that road density per se does not ensure the possibility of viewing a landscape, since roads usually bypass prominent topographic mesoforms and avoid crossing rivers and any prominent erosive forms.

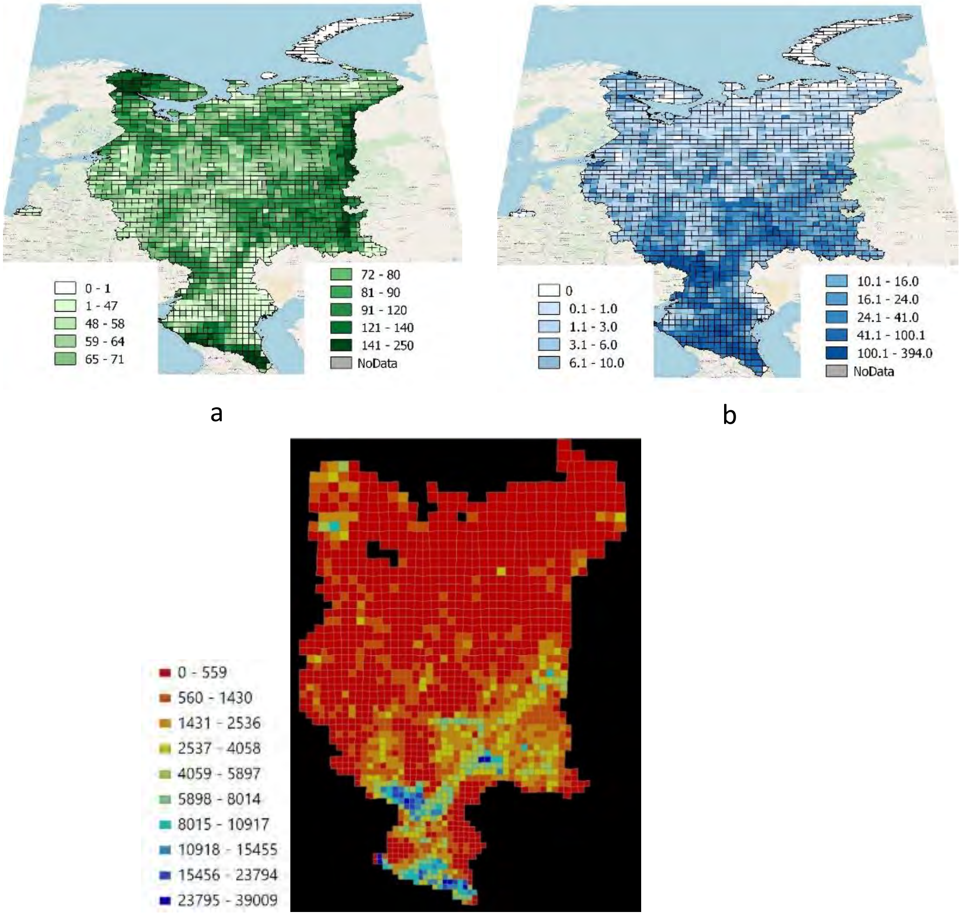


Figure 4.1.8.5. Generalized assessment of the provided volume of ecosystem and landscape aesthetic ES and possibilities for their use: a) provided ES – an integral index of landscape aesthetic quality with allowance for features of the topography, plant cover, and land use; b) the possibility of ES use – an integral index of landscape accessibility and observability; c) integral index of provided ES and the possibility of their use.

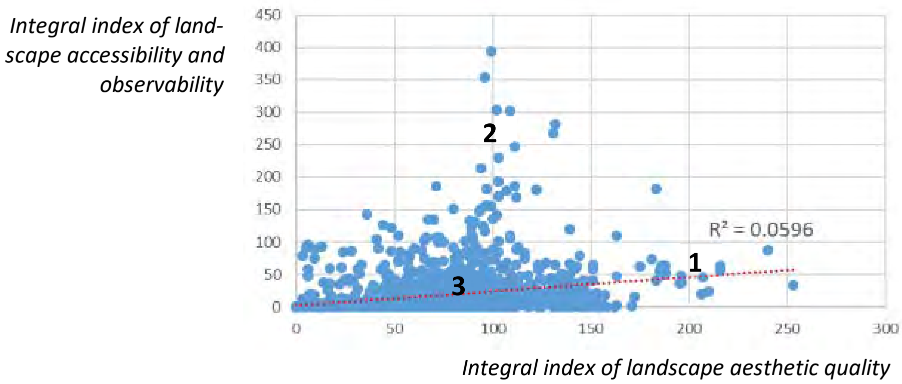


Figure 4.1.8.6. Relationship between indicators of provided aesthetic ES and the possibility of their use for 50-km squares within European Russia.

Opportunities for improving the assessment of aesthetic ES

1. More detailed assessments. The scale we studied can be considered as the limit regarding to the validity of the resulting conclusions. Without question, the larger the scale and the smaller the territorial assessment unit, the more correct and interpretable the result. In switching to an assessment level, let's say, within individual subjects of RF, more accurate viewshed grids may be plotted separately from the land use mosaic, and the features of the natural cover, in the form of combinations of forests of different sizes and configurations, can be taken into account; it also becomes possible to assess land use contours (e.g., combinations of fields with tree breaks and plantings) and the presence of towns and villages that have preserved their historical layouts.

2. The use of media photo services to assess the aesthetic quality of landscapes and consumed volume of aesthetic ES considering differences in its perception by different groups of observers. Opportunities to use media photo services are limited. The habit of snapping a photo of everything and anything is associated with the appearance of smart phones and is typical of younger age groups. At the same time, they are now associated more with an urban lifestyle and they are known for their "landscape blindness". A significant number of older people are entirely capable of assessing the beauty of a landscape, but they tend not to photograph their every view and especially not to upload photos to publicly available services.

3. Assessments of the used volume of aesthetic ES are hard to separate from the use of the components of other ES that are important to recreation, such as clean air and water at recreation areas (a recreational component of regulating services), picking mushrooms and berries, sport fishing and hunting (a recreational component of provisioning services), the opportunity for birdwatching (a recreational component of information services), and opportunities for active and extreme tourism that may be especially important for hard-to-reach areas. Methods for simultaneous accounting of the recreational components of different categories of ES, as well as accounting for different kinds of recreation, require refinement both to avoid double accounting of used services and to assess them more completely and comprehensively.

4.1.9. Features of ecosystem services geographically tied to cities and farmlands

The use of some ES is closely related either to cities or to agricultural land. At the current stage of research under the TEEB-Russia 2 project, the provided (potential) volume of these ES was estimated not for the entire area of ecosystems, but only for ecosystems that are adjacent to cities and agricultural land. This applies to the following ES:

–air purification by suburban forests – in zones from 3 to 20 km around cities (Section 4.1.3);

–creating natural conditions for weekend recreation – in zones from 25 to 50 km around cities (Section 4.1.7);

–crop pollination – with a buffer zone 1 km wide adjacent to arable land (Section 4.1.6).

Unlike estimation of the provided (potential) volume of most ES over the entire ecosystem area, this approach partially takes into account opportunities for ES use: air pollution from cities does not spread throughout the country (or European Russia), city dwellers usually don't travel hundreds of kilometers from home for weekend recreation, and natural pollinators cannot fly several kilometers to entomophilous crops. Thus, given the current structure of human settlement and land use, these ES cannot be used in any way at a significant distance from the areas where their users are concentrated.

Obviously, this approach violates the general logic for assessing provided, requires, and consumed ES, and its use for ecosystem accounting in Russia requires further discussion. In general, this discrepancy can be resolved when developing a scheme for ES assessment considering their spatial scale and direction of action (see the corresponding section in volume 1 of the Prototype of the National Report, Bukvareva, Zamolodchikov, 2018) and by developing a zoning system for ES assessment in Russia (see Section 6.4 of this report).

At this stage of ES assessment, however, this approach seems appropriate, since the inclusion of the area of ecosystems throughout the country (or European Russia) in estimates of provided ES will result in inadequate increase in values. Thus, it must be remembered that a direct comparison of provided (potential) volume of these ES with similar indicators of other ES, both in physical and in economic indicators, is wrongful, since they were calculated for different areas of ecosystems. The resulting estimates of provided ES spatially tied to cities or farmlands are a priori lower than for ES estimated based on ecosystem area over the entire country (or European Russia). This fact does not make these ES less valuable for the well-being of people and the economy.

4.1.10. Ecosystem services of the largest cities of Russia

Within the framework of the TEEB-Russia project, a preliminary assessment of ES, as well as the state and dynamics of green infrastructure in the largest cities of Russia, was made. The results of the assessment will be presented in the Volume 3 of the Prototype of the National Report on Ecosystem Services of Russia “Ecosystem Services of the Largest Cities of Russia”.

An assessment of urban ES and green infrastructure was carried out on two scales:

– for 15 largest cities of Russia with a population of more than 1 million people (Moscow, St. Petersburg, Novosibirsk, Yekaterinburg, Nizhny Novgorod, Kazan, Chelyabinsk, Omsk, Samara, Rostov-on-Don, Ufa, Krasnoyarsk, Perm, Voronezh, Volgograd), as well as for Tyumen, an assessment was made within their administrative borders without taking into account intracity heterogeneity;

– for Moscow, in addition, the assessment was made considering intracity heterogeneity – for 146 municipalities (districts).

The study is primarily aimed at finding approaches to integrating ES indicators into territorial planning and assessing the quality of urban environment in Russia. For this, the following main tasks were solved:

– an inventory of green infrastructure elements at the whole-city level was carried out for the largest cities in Russia (an example for Yekaterinburg is shown in Fig. 4.1.10.1 a); for Moscow, not only the area of green infrastructure was estimated, but also other indicators, in particular, the degree of fragmentation (an example is shown in Fig. 4.1.10.1 b);

– the main trends in green infrastructure area for the period 2000–2016 were analyzed (Fig. 4.1.10.2);

– the provided and required volumes of a number of key regulating, recreational and information ES were evaluated: air purification from pollution by vehicles and stationary sources; climate regulation, including the regulation of urban microclimate; runoff regulation; formation of natural conditions for recreation (an example for Moscow is shown in Fig. 4.1.10.3);

– on the example of Moscow municipalities, intra-urban variability in ES volumes and the factors of their provisioning were identified;

– the degree of inclusion of indicators of green infrastructure and ES in urban planning documents was analyzed.

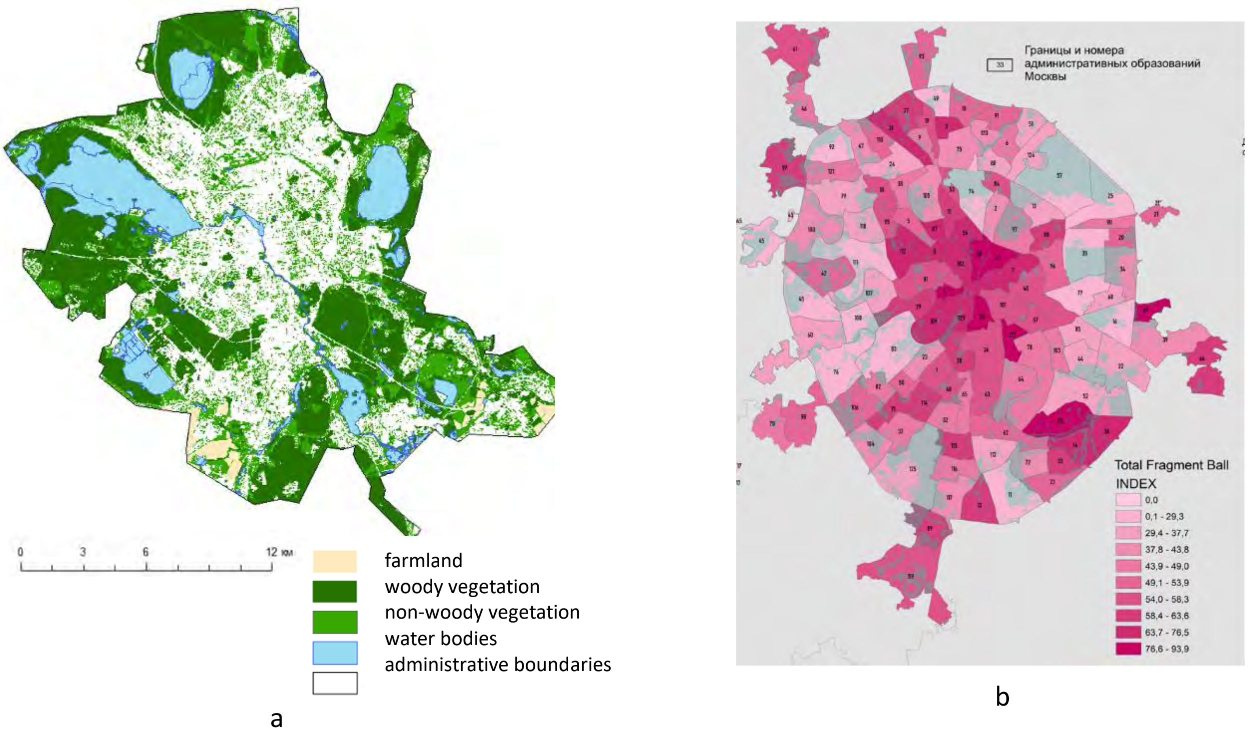


Figure 4.1.10.1. Examples of results of an inventory of urban green infrastructure:
a) the main elements of the green infrastructure of Yekaterinburg;
b) the fragmentation index of the green infrastructure of Moscow.

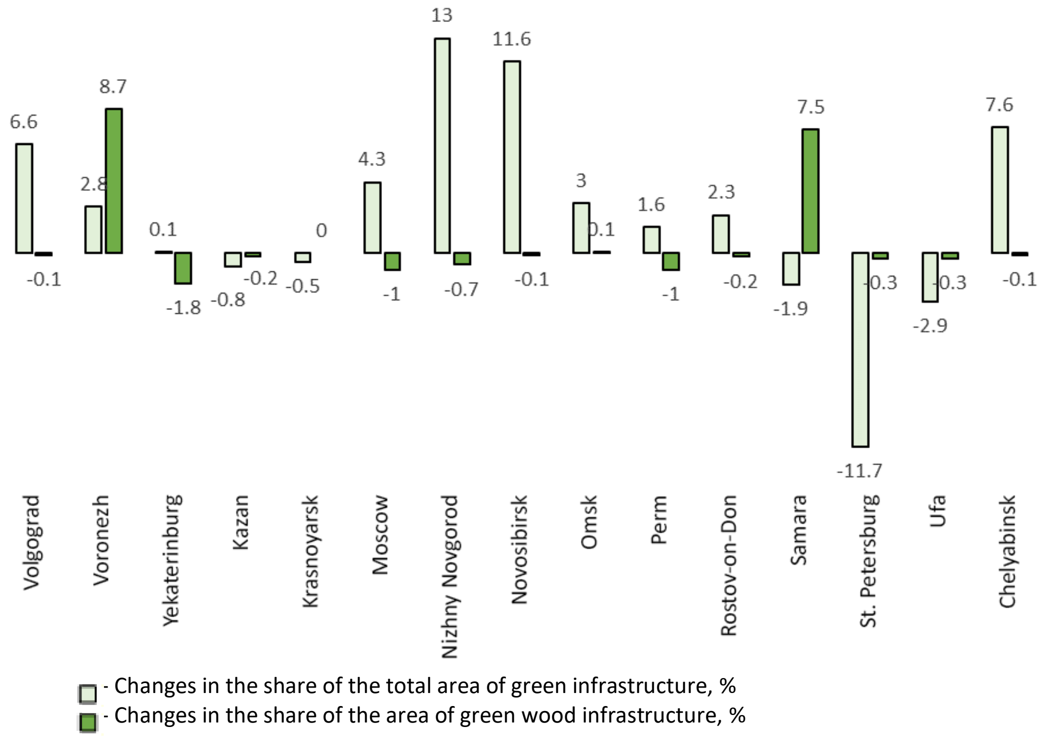


Figure 4.1.10.2. Change in the share of green infrastructure area from the city area for the 15 largest cities of Russia in 2000–2016.

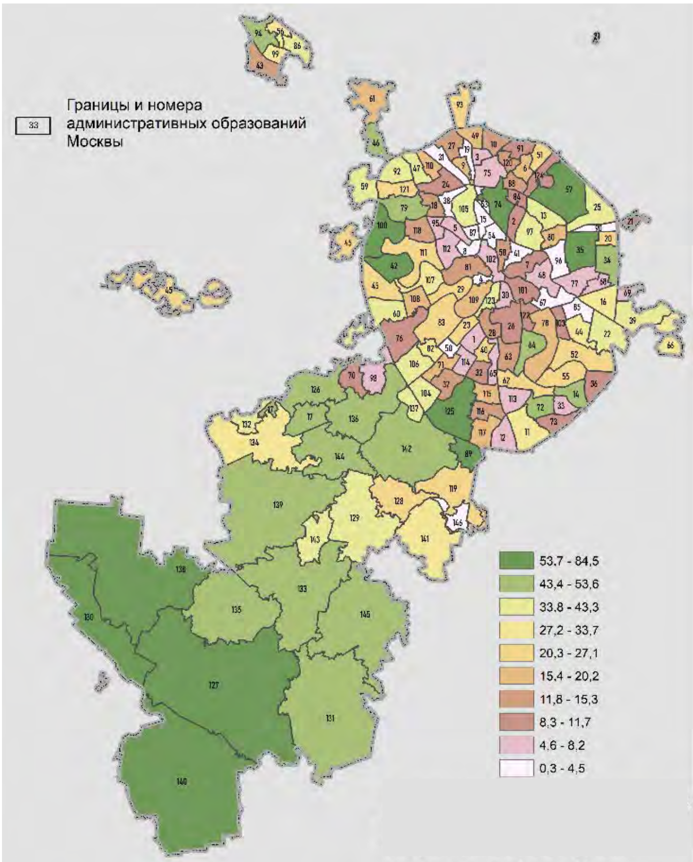


Figure 4.1.10.3. An example of one of the indicators for assessing the ES for the formation of natural conditions for recreation in Moscow: the share of area (%) ensuring preservation of conditions for recreation.

The obtained estimates of green infrastructure and ES of the largest cities in Russia allow us to draw the following preliminary conclusions.

1. Currently, due to the lack of statistical data on the state and dynamics of green infrastructure at the city level, the most accessible data sources for its inventory are remote sensing data and data from open geoportals (in particular, the Open Street Map). However, these sources contain data only on the location and area of green infrastructure elements, but not on its condition and quality. For more accurate assessments, reliable data on biodiversity, degree of disturbance, fragmentation of urban ecosystems and their ability to provide ES both for cities and intracity districts are needed.

2. The analysis of the current state of green infrastructure in the 15 largest cities of Russia showed that, despite the relatively similar natural factors of its formation, there are significant differences between cities in sustainability of green spaces and their availability for people. The most favorable conditions for the provision of ES are currently available in Yekaterinburg, Voronezh and Perm. The worst situation is typical for St. Petersburg and Krasnoyarsk.

3. The ES of air purification by urban vegetation is the most scarce and insufficient for the largest cities are. The degree of provision of the population with recreational ES in a number of cities can be considered acceptable, but these estimates need to be adjusted based on a more accurate determination of the maximum permissible recreational load, taking into account the specifics of urban ecosystems and types of recreation.

4. Green infrastructure is most severely reducing in the peripheral districts of cities. The area of peripheral urban green areas that produce the largest volume of regulating ES is declining, and their fragmentation is increasing. A clear tendency is revealed in the quantitative discrepancy between the areas formally having the status of protected areas and actually performing the functions of preserving urban ecosystems. A revision of the systems of urban protected areas is needed, primarily in Yekaterinburg and Krasnoyarsk.

5. The existing system of urban planning in Russia considers ES of green infrastructure to a minimum extent, although this issue is partially present in the master plans of cities in an implicit form. The methodologies for assessing ES for urban areas, which we tested for Moscow, show the possibility of including these indicators, as well as estimates of the quality of green infrastructure, in the urban planning procedure.

4.2. Importance of ecosystem services for preserving the culture and traditional way of life of indigenous peoples of Russia

4.2.1. Indigenous small-numbered peoples of Russia

The Common Inventory of Indigenous Small-Numbered Peoples of the Russian Federation[64] includes 47 peoples, (Fig. 4.2.1.1), the total population is 316,000 people according to the 2010 Census. 40 of whom (Aleuts, Aleutors. Veps, Dolgans, Itelmens, Kamchadals, Kereks, Kets, Koryaks, Kumandins, Mansis, Nanais, Nganasans, Negidalts, Nenets, Nivkhs, Oroks (Ulta), Orochs, Samis, Tazes, Telengits, Teleuts, Tofalars, Tubulars, Tozhu Tuvins, Udegeis, Ulchs, Khantis, Chelkans, Chukchis, Chulyms, Shors, Evenks, Evens, Ents, Eskimos, Yukaghirs) are included in the Inventory of Indigenous Small-Numbered Peoples of the North, Siberia and the Far East of the Russian Federation (ISNP). The total population according to the 2010 Census is 258,000 people. The indigenous peoples reside in 27 northern subjects of RF, where their total number is 0.2% on average of the federal subject population. In some of these federal subjects there are regions where the percentage of the indigenous population is larger and where traditional way of life and cultures are preserved more fully. These regions include Nenets, Yamal-Nenets, Khanty-Mansi, and Chukotka autonomous okrugs (NAO, YNAO, KNO, and ChAO) and three former autonomous okrugs (legal status changed in 2007), namely Taimyr (Dolgan-Nenets), Evenki and Koryak, the first two of which are now districts in Krasnoyarsk Krai and the latter is now Koryak Okrug in Kamchatka Krai.

Contemporary problems of the condition of traditional way of life are the result of the Soviet Union's state policy in natural resources management and northern exploration. The USSR has made industrial and mining development a priority since the early 1930s at the expense of the traditional sectors of the economy. As a result, extensive areas of intense pollution and environmental degradation emerged in the northern regions, and very often in regions most valuable to the local peoples. The negative impact of industrial facilities on reindeer pastures and hunting areas covers up to 40% of the area of traditional way of life. The rural population of the northern regions not only lost pastures and hunting areas, but also traditional places for fishing and gathering wild plants. Eventually, hunting for fur, fishing and marine mammal hunting decreased, and mushroom and berry picking reduced drastically.

A legal system that protects traditional livelihood and cultures of ISNP began to emerge in the 1990s. A number of laws defined several key concepts such as traditional way of life, native habitat, traditional livelihood and its territories. The right of the ISNP to use lands of various categories rent-free that are necessary for their traditional economy and crafts, the right to preferential use of wildlife, and the right to compensation for damages to the native habitat were codified. These preferences granted to ISNP do not extend to the entire area where they reside and are listed in the Inventory of Traditional Indigenous Habitats and Sites of Traditional Economic Activity of Indigenous Small-Numbered Peoples of the Russian Federation (approved by the government resolution N 631-r dated 8 May 2009).

And yet the law-enforcement practices of the above norms are currently unsatisfactory because of existing contradictions in the relevant legislation.

[64] RF Government Decree N 255 dated 24 March 2000 "On the Unified List of Indigenous Minorities of the Russian Federation (as amended on 25 August 2015) http://docs.cntd.ru/document/901757631

№ in the map	Population	
1	37942	Abazins
2	540	Aleuts
3	8743*	Aleutors
4	3122	Basermans
5	8240	Veps
6	7261	DolgansI-
7	327	Izhora
8	3180	Itelmens
9	2293	Kamchadals
10	8	Kereks
11	1494	Kets
12	8743**	Koryaks
13	3114	Kumandins
14	11482	Mansis
15	9600	Nagaibaks
16	12160	Nanais
17	834	Nganasans
18	567	Negidalts
19	41302	Nenets
20	5162	Nivkhs
21	346	Oroks
22	686	Orochs
23	1991	Samis

№ in the map	Population	
24	4249	Selkups
25	2769	Soyots
26	276	Tazes
27	2399	Telengits
28	2650	Teleuts
29	837	Tofalars
30	1565	Tubulars
31	4442	Tozhu Tuvins
32	1657	Udegeis
33	2913	Ulchs
34	28678	Khantis
35	855	Chelkans
36	1087	Chuvans
37	15767	Chukchis
38	656	Chulyms
39	3231	Shapsugs
40	13975	Shors
41	35527	Evenks
42	19071	Evens
43	237	Ents
44	1750	Eskimos
45	1509	Yukaghirs

Fig.4.2.1.1 The settlement of indigenous peoples of Russia (National Atlas of Russia, 2004–2008).

4.2.2. Significance of ecosystem services for traditional natural resource management

4.2.2.1. Reindeer herding: the ES of fodder production in natural pastures

In the early 20th century 17 northern indigenous peoples herded reindeer in Russia. Nowadays only 12 remain: the Dolgans, Komi, Koryaks, Nents, Samis, Toflars, Khants, Mansis, Evenks, Evens, Yukaghirs, and Chukchis (Fig. 4.2.2.1.1)

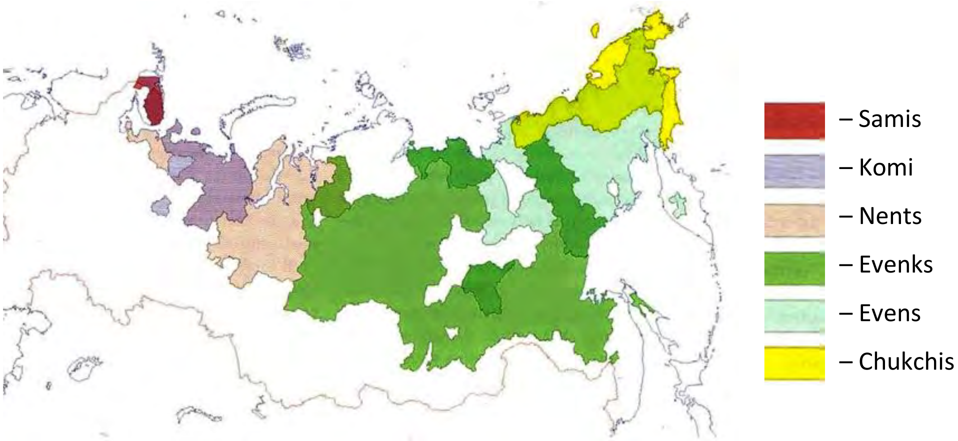


Figure 4.2.2.1.1*. The settlement of the main six reindeer herding peoples of Russia (according to Ulvevadet, Klokov, 2004).*

In 1990 Russia had 2,304,000 reindeer and by 2000 their number was almost halved to 1,244,000. In the 2000s, however, the population began to recover owing to the revival of the tradition of day-and-night and year-long grazing, and now there are 1,906,000 caribou in Russia (Results..., 2018 b). More than 50% of domesticated reindeer are now privately owned by reindeer herders. However, the overwhelming majority of private herders don't have any pastures assigned to them by law, and they graze their reindeer on the lands of former state and collective farms (which are now farm cooperatives and municipal unitary enterprises) by informal agreement.

A large portion of domesticated reindeer graze in Russia's Arctic, although areas of intense reindeer herding also extend into the taiga (Fig. 4.2.2.1.2).

Figure 4.2.2.1.2*. Zones of domesticated reindeer herding by IMN (according to Ulvevadet, Klokov, 2004): 1 – southern boundary of sporadic reindeer herding; 2 – areas of intensive reindeer herding.*

Large-scale commercial reindeer herding is practiced in tundra. Herds make extensive migrations for hundreds of kilometers here. In summer, the reindeer usually graze on the shores of northern seas and in winter, in forest-tundra and in the northern taiga. In forest-tundra and in the mountain taiga regions the herds stay in the same areas year-round because both tundra and forest landscapes provide them with good grazing conditions throughout the year. The migration routes don't exceed a hundred-kilometer radius. Small-scale reindeer herding is common in the taiga regions: small privately-owned reindeer herds (from a few dozen to several hundred animals) graze on their own, occasionally approaching the house or the temporary campground of their herders. In many instances the reindeer graze within fences.

The total area of reindeer pastures nationwide is currently 335.2 million ha (19.6% of the country's land fund). Out of this amount, 140 million ha are allocated to agricultural organizations, another 5.5 million ha are allocated to citizens who herd reindeer, and 56.6% of pastures are allocated to no one.

The pastures actually used (both by reindeer herding organizations and individual reindeer herders with their communities) reduce in number with each year because of their natural degradation and land alienation. This process began in the last decade of the Soviet period (from 1965 to 1990 the area of pastures in use reduced in number by 70.7 million ha), and today degraded pastures cover more than 250 million ha or 74.6% of the total pasture area (Lipsky, 2018). Large-scale industrial development of northern territories damages reindeer pastures, leading to contamination, a reduction in fodder reserves, and a deterioration in fodder quality. Oil – and gas-producing companies develop primarily elevated, well-drained parts of tundra that reindeer herders long used for the same reasons, and they play a key role in the structure of land use (individual pastures, paths to river crossings). The problem of pastureland alienation is aggravated by the fact that the industrial development made unfit not only the land allotted for pasture, but also the adjacent area. Pastures are threatened by the intensified fragmentation of tundra, alpine tundra and forest-tundra landscapes as a result of the road and pipeline construction and the uncontrolled traffic of tracked vehicles in the central districts of the Kola peninsula, in the polar Urals, around Norilsk, in Taimyr Dolgano-Nenets district of Krasnoyarsk Krai, and in the oil and gas-producing districts of Nenets, Yamalo-Nenets, and Khanty-Mansi autonomous okrugs (Fifth National ..., 2014). About 500 tribal lands were created in Khanty-Mansi autonomous okrug in the 1990s in compliance with the traditional settlement system. In 2003 they were converted into territories of traditional natural resource management, where fishing and hunting were practiced, and small reindeer herds grazed. Now these territories largely overlap with areas licensed for oil and gas exploration (Fig. 4.2.2.1.3).

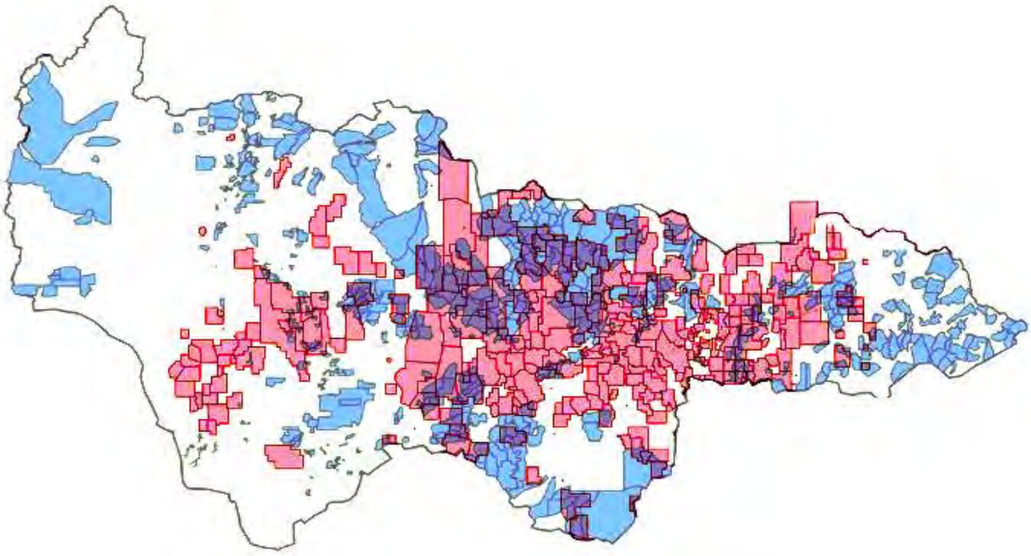


Figure 4.2.2.1.3. Overlap of territories of traditional natural resource management (shown in light blue) and license areas for industrial development (shown in red) (according to data from the Forestry and Forest Industry Directorate of the Department of Natural Resources and Non-Resource Sector of the Economy of the Khanty-Mansi Autonomous Okrug – Yugra).

The area reduction and pasture quality degradation result in overgrazing. This leads to destruction of the reindeer lichen cover and ultimately to a withdrawal of reindeer pastures from use. Besides, the herders also began to graze reindeer more often near their homes, which aggravates the problem of overgrazing. As a result, the damage from an excessive use of reindeer pastures is comparable to the damage from their anthropogenic degradation (Lipsky, 2018). The root cause of this process is, however, industrial exploration in these regions.

The pasture quality degradation and, consequently, the corresponding degradation of the ecosystem service of fodder production on those pastures pose a direct threat to the preservation of the traditional way of life of many indigenous peoples at the present time. The need to reduce the number of domesticated reindeer kept by individual herders is now being discussed.

4.2.2.2. Marine mammal hunting: the ES of production by marine ecosystems

Marine mammal hunting was common among all natives of the Arctic and Far Eastern coast in recent past. Coastal and continental inhabitants set up a product exchange: The former received the warm furs of land animals for clothing and the latter were given the hides of marine mammals needed to make belts, linings for skis and sled skids and to produce waterproof clothing and footwear. All indigenous peoples of the North use seal and bear fat as curatives. Marine mammal hunting is most fully preserved among the natives of Chukotka – Eskimos and Chukchi. All coastal inhabitants of the Arctic and Far East engage in it occasionally.

About 8,000–9,000 family members of hunters now live on Chukotka. There are 25 crews and communities (with around 300 hunters among them) engaged in marine mammal hunting. Each year they capture on average 100 whales and several thousand pinnipeds – walruses, bearded and eared seals (according to the data from the Chukotka autonomous okrug agricultural directorate for 2007 and 2009). The natives also fish in rivers and along the seacoast. In 2012 district associations of ISNP were assigned quotas of 175 tons of pink salmon [Oncorhynchus gorbuscha], 460 tons of chum salmon [Oncorhynchus keta], and 165 tons of red salmon [Oncorhynchus nerka]. Pinnipeds and gray whales are eaten not only by the inhabitants, but also by their sled dogs and farm animals. A little more than 110 kg of fish and marine mammal products are made per native of Chukotka. This equals to 304 g per day, while the norm is 1.8–2 kg of meat and fish per day per person.

The meat and fat of marine mammals, fish and aquatic birds are vital to the residents of the high latitudes as sources of energy and vitamins A, D, E, and K. There are currently not enough experienced hunters and/or usable hunting areas to provide enough meat and fat to all residents of the ethnic coastal villages and the reindeer herders associated with them (Bogoslovskaya, Krupnik, 2013; Bogoslovskaya, 2007).

Marine mammal hunting products are important not only as food for the coastal inhabitants, but also as the paramount component in the interaction between coastal and reindeer herding ISNP. The tradition of regular annual barter between marine mammal hunters and reindeer herders is more than just plain goods exchange – it is an essential cultural tradition of the North. This barter usually happens at the time of the summer reindeer slaughter. The coastal residents prepare earless and bearded seal hides, fat, and dried meat, beluga whale tendons for filaments, bearded seal skins for liners and belts for lassos, and earless seal hides for boots. They exchange that for reindeer meat, skins, lard, and ski skins, pants and boots (all made of reindeer skin of course). Such interaction among peoples helps them survive under the extreme conditions of the Chukotka peninsula, which is an area of “risky” reindeer herding, because the proximity of the sea with “open” water in winter often results in ice-coated winter pastures. In difficult years like these, marine mammal hunters always come to the rescue of reindeer herders, who in turn literally save marine mammal hunter communities from starving to death in very harsh winters when it is impossible to hunt marine mammals for various reasons.

In the last decade(s)? an increasing warming of the near-polar regions of the northern hemisphere began. One of the most significant consequences of this warming is a change in ice conditions in the Bering Strait. Autumn ice formation now happens on average 4 to 6 weeks later than in the 1950s and 1960s, and in the northern Bering Sea it comes 6 to 8 weeks later. Spring ice breakup is now earlier everywhere. As a result, the ice-free period lengthened by almost two months, while the time with a stable ice cover, by contrast, shortened by 8 to 10 weeks. Now, inhabitants of Chukotka are forced to modify their traditional cycle of ice cover use. Similar processes are also occurring in Alaska (Bogoslovskaya, Krupnik, 2013).

Over the last 100 years the number of coastal aboriginal settlements decreased (Fig. 4.2.2.2.1), while the population, whose primary food and sustenance still depend on traditional natural resource management, grew by a factor of 2–3. Because of that the problem of preserving the resource base of traditional natural resource management in historical settlements of ISNP needs increased attention.

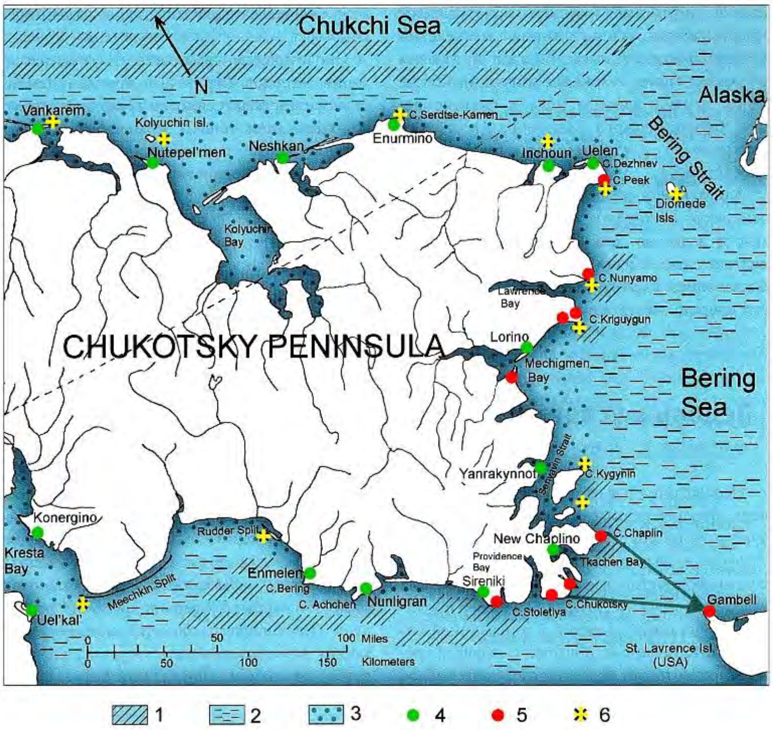


Figure 4.2.2.2.1. Distribution of marine ice landscapes along the shores of eastern Chukotka.
1 — ice openings; 2 — drift ice and ice clearings; 3 — shore ice; 4 — active villages;
5 — abandoned villages; 6 — coastal walrus breeding grounds (Bogoslovskaya, Krupnik, 2013).

Marine mammal hunting is also preserved in Kamchatka krai among the Aleuts of the Komandorsky islands, who mostly hunt northern fur seal and walruses, and among the coastal Koryaks and Itelmens, who hunt in the Sea of Okhotsk and the Bering Sea. In the 19th century, natives of Kamchatka also hunted whales. Now they retain only a whale veneration ritual held on the days of their autumn holiday. Marine mammal hunting on Kamchatka has a tendency to expand, but Federal Fisheries Agency does not approve of it. According to the information obtained from the Federal Fisheries Agency regional directorate, the number of applications for marine mammal hunting recently increased significantly – from 3,000 animals in 2014 to 8,000 in 2019. But the previous quota remains unchanged. More than 400 Kamchatka residents submitted the applications (when?). They were offered a quota of 0.09 ribbon seals [Phoca fasciata], 0.277 largha seals [Phoca larga] and 0.11 bearded seal [Erignanthus][65] per person.

4.2.2.3. Traditional fishing: the ES of provision by freshwater and marine ecosystems

Fish, just like venison, is the primary component of the diet of indigenous peoples. Reindeer herders eat venison from September through April. In summer, the herders try not to slaughter the cattle during their calving and fattening period. Hunting, fishing, and gathering obviously become more important in the warmest months. The natural diet of the indigenous population of the North, oriented toward high consumption of protein and animal fats, is the only possible way for maintaining the body's energy balance in the harsh conditions of the North (Khasnulin et al., 2005). It is mostly families with small herds or no reindeer at all that live by fishing. For them fish is the main protein source. According to the department for ISNP affairs, in the YNAO alone 3,700 natives engage in traditional fishing. Despite the essential importance of fishing to the ISNP, the current situation cannot be considered favorable.

Industrial exploration of the North, primarily mining, and the corresponding maritime transport infrastructure led to a depletion of fish resources. One example of that is the Ob River, the richest in fish river of those flowing into the Arctic Ocean. In the late 1970s, about 30,000 tons of fish were caught in the Ob each year. In the last half a century the catch in downstream and middle stream of the river dropped almost in half to 17,000–19,000 tons. At the time of this writing the wild sturgeon population is nearly destroyed. The

[65] https://www.kamchatinfo.com/news/kolhoz/detail/29588/

muksun [Coregonus muksun] is included in the Red List of Threatened Species of YNAO. The whitefishes [Coregonus] population is also decreasing. The rivers of the Yamal Peninsula are virtually fishless because of natural gas recovery. The construction of new ports to transport hydrocarbons threatens the existence of the semi-anadromous fish in the Ob basin. The man-made canals needed for large tankers to reach the port of Sabetta will make seawater, which today is restrained by the Ob shoals, flow through them far to the south and then travel to Cape Kamenny and the mouth of the Taz estuary. Such mixing of fresh water and saltwater will lead to crucial changes in the ecology of The Gulf of Ob and will very negatively affect the whole fish population of the entire Ob basin (Knizhnikov et al., electronic document).

The fish population of the Pechora river basin also dropped in number, where oil and natural gas have been produced since the 1960s. In the 1990s the pollution of the Pechora river and its tributaries plus fish poaching made the amounts of whitefish [Coregonus lavaretus], houting [Coregonus oxyrhynchus], Arctic cisco [Coregonus autumnalis] and salmon [Salmo] reduce several times. (By early 2001 the spawning populations of whitefish in the Pechora was no more than 50,000–60,000, while in 1989 it was about 150,000).

In addition to the degradation of the fish populations, there are serious problems with providing ISNP with access to them. Traditional fishing by the local and indigenous peoples is restricted by the local government in the interests of commercial fishing. Such restriction violates the law[66]. The government also grants fishing areas in the traditional habitations of ISNP for commercial, sport, and recreational use, cuts the allowable catch for traditional fishing, and establishes permitted traditional fishing seasons, which begin later than those for commercial fishing in the same river basins.

Although article 25 of Federal Law N 166 “On Fishing and the Preservation of Aquatic Bioresources” grants ISNP the right to fish to support their traditional way of life and engage in traditional indigenous economic activities without being allocated fishing areas and without being authorized to harvest aquatic bioresources (except rare and endangered species), each member of the ISNP (including children and the elderly) must have a personal application to catch fish approved. The procedure of application filing is unnecessarily complicated. As a result, only a few people obtain permits to catch fish. According to “Information about Harvesting (Catching) Aquatic Bioresources in Nenets autonomous okrug in 2015), individuals were issued just 150 permits for more than 7,500 Nenets people and 7 permits for their communities.

This problem is aggravated by a conflict between the local population and inspection agencies. ISNP of the North take the law literally and believe that, according to art. 25, part two, of the Federal law № 166, they need no fishing permits. The inspection agencies often do not recognize the right of ISNP to fish for their own needs and act repressively.

4.2.2.4. Traditional hunting on land: the ES of game production

Hunting wild animals is the oldest way to meet the human need for food and clothing. For ISNP, success in hunting is an integral trait of a successful person, and hunting skills are instilled from childhood. Among the majority of ISNP, both men and women may be hunters. This means that the proportion of potential hunters among them far exceeds this indicator among other peoples of Russia. Hunting not only provides food and clothing, but also is a major component of ISNP cultural traditions. In the current environment, the way hunting is organized and how ISNP are provided with access to hunting resources are crucial to maintaining the traditional place of hunting in the life of ISNP.

In Soviet times, state factory farms specializing in hunting and processing wild game were formed in traditional habitations. The Taimyr state industrial farm, located on the land of Nganasans, stood out among them. The state farm was converted from reindeer herding to hunting. The state factory farm processed raw material obtained from shooting wild reindeer – meat, hides, and antlers. In the past, the Nganasans hunted wild deer and kept large herds of domesticated deer. Hunting became a priority in the 1970s. It began to be more profitable for state enterprises to carry out large-scale wild deer culling than to support domestic deer herding. The last Nganasan reindeer were killed, and reindeer herding amongst the entire indigenous group ceased to exist. However, supporting domestic reindeer herding, not wild reindeer hunting, is extremely important for preserving small-numbered ethnic groups of reindeer herding peoples. A conversion to hunting was in no way a return to the Nganasans’ traditional way of life. On the contrary, they became participants

[66] Articles 48 and 49 of Law № 52 “On Wildlife” and Law № 166 “On Fishing…”.

in a new “industrial” type of wildlife resource use: large-scale wild caribou culling at river crossings. This “industrial” type of hunting at Taimyr and in Evenkia led to a drastic reduction in the wild caribou population.

Today “industrial” hunting is almost nonexistent. It is mainly local hunters who hunt the deer. But they are still economically dependent on those who arrange the export and sale of products (Klokov, 1998). This dependence deepens when the hunters are forced to buy food, spare parts, and other goods from the same suppliers. Corrupt relationships between monopolist traders and government agencies that oversee hunting result in bitter conflicts and keep the ISNP from accessing hunting resources. In the last few years, as a result of one such conflict in Taymyrsky and Evenkiysky districts of Krasnoyarsk Krai, the ISNP were no longer able to hunt legally for their personal needs without cost, as specified by the law. The current strategy of boosting commercial profit from hunting conflicts with the principle of free hunting resource use by the ISNP, who are used as hired workforce in this industry. This type of employment brought many indigenous hunters to servitude in recent years.

4.2.2.5. Problems of ISNP access to natural resources and ecosystem services

The previous survey shows that ES are crucial to the existence of the ISNP and to the preservation of their cultural identity. These services include, first of all:

– production of fodder at natural pastures;
– production of marine ecosystem products (primarily, marine mammals and fish);
– production of freshwater ecosystem products (primarily, fish);
– production of wild game hunting by terrestrial ecosystems.

At present time, we should highlight a number of key problems and approaches to solving them that are necessary for sustaining the existence of ISNP on the basis of the traditional use of northern ecosystems.

1. A decline in the production ES of reindeer pastures caused by large-scale industrial development in the northern territories, that leads to fragmentation, pollution, and a deterioration of the quality of natural fodder. A result of the degradation of this ES is forced overgrazing in areas where large-scale commercial reindeer herding is common. An ecological and socioeconomic balance between the needs of traditional reindeer herding for the production services of reindeer pastures and the needs of the thriving oil and gas industry in NAO, YNAO, and KMAO does not exist. The conflict continues to evolve. Nevertheless, reindeer herding is still the only sector of traditional natural resource management in which only the peoples of the North engage. The indigenous herders encounter almost no competition from the newcomers. Only administrative decisions of the government authorities pose a danger to traditional economy.

2. The ES of production (fish and game animals) by aquatic and terrestrial ecosystems, that support traditional fishing and hunting, are also largely undermined by industrial exploration of the North. But the problem of ensuring ISNP’s access to these services and resources is currently also important. In fishing and hunting, a competition between the ISNP and newcomers is fairly intense and growing as these sectors of the economy become more commercialized. The local government authorities and for-profit entities interfere with the unconditional fulfillment of the norms of current legislation regarding the ISNP’s right to free use of fish and game resources. The ISNP’s standard of living remains low and keeps them from entering on an equal footing into market and administrative relationships with respect to obtaining access to traditional bioresources.

3. To prevent an aggravation of the conflict over access to traditional bioresources, the capabilities of population groups and for-profit entities, which compete for bioresources, must be optimized. This pertains primarily to the owners of large reindeer herds, who must change the paradigm of developing large-scale reindeer herding to one that is clan-based. License holders for industrial and commercial development of natural resources in places where the ISNP traditionally settled and used natural resources must not expand their production even more, be it subsoil development or commercial use of forest, wild game, and fishing resources. Legislation must be refined. The jurists should not diminish the rights of indigenous peoples, but correct legal loopholes and ensure that ISNP exercise their right to access traditional resources.

4.2.3. Traditional knowledge as the basis for sustainable use of ecosystems and ES

The indigenous peoples of the North developed special environmental management strategies that are adapted to the low level of biodiversity and productivity of the northern ecosystems, and also possess high resistance to abrupt negative changes in environmental conditions. As L.S. Bogoslovskaya (2014) notes, a feature of the traditional way of life of the indigenous peoples of the North is its dynamic existence at the junction of polar ecosystems, each of which individually has a low species diversity, but as a result of their contact, local areas with an increased level of biological diversity and/or productivity. It was there where all traditional settlements of the North emerged. The indigenous peoples of the North traditionally exist "inside" ecosystems, being part of them, occupying the top of trophic pyramids, like large omnivorous predators. It makes them fundamentally different from the Western postindustrial societies living "above nature," outside of natural trophic ties. Living conditions compel the northerners to live an exclusively social life and show respect for nature within the bounds of their cultural tradition. With the help of spiritual and cultural traditions, the communities of the North maintain the level of biological diversity and ecosystem productivity necessary for their sustainable existence (Bogoslovskaya, 2014).

The complex system of traditional knowledge of the indigenous peoples can be divided into several main components.

The knowledge of the territory, natural conditions and properties of biological resources, i.e. domesticated and wild animals, wild edible and medicinal plants, characteristics of the territory and climate zones, make it possible for the indigenous peoples to survive in extreme conditions using local natural resources. Knowing the peculiarities of animal behavior, nomadic herders use different types of pastures in different seasons and under different weather conditions. Herders, fishermen and hunters determine the time of hunting and fishing, the most convenient routes, camp sites and product harvesting areas. Traditional land navigation skills based on a deep knowledge of the vast surrounding landscape is also important. The traditional calendar is based on a deep knowledge of the biological cycles of domesticated and hunted animals, edible plants, as evidenced by the names of some months in folk calendars. The preservation and development of knowledge of vehicles and animal-powered transport (deer, yaks, horses, sled dogs), methods routing, vehicle-making skills, construction of permanent and temporary settlements, construction of permanent and nomadic portable dwellings are especially important for traditional landscape development. The diet of the indigenous peoples of the North, in which meat and fish products predominate, is also the result of adaptation to the environment. Their absence in nutrition or their replacement with purchased products leads to an imbalance in metabolism, chronic stress, diseases (Khasnulin et al., 2005) and the gradual loss of the nomadic genotype formed by millennia, the carriers of which can survive in the conditions of a nomadic lifestyle or sea hunting in the ice. In traditional medicine, the healing properties of plants, blood, meat, and animal fat are used. The clothing of the indigenous peoples of the North is an adaptive invention for severe climatic conditions and abrupt fluctuations in temperature. Traditional knowledge gives methods for making clothing from natural materials such as animal skins and plant fibers.

Knowledge of natural resource management and forms of economic activity, related to reindeer herding and local livestock breeding, fishing, river, lake, and marine mammal hunting, fur hunting, and gathering of wild plants allow indigenous peoples to use ecosystems and ES for an unlimited time.

The system of seasonal and spatial location of stationary and temporary settlements, camps, and migratory routes is extremely important for a sustainable use of northern biological resources. In the past, the inhabitants of Chukotka had an ecologically adaptive system of colonization in the coastal zone. Even in places rich in natural resources, they usually created not one big settlement, but several ones at some distance from each other, with a small number of inhabitants in each one. With a decrease in productivity of one type of biological resources, the inhabitants could use another one. During periods of a marine mammal population drop, fishing, bird hunting, and gathering (including egg gathering in bird colonies) temporarily became more popular. Less than a century ago, the entire coast of the Chukchi Peninsula was an unbroken chain of Chukchi and Eskimo villages and territories with well-known borders, stationary settlements and seasonal hunting camps, nature management rules, close family and trade ties. The villages were located at the intersection of ecosystems, where biological diversity and productivity of natural complexes are always the highest, and the energy cost of hunting is minimal. Stationary settlements were created near the winter "open" water, which is a necessary natural basis for the marine mammal hunting culture in the Bering Strait region. The villages on the headlands, from which vast sea spaces are visible and to which whales, walruses, and seals have come close for millennia, were of special importance. An even distribution of small villages and seasonal hunting camps along the coast contributed to a decrease in marine mammal hunting and the anthropogenic impact on the environment (Bogoslovskaya, Krupnik, 2013; Bogoslovskaya, 2007).

One example of the traditional method of sustainable use of deer pastures is the so called "circular" grazing, which is practiced by reindeer herders of Yamal-Nenets autonomous okrug, Nenets autonomous okrug, on the Kola Peninsula and Chukotka. Such grazing of a large herd, especially in summer, is built on the principle of circular motion, i.e. grazing around the camp in an area with a radius of about 5 km. The herders during their watch send the herd far from the camp at night, and in the afternoon to the camp. The next herder again drives the herd away 5 to 7 km from the camp, but not exactly in the same direction where they went last night, but to the right (looking at the sun), and the herd also returns a little to the right of their trace. This creates a grazing pattern resembling petals or lace. Typically, there are 3 to 5 such petals around the camp, before the herders with their animals move to a new place, at a distance of 7–10 km. Even a large herd of several thousand animals during this rotation does not destroy the pasture but preserves it according to the Nenets proverb “the land remains after us” (Golovnev, 2019; Golovnev et al., 2016).

The regulation of the number of domesticated animals is provided by traditional knowledge of biology, veterinary medicine, breeding and animal ethology. They include methods for selecting animals during the annual winter and spring slaughter. Sick animals, infertile adult female reindeer, cocky young bulls, and last year ex-stud bulls are rejected. Based on their behavioral traits, the bulls are selected and castrated, and then trained to be used as working animals. During calving, adult female reindeer with calves are separated from the herd to provide them with calm conditions for feeding.

Wildlife population control is ensured by traditional bans on hunting and fishing during certain periods and in certain places. Marine mammal hunters respected a number of rules of personal and collective behavior, while hunting or being on the shore, and also performed various rituals. That helped to maintain a high level of biological diversity and productivity of marine ecosystems of the eastern Chukotka for thousands of years, despite a significant range of climatic changes that took place in the Bering Strait region.

Multiple technologies for food processing (drying, fermentation and pickling, freezing and others) allow you to harvest and store products for a future use and contribute to a rational management of renewable natural resources.

The traditional structure of social, economic and cultural self-organization also ensures the sustainability of renewable natural resource management and the transmission of environmentally and ethnically significant information through generations (Murashko, 2007; Murashko, 2014). Traditional social and cultural relations, values, stereotypes of interpersonal and social relations are determined by a central role of any given type of activity in the life of an indigenous population. Knowledge of the boundaries of patrimonial territories of cattle grazing, and knowledge of hunting and fishing areas ensures compliance with the social norms regarding the use of natural resources. The customs of mutual assistance between rich and poor families are retained and adopting single adults and orphan children. The traditional division of labor is aimed at ordering the family relationships. The men guard and graze deer and cattle, hunt and fish, take care of the safety of settlements and the conditions of migration. The women clean the house, carry water, prepare food, process hides, sew clothes and shoes from them, collect edible and medicinal herbs, berries, and prepare medicines. The traditional stereotype of reproductive behavior is aimed at a large number of children in the family who from an early age participate in all parts of life (Murashko, 2014).

The traditional worldview is based on the nature and ancestor worship (Khariuchi, 2012; Murashko, 2014; Shtammler, 2008). The faith in the master spirits of mountains, rivers, places of interest and ancestor worship is embodied in the custom of sacred places worship. Sacred tribal places are located along the migratory route, and it is forbidden to hunt, fish, gather berries, and make noise there. According to the natives, the rules of conduct and rituals performed in sacred places are necessary to maintain a person’s spiritual connection with the environment through the world of spirits. Therefore, the destruction of a sacred place or the impossibility of performing a ritual, in their opinion, leads to a dangerous destruction of these connections (Murashko, 2004). The rules of conduct in sacred places which ban disturbing the land, sacred stones, rocks, hills, reservoirs, plants and animals in these places are similar to the rules of behavior in specially protected areas and contribute to the conservation of biodiversity (Murashko, 2007).

A full transfer of traditional knowledge is possible only with a direct and long-term interaction between older and younger generations who communicate in their native language, in which the bulk of the vocabulary is represented by terms and concepts related to nature and its management. Ethnic methods of upbringing and training, first of all, the family environment, which practices an early inclusion of children in labor along with adults play an important role in the transfer of knowledge (Bogoslovskaya, 2014).

One example of traditional knowledge of nature is how the marine mammal hunters imagine sea ice as a special kind of cultural landscape. A detailed ethnic typology of ice can be traced according to the traditional nomenclature of ethnic names for different types of sea ice in national languages and dialects. Ethnic typologies differ considerably from the sea ice classifications used by skippers and glaciologists. “Ice dictionaries” in the languages and dialects of the natives often have up to 60–80 and sometimes more than 200 names for different types of ice and related phenomena. Collective (community) and individual knowledge about the peculiarities of the formation, use and degree of danger of each of the recognized types of ice and ice landscapes is passed from generation to generation. The long-established routes for traveling on ice with the corresponding ethnic names and specific landmarks on the shore and on ice are preserved. In many regions during the winter months, the area used by the local communities can double or even triple by adding sections of coastal sea ice. The knowledge about dangerous areas of the ice landscape passes between the natives. In many regions of the Arctic there are annually formed permanent ice cracks and wormwoods, which are well known to the local population. There are areas prone to regular tearing and spalling of fast ice. The hunters caught on such ice can be carried away for many months into dangerous ice drift. Information about these sites and stories about dangerous places (from a “ritual” point of view), as if they are possessions of some malicious or supernatural creatures, are stored in the community memory and passed on from generation to generation. In many parts of the Arctic, there are ice trails, berths, and even real roads annually created by the local communities for hunting and moving between their villages. They are supported, updated, and, like onshore formations, usually have their own names and groups of people responsible for maintaining them.

Traditional routes of reindeer herders are organized considering the mitigation of the consequences of natural disasters, such as snowstorm, ice, and avalanches. The reindeer herders, while migrating, look in advance for quiet places that can be used for sheltering the herds from snowstorms, vegetation on stony placers in the case of feedless, safe passageways in the mountains. Thus, the traditional skills of land navigation, based on a deep knowledge of the characteristics of the vast surrounding landscapes, aim to ensure the safety of people and domesticated animals (Murashko, 2007).

The whole range of traditional knowledge, providing a traditional way of life, migratory routes, opportunities for maneuver in emergency situations, sacred and forbidden places to visit, and related natural objects, is an important information ecosystem service that must be preserved for the sustainable development of nature management of the natives.

5. Relationships between Indicators

5.1. Indicators of ecosystem assets and climatic conditions

Relationships between indicators of climatic conditions and ecosystem assets are analyzed for the following indicators:

– climatic parameters: average annual temperature and average annual precipitation according to the data base Land Resources of Russia[67] (Stolbovoi, McCallum, 2002);

– indicator of the degree of territory transformation (indicator, inverse to the area of natural ecosystems) – area share of transformed ecosystems (see Section 3.1.1);

– indicators of ecosystem functioning: phytomass and productivity of natural ecosystems (see Section 3.1.3);

– biodiversity indicators: indicators of bird species richness in 50-km squares (see Section 3.2.3), indicators of species richness of vascular plants – the number of plant species per 100 thousand km^2 (see Section 3.3.1) and the number of species in local flora (see Section 3.3.2).

Relationships between indicators were analyzed on three scales:

a) for mean values of indicators for ecoregions, which were calculated as mean values of indicators in 50-km squares for each ecoregion;

b) for the values of indicators in 50-km squares within European Russia – the values of indicators of bird species richness were determined based on the actual number of bird species recorded in each 50 km square (see Section 3.2.3), the values of other indicators in 50-km squares were calculated by GIS methods (see Section 2.3);

c) for mean values of indicators for the subjects of RF within European Russia or within the whole country – mean values of indicators of bird species richness ere defined as mean values in 50-km squares within the territory of each subject of RF, mean values of other indicators within the territory each subject of RF were calculated by GIS methods (see Section 2.3).

The bulk of the analysis was done within European Russia, some relationships were analyzed for subjects of RF throughout the country based on the data of the TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018).

Dependencies revealed for ecoregions were analyzed both for individual ecoregions and for the following groups of ecoregions, within which dependencies are of a similar nature:

– a group of northern, forest and mountain ecoregions (Arctic deserts, tundra, northern taiga, southern taiga, mixed forests, mountain forests and tundra of the Urals, mountain forests of the Caucasus);

– a group of southern ecoregions (forest-steppe, steppe, semi-desert);

– a group of weakly transformed ecoregions (Arctic deserts, tundra, northern taiga, southern taiga, mixed forests, Urals, Caucasus, semi-desert);

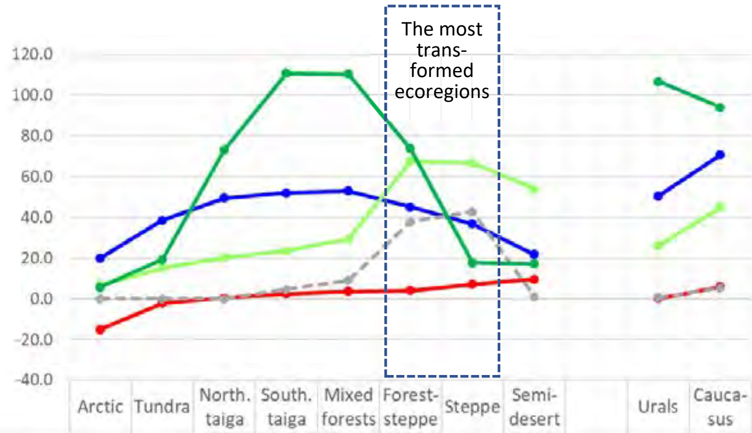
– a group of highly transformed (agricultural) ecoregions (forest-steppe and steppe).

At this stage of the research, given the significant amount of data analyzed, we considered it appropriate to consider a small number of groups of ecoregions, each of which includes quite diverse ecosystems. In further studies, it is obviously necessary to detail and correct the generalized groups of ecoregions that we have identified. So, it is obvious that the forest-steppe, assigned in this study to the group of southern ecoregions, in fact is a mosaic of forest and grass areas and requires a separate analysis. Mountain regions, as well as the Arctic deserts and tundra, included in the present study in the group of northern, forest, and mountain ecoregions, also require a separate analysis. A more detailed analysis of the dependencies within individual ecoregions is also needed.

[67] https://webarchive.iiasa.ac.at/Research/FOR/russia_cd/guide.htm

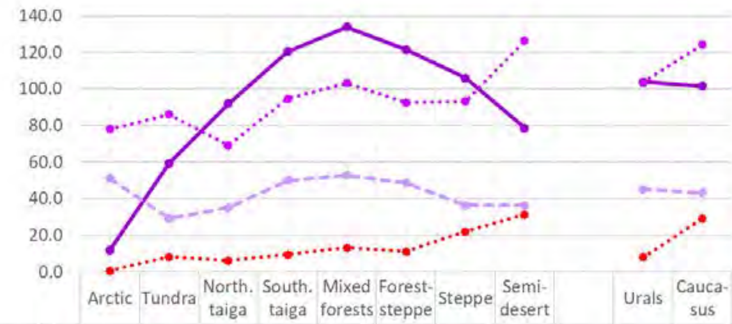
5.1.1. Mean values of indicators for ecoregions

Mean values of climatic parameters and indicators of ecosystem assets for ecoregions are shown in Fig. 5.1.1.1 a, b. These graphs show that some indicators change in a similar way on the north-south gradient. All indicators, except the average annual temperature and the overall index of the Red Book bird species (for the Red Book bird species indices, see Section 3.2.3.3), when moving from north to south, first increase and then decrease. They peak, however, in different ecoregions. The average precipitation, phytomass (Fig. 5.1.1.1 a) and the mean number of bird species per 50-km square (Fig. 5.1.1.1 b) have maximum values in forest ecoregions. Productivity and degree of territory transformation have maximum values in the forest-steppe and steppe (Fig. 5.1.1.1 a). The maximum productivity and territory transformation are characteristic of the two most transformed ecoregions (forest-steppe and steppe). In the semi-desert ecoregion, the productivity is also high, but territory transformation is low.



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Caucasus
Average annual temperature, °C	-15.0	-2.0	0.5	2.5	3.8	4.1	7.1	9.8		0.2	6.0
Average annual precipitation/10, мм	20.2	38.6	49.5	52.2	53.0	45.1	36.9	21.8		50.7	70.7
Area share of transformed ecosystems,%	0.0	0.1	0.1	4.7	9.1	37.7	42.9	1.3		0.7	5.5
Net primary production*100, kgC/m2/year	6.8	15.2	20.3	23.6	29.4	67.7	66.8	54.0		26.0	44.9
Phytomass*10, kg/m2, dry weight	5.9	19.4	73.3	110.9	110.5	73.8	17.8	17.2		106.8	94.2

a



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Caucasus
Mean bird species number per 50-km square	11.8	59.4	91.9	120.4	133.7	121.4	106.0	78.8		103.8	101.5
Share of registered in a square species of their total number in the ecoregion	51.1	29.1	34.9	50.0	52.9	48.7	36.3	36.3		45.1	43.2
Overall index of the Red Book bird species	0.6	8.1	6.1	9.5	13.3	11.0	22.0	31.3		7.9	28.9
Overall index of bird diversity*10	78	86	69	95	103	93	93	126		103	124

b

Figure 5.1.1.1. Average values of climatic parameters and indicators of ecosystem assets for ecoregions: a) climatic parameters and indicators of ecosystem condition; b) indicators of bird diversity.

5.1.2. Correlations between indicators of climate conditions and ecosystem assets

Correlation coefficients between climatic parameters and indicators of ecosystem condition and biodiversity for the three scales of analysis are given in Tab. 5.1.1.1, 5.1.1.2 and 5.1.1.3 (correlations between different indicators of bird diversity are discussed in Section 3.2.3). Pearson correlation coefficient was used for quantitative indicators, Spearman correlation coefficient was used for point indicators (overall index of the Red Book bird species and overall index of bird diversity).

Correlations are best manifested for actual values of indicators in 50-km squares, most weakly – for mean values of indicators for ecoregions.

Table 5.1.2.1. Correlations between mean values of indicators of climate, ecosystem condition, and bird diversity for ecoregions within European Russia.

	Average annual temperature	Average annual pre-cipitation	Area share of transformed ecosystems	Productivity	Phytomass
Average annual precipitation	.091	1			
Area share of transformed ecosystems	.770**	.333	1		
Productivity	.879**	.103	.879**	1	
Phytomass	–.006	.903**	.345	.091	1
Mean bird species number per 50-km square	.394	.588	.818**	.588	.733*
Mean share of registered in a square species of their total number in the ecoregion (%)	–.122	.255	.207	.012	.401
Overall index of the Red Book bird species	.927**	.176	.697*	.782**	.055
Overall index of bird diversity	.612	.358	.382	.515	.309

*** p<0.01; * p<0.05; n=10.*

Table 5.1.2.2. Correlations between actual values of indicators of climate, ecosystem condition, and bird diversity in 50-km squares within European Russia.

	Average annual temperature	Average annual pre-cipitation	Area share of transformed ecosystems	Productivity	Phytomass
Average annual precipitation	.000	1			
Area share of transformed ecosystems	.526**	–.221**	1		
Productivity	.585**	–.233**	.813**	1	
Phytomass	–.022	.676**	–.325**	–.349**	1
Bird species number in 50-rm squares	.278**	.213**	.150**	.138**	.353**
Share of registered in a square species of their total number in the ecoregion (%)	.101**	.215**	.017	.012	.394**
Overall index of the Red Book bird species	.461**	–.206**	.285**	.321**	–.184**
Overall index of bird diversity	.273**	–.042	.131**	.136**	.039

*** p<0.01; * p<0.05; n=1450 for bird diversity indicators, n=1655 for indicators of state of ecosystems.*

Table 5.1.2.3 Correlations between mean *values of indicators of climate, ecosystem condition, and biodiversity for subjects of RF within European Russia.*

	Average annual temper-ature	Average annual precipi-tation	Area share of trans-formed ecosys-tems	Produc-tivity	Phyto-mass	Mean plant species number in local flora	Plant species number per 100,000 km^2
Average annual precipitation	–.014	1					
Area share of transformed ecosystems	.434**	–.238	1				
Productivity	.588**	–.197	.860**	1			
Phytomass	–.236	.637**	–.400**	–.531**	1		
Mean plant species number in local flora	.298*	.539**	.282*	.443**	.102	1	
Plant species number per 100,000 km^2	.454**	.433**	.231	.319*	.428**	.634**	1
Mean bird species number per 50-km square	.178	.156	.243	.127	.467**	.301*	.664**
Overall index of the Red Book bird species	.613**	–.006	.256	.366**	–.157	.328*	.174
Overall index of bird diversity	.344*	.152	.109	.143	.195	.361**	.347*

*** p<0.01; * p<0.05; n=54.*

Significant positive correlations are revealed between the following indicators (Tab. 5.1.2.4): 1) between the average annual temperature, productivity, territory transformation, and the overall index of the Red Book bird species (values of these indicators increase from north to south); 2) between the average annual precipitation and phytomass of ecosystems. At the same time, negative correlations are revealed between the indicators listed above in group "1" and indicators listed in group "2". An exception is indicators of bird species richness, which are either positively related to other indicators, or there is no correlation. Plant species richness generally positively correlates to indicators of bird diversity (Tab. 5.1.2.3).

Table 5.1.2.4. Correlations between indicators of climate, ecosystem condition, and biodiversity at different scales of analysis.

Correlation sign	*Indicators*		*Scales of analysis*			*Comments*
			Ecoregions	*50 km squares*	*Subjects of RF*	
Indicators of ecosystem condition						
+	Productivity Territory transformation	Temperature	**	**	**	In general, values increase from north to south (Fig. 5.1.1.1 a)
+	Productivity	Territory transformation	**	**	**	Values have maximum values in the forest-steppe and steppe (5.1.1.1 a)
+	Phytomass	Precipitation	**	**	**	Values have maximum values in two southern forest regions – southern taiga and mixed forests (Fig. 5.1.1.1 a)
–	Phytomass	Productivity Territory transformation		**	**	
Biodiversity indicators						
+	Bird species number in 50-km squares	Territory transformation	**	**		The number of bird species has a maximum in the ecoregion of mixed forests, but when moving from this ecoregion to the south it does not decrease as much as when moving to the north, therefore, the change in this indicator on the north-south gradient is generally similar to changes in the degree of territory transformation (5.1.1.1 a, b)
+	Bird species number in 50-km squares	Phytomass	*	**	**	Values have maximum values in the middle of the north-south gradient (5.1.1.1 a, b)
+	Overall index of the Red Book bird species	Temperature Productivity	**	**	**	Values increase from north to south (5.1.1.1 a, b)

5.1.3. Climatic conditions – degree of territory transformation

The degree of territory transformation positively correlates to the average annual temperature at all scales of analysis (Tab. 5.1.2.1–5.1.2.3, Fig. 5.1.3.1 a, 5.1.3.2 a, 5.1.3.3 a) and negatively correlates to the average annual precipitation for 50-km squares and subjects of RF, although in the latter case correlation is statistically insignificant (Tab. 5.1.2.2, 5.1.2.3, Fig. 5.1.3.2 b, 5.1.3.3 b). No correlation between the amount of precipitation and the degree of territory transformation for mean values of indicators for ecoregions was revealed (Tab. 5.1.2.1, Fig. 5.1.3.1 b).

A positive relationship between the degree of territory transformation the temperature for 50-km squares within European territory of Russia may occur due to differences in the values of indicators between the group of northern, forest and mountain ecoregions (green in Fig. 5.1.3.4 a) and the group of southern ecoregions (orange in Fig. 5.1.3.4 a). Within these groups of ecoregions, the relationship is weak or absent.

A negative relationship between the degree of territory transformation and the amount of precipitation detected for the European territory of Russia can also arise due to differences in indicators' values in the group of northern, forest and mountain ecoregions, within which the dependence is practically absent and in the group of southern ecoregions, within which a positive dependence is revealed (Fig. 5.1.3.4).

Obviously, the degree of territory transformation, that is, the intensity of its use in agriculture, directly depends on climatic conditions. The revealed dependences are similar to the dependences between climatic parameters and productivity of natural ecosystems (see further in Section 5.1.5). Also, as expected, the degree of territory transformation is closely related to the productivity of natural ecosystems (Fig. 5.1.1.1, Tab. 5.1.2.1–5.1.2.3, Section 5.1.7), which corresponds to the general pattern of the greatest development of agriculture in the most productive areas. Therefore, the explanation of the revealed dependencies between the degree of territory transformation and climatic conditions is completely similar to that for the dependencies between the productivity of natural ecosystems and climatic conditions, which is given further in Section 5.1.5.

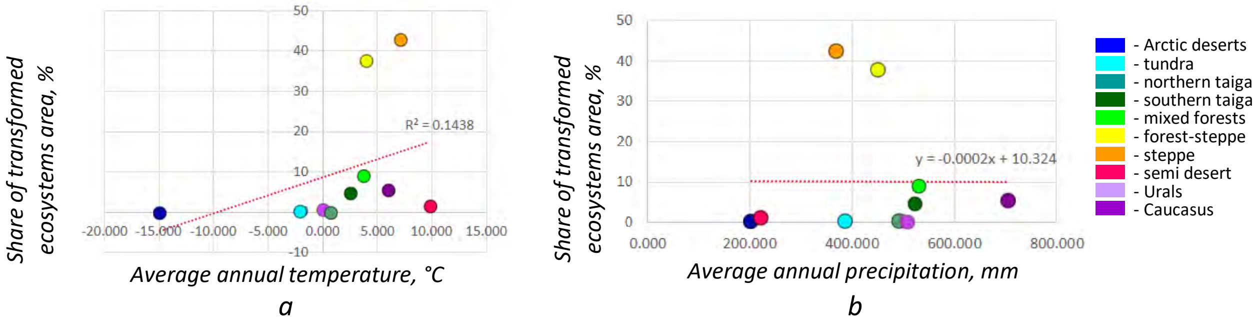


Figure 5.1.3.1. Relationships between the degree of territory transformation and climatic parameters for mean values in ecoregions. Mean values are shown in the colors corresponding to the map in Fig. 2.2.1.

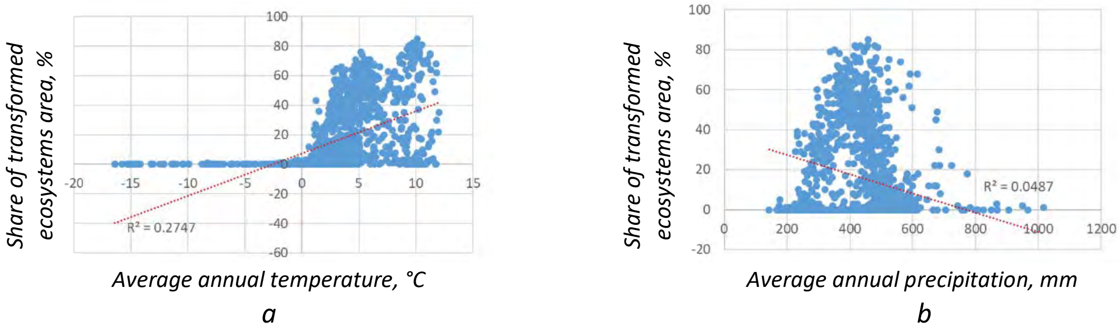


Figure 5.1.3.2. *Relationships between the degree of territory transformation and climatic parameters for 50-km squares.*

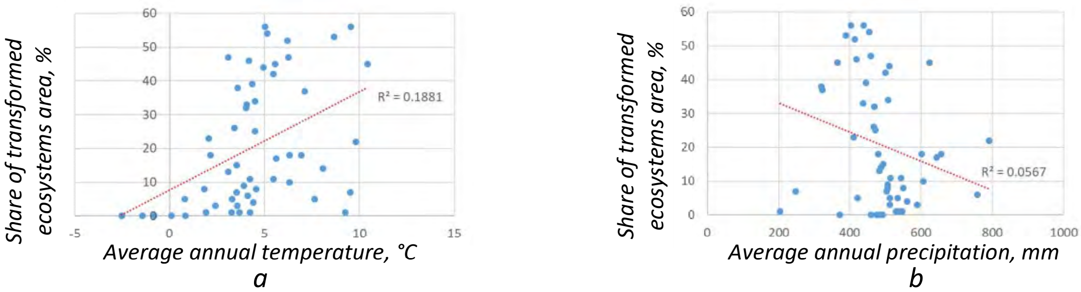


Figure 5.1.3.3. *Relationships between the degree of territory transformation and climatic parameters for mean indicator values for subjects of RF within European Russia.*

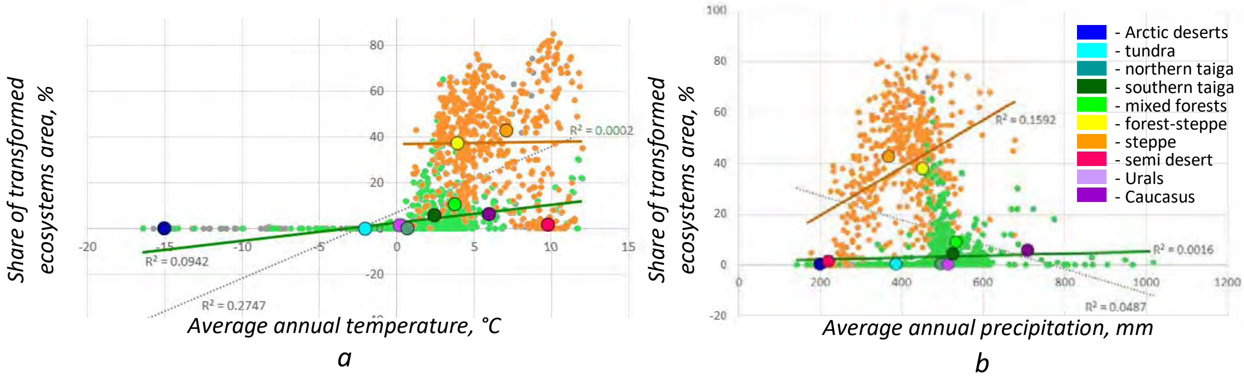
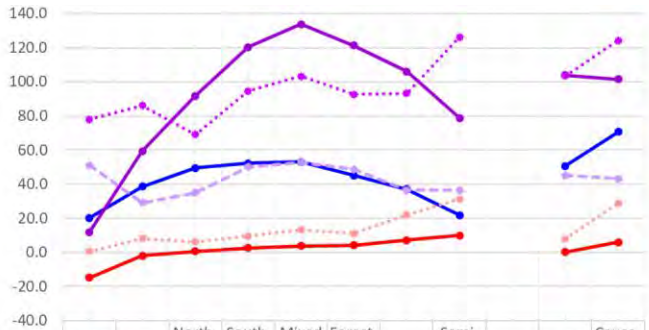


Figure 5.1.3.4. Relationships between the degree of territory transformation and climatic conditions for 50-km squares in the group of northern, forest and mountain ecoregions (green) and in the group of southern ecoregions (orange). Mean values for ecoregions are shown in the colors corresponding to the map in Fig. 2.2.1. Dependencies for the whole European Russia are shown by gray dotted lines.

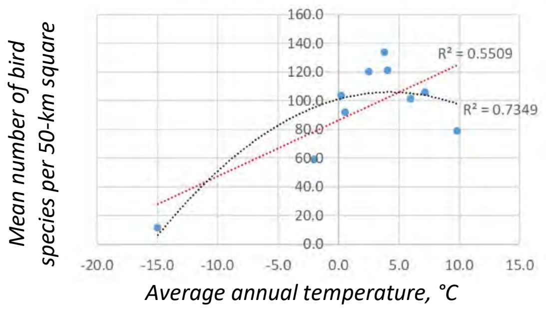
5.1.4. Climatic conditions – biodiversity

The indicators of bird species richness (mean species number per 50-km square and mean share of registered in a square species of their total number in the ecoregion) have maximum values in the middle of the north-south gradient (Fig. 5.1.4.1 a), similar to the average annual precipitation (except for a high outlying value of share of registered in a square species of their total number in the ecoregion of Arctic deserts; see also Section 3.2.3.2). The overall index of bird diversity nonmonotonously increases from north to south. The overall index of Red Book bird species (for Red Book bird species indices, see Section 3.2.3.3) monotonously increases from North to South, like the average annual temperature (Fig. 5.1.4.1 a).

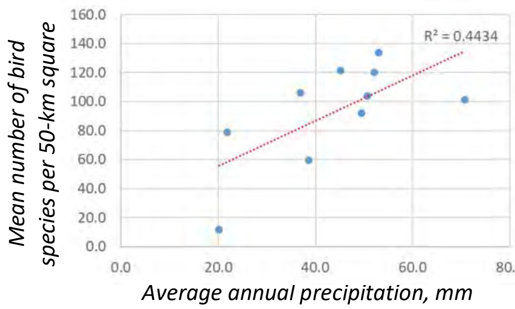


	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert	Urals	Caucasus
Average annual temperature, °C	-15.0	-2.0	0.5	2.5	3.8	4.1	7.1	9.8	0.2	6.0
Average annual precipitation/10, мм	20.2	38.6	49.5	52.2	53.0	45.1	36.9	21.8	50.7	70.7
Mean bird species number per 50-km square	11.8	59.4	91.9	120.4	133.7	121.4	106.0	78.8	103.8	101.5
Share of registered in a square species of their total number in the ecoregion	51.1	29.1	34.9	50.0	52.9	48.7	36.3	36.3	45.1	43.2
Overall index of the Red Book bird species	0.6	8.1	6.1	9.5	13.3	11.0	22.0	31.3	7.9	28.9
Overall index of bird diversity*10	78	86	69	95	103	93	93	126	103	124

a



b



c

Figure 5.1.4.1. Mean values of climate parameters and number of bird species per 50-km square for ecoregions: a) change in mean values on the north-south gradient; b) relationship between mean number of bird species per 50-km square and average annual temperature; c) relationship between mean number of bird species per 50-km square and average annual precipitation.

The results for all spatial scales are similar: biodiversity indicators are either positively related to temperature and precipitation, or there is no relationship (Tab. 5.1.2.1–5.1.2.3, Fig. 5.1.4.1–5.1.4.3). The exception is the negative correlation between precipitation and the overall index of the Red Book bird species and overall index of bird diversity for 50-km squares (Tab. 5.1.2.2). For all the scales of analysis, between indicators of species richness and temperature, in addition to a positive dependence, a unimodal dependence is also revealed with maximum values of species number at an average annual temperature of about 4–5 °C (Fig. 5.1.4.1 b; 5.1.4.2, left column of the graphs; 5.1.4.3 a).

Unimodal dependencies between species richness and average annual temperature may occur due to the different nature of the dependencies between these indicators in different climatic conditions. For

50-km squares, positive relationship between bird species number and temperature revealed for the whole European Russia breaks up into a significantly stronger positive dependence for the group of northern, forest and mountain ecoregions and a weak negative dependence for the group of southern ecoregions (Fig. 5.1.4.3 c). The latter can be explained by the fact that in this group of ecoregions, with increasing temperature, the climate becomes more arid and the conditions for birds become less favorable. The dependence of bird species number on precipitation is positive for both groups of ecoregions, but for the southern group it is less pronounced (Fig. 5.1.4.3 d). Within the ecoregions, the dependencies are multidirectional or absent (Fig. 5.1.4.3 e, f), that is, trends for the whole European Russia and groups of regions are more likely determined by mean values for ecoregions, rather than positive or negative dependencies within ecoregions.

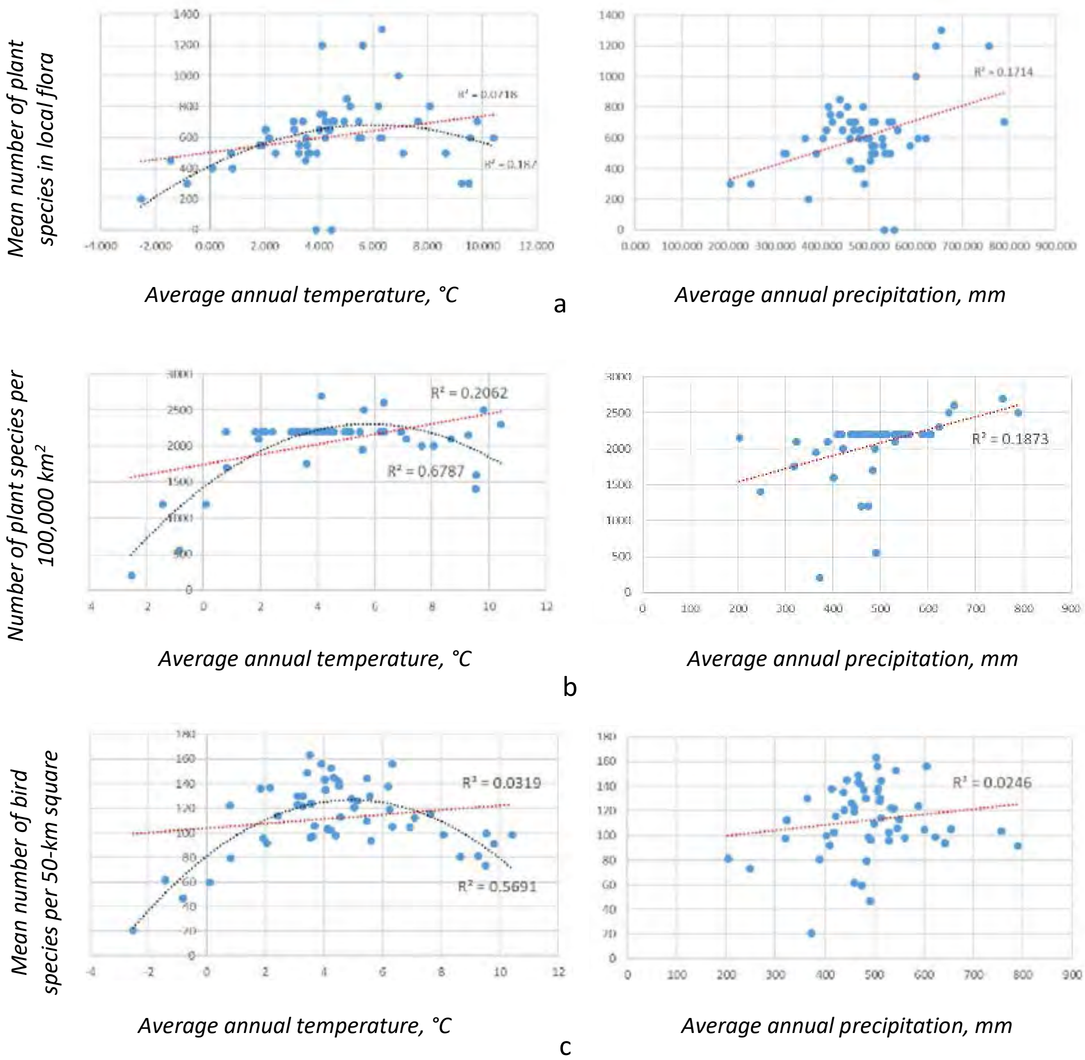


Figure 5.1.4.2. Relationships between biodiversity indicators and climate parameters for subjects of RF within European Russia: a) for mean number of plant species in local flora; b) for the number of plant species per 100,000 km²; c) for mean number of bird species per 50-km square.

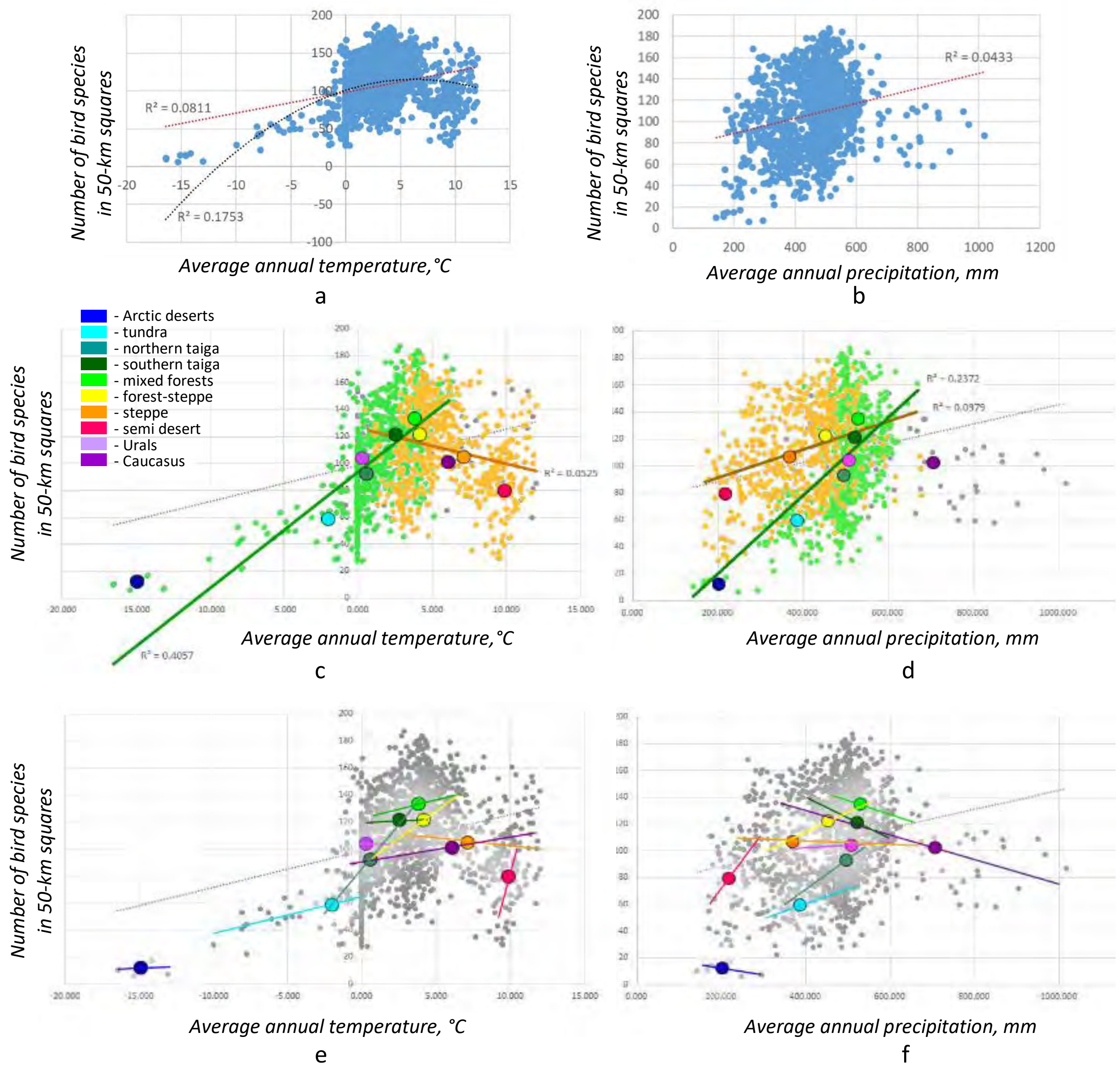


Figure 5.1.4.3. Relationships between bird species number in 50-km squares and average annual temperature (a, c, e) and average annual precipitation (b, d, f). Graphs "e" and "f" show relationships for individual ecoregions. On figures "c" and "d" the values and relationships for the group of northern, forest and mountain ecoregions are shown in green; the values and relationships for southern ecoregions are shown in orange. Average values for ecoregions are shown as circles, the color of which corresponds to the map in Fig. 2.2.1. Dependencies for the whole European Russia are shown by gray dotted lines.

Differences in the nature of the correlations between species number and temperature (the left column of the graphs in Fig. 5.1.4.2) and precipitation (the right column in Fig. 5.1.4.2) can be explained by the nature of the change in climatic conditions on the north-south gradient within European Russia. When moving from North to South, precipitation increases to the mixed forests, then decreases, while temperature monotonously increases (Fig. 5.1.4.1 a). This is also clearly visible for the relationship between precipitation and temperature for 50-km squares (Fig. 5.1.4.4) – in the group of northern, forest and mountain ecoregions, precipitation increases with temperature (blue points), in the southern group it decreases with temperature (brown points).

Later it will be necessary to analyze these results from the standpoint of the bioclimate optimum. Preliminary analysis shows that in flat ecoregions of European Russia the optimum of species diversity of birds and plants can be around 4–5 °C, that is, in ecoregions of mixed forests and forest-steppe. The patterns of distribution of species richness in mountain ecoregions require a separate analysis.

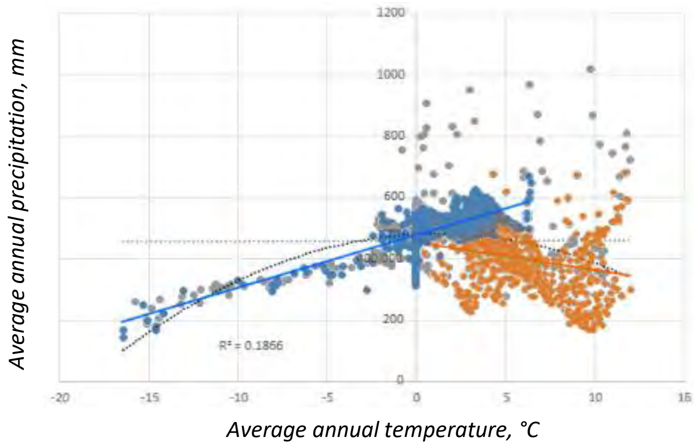


Figure 5.1.4.4. Relationships between climate parameters for 50-km squares within European Russia. Blue dots belong to the group of northern, forest and mountain ecoregions, brown dots belong to the group of southern ecoregions.

5.1.5. Climatic conditions – ecosystem functioning (phytomass, productivity)

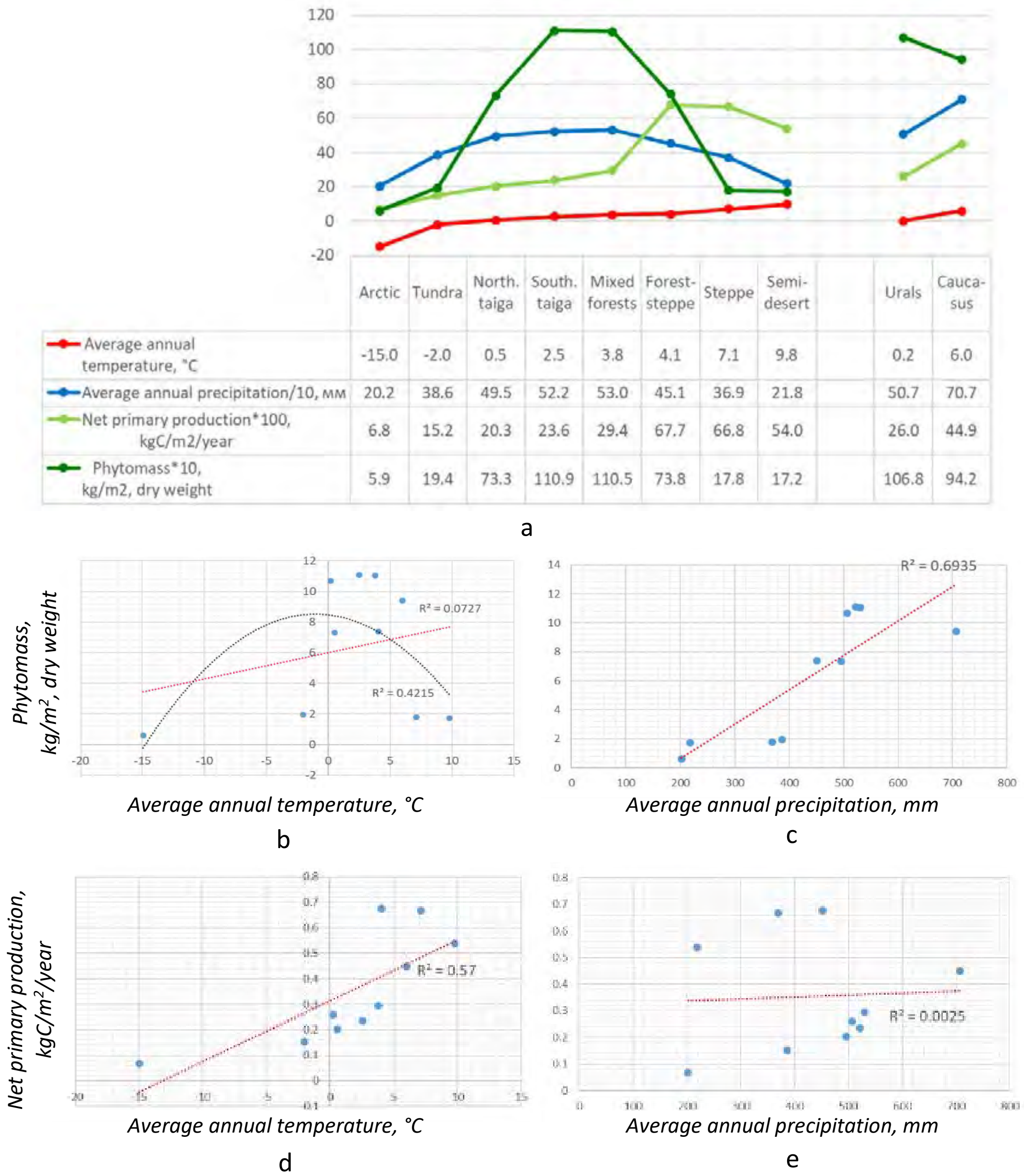
Total phytomass density (dry matter, kg/m^2) and net primary production (kgC/m^2/yr) (Section 3.1.3) are considered as indicators of ecosystem functioning. At all scales of analysis, phytomass and productivity depend on climatic parameters in the opposite way (Tab. 5.1.2.1–5.1.2.3, Fig. 5.1.5.1–5.1.5.3): for 50-km squares, phytomass depends positively on precipitation and does not depend on temperature; in contrast, productivity depends positively on temperature and does not depend on precipitation or depends on it negatively. Also, at all scales of analysis, a unimodal dependence is also revealed between phytomass and temperature, which is obviously determined by the maximum phytomass values of forest ecosystems in the ecoregions of southern taiga and mixed forests (Fig. 5.1.5.1 b; 5.1.5.2 a, 5.1.5.3 a). This unimodal dependence is similar to that for indicators of species richness (see Section 5.1.4).

The unimodal dependence of phytomass on temperature for the whole European Russia has a maximum at a temperature of about 2–4 °C. This dependence is formed due to a significant positive dependence of the phytomass on temperature in the group of northern, forest and mountain ecoregions and negative dependence in the group of southern ecoregions (Fig. 5.1.5.4 a, on left). The dependence of phytomass on precipitation is positive in both groups of ecoregions (Fig. 5.1.5.4 a, on right). Within individual ecoregions, the dependencies are multidirectional or absent (Fig. 5.1.5.4 b). In general, relationships between phytomass and climatic indicators are similar to relationships revealed for the number of bird species (Fig. 5.1.4.3). This indicates the likely similarity of the responses of species diversity and phytomass to changes in climatic parameters (in addition, a positive relationship is revealed between phytomass and bird species number, see Tab. 5.1.2.1–5.1.2.3 and Section 5.1.8).

The positive relationship between productivity and temperature for the 50-km squares within European Russia includes a slightly positive relationship for the group of northern, forest and mountain ecoregions and a “cloud” of values for southern ecoregions for which there is no relationship (Fig. 5.1.5.5 a).

A negative relationship was found between productivity and precipitation for the whole European Russia, but within the group of northern, forest and mountain ecoregions and within the group of southern ecoregions, this dependence is positive (Fig. 5.1.5.5 b). A negative dependence for the whole European Russia arises due to higher productivity in the group of southern ecoregions, even though precipitation in them is less than in forest ecoregions. This reflects the fundamental differences in the structure and functioning of forest and grass ecosystems in the northern and southern ecoregions (non-forest ecoregions of the Arctic deserts and tundra which are included in the group of northern, forest and mountain ecoregions in this research, further require special analysis).

Within the ecoregions, dependencies are multidirectional or absent (Fig. 5.1.5.5 b).



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Caucasus
Average annual temperature, °C	-15.0	-2.0	0.5	2.5	3.8	4.1	7.1	9.8		0.2	6.0
Average annual precipitation/10, мм	20.2	38.6	49.5	52.2	53.0	45.1	36.9	21.8		50.7	70.7
Net primary production*100, kgC/m2/year	6.8	15.2	20.3	23.6	29.4	67.7	66.8	54.0		26.0	44.9
Phytomass*10, kg/m2, dry weight	5.9	19.4	73.3	110.9	110.5	73.8	17.8	17.2		106.8	94.2

Figure 5.1.5.1. Mean values of climate parameters and indicators of ecosystem productivity and phytomass for ecoregions: a) change in mean values for ecoregions on the north-south gradient; b, c) relationships for phytomass; d, e) relationships for productivity.

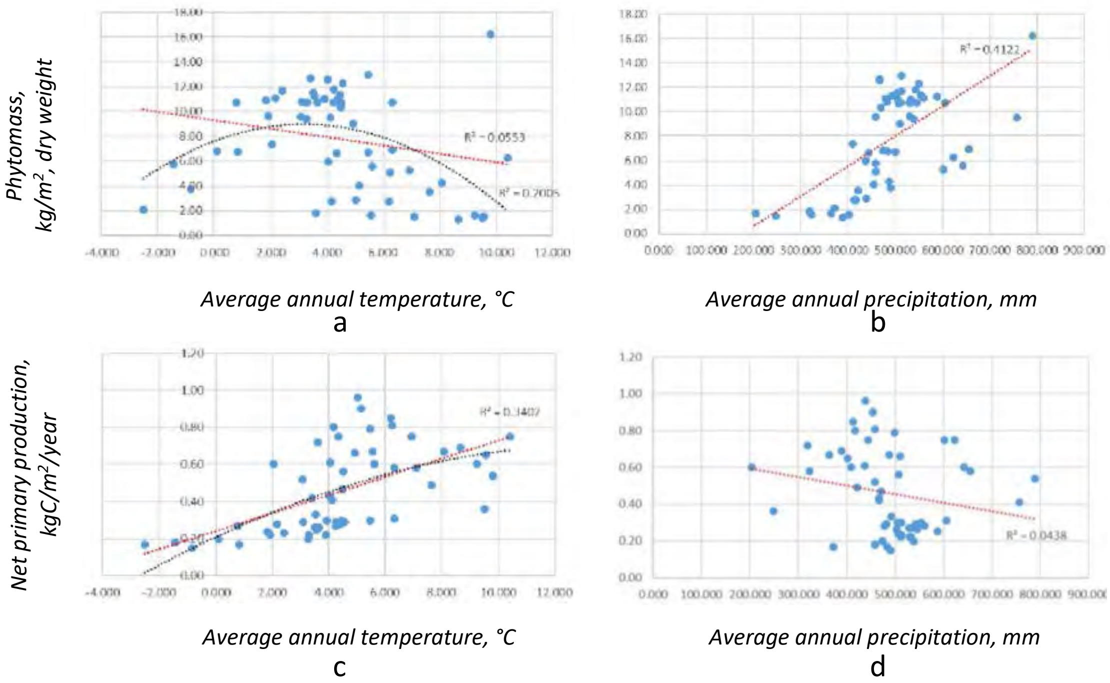


Figure 5.1.5.2. Relationships between climate parameters and indicators of ecosystem phytomass and productivity for subjects of RF within European Russia.

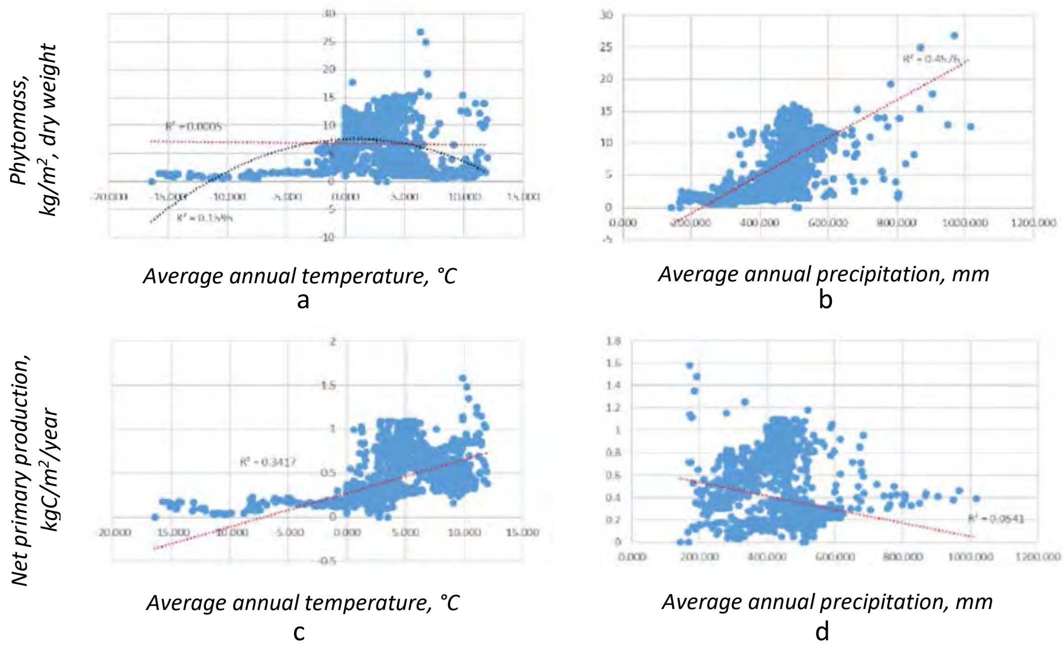


Figure 5.1.5.3. Relationships between climate parameters and indicators of ecosystem phytomass and productivity for 50-km squares within European Russia.

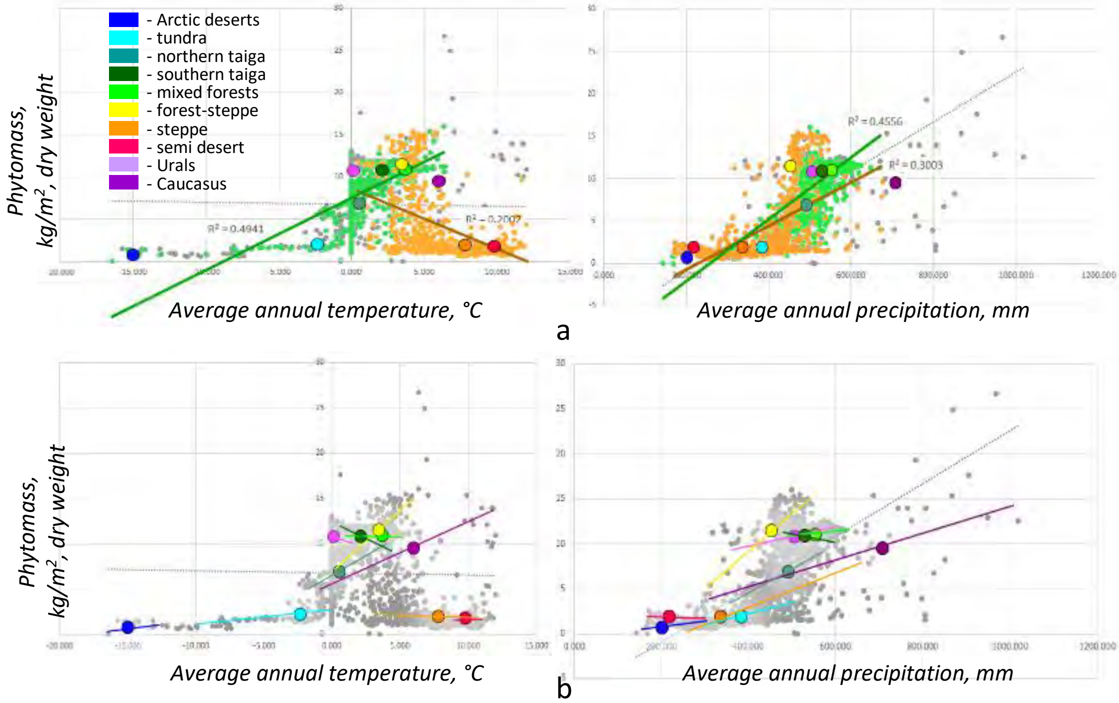


Figure 5.1.5.4. Relationships between phytomass and climate parameters for 50-km squares within European Russia: a) for the group of northern, forest and mountain ecoregions (green) and the group of southern ecoregions (orange); b) for individual ecoregions; mean values and relationships for individual ecoregions are shown in the colors corresponding the map in Fig. 2.2.1. Dependencies for the whole European Russia are shown by gray dotted lines.

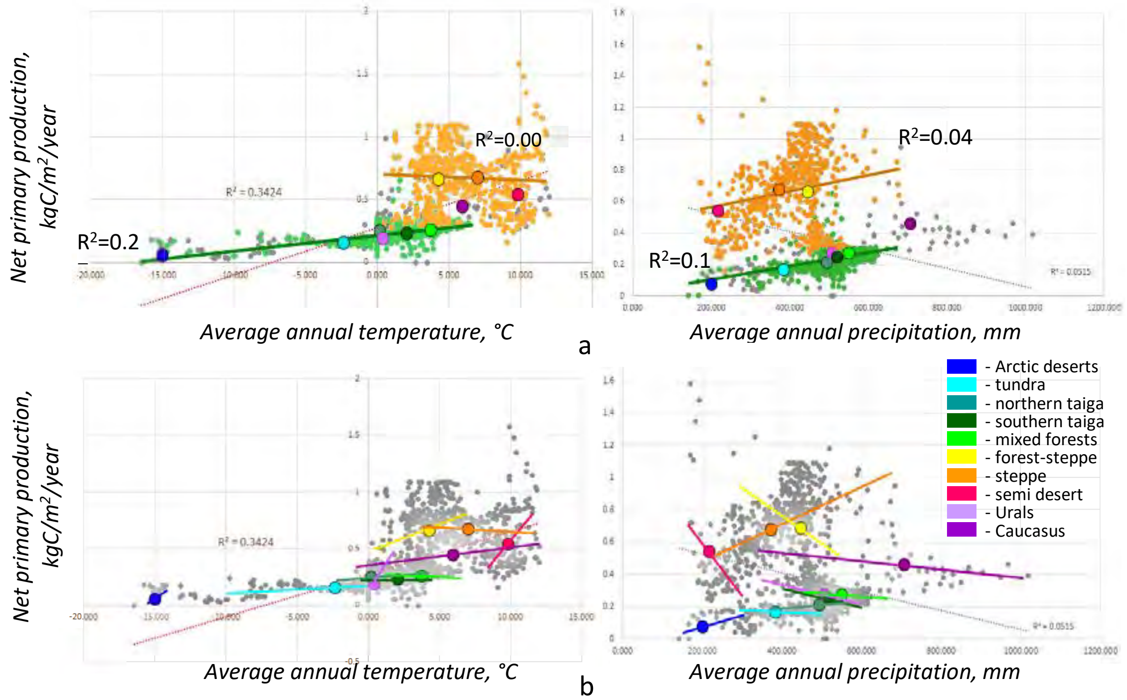
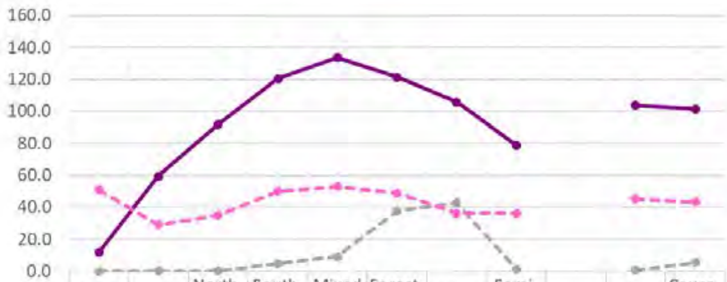


Figure 5.1.5.5. Relationships between productivity and climate parameters for 50-km squares within European Russia: a) for the group of northern, forest and mountain ecoregions (green) and the group of southern ecoregions (orange); b) for individual ecoregions; mean values and relationships for individual ecoregions are shown in the colors corresponding the map in Fig. 2.2.1. Dependencies for the whole European Russia are shown by gray dotted lines.

5.1.6. Degree of territory transformation – biodiversity

There are positive correlations between biodiversity indicators and the degree of territory transformation: for the mean number of bird species per square in the ecoregions (Tab. 5.1.2.1), for bird species number of in 50-km squares (Tab. 5.1.2.2) and for mean number of plant species in local flora for subjects of RF within European Russia (Tab. 5.1.2.3). In all other cases, there are no significant dependencies.

As noted above (Sections 5.1.1; 5.1.4), bird species richness increases from north to south to the mixed forest ecoregion, and then decreases (with the exception of the anomalously high value of mean share of registered in a square species of their total number in the ecoregion of Arctic deserts, see Section 3.2.3.2). Thus, bird species richness has maximum values in mixed forests, while the maximum degree of territory transformation is observed to the south – in the steppe and forest-steppe (Fig. 5.1.6.1 a). Nevertheless, a positive correlation is revealed between mean number of bird species per 50-km square for the ecoregions and the degree of territory transformation (Tab. 5.1.2.1, Fig. 5.1.6.1 b). For the indicator of the share of registered in a square species of their total number in the ecoregion positive correlation is not significant (Fig. 5.1.6.1 c). In both cases, unimodal dependencies are also detected (Fig. 5.1.6.1 b, c).



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Caucasus
Area share of transformed ecosystems, %	0.0	0.1	0.1	4.7	9.1	37.7	42.9	1.3		0.7	5.5
Mean bird species number per 50-km square	12	59	92	120	134	121	106	79		104	102
Share of registered in a square species of their total number in the ecoregion	51.1	29.1	34.9	50.0	52.9	48.7	36.3	36.3		45.1	43.2

a

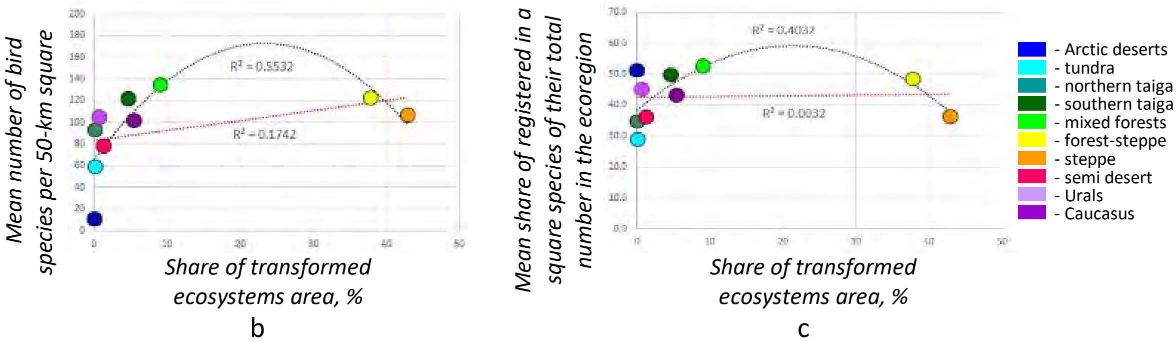


Figure 5.1.6.1. Mean values of indicators of bird species richness and degree of territory transformation for ecoregions: a) change in mean values of indicators for ecoregions on north-south gradient; b) relationship between mean bird species number per 50-km square in ecoregions and the degree of territory transformation; c) the same for the share of registered in a square species of their total number in the ecoregion. Mean values of indicators for ecoregions on graphs "b" and "c" are shown in the colors corresponding to the map in Fig. 2.2.1.

For subjects of RF, positive correlation is revealed for mean number of plant species in local flora within European Russia (Tab. 5.1.2.2; Fig. 5.1.6.2 a, b). Weak trends towards positive dependences are also noted for plant species number per 100 thousand km^2 for all subjects of RF (Fig. 5.1.6.2 c) and for mean number of bird species per 50-km square for subjects of RF within European Russia (Fig. 5.1.6.2 d), but they are not statistically significant.

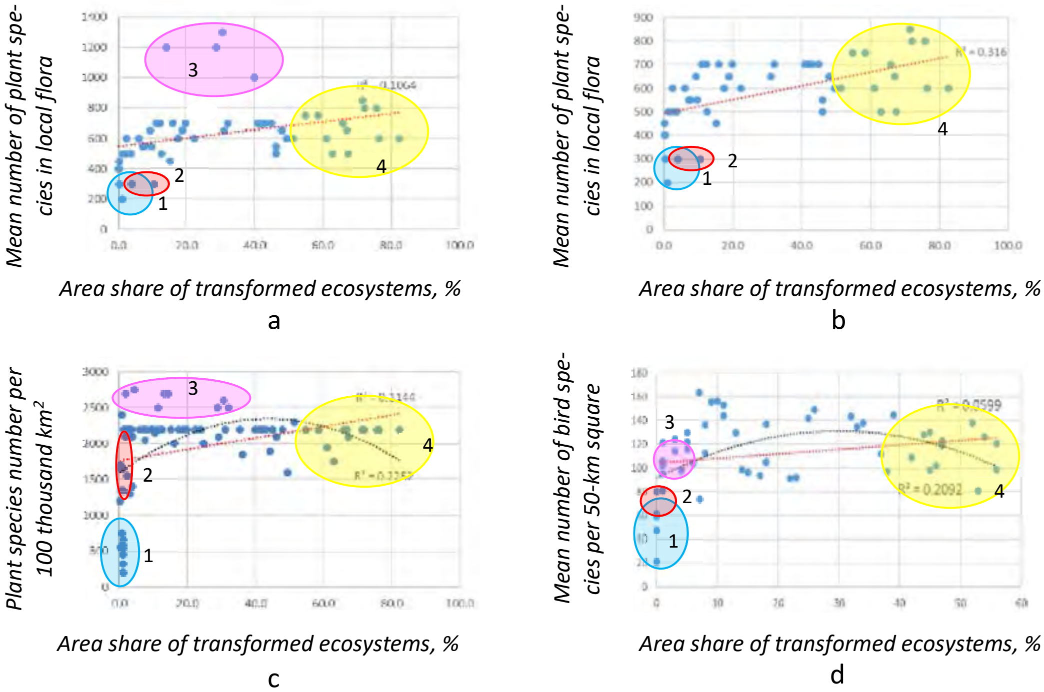


Figure 5.1.6.2. Relationships between biodiversity indicators and degree of territory transformation for subjects of RF: a) for mean number of plant species in local flora for all subjects of RF within European Russia; b) the same excluding montane regions; c) for plant species number per 100,000 km^2 in subjects of RF within the whole country; в) mean number of bird species per 50-km square for subjects of RF within European Russia. Figures indicate subjects of RF located mainly in the following ecoregions: 1 – tundra; 2 – semi-desert; 3 – montane; 4 – heavily transformed agricultural ecoregions.

The positive correlation between species richness and degree of territory transformation is counterintuitive. It seems that this dependence indicates that the more ecosystems are disturbed, the greater is species richness, although the opposite should be expected, namely, that the number of species should decrease in regions highly transformed by humans. However, on the scales studied, this positive correlation can only reflect the fact that the species richness of plants and birds, as well as the degree of territory transformation, increase in more favorable climatic conditions. Indeed, our data show that both the degree of territory transformation and species richness are positively related to the average annual temperature (see Sections 5.1.3, 5.1.4).

In general, species richness is the least in the northern and arid ecoregions, and the highest in the mountain, forest, and agricultural ecoregions. Subjects of RF, located mainly in the mountain regions, are characterized by a higher plant species richness compared to the flat regions, and at the same time, their territory is relatively weakly transformed (region 3 in Fig. 5.1.6.2 a, c). For flat territories (if we exclude from the analysis four subjects of RF located in the Caucasus mountain ecoregion – Ingushetia, Kabardino-Balkaria, Karachaevo-Cherkessia, North Ossetia-Alania), the positive correlation between species richness and the degree of territory transformation is enhanced – an example for mean number of plant species in local flora is shown in Fig. 5.1.6.2 b). However, such an increase in species number is not detected for birds – in the mountain ecoregions and in the subjects of RF located in them, bird species richness do not exceed those in the southern taiga, mixed forests, forest-steppe and steppe (Fig. 5.1.6.1 a; purple circles in Fig. .5.1.6.1 b, c; figure “3” in Fig. 5.1.6.2 d).

In addition to positive correlations, unimodal dependencies with maximum values of species richness at medium degree of territory transformation are also revealed at all scales of analysis (Fig. 5.1.6.1 b, c; 5.1.6.2; 5.1.6.3 a). The ascending branches of unimodal dependencies are formed by data from weakly transformed northern, forest, mountain, and arid ecoregions or subjects of RF located in these ecoregions, and the descending ones are formed by strongly transformed agricultural ecoregions or subjects of RF. In Fig. 5.1.6.3 an example is shown for bird species number in 50-km squares: the ascending branch of the unimodal curve (positive dependence) is formed by a group of weakly transformed ecoregions – northern, forest, mountain and semi-deserts (blue color in Fig. 5.1.6.3 b), and the descending (negative dependence) – by the most transformed forest-steppe and steppe ecoregions (red color in Fig. 5.1.6.3 b).

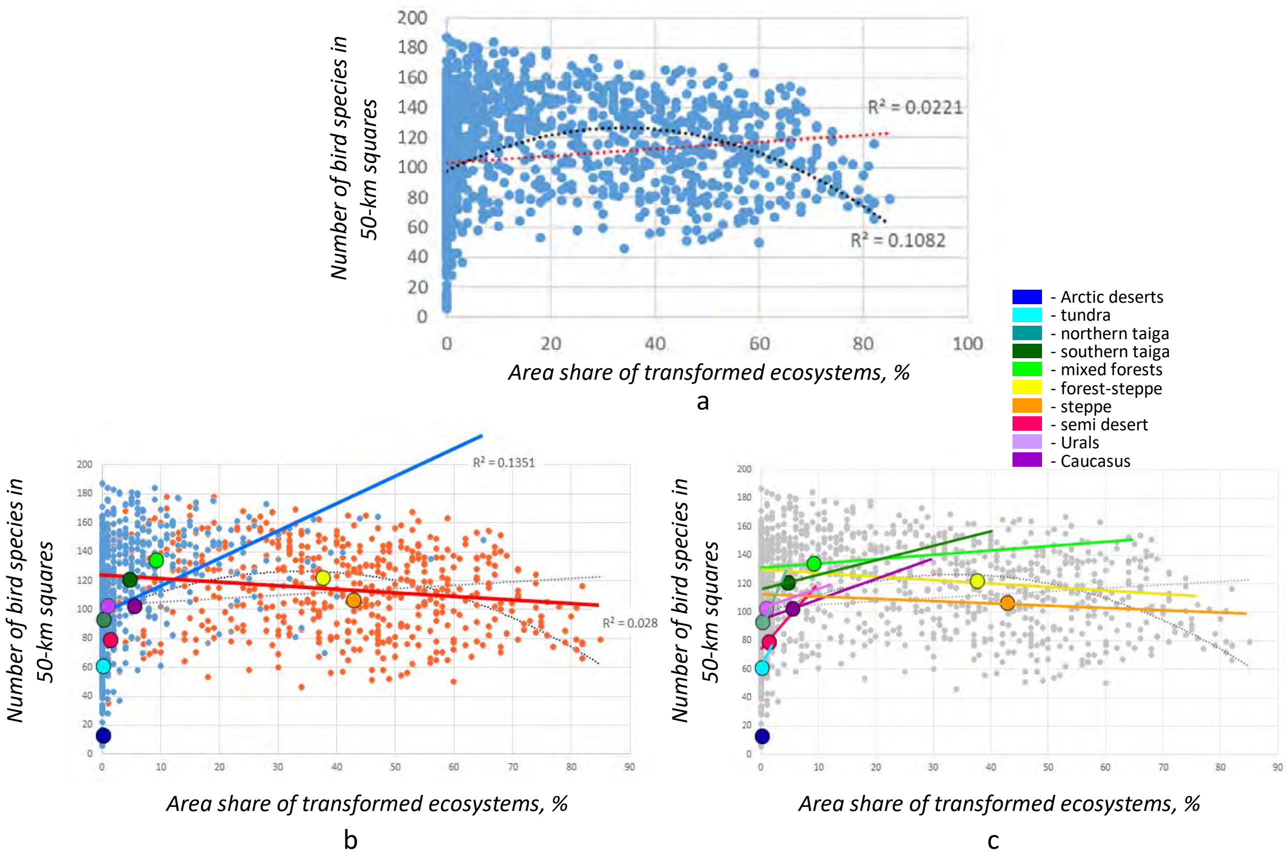


Figure 5.1.6.3. Relationships between bird species richness in 50-km squares and the degree of territory transformation: a) for the whole European Russia; b) for weakly transformed ecoregions (blue color) and strongly transformed ecoregions (red color); c) for individual ecoregions. The colors indicating mean values and dependencies for individual ecoregions correspond to the map in Fig. 2.2.1.

Thus, the unimodal relationship between species richness of plants and birds and the degree of territory transformation is universal for all scales of analysis. Ascending and descending branches of this unimodal dependence can be explained by the fact that in the group of northern, forest and mountain ecoregions the degree of their anthropogenic transformation and species richness simultaneously increase from north to south due to an increase in climate favorableness. In the agricultural ecoregions most transformed by humans, on the contrary, a tendency toward negative dependence is revealed, since there the degree of agricultural transformation of the territory depends on the climate to a lesser extent than in the more northern regions, and therefore negative anthropogenic impact on biodiversity begins to manifest itself more clearly. Moreover, the relationships between bird species number and the degree of anthropogenic transformation within individual ecoregions follow the same pattern – with an increase in the degree of transformation of the ecoregion, the positive dependence weakens at first and then becomes slightly negative (Fig. 5.1.6.4).

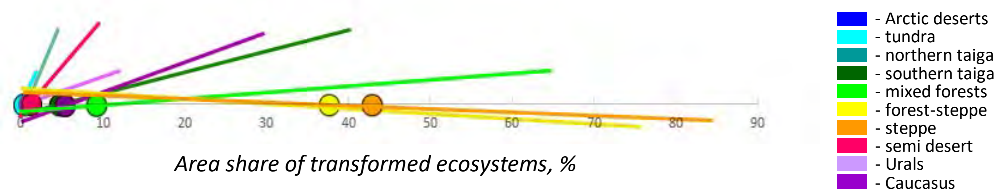


Figure 5.1.6.4. Change in the angle of inclination of dependencies within individual ecoregions with varying degrees of transformation of their territory. The colors representing the dependencies for individual ecoregions correspond to the map in Fig. 2.2.1.

The above examples show that in order to identify a causal relationship between biodiversity and the degree of transformation of territories, analysis is needed at the regional and local scales, when climatic conditions can be considered unchanged.

5.1.7. Degree of territory transformation – ecosystem functioning (phytomass, productivity)

Indicators of total phytomass density (dry matter, kg/m^2) and net primary production (kgC/m^2/yr) of natural ecosystems obtained from the database Land Resources of Russia (see Section 3.1.3) can be adjusted considering the degree of anthropogenic transformation of the territory, that is, in fact, the degree of plowing (see Section 3.1.1). At this stage of the study, we assume that all phytomass from cultivated areas is removed by humans, that is, it is not involved in ecosystem processes (the proportion of phytomass transferred from agricultural fields to ecosystems needs to be clarified in future estimates). With this assumption, adjusted phytomass and productivity can be obtained by multiplying values for natural ecosystems by the fraction of the area of natural ecosystems in the territorial units of analysis (50 km squares, constituent entities of the Russian Federation, ecoregions). For example, if natural ecosystems occupy only 50% of a square, then the adjusted productivity or phytomass in this square also makes up 50% of the value for natural ecosystems.

The adjusted phytomass is significantly reduced in the ecoregions of the southern taiga, mixed forests and steppes (the colored dots of the corresponding ecoregions below the "x = y" line in Fig. 5.1.7.1 a; the dark green dashed line in Fig. 5.1.7.2 a). Corrected productivity is significantly reduced in the ecoregions of the forest-steppe and steppe, the most plowed by humans (yellow and orange dots in Fig. 5.1.7.1 b; light green dashed line in Fig. 5.1.7.2 a). The adjusted productivity has maximum values in the semi-desert, the natural ecosystems of which are less plowed in comparison with the steppe and forest-steppe (Fig. 5.1.7.2 a).

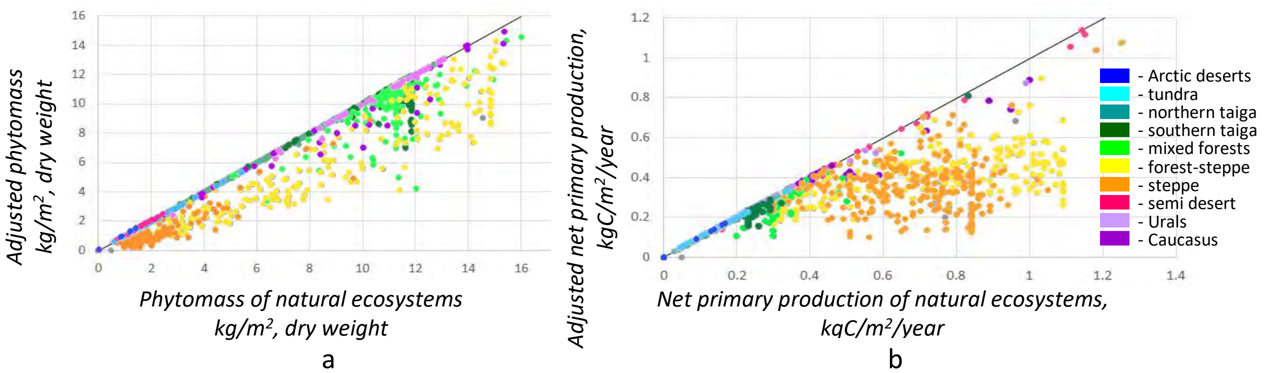
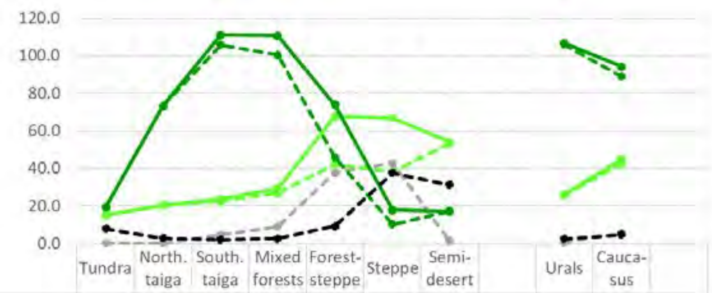


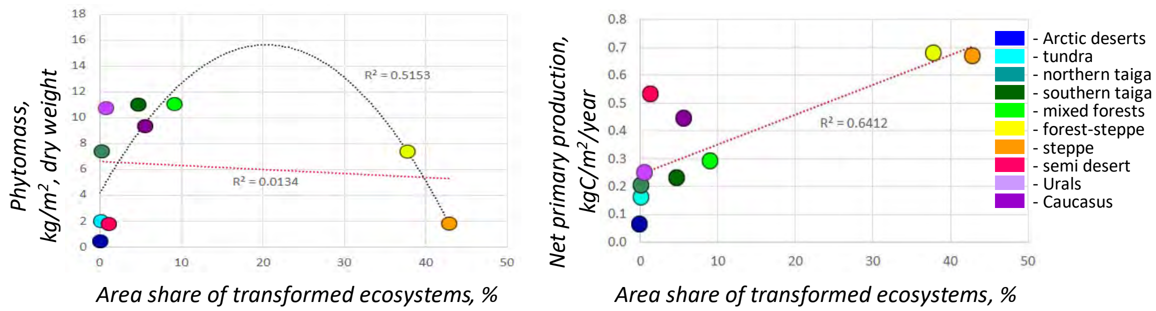
Figure 5.1.7.1. Dependencies for 50 km squares between indicators of phytomass (a) and productivity (b) for natural ecosystems and indicators adjusted for the degree of territory transformation.

Further in this section, only unadjusted indicators of productivity and phytomass of natural ecosystems are considered, since the task of the section is to analyze correlations between indicators of the functioning of natural ecosystems and the degree of territory transformation.



	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Caucasus
Area share of transformed ecosystems, %	0.1	0.1	4.7	9.1	37.7	42.9	1.3		0.7	5.5
Net primary production*100, kgC/m2/year	15.2	20.3	23.6	29.4	67.7	66.8	54.0		26.0	44.9
Adjusted net primary production*100, kgC/m2/year	15.2	20.3	22.5	26.7	42.1	38.2	53.3		25.8	42.4
Phytomass*10, kg/m2, dry weight	19.4	73.3	110.9	110.5	73.8	17.8	17.2		106.8	94.2
Adjusted phytomass*10, kg/m2, dry weight	19.4	73.2	105.7	100.4	45.9	10.2	17.0		106.1	89.0
Propuctivity/phytomass*100	7.8	2.8	2.1	2.7	9.2	37.5	31.3		2.4	4.8

a



b c

Figure 5.1.7.2. Mean values of indicators of ecosystem functioning and the degree of territory transformation for ecoregions: a) change in mean values of indicators for ecoregions on a north-south gradient; b, c) the relationship between phytomass and productivity of natural ecosystems and the degree of territory transformation. Mean values of indicators for ecoregions on graphs "b" and "c" are shown in the colors corresponding to the map in Fig. 2.2.1.

Either a negative correlation is revealed between the degree of territory transformation and phytomass of natural ecosystems (for 50-km squares and subjects of RF within European Russia, Tab. 5.1.2.2, 5.1.2.3, Fig. 5.1.7.3 a, 5.1.7.4 a), or its absence (for average values of indicators in ecoregions, Tab. 5.1.2.1, Fig. 5.1.7.2 b). A significant positive correlation is revealed between the degree of territory transformation and productivity of natural ecosystems for all three scales of analysis (Tab. 5.1.2.1–5.1.2.3; Fig. 5.1.7.2 c, 5.1.7.3 b, 5.1.7.4 b).

On the north-south gradient, the phytomass of natural ecosystems is maximal in the ecoregions of the southern taiga and mixed forests, while the productivity and the degree of territory transformation are maximal to the south – in the ecoregions of the forest-steppe and steppe (Fig. 5.1.7.2 a). An increase in the degree of territory transformation along with an increase in the productivity of natural ecosystems fully corresponds to the general pattern of more intensive agriculture in more productive ecoregions. The ratio of productivity to phytomass (i.e. production per unit of phytomass) is maximum in the most plowed steppe ecoregion. The negative correlation between the degree of territory transformation and phytomass can be explained by the fact that in agricultural regions the proportion of forest area, and, consequently, the average phytomass of ecosystems, is low.

A unimodal dependence is also revealed between the phytomass and the degree of territory transformation at all scales of analysis (Fig. 5.1.7.2 b, 5.1.7.3 a, 5.1.7.4 a). Slightly disturbed ecoregions (northern, mountainous, forest and semi-desert) form its ascending branch, and severely disturbed agricultural ecoregions (steppe and forest-steppe) form the descending one (Fig. 5.1.7.2 b; 5.1.7.5 a). An example for 50-km squares shows that for a group of slightly disturbed ecoregions (the blue color in Fig. 5.1.7.5 a, b) instead of a negative correlation, a positive one appears. This is because in these ecoregions the phytomass increases from north to south simultaneously with an increase in territory transformation and an increase in climate favorableness (Fig. 5.1.7.2 a). In the group of heavily transformed ecoregions (the red color in Fig. 5.1.7.5 a, b), the dependence remains negative, probably because the forest area has always been minimal in the most plowed areas. For individual ecoregions, dependencies are multidirectional or absent (Fig. 5.1.7.5 c). Dependencies between the productivity of natural ecosystems and the degree of territory transformation are everywhere positive (Fig. 5.1.7.5 b, d).

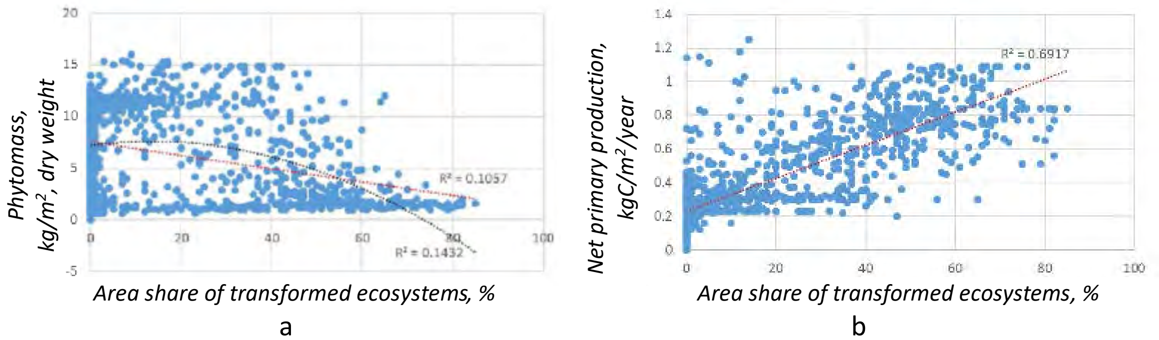


Figure 5.1.7.3. Relationships between the degree of territory transformation and indicators of phytomass (a) and productivity (b) for 50-km squares within European Russia.

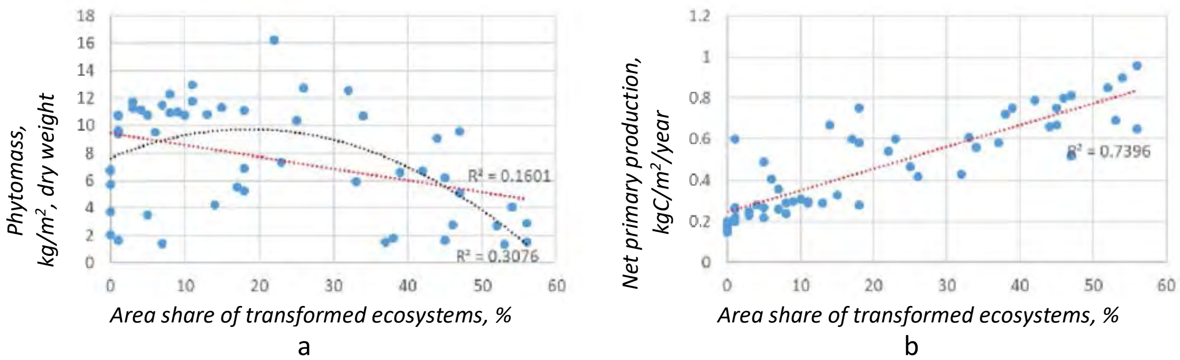


Figure 5.1.7.4. Relationships between the degree of territory transformation and indicators of phytomass (a) and productivity (b) for mean values of indicators for subjects of RF within European Russia.

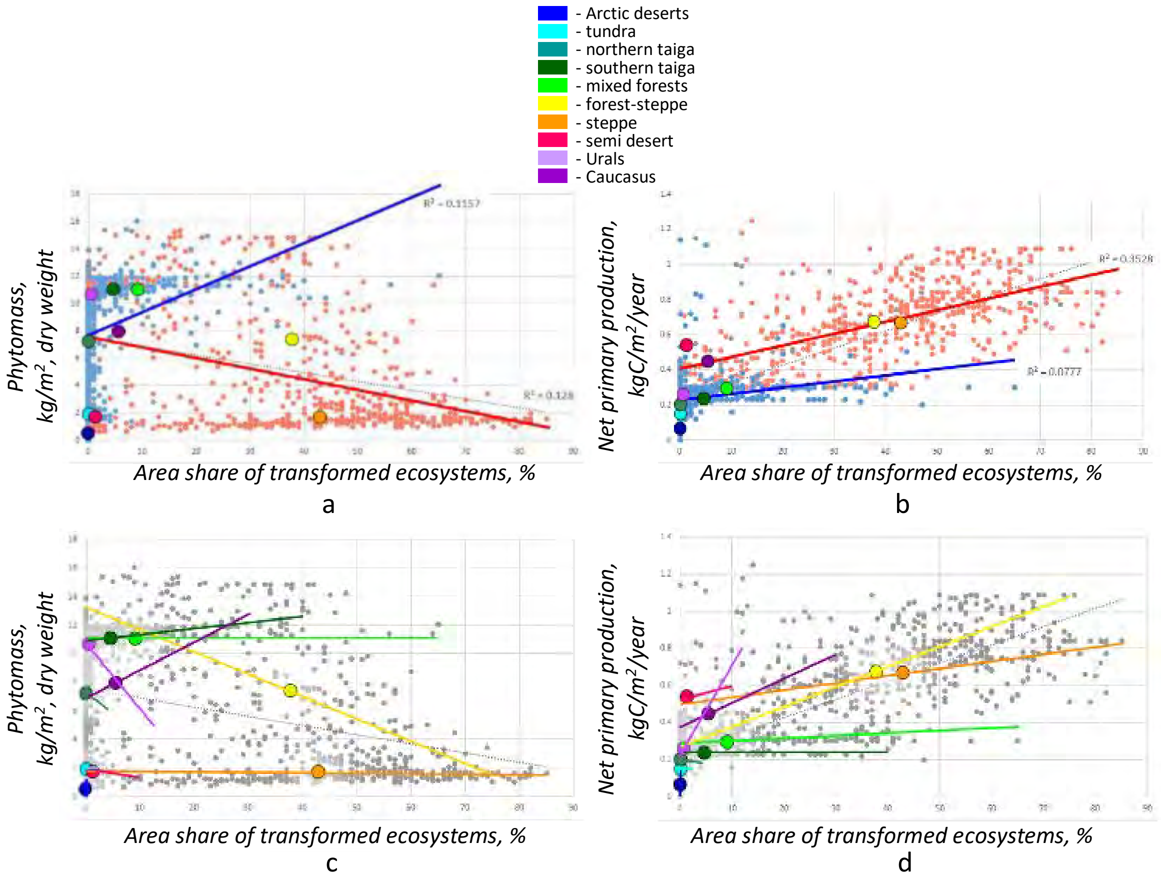
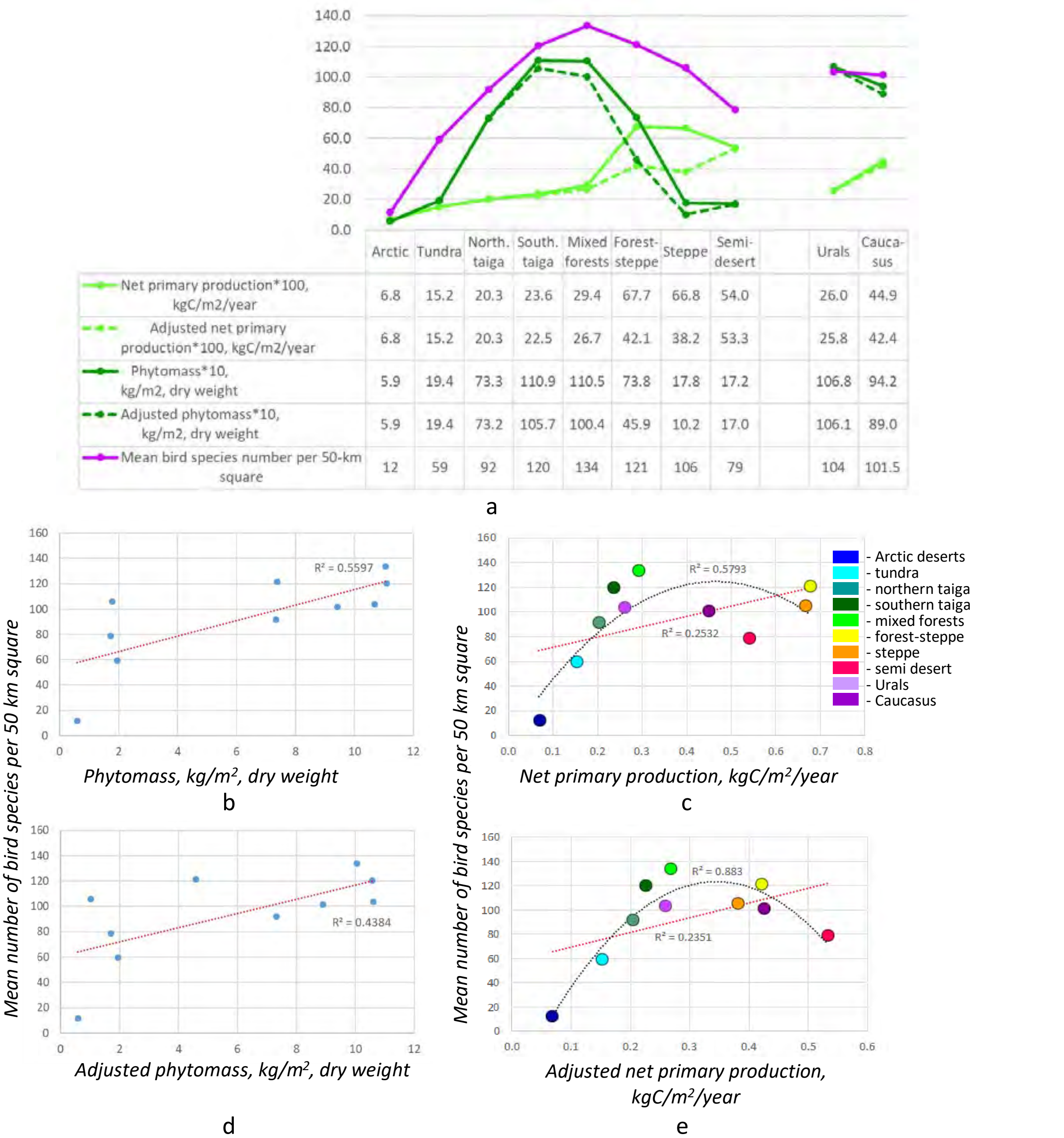


Figure 5.1.7.5. Relationships between the degree of territory transformation and indicators of phytomass (a, c) and productivity (b, d) for 50-km squares within groups of slightly and heavily transformed ecoregions (a, b) and for individual ecoregions (c, d). Blue color in graphs "a" and "b" denotes the group of slightly transformed ecoregions, red – heavily transformed ones. Circles denote mean values for ecoregions. The color of the circles and relationships for individual ecoregions on the bottom graphs correspond to the map in Fig. 2.2.1. Dependencies for the whole European Russia are shown by gray dotted lines.

5.1.8. Biodiversity – ecosystem functioning (productivity, phytomass)

Positive correlations are revealed between the indicators of species richness and the phytomass of natural ecosystems at all scales of analysis (Tab. 5.1.2.1–5.1.2.3, Fig. 5.1.8.1 b, 5.1.8.2 a, c, 5.1.8.3 a), except for mean number of plant species in local flora in subjects of RF, for which no significant dependence was found (Tab. 5.1.2.3, Fig. 5.1.8.2 e, g). Significant positive correlations between indicators of species richness and the productivity of natural ecosystems were revealed for indicators of plants species richness in subjects of RF and the number of bird species in 50-km squares (Tab. 5.1.2.2, 5.1.2.3; Fig. 5.1.8.2 d, f, h; 5.1.8.3 b), in other cases the dependences are statistically unreliable. As can be seen from Figures 5.1.8.1–5.1.8.3, relationships between the studied indicators are similar for all three scales of analysis. For bird species number in 50-km squares and the number of plant species per 100,000 km^2, correlations with phytomass are more pronounced than with productivity. The opposite is the case for plant species number in local flora.

The mean number of bird species per 50 km square for ecoregions has maximum values in ecoregions of southern taiga, mixed forests and forest-steppe (Fig. 5.1.8.1 a). This pattern is more similar to changes in the phytomass on the north-south gradient than to productivity which is maximum in the steppe and forest-steppe. Therefore, a statistically significant positive correlation with biodiversity indicators is detected for the phytomass (Fig. 5.1.8.1 b). For productivity, there is also a tendency to form a positive dependence, but in this case, it is rather unimodal with an ascending branch formed by a group of northern, forest and montane ecoregions and a descending one formed by a group of southern ecoregions (Fig. 5.1.8.1 c).



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert	Urals	Caucasus
Net primary production*100, kgC/m2/year	6.8	15.2	20.3	23.6	29.4	67.7	66.8	54.0	26.0	44.9
Adjusted net primary production*100, kgC/m2/year	6.8	15.2	20.3	22.5	26.7	42.1	38.2	53.3	25.8	42.4
Phytomass*10, kg/m2, dry weight	5.9	19.4	73.3	110.9	110.5	73.8	17.8	17.2	106.8	94.2
Adjusted phytomass*10, kg/m2, dry weight	5.9	19.4	73.2	105.7	100.4	45.9	10.2	17.0	106.1	89.0
Mean bird species number per 50-km square	12	59	92	120	134	121	106	79	104	101.5

Figure 5.1.8.1. Mean values of indicators for species abundance and ecosystem functioning in ecoregions: a) change in mean values on the north-south gradient; b, c) relationships between mean number of bird species per 50-km square and indicators of phytomass and productivity of natural ecosystems; d, e) the same for adjusted values of phytomass and productivity. Mean values of indicators for ecoregions on graphs "c" and "e" are shown in the colors corresponding to the map in Fig. 2.2.1.

For subjects of RF within European Russia, as mentioned above, either positive relationships or their absence was revealed between the analyzed indicators (Tab. 5.1.2.3, Figure 5.1.8.2). The exclusion from the analysis of 4 subjects of RF located in the Caucasian mountain ecoregion (Ingushetia, Kabardino-Balkaria, Karachay-Cherkessia, North Ossetia-Alania, highlighted in purple in Fig. 5.1.8.2 e, f) makes positive dependencies more pronounced. An example for mean number of plant species in local flora is shown in Fig. 5.1.8.2 "e", "g" and "f", "h". This is because these subjects of RF are characterized not by the highest values of phytomass and productivity, but by the maximum plant species richness. The resulting pattern is similar to that for the relationship between plant species richness and the degree of territory transformation (see Section 5.1.6, Fig. 5.1.6.2 a, b). However, for mean number of bird species per 50-km square in mountainous ecoregions this regularity does not appear (Fig. 5.1.8.1 a, c, e).

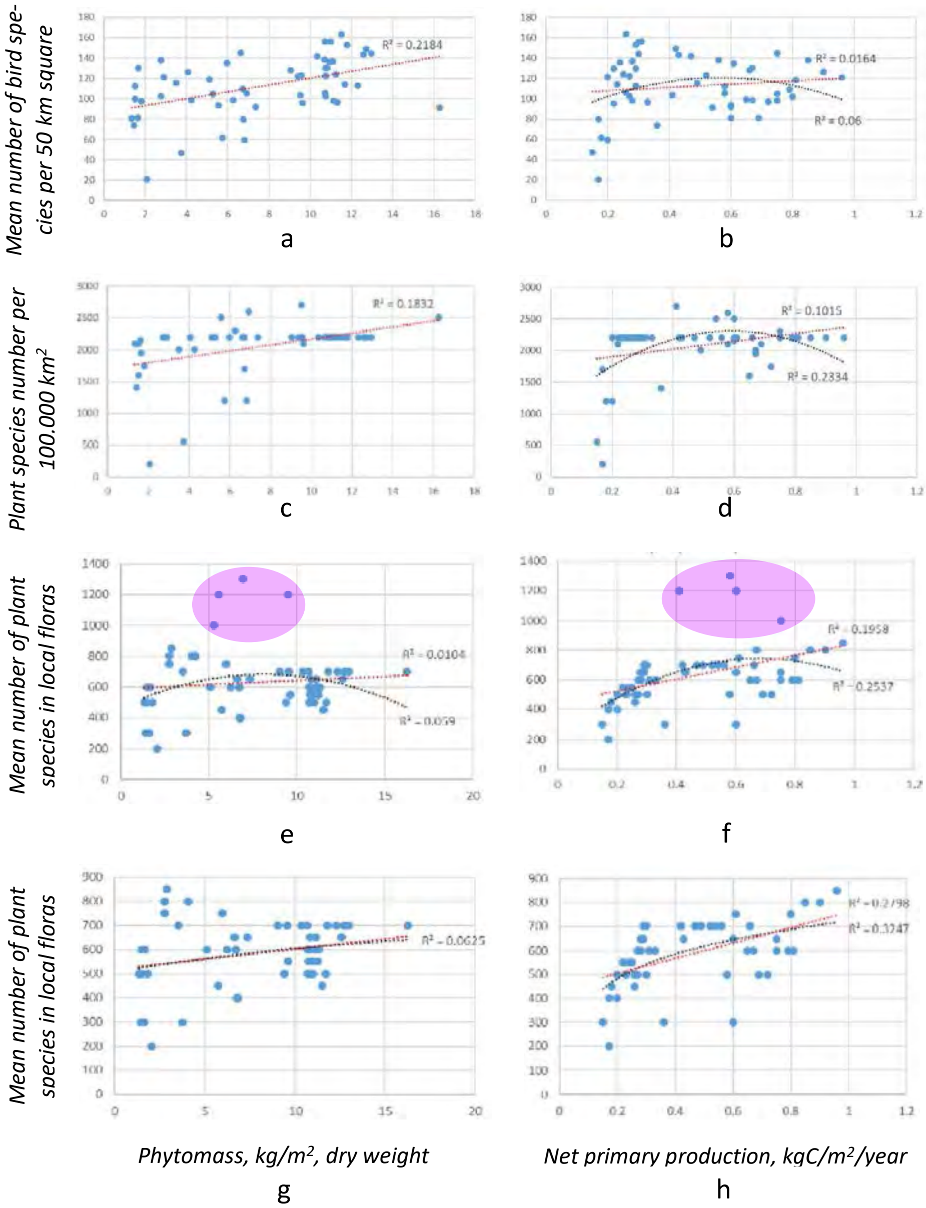


Figure 5.1.8.2. Relationships for average species richness and indicators of ecosystem functioning for subjects of RF: left column of graphs (a, c, e, g) – relationships between species richness and phytomass; right column of graphs (b, d, f, h) – relationships between species richness and productivity. Mountainous subjects of RF are highlighted in purple in graphs "e" and "f".

For 50-km squares, a positive relationship between the phytomass of natural ecosystems and bird species number is revealed (Fig. 5.1.8.3 a). A weak positive, but rather unimodal, dependence is revealed between the productivity and bird species number (Fig. 5.1.8.3 b).

Thus, revealed dependencies are similar for all scales of analysis: positive relationships are found between species richness and phytomass of natural ecosystems and positive or unimodal – between species richness and productivity.

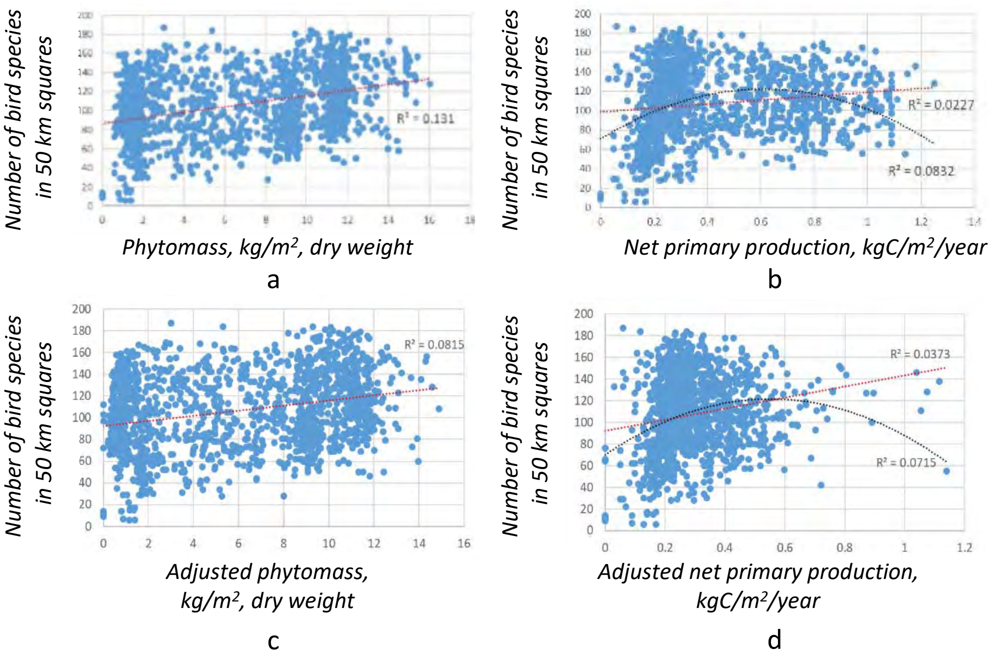


Figure 5.1.8.3. Relationships between bird species number in 50-km squares and indicators of ecosystem functioning: a, b) for phytomass and productivity of natural ecosystems; c, d) for adjusted values of phytomass and productivity.

A positive relationship between the phytomass of natural ecosystems and bird species number in 50-km squares remains within the group of northern, forest and mountain regions and within the group of southern ecoregions (Fig. 5.1.8.4 a). For productivity, the picture is not so uniform (Fig. 5.1.8.1 c, Fig. 5.1.8.4 b). The unimodal relationship between the productivity and bird species number includes an ascending branch formed by northern, forest, and mountain ecoregions (green color in Fig. 5.1.8.4 b) and a cloud of values without a pronounced dependence formed by southern ecoregions (orange color in Fig. 5.1.8.4 b). The positive relationships between bird species number and indicators of ecosystem functioning for the northern group of ecoregions are obviously explained by an increase in their values from north to south as climatic conditions improve. In the group of southern ecoregions positive dependency become weaker, and for productivity it disappears. Within individual ecoregions, the dependencies are multidirectional or absent (Fig. 5.1.8.4 c, d).

The use of adjusted phytomass and productivity indicators, which consider the degree of territory transformation (see Section 5.1.7), has little effect on revealed dependencies. For phytomass indicators, positive dependencies become slightly weaker, both for mean values in ecoregions (Fig. 5.1.8.1 d) and for values in 50-km squares (Fig. 5.1.8.3 c). For productivity indicators, positive and unimodal dependencies practically do not change or becomes slightly more pronounced (Fig. 5.1.8.1 e; 5.1.8.3 d). Dependencies revealed for the group of northern, forest, and mountain ecoregions and group of southern ecoregions also change little, despite the fact that productivity values for the two most transformed ecoregions (steppe and forest-steppe) move from the right end to the middle part of the dependence (compare Fig. 5.1 .8.4 a, b and Fig. 5.1.8.5 a, b).

Obviously, for more accurate valuation of the condition of ecosystem assets, actual phytomass and ecosystem productivity indicators are needed, which should reflect current changes in ecosystem condition.

It must be emphasized that the conclusion that the revealed correlations between biodiversity indicators and ecosystem functioning do not reflect causal relationships, but only correlations caused by a similar change in indicators in response to third factors, refers only to the national and subnational scales of analysis. At local and regional scales, biodiversity should be considered as a key factor in the functioning of ecosystems (see Section 6.1.3.1).

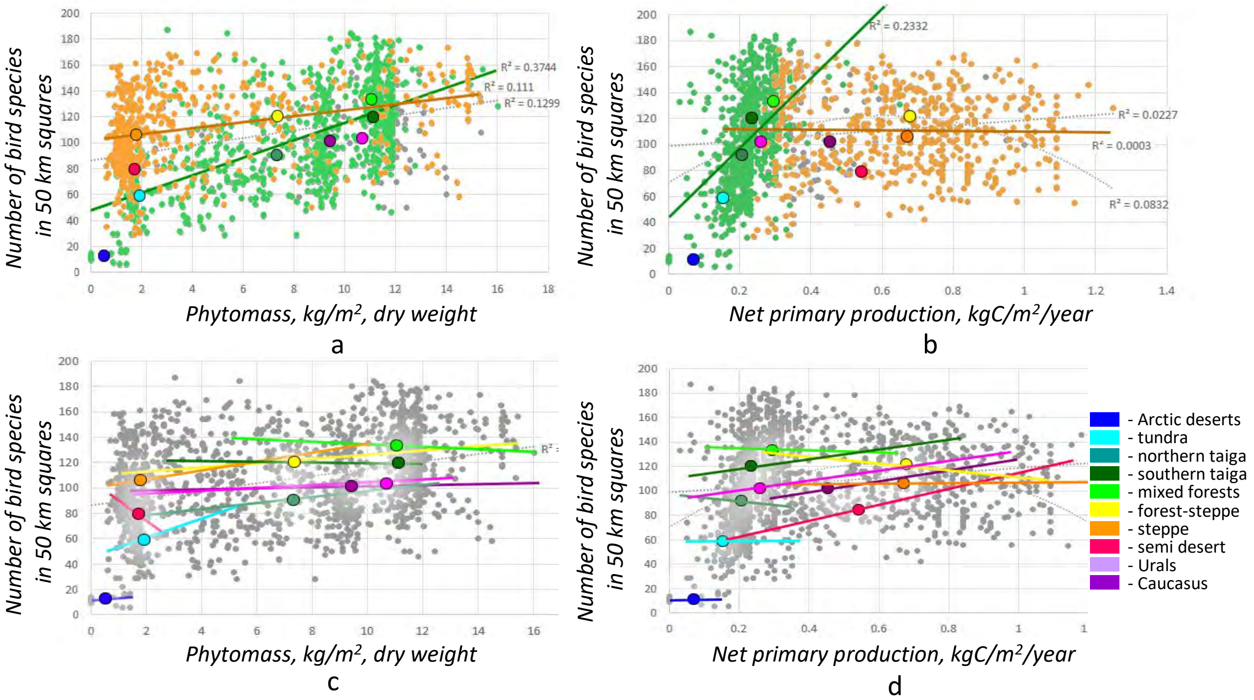


Figure 5.1.8.4. Relationships between bird species number in 50-km squares and indicators of phytomass (a, c) and productivity (b, d) of natural ecosystems: a, b) for the group of northern, forest and mountain ecoregions (green) and the group of southern ecoregions (orange); c, d) for individual ecoregions. Average values and dependencies for ecoregions are shown by colors corresponding to the map in Fig. 2.2.1.

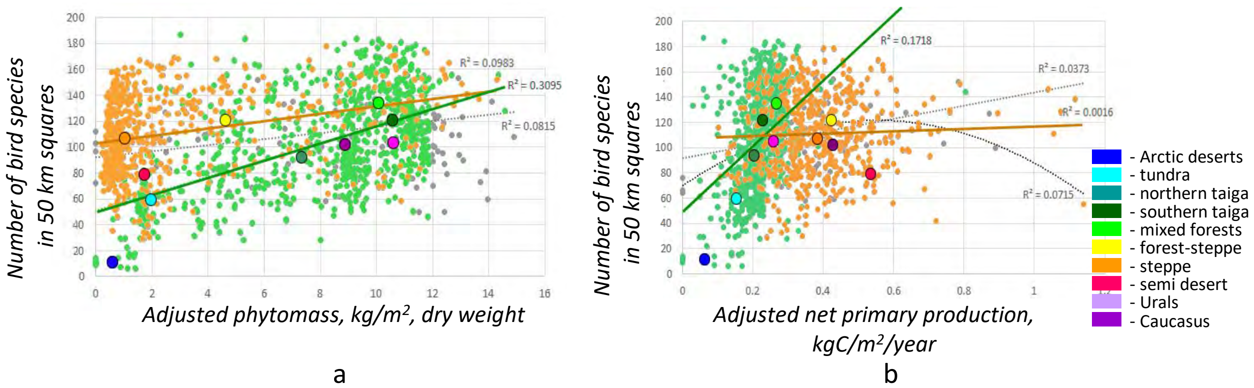


Figure 5.1.8.5. Relationships between bird species number in 50-km squares and adjusted indicators of phytomass (a, c) and productivity (b, d) for different ecoregions: a, b) for the group of northern, forest and mountain ecoregions (green) and the group of southern ecoregions (orange); c, d) for individual ecoregions. Average values and dependencies for ecoregions are shown by colors corresponding to the map in Fig. 2.2.1.

5.1.9. Phytomass – Productivity

Negative relationships were found between phytomass and productivity of natural ecosystems within European Russia for 50 km squares and subjects of RF (Tab. 5.1.2.2, 5.1.2.3, Fig. 5.1.9.1 a). A negative dependence (Fig. 5.1.9.1 b) was also detected for phytomass and productivity values, adjusted considering the degree of territory transformation (see Section 5.1.7).

Phytomass and productivity of ecosystems are key factors in determining the provided (potential) ES volume. For some ES, phytomass is primarily important (for example, for carbon storage, regulating the water cycle, purifying runoff, preventing soil erosion), and for others, productivity is primarily important (provisioning ES, carbon sequestration). Should the negative correlation between phytomass and productivity be considered the basis for a trade-off between these ES? Our analysis says no.

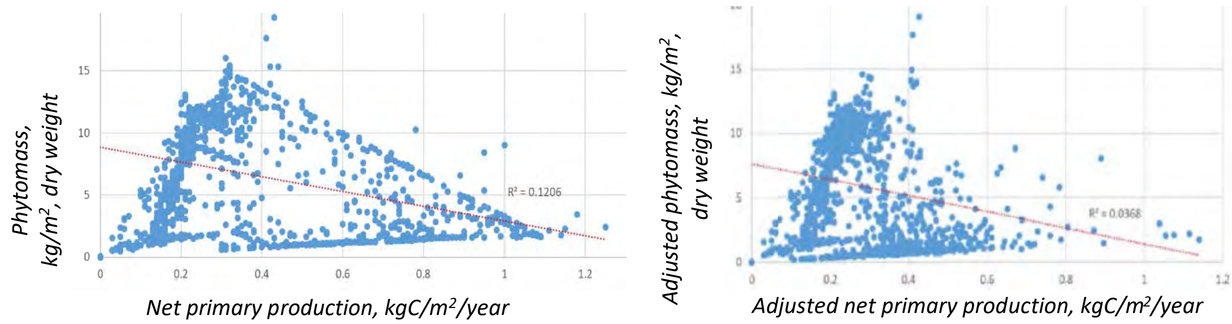


Figure 5.1.9.1. Relationships between phytomass and productivity for 50-km squares: a) for indicators of natural ecosystems; b) for indicators adjusted considering the degree of territory transformation.

The relationships between productivity and phytomass are different for three groups of flat ecoregions (mountain ecoregions are excluded from the analysis in this section): a) northern and forest ecoregions (green in Fig. 5.1.9.2); b) steppe and semi-desert (orange in Fig. 5.1.9.2); c) forest-steppe (yellow in Fig. 5.1.9.2). Within groups "a" and "b" positive dependencies were revealed, but with a different angle of inclination. For northern and forest ecoregions, the angle of inclination of the dependence is steeper than for the group including the steppe and semi-desert. This difference reflects the fundamental differences in the structure and functioning of forest and grassy ecosystems, which must be considered when assessing ES and ecosystem assets. The values of indicators for the ecoregions of the Arctic deserts and tundra (indicated by a blue circle in Fig. 5.1.9.2) in further analyzes can be assigned both to the group of northern and forest ecoregions, and to the group of grassy ecoregions.

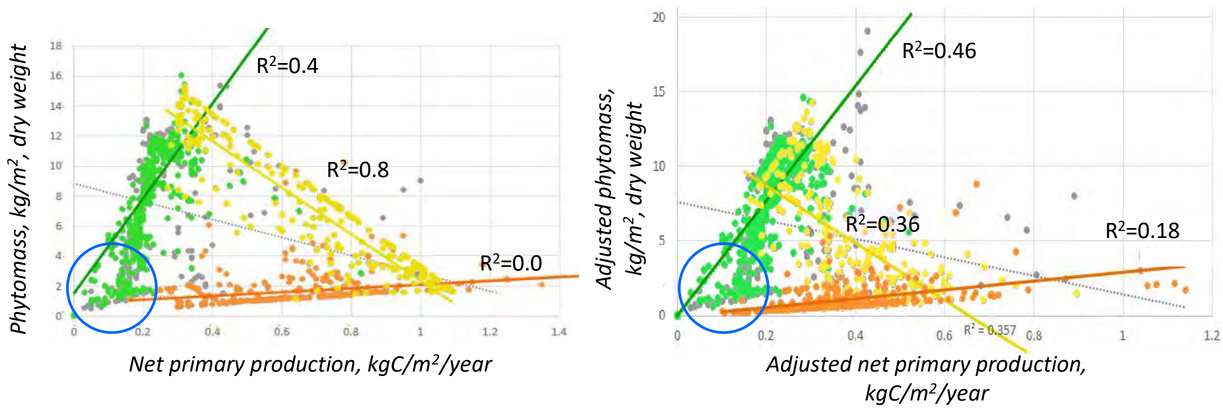


Figure 5.1.9.2. Relationships between phytomass and productivity for 50 km squares: a) for natural ecosystems; b) for indicators, adjusted considering the degree of territory transformation. The values for the group of northern and forest ecoregions are shown in green, the values for the steppe and semi-desert ecoregions are shown in orange, and for the forest-steppe ecoregion are shown in yellow. Blue circles highlight values for the Arctic deserts and tundra.

For the forest-steppe ecoregion, a negative relationship between phytomass and productivity was revealed, which forms the third side of the triangle on the general graph (yellow in Fig. 5.1.9.2). The formation of an almost straight outer side of this triangle for indicators of natural ecosystems (Fig. 5.1.9.2 a) can be explained by the fact that the forest-steppe ecoregion is a mosaic of forest and steppe plots and includes both almost completely forest squares (90% of the forest area) and completely treeless squares, as well as numerous intermediate variants. The values of indicators in forest squares are close to those in mixed forests, and the values in treeless squares are close to those in the steppe ecoregion. Squares with different ratios of forest and treeless areas are located on the line connecting these extreme values. The relationships for the adjusted indicators are similar, but the values for the forest-steppe and steppe ecoregions are significantly shifted towards lower values of productivity and phytomass due to the strong transformation of these ecoregions (Fig. 5.1.9.2 b).

Thus, the negative relationship between phytomass and productivity, revealed for the whole European Russia, does not reflect causal relationships, but is the result of a combination of data related to different groups of ecoregions. Within each of these groups, as mentioned above, the dependencies are positive, and a negative dependence is detected for the forest-steppe ecoregion for the above reasons. This pattern indicates that approaches to ecosystem management in forest and grassy ecoregions should be different. In the forest-steppe ecoregion, management approaches should be developed taking into account the spatial distribution and proportion of forest and treeless areas in target areas.

If squares transformed by man are dropped from the general sample for European Russia, the relationship between phytomass and productivity changes from negative to positive (Fig. 5.1.9.3). The squares of the forest-steppe and steppe ecoregions disappear from the samples, where squares with 90–100% of the area of natural ecosystems are represented.

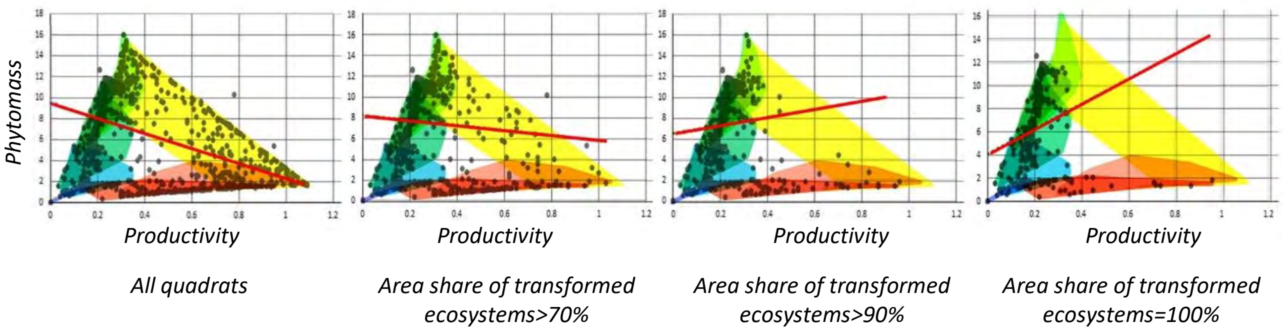


Figure 5.1.9.3. Change in the sign of the relationship between phytomass and productivity with the consecutive exclusion from the analysis of squares transformed by humans. The values for different ecoregions are highlighted in colors in accordance with the map in Fig. 2.2.1 and the graph in Fig. 5.1.9.5.

Values of phytomass and productivity, adjusted for the degree of territory transformation, are reduced in comparison with natural ecosystems. For productivity, this decrease is more significant (Fig. 5.1.9.4).

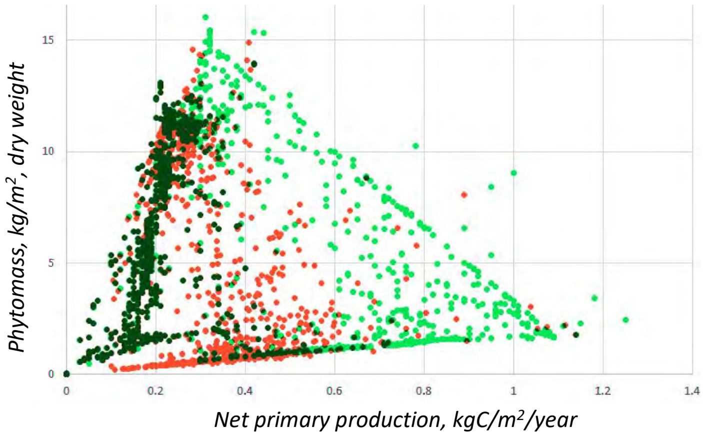
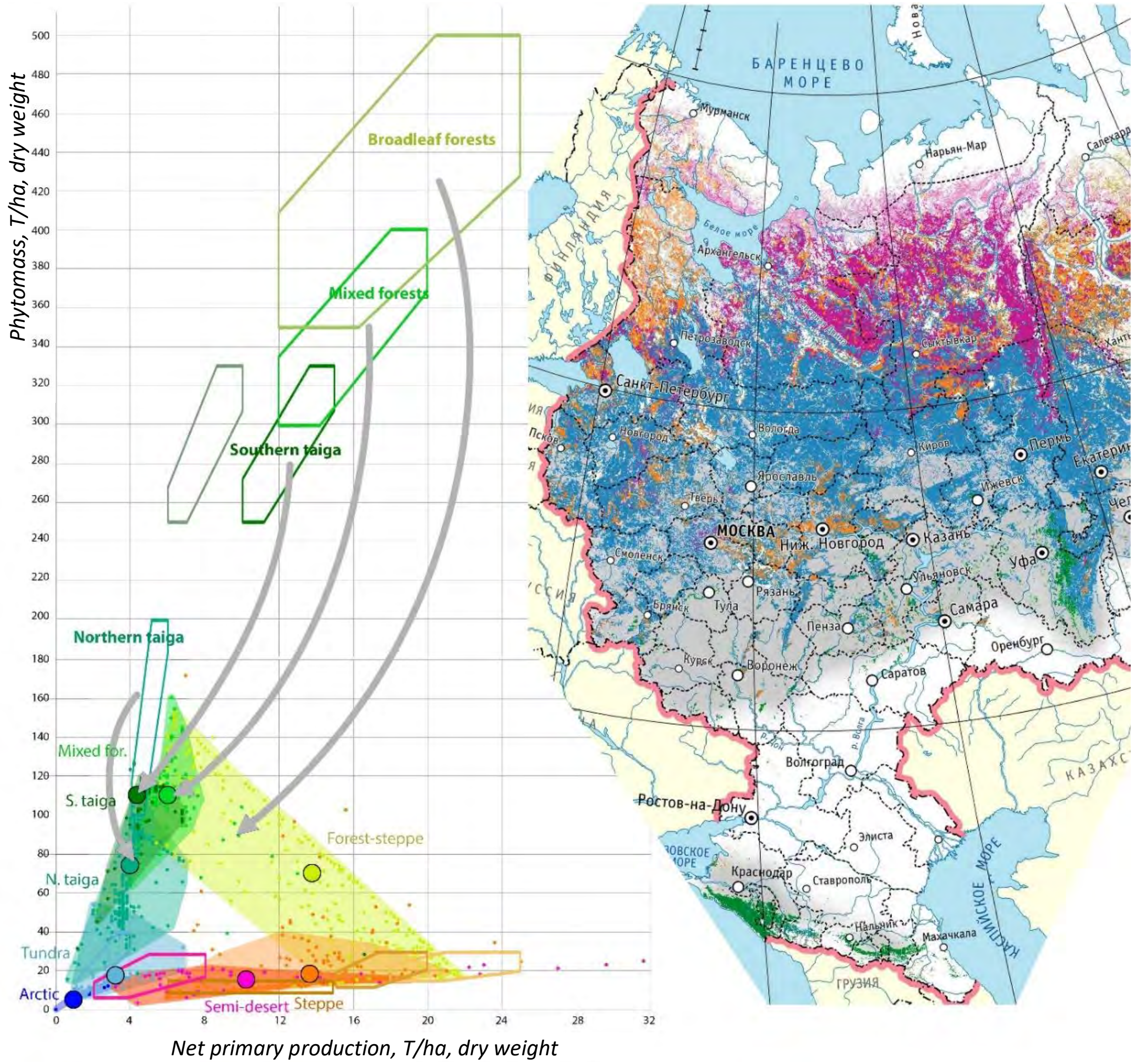


Figure 5.1.9.4. Comparison of phytomass and productivity indicators for natural ecosystems and the same indicators, adjusted for the degree of territory transformation: green dots – values for natural ecosystems, red – adjusted values, black – matching values.

Current values of phytomass of natural forest ecosystems are many times lower than values of climax communities according to A. A. Tishkov, 2005 (Fig. 5.1.9.5 a). The farther south the type of forest ecosystems is widespread, the more pronounced this difference. Obviously, before the transformation of territories by humans, not all communities were climax due to natural ecosystem disturbances, that is, the average phytomass values were lower than those characteristic of climax communities. However, the role of anthropogenic changes in ecosystems in the decrease in phytomass observed today is obvious. For taiga ecoregions, this is the result primarily of forest clearing for logging (i.e., the use of the provisioning ES of timber production). Due to forest felling, primary climax forests over most of these ecoregions have been replaced by secondary small-leaved forests, as is shown on the forest map (light blue on Fig. 5.1.9.5 b). The main factor of territory transformation in mixed forest ecoregion, and especially in forest steppe, is agriculture, as a result of which forests were replaced by farmlands. The gray on the forest map indicates the zone where forests can grow, but today are absent (Fig. 5.1.9.5 b). Anthropogenic transformation therefore substantially lowered phytomass and productivity of forest ecosystems. It can be assumed that these changes have led to a decrease in some important regulating ES.



a *b*

Figure 5.1.9.5. Probable changes in phytomass and productivity of ecosystems due to their anthropogenic transformation: a) current values of phytomass and productivity within European Russia and values for climax communities; b) fragment of the map of Russia's forests (Bartalev, et al., 2004). In the graph "a", values for different ecoregions are shown in the colors corresponding to the map in Fig. 2.2.1. Circles denote mean values for the ecoregions. Contour polygons show phytomass and productivity values for climax communities according to A.A. Tishkov (2005). Productivity values for 50 km squares are converted to dry weight for comparison with data on climax communities.

5.2. Indicators of ecosystem services and ecosystem assets

Relationships between ES and ecosystem asset indicators are analyzed in this section. Relationships between ES and climatic conditions have not been analyzed for the following reason. The provided (potential) volume of most ES does not depend directly on climate but is determined by the condition and functioning of ecosystems, that is, indicators of ecosystem assets. The latter, at this stage of research, are estimated on the base of indicators of territory transformation (an index inverse to area share of natural ecosystems), ecosystem functioning (productivity and phytomass of ecosystems), and biodiversity (species richness of birds and higher plants). Relationships between these indicators of ecosystem assets and climatic conditions were analyzed in Section 5.1. ES related to recreation, which are directly affected by the climate through human comfort, are the exception. This was considered in the methodology for valuating scores of certain recreation ES in TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018), but the ES scores were not used in the present research. Estimation of the recreational capacity of suburban forests in the present study (Section 4.1.7) is based on area of various ecosystem types in suburban zones and does not directly consider climate factors. Estimation of ES of air purification by suburban forests considers local meteorological conditions, but not the distribution of climatic parameters on the territory of European Russia. The only ES that directly depends on climatic conditions, namely, on average annual temperature, is pollination. The only ES that depends directly on climate, i.e., mean annual temperature, is the ES of pollination. Its dependence on climatic conditions is analyzed in Section 5.2.3.

Relationships between indicators were analyzed on three scales:

a) for mean values for ecoregions, which were calculated as mean values of indicators in 50-km squares within each ecoregion;
b) for values in 50 km squares within European Russia – the values of indicators of bird diversity are determined based on the actual number of bird species recorded in each 50-km square (see Section 3.2.3), the values of other indicators in squares are determined by GIS-methods (see Section 2.3);
c) for mean values for subjects of RF within European Russia or within the whole country — mean values of indicators of bird diversity are defined as mean values in 50-km squares within the territory of each subject of RF, mean values of other indicators within each subject are identified by GIS-methods (see Section 2.3).

On the first two scales, eight ES were analyzed, estimates of which were clarified in the TEEB-Russia 2 project (see Section 4.1):

– production of wood;
– carbon storage;
– air purification by suburban forests;
– regulation of runoff volume by terrestrial ecosystems;
– prevention of soil water erosion;
– pollination of farm crops by wild pollinators;
– creation of natural conditions for weekend recreation;
– the aesthetic value of ecosystems.

In addition to these eight ES, data of quantitative estimates of five other ES, which were obtained in TEEB-Russia 1 project were used for subjects of RF (the methods for estimates and the results are presented in the relevant sections of volume 1 of the Prototype National Report (Bukvareva, Zamolodchikov, 2018):

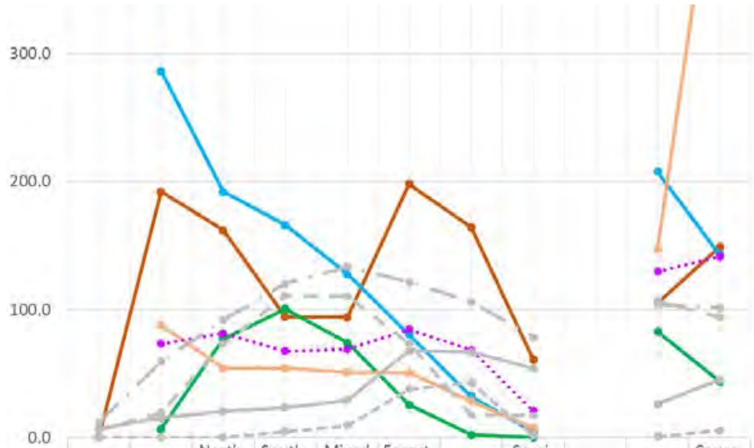
– non-wood production (mushrooms and berries),
– game production (exemplified by ungulates),
– production of livestock fodder at natural pastures,
– runoff quality assurance by terrestrial ecosystems,
– water purification in natural water bodies.

This section analyzes only indicators of provided (potential) ES volume, since consumed ES volume is largely determined by the socio-economic characteristics of the territories and should be analyzed simultaneously with them.

5.2.1. Mean values of indicators for ecoregions

All analyzed ES can be divided into two groups with respect to their spatial distribution: 1) ES that are provided by ecosystems throughout European Russia or the whole Russia; 2) ES that are provided in zones adjoining cities or croplands – pollination, air purification by suburban forests, weekend recreation (see Section 4.1.9).

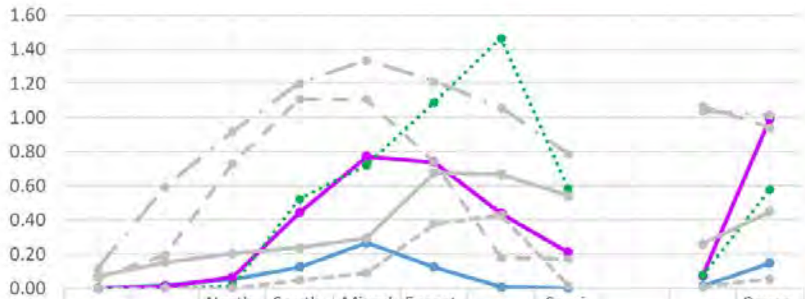
Mean for ecoregions values of indicators of ES from group 1 the estimates of which were clarifies in the TEEB-Russia 2 project, are shown in Figure 5.2.1.1. It shows that the ES of wood production expectedly peaks in forest ecoregions. The ES of runoff volume regulation (ecosystem runoff) and soil erosion prevention steadily decrease from north to south in plains ecoregions and increase in montane ecoregions, especially ES of erosion prevention. The ES of carbon storage has two prominent peaks in the north (in tundra and northern taiga), where carbon stocks are large in peat ecosystems, and in the south (in forest steppe and steppe), where black earth soils are carbon repositories. Aesthetic appeal index, that is a function of the landscape visual diversity and opportunities to view it, is highest in montane ecoregions and lowest in semideserts.



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Caucasus
Carbon stock in soil and phytomass, tC/ha	0.3	192.3	162.0	94.4	94.1	198.1	164.1	61.0		105.3	148.7
Wood stock, m3/ha		6.6	77.1	100.5	74.0	25.5	2.2	0.0		83.0	43.7
Runoff volume provided by terrestrial ecosystems/10, m3/ha/yr		286.4	192.3	166.0	127.6	80.7	32.0	4.5		208.0	142.7
Erosion prevented*100, t/ha		87.7	54.0	54.0	50.8	50.7	28.7	7.4		147.5	482.0
Aesthetic appeal index		73.2	81.4	67.5	68.9	84.5	68.3	20.8		129.6	141.5
Area share of transformed ecosystems, %	0.0	0.1	0.1	4.7	9.1	37.7	42.9	1.3		0.7	5.5
Net primary production*100, kgC/m2/year	6.8	15.2	20.3	23.6	29.4	67.7	66.8	54.0		26.0	44.9
Phytomass*10, kg/m2, dry weight	5.9	19.4	73.3	110.9	110.5	73.8	17.8	17.2		106.8	94.2
Mean bird species number per 50-km square	11.8	59.4	91.9	120.4	133.7	121.4	106.0	78.8		103.8	101.5

Figure 5.2.1.1. Changes in mean for ecoregions values of ES in group 1 (see the text for explanations) on the north-south gradient.

Mean for ecoregions values of indicators of ES from group 2 the estimates of which were clarifies in the TEEB-Russia 2 project, are shown in Figure 5.2.1.2. The methodologies for evaluating these ES used in the TEEB-Russia 2 project tie two of them – air purification by suburban forests and creating natural conditions for weekend recreation – to cities with a population greater than 100,000 (see Sections 4.1.3 and 4.1.7), while the ES of farm crop pollination by wild pollinators is tied to farm fields (see Section 4.1.6). This governs the pattern of change in mean values of these ES in the ecoregions. As Figure 5.2.1.2 shows, the pollination index is highest in the most-cultivated ecoregions of the steppe and forest steppe, while the ES of air purification and creation of recreation conditions are highest in the ecoregions of the southern taiga, mixed forests, forest steppe, and Caucasus ecoregion, where most cities are located within European Russia.



	Arctic	Tundra	North. taiga	South. taiga	Mixed forests	Forest-steppe	Steppe	Semi-desert		Urals	Caucasus
Absorption of dust and toxic gases from air, kg/ha/year	0.00	0.02	0.05	0.12	0.27	0.12	0.01	0.00		0.02	0.15
Recreational capacity, people/ha/year	0.00	0.01	0.06	0.44	0.77	0.74	0.44	0.21		0.07	0.99
Pollination index/10	0.00	0.00	0.02	0.52	0.72	1.09	1.47	0.58		0.08	0.58
Area share of transformed ecosystems, %	0.00	0.00	0.00	0.05	0.09	0.38	0.43	0.01		0.01	0.06
Net primary production*100, kgC/m2/year	0.07	0.15	0.20	0.24	0.29	0.68	0.67	0.54		0.26	0.45
Phytomass*10, kg/m2, dry weight	0.06	0.19	0.73	1.11	1.11	0.74	0.18	0.17		1.07	0.94
Mean bird species number per 50-km square	0.12	0.59	0.92	1.20	1.34	1.21	1.06	0.79		1.04	1.02

Figure 5.2.1.2. Changes in mean for ecoregions values of ES in group 2 (see the text for explanations) on the north-south gradient.

5.2.2. Correlations between indicators of ES and ecosystem assets

Correlation coefficients between indicators of ecosystem services and assets for three analyzed scales are presented in tables 5.2.2.1–5.2.2.3. For numerical indicators, the Pearson correlation coefficient was used, for point indicators (indices of aesthetic value of ecosystems, pollination index), the Spearman coefficient was used.

In the first group of ES, which are provided by ecosystems throughout European Russia or the whole country, we can distinguish a group of ES, to some extent related to the forest – wood production (wood stock, Tab. 5.2.2.1–5.2.2.3), non-wood (mushrooms and berries stocks) and game production (ungulate populations number, Tab. 5.2.2.3), the ES of soil erosion prevention (Tab. 5.2.2.2). These ES have a positive correlation on all scales of analysis (although it is not statistically reliable everywhere) with area share of forests and phytomass of ecosystems, and a negative correlation – with the degree of territory transformation and productivity of ecosystems. Similar correlations are also found for water-related ES (regulation of runoff and runoff quality assurance by terrestrial ecosystems, water purification by aquatic ecosystems, Tab. 5.2.2.1–5.2.2.3). However, in this case, revealed dependencies are rather the result of unidirectional correlations of indicators of ES and ecosystem assets with climatic conditions and surface runoff that largely govern the provided volume of water-related ES. In addition to ES mentioned, the indicator of the aesthetic value of ecosystems for 50-km squares also behaves in a similar way (Tab. 5.2.2.2).

The ES of carbon storage and fodder production in natural pastures behave in a manner opposite that of forest-related ES. Carbon storage in European Russia is to a large degree associated with the black earth soils of agricultural regions (along with the peat ecosystems of northern regions – see the map in Fig. 4.1.2 a). Therefore, this ES positively correlates with the degree of territory transformation and ecosystem productivity and negatively with the share of forest area and phytomass (Tab. 5.2.2.2, 5.2.2.3, for ecoregions, correlations are unreliable). The ES of natural fodder production behaves in a similar way, since it is associated with grassland ecosystems, but this ES has no relationship to the degree of territory transformation, since it is not associated with regularly plowed fields (Tab. 5.2.2.3).

ES in the second group (which are provided in zones adjoining cities and farmlands) are positively related to the degree of territory transformation and productivity, or there is no correlation. The positive correlations in this case are obviously explained by the fact that these ES “operate” primarily in territories with a fairly high population density, that is, in significantly transformed regions. The pollination potential on all three scales of analysis is most closely associated with the degree of territory transformation and with productivity, which are highest in agricultural regions (Tab. 5.2.2.1–5.2.2.3, Fig. 5.2.1.2). The ES of air purification and creation of conditions for recreation, in addition to the correlations mentioned above, are also positively related to the phytomass (or there is no correlations), since their provided volume within suburban zones substantially depends on the forest area (see Sections 4.1.3 and 4.1.7) .

Table 5.2.2.1. Correlation coefficients between the mean for ecoregions values of indicators of ecosystem condition, biodiversity and ES (the Arctic desert ecoregion is excluded from the analysis).

Group	Services	Productivity	Phytomass	Share of forest area	Mean bird species number per square	The degree of territory transformation
1	Wood stock	–.317	.910**	.961**	.594	–.297
	Reg. runoff volume	–.860**	.291	.476	–.307	–.566
	Erosion prevention	–.077	.419	.148	.065	–.226
	Carbon stock	.413	.142	.062	.458	.479
	Aesthetic value	.248	.467	.608	.273	.212
2	Pollination	.936**	.170	–.119	.729*	.960**
	Recreation	.557	.504	.009	.660*	.445
	Air purification	.069	.716*	.333	.659*	.083

*** p<0.01; * p<0.05; n=10*

Table 5.2.2.2. Correlation coefficients between actual values of indicators of ecosystem condition, biodiversity and ES in 50-km squares.

Group	Services	Productivity	Phytomass	Share of forest area	Bird species number in squares	The degree of territory transformation
1	Wood stock	–.525**	.676**	.877**	.103**	–.571**
	Reg. runoff volume	–.601**	.237**	.500**	–.182**	–.606**
	Erosion prevention	–.100**	.145**	.068**	–.055*	–.167**
	Carbon stock	.183**	–.244**	–.147**	–.079**	.177**
	Aesthetic value	.022	.195**	.260**	–.004	–.006
2	Pollination	.811**	–.003	–.450**	.369**	.868**
	Recreation	.154**	.165**	–.102**	.278**	.127**
	Air purification	–.022	.131**	.030	.186**	–.014

*** p<0.01; * p<0.05; n from 1396 to 1652 depending on indicators*

Table 5.2.2.3. Correlation coefficients between the mean for subjects of RF values of indicators of ecosystem condition, biodiversity and ES within European Russia.

Group	Services	Productivity	Phytomass	Share of forest area	Mean number of species in local flora	Number of species of plants per 100,000 km²	Mean bird species number per square	Degree of territory transformation
1	Wood stock	–.516**	.600**	.581**	.232	.287*	.278*	–.466**
	Mushroom stock	–.669**	.317*	.756**	–.397**	–.389**	–.137	–.550**
	Berry stock	–.462**	.036	.483**	–.343*	–.394**	–.341*	–.408**
	Ungulate population	–.172	.498**	.211	.205	.380**	.469**	–.177
	Reg. runoff volume	–.644**	.386**	.608**	–.040	–.191	–.309*	–.593**
	Runoff purification	–.763**	.325*	.779**	–.325*	–.368**	–.293*	–.733**
	Water purification	–.530**	.344*	.513**	.159	–.091	–.276*	–.570**
	Erosion prevention	.078	.088	–.019	.676**	.328*	–.144	–.073
	Fodder production	.331*	–.583**	–.477**	.237	–.144	–.325*	.133
	Carbon stock	.586**	–.409**	–.458**	.135	–.201	–.132	.668**
2	Pollination	.701**	–.161	–.514**	.371**	.097	.312*	.813**
	Recreation	.221	.306*	–.002	.485**	.483**	.325*	.140
	Air purification	.060	.191	.118	.093	.262	.242	.076

*** p<0.01; * p<0.05; n=54*

Among the revealed correlations of ES indicators with indicators of species richness, positive correlations with indicators of group 2 ES are noteworthy (Tab. 5.2.2.1–5.2.2.3). These positive relationships can be explained by the simultaneous increase in species richness and the degree of territory transformation with the improvement of climatic conditions on the north-south gradient (see Section 5.1.6). Wood stock positively correlates with some biodiversity indicators, – in cases when biodiversity indicators values, as well as wood stock are maximum in forest ecoregions (Fig. 5.2.1.2). Water-related ES correlate negatively with species richness, which is explained by the decrease in these ES from north to south, while species richness rises overall (see Section 5.2.4).

5.2.3. Degree of territory transformation – ecosystem services

As noted in Section 5.2.2, among ES that are provided by ecosystems throughout European Russia, the nature of correlations with the degree of territory transformation distinguishes ES related to some extent to the forest (wood, non-wood and game production, water-related ES, soil erosion prevention) and ES associated with non-forest ecosystems (livestock fodder production on natural pastures and carbon storage).

The "forest" ES on all three scales of analysis have, in most cases, negative correlations with the degree of territory transformation and positive ones with the share of forest area, or there are no statistically reliable correlations (Tab. 5.2.2.1–5.2.2.3). Examples of correlations for provisioning ES are shown in Fig. 5.2.3.1 and 5.2.3.2; for water-related regulating ES, in Fig. 5.2.3.3 and 5.2.3.4.

The ES of prevention of soil erosion is associated with the degree of territory transformation and the share of forest area in a similar manner. However, for ES absolute indicator (the volume of erosion prevented, t/ha), correlations appear only on the scale of 50 km squares. These are, respectively, negative and positive relationships with a fairly flat slope (Tab. 5.2.2.2). These relationships are manifest more strongly for the relative ES indicator – proportion of potential erosion prevented by ecosystems (see Section 4.1.5, Fig. 4.1.5.9). The values for the provided volume of this ES are highest in montane ecoregions (Fig. 5.2.3.5).

Negative correlations with the degree of territory transformation and positive correlations with the share of forest area found for this group of ES are defined both by correlations of all indicators with climatic conditions and, for a number of ES, causal relationships, i.e., the dependence of the provided ES on the area of forest and other natural ecosystems.

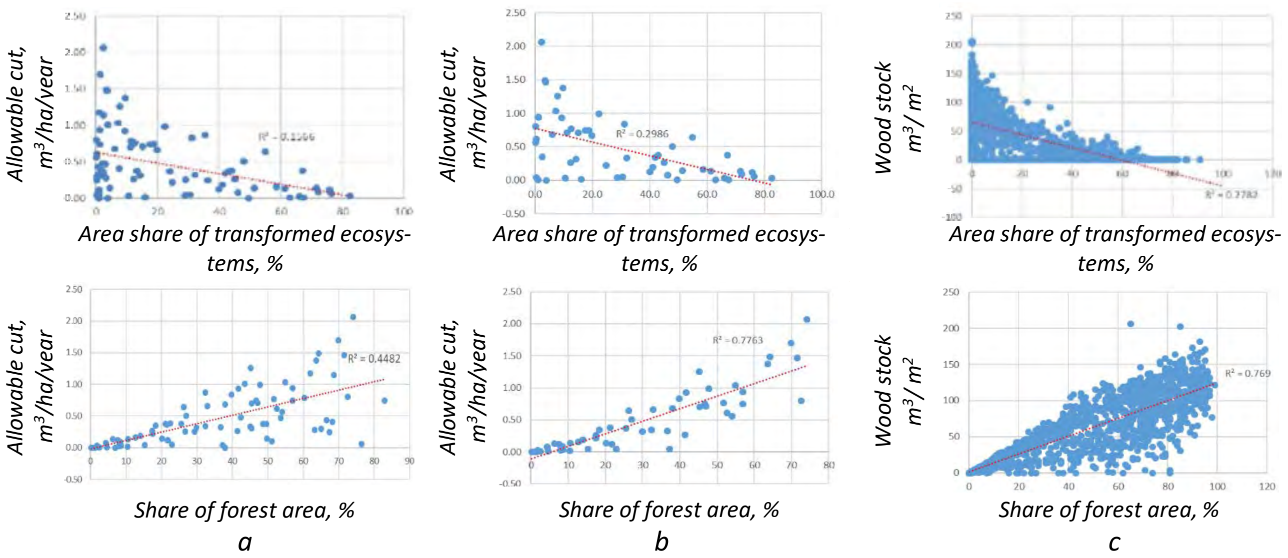


Figure 5.2.3.1. *Relationship between indicators of the provided ES of wood production and the degree of territory transformation (top row) and the share of forest area (bottom row): a) all subjects of RF; b) subjects of RF within European Russia; c) 50-km squares within European Russia.*

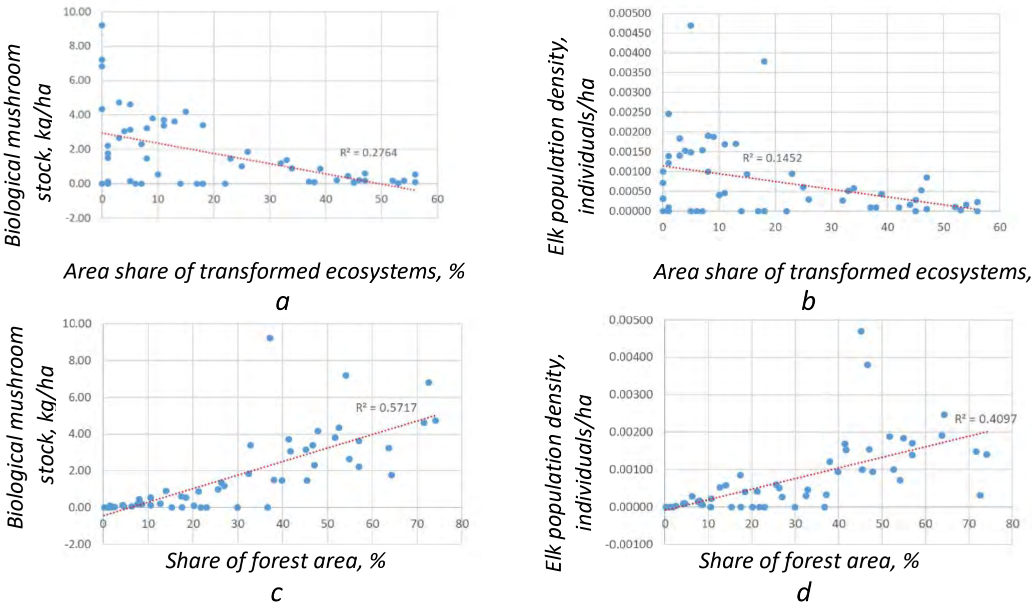


Figure 5.2.3.2. *Relationship between indicators of the provided ES of non-wood (mushrooms) and game (elk) production and indicators of the degree of territory transformation and the share of forest area. Data for subjects of RF within European Russia are shown.*

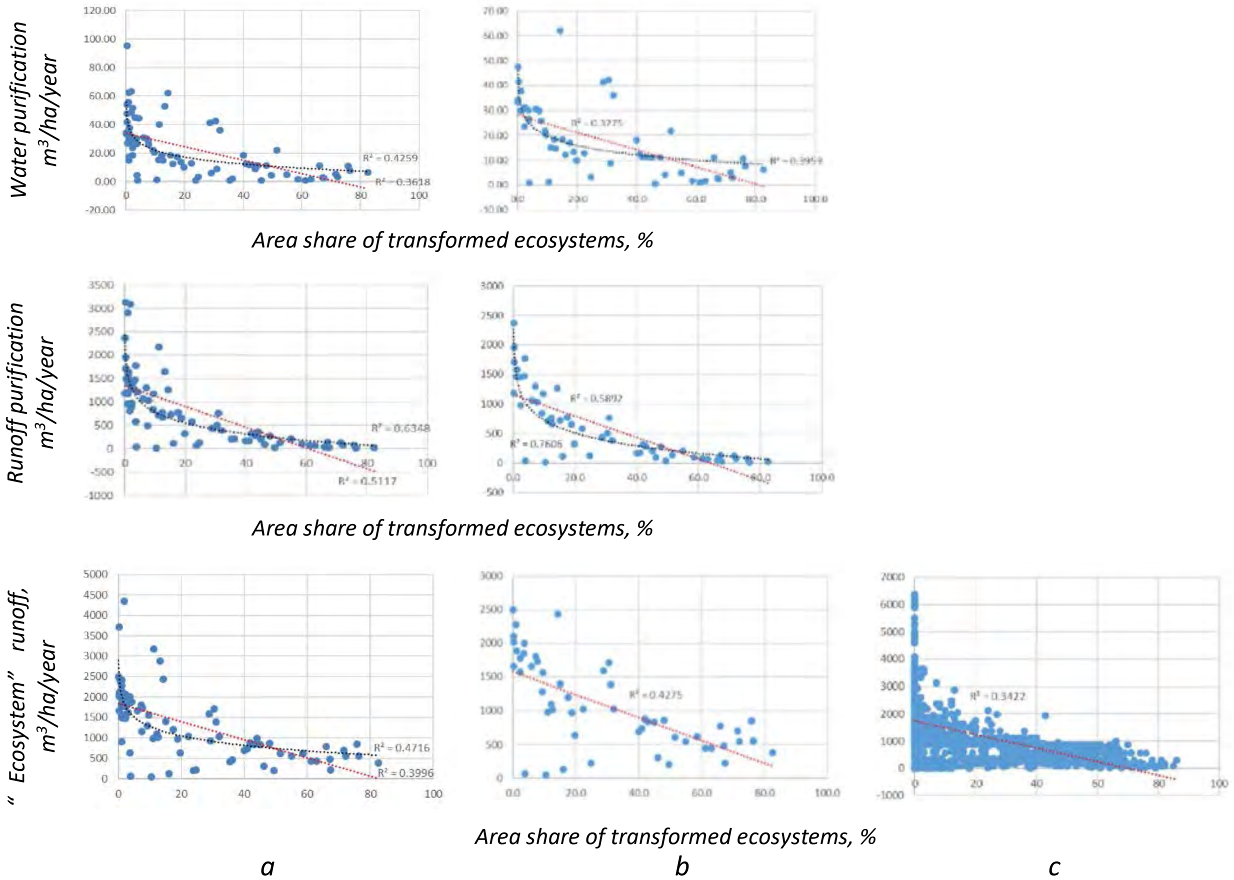


Figure 5.2.3.3. Relationship between indicators of the provided water-related ES and the degree of territory transformation: a) all subjects of RF; b) subjects of RF within European Russia; c) 50-km squares within European Russia.

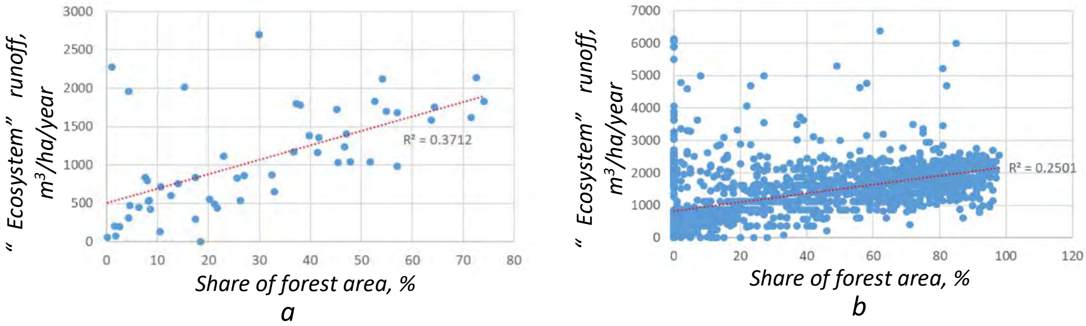


Figure 5.2.3.4. Relationship between the indicator of the provided ES of regulation of runoff volume by terrestrial ecosystems and the share of forest area: a) subjects of RF within European Russia; c) 50-km squares within European Russia.

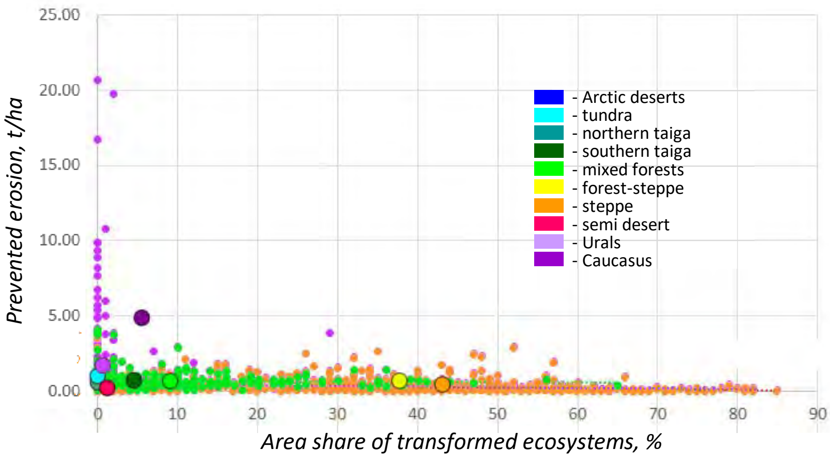


Figure 5.2.3.5. Values of indicator of ES of soil erosion prevention and the degree of territory transformation for 50-km squares within European Russia for groups of northern and forest (green dots), southern (orange dots), and montane (purple dots) ecoregions. Mean indicator values for different ecoregions are shown in the colors corresponding to ecoregion map in Fig. 2.2.1.

Indicators of forest-related provisioning ES are statistical data on wood stock, annual allowable cut, population number of ungulates, and stocks of mushrooms and berries. Obviously, these data reflect the effect of climate on wood stock and bioresources and the productivity of ecosystems (relationships between ES indicators and phytomass and productivity are discussed below in Section 5.2.5). However, as mentioned above, this influence is already reflected in the dependence of the provided ES on phytomass and productivity of natural ecosystems. Thus, the dependence of ES (except pollination) on climatic indicators was not considered in this analysis.

The methods used to estimate water-related ES that were used in TEEB-Russia 1 project determine the fact that their provided volume is highly dependent on the volume of total runoff (Bukvareva, Zamolodchikov, 2018). The negative correlations between water-related ES and the degree of territory transformation may therefore be explained by the fact that the total runoff in European Russia is highest in northern and montane regions (see, for example, the National Atlas of Russia, 2004–2008) which have been little transformed by man. In the Asian part of Russia, the pattern of runoff distribution is more complex, but negative correlations persist for all subjects of RF.

Causal relationships with the degree of territory transformation consist in the relationships of provided ES and the area of forest and other natural ecosystems, which either influences statistical data on the provided volume of ES or was included in the methodology we used to determine the provided volume of ES (see Section 4.1.1 of this report for the methodology for wood production ES; for the methodology for runoff quality assurance by terrestrial ecosystems, see Bukvareva, Zamolodchikov, 2018).

The group of "non-forest" ES might include the production of livestock fodder at natural pastures and carbon storage (see Section 5.2.2). In contrast to "forest" ES, the production of livestock fodder is negatively dependent on forest area (Tab. 5.2.2.3, Fig. 5.2.3.6), which is determined by estimation method of this ES (Bukvareva, Zamolodchikov, 2018). Correlation with the degree of territory transformation is not seen for this ES (Tab. 5.2.2.3).

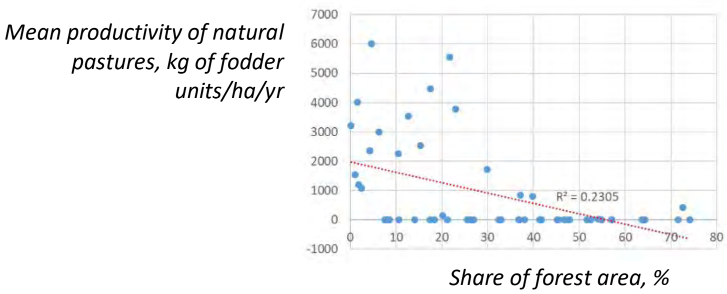


Figure 5.2.3.6. *Relationship between the provided volume of ES of production of livestock fodder at natural pastures and the share of forest area. Data for all subjects of RF are shown.*

There is a positive correlation between the S of carbon storage and the degree of territory transformation for subjects of RF and 50-km squares within European Russia (Tab. 5.2.2.2, 5.2.2.3; Fig. 5.2.3.7 b, c). This correlation can be explained by the high carbon content of black earth soils in regions severely transformed by agriculture. For the whole Russia, this correlation is weaker because of the high carbon content in peat bogs of Western Siberia, which have been little transformed by man (Fig. 5.2.3.7 a). But even this factor cannot outweigh importance of black earth regions, although the positive correlation is far weaker than for subjects of RF within European Russia (Fig. 5.2.3.7 b). Within European Russia, carbon content in black earth regions is higher than in boggy northern regions.

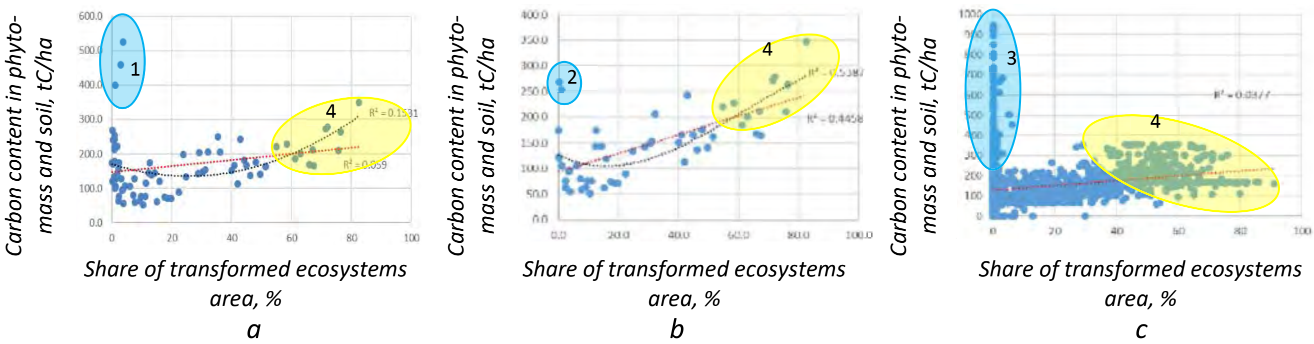


Figure 5.2.3.7. The relationship between carbon content in phytomass and soil and the degree of territory transformation: a) all subjects of RF; b) subjects of RF within European Russia; c) 50-km squares within European Russia; 1 – regions of Western Siberia; 2 – northern regions of European Russia – Murmansk Oblast and the Nenetsk autonomous district; 3 – boggy squares in tundra and northern taiga ecoregions within European Russia; 4 – black earth regions.

The weak positive dependence for 50-km squares within European Russia (Fig. 5.2.3.7 c) is composed of a slightly stronger positive relationship for heavily transformed ecoregions (steppe and forest steppe) and a negative relationship for all other regions (red and blue, respectively, in Fig. 5.2.3.8 a). Obviously, the positive correlation in the group of heavily transformed ecoregions can be explained by the fact that squares with a higher carbon content in chernozems are more plowed. In the northern regions, on the contrary, more carbon is found in peat ecosystems in the least developed squares.

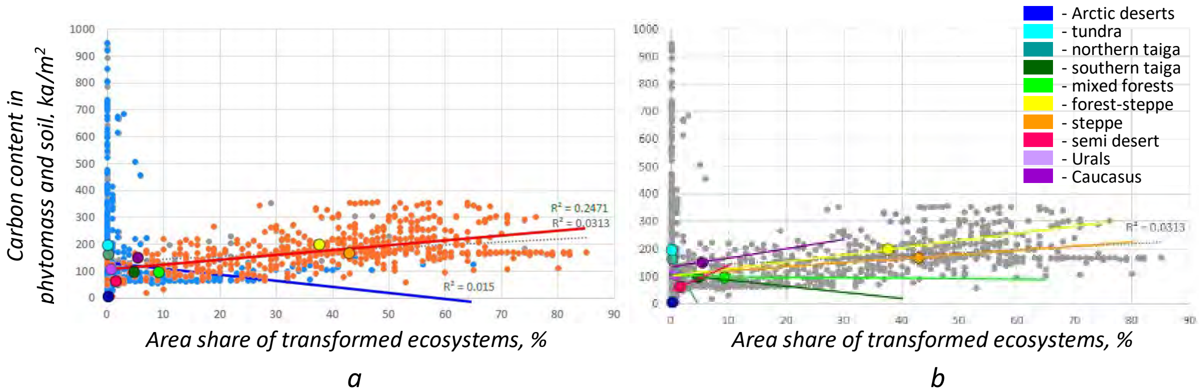


Figure 5.2.3.8. Relationships between carbon content in phytomass and soil and the degree of territory transformation within ecoregions: a) relationship for slightly-transformed ecoregions (all ecoregions except steppe and forest steppe) are shown in blue; relationships for heavily transformed ecoregions (steppe, forest steppe) are shown in red; b) relationships for individual ecoregions. Circles denote mean indicator values for ecoregions. Colors of the circles and relationships for individual regions on the bottom graphs correspond to the map in Fig. 2.2.1.

The provided volume of the ES of ecosystem aesthetic importance (index of aesthetic appeal) depends, accordingly to the method for assessing it, on a combination of open spaces, different types of vegetation, and land forms (see Section 4.1.8), i.e., not on the area of the ecosystems per se, but on the ratio of areas with different types of land cover. The dependence on the degree of territory transformation for this ES is not seen within European Russia (Tab. 5.2.2.1, 5.2.2.2). Like the ES of soil erosion prevention, the aesthetic importance of ecosystems and landscapes is highest in montane districts (Fig. 5.2.3.9).

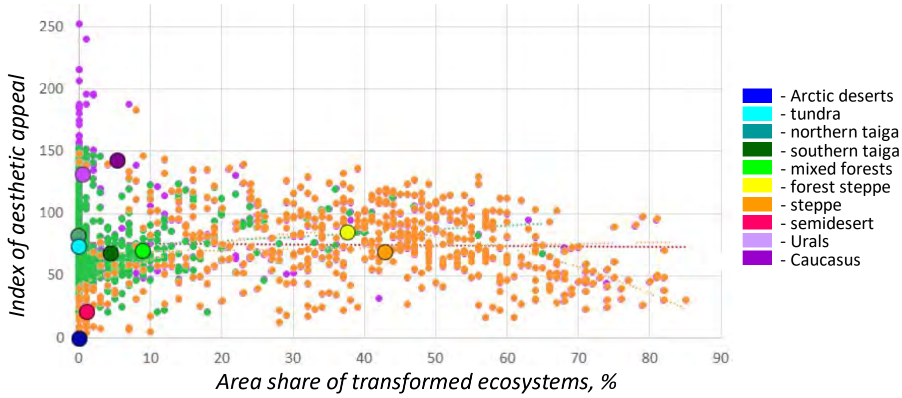
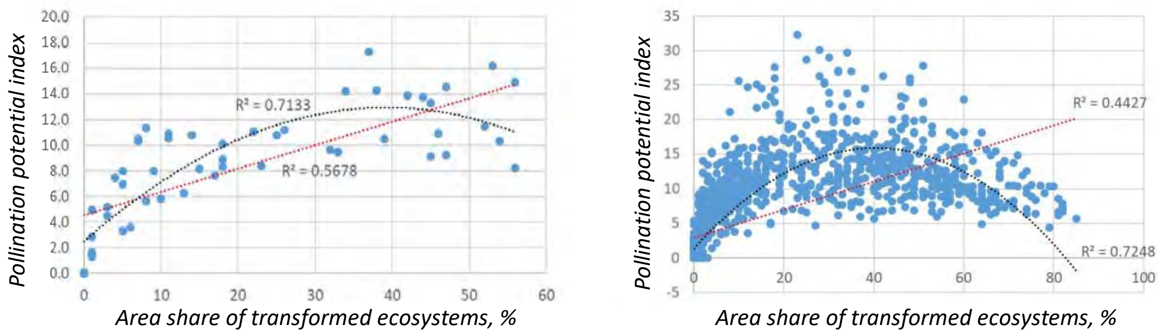


Figure 5.2.3.9. Values of indicators of aesthetic appeal and the degree of territory transformation for 50-km squares within European Russia for the groups of northern and forest (green dots), southern (orange dots), and montane (purple dots) ecoregions. Mean indicator values for individual ecoregions are shown in the colors corresponding to the map in Fig. 2.2.1.

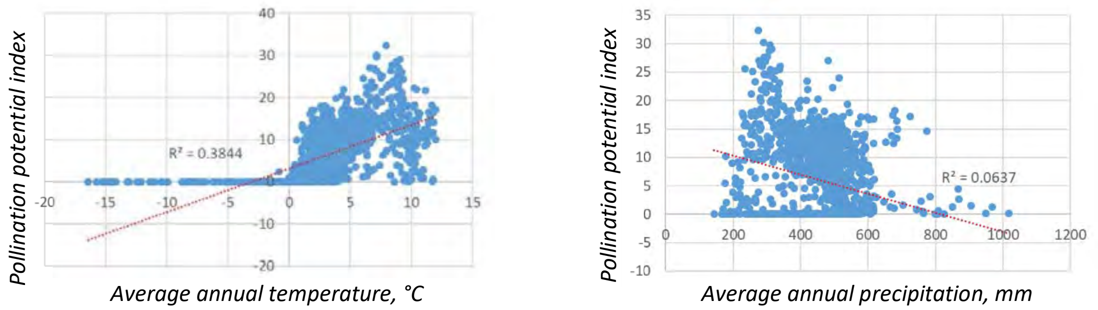
Among ES associated with farm fields and cities, the ES of farm crop pollination by wild pollinators is of greatest interest. The provided volume of this ES on all three scales of analysis positively correlates with the degree of transformation of the territory (Tab. 5.2.2.1–5.2.2.3), since this ES was calculated for areas adjoining farm fields (see Section 4.1.6). Besides the positive relationship there is also a unimodal one, i.e., the volume of this ES is highest at a certain plowing intensity of about 40% of the area (Fig. 5.2.3.9). Pollination index decreases if plowing is more intense, due to the lack of plots of natural ecosystems. These results illustrate the existence of an optimum degree of plowing for the pollination ES, which must be detailed in future estimates considering the spatial landscape structure.



a *b*

Figure 5.2.3.9. Relationship between the provided volume of the pollination ES and the degree of territory transformation: a) for subjects of RF within European Russia; c) for 50-km squares within European Russia.

It should be noted that pollination, unlike other ES analyzed in this report, directly depends on climatic conditions, namely, on average annual temperature, since the latter affects pollinator activity (see Section 4.1.6). As expected, the pollination potential index positively depends on the average annual temperature and negatively on the average annual precipitation (Fig. 5.2.3.10). The nature of these relationships is similar to the dependence of the degree of territory transformation on climatic conditions (Fig. 5.1.3.2).



a *b*

Figure 5.2.3.10. Relationship between the provided volume of the pollination ES and climatic conditions for 50-km squares within European Russia.

The two ES analyzed in this study that are associated with cities – the creation of natural conditions for recreation (see Section 4.1.7) and air purification by suburban forests (see Section 4.1.3) – are directly dependent on natural ecosystems within suburban zones. However, in general, these dependencies are practically not detected within European Russia, except for the relatively weak positive correlation between the recreational ES and the degree of territory transformation for 50-km squares (Tab. 5.2.2.2).

Thus, the dependencies between the analyzed ES and the degree of territory transformation are determined by both correlations with climatic conditions and the direct dependence of certain ES on the area of natural ecosystems and agricultural fields (Tab. 5.2.3.1).

Table 5.2.3.1. Ecosystem services, the provided volume of which is determined by the area of natural ecosystems or agricultural fields (only ES whose estimates were updated in the TEEB-Russia 2 project are included).

Ecosystem services	*Indicators affecting the provided volume of ES*
Wood production	Forest area
Non-wood production	Area of forests and other natural ecosystems
Game production	Area of forests and other natural ecosystems
Production of livestock fodder at natural pastures	Area of natural grassland ecosystems
Water quality assurance by terrestrial ecosystems	Area of forests, grassland ecosystems, and tillage
Prevention of soil erosion	Area of various types of natural ecosystems and tillage
Pollination of farm crops by wild pollinators	Area of natural ecosystems in buffer zones around farm fields
Creation of natural conditions for weekend recreation	Area of natural ecosystems in buffer zones around cities
Air purification by suburban forests	Area of forests in buffer zones around cities

5.2.4. Biodiversity – ecosystem services

Both positive and negative correlations between indicators of species richness and the provided (potential) volume of ES were found. In many cases no relationship was found (Tab. 5.2.2.1–5.2.2.3).

Like relationships between biodiversity and ecosystem functioning (Section 5.1.8), on the national scale and within European Russia, correlations between species richness and ES do not reflect causal relationships between them, although species diversity is a key factor of ecosystem functioning within biocenoses and ecosystems (see Section 6.1.3.1). On the national and sub-national (European Russia) scales these correlations are caused, first of all, by simultaneous change in different indicators on gradients of climatic conditions and relief.

An example are relationships between species richness of birds and plants and water-related ES – regulating the volume of runoff by terrestrial ecosystems (see Section 4.1.4), runoff quality assurance by terrestrial ecosystems and water purification in aquatic ecosystems (according to the TEBB-Russia 1; Bukvareva, Zamolodchikov, 2018). There are negative correlations between these indicators for 50-km squares and subjects of RF within European Russia and nationwide (Tab. 5.2.2.2, 5.2.2.3); for the mean for ecoregions values the dependences are not statistically significant (Tab. 5.2.2.1). An example for the ES of the runoff volume assurance by terrestrial ecosystems is shown in Fig. 5.2.4.1 and 5.2.4.2. Montane regions (purple circles in the left column of the charts in Fig. 5.2.4.1) have maximum values for plant species richness (Fig. 5.2.4.1, c, e), but for bird species number this is not so (Fig. 5.2.4.1 a). Removing montane regions from analysis strengthens the negative relationships for plant species richness. The right column of the charts (Fig. 5.2.4.1 b, d, f) shows that negative relationships are defined by a general tendency toward a decrease in species richness from south to north with a simultaneous increase in runoff (as stated above, water-related ES are largely governed by climatic conditions and surface runoff, which is relatively high in northern regions of European Russia (see Section 5.2.3).

Besides the negative relationships between species richness and water-related ES, there are also unimodal relationships (Fig. 5.2.4.1 b, d, f; 5.2.4.2 b). The ascending branch of these dependencies is formed by southern ecoregions (semideserts, steppe, forest steppe), while the descending branch is formed by northern and forest ecoregions (for bird species richness, also mountain ecoregions) and by the subjects of RF in these ecoregions. For the 50-km squares there is a separation of the slightly negative relationship revealed for the whole European Russian into ascending (for the southern ecoregion group) and descending (for the northern, forest, and montane ecoregion group) branches (Fig. 5.2.4.3).

The differences between groups of ecoregions can be explained by the fact that runoff volume provided by terrestrial ecosystems and species richness in the group of northern, forest, and montane ecoregions change in the opposite way on the gradient of climatic conditions: runoff decreases from north to south, while species richness, by contrast, grows. In the southern ecoregions group the changes in these indicators from north to south are unidirectional – all indicators decrease when moving to south from the forest-steppe to semi-deserts (Fig. 5.2.1.1).

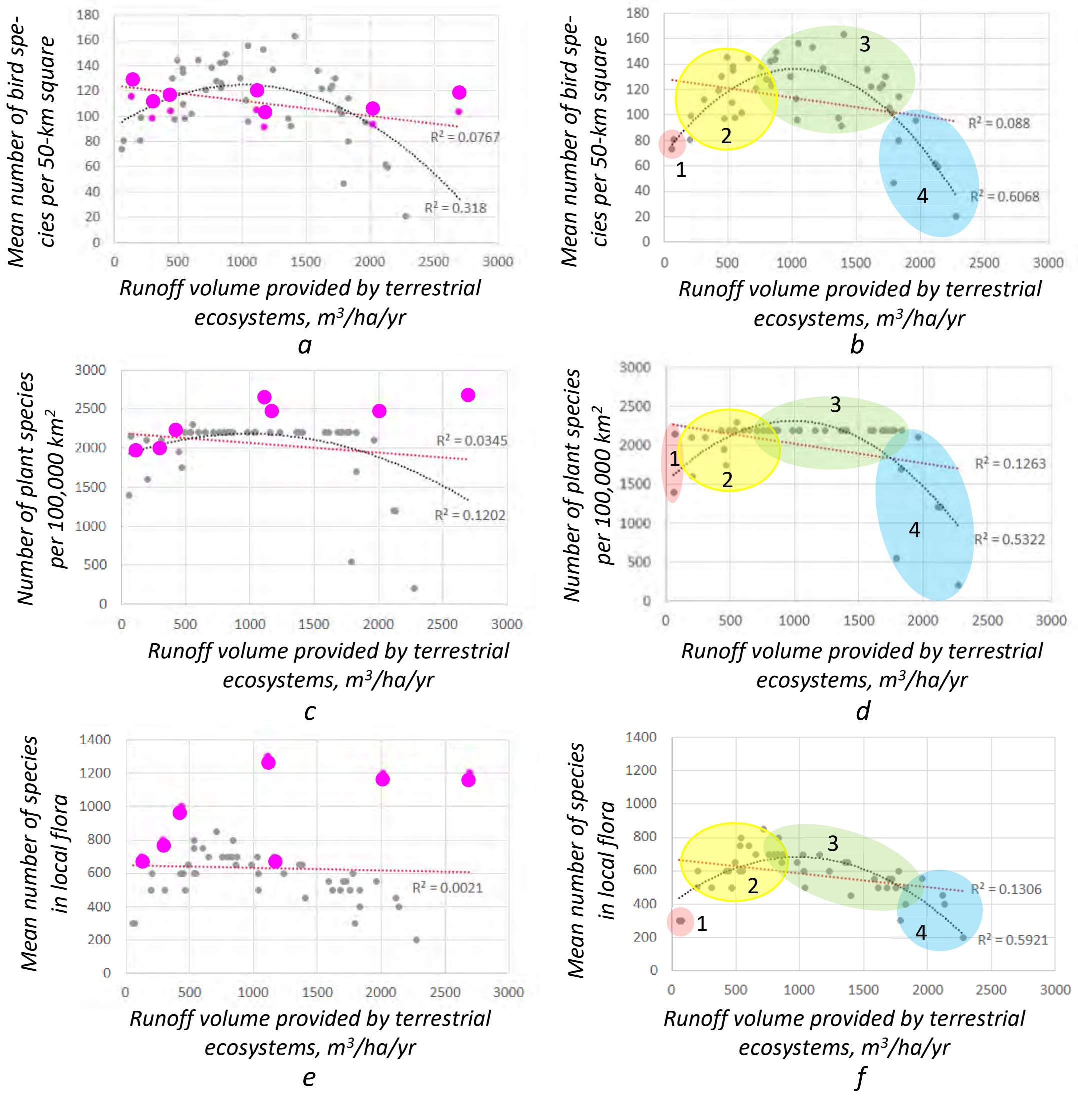


Figure 5.2.4.1. Relationships between provided ES of runoff volume assurance by terrestrial ecosystems and bird and plant species richness: left charts (a, c, e) – all subjects of RF within European Russia; montane regions marked with purple circles (from left to right: Dagestan, Chechnya, Ingushetia, North Ossetia – Alania, Adygea, Kabardino-Balkaria, Karachaevo-Cherkessia); right charts (b, d, f) – subjects of RF within European Russia, except montane regions; the numbers denote the following subjects of RF: 1 – located in the semi-desert; 2 – agricultural regions; 3 – located in forest ecoregions; 4 –located in northern ecoregions.

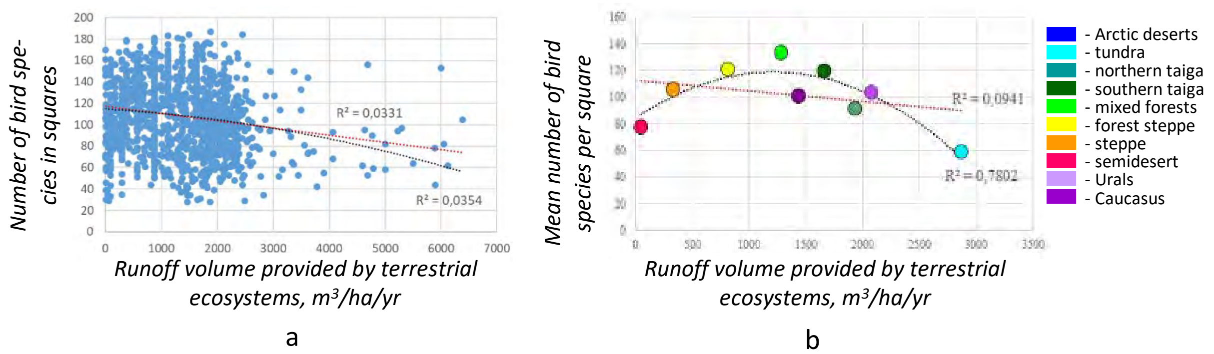


Figure 5.2.4.2. Relationships between provided ES of runoff volume assurance by terrestrial ecosystems and the number of bird species: a) in 50-km squares; b) mean values for the ecoregions. The average values for individual ecoregions are shown by colored circles in accordance with the map in Fig. 2.2.1. Arctic desert ecoregion excluded from analysis.

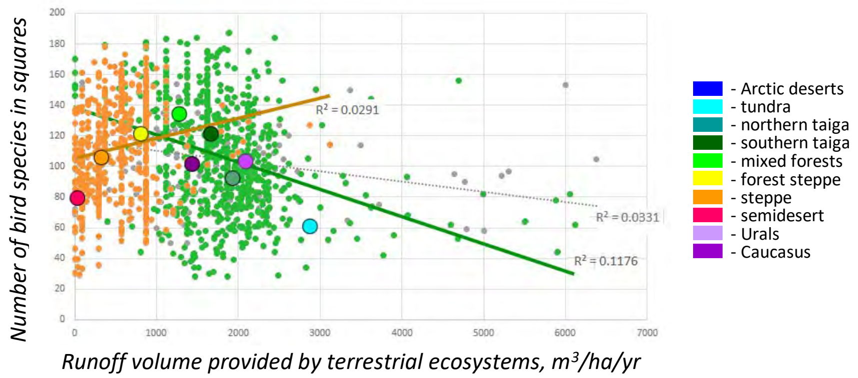
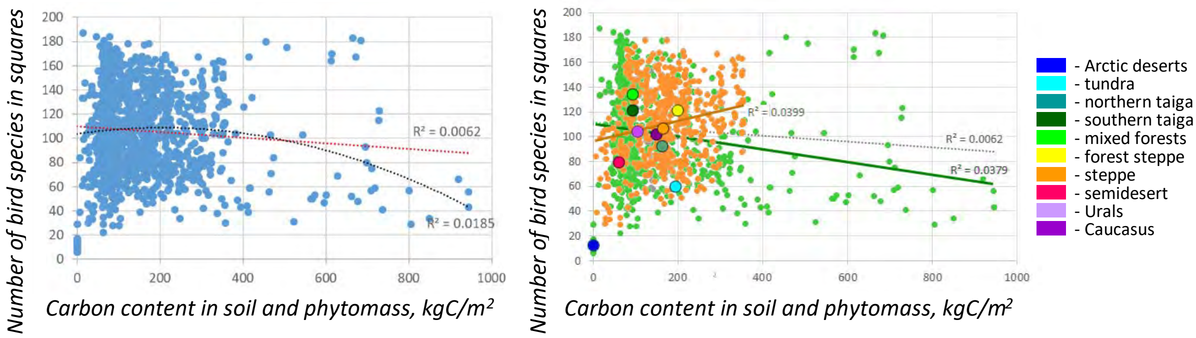


Figure 5.2.4.3. Relationships between provided ES of runoff volume assurance by terrestrial ecosystems and the number of bird species for 50-km squares within European Russia in the group of northern, forest and mountain ecoregions (green color) and in the group of southern ecoregions (orange color). The dependences for the whole European Russia are shown by dashed lines. The average values of indicators for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Arctic desert ecoregion excluded from analysis.

The ES of carbon storage weakly negatively correlates with bird species richness only on a scale of 50 km squares (Tab. 5.2.2.2, Fig. 5.2.4.4). This dependence, like relationshipы between water-related ES and biodiversity, also breaks down into a positive correlation for the southern ecoregion group and a negative correlation for the northern, forest, and montane ecoregion group (Fig. 5.2.4.4 b). This is because carbon stocks in the group of northern, forest and montane ecoregions (except the arctic desert ecoregion) decrease from north to south, while bird species richness grows. In contrast, in the group of southern ecoregions (forest steppe, steppe, semideserts), these indicators decrease simultaneously from the forest steppe to semideserts (Fig. 5.2.1.1).



a b

Figure 5.2.4.4. Relationships between bird species number and carbon storage ES for 50-km squares within European Russia: a) for all squares; b) for the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Dependencies for the whole European Russia are shown by dotted lines. The average values of indicators for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1.

The ES of farm crop pollination by wild pollinators is largely positively related to species richness on all scales of analysis (Tab. 5.2.2.1–5.2.2.3). In addition to positive correlations, unimodal dependencies are also revealed, in which the maximum number of species corresponds to mean values of pollination potential (see example for bird species richness in Fig. 5.2.4.5). In the group of northern, forest, and mountain ecoregions, a stronger correlation is revealed than for the entire European Russia; in the group of southern ecoregions, it is absent (Fig. 5.2.4.5 c). This is because pollination potential and species richness grow simultaneously from north to south in the group of northern ecoregions, and in the group of southern ecoregions, pollination potential is greatest in the steppe ecoregion, while species richness declines in the series “forest-steppe –

steppe-semi – desert" (Fig. 5.2.1.2). Overall these relationships are similar to those between bird species richness and the degree of territory transformation (see Section 5.1.6, Fig 5.1.6.4). As stated above, the pollination ES is closely tied to farm fields (see Sections 4.1.9 and 5.2.3, Fig. 5.2.3.9), and on the European Russia scale the pollination index to a certain degree reflects the degree of territory transformation. Therefore, the "species richness – pollination potential" and the "species richness – degree of territory transformation" relationships are quite similar.

The relationship of other ES with species richness is partially described in Section 5.2.2.

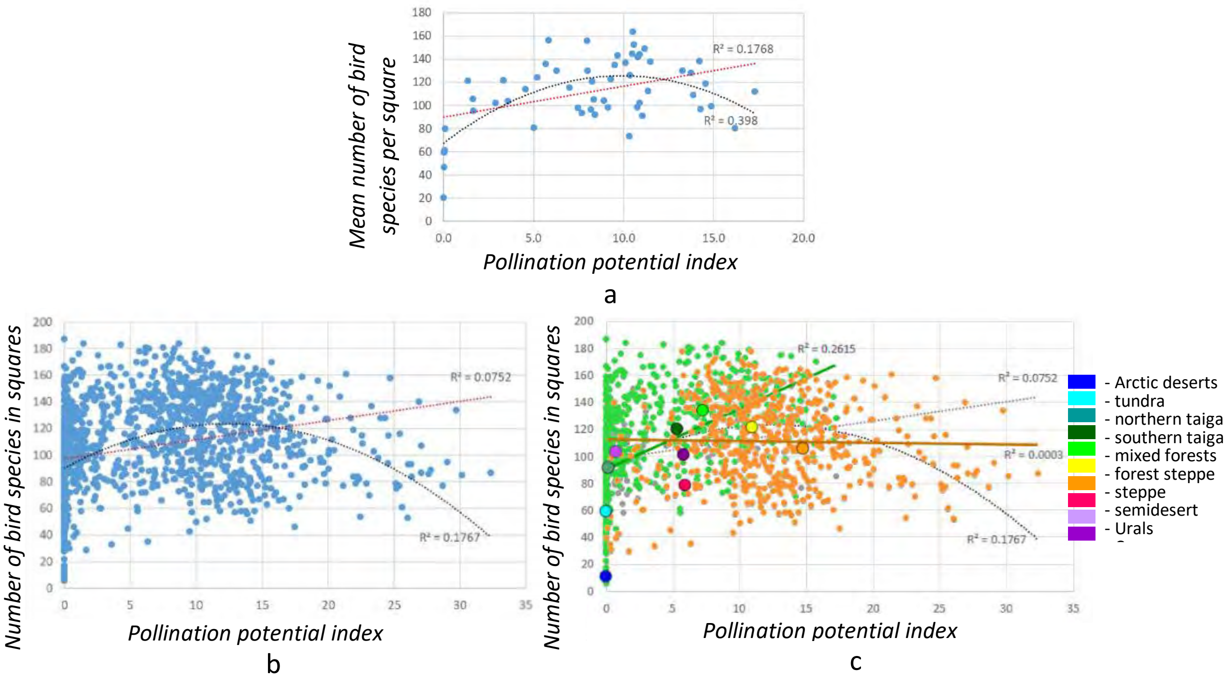


Figure 5.2.4.5. Relationship between bird species number and pollination potential within European Russia: a) for mean values for subjects of RF; b) for 50-km squares; c) for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Dependencies for the whole European Russia are indicated by dotted lines. The average values of indicators for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1.

It should be emphasized that the conclusion that revealed relationships between biodiversity and ES do not reflect causal relationships, but only correlations due to the simultaneous change in indicators in response to the action of third factors, refers only to national and subnational scales and indicators of species richness studied in the TEEB-Russia project. At local and regional scales, biodiversity should be considered as a key factor in ecosystem functioning and ES (see Section 6.1.3.1) which might directly affect corresponding indicators. Moreover, species richness and ecosystem diversity directly affect information ES and some recreational ES associated with the aesthetic and educational value of ecosystems and landscapes. These aspects were not specially analyzed in this study, but they should be analyzed in future ES assessments.

5.2.5. Ecosystem functioning (productivity, phytomass) – ecosystem services

As noted in the Section 5.2.2, ES provided by ecosystems throughout the country or a region can be divided into two main groups according to the nature of their correlations with ecosystem productivity and phytomass: ES associated to some degree with forest (wood, non-wood and game production, water-related ES, soil erosion prevention) and ES associated with non-forest ecosystems (livestock fodder production on natural pastures and carbon storage). The "forest" ES on all three scales of analysis have positive correlations with phytomass and negative ones with productivity, or there are no statistically reliable correlations (Tab. 5.2.2.1–5.2.2.3). Examples of correlations for provisioning ES are shown in Fig. 5.2.5.1; for water-related regulating ES, in Fig. 5.2.5.2.

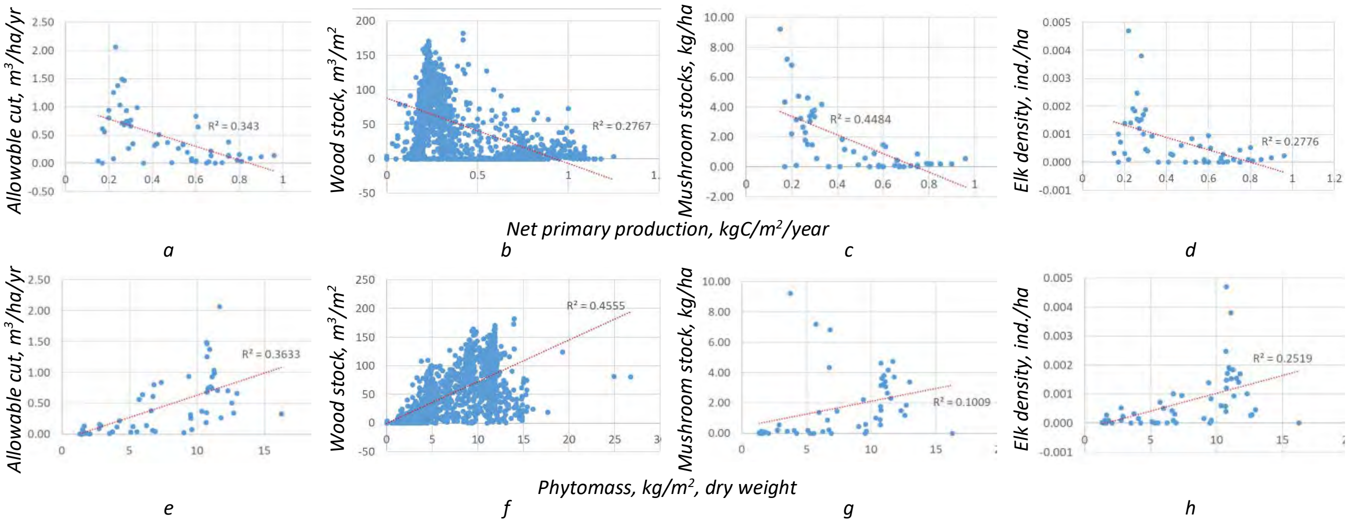


Figure 5.2.5.1. Relationships between indicators of ES of wood, non-wood, and game production and indicators of ecosystem productivity (top row) and phytomass (bottom row). Examples b and f are relationships for 50-km squares within European Russia; the other examples are relationships for subjects of RF within European Russia.

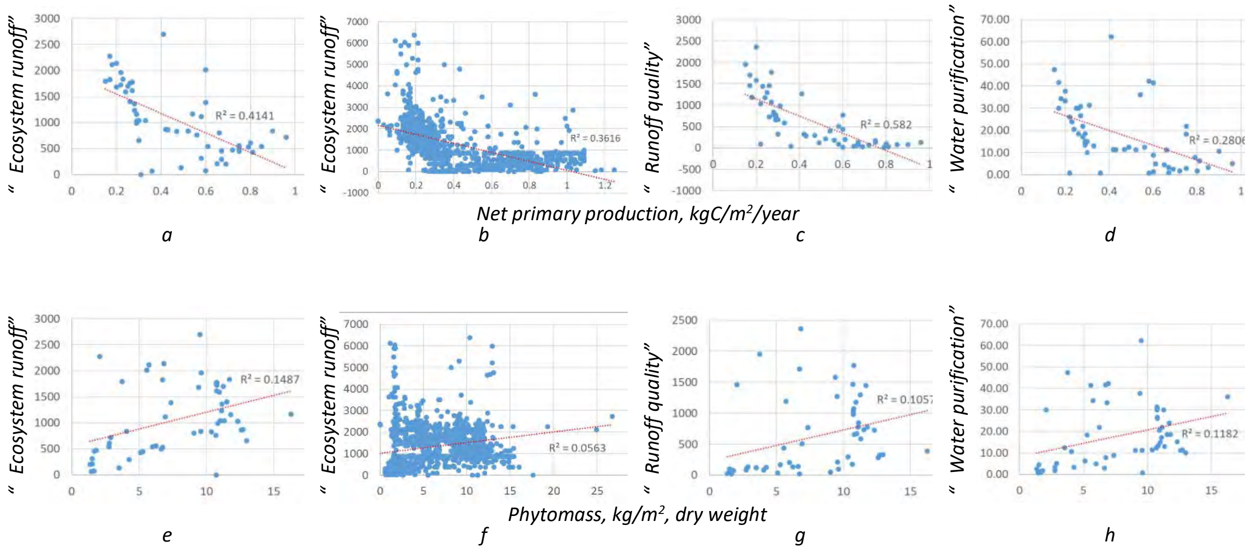


Figure 5.2.5.2. Relationships between indicators of water-related ES and indicators of ecosystem productivity (top row) and phytomass (bottom row). ES indicators: "ecosystem runoff" is the volume of runoff provided by terrestrial ecosystems, m^3/ha/year; "runoff quality" is the amount of runoff potentially purified by terrestrial ecosystems, m^3/ha/year; "water purification" is the amount of wastewater potentially purified by aquatic ecosystems, m^3/ha/year). Examples b and f are relationships for 50-km squares within European Russia; the other examples are relationships for subjects of RF within European Russia.

The reasons for correlations revealed for forest-related provisioning ES are obvious: positive correlations with phytomass are result of the highest phytomass values in forest ecoregions; negative correlations with productivity are result of the highest productivity values in non-forest southern ecoregions forest-steppe, steppe, and semidesert ecoregions (Section 5.1.1).

A negative relationship between ecosystem productivity and runoff volume provided by terrestrial ecosystems, found for the whole European Russia (Tab. 5.2.2.1–5.2.2.3) when analyzing values in 50 km squares for different groups of ecoregions, remains in the group of northern, mountain and forest ecoregions (green in Fig. 5.2.5.3 b), and in the group of southern ecoregions (forest-steppe, steppe and semi-desert) turns into weak positive dependence, which is not statistically significant (orange color in Fig. 5.2.5.3 b). The negative relationship in the group of northern, montane, and forest ecoregions is explained by opposing trends in changes in indicators moving from north to south; the tendency toward a positive relationship in the southern ecoregions group is consistent with a similar change in both indicators moving from north to south (Fig. 5.2.1.1).

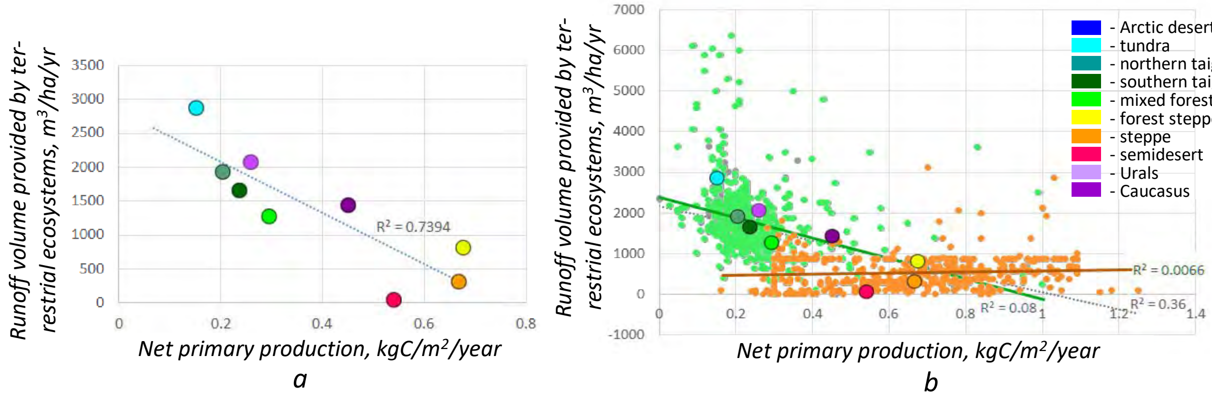


Figure 5.2.5.3. Relationships between ecosystem productivity and ES of runoff volume assurance by terrestrial ecosystems within European Russia: a) for mean values for ecoregions; b) for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Dependencies for the whole European Russia are indicated by dotted lines. The average values of indicators for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Arctic desert ecoregion excluded from analysis.

The positive relationship between water-related ES and phytomass is somewhat weaker (Tab. 5.2.1.2, 5.2.1.3, Fig. 5.2.5.2), and for mean values for ecoregion it is statistically insignificant (Tab. 5.2.1.1, Fig. 5.2.5.4 a). The example of the 50-km squares shows that positive dependence found for whole European Russia breaks down into the negative relationship for the group of northern, montane and forest ecoregions (green on Fig. 5.2.5.4 b) and the positive relationship for the southern ecoregions group (orange on Fig. 5.2.5.4 b). The explanation for these relationships is the same as that for productivity.

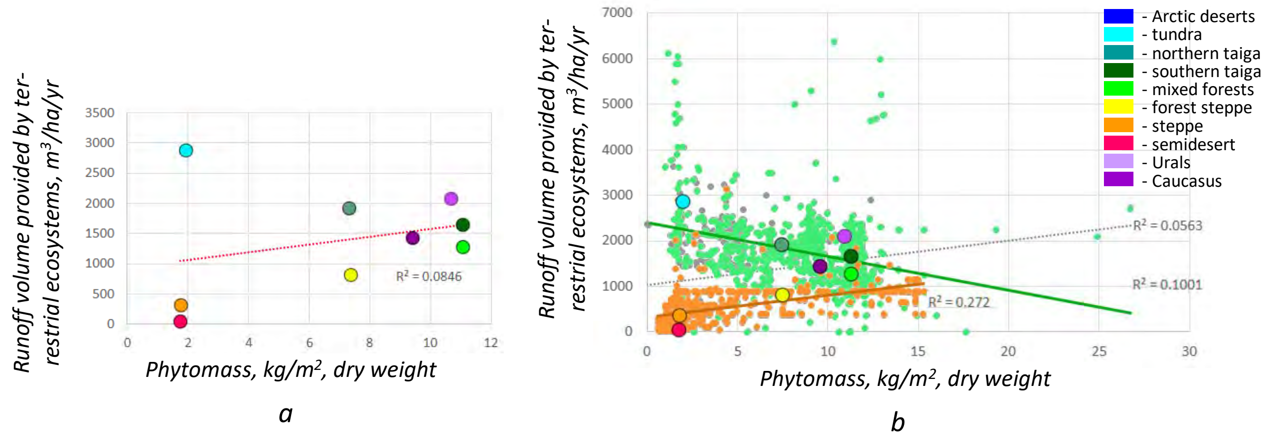


Figure 5.2.5.4. Relationships between ecosystem phytomass and ES of runoff volume assurance by terrestrial ecosystems within European Russia: a) for mean values for ecoregions; b) for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Dependencies for the whole European Russia are indicated by dotted lines. The average values of indicators for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Arctic desert ecoregion excluded from analysis.

If we change the axis when analyzing correlations between phytomass and the runoff provided by terrestrial ecosystems, then in addition to the positive dependence (Fig. 5.2.5.4), a unimodal dependence is revealed. The ascending branch of it includes southern ecoregions (semidesert, steppe, forest steppe) and a descending branch includes northern, forest, and montane ecoregions (Fig. 5.2.5.5 a). The positive relationship for southern ecoregions (the orange on Fig. 5.2.5.5. b) and negative relationship for northern, forest, and montane ecoregions (the green on Fig. 5.2.5.5. b) become more pronounced.

Relationships within individual regions are weak and do not follow this pattern (Fig. 5.2.5.5. c), that is, the positive and negative branches identified for the northern and southern groups of regions are formed precisely in these groups of ecoregions, and not in individual ecoregions.

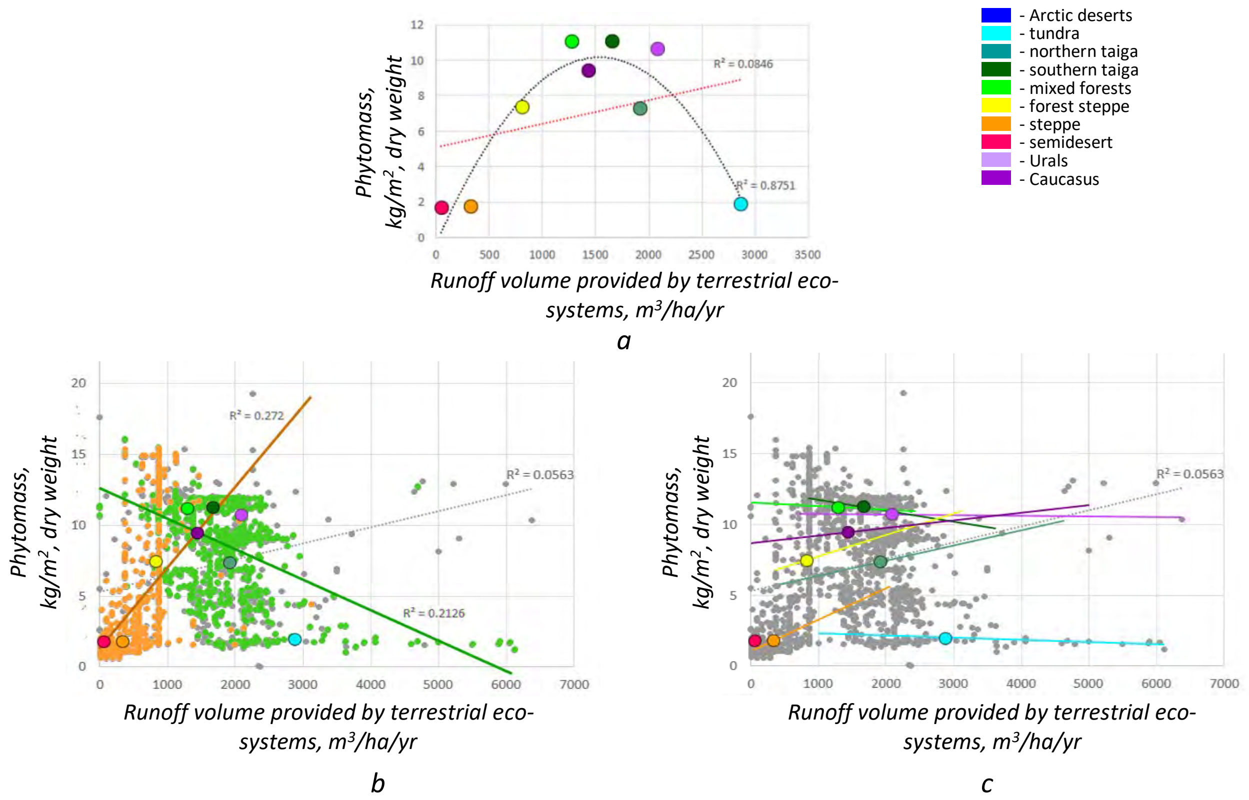


Figure 5.2.5.5. Relationships between ecosystem phytomass and ES of runoff volume assurance by terrestrial ecosystems within European Russia: a) for mean values for ecoregions; b) for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange); c) for 50-km squares in individual ecoregions. Mean values for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Dependencies for the whole European Russia are indicated by dotted lines. Arctic desert ecoregion excluded from analysis.

The second group includes ES related with non-forest ecosystems – the production of livestock fodder at natural pastures and carbon storage (see Section 5.2.2). Carbon storage ES is also associated with northern peat ecosystems. Within European Russia, despite the high carbon content in some northern 50-km squares (Fig. 5.2.3.7 c), when comparing subjects of RF, carbon stocks in agriculture black-earth regions are a more important component of this ES (Fig. 5.2.3.7 b). In European Russia, therefore, this ES is positively related to the degree of territory transformation. The ES of natural fodder production is associated with not plowed grassland ecosystems, and thus, has not positive correlation with the degree of territory transformation (Tab. 5.2.2.3). In contrast to forest-related ES, the ES from this group correlate positively with productivity and negatively with ecosystem phytomass (Tab. 5.2.2.1–5.2.2.3). Fig. 5.2.5.6 presents examples of relationships for ES of carbon storage.

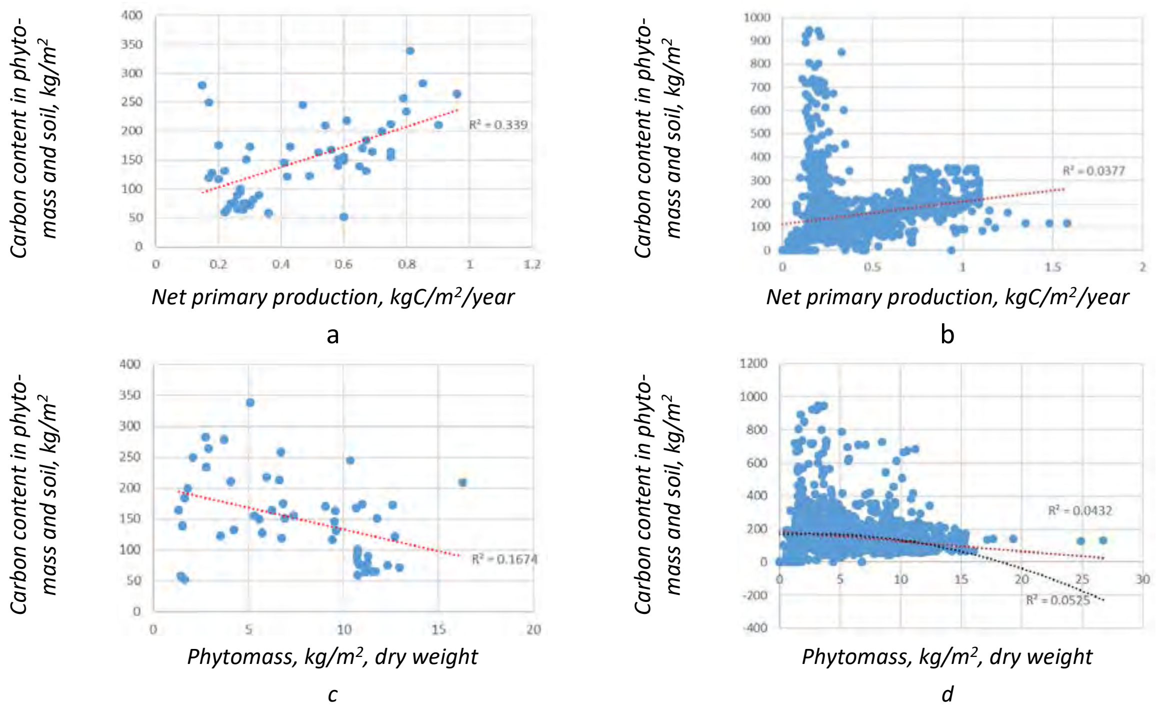


Figure 5.2.5.6. Relationship between carbon content in soil and phytomass and ecosystem productivity (top row) and phytomass (bottom row) within European Russia. Examples "a" and "c" are given for subjects of RF; examples "b" and "d" – for 50-km squares.

The positive relationship between carbon stocks and ecosystem productivity, identified for the whole European Russia, breaks down into two branches forming a U-shaped dependence (Fig. 5.2.5.7 a). The descending branch is formed by the group of northern, montane, and forest ecoregions; the ascending one, by southern ecoregions. In the group of northern, montane, and forest ecoregions, carbon stock decreases as productivity increases, since carbon stock is associated with low-productivity peat ecosystems. Carbon stock in the southern ecoregions increases along with productivity, since there it is maximal in the most productive black-earth soils (Fig. 5.2.5.7 a, b).

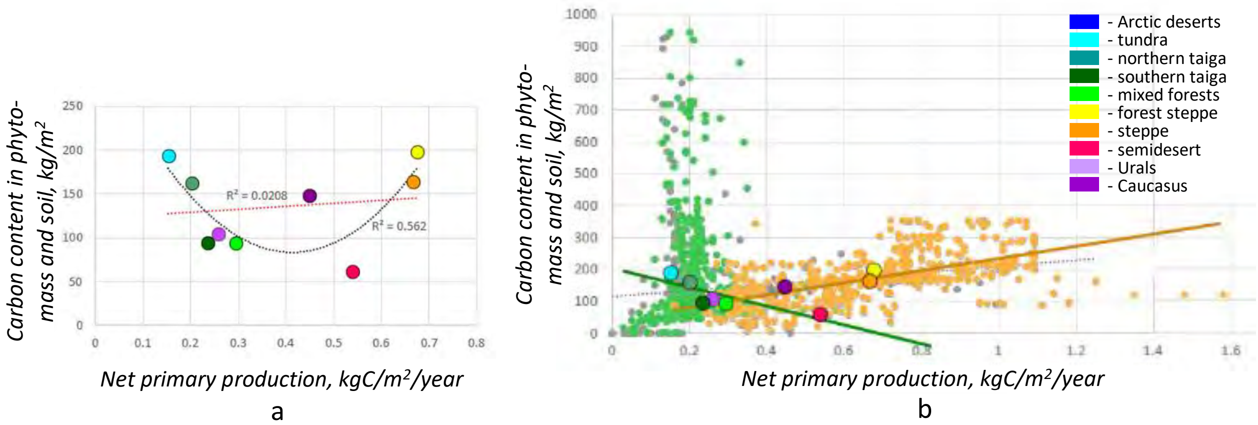
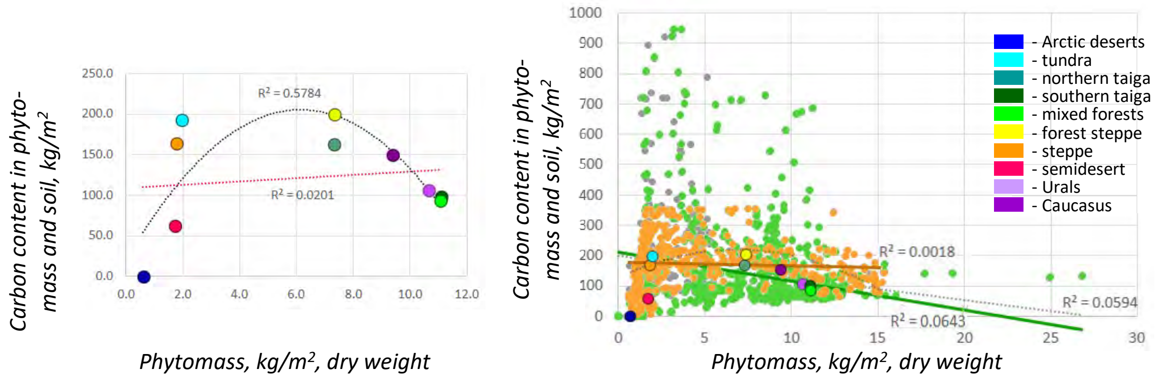


Figure 5.2.5.7. Relationship between carbon content in phytomass and soil and ecosystem productivity: a) mean values for ecoregions; b) values for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Mean values for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Dependencies for the whole European Russia are indicated by dotted lines. Arctic desert ecoregion excluded from analysis.

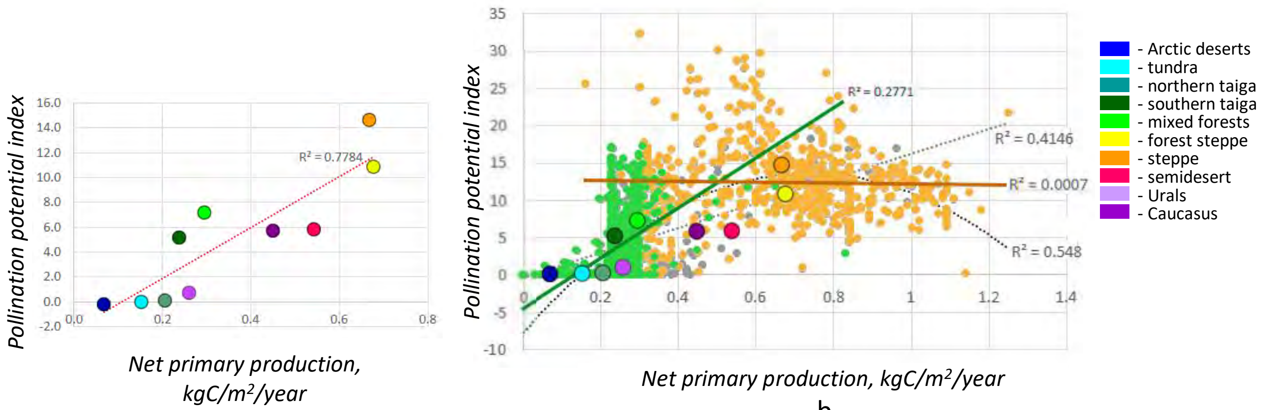
As for relationships between carbon stock and ecosystem phytomass, the negative dependence remains in the group of northern, mountain and forest ecoregions, and it disappears in the group of southern ecoregions (Fig. 5.2.5.8 b). The graph for mean for ecoregions values (Fig. 5.2.5.8 a) shows that in this case a difference can be revealed between the group of northern and southern grassy ecoregions (Arctic deserts, tundra, steppe, semi-desert) and the group of ecoregions with forest ecosystems (forest, mountain ecoregions and forest-steppe). Grassy ecoregions form an ascending branch of unimodal dependence, that is, in this group of ecoregions carbon stock positively correlates with phytomass, forest ecoregions and forest-steppe form a descending branch, where carbon stock is negatively associated with phytomass.



a b

Figure 5.2.5.8. Relationship between carbon content in phytomass and soil and ecosystem phytomass: a) mean values for ecoregions; b) values for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Mean values for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Dependencies for the whole European Russia are indicated by dotted lines.

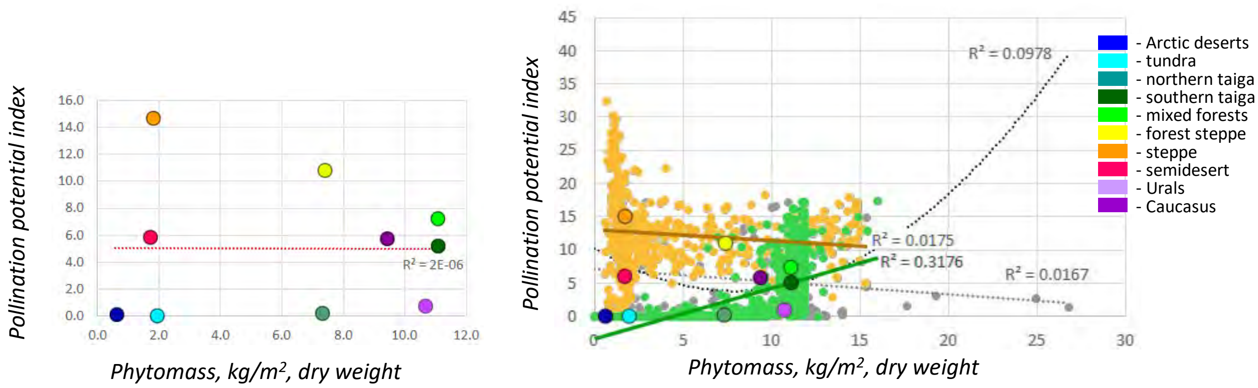
Pollination ES is associated with farm fields, therefore relationships between this ES and indicators of phytomass and productivity are largely determined by the correlations of these indicators with the degree of territory transformation, i.e., with the share of farmland. Pollination potential positively correlates with ecosystem productivity on all scales of analysis (Tab. 5.2.2.1–5.2.2.3; Fig. 5.2.5.9), since productivity positively correlates with the degree of agricultural development of an area (see Sections 5.1.2, 5.1.7). Moreover, the positive and unimodal relationships found for 50-km squares (Fig. 5.2.5.9 b) practically repeat the relationships between pollination potential and the degree of territory transformation (Fig. 5.2.3.9 b).



a b

Figure 5.2.5.9. Relationship between pollination potential and ecosystem productivity within European Russia: a) mean values for ecoregions; b) values for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Mean values for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Dependencies for the whole European Russia are indicated by dotted lines.

For European Russia as a whole there is no correlation between pollination potential and phytomass (Tab. 5.2.2.1–5.2.2.3, Fig. 5.2.5.10), however within the group of northern, forest, and montane ecoregions a positive relationship is revealed (Fig. 5.2.5.10 b). It is interesting that the nature of relationships between pollination potential and indicators of phytomass and productivity within the northern and southern ecoregions groups are the same: positive relationships for the northern ecoregions group and no relationship for the southern ecoregions (Fig. 5.2.5.9 b; 5.2.5.10 b), while the relationships for European Russia as a whole are different: for productivity there is positive relationship and there is no relationship for phytomass.



a b

Figure 5.2.5.10. Relationship between pollination potential and ecosystem phytomass within European Russia: a) mean values for ecoregions; b) values for 50-km squares in the group of northern, forest and montane ecoregions (green) and the group of southern ecoregions (orange). Mean values for individual ecoregions are shown in colors in accordance with the map in Fig. 2.2.1. Dependencies for the whole European Russia are indicated by dotted lines.

Therefore, the correlations found for European Russia reflect primarily a simultaneous change in indicators of ecosystem functioning and ES on the gradient of climatic conditions. At the same time, it is obvious that ecosystem phytomass and productivity must directly affect provisioning and regulating ES. However, the identification of causal relationships should be expected when comparing similar ecosystems at local or regional levels within the same climatic conditions. To identify these relationships, it is necessary to use values of ecosystem productivity and phytomass relevant for a given point in time.

5.2.6. Correlations between various ecosystem services

In this section, as well as in the previous Sections 5.2.1–5.2.5, the indicators of the provided (potential) volume of ES are analyzed. The ES set and their division into two groups are the same as in Section 5.2.2. To estimate correlations (Tab. 5.2.6.1–5.2.6.3), the Pearson correlation coefficient was used for numerical indicators, the Spearman coefficient was used for point indicators (ecosystem aesthetic and pollination indices). The ES set in the tables varies, since not all of ES were evaluated on all three scales of analysis.

Both positive and negative correlations between indicators of ES were identified (Tab. 5.2.6.1–5.2.6.3). Correlations between ES indicators are similar at all scales of analysis, but they are most weakly expressed for mean for ecoregions values (Tab. 5.2.6.1).

Forest-related ES (wood, non-wood, and game production, water-related ES, the soil erosion prevention, for which similar positive correlations with phytomass and the share of forest area and negative correlations with the degree of territory transformation and productivity were found in Section 5.2.2), are either positively related to each other, or there is no statistically significant correlation between them. Forest-related ES negatively correlate with the ES of carbon storage and livestock fodder production that are provided by non-forest ecosystems. However, these “non-forest ES” do not correlate with each other, since, as stated in Section 5.2.2, carbon storage within European Russia is primarily provided by black earth regions, which are the most transformed by man, and livestock fodder production is provided by natural grassy ecosystems.

Relationships identified for ES from group 2 (Tab. 5.2.6.1–5.2.6.3) are governed primarily by their association with farm fields and cities.

Table 5.2.6.3 shows correlations between provided (potential) ES with the cost of agriculture product in subjects of RF (according to Federal State Statistic Service). The Prototype of the National Report on the Ecosystem Services of Russia does not consider agriculture products as an ES, but this comparison many be of interest since it is included in ES by CICES classification. Relationships between ES and the cost of agriculture product are, as expected, similar to the relationships between ES and the degree of territory transformation (see Sections 5.2.2 and 5.2.3). This relationship is negative for forest-related ES, and positive for carbon storage ES.

Table 5.2.6.1. Coefficients of correlation between mean values of ES for ecoregions (Arctic desert ecoregion excluded from analysis).

ES group	ES	Wood stock	Carbon content	Runoff volume regulation	Erosion prevented	Aesthetic value	Pollination potential	Weekend recreation
1	Carbon content	.023	1					
	Runoff volume regulation	.420	.303	1				
	Erosion prevented	.176	.172	.246	1			
	Aesthetic value	.486	.600	.450	.757*	1		
2	Pollination potential	–.082	.213	–.883**	–.398	.073	1	
	Weekend recreation	.168	.279	–.382	.592	.439	.645*	1
	Air purification	.511	.116	.009	.399	.326	.270	.784**

*** p<0.01; * p<0.05; n=9*

Table 5.2.6.2. Coefficients of correlation between ES indicators in 50-km squares.

ES group	ES	Wood stock	Carbon content	Runoff volume regulation	Erosion prevented	Aesthetic value	Pollination potential	Weekend recreation
1	Carbon content	–.232**	1					
	Runoff volume regulation	.511**	–.052*	1				
	Erosion prevented	.024	–.053*	.172**	1			
	Aesthetic value	.098**	.171**	.154**	.498**	1		
2	Pollination potential	–.451**	.100**	–.737**	–.287**	–.021	1	
	Weekend recreation	–.027	–.043	–.180**	.076**	.109**	.288**	1
	Air purification	.105**	–.050*	–.013	.032	.036	.211**	.545**

*** p<0.01; * p<0.05; n from 1576 to 1619 for different ES*

Table 5.2.6.3. Coefficients of correlations between mean values of ES for subjects of RF within European Russia.

	2	3	4	5	6	7	8	9	10	11	12	Farm product, rubles / ha
2. Wood stock	1											–.115
3. Mushroom stock	.356**	1										–.473**
4. Berry stock	.156	.634**	1									–.378**
5. Ungulate population	.360**	–.008	–.181	1								.083
6. Livestock fodder	–.310*	–.412**	–.209	–.205	1							–.023
7. Carbon stock	–.333*	–.227	–.100	–.273*	.062	1						.491**
8. Regulation of runoff volume	.544**	.514**	.432**	–.045	–.275*	–.162	1					–.371**
9. Runoff purification	.472**	.734**	.633**	.093	–.331*	–.270*	.777**	1				–.525**
10. Water purification	.519**	.415**	.447**	.174	–.188	–.169	.743**	.753**	1			–.153
11. Erosion prevention	.361**	–.211	–.116	–.008	.247	.012	.347*	.068	.586**	1		.229
12. Air purification	.132	–.062	–.130	.192	–.242	.080	.046	.005	–.003	–.096	1	.241
13. Recreation	.126	–.220	–.345*	.354**	.040	.025	–.164	–.279*	–.003	.301*	.359**	.403**

*** p<0.01; * p<0.05; n=54*

The modern concept of ES implies that positive correlations among them indicate their synergy, while negative correlations indicate trade-offs between ES. This interpretation of correlations between ES identified on the national/sub-national scale is valid only in part. The existence of positive correlations between the volume of provided forest-related ES may indeed be interpreted as synergy, because they are performed by one type of ecosystem – forest ecosystems, and the preservation of these ecosystems simultaneously contributes to the performance of all these ES. However, when using these ES, conflicts can arise between them (for example, logging can reduce the possibility of collecting non-timber products, hunting, and regulating the water cycle).

Negative correlations between ES identified for the whole Russia or European Russia can reflect the fact that they are most likely performed by different types of ecosystems, located mainly in different ecoregions. Negative relationship between recreation ES and ES of runoff volume assurance indicates only that, in northern regions, where runoff volume is highest, there are relatively few cities. Negative correlations between the ES of livestock fodder production and ES of non-wood production as well as water-related ES reflect the fact that these ES are performed in the first case by grassy ecosystems and in the second by forest ecosystems. There may be a trade-off between these ES if there are large-scale changes in land cover and land use, e.g., during large-scale forest removal and the conversion of these areas into grassland communities or, the opposite, when meadows and steppe are overgrown by forest.

Negative correlations between carbon storage ES and forest-related ES in general cannot be interpreted as a trade-off. Bulk carbon stocks in European Russia in black earth regions have been accumulated for many centuries by the former ecosystems that have been transformed into agricultural fields today. Their current agricultural use leads to a loss of carbon, while the overgrowth of these fields by forest, to the contrary, might promote the preservation of carbon stock. That is, despite the negative correlation between the ES, we should rather expect their synergy, not a trade-off.

Synergy and trade-offs between ES might be strongest on the local scale within one landscape. The biological reason for trade-offs between different ES is the different response of biodiversity to management activities aimed at maintaining and using ES (Bukvareva, Zamolodchikov, 2018). For example, while maintaining regulating ES requires the preservation of undisturbed optimum levels of biodiversity, the use of provisioning ES associated with the removal of biomass from natural ecosystems “moves away” populations of commercial species from their optimal state (Bukvareva, Aleschenko , 2013) which affects the entire ecosystem.

6. Preliminary Approaches to the Inclusion of Ecosystem Assets and Ecosystem Services in the National Accounts of Russia

6.1. Physical indicators of ecosystem assets and ecosystem services

This section proposes the set of indicators for ES and ecosystem assets that were tested in TEEB-Russia 1 and 2. These indicators may be used to solve various tasks in the field of monitoring, assessment, and management of ecosystems and ES. Subsequently this set of indicators can be adjusted in accordance with the ideology of SEEA-EEA and the principles of the system of national accounts of Russia (see Section 6.3) and serve as the basis for proposals for the development of ecosystem accounting in Russia.

6.1.1. Indicators of ecosystem services

Ecosystem service indicators including the following groups of indices of ES quantity and volume (Bukvareva, Zamolodchikov, 2018).

a) **ES provided by ecosystems** corresponds to the ecosystems' potential ability to perform functions useful to humans and satisfy their needs. Provided ES volume is determined by natural factors and by the condition of ecosystems – the intensity and stability ecosystem functioning and the degree of disturbance. This indicator should be assessed considering the sustainable use of ecosystems and their components, i.e., it equals the volume of services, the potential use of which does not have a serious adverse effect on the ecosystems' structure and functioning (e.g., the volume of bioresources removed without disturbing the structure, reproduction and ecosystem functions of commercial populations).

b) **Demanded (required) ES** corresponds to the ES required to meet people's needs and the normal development of the economy in a specific area in the reporting period.

c) **Consumed ES** corresponds to the benefit that people and economic bodies derive from ES in the reporting period.

Ratios and differences between provided, demanded and consumed ES show **the degree of ES use** ($V_{consumed} / V_{supplied} \times 100\%$ or $V_{supplied} - V_{consumed}$), **the potential satisfaction of the demand for ES** ($V_{supplied} / V_{demanded} \times 100\%$ or $V_{demanded} - V_{supplied}$) and **the actual satisfaction of the demand for ES** ($V_{consumed} / V_{demanded} \times 100\%$ .or $V_{demanded} - V_{consumed}$) (Bukvareva et al., 2017).

Examples of provided, demanded, and consumed ES and of the ratios between them for different categories of ES could be found in volume 1 of the Prototype of the National Report (Bukvareva, Zamolodchikov, 2018). The proposed set of ES indicators conforms to guidance on SEEA EEA which separates provision of ES by ecosystems and ES consumption by people (System of Environmental-Economic…, 2014 b).

ES were evaluated by three methods in the TEEB-Russia project (Bukvareva, Zamolodchikov, 2018):

a) **direct quantitative evaluation** when statistical data are available on provided, demanded and consumed ES;

b) **indirect quantitative evaluation** based on a combination of other quantitative and cartographic data on regional ecosystems and economy;

c) **estimation of ES scores** if there is no data to evaluate an ES and it is only possible to estimate factors affecting it: scores of provided ES show the relative intensity of natural factors that determine the performance of ES; scores of demanded and consumed ES show the relative intensity of social and economic factors that determine the need for ES and their use (in TEEB-Russia 2 project, ES scores were not used to identify correlations between indicators).

The current state of state statistics in Russia and available scientific knowledge about provision of various categories of ES by ecosystems make it possible to start preparing for the implementation of SEEA-EEA in Russia. Today at least one third of ES can be quantified in physical indicators. Half of these ES may be directly estimated/accounted for on the basis of current statistics (Tab. 6.1.1.1). Another 1/3 of ES may be estimated in scores, but the appropriateness of using point scores in SEEA-EEA requires further discussion.

Two-thirds (17 of 25) of all quantitative indicators used to assess ES in the TEEB-Russia project were obtained from open databases of Federal State Statistics Service of RF and other agencies (Tab. 6.1.1.1). Table 6.1.1.2 lists the data sources for indirect quantitative ES assessment.

Table 6.1.1.1. Methods and indicators for ES assessment. Numbers in the column "ES" correspond to the assessment methods: 1 (green color) direct quantitative ES evaluation; 2 (light green) indirect quantitative ES evaluation; 3 (yellow) estimation of ES score; 4 (gray) statement of the task of ES assessment. The main data sources: ***FSSS*** *– Federal State Statistics Service;* ***FFA*** *– Federal Forest Agency;* ***HD*** *– Department of State Policy and Regulation of Hunting and Conservation of Hunting Resources;* ***UNFCCC*** *– reports by Russia to the UNFCCC;* ***MV*** *– map of vegetation of Russia (Bartalev et al., 2003, 2011).*

ES	*Indicators of provided ES (V_s)*	*Indicators of consumed ES (V_c)*	*Indicators of demanded ES (V_d)*	*Indicators of the degree of ES use or satisfaction of the demand for ES*
Productive (provisioning) ES				
Wood production (1)	Annual allowable cut (m^3/ha/yr) **FFA**	Logging volume (m^3/ha/yr) **FFA**	*Not assessed*	Degree of ES use (V_s–V_c) – unused residual of annual allowable cut (m^3/ha/yr)
Non-wood production of terrestrial ecosystems (1)	Biological stocks of mushrooms and berries (kg/ha)	Mushroom and berry harvest (kg/ha/yr)	*Not assessed*	Degree of ES use (V_c/V_s)100%) – the share of harvested mushrooms and berries of their stock (%)
Production of fodder on natural pastures (2)	Productivity of natural pastures, (kg/ha/yr of fodder units)	Amount of natural fodder eaten by livestock (kg/ha/year of fodder units)	*Not assessed*	Degree of ES use (V_c/V_s)100%) – share of natural fodder eaten by livestock (%)
Freshwater ecosystems' production, primarily fish (4) – *Not assessed*				
Game production (1)	Total numbers of game animals were used as a proxy (numbers/ha) **HD**	Game harvest (numbers/ha/yr) **HD**	*Not assessed*	Degree of ES use (V_c/V_s)100% – the the share of harvested game animals of their total number (%)
Production of honey in natural areas (4) – *Not assessed*				
Environment-forming (regulating) ES				
Carbon storage (1)	Total carbon content in phytomass and soil (tC/ha)	Carbon stores in managed forests (tC/ha) **UNFCCC**	*Not assessed*	Degree of ES use (V_c/V_s)100% – percentage of the regional carbon stock accounted in managed forests
Regulation of CO_2 flows (1)	Carbon balance (tC/ha/yr)	Carbon balance of managed forests (tC/ha/yr) **UNFCCC**	*Not assessed*	Degree of ES use (V_c/V_s)100% – percentage of the regional carbon balance attributed to managed forests
Biogeophysical climate regulation (4) – *Not assessed*				
Air purification by vegetation (absorption of pollutants by suburban forests) (2)	Maximum amount of pollutants that can be captured by vegetation from the air without significant damage to it (kg/ha/yr) **MV+ other data**	Amount of pollution actually captured by vegetation from the air (kg/ha/yr) **MV+ other data**	Toxic gas emissions (kg/ha/yr) **FSSS**	Satisfaction of the demand for the ES: a) (V_s/V_d)100% – percentage of pollutants absorbed by suburban forests (%), b) maximum percentage of emissions that can be potentially absorbed by suburban forests (%); c) remaining emissions that cannot be absorbed by suburban forests (kg/ha/yr)
Regulation of runoff volume (2)	Amount of runoff provided by the functioning of terrestrial ecosystems (m^3/ha/yr)	Use of freshwater (m^3/ha/yr) **FSSS**	*Not assessed*	Degree of ES use (V_s–V_c) – unused residue of "ecosystem" runoff (positive values) or the excess of water use over "ecosystem" runoff (negative values), m^3/ha/yr
Regulation of runoff variability (runoff stabilization) (2)	Ecosystem regulation of runoff variability (mm; score)	Regional GDP per unit of area of a region as a proxy of prevented damage (RUB/ha/yr; score) **FSSS**		The balance of natural and socio-economic factors – difference between scores V_s–V_c
Water quality assurance by terrestrial ecosystems (2)	Amount of potentially purified runoff (m^3/ha/yr) **MV+ other data**	Amount of purified runoff (m^3/ha/yr) **MV+ other data**	Volume of polluted runoff (m^3/ha/yr)	Satisfaction of the demand for the ES (V_d–V_s) – residual unpurified runoff (m^3/ha/yr); Degree of ES use (V_c/V_s)100% – actual purified runoff as a percentage of potentially purified runoff (%)

ES	*Indicators of provided ES (V_s)*	*Indicators of consumed ES (V_c)*	*Indicators of demanded ES (V_d)*	*Indicators of the degree of ES use or satisfaction of the demand for ES*
Water quality assurance by freshwater ecosystems (2)	The volume of wastewater that can potentially be diluted and purified to a safe concentration (m^3/ha/yr)	The volume of purified and diluted wastewater (m^3/ha/yr)	Discharge of polluted wastewater (m^3/ha/yr) **FSSS**	Satisfaction of the demand for the ES (V_s–V_d) – untreated wastewater remainder (negative values) or unused capacities of ecosystems to purify wastewater (positive values), m^3/ha/yr
Soil protection from water erosion (3)	The amount of soil erosion avoided due to terrestrial ecosystems (t/ha) **MV + other cartographic data**	– Proportion of crop area **FSSS** – Proportion of area with eroded agricultural lands in regions		Balance of natural and socioeconomic factors – difference between scores (V_s–V_c)
Soil protection from wind erosion (3)	Proportion of natural ecosystem area in 1-km-wide buffer zones around croplands **MV**			
Prevention of damage from soil washing into water bodies (4) – *Not assessed*				
Prevention of damage from landslides and mudflows (4) – *Not assessed*				
Formation of soil bioproductivity (4) – *Not assessed*				
Self-purification of soils (3)	Capacity for soil self-cleaning	– Population density **FSSS** – Proportion of crop area **FSSS** – Proportion of polluted area		The balance of natural and socio-economic factors – difference between scores (V_s–V_c)
Regulation of cryogenic processes (2)	Change in surface temperature without vegetation and snow cover (°C)	Anthropogenic heating of permafrost (°C)	*Not assessed*	Degree of ES use (V_s–V_c)) – unused residue of ecosystem capacity to protect permafrost or the excess of anthropogenic heating over "ecosystem" capacity (°C)
Ecosystem regulation of species with economic importance (agricultural and forest pests) (4) – *Not assessed*				
Pollination of farm crops (3)	Pollination potential **MV**	The proportion of the area of entomophilous cultures **FSSS**		The balance of natural and socio-economic factors – difference between scores (V_s–V_c)
Ecosystem regulation of species with medical, biomedical and veterinary importance (4) – *Not assessed*				
Informational ES				
Genetic resources of wild species and populations (3)	– Plant species richness – Proportion of natural ecosystems area **MV**	– Population density **FSSS** – Road density **FSSS** – Research costs **FSSS**		The balance of natural and socio-economic factors – difference between scores (V_s–V_c)
Information on the structure and functioning of natural systems that can be used by humans (3)	– Diversity of ecosystems – Proportion of natural ecosystems area **MV**	– Population density **FSSS** – Road density **FSSS** – Research costs **FSSS**		The same
Aesthetic and educational importance of natural systems (3)	– Diversity of ecosystems – Proportion of natural ecosystems area **MTE**	– Population density **FSSS** – Road density **FSSS**		The same
Ethical, spiritual and religious importance of natural systems (4) – *Not assessed*				
Recreational ES – formation of natural conditions for recreation				
Formation of natural conditions for weekend recreation (2)	The number of people who can recreate in the suburban forests on weekends	– Population density **FSSS** – Road density **FSSS**		The balance of natural and socio-economic factors – difference between scores (V_s–V_c)
Daily and weekend recreation, recreation at summer cottages (3)	– Comfort of natural conditions for people – Nature degradation			
Educational and active tourism in the nature (3)	– Comfort of natural conditions for people – Nature degradation – Landscape diversity	– Urban population **FSSS** – Road density **FSSS** – Density of natural history museums – Tourist infrastructure		The same
Resort recreation (except seacoasts) (4) – *Not assessed*				

*Table 6.1.1.2. Data used for indirect ES evaluation. Data types: ■ – cartographic materials; ▲– statistical data; ●– coefficients and equations. Data sources: **FSSS** – Federal State Statistics Service; **FSHEM** – Federal Service for Hydrometeorology and Environmental Monitoring; **MV** – map of vegetation of Russia (Bartalev et al., 2003, 2011); **LRR** – database "Land Resources of Russia" (Stolbovoi and McCallum, 2002); **ND** – normative documents of the Russian Federation; **L** – data from literature.*

ES indicators	*Data for indirect evaluation*
Production of fodder on natural pastures	
Supplied ES Productivity of natural pastures, (kg/ha/yr of fodder units)	■ Map of agricultural regions where natural pastures are used **LRR** ■ Map of net primary production **LRR** ● Conversion factor of net primary production to conditional fodder units **ND**
Consumed ES Amount of natural fodder eaten by livestock (kg/ha/year of fodder units)	■ Map of agricultural regions where natural pastures are used **LRR** ▲ The numbers of cattle, sheep, goats, deer and reindeer per region **FSSS** ● Conversion factor of numbers of cattle, sheep, goats, deer and reindeer to conditional livestock units **FSSS** ● Fodder consumption rate per livestock unit **FSSS**
Air purification by suburban forests	
Supplied ES Maximum amount of pollutants that can be captured by vegetation from the air without significant damage to it (kg/ha/yr)	■ Area of suburban forests **MV** ● The maximum amount of toxic gases that forest can absorb **L**
Consumed ES Amount of pollution actually captured by vegetation from the air (kg/ha/yr)	■ Area of suburban forests **MV** ● The average amount of toxic gases that forest can absorb **L**
Demanded ES Toxic gas emissions (kg/ha/yr)	▲ Direct data per region **FSSS**
Regulation of runoff volume	
Supplied ES Amount of runoff provided by the functioning of terrestrial ecosystems (m^3/ha/yr)	■ Map of total runoff **LRR** ■ Map of underground runoff **LRR** ■ Map of precipitation **LRR** ■ Map of evapotranspiration **LRR** ● Water balance equation **L**
Consumed ES Use of freshwater (m^3/ha/yr)	▲ Direct data per region **FSSS**
Water quality assurance by terrestrial ecosystems	
Supplied ES Amount of potentially purified runoff (m^3/ha/yr)	■ Area of agriculture fields, grasslands and forests **MV** ▲ The ability of different land cover types to retain rainwater pollutants **L**
Consumed ES Amount of purified runoff (m^3/ha/yr)	■ Area of agriculture fields, grasslands and forests **MV** ● The ability of different land cover types to retain rainwater pollutants **L** ● Percentage of persistently polluted area for regions **L**
Demanded ES Volume of polluted runoff (m^3/ha/yr)	■ Map of surface runoff **LRR** ● Percentage of persistently polluted area for regions **L** ● Maximum allowable concentrations for fishery water bodies **ND** ● Concentrations of pollutants in surface runoff from developed surfaces **ND**
Water quality assurance by freshwater ecosystems	
Supplied ES The volume of wastewater that can potentially be diluted and purified to a safe concentration (m^3/ha/yr)	■ Map of runoff **LRR** ● Equation of dynamics of pollutant content in water bodies **L** ● Water self-purification constants **L** ● Flow time from headwaters to river mouth **L**
Consumed ES The volume of purified and diluted wastewater (m^3/ha/yr)	is determined by the ratio of ES supply to demand in the regions
Demanded ES Discharge of polluted wastewater (m^3/ha/yr)	▲ Direct data per region **FSSS** ● Maximum allowable concentrations for fishery water bodies **ND**
Regulation of cryogenic processes	
Supplied ES Change in surface temperature without vegetation and snow cover (°C)	▲ Duration of cold and warm periods **FSHEM** ▲ Surface temperature of the vegetation/snow cover **FSHEM** ▲ Surface temperature of the soil **FSHEM** ● Equation of temperature fluctuations on the surface of vegetation/snow cover and on the soil surface **L**
Consumed ES Anthropogenic heating of permafrost (°C)	■ Map of permafrost temperature **LRR** ■ Map of ice content in permafrost **LRR** ▲ Consumption of electricity per region **FSSS** ● Equation of amount of heat necessary to melt ice per unit of soil volume **ND**

6.1.2. Indicators of ecosystem assets

Indicators of ecosystem assets analyzed in TEEB-Russia 1 and 2 on the national and sub-national (European Russia) scales include the following basic groups of indices.

1) Extent of ecosystem assets: area of ecosystems (indices for fragmentation are important for more detail management levels – local and, possibly, regional). The accounting of area of ecosystems may be based on a regularly updated map of vegetation of Russia (Space Research Institute of the Russian Academy of Sciences). Currently, this map makes it possible to calculate area of 22 classes of land cover, which is sufficient to begin accounting of ecosystem assets on the national level in Russia.

2) Condition (quality) of ecosystem assets:

– ecosystem functioning – productivity and phytomass of ecosystems (accurate assessments require the use of actual updated indices of ecosystem phytomass and productivity);

– biodiversity – number of bird and plant species (opportunities to use other taxonomic groups as biodiversity indicators require separate analysis).

Table 6.1.2.1 presents the indicators that can be currently used in Russia to account for the condition of ecosystem assets

Table 6.1.2.1. A list of indicators of ecosystem assets condition at the national level in Russia and the main possible data sources for their assessment (marine ecosystems are not considered).

Indicators	*Data sources*
Area and the degree of ecosystem disturbance	
Area of ecosystems	– Vegetation map (regular updates required) – Remote sensing data
Fragmentation of natural ecosystems	
Biomass and productivity	
Phytomass of ecosystems	Remote-sensing data
Wood stock	Federal Forestry Agency of RF
Ecosystem productivity	Remote-sensing data
Biodiversity	
Diversity of ecosystems	– Vegetation map (regular updates required) – Remote sensing data
Species diversity of birds	– Atlas of breeding birds of European Russia – Regional and local surveys – for the Asian part of Russia
Species diversity of vascular plants	– For Central Federal District – projects "Flora of the Oka Basin" and "Flora of the Central Black Earth Region" – For the rest of country – local surveys
Species diversity in PAs	Ministry of Natural Resources and Ecology of RF
The number of Red List species	Ministry of Natural Resources and Ecology of RF
Abundance and diversity of game animals	Ministry of Natural Resources and Ecology of RF
Abundance and diversity of freshwater commercial fish	Federal Agency for Fisheries of RF
Abiotic indicators	
Runoff volume	Federal Service for Hydrometeorology and Environmental Monitoring
Runoff variability	
Pollution	
Air pollution	– Federal State Statistics Service – Federal Service for Hydrometeorology and Environmental Monitoring
Water pollution	
Soil pollution	

6.1.3. Significance of relationships between indicators for ecosystem accounting

6.1.3.1. Overview of modern concepts of the relationship between biodiversity and ecosystem functions and services

There is now general scientific consensus that biodiversity is one of the key factors in determining the mean level and stability of ecosystem functioning (EF), such as biomass production, decomposition and carbon sequestration. The impacts of diversity loss on ecological processes are of comparable magnitude to the effects of other global drivers of environmental changes such as climate change, ultraviolet radiation, increase in the concentration of CO_2, nitrogen addition, droughts and fires. Biodiversity loss impairs ecosystem functioning and, hence, ES (IPBES, 2018, Section 3.2, pp. 196–205).

There is also increasing information regarding the dependence of ES on biodiversity. However, for many ES the nature of their dependence on biodiversity remains unclear, including examples of both positive and negative relationships, or data are insufficient for a definite conclusion. Differences between the "biodiversity – EF" and "biodiversity – ES" relationships are determined by human perception of the benefits derived from nature. For example, the aesthetic importance of a landscape is a function of opportunities to view it, and the most attractive to people the so-called "cultural landscapes" along with natural ecosystems should include human settlements, architectural and agricultural components, the presence of which, obviously, reduces the functioning of the natural ecosystems of this landscape. However, despite the lack of clarity with respect to certain ES, it is obvious that long-term support for the entire ES complex also requires preservation of biodiversity (IPBES, 2018, Section 3.2, pp. 196–205).

Maintaining EF and ES require preservation biodiversity on all hierarchical levels – genetic and phenotype diversity within populations and species, species diversity within ecological communities, and ecosystem diversity in the landscape and region (IPBES, 2018, Section 3.2.4, pp. 202–203; Shin, Y.–J. et al., 2019, Section 4.2.1). TEEB-Russia project considered indicators only of species diversity exemplified by birds and higher plants, thus, further review focuses to this level of diversity.

The causal relationship of EF and ES on species diversity, i.e., the effect of species number on EF and ES, is manifested at the level of individual biocenoses and ecosystems (Bukvareva, Aleshchenko, 2013; Bukvareva, 2018). This means that the functioning of a particular biocenosis or ecosystem weakens and destabilizes in case of loss of species. On larger scales these causal effects are clouded by correlation between indicators of biodiversity, EF and indicators of climatic and geographical conditions over large areas, as was shown in Sections 5.1 and 5.2 of this report for European Russia and the whole Russia.

Within one landscape with uniform relief (plain or montane) and a homogeneous climate there is a mosaic of biocenoses (natural ecosystems) – various types of forests, grasslands, marshes, water bodies, etc. These biocenoses are, to varying degrees, disturbed by humans. (as a result of clear cutting, draining marshes, cattle grazing, recreation, etc.) and are at different stages of anthropogenic or natural succession. The effect of species diversity on EF and ES can be detected within a landscape when comparing biocenoses of the same type, disturbed to different degrees (or during special experiments which has been done in hundreds of works – see overviews: Bukvareva, Aleshchenko, 2013; IPBES, 2018, Section 3.2, pp. 196–205).

According to the principle of optimum biodiversity (Bukvareva, Aleshchenko, 2013), undisturbed climax biocenoses have near-optimum biodiversity level that ensures maximum EF values. Anthropogenic deviations from optimum biodiversity (in most cases this means a decrease in biodiversity indices) lead to EF weakening and destabilization. Thus, when comparing ecosystems of the same type within the same landscape, species diversity can serve as a direct indicator for decision-making, since a decrease in it indicates a weakening of the EF and ES of this ecosystem.

When comparing ecosystems of different types (for example, swamps and forests) even within the same landscape, the species diversity criterion no longer works, since different biocenoses are adapted to different local conditions and have different optimal levels of biodiversity. For example, species diversity typical for peat bogs is far lower than that for a mixed forest, but this does not mean that peat bogs are less valuable for maintaining ES. In general, biocenoses (ecosystems) adapted to scarce or unstable conditions have a relatively lower species diversity, however, such a level of biodiversity is optimal under these conditions and ensures the most efficient functioning of such ecosystems (Bukvareva, Aleschenko, 2013).

An important indicator of ecosystem assets is also the diversity of the ecosystems themselves within the landscape or region, which must also be preserved.

Intrapopulation (genetic and phenotypic diversity within populations) and intraspecific diversity (local populations, ecological and morphological forms within species) are also critical to adaptability of populations and species and to their long-term survival under changing conditions (IPBES, 2018, chapter 3.2.4, p. 202). Accounting for and monitoring of intrapopulation and intraspecific diversity is critical for the following categories of species:

– species that are direct suppliers of ES – species of trees of forestry importance, commercial species of animals (fish, hunting animals and birds), pollinators, etc.;

– edificator and key species which directly determine the functioning and sustainability of ecosystems;

– rare and endangered species.

6.1.3.2. Significance of correlations identified in TEEB-Russia for ecosystem accounting in Russia

Fig. 6.1.3.2.1 and 6.1.3.2.2 show the interrelationships between indicators of climatic conditions, ecosystem assets, and ES identified on the national and sub-national (European Russia) scales of analysis. This set of indicators includes the following categories:

a) indicators of climatic conditions: average annual temperature and average annual amount of precipitation (based on data of Land Resources of Russia, Stolbovoi, McCallum, 2002);

b) indicators of the condition of ecosystem assets – phytomass and productivity of natural ecosystems (Section 3.1.3), indices of plant and bird species richness (Sections 3.2 and 3.3);

c) an indicator of the area of ecosystem assets, expressed in this project as an index that is the inverse of the area of natural ecosystems, i.e., the share of the area of transformed ecosystems (Section 3.1.1);

d) indicators of four groups of ES which were quantitatively assessed in TEEB-Russia 1 and TEEB-Russia 2 projects:

– forest-related provisioning ES (wood, non-wood and game production);

– water-related ES (runoff volume assurance by terrestrial ecosystems, runoff quality assurance by terrestrial ecosystems, water purification in natural water bodies);

– ES associated primarily with non-forest ecosystems (production of livestock fodder in natural pastures, carbon storage);

– ES of pollination of farm crops by wild pollinators as an example of an ES associated with farm fields.

Relationships between climatic conditions and indicators of ecosystem assets (Fig. 6.1.3.2.1) were discussed in detail in Section 5.1; relationships between indicators of ecosystem asset and ES (Fig. 6.1.3.2.2) were discussed in Section 5.2.

At this stage in the studies, indicators of ecosystem functioning (productivity and phytomass of natural ecosystems, Section 3.1.3) and indicators of plant and bird species richness were used as indicators of the condition of ecosystem assets. Later, more accurate assessments of the condition of ecosystem assets will require the use of actual values of phytomass and productivity which reflect ongoing changes in ecosystems condition. Biodiversity indices must be supplemented by biodiversity indices on other hierarchical levels – indicators of intraspecific and intrapopulation diversity for the most important species and indicators of ecosystem diversity on the landscape and regional levels of analysis (Section 6.1.3.1).

The index of the degree of territory transformation reflects anthropogenic changes in the area of ecosystems. Obviously, the anthropogenic impact involves not just changes in ecosystems area, but also a change in the condition of ecosystem assets – indices of phytomass, productivity, and species abundance and richness – but these effects were not analyzed in the TEEB-Russia 1 and 2 projects and must be analyzed in the future.

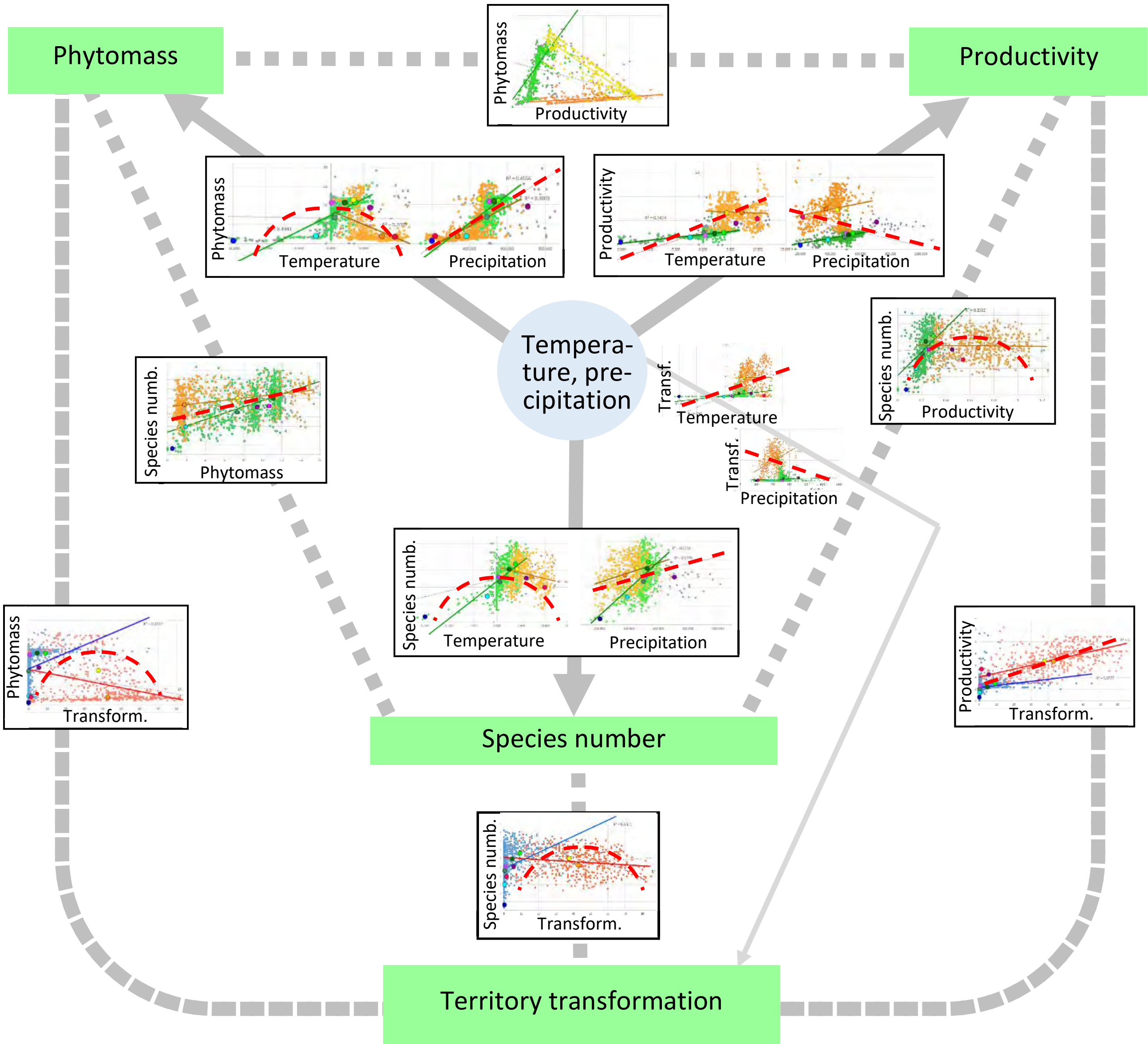


Figure 6.1.3.2.1. Relationships between indicators of ecosystem assets and climatic conditions identified at the national/subnational level

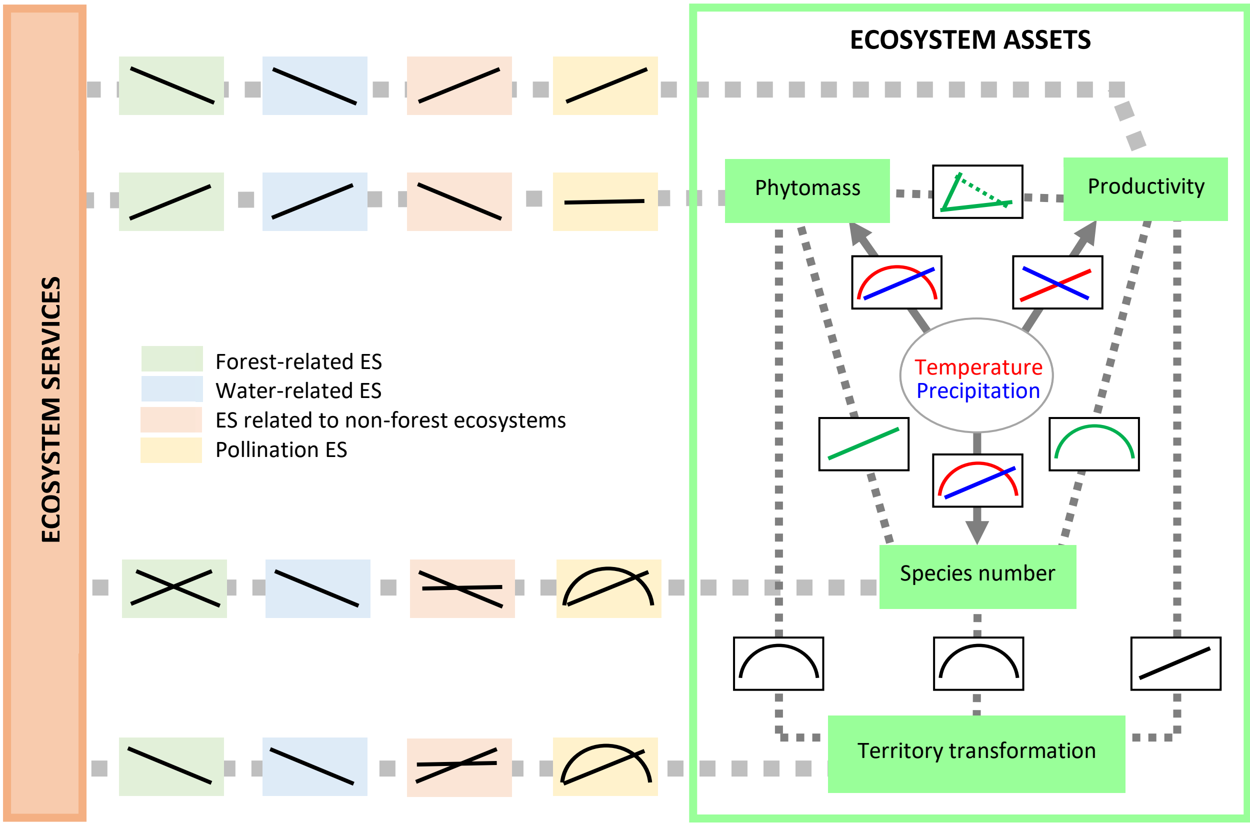


Figure 6.1.3.2.2. Relationships between indicators of ecosystem assets and ES identified at the national/subnational level. The gray arrows show the impact of climate parameters on ecosystem assets. The dashed lines show correlations between indicators of ecosystem assets and ES; in the rectangles located on the dashed lines, the nature of the revealed correlations is shown in a generalized form. The nature of correlations for ES related to agricultural fields and cities is not shown in the diagram.

A preliminary analysis of the revealed correlations allows us to draw the following conclusions, which can be useful for the development of ecosystem accounting in Russia.

Conclusion 1. Correlations between indicators do not always reflect real causal relationships, which can be the basis for decision making.

The interpretation of the values of indicators for ecosystem assets and ES must considers relationships between them. In particular, it is necessary to clearly understand whether the revealed relationships between indicators reflect causal relationships that must be taken into account when making decisions, or whether these dependencies are only a result of reaction of analyzed indicators to changes in other factors.

Figures 6.1.3.2.1 and 6.1.3.2.2 show relationships between indicators of climatic conditions, ecosystem assets, and ES identified on the national and sub-national (European Russia) scales of analysis. Solid arrows show relationships that are assumed to be causal relationships on the national and sub-national (European Russia) scales within TEEB-Russia 1 and 2 projects. Dotted lines show correlations between indicators, determined mainly by a change in indicators in response to the action of the third factor, although in some cases also include causal relationships.

This study assumes that climate parameters are external, i.e., ecosystems do not influence them. This assumption is made because analyzed climate-regulating ES of carbon storage and the regulation of greenhouse gas flows act on a global scale, i.e., they affect Russia's climate indirectly – through global climate changes. The influence of ecosystems on the climatic indicators of the regions of Russia is determined by biogeophysical climate regulating ES, which at this stage of the study were not evaluated (Bukvareva, Zamolodchikov, 2018). Valuation of biogeophysical ES of Russian ecosystems is a key task for future assessments, both on the national, and on the regional/ local levels.

Accounting for the impact of climatic conditions on the degree of territory transformation, i.e., actually, on the degree of agricultural development (the thin arrow on Fig. 6.1.3.2.1) should probably not be considered a task of ecosystem accounting. Moreover, as stated in the Section 5.1.3, the impact of climate on the degree of territory transformation replicates the impact of climate on ecosystem productivity. A close positive relationship between productivity and the degree of territory transformation is included in the general analysis of the relationships between indicators, therefore, we do not consider the dependence of the degree of territory transformation on climatic indicators in this section.

It should be emphasized that at the local level, these relationships may be different. In particular, at the local level, between indicators of biodiversity and indicators of ecosystem functions and services, causal relationships should be expected (Section 6.1.3.1).

On the national and sub-national levels of analysis in Russia correlations between indicators of ES and ecosystem assets in many cases reflect not a causal relationship, but simultaneous change of indicators depending on climatic conditions and the degree of anthropogenic transformation of the territory, which itself depends on climatic conditions. This pertains to the following correlations:

a) *correlations between indicators of ecosystem assets and climatic conditions* (Fig. 6.1.3.2.1):

– a positive relationship between the number of species and ecosystem phytomass (Section 5.1.8);

– a positive or unimodal relationship between the number of species and ecosystem productivity (Section 5.1.8);

– a negative relationship between ecosystem productivity and phytomass for European Russia and for the forest steppe ecoregion and positive relationships for the remaining ecoregion groups (Section 5.1.9);

– a positive or unimodal relationship between the number of species and the degree of territory transformation (Section 5.1.6);

– a negative or unimodal relationship between the ecosystem phytomass and the degree of territory transformation (Section 5.1.7);

– a positive relationship between ecosystem productivity and the degree of territory transformation (Section 5.1.7);

b) *correlations between indicators of ecosystem assets and ecosystem services* (Fig. 6.1.3.2.2):

– correlations of ES with ecosystem functioning indices: for forest- or water-related ES – negative correlations with ecosystem productivity and positive correlations with ecosystem phytomass; for ES related to non-forest ecosystems and farm fields, by contrast, positive correlations with ecosystem productivity and negative (or no) relationships with ecosystem phytomass (Section 5.2.5);

– correlations of ES with species richness: negative for water-related ES and positive for ES related to farm fields and cities (Section 5.2.4);

– correlations of ES with the degree of territory transformation: negative for water-related ES and positive for carbon storage ES (Section 5.2.3).

These correlations cannot be a direct basis for decision making. For example, the positive correlation between the degree of territory transformation and biodiversity does not allow us to conclude that the plowing of the territory will lead to an increase in biodiversity. Another example: the negative correlation between biodiversity and water-related ES does not indicate that a decrease in biodiversity will improve the delivery of these ES.

However, for a number of ES, correlations with the degree of territory transformation (i.e., also with the area of natural ecosystems) are also partially determined by the casual dependencies of ES indicators on the area of natural ecosystems or the area of agricultural fields (Section 5.2. 3, Tab. 5.2.3.1). This pertains to the following ES:

– forest-related provisioning ES (wood, non-wood and game production);

– production of livestock fodder at natural pastures;

– runoff quality assurance by terrestrial ecosystems;

– soil erosion prevention;

– farm crop pollination by wild pollinators;

– creating conditions for weekend recreation;

– air purification by suburban forests.

However, in these cases, causal relationships only partially explain the revealed correlations; therefore, it is necessary to make managerial decisions considering regional differences in natural and socio-economic conditions (see below).

Conclusion 2. There are bundles of indicators similarly correlating with other factors.

Analysis of revealed correlations allows preliminary identification of indicator complexes on the sub-national (European Russia) scale, systems of indicators of ecosystem assets and ES that change similarly in response to changes in other factors. Such a group is, in particular, formed by indicators of species richness and phytomass, which are positively related both in European Russia as a whole, and for group of northern, forest and mountain ecoregions and group of southern ecoregions (Section 5.1.8). These indicators depend similarly both on climatic conditions and on the degree of territory transformation, as seen on the general diagram in Fig. 6.1.3.2.1:

– species richness and phytomass positively depend on temperature in the group of northern, forest and montane ecoregions and negatively in the group of southern ecoregions, resulting in the unimodal relationship in the whole European Russia; species richness and phytomass positively depend on precipitation in both groups of ecoregions, and the dependence for the whole European Russia is also positive (Sections 5.1.4 and 5.1.5);

– species richness and phytomass positively correlate with the degree of territory transformation in the group of slightly transformed ecoregions and negatively or not at all in the group of heavily transformed ecoregions, resulting in the unimodal relationship in the whole European Russia (Sections 5.1.6 and 5.1.7).

Ecosystem productivity correlates with climate and territory transformation differently than phytomass and species richness:

– productivity almost does not depend on temperature within the group of northern, forest and mountain ecoregions and within the group of southern ecoregions, but in general a positive dependence is formed in European Russia; productivity positively depends on precipitation within both groups of ecoregions, but in general a negative relationship is formed in European Russia (Section 5.1.5);

– productivity and the degree of territory transformation are positively related both for European Russia as a whole and within the groups of heavily and slightly transformed ecoregions (Section 5.1.7).

However, at this stage of the research, it cannot be concluded yet that a change in one indicator may indicate similar changes in other indicators included in such a complex, since, as mentioned above, the revealed correlations are determined, for the most part, not by cause-effect relationships, but by the reaction of indicators to third factors. Further research is needed.

Among ES indicators analyzed in this study, the following three sets of indicators can be preliminarily distinguished:

1) ES to some degree related to forest (forest-related provisioning ES, water-related regulating ES, and soil erosion prevention ES). On the national and sub-national scales, they are similarly related to indicators of ecosystem assets (Fig. 6.1.3.2.2):

– negatively with the degree of territory transformation (Section 5.2.3);

– negatively with productivity of natural ecosystems (Section 5.2.5);

– positively with phytomass of natural ecosystems (Section 5.2.5).

1) ES mostly related to non-forest ecosystems (livestock fodder production and carbon storage) which in a number of cases are associated with indicators of ecosystem assets opposite to forest-related ES (Fig. 6.1.3.2.2):

– positively (or not at all) with the degree of territory transformation (Section 5.2.3);

– positively with productivity of natural ecosystems (Section 5.2.5);

– negatively with phytomass of natural ecosystems (Section 5.2.5).

3) ES associated with arable lands or cities (pollination, air purification by suburban forests, creating conditions for weekend recreation, see Section 4.1.9). Since these ES are provided by ecosystems not everywhere, but only in buffer zones around fields and cities, their correlations with other indicators within European Russia largely depend on the spatial distribution of cities and fields.

Obviously, the relationship of various ES complexes with different types of ecosystems is not absolute but reflects the relative distribution of ES volume provided by different ecosystems. Nevertheless, the consideration of this factor may be useful in the formation of ecosystem accounting in Russia.

Conclusion 3. The interpretation of the identified correlations between indicators of ecosystem assets and ES depends on the scale of the analysis.

The structure and sets of indicators and their interpretation on the national/sub-national level must consider the probability of a substantial change in relationships between indicators on other management levels. Relationships among indicators of ecosystem assets and ES may vary on different scales of analysis and management levels up to a change of sign.

When moving from the level of the whole country or European Russia to level of a group of ecoregions or individual ecoregion, positive dependencies can change to negative, and vice versa. The absence of correlations for the territory of the whole country or European Russia does not mean the absence of correlations between the same parameters within groups of ecoregions, and vice versa (Tab. 6.1.3.2.1).

Table 6.1.3.2.1. Examples of inconsistencies in dependencies identified across whole Russia or European Russia and within groups of ecoregions.

Correlation	*Relationship on the national or sub-national (European Russia) scale*	*Relationship within the group of northern, forest, and montane ecoregions* or the group of slightly transformed ecoregions***	*Relationship within the group of southern ecoregions *** or the group of heavily transformed (agricultural) ecoregions*****	*Section*
plant and bird species richness – degree of territory transformation	positive or unimodal	positive	none	5.1.6
phytomass of ecosystems – degree of territory transformation	negative or unimodal	positive	negative	5.1.7
plant and bird species richness – productivity of ecosystems	positive or unimodal	positive	none	5.1.8
Phytomass of ecosystems – productivity of ecosystems	negative	positive	positive (for forest-steppe – negative)	5.1.9
water-related ES – plant and bird species richness	negative or unimodal (montane regions are excluded)	negative	positive	5.2.4
pollination ES – bird species richness	positive or unimodal	positive	none	5.2.4
ES of runoff volume assurance – productivity of ecosystems	negative	negative	none	5.2.5
ES of runoff volume assurance – phytomass of ecosystems	positive or unimodal	negative	positive	5.2.5
pollination ES – productivity of ecosystems	positive or unimodal	positive	none	5.2.5

**The northern, forest, and montane ecoregions group includes Arctic deserts, tundra, northern taiga, southern taiga, mixed forests, the Urals, and the Caucasus.*

*** The slightly transformed ecoregions group includes Arctic deserts, tundra, northern taiga, southern taiga, mixed forests, the Urals, the Caucasus, and semi-desert.*

****The southern ecoregions group includes forest steppe, steppe and semidesert.*

*****The heavily transformed (agricultural) ecoregions group includes forest steppe and steppe.*

Although correlations between indicators of ecosystem assets and ES on the national and sub-national scales cannot be a direct basis for management decisions, at the local level, causal relationships should be expected that reflect the impact of biodiversity on ecosystem functioning and ES (Section 6.1.3.1).

Dependencies and their interpretations on one scale of analysis therefore cannot be directly transferred to other scales.

Conclusion 4. A regionally differentiated approach to the selection and interpretation of indicators should be applied.

Structure of sets of indicators, and their interpretation should be regionally differentiated, that is, they should consider differences in the structure and functioning of ecosystems in regions with different natural conditions and varying degrees of anthropogenic transformation. In all the analyzed cases, significant differences were found between the average values of indicators of ecosystem assets and ES for different ecoregions. In some cases, differences in the nature of correlations between indicators in different groups of ecoregions were found.

Overall, lower levels of species diversity, phytomass and productivity of ecosystems are typical for regions with harsher conditions – northern and arid. However, this does not mean that ecosystem assets (ecosystems) of these regions are less valuable for preserving biodiversity and performing ES, since relatively low biodiversity and phytomass in undisturbed ecosystems are adaptation to severe climatic conditions are adaptation to severe climatic conditions and ensure optimal functioning of such ecosystems (see Section 6.1.3.1).

By the nature of relationships between indicators of environmental conditions, ecosystem assets and ES, two main groups of ecoregions can be distinguished in European Russia: a) northern, forest and mountainous (Arctic deserts, tundra, northern taiga, southern taiga, mixed forests, Urals, Caucasus); b) southern ecoregions (forest-steppe, steppe, semi-desert). Differences in correlations between indicators within these groups were revealed for correlations between the following indicators (see also Tab. 6.1.3.2.1):

– the degree of territory transformation and climate indices (Fig. 5.1.3.4);
– the number of bird species and average annual temperature (Fig. 5.1.4.3 a);
– ecosystem phytomass and average annual temperature (Fig. 5.1.5.4 a);
– ecosystem productivity and climate indices (Fig. 5.1.5.5);
– bird species number and ecosystem productivity (Fig. 5.1.8.4 b);
– ecosystem phytomass and productivity (Fig. 5.1.9.2);
– ES of runoff volume assurance by terrestrial ecosystems and bird species number (Fig. 5.2.4.3);
– carbon storage ES and bird species number (Fig. 5.2.4.4);
– pollination ES and bird species number (Fig. 5.2.4.5);
– ES of runoff volume assurance by terrestrial ecosystems and ecosystem productivity (Fig. 5.2.5.3 b);
– ES of runoff volume assurance by terrestrial ecosystems and ecosystem phytomass (Fig. 5.2.5.4 b; 5.2.5.5 b);
– carbon storage ES and ecosystem phytomass (Fig. 5.2.5.8 b);
– pollination ES and ecosystem productivity (Fig. 5.2.5.9 b);
– pollination ES and ecosystem productivity (Fig. 5.2.5.10 b).

The numerous differences listed above in the nature of correlations reflect the fundamental differences in the structure and functioning of forest and grassy ecosystems, which must be considered when assessing ecosystem assets and services. Ecosystems in forest and grassland ecoregions must be managed differently. Management approaches in ecoregions such as forest-steppe, which are a mosaic of forest and grassy (now in most plowed) plots, should be developed at a more local (than the whole ecoregion) level and consider the spatial structure of forest and non-forested plots. Perhaps the same applies to part of the ecoregion of mixed forests.

Specific values and relationships for several indicators have been identified for mountain ecoregions. Mountain regions are characterized by the highest values of species richness of plants, although such a pattern for birds was not revealed in any of the analyzed scales (see Sections 5.1.6, 5.1.8, 5.2.4). The high species richness of higher plants can probably be explained by the influence of the relief on the diversity of habitats and biocenoses. Mountain regions differ significantly from the plains also in higher indices of several ES, the provided volume of which substantially depends on the characteristics of the relief, for example, erosion prevention (Fig. 5.2.3.5) and aesthetic value of ecosystems and landscapes (Fig. 5.2.3.9).

Significant differences were found between ecoregions weakly transformed by humans (northern, forest, mountain ecoregions and semi-desert) and heavily transformed agricultural regions (forest steppe, steppe). Anthropogenic transformation changes the structure and functioning of ecosystems. Therefore, it is necessary to take into account the differences between relatively weakly transformed ecoregions and strongly transformed agricultural ecoregions, for which there are different relationships between the degree of territory transformation and other indicators of the condition of ecosystem assets (indicators of biodiversity and ecosystem functioning, Sections 5.1.6, 5.1.7) and between the degree of territory transformation and ES (Section 5.2.3; Tab. 6.1.3.2.1).

6.1.4. Spatial units for accounting for ecosystem services and assets

The guidelines of Experimental Ecosystem Accounting (System of Environmental-Economic…, 2014) propose identifying three interrelated groups of spatial accounting units. These include, in increasing hierarchical order:

1) basic spatial units (BSU);
2) land cover/ecosystem functional units (LCEU);
3) ecosystem accounting units (EAU).

The results of TEEB-Russia 1 and 2 projects allow us to propose a preliminary list of possible spatial units for their further discussion in preparation for ecosystem accounting in Russia (Tab. 6.1.4.1).

Table 6.1.4.1. Spatial units for ecosystem accounting in Russia.

Groups of spatial accounting units	*Examples of spatial accounting units*
Basic spatial units (BSU)	– Pixels on the vegetation map of Russia (1 km in TEEB-Russia 1 and 250 m in TEEB-Russia 2)* – Minimum polygons of land cover in Open Street Maps layers – Minimum plots of the Land Cadaster
Land-cover/ecosystem functional units (LCEU)	– Plots of homogeneous ecosystems identified on the map of terrestrial ecosystems of Russia * – Polygons of uniform land cover in layers of Open Street Maps*
Ecosystem accounting units (EAU).	– Russian Federation* – subjects of RF* – Administrative districts – Municipalities – Specially protected nature areas

*used in TEEB-Russia 1 and 2 projects.

6.2. Pilot economic valuation of ecosystem services and ecosystem assets in Russia

This section presents the results of a preliminary economic valuation of ES quantified in physical indicators in TEEB-Russia 1 and 2 projects (Section 6.2.2). Next, based on the economic valuations, an attempt was made to analyze various approaches to valuate ecosystem assets which provide these ES (Section 6.2.3). The development of a conceptual apparatus for assessing ES and ecosystem assets is now far from finish (Section 6.3), and economic valuations of ES and ecosystem assets performed in TEEB-Russia project differ substantially from the principles of the System of National Accounts (System of National Accounts..., 2009) and the Central Framework of the System for Environmental Economic Accounting (System of Environmental Economic…, 2014 a). Nevertheless, the analysis of possible approaches to assessing ES and ecosystem assets presented in this section may be useful in finding ways to solve two basic problems:

– to understand the probable extent of the economic importance of ES and ecosystem assets of Russia to ensure an adequate quality of life for the population and sustainable development of the economy;

– to begin the search for approaches to the economic valuation of ES and ecosystem assets in accordance with the concept of the system of national accounts and SEEA-EEA for the development of ecosystem accounting in Russia.

6.2.1. Basic methods for economic valuation of ecosystem services

The concept of total economic value is the most promising for ES valuation. This concept has received global recognition both theoretically and practically and has been adapted for Russian conditions (Tishkov, 2002; Pearce et al., 2002). The concept constitutes an integrated approach to ES valuation, including provisioning, regulating, and cultural ES, and is the most promising among existing economic valuation approaches.

There are a number of economic approaches that may be used for economic valuation of ecosystems. The following main groups can be distinguished for determining the total economic value of ecosystems:

- based on market valuation;
- based on a cost approach;
- based on alternative value;
- based on a subjective valuation.

The minimum value of ecosystems could be the sum of the market prices of the natural resources they provide – the price of drinking water, fish, berries, etc. Traditional market prices can be used to valuate provisioning ES and, in some cases, water. The most important regulating and informational ES are not reflected in market prices.

Market valuations are often supplemented by a rent approach, which is based on the rarity and uniqueness of resources. Economic rent is the price or lease fee paid for the use of ecological goods, the quantity of which is limited. Rent arises when the supply of a resource is inelastic in the long term or is monopolized. The basis for rent is the quality of the resource, which does not depend on labor or technologies. Differential rent arises thanks to the different quality of resources and their location, since the highest-quality or best-located resource will, all else being equal, produce greater economic benefit. Nevertheless, the use of the rent approach creates the problem of separating rent from profit.

Cost methods estimate the costs of maintaining ES. The main advantage of this group of methods is that costs are easier to represent in monetary form than are benefits, which often cannot be represented in market terms. The main disadvantage of this group of methods is that costs are not equivalent to effect. The cost method is widely used to estimate the value of recreating an ecological good if it has been lost or degraded. In this instance potential compensatory costs necessary to replace a lost or damaged resource with an identical one in a given or alternative place are calculated. However, restoration of extinct ecosystems is often overly complex or even impossible. Preventive cost method determines the costs to prevent damage. Relocating costs are defined as costs to move objects and are used in large-scale relocation, e.g., during the construction of water reservoirs or dams or the establishment of protected area. Replacement costs are costs to replace ecosystem goods and services with artificial ones.

The concept of alternative value (forgone gain) is one of the fundamental concepts of economic theory. In environmental economics alternative values make it possible to valuate a natural feature or resource with an understated or non-existent market value using the forgone revenue or gain that might be obtained if that feature or resource is used for other purposes. For example, the alternative values of protected nature areas are the benefits that individuals or society loses because of the conservation of the areas. These costs include failure to obtain product from protected areas (animal, plant species, wood). Alternative values also include benefits that might have been obtained from alternative use (the development of agriculture, intensive forestry, etc.).

Methods in the theory of "willingness to pay", the construct "surrogate" markets, and sociological surveys are used to estimate the value of non-use.

There are a number of specific valuation methods for valuing ES that do not have a market.

Shadow prices method uses market prices adjusted for transfers, market failures and politics.

Hedonistic pricing method is designed to obtain an estimate of ecological good on the basis of real estate market or labor market prices. Hedonistic pricing method assumes that the difference in real estate prices (wages) for a site with a number of identical parameters is attributable to the difference in the quality of the environment and reflects, among other things, the value of ES. But this method requires a developed real estate (labor) market. This approach may be used in assessing regulating and cultural ES.

The production functions method determines the value of ecosystem resources and functions that do not have a market by modeling the change in economic results as a function of the contribution made by the resources and functions. This approach may be used in analyzing the economy value of regulating ES.

The method of goods and services substitution uses information about the relationship between goods and services that do not have markets and goods and services that do. An ecosystem service is therefore assigned its valuation based on the prices for market goods (services) with similar functions.

Among popular approaches to determining the value of a wide range of ES are assessments based on identifying preferences; these approaches include travel methods and the willingness to pay and readiness to receive compensation method. Travel method is usually used to assess specific geographic areas or the cultural and recreational functions of ecosystems and assumes that an individual's costs to visit a natural feature reflect the value of that feature. These costs are determined using surveys with questions about where the person came from, his costs to visit the feature, primarily transportation, the number of visits, and the period of time. The ratio of costs to the number of visits yields a decreasing relationship on the basis of which a demand curve can be plotted. Readiness to pay and readiness to receive compensation methods are based on people's declared preferences. In this instance people are asked about their willingness to pay for ecological goods and services or to receive compensation if these goods are lost.

6.2.2. Evaluation of Russia's ecosystem services (consumed volume)

In TEEB-Russia 2 project a preliminary economic valuation of a number of provisioning and regulating ES was performed on the basis of physical estimates of consumed volumes of these ES obtained as a result of TEEB-Russia 1 (Bukvareva, Zamolodchikov, 2018), as well as estimates of ES of prevention of water erosion of soils and the creation of natural conditions for weekend recreation obtained in the TEEB-Russia 2 project (see Sections 4.1.5 and 4.1.7). Informational (cultural) ES (scientific, educational, aesthetic, and ethical importance of ecosystems) are most difficult to quantify. This category of services in the TEEB-Russia project was partially evaluated only in points; their quantitative evaluation was not carried out. The results of the economic valuation of ES for Russia as a whole are presented in Table 6.2.2.1.

Table 6.2.2.1. Preliminary economic valuation of consume volume of ES of Russia.

ES category	*ES*	*Share of the ES value of ES total value, %*	*Share of the ES category value of ES total value, %*	*ES value in relation to GDP*, %*
Provisioning	Wood production	2,83	5,7	0,2–0,23
	Fodder production at natural pastures	2,43		
	Other provisioning ES	0,44		
Regulating	Regulation of CO_2 flow	43,6	94	1,2–3,2
	Runoff quality assurance by terrestrial ecosystems	33,4		
	Runoff volume assurance by terrestrial ecosystems	4,1		
	Water purification in freshwater ecosystems	3,6		
	Soil erosion prevention	9		
	Other regulating ES	0,3		
Recreational	Natural conditions for weekend recreation	0,3	0,3	0,01

*GDP for 2018 according to Federal State Statistic Service.

6.2.2.1. Valuation methods of provisioning ES

Wood production

To evaluate wood production, it is advisable to use market prices in conjunction with the rental approach. For aggregated estimates, a weighted average roundwood price is used, which is determined based on the current price of fuel wood and the price of roundwood, considering the share of fuel wood in the total production. Also, a component of its cost was defined for this ES, which corresponds to the cost of labor, technology and other resources spent by people on the extraction and transportation of wood.

To estimate the cost of wood for subjects of RF, we used the data of the TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018) on wood stock (indicator of stock for valuation of ecosystem assets), annual allowable cut (indicator of provided ES) and timber harvesting (indicator of consumed ES).

In the future, for the economic evaluation of this ES, it is advisable to use the method of market prices for wood minus the cost of resources spent on its extraction and transportation, taking into account regional differences in prices.

Non-wood production

The value of mushrooms and berries produced by ecosystems was assessed based on market price method. A mean wholesale mushroom price was used to valuate mushroom product. The value of ES and the stocks for subjects of RF were estimated using data from T.L. Egoshina (2005) on the biological and exploitable stocks of mushrooms and harvesting volumes. Biological stocks are considered an index of the stocks of these ecosystem assets; exploitable stocks – an index of provided ES; harvesting volumes – an index of consumed ES.

A mean wholesale price of berries was used to valuate berries production. In TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018) this ES was assessed using cowberries. At this stage of the study a preliminary estimate for all basic edible berries was made. To estimate the value of ecosystem assets in Russia we used data on the total stocks of cowberries, huckleberries, cranberries, blueberries, and raspberries (Egoshina, 2005). The distribution of the cost of ES and ecosystem assets by subjects of RF was estimated using correction factors to convert estimates for cowberries obtained in TEEB-Russia 1 for all berries. According to Egoshina (2005) total biological stock of all berries is 4,260,000 tons, cowberry stock is 481,000 tons; the total exploitable stocks of all berries is 1,388,000 tons; cowberries – 157,000 tons. Thus, the coefficient for recalculating the cost of services for all berries is 8.8. At this stage, this approximation is acceptable for updating the value of various categories of ecosystem assets, but in the future, the value must obviously be updated individually for each plant species.

In the future, the mushroom and berry market price method should be used for an economic valuation of this ES. An updated assessment of ES may be done separately for the volumes of its use for personal consumption (at regional market prices) and for volumes of mushroom and berry gathering for sale (at regional purchase prices). The determination of the ratio of volumes of mushroom and berry gathering for personal consumption and for sale is a separate subject of investigation.

Production of fodder at natural pastures

Evaluation of ES is made by the method of market prices based on the data of wholesale websites. This price will have to be adjusted later to account for the cost of resources expended on hay harvesting, drying and transport. Data on provided and consumed volumes of ES were taken from the results of TEEB-Russia 1 (Bukvareva, Zamolodchikov, 2018).

In the future, the economic valuation of this ES should be performed using a method based on the market prices for fodder minus the cost of resources expended to store and transport it with allowance for regional differences in prices.

Game production

A preliminary estimate of this ES was made by market price method, but only for ungulate animal species. The average price of wild ungulate meat and the proportion of meat in the carcass 0.85 were used[68]. In TEEB-Russia 1 (Bukvareva, Zamolodchikov, 2018) this ES was assessed using elk as an example. At this stage of the study a preliminary valuation was made for all main species of commercial ungulates (elk, red deer, roe deer, wild boar, musk deer, wild reindeer, sika deer, mountain ungulates). The value of ecosystem assets of Russia was estimated using data on the total ungulate population (stock indicator for valuation the ecosystem asset), the allowed harvest limit (indicator of provided ES) and harvest (indicator of consumed ES) according to statistical compilation "The Status of Hunting Resources in the Russian Federation in 2008–2010". The distribution of the cost of ES and assets by subjects of RF was estimated using correction factors to convert estimates for elks obtained in TEEB-Russia 1 for all ungulates. Data on the total population number of all these ungulate species and the mean weight of animals were used to estimate the value of the total stocks of all ungulates as 159,777 million rubles, the value of provided ES as 10,024 million rubles, and the value of used ES as 6040 million rubles. For elk these indices are 106,216 million rubles, 4767 million rubles and 3216 million rubles, respectively. Coefficients for converting the data for the elk into estimates for all ungulates were 1.5, 2.1, and 1.96 respectively. At this stage, this approximation is acceptable for updating the value of various categories of ecosystem assets, but in the future the value must obviously be updated individually for each animal species.

In the future, the economic valuation of this service should be performed using a method based on the market prices of meat and pelts minus the cost of resources expended to store and transport them with allowance for regional differences in prices.

6.2.2.2. Valuation methods of regulating ES

Carbon cycle regulation

The value of the ES was estimated on the basis of data from TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018) on carbon stock and CO_2 balance in terrestrial ecosystems of Russia and a carbon price of \$10/tCO_2 [69]. In the future economic valuation of this ES should be based on specific approaches to valuation of the ES of greenhouse gas flows regulation (absorption/emission of CO_2 and other gases) and ecosystem assets that provide carbon storage in peat, soil, and permafrost.

[68] http://www.gks.ru/dbscripts/cbsd/DBInet.cgi

[69] https://openknowledge.worldbank.org/handle/10986/31755, https://icapcarbonaction.com/ru/

Air purification by suburban forests

For the valuation of ES of air purification by forests, it is advisable to apply approaches based on estimates of prevented damage to public health. Such approaches combine market price and cost methods. To valuate this ES in Russia we used data on prevented damage to health obtained in the USA, Canada, and Great Britain. To apply these damage estimates, adjustment is necessary in the Russian context based on per capita income indices, including GDP per capita, disposable income per capita, as well as the nominal exchange rate of the ruble against the euro and the dollar, or a rate based on purchasing power parity.

The amount of gases (NO_2, CO, SO_2) and dust absorbed by suburban forests was calculated using data on forest area in 5-km zones around cities obtained in TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018) and absorption factors determined for Canada (Nowak et al., 2018): NO_2 – 5.5 kg/ha, CO – 0.3 kg/ha, SO_2 –2.1 kg/ha, dust – 1.5 kg/ha. Based on these data and estimates of gas and dust damage in the UK, considering the correction factor for Russia, ES value were estimated for gas absorption at 1,177 million rubles a year and for dust absorption at 3,943 million rubles a year. The total value of the ES is more than 5 billion rubles per year.

In Canada the mean value of prevented damage to human health is estimated at CAD 511/ha of forests (Nowak et al., 2018); in the USA – USD 480/ha of forests (Nowak et al., 2014), which, given the diminishing factor for Russia, is about RUB 3,000/ha of forests. The total value of the ES for Russia, according to forest area in 5-km zones around cities obtained in TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018) is more than 8 billion rubles per year.

Estimates based on data on health damage prevented by forests in Great Britain, the USA and Canada therefore produced similar results of several billion rubles per year.

In the future, for the economic evaluation of this service, it is advisable to use the method of assessing the prevented damage to health for a full range of pollutants, considering regional differences.

Assurance of runoff volume by terrestrial ecosystems

The monetary valuation of this ES should be done by cost method (costs to reproduce aquatic resources) and substitution cost method (costs to substitute ES with artificial services). Calculations of costs for water use based on an aggregation of components and stages of water treatment in all industries and water basins nationwide yielded this result: 3.8 RUB/m^3 (Artemenkov et al., 2016; Artemenkov, Medvedeva, 2017).

Evaluation of this ES and corresponding assets in Russia were based on estimates of the volume of ecosystem runoff regulation (provided ES) and the volume of freshwater used by people (consumed ES) obtained in TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018).

In the future, economic valuation of this ES should be done by substitution cost method and an estimate of damage in case of the degradation of this ES.

Assurance of water quality by terrestrial and freshwater ecosystems

To evaluate the ES of water quality assurance by terrestrial and freshwater ecosystems we used the substitution cost method, i.e., costs for substituting the ES with technical means. Providing the population with drinking water in the housing and utilities sector includes stages of water purification, which to some degree may be treated as the equivalent of these ES. According to Federal State Statistic Service, the consumer price for water is 20 RUB/m^3. The use of this price in preliminary valuation of water purification ES is acceptable, since, unlike the cost of the water itself in the case of the ES of runoff volume assurance, it should also include the cost of purification systems (pipes, filters, pumps, etc.) and their maintenance. Based on the range of prices for the simplest water treatment stations (RUB 960,000–11,200,000) and their capacity (24–729 m^3/day)[70], it turns out that, if a station runs continuously for 10 years, even disregarding its maintenance and energy consumption, the price of water treatment is from 4 to 10 RUB/m^3, and including maintenance and energy consumption it is in the tens of rubles per 1 m^3.

Evaluation of the two ES of water purification by terrestrial and aquatic ecosystems and the corresponding assets were based on data on potential (provided ES) and actual volumes of purified water (consumed ES) obtained in TEEB-Russia 1 (Bukvareva, Zamolodchikov, 2018) and a price of 20 RUB/m^3.

[70]See, for example: http://www.nano-plast.com/modulnye_stantsii_ochistki_vody

In the future, economic valuation of these ES should be done by substitution cost method and an estimate of damage in case of the degradation of these ES.

Regulation of runoff variability – reduction in flooding damage

The method of compensatory costs needed to restore or substitute a lost or damaged resource should be used to evaluate this ES. Every year there are major floods in Russia which exceed all other natural disasters in terms of area covered and financial damage caused. An area of the country totaling 400,000 km^2 is at risk of potential flooding, and every year about 50,000 km^2 are inundated. At different times inundation may affect more than 300 cities, tens of thousands of small towns with a total population of more than 4.6 million, and more than 7 million ha of farmland. According to the Russian Meteorological Service, the long-term average annual damage from floods in Russia is about RUB 43 billion (Second Assessment..., 2014). The largest floods occurred in 2013. According to the estimate from the Russian Federation Government, the 2013 flooding that covered the Far East caused direct damage to the country's economy of RUB 85–90 billion and indirect damage of RUB 439 billion. The total damage from 2013 floods came to RUB 527 billion (Second Assessment…, 2014). Preliminary damage from spring flooding in Irkutsk Oblast in July 2019 came to RUB 29 billion. Information from the Russian Emergency Situations Ministry shows significant year-to-year fluctuations in damage from dangerous hydrological events. An estimate of financial damage from dangerous hydrological events in the range of RUB 2–50 billion therefore seems reasonable.

The average value of ecosystem regulation of runoff variability for the territory of Russia was calculated according to data of TEEB-Russia 1 project (Bukvareva, Zamolodchikov, 2018) on the magnitude of the ecosystem regulation of runoff variability in the subjects of RF. This estimate is 12% of the total runoff variability. Therefore, the value of this ES can be estimated as 12% of the total flood damage. If we rely on Russian Meteorological Service data on mean long-term annual damage, we about RUB 5 billion/yr.

In the future, the compensatory cost method should be used for an economic valuation of this service. However, given large inter-regional differences, both in ecological conditions and in economic development, evaluation of this ES should be done separately for each region.

Prevention of soil water erosion

Evaluation of ES was based on estimates of prevented damage to agriculture for subjects of RF within European Russia according to data on volumes of prevented erosion obtained in TEEB-Russia 2 project (Section 4.1.5). Mean harvest losses for different degrees of erosion (Tab. 6.2.2.2.1) and the value of agricultural products in subjects of RF (Federal State Statistic Service database) were used to calculate prevented damage for European Russia equal to RUB 328 billion/yr.

In the future the economic valuation of this ES should be done using this method, with details on harvest losses in different degrees of erosion for different crops and land under cultivation with different crops in regions.

Table 6.2.2.2.4. Mean harvest losses for different degrees of erosion (Balakai, 2013).

Degree of erosion	*Extent of mean annual soil washout*	*Harvest losses*
insignificant	to 0.5 t/ha	none
minor	0.5–1 t/ha	15%
moderate	1–5 t/ha	50%
major	5–10 t/ha	80%

6.2.2.3. Valuation methods of recreational ES

Attempts were made to use various approaches to estimate the value of recreational ES. In particular, the recreational ES of PAs were assessed based on costs to maintain these PAs and the number of visitors to them. Expenses for stays at health resorts and suburban hotels calculated based on average consumer prices for different kinds of cultural and leisure services and the number of visitors were proposed as proxy values of the recreation.

One possible approach is the method of estimating travel costs and readiness to pay. A global study by Siikamäki et al. (2015) based on a meta-analysis of data from different countries predicts cost estimates for recreation per hectare of forest cover by countries. The monetary value was calculated for 2013 and adjusted for inflation in specific countries. Hunting and sport fishing were included as recreational functions along with recreation itself.

Evaluation of the ES for the formation of natural conditions for recreation within European Russia showed that in the suburban areas of cities there are more than 10 million hectares of forests (Section 4.1.7), which using data from Siikamäki et al. (2015) provide recreational ES worth RUB 900 million/yr. It should be noted that this estimate was made only for suburban areas within European Russia. The inclusion of possible recreation in other types of natural and semi-natural ecosystems may substantially change this estimate. In addition to forests, suburban zones also have about 14 million ha of grasslands, the recreational capacity of which is double that of forests (Section 4.1.7).

One of the most appropriate approaches to evaluation of recreational ES may be to estimate the damage to human health prevented by outdoor recreation. This estimate showed that 148 million people may be enjoying weekend recreation in suburban zones of European Russia (Section 4.1.7) and the total value of the salutary effect of outdoor recreation on health may be very high.

In the future, the economic valuation of this ES should be based on methods of estimating travel costs, readiness to pay, and prevented health damage.

6.2.2.4. Value of ES of different categories and in different regions

This section discusses economic estimates of the consumed volume of different ES. The total value of all estimated provisioning and regulating ES in Russia is only 3.6% of the GDP of Russia in 2018 (Fig. 6.2.2.4.1).

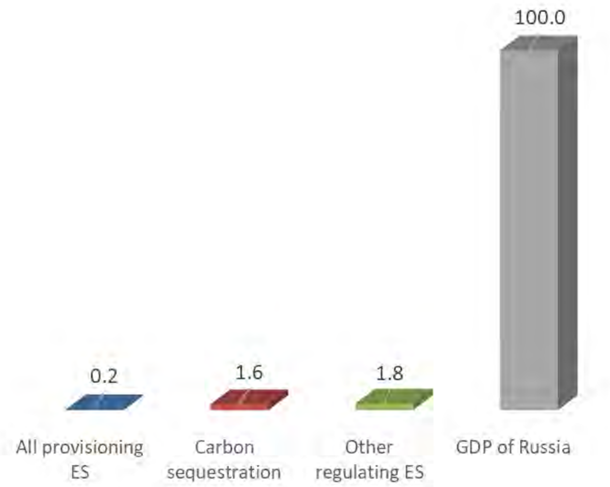


Figure 6.2.2.4.1. The value of consumed ES, expressed as a percentage of Russia's GDP, %.

However, this ratio varies widely across Russia's regions, and in many subjects of RF the value of consumed ES exceeds 10% of GRP [gross regional product), reaching 56% of GRP in Tuva (Fig. 6.2.2.4.2). In these regions, ES substantially impact on the overall well-being of the population and economy. These regions include primarily “forest” regions, and the Tuva, Altai, and Kalmyk republics, where the value of nature livestock fodder is relatively high given the modest GRP. Regions where ES value account for an insignificant portion comparing with GRP include mainly the Jewish Autonomous Oblast, Magadan Oblast, Chukotka, and Kamchatka because of carbon emissions, which result in negative values for the ES of carbon cycle regulation.

These group also includes the oil-producing regions of Western Siberia and the agricultural regions of central and southern European Russia, since their GRP today is determined either by oil and gas production or by the labor and resources invested into agriculture. However, the situation in agricultural regions may change substantially with another approach to assessing water-regulating ES if consider damage from drought.

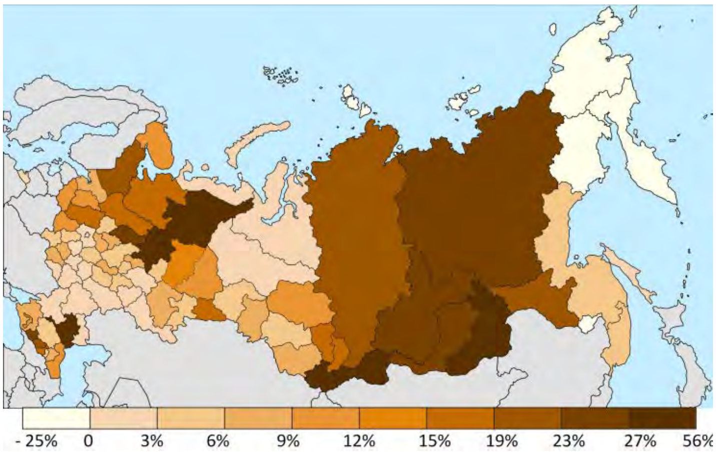


Figure 6.2.2.4.2. Value of consumed ES expressed as a percentage comparing with GRP, %.

Although, from the formal standpoint of the SEEA-EEA, a comparison of the ES value and GPD is not entirely correct (see Section 6.3), at this stage we used it to demonstrate the possible scale of the economic value of ES in comparison with national and regional economic indices.

Strong regional differences in ES value relative to GRP demonstrates the need for a differentiated approach to ES accounting in Russian regions with different environmental conditions, level of economic development, and the prevalence of certain sectors in their economies.

Provisioning ES account for only 5.5% of the total value of estimated provisioning and regulating ES.

Almost half of the value of regulating services comes from CO_2 flow regulation (Fig. 6.2.2.4.3).

Half of the value of provisioning ES comes from wood production and another 42% from livestock fodder on natural pastures; the remaining bioresources account less than 8% (Fig. 6.2.2.4.4)

The ES of CO_2 flow regulation accounts for almost half (44%) of total value of regulating ES, as already stated above. Among the remaining “non-carbon” regulating ES, the largest share is the ES of runoff quality assurance by terrestrial ecosystems (65.5%) and the prevention of soil water erosion (18.8%) (Fig. 6.2.2.4.5).

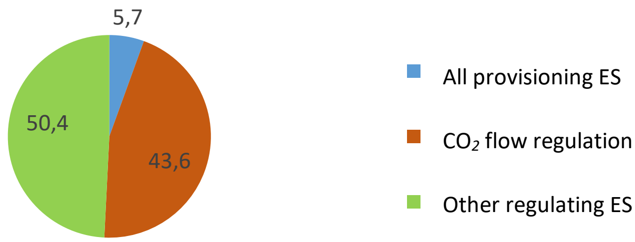


Figure 6.2.2.4.3. The ratio of the value of provisioning ES, ES of regulating CO_2 flows and other regulating ES, % of the total value of all estimated ES.

Figure 6.2.2.4.4. The ratio of the value of various provisioning ES, % of the total value of all provisioning ES.

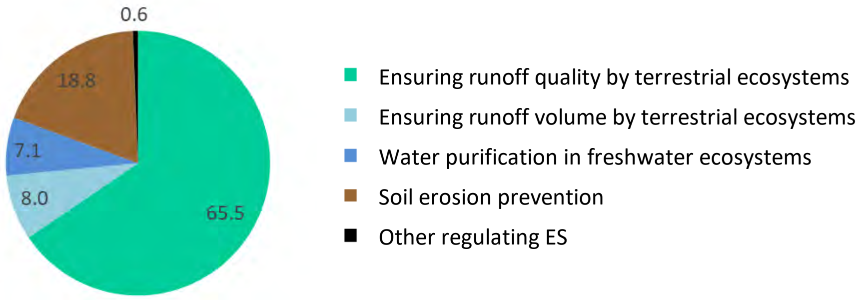


Figure 6.2.2.4.5. The ratio of the value of various regulating ES, % of the total value of all regulating ES.

It is obvious that these ratios vary widely by region. The determination of these differences and their interpretation for management purposes may be a subject of separate investigation. Elaboration of prices and the use of other evaluation methods may change these ratios.

6.2.3. Valuation of ecosystem assets

6.2.3.1. Approaches to the valuation of ecosystem assets

According to the System of National Accounts (2008) and the Central Framework of the System of Ecological and Economic Accounting (System of Environmental Economic…, 2014 a), one of the basic attributes of "assets" is that they benefit their owners (see Section 6.3). If we consider ecosystem assets as ecosystems that provide certain ES, the indicator that most closely satisfies this condition is consumed ES, valuation of which is presented in Section 6.2.2. Preliminary attempts to evaluation of ecosystem assets could be based only on this ES indicator, but in the preparatory stage before ecosystem accounting introduction in Russia, it seems appropriate, to complete the picture, to analyze a wider range of approaches. Obviously, the approaches to evaluate ecosystem assets presented in this section don't match exactly SEEA-EEA principles. Nevertheless, their analysis at this stage may be useful to formulate a methodology for assessing ecosystem assets that is now only being developed.

If we do not limit ourselves to formal SEEA-EEA criteria, two basic approaches to evaluation of ecosystem assets are possible: a) based on the value of stocks of the biological components of ecosystems (bioresources stocks); b) based on the value of ES provided by those assets over a specific time period. In the latter case the evaluation can be based on both the consumed ES and provided (potential) ES, regardless whether there are users for these ES.

Evaluation of ecosystem assets by stocks of bioresources and carbon

Only provisioning ES, not regulating ES, can be assessed by stocks. When using provisioning ES, part of the biological components of biosystems (biomass or mortmass) is extracted from ecosystem, and total biomass or the number of biological components of ecosystems (the so-called stock of a given bioresource) can be considered as an indicator of this ecosystem asset. In most cases there is no double counting of assets, since each component (species of commercial animals or plants, tree species used in logging) produces only one specific type of product. However, if one animal or plant species simultaneously produces two or more kinds of products (e.g., the cedar produces pine nuts and wood; rabbits produce hides and meat; the cowberry products berries and leaves), there may be double accounting of an asset when it estimated by ES.

Stocks describe the condition of the biological components of ecosystems and have no temporal dimension, but they may increase or decrease over time.

In the case of regulating ES, humans benefit from the functioning of species and ecosystems, not from the consumption of biomass. That is, indicators for valuation of regulating assets should be ecosystem functions and ES which depend on extent (area, population number) and condition (biodiversity) of assets. Indicators of ecosystem functions and ES reflect their volume (quantity) per unit time.

An exception is climate regulating ES that regulate carbon cycle, which include two related, but independently important components: the regulation of CO_2 flow and storage of carbon accumulated in the ecosystems. The first component may be compared with other ES and is expressed as the quantity of absorbed/released carbon per unit of time. The second is the stock of organic carbon that ecosystems accumulated over previous centuries or even millennia and is expressed as the quantity of carbon in ecosystems. This stock, like the other stocks, may increases or decrease over time. Carbon stock is the indicator of climate-regulating ES no less important than carbon balance. It shows an ecosystem's potential for both emission and absorption of carbon. Carbon stocks in peat ecosystems and in soils are the most important, since they may be stored and accumulate for centuries and even millennia.

Evaluation of ecosystem assets by the volume of ES over a specific time period

In TEEB-Russia project the most ES are estimated by two indicators – provided and consumed volumes (Bukvareva, Zamolodchikov, 2018; Section 4 of the present report).

ES volume provided by ecosystems corresponds to the ecosystems' potential ability to perform functions useful to humans and to satisfy their needs, regardless whether there are consumers of ES at the given time. Provided ES volume is determined by natural factors, area and condition of ecosystems. For most ES (all provisioning and a most regulating ES, except for ES spatially related to farm fields and cities), the provided volume is performed by ecosystems throughout the whole territory of country. ES spatially related to farm fields and cities (pollination, prevention of soil erosion, purification of air by suburban forests, creation of natural conditions for the recreation of citizens) do not work throughout the country, but only in areas adjacent to farmland and cities (see Section 4.1.9), therefore, their provided volume is obviously less than that of other ES.

Consumed ES volume corresponds to the benefit that people derive from ES in a reporting time period. Consumed volume is either the part of an ecosystem product taken by man (for provisioning ES) or the result of partial use of the potential of regulating ES. Consumed volume is determined by the provided ES (how much ES can be consumed) and the socioeconomic parameters of a geographic area (the presence of ES consumers and a request for ES).

In some cases, we considered the provided (potential) ES as equal to consumed ES. For four ES (carbon sequestration, air purification by suburban forests, water erosion prevention, and reduction of flood damage), we assumed that provided and consumed ES are equal. Determining the consumed volume of ES of carbon sequestration is methodologically problematic. In TEEB-Russia 1 project this indicator was estimated as carbon sequestration only by managed forests, while the provided ES volume corresponds to carbon sequestration by all terrestrial ecosystems. It was shown that accounting for this ES only in managed forests results in its substantial under-estimation and produces a distorted picture of its spatial distribution across Russia. At this stage, therefore, we decided to use only indicator of carbon sequestration by all terrestrial ecosystems, i.e., not to segregate consumed ES volume and to assume that it equals provided ES. The provided ES of air purification by suburban forests equals consumed volume, since this ES is used completely (and it is even insufficient) in all subjects of RF. For the ES of water erosion prevention, it was assumed that provided volume equals consumed volume, given the local (point) scale of the effect of this ES and its close association with farmlands (see Section 4.1.9). A preliminary estimate of the ES of regulating runoff variability based on prevented flooding damage was also used for both provided and consumed ES, since more detailed evaluation of this ES have not yet been done.

There are therefore two possible basic groups of approaches to evaluation of ecosystem assets: a) an approach that combines estimates of stocks for provisioning and carbon-regulating ES with estimates of regulating ES over a specific time period; b) an approach that combines estimated of various ES over a specific time period.

Then the four approaches to economic valuation of ecosystem assets were analyzed:

1) by stocks and provided (potential) ES over 10 and 30 years:

– ecosystem assets that provide provisioning ES (bioresources) were evaluated by their biological stocks in nature: wood stock of standing timber, biological stocks of mushrooms and berries, phytomass of plants in natural pastures (at this study this index was set equal to the annual productivity of natural pastures, which is accurate for annual plants, but must be adjusted for perennials), the population numbers of game ungulate species;

– ecosystem assets that provide carbon-regulating ES were evaluated by carbon stocks in ecosystems;

– ecosystem assets that provide other regulating ES were evaluated by potential (provided) ES over 10 and 30 years;

2) by provided (potential) ES over 10 years: all assets were evaluated by provided (potential) volume of corresponding ES;

3) by provided (potential) and consumed ES over 10 years:

– ecosystem assets that provide provisioning ES (bioresources) and carbon- regulating ES were evaluated by provided (potential) ES over 10 years;

– ecosystem assets that provide other regulating ES were evaluated by consumed ES over 10 years;

4) by consumed volume of all ES over 10 and 30 years.

A separate issue is valuation of biological diversity. Some ES classifications include ES such as conservation of biological diversity, conservation of habitats, maintenance of migration routes, etc. However, in essence, biodiversity is not an ES, but a structural biological basis that provides ES (Section 6.1.3.1). The classification of ES adopted in the Prototype National Report on Ecosystem Services of Russia does not include biological structures and their maintenance in the number of ES (Bukvareva, Zamolodchikov, 2018). Thus, we consider biodiversity as an indicator of condition of ecosystem assets, which corresponds to SEEA-EEA concept (System of Environmental Economic…, 2014 b). Approaches to determining the value of biodiversity as a characteristic of condition of ecosystem assets, first of all, should take into account its importance as a structural basis for ecosystem functioning and ES implementation of provisioning and regulating ES. In the case of information and recreational ES (the scientific, cognitive, aesthetic and ethical importance of ecosystems) biodiversity directly affects provided volume of ES and corresponding component of biodiversity value should be included in value of these ES.

Valuation of rare and endangered species requires specific approaches. They obviously cannot be evaluated by the same approaches as bioresources, since their exploitation is prohibited. Valuation of rare species only as functional components of ecosystems which perform ES is also insufficient, considering the need for priority attention to their conservation. An approach often proposed to such species valuate them through the cost of restoring their populations also suffers from a number of fundamental deficiencies, since the restoration of all rare or endangered species cannot be fully guaranteed. It may be difficult or simply impossible to restore an extinct population, not just economically, but also biologically.

In addition to the above aspects of biodiversity value, categories of its intrinsic value, value of existence, value of heritage, etc., related to the desire of people to save biodiversity as an integral feature of wildlife for future generations are also discussed.

TEEB-Russia projects 1 and 2 did not address issues of economic valuation of biodiversity. This task should be included in the next stages of preparation for the development of ecosystem accounting in Russia.

6.2.3.2. Total value of ecosystem assets in different valuation approaches

The choice of valuation approach greatly affects both total value of ecosystem assets and the ratio of assets which provide different ES. Figure 6.2.3.2.1 compares value of ecosystem assets estimated by various methods with fixed capital in the Russian economy (RUB 350,038,577 million at the current market value at the end of 2017 as reported by Rosstat[71]).

[71] http://old.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/accounts/#

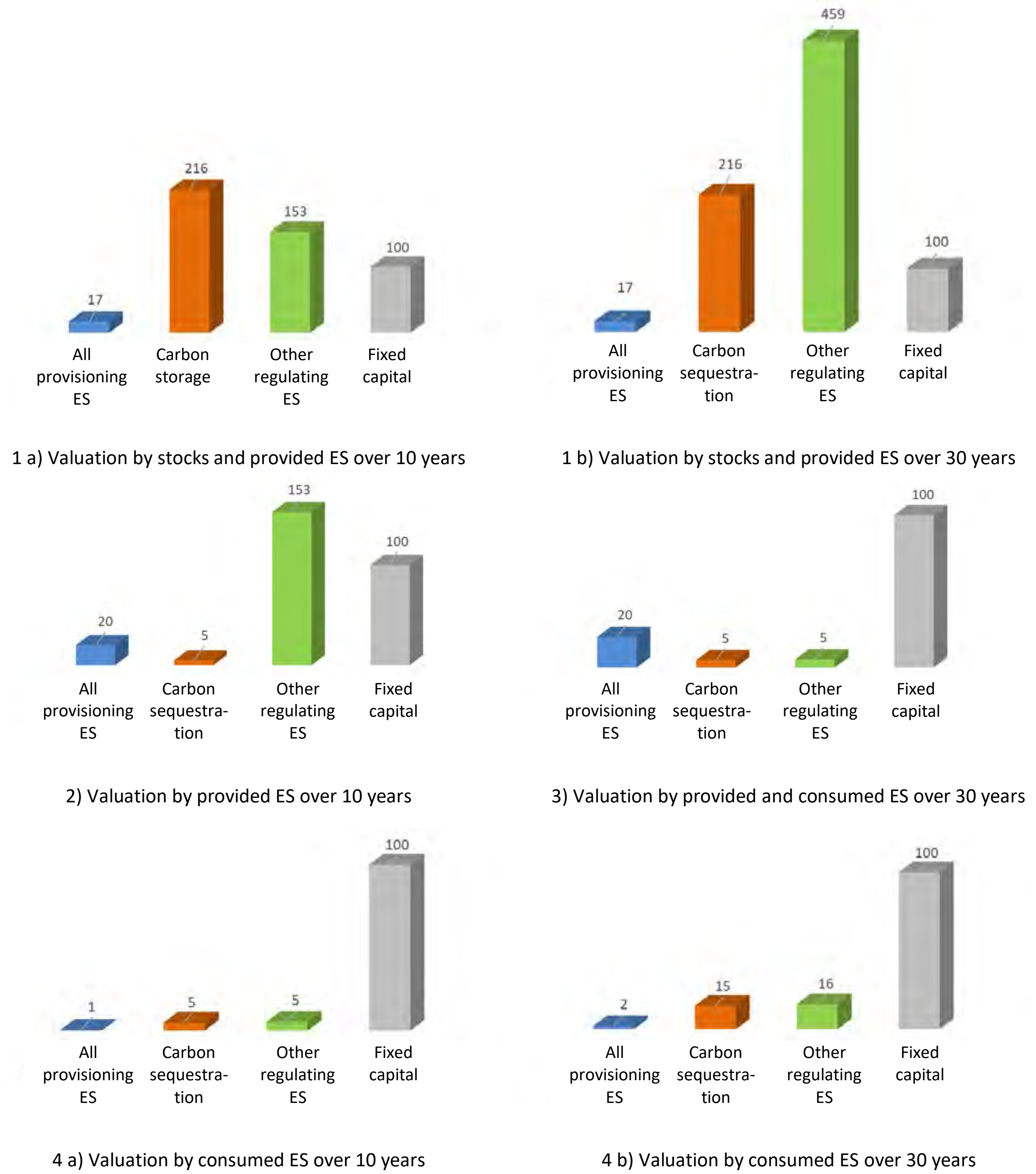


Figure 6.2.3.2.1. Value of ecosystem assets providing the main groups of ES expressed as a percentage comparing with fixed capital in the economy, with different approaches to valuation.

Although from the formal standpoint of SEEA-EEA, a comparison of value of ecosystem assets with fixed capital in economy of Russia and regional fixed assets (see Section 6.2.3.3) may be not entirely correct (see Section 6.3), at this study we used it to demonstrate differences in estimates with different approaches and to demonstrate regional differences (Section 6.2.3.3).

Estimates of the value of ecosystem assets exceed fixed assets in some cases, but not in others (Fig. 6.2.3.2.1). Estimates of the value of ecosystem assets based on stocks and provided ES for 10 and 30 years (options 1a and 1b) are 7 and 12.5 times higher than fixed capital in the economy because of the large carbon stock in ecosystems. Value of regulating assets based on provided ES also exceed fixed capital. And in the 30-year calculation value of regulating assets is more than twice the value of carbon stocks (option 1b). The increase in the time period for assessing regulating assets will increase their value even more.

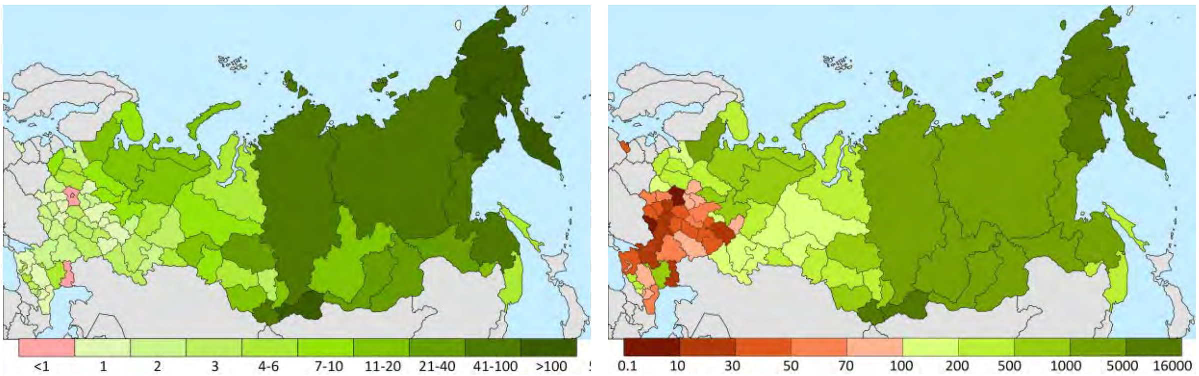
Value of ecosystem assets based on provided ES over 10 years (option 2) exceeds fixed capital by a factor of 3.2 because of the high value of potential regulating ES. Value of provisioning assets slightly exceed their value based on stocks (compare options 1 and 2), however as shown below, the ratio of value of different provisioning ES changes greatly. Value of carbon assets based on provided ES of regulation of CO_2 flows over 10 years is almost 50 times less than the value of carbon stocks, is many times less than the value of other regulating assets and is even less than the value of provisioning assets.

When combining provided volume of carbon-regulating and provisioning ES and consumed volume of other regulating ES (option 3), provisioning assets are the most valuable. With a 10-year period the total value of ecosystem assets is less than fixed capital, but with a 30-year period it will exceed it.

Estimation of the total value of all ecosystem assets by consumed ES volume does not exceed fixed capital for both a 10-year and a 30-year period (options 4a and 4b). The ratio of the value of different assets is the same as for consumed ES (Fig. 6.2.2.4.3): regulating assets account for half of the value, another almost half comes from carbon assets, and provisioning assets represent less than 6%.

6.2.3.3. Ratios of value of ecosystem assets and fixed capital in the economies of Russia's regions

The ratios of the total value of ecosystem assets and regional fixed assets in the economy vary widely across Russia. The nature of the change in these ratios across subjects of RF is similar when evaluating assets by stocks and provided ES over 10 years (option 1a) and when evaluating assets by provided volume of all ES (option 2) (Fig. 6.2.3.3.1 a, b). In both cases the ratio of the total value of ecosystem assets to regional fixed assets increases from the central and southern regions of European Russia toward Siberia and the northern Far East. In the first case ecosystem assets are less than fixed assets in only two subjects of RF (Moscow and Astrakhan oblasts). In the second case regional fixed assets in almost all regions in the central and southern part of European Russia (except Kalmykia and the North Caucasus republic) exceed value of ecosystem assets.



a b

Figure 6.2.3.3.1. Ratio of value of ecosystem assets and regional fixed capital: a) value of provisioning and carbon ecosystem assets is estimated by stocks and value of other regulating assets is estimated by provided ES volume over 10 years: how many times the total value of ecosystem assets exceeds regional fixed assets in the economy; b) value of all ecosystem assets is estimated by provided ES volume over 10 years: the total value of ecosystem assets expressed as a percentage comparing with the value of regional fixed assets in the economy, %.

The pattern of the distribution of ratios between ecosystem assets and regional fixed assets differs radically when ecosystem assets are estimated by consumed ES (Fig. 6.2.3.3.2). First, ecosystem assets in most regions are less than regional fixed assets. The least ecosystem assets (compared with fixed assets) are typical not for agricultural regions in southern European Russia, for Western Siberian oil and gas regions and for southern Far East. Moreover, regions in northern Far East and the Jewish Autonomous Oblast have negative value of ecosystem assets because of carbon emissions and thus, negative values for ES of regulating the CO_2 balance. The value of ecosystem assets aligns with more than 50% of regional fixed assets in European and Siberian forest regions. Value of ecosystem assets exceeds regional fixed assets in only three subjects of RF (Irkutsk Oblast, the Altai and Tuva republics).

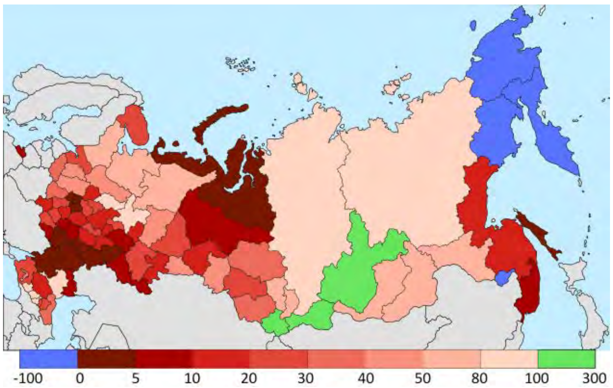


Figure 6.2.3.3.2. Value of ecosystem assets estimated by consumed volume of all ES for 10 years, expressed as a % of the value of regional fixed assets.

6.2.3.4. Ratios of value of different groups of ecosystem assets estimated by different methods

Table 6.2.3.4.1 shows the ratio of the value of different ecosystem assets valued in different ways.

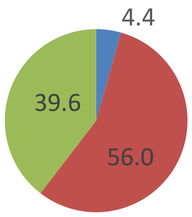
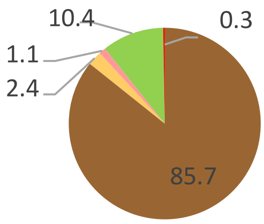
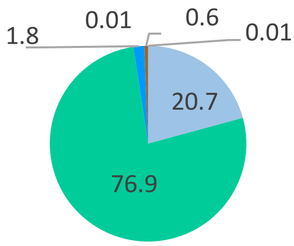
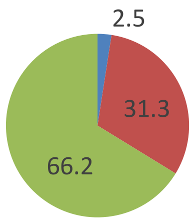
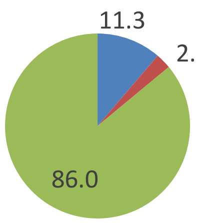
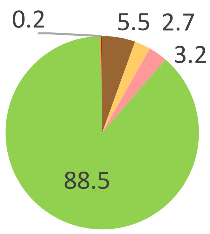
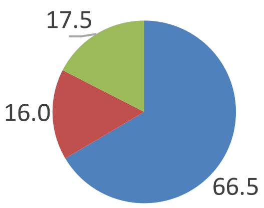
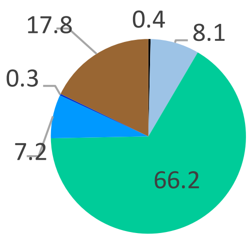
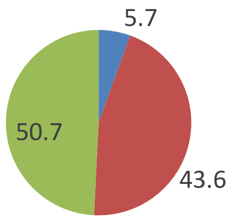
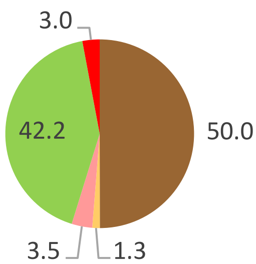
Carbon assets represent the largest or a substantial share of the total assets value estimated by stocks of bioresources and carbon and provided volume of regulating ES (options 1a and 1b) and when assets are estimated by consumed ES (option 4). Share of carbon assets is highest (56%) when assets are estimated by stocks (1a) because of large carbon stocks in Russia ecosystems. But when the time period for potential volume of other regulating ES increases to 30 years (option 1b), carbon assets are of lesser value than other regulating assets. When estimation by consumed ES (option 4), a large proportion of carbon's value is explained by the relatively small consumed volumes of other regulating ES compared with carbon-regulating ES, for which consumed and provided volumes are set equal and encompass ecosystems countrywide. Carbon assets accounts for the smallest percentage (2.7% and 16%) of the total assets value when other ES are estimated by provided volume encompassing all the country's ecosystems (options 2 and 3). In these cases, the value of carbon assets drops below even that of provisioning assets.

Value of regulating assets (except carbon-regulation) represents a substantial proportion of the total assets value, which is as high as 86% when assets are estimated by provided ES (option 2). They represent less than half of the total value in two cases: 40% when their 10-year provided volume is combined with stocks of bioresources and carbon (option 1a) and 17% when regulating assets are estimated by consumed ES volume and all other assets (provisioning and carbon) are estimated by provided volume, i.e., they included ecosystems countrywide (option 3).

Within the group of regulating assets there are two alternative ratios of the values of different assets: when assets are estimated by provided ES (options 1 and 2) and when assets are estimated by consumed ES (options 3 and 4). In the first case almost the entire value of regulating assets is determined by ES of runoff quality assurance by terrestrial ecosystems (77%) and ES of runoff volume assurance by terrestrial ecosystems (21%). The remaining ES make a minuscule contribution. ES of runoff quality assurance by terrestrial ecosystems also predominates in the second case, but water erosion prevention ranks second in value (18%). These differences between estimates by provided and consumed ES are determined by the very large provided volumes of runoff-related ES when ecosystems countrywide are considered. The share of ES of erosion prevention is substantial in estimate based on consumed ES, but becomes small in estimate based on provided ES, since this service is performed only by ecosystems adjoining farmlands.

The ES of air purification represents a tiny share of the total value of regulating assets since it is performed only by suburban forests. However, the local value of these ES is very high. The value of ecosystem assets providing ES operating locally and spatially linked to farmland and cities needs to be assessed at the local and regional levels.

Table 6.2.3.4.1. The ratio of the value of various ecosystem assets evaluated by different methods (the pie charts indicate the proportion (%) of the value of ecosystem assets or their groups from the total value of ecosystem assets in each case).

Valuation-method	*All assets*	*Provisioning assets*	*Regulating assets*
	All prod. services Carbon cycle regulation Other regul. services	Wood products Non-wood prod. (mushrooms) Non-wood product (berries) Products of natural pastures Hunting product (ungulates)	Air purification Ensuring runoff volume by terrestr. Ensuring runoff quality by terrestr. Water purification by aquatic ecos. Decrease in flooding damage Prevention of water erosion
1a Stocks and provided ES over 10 years			
1b Stocks and provided ES over 30 years			
2. Provided ES over 10 years			
3. Provided and con-sumed ES over 10 years			
4. Con-sumed ES over 10 years			

Provisioning assets represent a large portion of the total value of assets (67%) only if they are estimated by provided ES volume (i.e., for ecosystems in the entire Russia), while regulating assets are estimated by consumed ES volume (option 3). Production assets account for an appreciable share (11%) when all assets are estimated by provided ES (option 2). Other valuation approaches show small proportion of provisioning assets.

Within the group of provisioning assets there are three value ratios – when assets are estimated by stocks (option 1), by provided ES (options 2 and 3) and by consumed ES (option 4). In the first case wood stock represents a major portion of the total value of provisioning assets (86%), since in terrestrial ecosystems tree biomass is many times greater than the biomass of other biological components. The value of natural fodder is 10% of the total value of the assets. But if assets are estimated by provided ES volume, the value ratio of these assets is mirrored: natural fodder is 88%, while wood stock is only 5.6%. These differences in ratios are explained by a 7-fold differences in the degree of use of wood stocks (0.2% annually) and natural fodders (1.4% annually) (Ecosystem services…, 2016). The reasons for this are both economic and biological, since the productivity of herbs per unit of biomass is substantially higher than that of trees. If assets are estimated by consumed ES, the total value is divided approximately in half between wood (50%) and natural fodder production (42%).

6.3. Ecosystem accounting and the system of national accounts

6.3.1. Ecosystem accounting as part of the system of environmental economic accounting in the context of national accounts

One of the key issues of ecosystem accounting are macrostatistical estimates of ecosystem assets and ES expressed in physical and monetary terms. Cost estimations must be based on:

a) physical indicators of ecosystem assets and ES;

b) an ordered, methodologically consistent and, most importantly, unified constructions associated with a general system of macro-statistical indicators, reflecting the main economic proportions, stocks and flows of various assets, as well as production, flows, consumption and accumulation of goods and services in a country's economy, and so on.

The System of National Accounts (SNA) is currently almost universally recognized as a macrostatistical model reflecting the main macroeconomic characteristics. The SNA is an assemblage of accounting terms, concepts, principles, rules, structures and classifications, which together define an internationally agreed standard for measuring and analyzing various types of natural resources, including macro accounting of negative environmental impacts, as well as for protecting and restoring the environment. The SNA is a modern, strictly ordered system utilizing statistical data to describe, analyze, develop and regulate a market economy at the macro level. In other words, the indicators, groupings, classifications and other tools of this system reflect, on the whole, the structure of an economy, its institutions and mechanisms in relation to each country. The SNA uses some of the basic concepts and methods of accounting, in particular, double-entry bookkeeping. To some extent, the goals of the SNA are also adequate to the goals of accounting, primarily in terms of providing information for management decision-making. The main differences, primarily, lie in the fact that in classical accounting information is used for decision-making at the level of individual economic agents (enterprises, companies), while in the SNA it is used as the basis for large-scale corporate and government economic decision-making, for groups of economic agents, such as various enterprises, organizations, institutions and households, or at the level of the total economy. In a sense, the SNA is a kind of accounting reflecting all the elements of a country's economy. Statistical characteristics in the SNA are recorded in specific tools called *accounts*.

The SNA operates with a limited set of interconnected aggregate measures, in particular, gross domestic product, gross value added, gross mixed income, gross national income, gross national disposable income, final consumption, gross capital formation, investments, to name a few. Also, one of the key categories in the SNA are such aggregate indicators as economic assets and national wealth.

The basic postulates of contemporary economics provide a general theoretical basis for the SNA. Economics define such key concepts as economic need, economic good, economic activity, supply and demand, value and price, factors of production and associated costs, results of economic activity, and so on. The methodology of calculating and analyzing general economic aggregates and, therefore, government decision-making largely depends on the general ideology of economic policies employed by the government.

The term "economic activity" in the SNA is understood to mean a purposeful *human activity* aimed at satisfying their natural, material and spiritual needs. Material goods and services that have a certain economic usefulness, i.e., their ability to meet the needs of society, are the result of this activity.

The relationship of the SNA with specific mechanisms of natural resource management and environmental preservation is currently presented primarily as part of the methodological concepts of System of National Accounts, 2008 (System…, 2009; hereinafter, SNA-2008), which is an international standard. The relevant aspects are described in more detail in The System of Environmental-Economic Accounting 2012—Central Framework (System…, 2014 a; hereinafter, SEEACF-2012), which is also an international standard, and, in addition, in the international supplemental (to the SEEACF-2012) recommendations System of Environmental-Economic Accounting 2012—Experimental Ecosystem Accounting (System…, 2014 b; hereinafter, EEA-2014). Currently, there is active theoretical and methodological research in ecosystem accounting in the leading international organizations (see, for example, Technical Recommendations…, 2019).

Reflection of ecosystem assets and services within EEA framework requires mandatory observance of the main principles of the SNA and SEEA (understanding that SEEA is a part of SNA, then for brevity we use hereinafter SNA-SEEA). Violation of this requirement and/or an eclectic mixing of the SNA foundations with other principles and research methods is likely to lead to a different understanding of the structure and content of the aggregate indicators in use, to confusion in the categories and terms in use, and most importantly to the essential and methodological uncertainty of the final data obtained by direct calculations and/or indirect estimations. As a result, most likely, the joining of natural resources and their ecosystem parameters with the aggregate indicators describing the course and results of a country's economy would become virtually impossible to create.

Creating an ecosystem accounting structure is also possible beyond the boundaries of national accounting and the SEEA. But in this case, it is necessary to clearly define the meaning of the relevant terms and categories which are supposed to be used, and to admit the impossibility of associating the obtained ecosystem aggregates with the aggregates of the SNA-SEEA.

The SEEACF-2012 emphasizes that its recommendations, like other international statistical standards, will be introduced gradually, taking into account the requirements and capabilities of national authorities of natural resources, environment and statistics, and other interested parties. To ensure such an approach, the SEEACF-2012 provides a flexible and modular procedure for its implementation, which, in principle, can secure compliance of specific management requirements, on the one hand, with the already available necessary data or the ability to get such data in the near future, on the other hand (SEEACF-2012, p. viii). In general, the SEEACF-2012 implementation is practically uncontested. Rejecting it equals abandoning the internationally agreed development of the SNA-SEEA-EEA with all national and international negative consequences.

It is worth noting that, as the specific aspects of the SNA-SEEA-EEA are examined consecutively, domestic experts may express a fundamental criticism of the impossibility and/or inappropriateness of implementing certain elements of the SNA-SEEA-EEA in existing national working practices. However, such objections would require evidence-based and convincing arguments supported by the SNA-2008, the SEEACF-2012 and the EEA-2014. That is an additional reason for the need for an accelerated and thorough study of the entire set of that documents.

Therefore, the methods of calculation and estimation and specific algorithms used earlier, as well as the obtained numerical data, must be checked for their compliance, on the one hand, with the general concepts of national accounting as a whole, and on the other hand, with the SNA-SEE-EEA. Only after such verification and adjustment it is advisable to operate with the results of calculations and estimates, to conduct analysis and comparisons, including international scale. Since this methodology is not an international standard yet and is being constantly revised and expanded, the methods of calculation used in Russia on national level may change in the future after adopting the relevant international standards.

The need for verification and adjustment also concerns the conceptual and terminological apparatus of ecosystem accounting, which not only is not an international standard, but also sometimes diverges in the concepts in use and their definitions even among domestic experts, i.e., it has to be verified and standardized in the future.

6.3.2. Main features of the reflection of ecosystem services and associated macro-statistical EEA parameters within the framework of the SNA-SEEA

Valuing ES and associated aggregate indicators is a difficult and complex task. Many ES, in particular, such key regulating ES as assurance of runoff quantity and quality, water purification in aquatic ecosystems, and erosion prevention are not marketable. Therefore, not only the physical parameters of the relevant aggregate indicators should be evaluated, but also market and nonmarket methods for determining their price (value) should be implemented

The range of ES, the benefits received from them, as well as the issues of degradation of various ecosystem assets and the associated reduction in ES are not considered in detail in the SNA-2008 and the SEEACF-2012. A fairly overall analysis of the mentioned issues is available in the EEA-2014.

The concept of ES, that is, services "produced" by ecosystems, is quite unusual for macroeconomic statistics in Russia. According to Russian national accounting, services are the result of *human activities* that satisfy personal and social needs, but not embodied in specific products. In other words, services are the result of market or nonmarket transactions between two or more equal economic agents. The understanding of ES in the EEA is different: they are the contributions of ecosystems and their components to benefits used in economic and other human activity. ES may be embodied in certain products of natural origin, in ensuring acceptable quality of the environment or in intangible aesthetic, spiritual and cognitive aspects. Since ES are the result of natural ecological processes, and not the result of human activities, for many SNA experts this approach seems insufficiently valid and requiring a revision of a number of basic postulates of not only macroeconomic statistics, but also general economics. In this regard, one of the most important tasks in preparing an implementation of ecosystem accounting is a certain modification of the mentioned general economic ideas, including a substantial adjustment of the concept of economic activity and a clarification of related concepts and terms.

Currently, the conceptual and terminological apparatus of ecosystem accounting is in a stage of continuous development and refinement. There are many diverging interpretations and word choices. Moreover, in a number of documents prepared in recent years by various international organizations, nonstandard definitions are used, with varying degrees of reference to the terminology of the SNA-2008 and the SEEACF-2012. The situation is aggravated by translation ambiguity. All these shortcomings should be gradually eliminated, including the ones prepared by Russian experts.

Assuming that a correct valuation of ES based on the SNA is possible in principle, the overall logic of creating ES accounts would be reasonably close to standard accounts, which describe the volumes of output and distribution, volumes of consumption and savings of ordinary products in the form of a wide variety of goods and services, as well as economic assets with their changes.

In this regard, it is proposed to divide all ES and related aggregate indicators into two groups within the SNA-2008, the SEEA-2012, and especially the EEA-2014 frameworks. The first group consists of ES and aggregates chosen on the basis of standard requirements and within the standard frameworks of national accounts, primarily on the basis of market characteristics of the services. The second group consists of ES and aggregates also chosen on the basis mentioned above, but this time transactions that are not reflected in standard national bookkeeping (beyond its scope) are mainly subject to accounting.

In the context of ES, the most important and difficult task is not only to evaluate their hypothetical "value", but to completely re-calculate such fundamental indicators in the standard terminology of national accounts as gross output (the total value of ecosystem services received/produced for a given time period), gross value added (gross output less intermediate consumption, i.e., material costs), gross domestic product (gross value added plus net taxes on products), gross capital formation (as part of the final use of GDP) and a number of other fundamental SNA aggregates. Specific methods of this types of estimation are still largely undeveloped.

The EEA-2014 also recognizes the need to include and statistically describe ecosystem "disservices", which are often closely intertwined with "positive" ES. Some examples of disservices are damage by insects, which can also act as pollinators, damage to garden berries and fruits by birds, which also destroy pest insects, and so on. However, there is no clear algorithm in the EEA-2014 for accounting such disservices.

6.3.3. Main features of the reflection of natural and ecosystem assets in the SNA-SEEA-EEA

6.3.3.1. Basic characteristics of the category of "assets" in the SNA-SEEA-EEA

The SNA defines *"assets"* as things that meet the following criteria.

1) Objects should be owned by an economic subject or a group of economic subjects (including government ownership).

2) Objects must have certain restrictive criteria for the size and the extent of distribution. For example, both in the SNA-2008 and the SEEA-2012, it is noted that ocean water and atmospheric air are excluded from environmental assets not only because of the impossibility of any precise ownership determination, but also because their resources (or stocks) are too large to be of any significance for specific analytical and statistical purposes (System…, 2014 a, p. 29; System…, 2009, p. 8). the SNA-2008 and the SEEA-2012 do not provide clear guidance on the allowability or unallowability of considering a number of environmental factors, in particular, sunlight or wind (wind energy) as environmental assets. By the above criteria, such a consideration is regarded as incorrect.

3) Objects should yield economic benefits to the owner or owners. The latter get them through ownership or use over a certain time period.

In relation to *natural resources*, represented in the SNA as assets, it is necessary first of all to use the criterion of ownership. Natural resources such as land, mineral deposits, uncultivated forests and other vegetation, wild animals, and so on, are included in assets only under the condition that the relevant economic subjects really exercise the ownership of these resources, that is, they actually can benefit from these resources.

At the same time, there is a certain part of these assets such as, for example, land resources that are, in particular, owned by government, and that will have either zero value (value estimate) or potential value in the future.

When developing the SNA-2008 and the SEEA-2012, it was decided not to include economically unsuitable (unprofitable) mineral deposits in environmental assets, since they cannot yield any benefits to their owners taking into account currently existing technologies and/or prices.

Similarly, within the SNA, a significant amount of forest timber, primarily as part of protective forests cannot be considered an asset, since it does not explicitly generate income to its owner, i.e. the government (with significant expenses for protecting and restoring such forests). As for reserve forests, it seems that they can only have zero value. At the same time, within the EEA, protective forests should be included in ecosystem assets, as they produce the most important regulating ES. Additional theoretical studies are required to determine potential place of reserve forests among other ecosystem assets. It is possible that a significant part of this group of Russian forests will be recognized as ecosystem assets in future.

Thus, any environmental asset is a natural resource, but not every natural resource can and should be an environmental asset. Similarly, any ecosystem asset is an ecosystem, but not every ecosystem can and should be an ecosystem asset.

6.3.3.2. Basics of accounts (balance sheets) of environmental assets

The valuation of environmental assets in the SNA and the SEEA is carried out in both physical and monetary terms by using a rather limited number of calculation methods. The necessary data are recorded in balance sheets as described in the SNA-SEEA (liabilities in this case are not recorded). A general structure of the monetary account of an environmental asset is shown in table 6.3.3.2.1.

Table 6.3.3.2.1. *General structure of the monetary account of an environmental asset.*

Opening stock of resources (beginning of accounting period)
Additions to stock
Growth in stock—natural (net of normal natural losses)
Growth in stock—through human activity
Discoveries of new stock
Upward reappraisals
Reclassifications
Total additions to stock
Reductions in stock
Extractions
Normal loss of stock
Catastrophic losses—human activity
Catastrophic losses—natural events
Downward reappraisals
Reclassifications
Total reductions in stock
Revaluations
Closing stock of assets (end of accounting period)

Compared to asset accounts in physical terms, asset accounts in monetary terms contain only one additional indicator, that shows final revaluations of the asset at the end of the accounting period (see the penultimate line in table 6.3.3.2.1). In this case the revaluations describe only changes in the asset values caused solely by changes in their prices. They also show the so-called nominal holding gains and/or nominal holding losses on the environmental assets. In particular, the nominal holding gain on a given quantity of an asset is defined as the value of the profit accruing to the owner of that asset as a result of a change in its price or, more generally, its monetary value over time. When calculating nominal holding gains, it is desirable to clarify how the change in the monetary value is correlated with inflation. If the price of an asset changed in the same proportion as the general price level (i.e., kept pace with the general rate of inflation or deflation), then the value of the accrued holding gain is called a neutral (i.e., zero) holding gain. The difference between a nominal holding gain and a neutral holding gain is called a real holding gain. In other words, a real holding gain is the value of the additional command over real resources accruing to the holder of an asset as a result of a change in its price relatively to the prices of goods and services in general in the economy.

The SNA emphasizes that changes in asset prices should be distinguished from changes in their quantity and quality. For environmental assets, the quality of their constituents, such as land and water resources, may change as a result of pollution or, conversely, an improvement in their quality after treatment measures are carried out. Ideally, a change in the asset price related to a change in the asset quality should be considered as a result of a change in the asset volume (stock size), and not as a consequence of its revaluation. Ultimately, we can assume that there is a reclassification between different qualities of the same asset.

There has been some development in the valuation of environmental assets using the requirements of the SNA and the SEEA in recent years in Russia. In 2019, the Russian Federal State Statistics Service (Rosstat) officially published the data for 2017 on the following resources/assets: fossil fuels and minerals, natural timber, and animals (mainly game animals and birds) (Russia in figures, 2020).

6.3.3.3. Basics of accounts (balance sheets) of ecosystem assets

The general principles of ecosystem asset accounts (balance sheets) are close to the structure of environmental asset accounts (balance sheets) presented earlier in table 6.3.3.2.1. The specifics of the EEA are that only those assets are subject to recognition which produce (provide) ES yielding various benefits (profits, goods, incomes, and so on). The related flows characterizing both an increase in these assets (caused, inter alia, by environmental restoration measures) and a decrease in them (caused by degradation, etc.) should be recorded in a balance sheet. These flows are evaluated primarily through the ability of ecosystem assets to produce (provide) related ES.

The EEA differentiates the concepts of "*depletion"* of environmental/ecosystem assets/resources and their "*degradation"*.

The depletion of natural resources/environmental assets is associated with their *quantitative* overexploitation, that is, physical use/consumption in such a scale and form that can limit the possibilities of future environmental management. Unlike fixed assets in industry, the concept of "physical depreciation" does not apply to ecosystem assets (SEEACF-2012). In accordance with the principles of the SNA-2008 and the SEEACF-2012, a decrease in the volume of a natural resource/environmental asset as a result of force majeure negative events (i.e., emergencies and disasters) is not identified as their depletion. That is, depletion should be considered only as a consequence of systematic excess withdrawals of natural resources by economic units.

If we take timber resources as an example, the depletion of natural timber assets in physical terms is equal to the difference between logging and sustainable timber production (sustainable reproduction) with a positive total value. Using domestic forestry terminology, the indicator of depletion in relation to timber resources is inherently close to the positive difference between the actual annual volumes of main forest cutting and the allowable annual cut. To be even more precise, depletion occurs only in cases where the volume of logging exceeds the normal (average annual) value of the natural growth (minus the natural losses) plus the actual, i.e., balanced, growth due to tree-sowing and tree-planting minus dead newly planted trees.

The *depletion or growth* of biological resources/assets is determined by the ratio of their extraction volumes (timber harvested, fishes caught, game animals hunted, and so on) and their recovery volumes as result of natural processes or special measures (reforestation, fish breeding to maintain fish populations under natural/wild conditions, measures that contribute to the restoration of game animal populations, etc.). Unlike bioresources, the depletion or growth of mineral resources/assets is determined by the ratio of their extraction volumes and the volumes of newly discovered deposits as a result of exploration or the conversion of previously unprofitable deposits into profitable ones due to the introduction of new mining technologies.

The degradation of natural resources/environmental (including ecosystem) assets, in accordance with the principles of the SNA, the SEEA and the EEA, is manifested primarily in the form of negative changes in *the quality* of assets/resources. This degradation (caused, inter alia, by human activity) leads to a reduction in a wide range of ES. For example, forest resources/assets include regulating ES such as ensuring runoff quality and quantity, air purification by suburban forests, prevention of soil erosion, carbon storage, regulation of greenhouse gas flows, various recreational ES, etc. Thus, degradation acts here as a specific, i.e., qualitative, form of asset depletion and is expressed in a decrease in flows of various ES.

The degradation or restoration of resources/assets is determined by the ratio of the amount of the degradation of ecosystems and populations (caused by pollution, fragmentation of habitats, recreational degradation, violations of the species composition of biocenoses, intraspecific structure and diversity in turn caused by selective exploitation, invasive alien species, and so on) and the amount of their restoration as a result of natural processes and environmental protection measures.

In general, while determining the physical and monetary values of the *depletion and growth* of environmental assets is of primary importance in the SEEACF-2012, defining the physical and monetary value of the *degradation and restoration* of the quality of ecosystem assets during reporting period plays the same role in the EEA. There are certain relationships and interdependencies between these processes and the corresponding accounting and statistical estimates, which must be considered in order to eliminate possible double counting. A clear determination of these interconnections and interdependencies should be a mandatory subject for further research.

The benefits that people can get from regulating ES are fundamentally different from the benefits they get from using natural resources. Hence, unlike provisioning ES that produce timber, fish, animal furs, and so on, regulating ES vital for humanity do not produce goods that could be sold on the market. Therefore, approaches to ecosystem asset accounting in the EEA differ from environmental asset accounting per se and a statistical characterization of a number of other macro-statistical aspects described in the SNA-SEEA. It should be noted that during an initial formulation of the SNA-SEEA in 1993, correct definitions of the values of certain ecosystem assets already became one of the problems that cannot be completely resolved only within the SNA-SEEA frameworks. These primarily include issues of compiling ecosystem asset accounts, which describe their stocks (resources) and flows associated with changes in these assets due to degradation and/or restoration of ecosystems, and the like. Russian experts faced similar issues already at the beginning of understanding and implementing certain recommendations of the SNA-SEEA.

In particular, it turned out that such unique natural objects as Lake Baikal or a huge part of Russian forests (reserve and protective forests) would have zero or minimum value as economic assets, since the value of their rent (income) in the traditional economic sense is either insignificant, absent or even negative.

An essential problem is that there is currently no unified (unitary), agreed and internationally recognized (not only as an international standard, but even as recommendations of relevant international organizations) classification of ecosystem assets and the ES they produce. Some differences between ES classifications used by the European Union (The Common International Classification of Ecosystem Services (CICES)), The Economics of Ecosystems and Biodiversity (TEEB), the TEEB-Russia, and the Millennium Ecosystem Assessment Report, (2005) are examined in the Volume 1 of Prototype National Report on Ecosystem Services of Russia (Bukvareva, Zamolodchikov, 2018). Developing ecosystem accounting in Russia needs certain measures that would help interested parties to agree on the initial classifications.

A simplified structure of ecosystem asset accounts/balance sheets is shown in table 6.3.2.3.1. In the case of valuation in monetary terms, a line should be added showing changes in profits as a result of price changes (see the analogue in table 6.3.2.2.1).

Table 6.3.2.3.1. General structure characterizing changes in the extent and condition of ecosystem assets (in relation to land cover units/ecosystem functional units, a simplified version).*

Indicator *(examples)*	***Characteristics of ecosystem extent and condition***				
	Vegetation *(Leaf area index, biomass, mean annual increment)*	Biodiversity *(Species richness, relative abundance)*	Soil *(Soil organic matter content, soil carbon, groundwater table)*	Water *(River flow, water quality, fish species)*	Carbon *(Net carbon balance, primary productivity)*
Extent and condition at beginning of accounting period					
Increase in extent and/or improvements in condition					
Due to natural regeneration (net of normal natural losses)					
Due to human activity					
Decrease in extent and/or reductions in condition					
Due to extraction and harvest of resources					
Due to ongoing human activity					
Catastrophic losses due to human activity					
Catastrophic losses due to natural events					
Extent and condition at end of accounting period					

*see Section 6.1.4

6.3.3.4. General principles of valuing environmental and ecosystem assets

Asset valuation can be carried out using various approaches based on different initial principles, many of which are defined in the relevant international documents. However, the SNA recommends the so-called **income method** as the preferred one, which is based on incomes received by the owners of assets primarily from their use.

Within the SNA-SEEA methodologies the relevant group (element) of incomes is determined based on *economic rent* or, more precisely, *natural resource rent*. It is considered as part of the surplus value received by economic units (owners, including the government) and/or specific nature users primarily on the basis of the relevant assets. The value of this rent is calculated based on all the costs incurred, the average amount of entrepreneurial income and a number of other components. In other words, when using this approach, that is, identifying the residual value of the total income, the resource rent, $\boldsymbol{RR_t}$, will be equal to:

$$\boldsymbol{RR_t = B - E - S + N - A - p \times C} \qquad (1)$$

where

$\boldsymbol{B}$ is revenue or total income from the use or withdrawal (extraction, cutting, catching, shooting, etc.) of an environmental/ecosystem asset;

$\boldsymbol{E}$ are non-capital costs (current costs) of a specific type of environmental management, including expenses for fuels and lubricants, raw materials, semi-finished products and auxiliary materials, maintenance of the relevant equipment, salaries of employees, etc. (except for depreciation of fixed assets and taxes);

$\boldsymbol{S}$ are targeted (special) subsidies for a specific type of environmental management or withdrawal of an environmental/ecosystem asset by the government in order to fully or partially cover the costs and maintain (stimulate) such type of management or withdrawal;

$\boldsymbol{N}$ are targeted (special) taxes for a specific type of environmental management, including the withdrawal of an environmental/ecosystem asset by the government (fiscal and/or regulatory authorities);

$\boldsymbol{A}$ is depreciation of fixed (produced) capital;

$\boldsymbol{p \times C}$ are incomes from fixed (produced) capital, calculated as the product of the replacement cost of this capital, $\boldsymbol{C}$, by the average rate of return, $\boldsymbol{p}$. The latter may be substituted by the average rate of return on long-term government bonds.

The above algorithm does not exclude the application of the principle of closing costs, that is, obtaining estimates of resource rent based on comparisons of these costs with actual costs. This generally corresponds to the classical understanding of the origin of such concept as resource rent, which utilizes the notion of production cost in natural resource areas that have the worst productivity and/or location in the form of their assets, incl. ecosystem assets.

The value obtained as the result of successive subtractions given in formula (1) by the **residual value method**, of course, cannot be considered the value of an environmental/ecosystem asset. An adjustment of this value for the entire hypothetical period of the asset's use is necessary, possibly with a discounting of the calculations. For this, the so-called **net present value (NPV)** approach is employed.

The logic of this approach, used as a valuation tool and recommended in the SNA, the SEEA and the EEA, requires the determination of the total amount of resource rent, which is supposed to be obtained in the future, taking into account its discounting in relation to the current moment. There are a number of different theories that determine the specifics and dominance of various derivation aspects of resource rent, when the latter is received by economic units from the extraction/withdrawal/other use of an environmental asset. In particular, the sources of potential resource rent include differential rent, scarcity rent, and entrepreneurial rent (entrepreneurial income, owner's income). Different sources of resource rents are not mutually exclusive. Consequently, the estimates of this rent that underlie the valuation using the NPV approach in the SEEA should not be considered as the final result of only one source of this rent (System…, 2014 a).

The economic basis of the NPV approach is formally equating the value of an environmental/ecosystem asset to the hypothetical total income that can be obtained over the entire asset life, that is, the expected time over which an asset can be used in production or the expected time over which extraction from a natural resource can take place (SEEACF-2012, System…, 2014 a, p. 155) In accordance with the recommendations of the SEEACF-2012, a general algorithm has the following form: the average annual value of rent is multiplied by the existing and forecasted volumes of an environmental/ecosystem asset. The asset may continuously decrease due to anthropogenic and non-anthropogenic reasons both in quantity and quality (depletion and/or degradation. In this regard, future total incomes must be discounted by an appropriate amount to the present accounting period for a summary valuation.

The SEEACF-2012 (in particular, in Appendices 1 and 2 to Chapter 5) provides a detailed analysis of rather complex calculations of the desired asset values. However, we can limit ourselves to using a simplified formula of discounted estimates:

$$\boldsymbol{V_t} = \frac{\sum_{t=1}^{N_t} \boldsymbol{RR_t}}{(\mathbf{1}+\boldsymbol{r})^{t}} \qquad (\mathbf{2})$$

where $\boldsymbol{V_t}$ is the value of an asset at the end of period $\boldsymbol{t}$, $\boldsymbol{RR_t}$ is the resource rent, $\boldsymbol{r}$ is a nominal discount rate effective for period $\boldsymbol{t}$.

In this typical discount formula, the numerator characterizes the total income from any non-renewable (exhaustible) resource involved in the economic process for a certain period of time. In other words, $\boldsymbol{RR_t}$ consists of two components: the quantity (volume) of the resource, $\boldsymbol{S_t}$, and the unit price of the resource, $\boldsymbol{P_{st}}$. Therefore, $\boldsymbol{RR_t} = \boldsymbol{S_t} \times \boldsymbol{P_{st}}$. In relation to the SNA, the SEEA and the EEA methodologies, $\boldsymbol{P_{st}}$ should be equivalent to the amount of rental payments per unit of the resource/asset used or withdrawn until it is completely depleted (exhausted) or degraded, and $\boldsymbol{S_t}$ should be equivalent to the available volume of this resource/asset, which may yield income until it is totally absent in the environment.

Valuing the stock of a natural resource rests on the following: the asset value at the end of period $\boldsymbol{t}$, $\boldsymbol{V_t}$, should be equal to the total discounted flow of the expected (forecasted) resource rent, $\boldsymbol{RR_t}$, assuming that its annual volume is $\boldsymbol{N_t}$. Naturally, the estimates of resources/assets being withdrawn or the volumes of their actual use in the future may change over time, so $\boldsymbol{N_t}$ must depend on $\boldsymbol{t}$. In the simplest case, i.e., between any clearly defined beginning and end times of the resource use, the annual rent $\boldsymbol{N_t}$ should proportionally decrease for each time interval as $\boldsymbol{t}$ increases. If the natural resource use is assessed as sustainable, then $\boldsymbol{N_t}$ may theoretically be of infinite value, although in practice its volume will in most cases be limited.

Using the NPV approach, it is possible to obtain estimates of asset values in the form of natural resources, primarily by implementing **the residual value method** (see earlier about it). Also, as follows from formula (1), the estimate (in the general form) of the resource rent for the initial year is carried out by subtracting targeted (special) subsidies from gross income and adding targeted (special) taxes, as well as subtracting the expenses of asset users.

The SEEACF-2012 highlights that if, after adjusting for targeted (special) taxes and targeted (special) subsidies, the total value of resource rent is negative, then the volume of the net present value of assets is assumed to be zero. In other words, this indicates that the consumption of the environmental/ecosystem resources/assets is not entirely market-determined. Nevertheless, according to the authors of the SNA and the SEEA, this conclusion should not rest only on the zero or negative value (current or expected in the nearest meaningful time period) of resource rent. It is also necessary to study the prospects and likelihood of future commercial incomes. At the same time, it is worthwhile to analyze the same prospects for targeted (special) taxes and subsidies.

In some cases, the withdrawal of a natural resource (asset) may continue without obtaining a notable income for a sufficiently long time, since the level of targeted (special) subsidies may prove to be enough to cover the costs and work conducted by any economic units when the net present value is zero. However, in such a situation, the transfers should not be part of the income from the relevant natural resource assets. They should be considered only as the result of a general redistribution of all incomes in the economy.

According to the authors of the SEEACF-2012 as well as the EEA-2014, the main difficulty in implementing the NPV approach in relation to various environmental/ecosystem assets is a lack of objective and sufficient (for the relevant valuations) data in many countries. This does not allow to develop reliable forecast models for future use. For that reason, a simplified approach can be applied, which assumes (for estimations) that the current composition, structure and content of an asset will remain unchanged for its entire life cycle. In addition, other assumptions and simplified approaches may also be employed.

When choosing a specific *discount rate*, it may be useful to consider the following arguments emphasized by the SEEACF and especially the EEA. Higher rates, if selected for use in calculations, will in one way or another reflect the desire of asset owners to receive income in the shortest time possible, rather than delay this process. This approach also reflects the wish of asset owners/users to avoid possible risks, the likelihood of which increases as the time of resource (asset) use increases. It is relevant to note that both the SEEACF and the EEA repeatedly underline that entrepreneurs and corporations will undoubtedly prefer higher rates. However, besides their private economic needs, there are also economic needs of society. The latter, as a rule, demand the use of socially oriented and lower levels of discounting, since environmental assets are generally of very large-scale and long-term significance to society as a whole. "… lower rates will place higher relative importance on income earned by future generations. From this, it is often inferred that estimates of NPV that use market-based discount rates do not value future generations and the total values obtained are too small, since they do not give sufficient weight to these future incomes." (SEEACF-2012, System…, 2014 a, p. 157).

The NPV approach to estimating the aggregate value of any environmental/ecosystem asset is used in some way or another in the vast majority of all available methods for calculating the above value.

The SEEACF-2012 allows the use of other approaches (or methods) to calculations. **The appropriation method** estimates the resource rent using the actual payments made to owners of environmental assets. In many countries, including Russia, governments are the legal owners of environmental assets on behalf of the country. As legal owners, governments could in theory collect the entire resource rent derived from extraction of the resources that they own (System…, 2014 a, p. 154). The amount of taxes, royalties and fees received by the government for a given time period constitutes the basic for further calculations of the total aggregated income that can be received over the entire asset life (with possible discounting of the volume). This aggregated value is equated to the asset value.

The access price method is based on the fact that access to resources may be controlled through the purchase of licenses and quotas, as is commonly observed in the forestry and fishing industries. When these resource access rights are freely traded, it is possible to estimate the value of the relevant environmental asset from the market prices of the rights. The economic logic parallels the residual value method, since it is expected that, in a free market, the value of the rights should be equivalent to the future returns from the environmental asset (after deducting all costs, including user costs of produced assets). Where the resource access rights that are purchased provide a very long term or indefinite access to the assets, the market value of the rights should provide a direct estimate of the total value of the asset rather than simply an estimate of the resource rent. In this case, no discounting of future flows of resource rent is needed. If the rights are for a more limited period (e.g., for one year in the case of entitlements), this can provide a direct estimate of the resource rent for that period (SEEACF-2012, System…, 2014 a, p. 154)."

The cost method estimates the value of an environmental/ecosystem asset using the amount of costs incurred to maintain its quantitative and qualitative characteristics throughout the entire asset life. However, this method, according to the SNA-SEEA, should be used only when all other methods based on market mechanisms cannot be applied.

The SEEACF-2012 and the EEA-2014 also offer another two methods that are quite close to the algorithms for estimating the value of environmental assets described above. The first of these is the principle of **welfare economic values**. It aims to determine the total—market and non-market—costs and benefits associated with ES and ecosystem assets. The second is the principle of **exchange values**. "When there are no observable prices because the items in question have not been purchased or sold on the market in the recent past, an attempt has to be made to estimate what the prices would be if a regular market existed and the assets were to be traded on the date to which the estimate of the stock relates (SNA-2008, System…, 2009, p. 262)". The first approach is mainly based on the use of adjusted replacement cost. The value of a functioning asset at any time during its "life cycle" is equal to the acquisition cost (at the current acquisition price), i.e. equivalent to the value of a new asset, after deducting the accumulated consumption of capital for a functioning asset over its entire life. The second approach is mainly based on the use of the discounted value of future income. For many natural resource assets, their specific cost expression at their location (in situ) is often missing. In this case, the discounted value method of future income is used, that is, the net present value algorithm (NPV). In other words, this approach consists in assessing future total beneficiary incomes that should result from the use of the asset.

When ES are associated with the output value calculated according to the standard SNA methodology, that is, by exchange value, the relevant estimates should focus on determining the "contribution" of ES to the product's market price. For example, the "contribution" of cultivated melliferous plants to the honey crop, the "contribution" of biological products for plant protection to a higher output by means of cultivating and distributing insectivorous insects, and so on.

If there is no market and, therefore, no market prices, it is proposed to use standard procedures of national bookkeeping, in which the cost of production is taken as a basis. In other words, with this approach, the value of a service is equated to the sum of its receipt/production costs.

6.4. Approaches to ecosystem accounting zoning in Russia

Territory of Russia is extensive and extremely diverse in both natural and socioeconomic conditions. Thus, development of a zoning scheme for the territory of Russia is necessary task which must be completed during preparations for the introduction of SEEA-EEA in the country. A fundamental requirement for assessing and managing ES and ecosystem assets is to combine indicators of natural systems (ecosystems, species, populations) that supply ES and the socioeconomic systems that consume them. It is therefore obvious that zoning principles should consider both natural and socioeconomic indicators and, accordingly, the boundaries of natural and socioeconomic systems.

Terrestrial bioresources and ecosystems in Russia are managed within administrative units of different levels and therefore they must be represented in the ecosystem accounting system. However, assessment of ES and ecosystem assets within administrative boundaries might contain distortions because the natural heterogeneity of the regions and the uneven distribution of ES and ecosystem assets within them. The first ES pilot assessment done in TEEB-Russia 1 project for subjects of RF revealed fundamental challenges related to the face that territory of many subjects is extremely diverse and requires division into more homogeneous parts to adequately assess ES even at the national level (Bukvareva, Zamolodchikov, 2018). TEEB-Russia 2 project revealed fundamental dissimilarities in relationships between indicators of ES and ecosystem assets for different ecoregions within European Russia, which demonstrates the need for a regionally differentiated approach to SEEA-EEA in Russia (Sections 5 and 6.1.3.2).

Assessment of ES and ecosystem assets within administrative units must consider the contributions of various landscapes to analyzed territory. Specifically, estimates of ES and ecosystem assets obtained for an entire subject of RF should be distributed over its territory in accordance with the uneven distribution of zonal landscape types.

The possibility of integrating natural and socioeconomic indicators in ecosystem accounting is built into the three-tier system of spatial accounting units (System of Environmental-Economic…, 2014 b), the smallest of which (BSU, LCEU) are tied to natural systems, while administrative units are presented on the top level (EAU) (Section 6.1.4, Tab. 6.1.4.1).

The objective of this Section is to analyze possible approaches to ecosystem accounting zoning exemplified by Kostroma Oblast of the Central Federal District.

6.4.1. Physiographic zoning units as a possible basis for ecosystem accounting

Physiographic zoning units (provinces, districts, regions)[72] are identified based on similarity of combinations of landscape types. Knowledge of the proportions of landscape types with components typical for each of them (rocks and landforms, water, air masses and climate, soils, vegetation, animals) makes it possible to estimate the total area of landscape units that provide different ES. Landscape maps, which usually underlie physiographic zoning, allow for an interpretation adapted to ES assessment.

Basin units with prominent and directed flows of water and associated matter are important along with physiographic zoning units for assessing water-related ES (production of freshwater ecosystems, regulation of runoff volume, runoff quality assurance by terrestrial ecosystems, water purification in water bodies).

The use of physiographic zoning units as the basis for ecosystem accounting is justified by the fact that the same parameters for calculating ES volume may be used within them. The requirement is the availability of raster data, when each pixel corresponds to a series of natural or socio-economic characteristics. Sources for this information are the numerous indices that are calculated based on multichannel space images and that describe ecosystem functioning (humidity, productivity, reflectivity, etc.) and classified images. Modern digital relief models (DEM, SRTM) make it possible to calculate geomorphological (slope, exposure, curvature, roughness, mass balance, etc.) and hydro-geomorphological (watershed area, relief erosion index, runoff accumulation measure, topographic wetness index, etc.) characteristics pixels by pixel.

[72] A physiographic province (plain) is part of a zonal area distinguished from neighboring parts by basic features of geological structure and geomorphological peculiarities, the nature of neotectonic movements, and climate (Gvozdetsky, Samoilova, 1989). A physiographic district is identified based on repeating landscape types.

Characteristics of point objects (towns, animal shelters, etc.) can be converted to raster form using the density and unevenness (hot and cold spots) of their spatial distribution. Finally, characteristics that have primarily discreet 2D distribution (areas of exposure of rock and Quaternary sediments on the surface, farmlands, forest formations, etc.) can be rasterized from digitized maps. Thus, in many respects, the dependence of calculations on statistical data that is available for administrative units, forestries, and agricultural enterprises can be removed.

As will be shown below, the principles of physiographic zoning make it possible to consider not only the natural conditions that affect the provided ES volume, but also geographic distribution of the population and economic structures that govern ES demand and consumption.

In addition to indicators of natural and socioeconomic conditions (climate, hydrology, relief, area of ecosystems of different types and farmlands, the distribution of population and economic structures, etc.), the geometric parameters of combinations of natural ecosystems and areas developed by man are important. Following are examples of the different roles of natural landscapes as ES providers depending on spatial context for 4 types of spatial structures.

Massive or massive-hole structure (Fig. 6.4.1.1 a) with a dominant type of landscape cover, amid which there may be rare (up to 10% of the area) spotty or striated mottling of a different type, e.g., a predominance of forest landscapes with spots of grasslands, marshes, or fields. Provided ES volume is determined by area of the landscape that provides it and the concentration of the ES per unit of area. Examples: a) wood production ES in commercial forest regions; b) the information ES of storage of genetic and biochemical resources in nature reserves with a full representative set of typical ecosystems; c) the regulating ES of biogeophysical climate regulation in forest regions.

Regular-mosaic structure (Fig. 6.4.1.1 b) with co-dominance and regular alternation of several types of landscapes, e.g., forest and field, forest and steppe. Provided ES volume results from a proportion of different landscapes and their even spatial distribution. Landscape types are complementary, creating new quality as a result of their interaction. Examples: a) the ES of runoff regulation through a combination of forest, grassland, and field landscapes that, within a basin, stabilize runoff due to non-simultaneous snow melting and differences in infiltration; b) the ES of the creation of soil bioproductivity through the climate-regulating and water-regulating role of forest outliers in relation to fields in forest steppe landscapes; c) the information ES that provides an aesthetic perception of the diverse lake-forest-field landscape.

Cluster structure (Fig. 6.4.1.1 c, d) with relatively rare fragments of a rare landscape amid a dominant landscape of a different type. ES are created by spots, strips (or clusters of them) of rare landscape amid either a natural or heavily transformed anthropogenic landscape that represent other types of ES. In such structures, the relative location, orientation and configuration of contrasting landscape types are most important, their area is secondary. Examples of ES: a) regulating ES provided by forest parcels that neutralize the adverse effects of field plowing; b) recreational and information ES (ecological education, religious needs, etc.) provided by rare landscapes amid a territory that has lost the traits of zonal nature.

Gradient structure with a series of gradual and natural transitions between landscape types as the value of a certain leading factor changes. Provided ES volume results from the necessary combination, in space or time, of conditions for satisfying a particular need. No one individual element of a gradient structure is sufficient to provide ES. Examples: a) the ES of livestock fodder production for distant pasture cattle husbandry using the fodder resources of different altitude belts in different seasons; b) the ES of fodder production for migratory reindeer herding in the tundra/forest tundra/northern taiga.

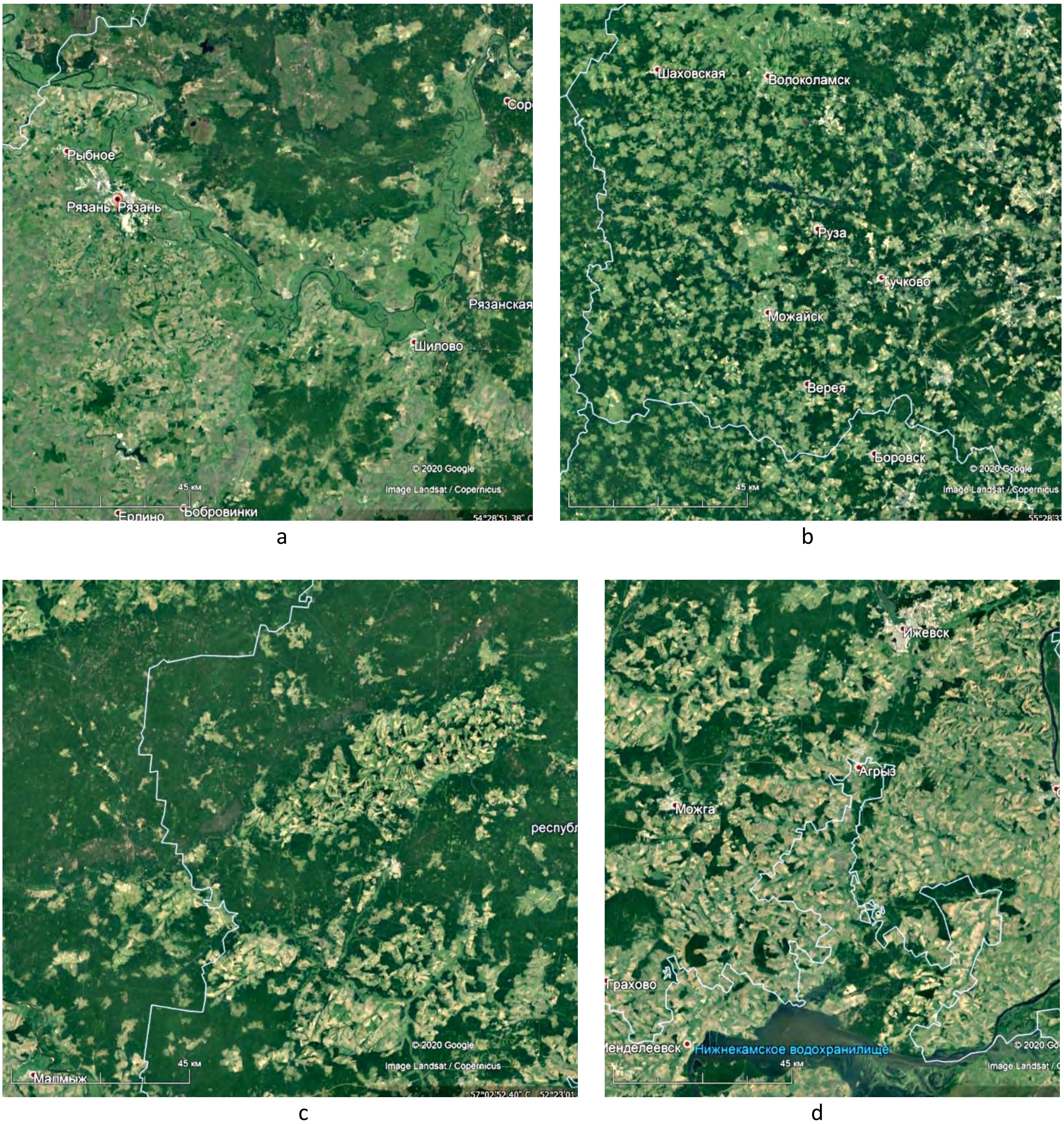
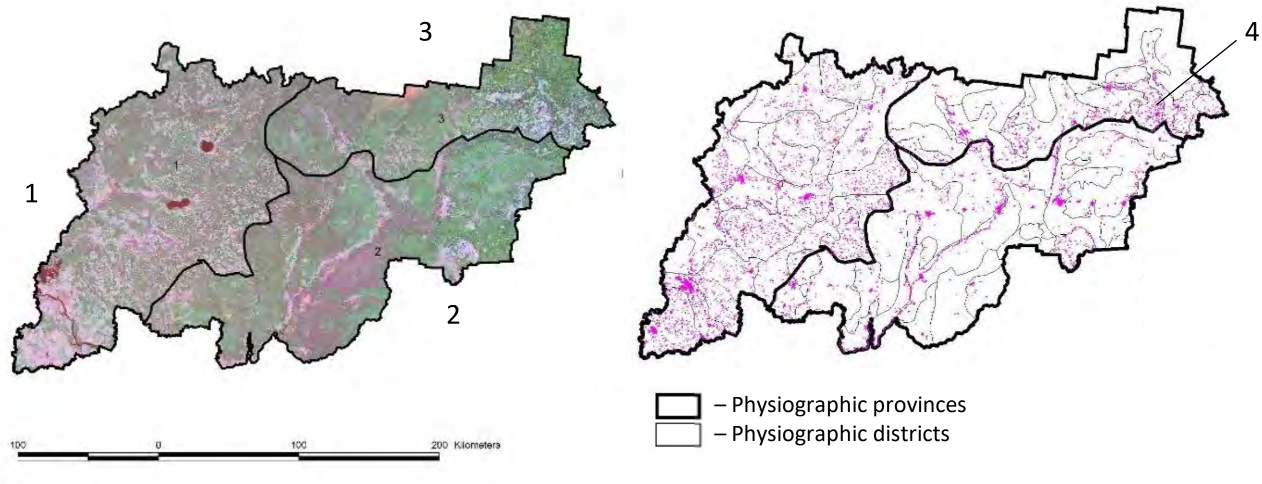


Fig. 6.4.1.1. Examples of different types of landscape spatial structure: a) massive pattern of landscape cover in northern Ryazan Oblast in forest landscapes of glaciofluvial plains; b) mosaic cover of hilly-moraine landscapes in western Moscow Oblast; c) spots of tilled plains amid forested glaciofluvial and alluvial plains in central Udmurtia; d) spots of forested glaciofluvial and alluvial plains amid tilled plains in southern Udmurtia.

The importance of physiographic provinces in assessing ES and ecosystem assets exemplified by Kostroma Oblast

Kostroma Oblast is located within three physiographic provinces (Khoroshev et al., 2013, Fig. 6.4.1.2 a), which differ in the following characteristics important for assessing ES: a) the spatial pattern of landscapes, including relief, vegetation, and economic use, b) the ratio of key natural resources; c) the set of actual and potential natural hazards; d) climate and related hydrological characteristics; e) the settlement pattern (Fig. 6.4.1.2 b).



a b

Fig. 6.4.1.2. Physiographic provinces in Kostroma Oblast: a) province boundaries: 1 – Upper Volga, 2– Vetluga-Unzha, 3 – North Ridge; b) Kostroma Oblast settlement system within the boundaries of physiographic provinces and districts (4 – Vokhomsky district).

The Upper Volga province with southern taiga and taiga sub-provinces is characterized by intensive cultivation and high population density, which is concentrated at moraine hilltops along the edges of river valleys and lake basins. Forest resources are largely depleted, and secondary small-leaved and small-leaved-pine forests are exploited. Because of its advantageous historical and geographic position, large lakes and fertile soils, the province has great potential for information and recreation ES. Characteristics important for ES assessment are as follows:

a) mosaic relatively uniform distribution of forested and unforested, elevated and lowland areas as a factor regulating runoff, microclimate, and the aesthetic importance of landscapes;

b) a low proportion of zonal southern taiga ecosystems, which increases their social and environmental importance in a densely populated region, including satisfying recreational and provisioning ES;

c) the ubiquitous proximity of settlements (Fig. 6.4.1.2 b) to zonal ecosystems, i.e., geographic units that consume and provide ES, which determines both the high demand for ES and the large number of anthropogenic threats to landscapes and land use trade-offs;

d) the province's position within basins of large lakes and ancient glaciolacustrine basins, which determines the close linkage of land use with the condition of the lakes and the historical, cultural, and aesthetic uniqueness of the area;

e) a high proportion of sloped surfaces and highly intense lateral matter flows, which increases the importance of soil- and water-protective ES performed by zonal ecosystems under significant anthropogenic loads;

f) high internal patchiness of the territory due to frequent changes in steepness, curvature, and exposure of surfaces, which makes it difficult to extrapolate local measurements to large areas.

The southern taiga Vetluga-Unzha province is heavily bogged and well-forested mainly by pine forests. Low soil fertility hinders agricultural development. Settlements are focused, mostly along narrow bands along the edge of river valleys and along roads and railroads. The ES of wood production by conifer forests is the most important. Major consumers of this ES are large, nationally important wood-processing enterprises in Sharya and Manturovo. The main transportation axis is the railroad that crosses the province latitudinally. Characteristics important for ES assessment are as follows:

a) massive-hole structure (Fig. 6.4.1.1 a) with uneven distribution of zonal and disturbed ecosystems with a sharp predominance of zonal ecosystems;

b) a high concentration of settlements in narrow unforested bands along rivers and roads (Fig. 6.4.1.2 b), which results in the high polarization of anthropogenic loads and increases the importance of the water-protecting ES of forests and grasslands on the local scale along river valleys;

c) high potential for the ES of wood production and its major consumers while, in contrast to the Upper Volga province, places of ES provisioning and consumption are far from one another;

d) the province's large contribution to ES of biogeochemical climate regulation by large areas of forests and bogs;

e) the high dependence of runoff from the Unzha, Vetluga, and Neya rivers on the transpiration function of the vegetation in their basins – marshes, young, middle-aged, and old forests and the ratios of their areas as a function of the time elapsed since cutting or fires;

f) a low proportion of sloped surfaces, the low intensity of lateral flows, and the major role of underground runoff within sandy plains, which reduces the significance of forest ES of soil erosion prevention, but increases their significance in ground water protection;

g) the high potential of aesthetic, recreational and provisioning ES of the valleys of the three largest rivers amid the generally undifferentiated terrain, boggy, and low accessibility of most of the province;

h) relatively low internal patchiness of the territory, which expands opportunities for extrapolating local measurements to larger territories.

The southern taiga province of North Ridge is characterized by high erosive ruggedness, remoteness from federal roads, and the relatively low population density of most of the territory. The population is concentrated in agricultural landscapes with fertile soils. ES potential is split among spruce and fir-spruce forests and unforested agricultural landscapes. Characteristics important for ES assessment are as follows:

a) position in the general drainage system of the East European Plain near watershed in the upper reaches of Kostroma Oblast's two largest rivers (Vetluga and Unzha) that are the largest right-bank tributaries of upper Volga, which makes the runoff-regulating ES performed by the province's ecosystems important not only outside the province, but also outside Kostroma Oblast;

b) uneven population distribution, which results in the polarization of places of provisioning regulating ES and demand for them;

c) large agricultural centers with the extremely high importance of residual spots and bands of zonal ecosystems as providers of regulating and recreational ES of local importance;

d) the high proportion of sloped surfaces and high intensity of lateral flows, which is controlled by the ratio of forested and unforested areas;

e) the high proportion of inaccessible areas because of the sparse road network, which increases the province's importance as a center for preservation of zonal ecosystems and biodiversity.

The physiographic provinces therefore differ significantly from one another with respect to conditions for ES provisioning and consumption. This approach to zoning, in which the linear size of spatial units is few hundreds of kilometers, is useful in determining priority ES and in assessing the remoteness and adjacency of ES-providing ecosystems and ES consumers. The key general property of landscapes forming a single province is the energy of the relief, which determines the significance of the ecosystems' contribution to the regulating ES associated with lateral matter flows (soil protection from erosion, runoff regulation and runoff quality assurance by terrestrial ecosystems) and to recreational ES, which are attributable to the contrast among land forms.

An informative general characteristic for estimation of ES of a province can be the fragmentation of the landscape structure with indicators of average plot areas and their internal mosaic.

The latter is important as a factor affecting the accuracy of the recalculation of specific indicators (e.g., m^3/ha of wood) for the entire area: the more internal mosaic of a site, the greater the possible error in recalculating and extrapolating data if the size of the operational territorial unit (for example, pixel) is incorrect.

The province as a zoning unit is convenient for calculating water-regulating ES associated with river and lake basins because the majority of basins in a province have common structural features (typical areas, the runoff-forming conditions of the relief in the upper and lower parts of the basin, geochemical contrast, etc.).

The importance of physiographic districts in assessing ES and ecosystem assets exemplified by Kostroma Oblast

Physiographic districts are a more fractional zoning units within a province which are defined by a set of typical landscapes. Within an elevated physiographic province (e.g., Northern Ridge) districts may vary in the depth of landform stratification, the abundance of surface rock and Quaternary sediments, typical plant communities. For example, in the Vetluga-Unzha province, landscapes of flat, glaciofluvial plains with pine forests are absolutely predominant, but in the North Ridge province they are distributed locally in strips along rivers on a dominant background of moraine and moraine-glaciofluvial plains.

The set of typical landscapes within a physiographic district may appear either in uniform alternation or in a succession from a core outward in different directions. The population distribution pattern is also specific to districts and defines the proportions and relative location of natural plots that preserve or lose their zonal nature. While the bulk of regulating and information ES is provided primarily by zonal natural ecosystems, provisioning and recreational ES may be provided by ecosystems and landscapes substantially transformed by humans (e.g., forest plantations or so-called "cultural" landscapes). The accessibility and value of zonal plots and the degree of provision of the population with necessary ES vary depending on the proportion of the landscape that has lost its zonal nature.

In Vokhomsky district, the North Ridge province ("4" on Fig. 6.4.1.2 b), which is characterized by fertile and well-drained soil, the extent of tillage and population density are so high that there are very few zonal forests. The population has been deprived of the ability to use recreational ES provided by these forests, since their per capita area is small, they are hard to reach because there are no access roads, they have strict conservation restrictions (specially protected forest plots, protective forests in water conservation zones, sanitary protection zones of water sources, etc.) or their current use is incompatible with recreational purposes (solid waste landfills, military facilities, village cemeteries). At the same time, in neighboring physiographic districts where the soils are poor and waterlogged, the network of settlements is far sparser, and not one of them is farther than walking distance from forests. Because of a similar combination of landscapes within a physiographic district, common parameters may be selected for equation relating ES with characteristics of drainage basin or valley. For example, for water-protection ES of valley forests, water quality will depend not only on the area of these forests, but also on the steepness and length of slopes, the width of the forest belt between tilled fields and the unforested valley bottom, and the mean distance from the foot of a slope to valley bottom. The contribution of each of these variables is amenable to statistical estimating if there are enough basins with similar physiographic characteristics. After obtaining the equation for calculating ES within a physiographic district, we can calculate the optimum ratio of land cover types that provides a given ES in full. This makes it possible to design measures to prevent ES loss or recovery. When moving to another district, the set of significant variables may remain the same, but the parameters may change.

6.4.2. Zoning to assess individual ES categories

Special kinds of zoning to assess specific ES can be based on combinations of digital raster maps. To do this, a number of conditions are set that the territories must meet in order to be considered providers of the studied ES. For example, the ES of soil erosion prevention requires preservation of forests on slopes (Fig. 6.4.2.1 a, b) especially on easily eroded slopes (Fig. 6.4.2.1 c). If such forests are cut down or plowed, substantial expenditures will be required to compensate the damage from the loss of this ES (erosion control, restoration of soil fertility, restoration of aquatic ecosystems after sedimentation and eutrophication, dredging, etc.). Further, the threshold values for the parameters determining the implementation of this ES can be determined, e.g., share of area of these forests, and administrative districts or zoning units can be ranked based on these gradations.

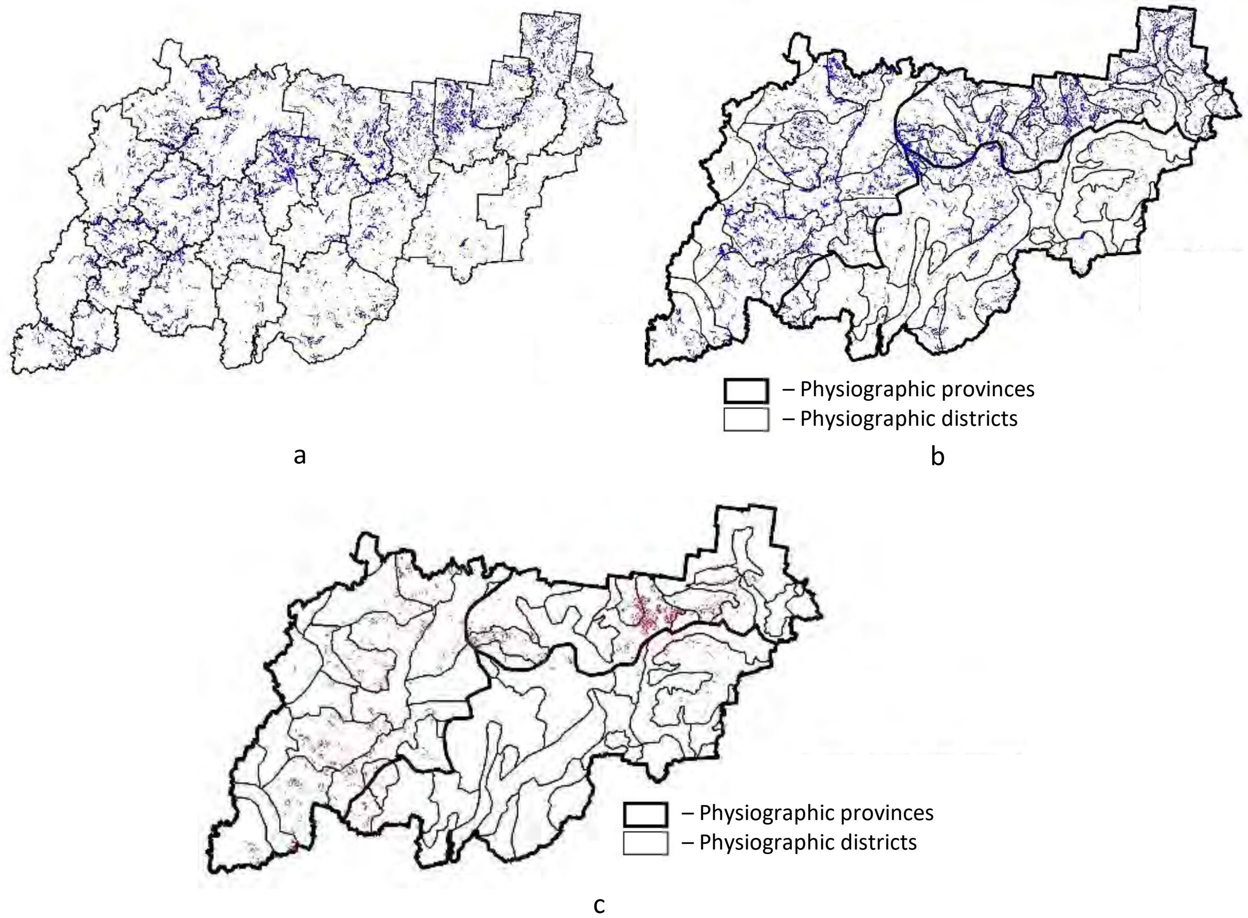


Figure 6.4.2.1. Mapping of erosion-preventing forests for zoning erosion prevention ES within Kostroma Oblast: a) forests on slopes within administrative districts; b) forests on slopes within physiographic districts; c) forests on easily eroded loessy loam slopes within physiographic districts.

6.4.3. Identification of connection districts

As stated above, ES assessment must consider both natural conditions that govern the provided (potential) volume of ES and socioeconomic parameters of the geographic areas that affect required and consumed ES volumes: population density, the proximity of towns, enterprises, and related infrastructure. Areas of ES provisioning and use may not coincide and may be connected by several types of spatial relationships (in situ, central, multidirectional, directional, non-directional) (Burkhard, Maes, 2017). To take these relationships into account, a specific zoning approach is used – identification of connection districts which unite material and non-material ES "flows" that pass from places of ES provisioning to places of ES consumption. For example, if parts of a territory differ in forest cover, the identification of connecting districts will allow to unite forest part that provide ES and are linked by ES flow with consumers in unforested part. ES flows may include wood and game production, recreational opportunities, runoff regulation, etc., i.e., all cases when ES are provided in the forested part but are used by people and enterprises outside it. An important characteristic of connection districts is the intensity of the gradient of certain natural feature that governs ES provisioning that is opposite the gradient of certain social feature that governs ES consumption.

An example may be an approach to identification of connection districts for the ES of creation natural conditions for weekend recreation (see Section 4.1.7). Demand for weekend outdoor recreation among city dwellers is obviously higher than among rural inhabitants. Therefore, share of urban area or the density of the urban population calculated pixel by pixel could serve as the variables that determine the demand for the ES in the equation for the flow of this ES. The size of a geographic area for calculating ES flows can be determined from a family's reasonable travel distance for Sunday recreation (in Section 4.1.7 a distance of 50 km around major cities in European Russia was used). Indices of provided ES, i.e., the recreational capacity of different types of ecosystems (see Section 4.1.7) and the recreational appeal index are calculated for this area. Various parameters may be used to determine recreational appeal, including the landscape's aesthetic value (see Section 4.1.8), travel accessibility, and availability of touristic infrastructure. After calculating these indices pixel by pixel, we can apply the method of constructing a regression equation in a moving square (or circle) for each pixel. Then, based on determination and regression coefficients, we can identify districts in which a decrease in required ES is linked to an increase in provided ES. This will allow us to build a map of the preferred directions of the movement of people to receive recreational ES along the corresponding gradients. The steeper this gradient, i.e., the least distance at which indices change, the stronger the use of the ES and its flow from places of it provisioning to places of consumer localization. For example, if a large urban area is located close to a beautiful forest lake area, the flow of city dwellers seeking recreation will be conspicuous. If the distance is long and the gradient less steep, it is highly probable that the flow of city dwellers will decrease and they will select accessible options closer to city, even if they are of lower quality, e.g., in suburban parks.

6.4.4. Zoning by the similarity of relationships between indicators of ES and ecosystem assets

A method for identifying districts on the basis of the similarity of relationships between indicators of ES and ecosystem assets, which include natural and socioeconomic characteristics, offers special capabilities for assessing ES. For this, a series of GIS raster layers is used, on the basis of which the relationships between different indicators are described by regression equations. Zoning is based on determination and regression coefficients. Districts with similar determination coefficients, which implies a reliable association, are preliminarily identified. Then the districts are detailed based on the similarity of relationships between indicators (i.e., regression coefficient sign and modulus). There are two possible ways to calculate regression. The first method involves calculation in a sliding window when all window pixels have equal weight in the equation. The second method assigns equal weights to pixels for a locality as a function of distance to the central pixel.

If the study area is provided not with pixel-by-pixel, but irregular point data, than according to the method of geographically weighted regression, coefficients can either be calculated based on a given number of neighboring points, or in a given neighborhood, or select the optimal size of the neighborhood for the calculation to achieve the highest quality equation (Fotheringham et al., 2002; Kupfer, Farris, 2007).

This approach provides two capabilities for ES assessment.

Identification of ES flows (see Section 6.4.3). Within a district identified by similarity of relationships between indicators, these indicators change in conjunction. If one indicator increases in a certain direction, then another either also increases or decreases. For example, if there is a negative relationship between forest area and population density (the higher the population density, the lower the forest area), the ecosystems providing forest-related ES and the consumers of these ES are spatially separated. In this case, ES flow directed along the gradient of decreasing forest area and increasing population density should be expected. An opposite flow is also probable in this same district: people, as consumers of the recreational and information ES of forest ecosystems, move to the places providing these ES, toward an increase in forest area (Section 6.4.3).

Identification of synergy or trade-off between ES. In a simplified example, we can assume that runoff regulating ES are mainly produced by swamps, wood production – by forests, and ES of ensuring soil fertility is most important for arable land. It should be expected that indicators of area share of forests, swamps and arable land relate to each other, and the latter indicator in most cases should be in antagonism to the first two. Section 5.2.3 presents examples of negative correlations between indicator of the degree of territory transformation and indicators of forest area and water-related ES, as well as positive correlations between water-related ES and forest area. Positive correlations between indices of forest-related and water-related ES and negative correlations between all these ES and agricultural production have also been found (Section 5.2.6). These dependencies have been identified for the whole Russia or European Russia, but within individual ecoregions of these vast territories they vary. Moreover, correlations identified for vast geographic areas largely reflect not causal relationships, but merely correlations explained by simultaneous reaction of indicators to some third factor, e.g., climatic conditions. Thus, identifying a synergy or trade-off between ES requires more detailed analysis within regions with uniform natural conditions. Methods of geographically weighted regression or regression in a sliding window make it possible to identify areas with similar relationships between indicators. A map of regression coefficients and a map of relationship classes derived from it (the result of classifying geographic areas based on regression coefficient values) may reveal the presence of the following basic ratios of area share of swamps, forests, arable land.

A) The greater share of swamp area, the lower share of forest and arable land area. This is typical for many districts of the western Siberian taiga and eastern European taiga, where the limiting factor is excessive moisture. In many areas, as relief roughness and drainage increase, swamps are first replaced by forests, and then forests are replaced by arable lands. In such areas, there is a trade-off between ES of ensuring soil fertility and other ES (regulating runoff and wood production).

B) The greater share of swamp and forest area, the lower share of arable land area. In that case most of the forests are swampy and only in rare spots or stripes (e.g., along valley edges) swamps are impossible. All drained forests are transformed to arable land. Treeless swamps are practically absent. The ES of regulating runoff and timber production are spatially combined, and the soil fertility ES is in antagonism to them.

C) The greater share of forest area and the lower share of swamp area, the greater share of arable land area. Such a situation is possible when only the presence of treeless swamps completely excludes the possibility of plowing, and outside the swamps forests and arable lands alternate creating a relatively monotonous pattern. In this case the ES of wood production and soil productivity are essentially compatible in space, and the actual distribution of farm lands and forests is the result either of the owners' willful decisions or the result of adaptation to smaller landscape units (e.g., when flat surfaces are cultivated and slopes are forested).

6.5. Overview of landscape and territorial planning in Russia and the USSR

6.5.1. Forms of territorial planning previously used in the USSR and the Russian Federation

Of the earlier forms of territorial planning it makes sense first and foremost to use some still-relevant methods and results of the District Plan and Territorial Integrated Conservation Plans (TerICP). District plans cover the geographic areas of many subjects of RF and their districts. This was a mandatory form of planning. TerICPs were also drawn up widely, although optionally, primarily for areas with special conservation problems.

Regional planning is a kind of planning done until 1998, the main goal of which was the efficient, interrelated siting of industrial enterprises, cities and towns, transportation arteries, utilities, and recreation areas in a specific geographic area. Regional plans were based on a comprehensive assessment of an area with allowance for geographic, economic, architectural, planning, engineering, technical, and ecological conditions and factors. There were two levels of planning: regional plans and projects, which differed in the sequence of development, size of the geographic area involved, the specifics of the objectives, and the level of detail of analysis. Regional plans were made for subjects of RF. Regional projects were implemented for municipalities and groups of municipalities, zones of influence of large cities, resort areas, etc. The current urban planning code eliminated regional planning, but existing plans and projects are considered during new planning. Also, some procedural techniques of regional planning remain valid. The content of regional planning is reflected in the list of maps and schemes included in them (Tab. 6.5.1.1).

Table 6.5.1.1. Maps and schemes included in regional planning.

Section	*Maps and schemes*
Basic materials	– Current condition of the geographic area – Functional zoning – Project plan – Priority activities
Supplement materials	– Geographic position – Integrated assessment of the area – Geotechnical conditions and mineral resources – Settlement and planning structure – Farming and forestry – Cultural and social services – Organization of public recreation – Conservation of nature and cultural monuments – Transportation systems and structures – Water supply – Energy supply – Land amelioration and development – More detailed fragments of certain maps and diagrams for the most developed segments of the area (at the customer's request) – Medical zoning (for resorts) – Options for planning the organization of the territory
Ancillary materials	Working diagrams that support the integrated assessment of the area (geological structure, soils, vegetative, etc.)

In Soviet times, regional planning was a progressively developing form of project activity, an important channel for the introduction of environmental ideas and landscape-ecological principles into environmental management practices. However, a number of its features did not contribute to the implementation of the concepts of environmentally sustainable regional development. Being one of the links in the hierarchical system of territorial planning, the district planning obeyed its general principles that had been established during the period of strict vertical planning "from top to bottom", and therefore it carried the features of centralized economic management.

The most significant features of this system are:

– the priority of the interests of the economy and of the area's economic development;

– reliance on general settlement plans and planning solutions;

– the subordinate role of nature conservation;

– the fact that planning proposals were to some degree optional, as seen, for example, in the fact that land use boundaries were legally codified in other documents: land management plans that were independent of regional planning and were made on a larger scale;

– executive agencies reviewed and approved only a portion of planning materials, however, even after approval these materials could be revised.

The Territorial Integrated Conservation Plan (TerICP) is an integrated conservation plan developed in the 1980s and 1990s for a geographic area – a region or natural object. The plan included the setting of standards for anthropogenic impacts on the environment, defined problem areas and restrictions on the siting of enterprises. The TerICP also included recommendations on the environmental management system and a long-range environmental protection plan. The planning code that was in effect until 2004 made the production of a TerICP optional; new plans are not currently prepared, but many of the principles of the old ones remain relevant.

TerICPs usually included maps reflecting the following factors: – existing anthropogenic impacts on natural objects,

– the resilience of natural objects against anthropogenic impacts,

– the current condition of natural features,

– planned impacts on the territory,

– the severity of conservation problems and conflicts,

– recommended conservation activities.

TerIPCs were usually developed either as the conservation part (section) of regional plans or as an independent form of regional territorial planning. Often the content of these plans turned out to be wider in practice than purely environmental protection. The scope, content of the maps, and the way in which data is presented could vary significantly. An example of such a series of maps is medium-sized maps of the territory of the Kursk region prepared by a team of employees of the Institute of Geography of the Russian Academy of Sciences. In both their legal aspects and their content TerICPs had a number of drawbacks:

– the status of the plans was not defined by a special regulation;

– the plans have not been explicitly incorporated into the in the hierarchical system of territorial planning;

– the purpose of the plans, their structure (content) and developers were not defined by regulations;

– the analytical sections of plans did not consider socioeconomic trends;

– the financial, material, and resource capabilities for implementing activities recommended by plans were not discussed;

– there was no provision for the monitoring of the results of plan execution or correction of recommended activities.

Despite the drawbacks, the advantages of these plans are obvious. Like no other form of territorial planning TerICPs contributed to solving the environmental problems of the territory, as they assessed the sustainability of various landscape components, predicted the consequences of their use and were aimed primarily at conservation measures rather than the use of the territory.

6.5.2. Modern forms of territorial planning

Currently, territorial planning is determined by the following main documents:

– Federal Law of June 28, 2014, № 172 "On Strategic Planning in the Russian Federation", Articles 32 and 38;

– The Urban Planning Code of the Russian Federation of December 29, 2004, № 190 (as amended on December 27, 2019), Articles 10 and 30;

– Federal Law "On Land Management" dated June 18, 2001, № 78, article 19;

– Forest Code of the Russian Federation dated 04.12.2006, № 200 (as amended on 01.07.2017), Article 86.

The Urban Planning code of the Russian Federation (UPC RF) defines territorial planning as a tool for urban planning, i.e., the development of geographic areas, including cities and other settlements, carried out in the form of territorial planning, urban zoning, architectural planning, construction, capital repair, reconstruction of capital structures, operation of buildings, structures, and amenities, including to establish functional zones, identify the planned sites for facilities of federal, regional and local importance.

This definition covers not only the area of different kinds of settlements, but also the entire space of municipalities, regions of Russia and, ideally, the entire country. According to the UPC RF, territorial planning is carried out in the form of territorial planning schemes (TPS). There are not yet TPSs developed for the entire country. On the country scale there are only TPS components in the form of plans for the development of transport, energy, and certain other components. But they are available (have been published) mostly in the form of texts, not maps.

In a broad understanding forms of territorial planning include forest planning, land use planning, water management, and conservation planning. These forms are codified in regulations and are used on different hierarchical levels. Regional and lower levels are specified for forest planning; federal and regional for conservation; municipal, regional, and federal for urban and land use planning. The content of plans on each of these levels differs, and they must be organized so that the results of one level complement the results of another.

Landscape planning is also a form of territorial planning by the nature of its content. But it has not been codified in regulations, and therefore is not used by authors of other types of plans, although the benefit from integrating TPSs and landscape planning could be significant Customers (administrations of municipalities, settlements and regions) also do not consider it necessary to finance landscape planning.

More specific forms of territorial planning are rarely developed as independent plans, but methodologically they are of certain interest.

Functional zoning is the most developed and methodologically rich form of spatial planning and was codified in the 2004 UPC RF. This form basically serves as a component of urban planning, as a result, functional and territorial zones are established: residential, public-business, industrial, engineering and transport infrastructure, agricultural, recreational, protected natural areas, special purpose and others. Of special environmental importance are the following types of zones:

– A buffer zone is identified around protected nature areas to protect them against adverse anthropogenic impacts from the outside, special conditions for economic activity are established within a zone.

– A zone of protection (for example, the zone of protection of historical and cultural monuments, the sanitary and water protection zones around resorts, industrial enterprises, water objects) – the territory adjacent to the protected object, designed to protect it from negative anthropogenic influences from the outside;

– A recreation zone is a special zone for short-term public recreation by residents of a settlement that is located within a green zone or within the parks or squares of settlements.

– An environmental emergency zone is an area where economic or other activities have resulted in persistent negative changes in the natural environment that threaten public health, the condition of natural ecosystems, and the gene pools of plants and animals.

– An environmental disaster zone is an area where economic or other activities have resulted in profound, irreversible changes in the natural environment that entail a substantial deterioration of public health, disruption of the natural environmental balance, destruction of natural ecosystems, and the degradation of flora and fauna. Within an environmental disaster zone economic facilities are shut down except those that serve the population living within the zone, the construction and reconstruction of economic facilities are prohibited, all kinds of natural resource use are substantially restricted, and prompt measures are taken to restore and reproduce natural resources and to revitalize the natural environment.

Planning of the natural ecological framework of an area and the construction of environmental networks is aimed at preserving or creating an ecological framework, that is, a system of cores (sites for strict species protection, habitat protection and landscape protection) and corridors connecting them (bands connecting cores into the system) of different levels with environmental management regimes that prevent the loss of biological diversity and degradation of the landscape, and also support its optimal functioning and dynamic stability..

6.5.3. Territorial planning features useful for assessing ecosystem services in Russia.

Currently, there are a number of geographical approaches that allow us to evaluate and take into account ES in the course of territorial planning (TEEB-Prozesse..., 2014; Erfassung und Bewertung..., 2014).The usefulness of forms of territorial planning to identify and analyze ES in Russia is based on the following basic features of these forms:

– the ability to interpret the properties of a geographic area which are taken into account in planning, as indicators of ES;
– displaying the properties of the territory in cartographic form with reference to the borders of certain territories;
– the spatial scale of planning materials and the spatial hierarchy of these materials;
– the properties of the spatial cells to be used;
– the reliability (credibility) of planning materials, including their availability of empirical data.

The usefulness of different forms of territorial planning for assessing ES is determined by their following characteristics:

– urban planning, in particular, territorial planning schemes, cover large territories, has a hierarchical structure, provides a comprehensive assessment of the territory, its suitability for different needs, recommends suitable uses of the territory, includes functional zoning;

– forest management plans contain taxation materials (data on wood reserves, age, dynamics and species composition of stands), determines the estimated cutting area and allowable volumes of forest use;

– land management covers large areas (except forest lands and settlements), has a hierarchical structure, contains information about the value (bonitet) of soils.

Territorial planning schemes are supposed to be the embodiment of the Strategies for the socio-economic development of the regions but are not adequately based on previous results of spatial analysis of the territories. The Federal Law on Strategic Planning in Russia (Federal Law N 172 dated 28 June 2014**)** did not turn spatial analysis into a tool of territorial planning because the mechanisms for carrying out many of its directives remain unclear. The law did not assign regulatory status to landscape planning, despite its unquestionable usefulness. One of the reasons is that Russia is traditionally weak in systematic thinking and in practical work in both the legislative and executive branches of government. An industry-, agency-centered approach still prevails.

Despite the lack of regulatory status, landscape planning may be used as methodical approach to the description and assessment of ES of Russia as it has the following useful qualities.

– It analyzes meaning of all biotopes and other morphological elements of a landscape structure, recommends the use of the most appropriate environmentally and compatible landscape components in environmental management practices;
– It strives to minimize natural resource use conflicts and involves all users of natural resources in making decisions on the use of the landscape;
– It defines the ecological, not just the exclusively consumption-oriented, significance and sensitivity of habitats or biotopes and ascertains the allowable degree of their use;
– It considers possible changes in the geographic area;
– It can be used for residential areas.

For assessing ES, the ideas about landscape main functions and methods for assessing the significance and sensitivity of its morphological structures, primarily biotopes, that are used in landscape planning can be useful.

The following groups of landscape functions can be identified:

– bioproduction and bioresource;
– biotopic, which contributes to the biodiversity preservation;
– gas exchange, water– and climate-forming, and water– and climate-regulating;
– soil-forming, in some measure also mineral and rock-forming;
– residential, transport, forest, water, and agricultural;
– public health, hygiene and recreational;

– informational and culture-forming overall including the formation of the emotional and psychological features of human nature, knowledge and world view.

It is not hard to notice that this list is quite similar to the list of ES adopted by the conceptual framework of the Millennium Ecosystem Assessment (2005). But it was formulated much earlier in the conceptual framework for landscape use. The list of basic landscape functions helps to consider all their diversity and in combination with assessments of their significance and sensitivity to impacts, to find paths toward the least controversial use.

The significance of a landscape component or structural element depends on two basic factors. First, its position within the system of functional connections (in a range of options from very important to completely unimportant). Second, its ability to successful perform its role under different loads or levels of use. This ability in turn depends on the component's sensitivity to loads.

In landscape planning the category “sensitivity” means the ability of a given natural component (or element of its morphological structure) to modify its properties and dynamic characteristics under the influence of human economic activity.

Recommendations on defining these categories are found in published monographs, manuals, and textbooks on landscape planning (Antipov et al., 2001, 2001; Drozdov, 2006).

The objectives of landscape planning, which are advisable to keep in mind when performing work to identify and evaluate ES:

– preservation of the basic functions of a landscape as a holistic life-support system;
– identification of the interests of different natural resource users and analysis of conflicts arisen;
– development of a plan of actions necessary to resolve any conflicts and to achieve agreed goals for natural resource use;
– determination of the value (significance) of lands or biotopes in the broad context, including their strategic role in the biosphere;
– determination of the relationship between the needs of users who are developing the resources of a specific landscape and society's long-term interests.

6.5.4. Key opportunities and challenges of using available territorial planning materials to evaluate ecosystem services

Currently, the most common are urban planning materials – territorial planning schemes (TPS). They are compiled for many regions and municipalities of the country. Some of them are available on the Internet, but there they usually have low resolution. Originals can be obtained from the administrations of regions and municipalities.

Forest inventory materials are also widespread, but their quality is often not high enough. Forest plans are also available in regional administrations and on the Internet.

Land management materials back in the 60s were quite benign. Now they are very outdated, many have not survived. Modern land management schemes are very few.

For some territories, the sources of useful information may be materials from previous regional plans and Territorial Integrated Conservation Plans (TerICPs).

For a number of regions there are schemes of the natural-ecological framework of the territories, although they are not numerous. Sometimes they are included in the TPD areas.

Important is the information on plans for the use of the territories contained in the TPS. They should be taken into account when assessing the likely changes in the quality and composition of ES that the territory in question has at the time of the assessment but may lose them during the implementation of the TPS.

Landscape planning is currently performed for only a few regions of the country. The most numerous plans of various purposes and scale were compiled in the Baikal region by the Institute of Geography of the Siberian Branch of RAS. Methodically, this is a well-developed tool.

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Appendix

Spearman correlation of bird diversity indices inside ecoregions (R_s, *p<0.05, ** p<0.0001, ns – not significant).

	Total number of species in a square **(I)**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Arctic deserts (n=16)							
Share of species in a square of their total number in the ecoregion **(II)**	1						
Number of species listed in the Red Data Book of RF **(III)**	–0.035, ns	–0.035					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	–0.035, ns	–0.035	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	–0.061, ns	–0.061	0.994**	0.994**			
Share of RB species in a square of the total number of all bird species in the respective ecoregion **(VI)**	–0.035, ns	–0.035	1*	1*	0.993**		
Overall index of the Red Book species **(VII)**	–0.035, ns	–0.035	1*	1*	0.993**	1*	
Overall index of bird diversity **(VIII)**	0.686*	0.686*	0.683*	0.683*	0.674*	0.683*	0.683*
Tundra (n=68)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.484**	0.484**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.484**	0.484**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.038, ns	0.038, ns	0.871**	0.871**			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.484**	0.484**	1*	1*	0.871**		
Overall index of the Red Book species **(VII)**	0.534**	0.534**	0.978**	0.978**	0.820**	0.978**	
Overall index of bird diversity **(VIII)**	0.543**	0.543**	0.772**	0.772**	0.613**	0.772**	0.742**
Northern taiga (n=340)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.659**	0.659**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.659**	0.659**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.479**	0.479**	0.966**	0.966**			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.659**	0.659**	1*	1*	0.966**		
Overall index of the Red Book species **(VII)**	0.670**	0.670**	0.997*	0.997*	0.959**	0.997*	
Overall index of bird diversity **(VIII)**	0.769**	0.769**	0.919**	0.919**	0.849**	0.919**	0.919**

	Total number of species in a square **(I)**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Southern taiga (n=179)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.688**	0.688**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.688**	0.688**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.523**	0.523**	0.973**	0.973**			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.688**	0.688**	1*	1*	0.973**		
Overall index of the Red Book species **(VII)**	0.691**	0.691**	0.995**	0.995**	0.965**	0.995**	
Overall index of bird diversity **(VIII)**	0.776**	0.776**	0.933**	0.933**	0.866**	0.933**	0.928**
Mixed forests (n=201)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.813**	0.813**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.813**	0.813**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.720**	0.720**	0.987**	0.987**			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.813**	0.813**	1*	1*	0.987**		
Overall index of the Red Book species **(VII)**	0.805**	0.805**	0.997**	0.997**	0.985**	0.997**	
Overall index of bird diversity **(VIII)**	0.864**	0.864**	0.947**	0.947**	0.912**	0.947**	0.942**
Forest steppe (n=242)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.773**	0.773**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.773**	0.773**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.609**	0.609**	0.969**	0.969**			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.773**	0.773**	1*	1*	0.969**		
Overall index of the Red Book species **(VII)**	0.764**	0.764**	0.992**	0.992**	0.963**	0.992**	
Overall index of bird diversity **(VIII)**	0.818**	0.818**	0.916**	0.916**	0.849**	0.916**	0.913**

	Total number of species in a square **(I)**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Pontic steppe (n=270)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.502**	0.502**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.502**	0.502**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.188*	0.188*	0.931**	0.931**			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.502**	0.502**	1*	1*	0.931**		
Overall index of the Red Book species **(VII)**	0.546**	0.546**	0.991**	0.991**	0.899**	0.991**	
Overall index of bird diversity **(VIII)**	0.671**	0.671**	0.913**	0.913**	**0.759****	0.913**	0.923**
Caspian lowland semi-deserts (n=41)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.861**	0.861**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.861**	0.861**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	–0.144, ns	–0.144, ns	0.301, ns	0.301, ns			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.861**	0.861**	1*	1*	0.301, ns		
Overall index of the Red Book species **(VII)**	0.856**	0.856**	0.992**	0.992**	0.284, ns	0.992**	
Overall index of bird diversity **(VIII)**	0.799**	0.799**	0.784**	0.784**	0.083, ns	0.784**	0.806**
Caucasus forests (n=40)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.828	0.828					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.828	0.828	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.429*	0.429*	0.826	0.826			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.828	0.828	1*	1*	0.826		
Overall index of the Red Book species **(VII)**	0.825	0.825	0.992	0.992	0.819	0.992	
Overall index of bird diversity **(VIII)**	0.752	0.752	0.826	0.826	0.708	0.826	0.831

	Total number of species in a square **(I)**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Ural montane forests and tundra (n=55)							
Share of species in a square of their total number in the ecoregion **(II)**	1*						
Number of species listed in the Red Data Book of RF **(III)**	0.612**	0.612**					
Share of Red Book species in a square of the total number of RB species in the respective ecoregion **(IV)**	0.612**	0.612**	1*				
Share of Red Book species in a square of the total number of species in the same square **(V)**	0.364*	0.364*	0.950**	0.950**			
Share of Red Book species in a square of the total number of all bird species in the respective ecoregion **(VI)**	0.612**	0.612**	1*	1*	0.950**		
Overall index of the Red Book species **(VII)**	0.650**	0.650**	0.985**	0.985**	0.921**	0.985**	
Overall index of bird diversity **(VIII)**	0.404*	0.404*	0.662**	0.662**	0.641**	0.662**	0.648**

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Abbreviations Used

CFO – Central Federal Okrug of the Russian Federation
EEA – Experimental Ecosystem Accounting
ES – ecosystem services
RF – Russian Federation
SEEA – System of Environmental Economic Accounting
TEEB – The Economics of Ecosystems and Biodiversity