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Article

TEEB-Russia: Towards National Ecosystem Accounting

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Abstract: Russia's ecosystems and ecosystem services (ES) are critical not only for the country's economy and well-being of the people but also for maintaining biodiversity and biosphere regulation around the world. Thus, the introduction of ecosystem accounting in Russia is an urgent national and international goal to which the TEEB-Russia project is dedicated. In this publication, we briefly review and discuss the main project results. Based on currently available open statistical and cartographic data, TEEB-Russia project conducted the first national assessment of terrestrial ES in Russia to derive methodological approaches to national ecosystem accounting. A range of indicators were used to assess the ES provided by ecosystems (potential) as well as the level of demand and consumption of ES by Russia's regions, both for populations and economies. Indicators of ecosystem assets include extent (ecosystem size) and condition (productivity, phytomass, bird and plant species diversity). An analysis of the correlations between indicators of ES and ecosystem assets showed that a system of national ecosystem accounting in Russia should be regionally differentiated to take account of the strong heterogeneity of natural conditions and the socio-economic development at this level. Decision-making in spatial planning and ecosystem management should carefully consider the difference between causal relationships between indicators and correlations that arise from the simultaneous response of indicators to changes in other factors. Differences in relationships between indicators at different spatial scales should also be taken into account.

Keywords: ecosystem accounting; ecosystem services; biodiversity

1. Introduction: TEEB-Russia Project

Clearly, one prerequisite for sustainable development is to understand the real value of ecosystems and biodiversity as well as their condition and current changes. In the future, there should be "no balance sheets without nature", either at the state or the corporate level. Today, the rapidly evolving concept of ecosystem services (ES) and approaches to ecosystem accounting within the frameworks of the System of Environmental-Economic Accounting (SEEA-EA) [1] and the Integrated system of Natural Capital and ecosystem services Accounting in the EU (INCA) [2] are effective ways of ensuring that the concerns of nature are given due consideration. In Europe, this process is rapidly evolving both at the national level and at the European Union level [3–5].

Russia's ecosystems and ES are of global importance. The country has the world's largest extent of natural ecosystems, which are critical for biosphere regulation and to safeguard biodiversity in Northern Eurasia. Russia's ES are also crucially important for the economy as well as for the health and the comfort of local people [6,7]. Thus, the establishment of ecosystem accounting in Russia is a prerequisite not just for the sustainable development of the country but also for the entire world.

TEEB (The Economics of Ecosystems and Biodiversity) is a global initiative dedicated to "making nature's values visible" at all levels of decision-making. In the case at hand, the TEEB-Russia project aims to develop approaches to assessing the value of ecosystems and ES in Russia. Implemented by the Biodiversity Conservation Center (Moscow) in cooperation with the Leibniz Institute of Ecological Urban and Regional Development (Dresden), the project was commissioned by the German Federal Agency for Nature Conservation (BfN) with funding from the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU) and is supported by the Ministry of Natural Resources and Environment of the Russian Federation.

The TEEB-Russia project differs significantly from other national assessments in Europe and the EU MAES (Mapping and Assessment of Ecosystems and their Services) framework concept in objectives, main tasks, and approaches to assessing ecosystems and ecosystem services. The main difference lies in the goals of the project. While many national assessments and MAES project aim to provide information on current state and temporal trends of ecosystems and ES for decision-making and the implementation of environmental laws or strategies [3–5], the TEEB-Russia project is aimed only at the preparatory phase of this work, namely, at the search and the substantiation of methodological approaches to assessing the current state of ecosystem assets and services in Russia. This goal is determined by the limited resources of the project, the large territory of the country, and the relatively weak national statistical and information support for ecosystem accounting at the present time. The TEEB-Russia project, unlike other national assessments, did not receive funding from national sources but was carried out as part of the Germany-Russia policy transfer process [8].

The first phase of the project (TEEB-Russia 1, 2013–2015) resulted in the first national pilot assessment of ES in Russia. Terrestrial ES were estimated in physical terms based on data for 2012 for the subjects (subjects of the Russian Federation are top-level constituent entities of the federal state) of the Russian Federation. The importance of ES for the regions of Russia and the possible methodological approaches for their assessment at the federal level were shown. 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 [6].

However, ES accounting is not sufficient to secure sustainability of ecosystems. It is also necessary to evaluate and incorporate ecosystem assets, i.e., ecosystems and biodiversity producing ES, as suggested by the concepts of TEEB and SEEA-EA. Therefore, the second project phase (TEEB-Russia 2, 2018–2019) aimed to find ways of implementing SEEA-EA in Russia at the national level. The main tasks were to analyze currently available data to assess the country's ecosystem assets and ES as well as to determine the basic principles of their interpretation for decision-making. The analytical part of the TEEB-Russia 2 project specified indicators of ecosystem assets, ES, and external drivers (climatic conditions and the anthropogenic transformation of land). Further, the relationships between these indicators were analyzed (Figure 1). Thus, the TEEB-Russia project, despite the preliminary methodological focus, analyzed the relationships between the main groups of indicators, including those between biodiversity and ES, which are rarely considered in national assessments [5]. As is shown below, the results of this analysis can be useful in determining the general structure of national ecosystem accounting in Russia. The main results of TEEB-Russia 2 are published in Volume 2 of the Prototype National Reports on the Ecosystem Services of Russia [7].

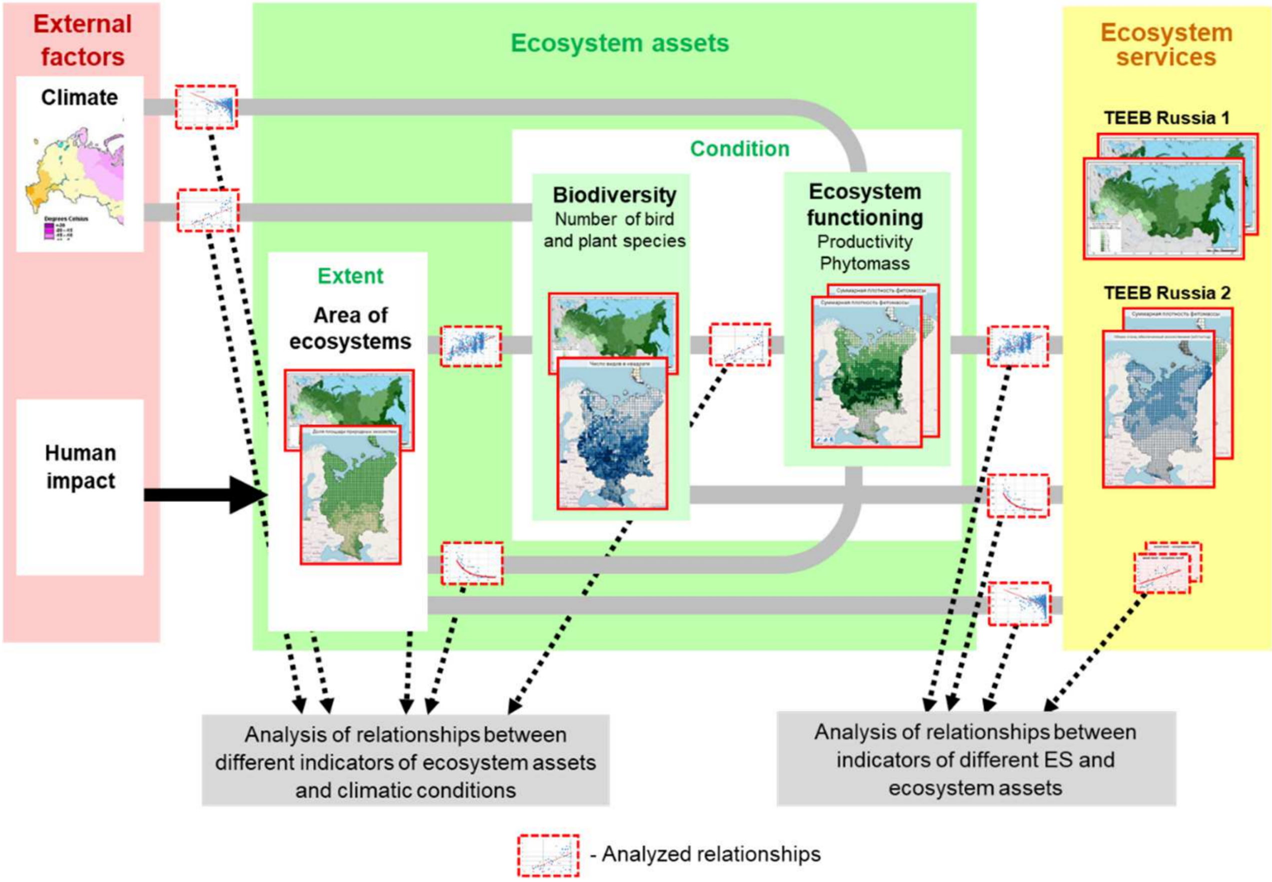


Figure 1. The analytical part of the TEEB-Russia 2 project [7].

In this publication, we briefly review the main results of the TEEB-Russia 1 and the TEEB-Russia 2 projects. First, we give an overview of the TEEB-Russia project (Introduction) and describe the main data sources and analysis methods used in the project (Section 2) before giving a short presentation of results (Section 3). In Section 4, we discuss the meaning of our results for decision-making at national scale, including the importance of biodiversity indicators (Section 4.1) and the main implications for the managerial interpretation of ecosystem accounting data, which were identified from the correlations between indicators (Sections 4.2–4.4). At the end of this section, the main issues related to the lack of data for ecosystem accounting are briefly discussed (Section 4.5). In this article, we present and discuss only a few of the project results and selected examples of tested indicators of ES and ecosystem assets. More complete information is set out in Volumes 1 and 2 of the Prototype National Report on the Ecosystem Services of Russia [6,7].

2. Materials and Methods

2.1. Data Sources, Scales of Analysis, and Data Processing

The TEEB-Russia project uses only currently available statistical and cartographic data from open databases as well as data/results published in the relevant literature. This article provides examples derived from the following data sources:

- public databases of the Federal State Statistics Service (FSSS): "Regions of Russia. Socioeconomic indicators"; "Agriculture, Hunting and Game Management, Forest Management in Russia";
- the digital cartographic database "Land Resources of Russia" [9];
- the map of terrestrial ecosystems of northern Eurasia at resolution 1 km [10] and the map of Russia's vegetation at resolution 250 m [11];

- data on bird diversity from the Atlas of Breeding Birds of the European part of Russia, collected and managed by the Zoological Museum of Moscow Lomonosov State University [12];
- literature: statistical digests, scientific studies, published maps (National Atlas of Russia, National Atlas of Soils of Russia), etc.

Data analysis and the evaluation of ES were carried out at the following scales:

- ecoregions within the European Russia, according to Olson et al. [13];
- subjects of the Russian Federation (RF) as of 2012 (83 subjects);
- squares of 50 × 50 km within European Russia according to the grid used in the Atlas of Breeding Birds of European part of Russia.

ArcGIS and NextGIS QGIS were used to calculate indicators of ecosystem assets and ES as well as to map the results. Digital maps (e.g., from the database Land Resources of Russia) were converted from vector to raster format and then analyzed using the same methods as raster layers of the vegetation map of Russia. The methods of zonal statistics and proximity analysis in ArcGIS were used to calculate the indicators of ecosystem assets and ES in 50 km squares and for subjects of RF.

Regression-correlation analysis was applied to detect relationships between indicators of ecosystem assets and provided ES. Pearson's correlation coefficient was used to identify correlations between quantitative indicators, and Spearman's rank correlation coefficient was applied to identify correlations between indicators evaluated as scores as well as correlations between these and quantitative indicators.

2.2. Indicators of Ecosystem Assets Tested in the TEEB-Russia Project

Ecosystem assets provide ecosystem services and are defined as "contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions" [1]. In order to create an exhaustive accounting system of ecosystem conditions and services, it is necessary to have a shared informational base that records changes in the spatial extent of diverse ecosystems (i.e., ecosystem extent account). The ecosystems must be classified in such a way as to meet the requirements of the subsequent accounting of their condition and services, which can vary greatly depending on regional and local ecological, economic, and social conditions [14,15].

The TEEB-Russia 2 project tested the following ecosystem asset indicators, which are currently available at the national level in Russia [7].

(1) Indicators of the extent of ecosystem assets:
   - area of ecosystems derived from the map of Russia's vegetation [10,11];
   - the degree of anthropogenic transformation of territory assessed by the relative proportions of anthropogenic areas (arable and urban lands) and the complementary indicator of the proportionate share of natural ecosystems. These indicators were also derived from the map of Russia's vegetation [10,11].

(2) Indicators of the condition of ecosystem assets:
   - indicators of fragmentation of natural ecosystems, namely the ratio of the perimeter to the area of plots of natural ecosystems (PAR) and the average distance between plots of natural ecosystems (DISTANCE). Our analysis showed that, at the national scale, these indicators unambiguously correlate with the previously named indicator of territory transformation, i.e., these indicators reflect the same processes at that scale. Therefore, we do not discuss these indicators further here. Fragmentation indicators are likely to be useful at more detailed scales of analysis, e.g., local and, possibly, regional;
   - indicators of ecosystem functioning—productivity (net primary production, kgC/m^2/yr) and phytomass (total phytomass density, dry matter, kg/m^2) of natural ecosystems. For preliminary testing, we used indicators derived from digital maps of productivity/phytomass of typical natural ecosystems from the database "Land Resources of Russia" [9];

- biodiversity indicators—indicators of vascular plant species richness (species number per 100,000 km^2 according to the National Atlas of Russia [16] and number of plant species in local flora based on data from O. Morozova [17]), several indicators of bird species richness, level of bird synanthropization and Red Data Book status based on data from the "Atlas of Breeding Birds of European part of Russia" [12] and Red Data Book of Russian Federation (2001) [7].

2.3. Ecosystem Services Considered in the TEEB-Russia Project

Ecosystem services are understood as all kinds of benefits, both tangible and intangible, obtained by people from ecosystems and species. The classification of terrestrial ES adopted in the TEEB-Russia project and the Prototype Report on Ecosystem Services of Russia [6,7] combines international ES classifications (SEEA-EA [1], Millennium Ecosystem Assessment [18], CICES [19]) and the National Strategy of Biodiversity Conservation in Russia [20]. We considered 31 ES, grouped into four categories:

(1) Six provisioning ES, i.e., the production of biomass which can be withdrawn by people from ecosystems: wood, non-wood products, fodder from natural pastures, products from freshwater ecosystems (e.g., fish), game products; honey harvested from naturel ecosystems.

(2) 18 regulating (environment-forming) ES, i.e., the creation and the maintenance of environmental conditions favorable to human life and economic development:

- regulation of climate and atmosphere: carbon storage, regulation of CO_2 flows; biogeophysical climate regulation; air purification by suburban forests;
- hydrosphere regulation: regulation of runoff volume; regulation of runoff variability; assurance of water quality by terrestrial ecosystems; water purification in freshwater ecosystems;
- soil formation and protection: soil protection from water erosion; soil protection from wind erosion; prevention of soil drift into water bodies; prevention of landslides and mudflows; establishment of soil bioproductivity; soil self-purification; regulation of cryogenic processes;
- regulation of biological processes important for economy and health: ecosystem regulation of economically important species such as agricultural and forests pests; crop pollination by wild pollinators; ecosystem regulation of species important for medicine and veterinary.

(3) Cultural Four cultural ES, i.e., various forms of information contained in natural ecosystems which can be used by people: genetic resources of wild species and populations; information on the structure and functioning of natural systems; aesthetic and educational value of ecosystems; ethical, spiritual, and religious value of ecosystems.

(4) Three recreational ES, i.e., creation and maintenance of natural conditions for various forms of recreation: local daily and weekend recreation; outdoor tourism; recreation in resorts.

While most ES examined in the Prototype National Report correspond to the abovementioned international classifications, there are several differences (for details, see [21]). Alongside the main categories of provisioning, regulating, and cultural ES, we separately define recreational ES as integrative services which are derived from the first three categories of ES to varying degrees depending on the type of recreation. The Prototype National Report does not consider supporting ES (MEA), ES of habitat, and lifecycle maintenance (SEEA-EA, CICES) because we view these as ecological processes within ecosystems rather than services. Further, we do not consider the ES of agricultural/aquacultural production (MEA, SEEA-EA, CICES); in this case, we believe that the natural conditions for these industries are created by regulating ES related to climate, water, and soil. Water provisioning is not included in the category of provisioning ES since the role of ecosystems is primarily to regulate the water cycle and not to create water as a chemical substance.

In view of the extreme diversity of natural and socioeconomic conditions within Russia, it is necessary to assess separately the potential ES in a particular region and the level of ES required and used by local people and economies. The most common pattern in Russia is an inverse relationship between the area of natural ecosystems that provide ES and the population density of consumers of ES (population and businesses), since economic activity generally leads to a reduction in the area of natural ecosystems [6]. Thus, the Prototype National Report suggests evaluating the following three ES volumes:

- provided ES, i.e., potential ES produced by ecosystems, regardless of the presence or absence of consumers of ES;
- required (demanded) ES, i.e., ES volume needed to meet the needs of the population and the economy of the region; in the projects TEEB-Russia 1 and 2 [6,7], required ES were only estimated for the removal of pollutants from the environment as the volume of pollutants that must be neutralized by ecosystems (annual pollutant emissions were used as a proxy);
- consumed (used) ES, i.e., ES volume that is materially or intangibly used by the population or from which people currently benefit.

Such an approach is similar to that in other European national ES assessments (e.g., [22]) and in the MAES framework [4,23].

The following relative indices were derived from provided ($V_{provided}$), required ($V_{required}$), and consumed ($V_{consumed}$) ES (for details, see [6,7,21,24]):

- the degree of ES use ($V_{consumed}/V_{provided} \times 100\%$ or $V_{provided} - V_{consumed}$);
- the potential satisfaction of demand for ES ($V_{provided}/V_{required} \times 100\%$ or $V_{required} - V_{provided}$);
- the actual satisfaction of demand for ES ($V_{consumed}/V_{required} \times 100\%$ or $V_{required} - V_{consumed}$);
- the deficit or excess of the service ($V_{demanded} - V_{supplied}$).

2.4. Methods of ES Assessment and Data Processing

Depending on the completeness of currently available datasets, ES were evaluated by one of the following three methods.

(1) Direct quantitative valuation of ES in biophysical terms—when values of supplied, consumed, and demanded ES were given in statistical reports.

(2) Indirect quantitative valuation in biophysical terms—when direct statistical data were lacking but we could make use of cartographic data and previous studies to evaluate the desired indicators based on simple calculations or GIS modeling. Table 1 gives short descriptions of this method for the example of provided ES volumes (for details, see [6,7]).

(3) ES were assigned a score of 1–10 if there were no data to evaluate the ES themselves, and it was only possible to assess natural factors affecting provided/potential ES as well as socio-economic factors impacting required and consumed ES [6]. The difference in the scores of provided and consumed ES reflects the ratio of natural and socioeconomic factors in a region. Negative values indicate that socio-economic factors linked to a high demand for ES and their intensive consumption outweigh natural factors that determine the provision of ES by ecosystems. Positive values indicate that natural factors outweigh socio-economic factors. Zero values indicate a relative balance of factors that determine the provision and use of ES. Figure 2 gives an example of this assessment method for the ES of wild genetic resource storage in natural ecosystems.

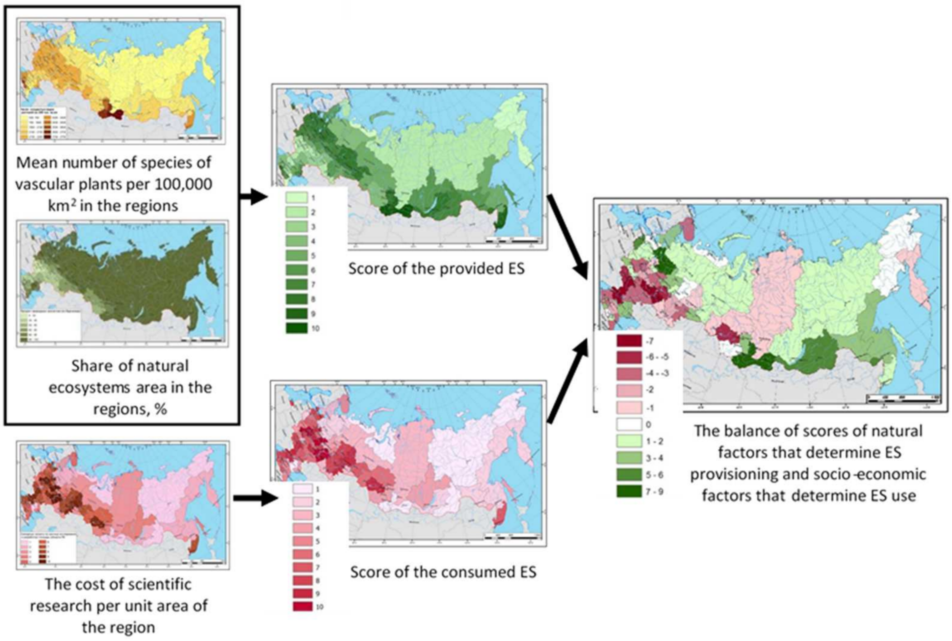


Figure 2. Example of ES scoring in the TEEB-Russia 1 project [6]: the ES of genetic resource storage in natural ecosystems.

Table 1. Indirect quantitative valuation methods for provided ES used in TEEB-Russia.

ES	Indicators	Data Sources	Valuation Methods
Fodder production in natural pastures and hayfields [1]	Productivity of natural pastures, (kg/ha/year of fodder units)	Vegetation map of Russia Land Resources of Russia	Determined by the area of grassy ecosystems (potential pastures) and their productivity
Air purification by suburban forests [1,2]	Potential absorption of air pollution (dust and gases), kg/ha/year	Vegetation map of Russia Coefficients from literature	Determined by the area of different types of forests in the buffer zones of cities (from 3 to 20 km depending on emission volume and climatic index of air pollution) and absorption indexes for Canadian cities
Regulation of runoff volume [1,2]	Runoff provided by terrestrial ecosystems ("ecosystem runoff"), m^3/ha/year	Land Resources of Russia	For geographic areas with excess moisture, "ecosystem runoff" equals the difference between surface and hypothetical runoff (hypothetical runoff is the difference between average annual precipitation and average annual evapotranspiration). For geographic areas with normal or insufficient moisture, "ecosystem runoff" equals surface runoff
Assurance of water quality by terrestrial ecosystems [1]	Potentially purified runoff, m^3/ha/year	Vegetation map of Russia Coefficients from literature	Determined by the area of polluted territories, area of different types of forests, grassy ecosystems, and arable land and the coefficient of preventing surface drift of contaminants

Table 1. *Cont.*

ES	Indicators	Data Sources	Valuation Methods
Assurance of water quality by freshwater ecosystems [1]	The volume of wastewater potentially diluted and purified to a safe concentration, m^3/ha/year	FSSS database Land Resources of Russia Coefficients from literature	Determined by the wastewater volume, surface runoff, and coefficients of biochemical transformations of pollutants in water bodies
Prevention of water erosion of soil [2]	Avoided erosion, t/ha	Vegetation map of Russia Coefficients from literature	GIS modeling based on a universal soil loss equation considering landcover, relief, land use, soil, and precipitation indices
Regulation of cryogenic processes [1]	Change in surface temperature without vegetation and snow cover, °C	Land Resources of Russia Coefficients from literature	Determined by the climatic conditions, permafrost area, cooling, and heating coefficients of vegetation and snow
Providing natural conditions for weekend recreation [2]	Recreational capacity of ecosystems, i.e., the maximum number of permitted visitors with no degradation of ecosystems	Vegetation map of Russia Coefficients from literature	Determined by the ecosystem area in suburban zones (25–50 km depending on city population) and the maximum recreational capacities according to the recommendations of the State Committee on Forestry of USSR

[1] Evaluated for subjects of the Russian Federation [6], [2] evaluated for subjects of the Russian Federation and 50 km squares within European Russia [6].

In total, 13 ES were quantified, and 8 ES were scored (Figure 3).

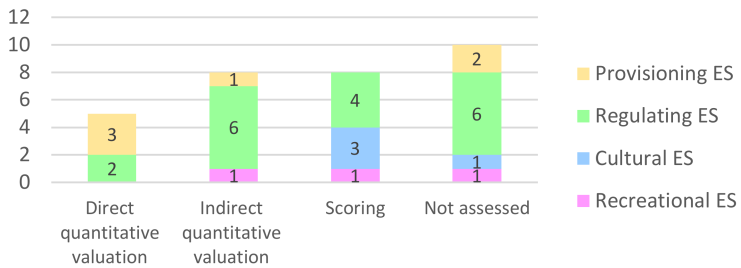


Figure 3. The numbers of ES evaluated by the different methods in the TEEB-Russia project.

A pilot economic evaluation of ES was performed on the basis of physical estimates of the consumed volumes and the various forms of monetary valuation: market prices of biological products for provisioning ES, cost of preventing damage to health and the economy, and costs of replacing ecosystem services with artificial analogs (for details, see [7]).

3. Results

3.1. Data Availability and Suggested Indicators for Ecosystem Accounting

Indicators of ecosystem assets and ES tested in the project showed their applicability for further elaboration of SEEA-EA indicators in Russia. Based on the analysis of currently available data, we propose the main groups of indicators of ecosystems assets and ES as listed in Tables 2 and 3. Examples of ES indicators are shown in Figures 4–6, Figure 7a, Figure 8a. Examples of indicators of ecosystem assets are shown in Figures 7b, 8b, 9a,b, 10a.

Table 2. Proposed indicators of ecosystem assets at the national level.

Main Characteristics	Indicators	Data Sources
Extent		
Area of ecosystem assets	Area of different types of ecosystems	Vegetation map (regular updates required) Remote sensing data [1]
The degree of anthropogenic territory transformation	The share of area of natural ecosystems	Ditto
Condition		
Ecosystem functioning	Productivity of ecosystems Biomass of ecosystems	Remote sensing data [1] Remote sensing data [1] Data on wood stocks from Forest Cadaster of Federal Forestry Agency
Diversity of ecosystems		Vegetation map (regular updates required) Remote sensing data [1]
Species diversity	Bird species richness Index of synanthropization of bird population	Atlas of Breeding Birds of the European part of Russia (currently covers only European Russia and should be extended to the rest of the country)
	Plant species richness	Local surveys on plant species diversity (currently data available for several subjects of the RF, these surveys should be extended to the rest of the country)
Red Data book indices [1]	Number and proportion of Red Data Book species of plants and animals	Red Data Books of subjects of the RF Atlas of Breeding Birds of the European part of Russia
Pollution [1]	Air pollution Water pollution Polluted territories	Federal State Statistics Service Federal Service for Hydrometeorology and Environmental Monitoring

[1] Not examined in the TEEB-Russia project.

Table 3. Proposed quantitative indicators of ES at national level.

Ecosystem Services	Provided ES	Consumed ES	Demanded ES
Provisioning ES			
Wood production	Annual allowable cut (m^3/ha/year) [1]	Logging volume (m^3/ha/year) [1]	Logging volume necessary for regional economy and household welfare [2]
Non-wood production of terrestrial ecosystems	Biological stocks of mushrooms and berries (kg/ha)	Mushroom and berry harvest (kg/ha/year)	Harvest of bioresources needed for regional economy and household welfare [2]
Production of fodder on natural pastures	Productivity of natural pastures (kg/ha/year of fodder units)	Amount of natural fodder eaten by livestock (kg/ha/year of fodder units)	Amount of natural fodder needed for regional economy and household welfare [2]
Game production	Allowable harvest (or total numbers of game animals as a proxy (numbers/ha) [1]	Actual game harvest (numbers/ha/year) [1]	Game harvest necessary for regional economy and household welfare [2]
Regulating ES			
Carbon storage	Total carbon content in phytomass and soil (tC/ha)	Carbon stock in managed forests (tC/ha) [1]	Carbon stock necessary for effective climate regulation [2]
Regulation of CO_2 flows	Carbon balance (tC/ha/year)	Carbon balance of managed forests (tC/ha/year) [1]	Carbon balance necessary for effective climate regulation [2]
Air purification by vegetation (absorption of pollutants by suburban forests)	Maximum amount of air-borne pollutants that can be captured by vegetation without significant damage (kg/ha/year)	Amount of air-borne pollution actually captured by vegetation (kg/ha/year)	Toxic gas emissions (kg/ha/year) [1]

Table 3. *Cont.*

Ecosystem Services	Provided ES	Consumed ES	Demanded ES
Regulation of runoff volume by terrestrial ecosystems	Amount (share) of runoff provided by the functioning of terrestrial ecosystems (m^3/ha/year)	Use of freshwater (m^3/ha/year) [1]	Runoff necessary for regional economy and household welfare [2]
Water quality assurance by terrestrial ecosystems	Amount of potentially purified runoff (m^3/ha/year)	Amount of purified runoff (m^3/ha/year)	Volume of polluted runoff (m^3/ha/year)
Water quality assurance by freshwater ecosystems	Volume of wastewater potentially diluted and purified to a safe concentration (m^3/ha/year)	Volume of purified and diluted wastewater (m^3/ha/year)	Discharge of polluted wastewater (m^3/ha/year) [1]
Soil protection from water erosion	The amount of soil erosion avoided due to terrestrial ecosystems (t/ha)	Economically important share of avoided soil erosion [1]	ES volume required to prevent damage [2]
Regulation of cryogenic processes	Change in surface temperature without vegetation and snow cover (°C)	Anthropogenic heating of permafrost (°C)	ES volume required to prevent damage [2]
Recreational ES			
Formation of natural conditions for weekend recreation	Number of people who can spend recreational time in the suburban forests on weekends	Actual number of people who can spend recreational time in the suburban forests on weekends [2]	The number of visitors to nature required to ensure the health and well-being of the population [2]

[1] Indicators directly obtained from the open state statistics, [2] indicators not examined in the TEEB-Russia project.

Indicators of the condition of ecosystem assets, i.e., biodiversity, ecosystem phytomass, and productivity, are important markers of their potential to deliver ES.

Currently, the biodiversity indicator with the most extensive dataset is bird species diversity. This indicator covers the European Russia due to the recent project "Atlas of Breeding Birds of the European part of Russia" carried out by Zoological Museum of Moscow Lomonosov State University. In future, it will be necessary to expand the gathering of biodiversity data throughout the country and for as many groups of organisms as possible (plants, insects, and other animals).

For the preliminary testing of indicators of productivity and phytomass, we used available data from digital maps of productivity and phytomass of typical natural ecosystems drawn from the database Land Resources of Russia [9]. When, in the upcoming years, Russia implements a system of ecosystem accounting, it will be necessary to acquire current values of productivity and phytomass based on field measurements and remote sensing data.

Of the 31 considered ES, 13 were quantified, 8 were scored, and 10 were not assessed. Examples of ES maps for subjects of the RF and 50 km squares are shown in Figures 2, 4, 7a, 8a.

Only five ES were directly derived from government statistics data and published statistical digests: three provisioning ES (wood, non-wood, and game products) and two carbon-regulating ES (carbon storage and regulation of CO_2 flows). Today, the possibilities of this valuation method are limited in Russia. Eight ES were indirectly quantified (Table 1): one provisioning ES (fodder), six regulating ES (air purification; regulation of runoff volume; assurance of water quality by terrestrial ecosystems; water purification by freshwater ecosystems; prevention of soil erosion by water; regulation of cryogenic processes), and one recreational ES (providing natural conditions for weekend recreation). Eight ES were scored: four regulating ES (regulation of runoff variability (runoff stabilization), soil protection from wind erosion; soil self-purification; pollination), three cultural ES (aesthetic value of landscapes; wild genetic resources; scientific value of natural systems), and one recreational ES (formation of natural conditions for tourism in nature).

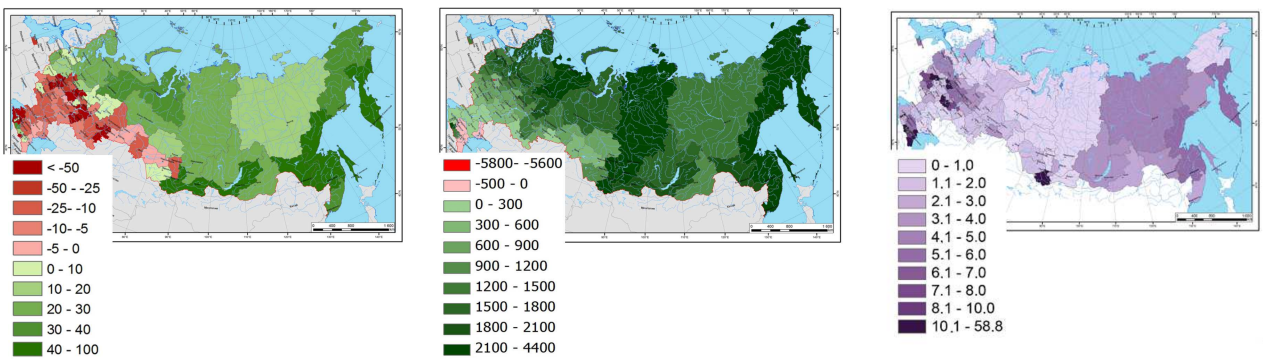
Currently, therefore, provisioning ES are most amenable to direct statistical evaluation. Indirect quantification was mainly undertaken for regulating ES services. Cultural ES were largely scored, and the majority of unassessed ES were regulating services (Figure 3).

Each ES was characterized by at least two indicators (potential and used volumes). Nine of 27 quantitative ES indicators were obtained directly from open governmental statistics (Table 3). Another eight indicators used to quantify and score ES were calculated based on governmental statistics. Data for calculating other indicators were obtained from statistical compilations, analytical reviews, and cartographic materials, which are issued by various institutions and are not updated with a fixed frequency [7].

3.2. Importance of Ecosystems and Ecosystem Services of Russia

The TEEB-Russia project highlighted the central importance of ES for the well-being of the Russian people and the sustainability of regional economies [6,7]. For the local population, ES ensure favorable environmental conditions such as clean air and water as well as conditions for recreation. For the economy, ES produce key biological resources (primarily wood), purify water and air, prevent soil erosion, and regulate the water cycle, all of which are necessary for the economic development of the country's regions. Better preservation of ecosystems and maintenance of ES in Russia's regions will significantly reduce the damage to the economy and to human health from negative environmental changes as well as the cost of technological solutions necessary to remedy these.

In many regions, the volume of provided ES is comparable with the needs of the population and the economy regarding environmental regulation and natural bioproducts. This is confirmed by the similarity of the volumes of provided, required, and consumed ES. In certain regions, however, several key regulating ES can no longer cope with the task of maintaining favorable environmental conditions. Such ES include the assurance of runoff volume and water quality by terrestrial and aquatic ecosystems [6] as well as air purification by suburban forests [6,7]. In most of Russia's economically developed regions, freshwater ecosystems are unable to deal with the current level of wastewater input (shown in red in Figure 4a). In several southern regions, the surface runoff provided by terrestrial ecosystems is fully consumed by people or indeed there is an overconsumption of water resources (light green and pink in Figure 4b). Suburban forests cannot completely absorb air pollution throughout the country. In most regions, forests absorb less than 10% of pollution, while in only a few regions does the level range from 10% to 60% (dark purple in Figure 4c).



(**a**) (**b**) (**c**)

Figure 4. Examples of the lack of ES for environmental purification from the results of the TEEB-Russia 1 project [6]: (**a**) deficit or excess in the securing of water quality by freshwater ecosystems (negative values, red spectrum—the volume of untreated wastewater; positive values, green spectrum—unused capacities of ecosystems to purify wastewater (m^3/ha/year)); (**b**) the level of use of runoff volume secured by terrestrial ecosystems—"ecosystem runoff" unused by people (positive values, green spectrum) or water use exceeds "ecosystem runoff" (negative values, red spectrum), m^3/ha/year; (**c**) satisfaction of the demand for air purification—share of pollutants absorbed by suburban forests (%).

The pilot economic evaluation of ES by considering prices close to the lower boundary of the existing price range showed that the cost of evaluated provisioning and regulating ES currently consumed by the people and the economy of Russia is 3.6% of the country's gross domestic product. However, in many regions, the cost of ES exceeds 10% of the gross regional product (Figure 5), underlining the important contribution of ES to the well-being of these regions. Clearly, therefore, the degradation of ecosystems and ES can impede economic growth and negatively impact living standards in Russia's regions. The most important ES are regulating services, which generally account for more than 90% of the total economic value of the estimated ES [7].

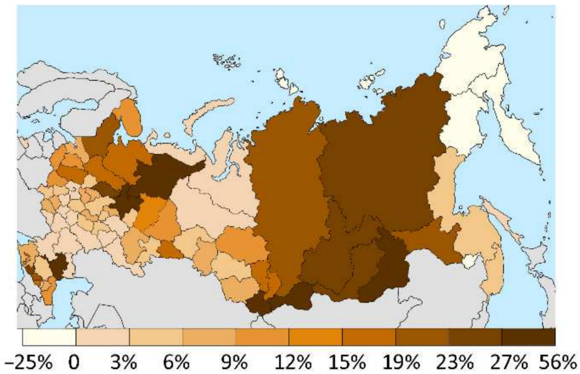
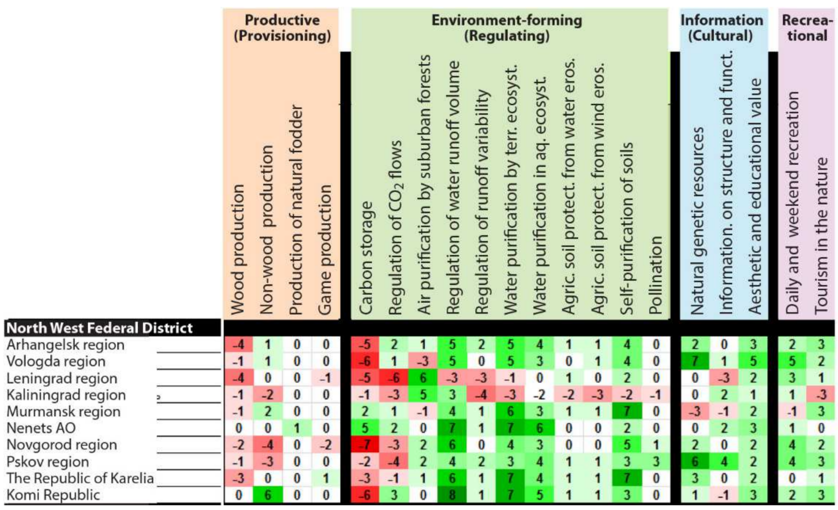


Figure 5. Economic value of currently consumed ES compared to the gross regional product, percentage of GRP [7].

3.3. Comparing ES of Regions

The comparison of regional ES pinpointed those regions which are net donors and those which are net consumers of ES. The deficit or the excess of ES (Figure 4a), the degree of ES use (Figure 4b), and the level of satisfaction of demand for ES (Figure 4c) are direct quantitative indicators of donor–consumer relationships between regions. However, as mentioned earlier, fewer than half of the considered ES were quantified. The inclusion of ES scores in the analysis provided a broader empirical basis for interregional comparison. To this end, quantitative ES indicators were converted into scores. Comparative matrices show the distribution across regions of (a) provided and (b) consumed ES scores as well as (c) differences between these scores ($V_{provided} - V_{consumed}$). One part of this last matrix is shown in Figure 6.



	Productive (Provisioning)				Environment-forming (Regulating)											Information (Cultural)			Recreational	
North West Federal District	Wood production	Non-wood production	Production of natural fodder	Game production	Carbon storage	Regulation of CO_2 flows	Air purification by suburban forests	Regulation of water runoff volume	Regulation of runoff variability	Water purification by terr. ecosyst.	Water purification in aq. ecosyst.	Agric. soil protect. from water eros.	Agric. soil protect. from wind eros.	Self-purification of soils	Pollination	Natural genetic resources	Information. on structure and funct.	Aesthetic and educational value	Daily and weekend recreation	Tourism in the nature
Arhangelsk region	-4	1	0	0	-5	2	1	5	2	5	4	1	1	4	0	2	0	3	2	3
Vologda region	-1	1	0	0	-6	1	-3	5	0	5	3	0	1	4	0	7	1	5	5	2
Leningrad region	-4	0	0	-1	-5	-6	6	-3	-3	-1	0	1	0	2	0	0	-3	2	3	1
Kaliningrad region	-1	-2	0	0	-1	-3	5	3	-4	-3	-2	-2	-3	-2	-1	0	2	1	1	-3
Murmansk region	-1	2	0	0	2	1	-1	4	1	6	3	1	1	7	0	-3	-1	2	-1	3
Nenets AO	0	0	1	0	5	2	0	7	1	7	6	0	0	2	0	0	2	3	1	0
Novgorod region	-2	-4	0	-2	-7	-3	2	6	0	4	3	0	0	5	1	2	0	2	4	2
Pskov region	-1	-3	0	0	-2	-4	2	4	2	3	4	1	1	3	3	6	4	2	4	3
The Republic of Karelia	-3	0	0	1	-3	-1	1	6	1	7	4	1	1	7	0	3	0	2	0	1
Komi Republic	0	6	0	0	-6	3	0	8	1	7	5	1	1	3	0	1	-1	3	2	3

Figure 6. The interregional comparative matrix of ES for subjects of the Russian Federation: an example for the North West Federal District [6].

This matrix reflects the balance between the natural factors determining ES provisioning by ecosystems and the socioeconomic factors determining ES use. Values close to zero (light cells) indicate that natural and socio-economic factors are roughly balanced. Positive (green cells) and negative scores (red cells) indicate the relative predominance of ES provisioning and ES consumption factors, respectively (for details, see [6,21]). These matrices resemble assessment matrices proposed by B. Burkhard et al. [25,26] but instead of land cover types, there are subjects of the Russian Federation.

3.4. Relationships between Indicators of Ecosystem Assets and ES

Both negative and positive correlations were found between various indicators of ecosystem assets and provided volumes of different ES [7]. Table 4 gives some examples of correlation coefficients for selected ES in subjects of the RF within European Russia. A similar pattern of correlation was found at other scales (ecoregions and 50 km squares within European Russia). However, correlations became more apparent when the spatial focus of the analysis was smaller, i.e., the best results were obtained for 50 km squares, moderate results for subjects of the RF, and weak results for ecoregions [7].

Table 4. Correlation coefficients for the mean values of indicators of ecosystem assets and provided ES for subjects of RF within European Russia. Group 1 includes ES which are provided by ecosystems over the whole territory of European Russia. Group 2 encompasses ES which are provided by ecosystems in zones adjoining cities and farmlands.

ES Group	ES	Productivity	Phytomass	Share of Forest Area, %	Share of Area of Transformed Ecosystems, %	Mean Number of Species in Local Flora	Mean Bird Species Number per Square
1	Wood production	−0.516 **	0.600 **	0.581 **	−0.466 **	0.232	0.278 *
	Runoff regulation	−0.644 **	0.386 **	0.608 **	−0.593 **	−0.040	−0.309 *
	Erosion prevention	0.078	0.088	−0.019	−0.073	0.676 **	−0.144
	Fodder production	0.331 *	−0.583 **	−0.477 **	0.133	0.237	−0.325 *
	Carbon storage	0.586 **	−0.409 **	−0.458 **	0.668 **	0.135	−0.132
2	Pollination	0.701 **	−0.161	−0.514 **	0.813 **	0.371 **	0.312 *
	Recreation	0.221	0.306 *	−0.002	0.140	0.485 **	0.325 *

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

To understand the nature of the correlations, we also studied the dependence of indicators of ecosystem assets on climatic indicators. The examples of correlation coefficients for subjects of the RF within European Russia are presented in Table 5.

Table 5. Correlation coefficients for mean values of indicators of climate and ecosystem assets for subjects of RF within European Russia.

Indicators of Ecosystem Assets	Average Annual Temperature	Average Annual Precipitation	Share of Area of Transformed Ecosystems, %	Productivity	Phytomass
Share of area of transformed ecosystems	0.434 **	−0.238	1		
Productivity	0.588 **	−0.197	0.860 **	1	
Phytomass	−0.236	0.637 **	−0.400 **	−0.531 **	1
Mean plant species number in local flora	0.298 *	0.539 **	0.282 *	0.443 **	0.102
Mean bird species number per 50 km square	0.178	0.156	0.243	0.127	0.467 **

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

3.5. Regional Differences in Values and Relationships between Indicators of Ecosystem Assets and ES

Differences in the average values of indicators of ecosystem assets and ES for ecoregions (Figures 7c and 10b) and subjects of the Russian Federation (Figures 8c and 9c) reflect regional variations in the natural and socio-economic conditions throughout this vast territory.

Moreover, the nature of the relationships between indicators also varies depending on the region. The strongest differences were found 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). For example, Figure 7 shows a slightly negative correlation between indicators of bird species richness and the ES of runoff regulation for the whole of European Russia (Figure 7c,d); yet, within the above mentioned groups of ecoregions, the correlation may change sign, e.g., a negative correlation in the north, which is stronger than the general trend (green line in Figure 7d), becomes a positive correlation in the south (orange line in Figure 7d). This can be explained by the fact that the gradient of climatic conditions in the group of northern, forest, and montane ecoregions affects runoff volume and species richness in opposite ways: runoff decreases from north to south while species richness grows. In the group of southern ecoregions, the trends in these indicators from north to south are unidirectional, i.e., all indicators decrease as the climate becomes more arid when moving south from the forest-steppe to the semi-deserts.

Mountains, in some cases, have characteristics that differ from other ecoregions. One example for mountain regions is shown in Figure 9c. The subjects of RF located mainly in mountain regions (purple zone number 3) are characterized by higher plant species richness than lower-lying regions. However, such an increase in species number was not detected for birds in mountain Ural and Caucasus ecoregions (Figure 7c,d; Figure 8c). A further example is a significant positive correlation between the flora diversity and the ES of prevention of soil erosion (Table 4), which has maximum values in mountainous regions.

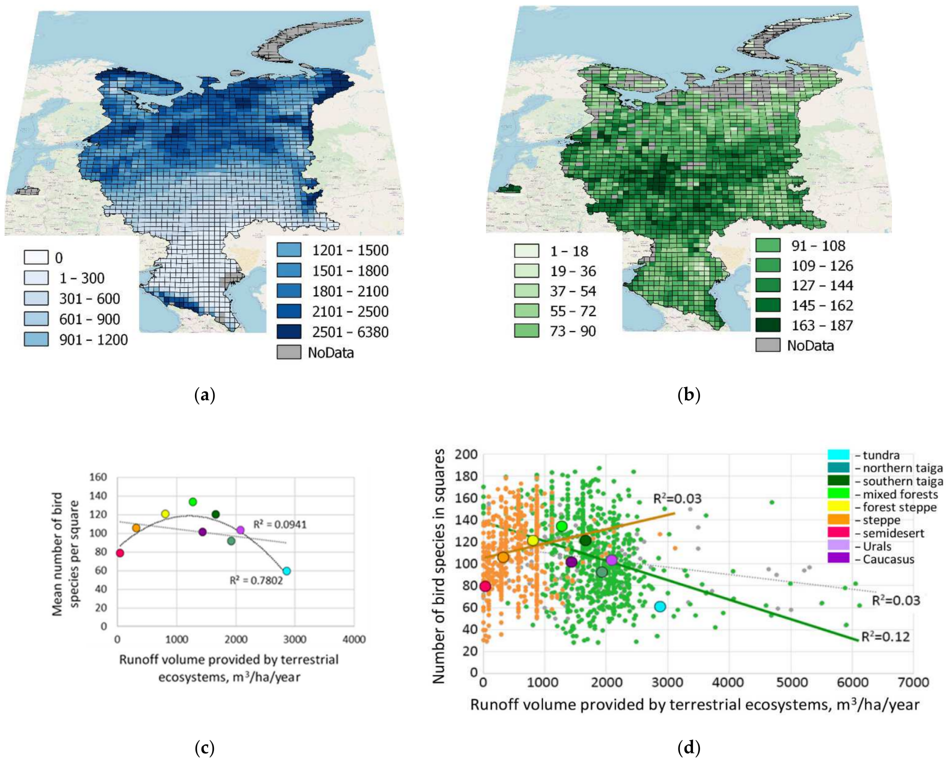
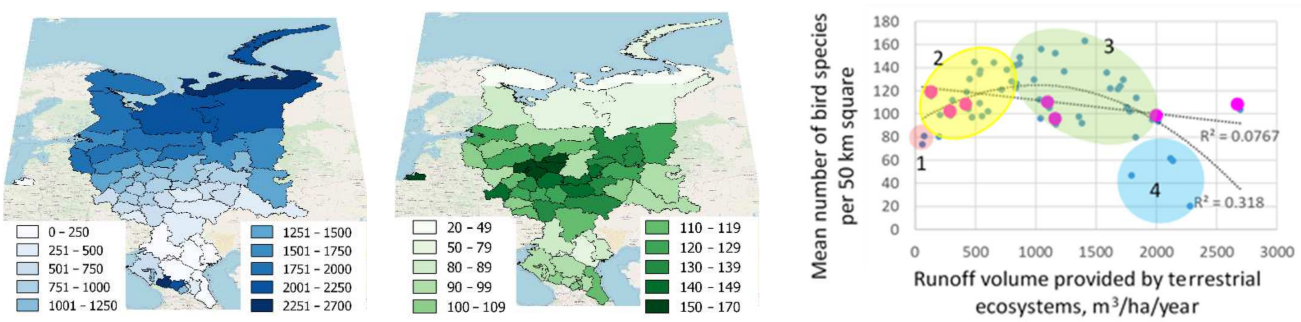
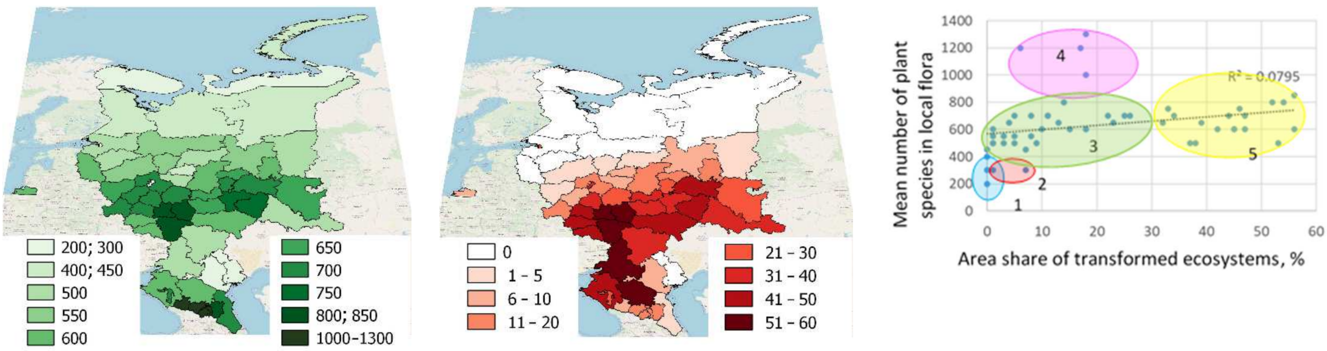


Figure 7. Relationships between bird species richness and provided ES of runoff volume assurance by terrestrial ecosystems calculated for 50 km squares within European Russia from the results of the TEEB-Russia 2 project [7]: (**a**) runoff provided by terrestrial ecosystems, m^3/ha/year; (**b**) bird species number per square; (**c**) relationships between the mean values of indicators per square in the ecoregions; (**d**) relationships for the group of northern, forest, and mountain ecoregions (shown in green) and the group of southern ecoregions (shown in orange). The relationships for the whole dataset of European Russia are indicated by dashed lines. The mean values of indicators in individual ecoregions are indicated by circles colored according legend in the chart (**d**).



(**a**) (**b**) (**c**)

Figure 8. Relationships between bird species richness and provided ES of runoff volume assurance by terrestrial ecosystems from the results of the TEEB-Russia 2 project [7]. Mean values of indicators per 50 km square for subjects of the RF within European Russia are shown: (**a**) runoff provided by terrestrial ecosystems, m3/ha/year; (**b**) mean number of bird species per square; (**c**) relationships between indicators; montane regions indicated by purple circles; the numbers denote the subjects of RF located in semi-desert (1), agricultural regions (2), forest regions (3), and northern regions (4).



(**a**) (**b**) (**c**)

Figure 9. Relationships between plant species number in local flora and the degree of territory transformation for subjects of RF from the results of the TEEB-Russia 2 project [7]: (**a**) mean number of plant species in local flora; (**b**) proportionate area of transformed ecosystems (%); (**c**) relationship between mean values of indicators; the numbers denote those subjects of RF located mainly in the following ecoregions: 1—tundra; 2—semi-desert; 3—forest; 4—montane; 5—heavily transformed agricultural ecoregions.

Significant differences in correlations between indicators were also revealed for weakly transformed ecoregions (northern, forest, mountain ecoregions, and semi-desert) and strongly transformed agricultural regions (forest-steppe, steppe). For example, a slightly positive correlation between indicators of bird species richness and the degree of territory transformation was detected for the whole of European Russia (Figure 10b); however, this relationship was different in weakly and strongly transformed ecoregions, namely strongly positive (blue in Figure 10c) and slightly negative (red in Figure 10c), respectively.

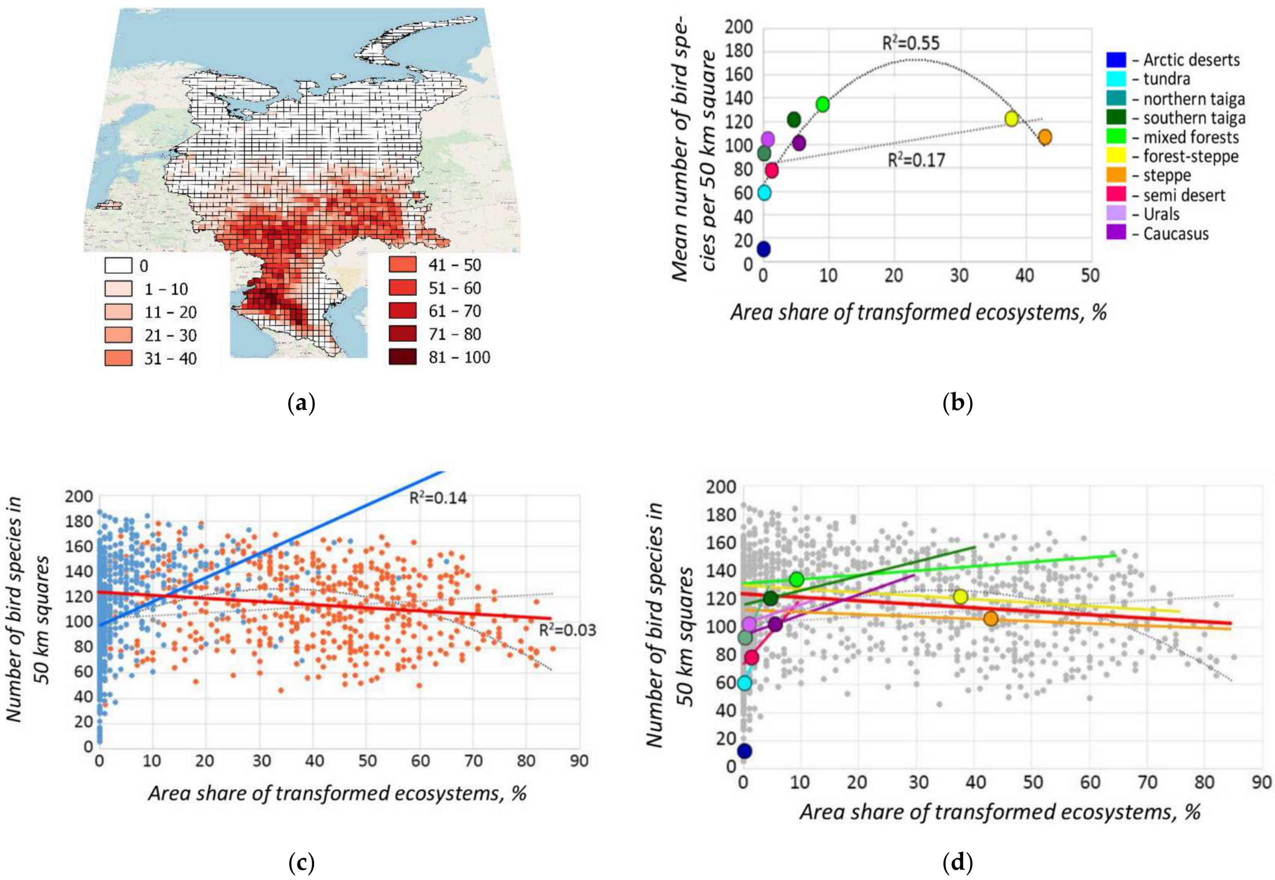


Figure 10. Relationships between bird species richness and the degree of territory transformation within European Russia from the results of the TEEB-Russia 2 project [7]: (**a**) proportionate area of transformed ecosystems (%); (**b**) correlations between mean indicator values in the ecoregions; (**c**) relationships between values in 50 km squares in the group of weakly (blue) and strongly transformed (red) ecoregions; (**d**) relationships between values in 50 km squares for individual ecoregions. The relationships for the whole dataset of European Russia are indicated by dashed lines. The mean indicator values for individual ecoregions are denoted by circles colored according legend in the chart (**b**).

This can be explained by the fact that, in northern regions of European Russia, the degree of territory transformation and the species richness simultaneously increase when moving further south due to the more favorable climatic conditions. In agricultural ecoregions heavily transformed by humans, on the contrary, we found a tendency towards a negative correlation, since, there, the degree of agricultural transformation of the territory depends less on the climate than in the more northern regions, and thus negative anthropogenic impact on biodiversity begins to manifest itself. Moreover, relationships in individual ecoregions follow the same pattern: with an increasing degree of transformation of the ecoregion, the slope of the positive correlations first weakens before becoming slightly negative (Figure 10d).

4. Discussion: Implications of the Results of the TEEB-Russia Project for the Organization of Ecosystem Accounting in Russia

4.1. Implications of Results of Biodiversity Indicator Testing

Biodiversity indicators are a necessary component of ecosystem accounting. There is now a general scientific consensus that biodiversity is one of the key factors in determining ecosystem functioning [27–30] and is important for long-term support for multiple ES [31–33]. The management of real-world ecosystems requires understanding relationships between biodiversity and indicators of ecosystem functioning and services at different spatial scales and under different conditions [29,30,34–36].

Currently, there is no biodiversity monitoring system for the entire territory of Russia. However, given the methodological importance of this issue, we included a preliminary analysis of relationships between biodiversity, ecosystem productivity, biomass, and ES among the main task of the TEEB-Russia 2 project.

Studies of real-world ecosystems in most cases found positive effects of species richness on ecosystem functioning and services (for example, for terrestrial ecosystems, see [29,30,37–41]). The influence of biodiversity on ecosystem functioning is revealed using various methods of statistical analysis (e.g., structural equation modeling) which separate the effects of biodiversity from the effects of other natural and anthropogenic factors on ecosystem functioning and biodiversity itself. However, at this stage of the methodological analysis, we were solving another problem—namely, to identify the specifics of the values of biodiversity indicators and correlations between biodiversity and other indicators under different conditions throughout the vast territory of Russia.

On national and subnational (within European Russia) scales, we identified both positive and negative correlations which reflect not causal relationships but simultaneous changes in indicators on broad gradients of geographic conditions. They cannot be used as a direct guidance for decision making (see Section 4.3). However, these results allow us to draw the following conclusions, which can be useful for ecosystem accounting in Russia.

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 ecosystem assets in these regions are less valuable for biodiversity conservation and provision of ES. Relatively low levels of biodiversity and phytomass in undisturbed ecosystems in these regions are adaptations to climatic and geographical conditions, providing the most effective and sustainable ecosystem functioning under these conditions [42,43].

The different nature of correlations between biodiversity and various ES allows us to make assumptions about the most important natural and anthropogenic factors that affect them (some examples are given below in Section 4.3).

Although most studies show similar positive effects of plant and animal species richness on ecosystem functioning and services [44,45], we found some differences for the analyzed data on higher plants and birds. For example, mountainous regions are characterized by the highest diversity of plants (Figure 9c) but not birds (Figure 8c). The exact reason for this remains to be determined, but these differences may be important for planning biodiversity conservation measures.

4.2. Regionally Differentiated Approach to Ecosystem Accounting

The revealed disparities in the average values of indicators and the nature of the relationships between them in different ecoregions (Section 3.5) reflect fundamental differences in the structure and the functioning of different types of ecosystems, which should be considered when assessing ecosystem assets and ES. Analysis of ecosystem assets indicators within individual biogeographic regions was also proposed in the framework of the MAES project [46].

Our preliminary analysis revealed the strongest differences between (a) the group of northern, forest, and mountain ecoregions and (b) the group of southern ecoregions with a significant proportion or predominance of herbaceous ecosystems. Mountain regions differed from others in some indicators, for example, in plants species richness, ES of prevention of soil erosion, and aesthetic value of landscapes, although there were no significant differences in other indicators.

The ecoregional approach differs from the ecosystem accounting within individual ecosystem types (agroecosystems, forests, wetlands, grassland, etc.) used in the MAES project [4,46], since various ecosystems can be present within individual ecoregions but in different proportions. Moreover, ecoregions differ not only in natural conditions and specific composition of ecosystems but also in the degree of anthropogenic transformation. Our analysis revealed significant differences between slightly transformed ecoregions (northern, forest, mountain, and semi-desert ecoregions) and strongly transformed agricultural regions.

Additionally, regions differ greatly in terms of the level of socio-economic development and the ratio of the economic value of ecosystem assets and economic assets. However, in this case, we are not talking about natural regions but about administrative or economic units.

Across subjects of the Russian Federation, the distribution of ES volume and the value of ecosystem assets is extremely uneven (Figure 11). In economically developed regions with a high population density, ecosystem assets are significantly degraded due to human activities, and their value is low compared to the value of assets in the economy; at the same time, demand for ES is high. However, in regions with low population density and weakly modified ecosystems, the value of ecosystem assets may exceed that of standard economic assets, yet the demand for ES is relatively low. Approaches to the economic valuation of ES and ecosystem assets and their interpretation for decision-making should consider these differences.

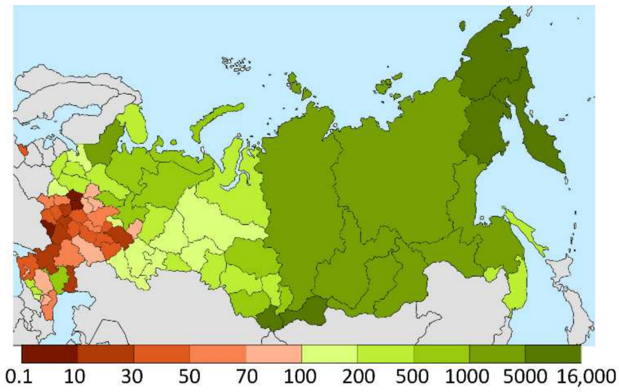


Figure 11. Economic value of ecosystem assets based on the provided volume of valuated ES for 10 year period, expressed as a percentage of the value of a region's fixed economic assets [7]. Red regions are those where ecosystem asset value is less than fixed assets; green regions are those where ecosystem asset value exceeds fixed assets.

Thus, indicators of ecosystem assets and ES should be regionally differentiated (along with their interpretation for decision-making) to take account of the natural conditions of each region as well as the degree of anthropogenic transformation of ecosystems and the socio-economic development. However, the question remains: what should be the basis of such a regional approach—types of ecosystems, ecoregions, or groups of administrative or economic territorial units?

4.3. Different Management Interpretations of Correlations and Causality

What is the meaning of revealed correlations between indicators of ecosystem assets and ES (Tables 4 and 5) for decision-makers? In Table 6, we present variants of direct management interpretations of various correlations, here aiming to improve ES and preserve biodiversity (improved indicators) by means of targeted changes in the extent and the condition of ecosystem assets (operating indicators). However, as discussed below, correlations identified in TEEB-Russia 2 at national and subnational scales do not generally reflect direct causal relationships but the simultaneous reaction of indicators to changes in geographic conditions (climate and the degree of territory transformation) over a wide area. Therefore, many of the direct interpretations can turn out to be false and lead to negative management results.

Table 6. Examples of direct management interpretations of revealed correlations between indicators of ES and ecosystem assets.

Operating Indicators	Improved Indicators	Correlation	Direct Management Interpretations of Correlations	Meaning for Real World
Productivity	Wood production Runoff regulation	Negative	1. Primarily to protect less productive ecosystems or reduce the productivity of ecosystems	Wrong Wrong
	Fodder production Carbon storage Pollination	Positive	2. Primarily to protect high productive ecosystems or increase productivity of ecosystems	Right/Wrong [1] Wrong Right/Wrong [1]
Phytomass	Wood production Runoff regulation	Positive	3. Primarily to protect ecosystems with greater phytomass or increase phytomass of ecosystems	Right/Wrong [1] Right/Wrong [1]
	Fodder production Carbon storage	Negative	4. Primarily to protect ecosystems with smaller phytomass or decrease phytomass of ecosystems	Wrong Wrong
Species richness	Wood production Prevention of soil erosion Pollination Recreation	Positive	5. Primarily to protect ecosystems with high species diversity or increase diversity in ecosystems	Right/Wrong [1] Right/Wrong [1] Right/Wrong [1] Right/Wrong [1]
	Runoff regulation Fodder production	Negative	6. Primarily to protect ecosystems with low species diversity or reduce diversity in ecosystems	Wrong Wrong
The degree of territory transformation	Carbon storage Pollination Plant species richness	Positive	7. Primarily to protect more transformed ecosystems or increase the degree of transformation of existing ecosystems	Wrong Wrong Wrong
	Wood production Runoff regulation	Negative	8. Primarily to protect less transformed ecosystems or decrease the degree of transformation of existing ecosystems	Right Right

[1] This is "Right" for ecosystems of the same type within the same region and "Wrong" for different ecosystem types at the regional/national scale.

In the group of ES provided over the whole territory (the first group in Table 4), we can distinguish services which have a positive or no correlation with ecosystem phytomass and forest share, and negative correlations with ecosystem productivity and the degree of territory transformation. These are ES of wood production (as well as other forest-related ES such as mushroom/berry production and gamey yield) and ES of runoff regulation (as well as other water-related ES such as assurance of runoff quality by terrestrial ecosystems, water purification by aquatic ecosystems). Revealed dependencies are the result of changes in indicators over climate gradients. On the European Plain of Russia, the average annual temperature rises steadily from north to south, precipitation is maximum in the forest zone (decreasing both to the north and south), while surface runoff generally decreases from north to south. Productivity follows temperature (positive correlation in Table 5). Phytomass more strongly depends on precipitation (positive correlation in Table 5) while correlating positively with temperature in northern regions and negatively in southern arid regions. Productivity is positively correlated with the degree of territory transformation which reflects mainly the degree of plowing and increases towards the south, while phytomass is negatively correlated with the degree of plowing since it is tied to forests, which are lacking in agricultural areas. Ecosystem productivity and phytomass are inversely related to each other (Table 5) [7].

The ES of carbon storage and fodder production in natural pastures behave in a manner opposite to the previously described ES. Unlike Siberia's extensive peat bogs, carbon reserves in the European Russia are located primarily in the chernozem soils in agricultural regions (although there are also significant reserves in peat ecosystems in the northern regions). Therefore, carbon storage correlates positively with ecosystem productivity and the degree of territory transformation and correlates negatively with phytomass and the proportion of forested area. The ES of natural fodder production behaves in a similar way, since it is associated with grassy ecosystems; yet, this ES has no relationship to the degree of territory transformation, because it is not tied to plowed fields.

Thus, the revealed correlations between these ES and indicators of ecosystem assets do not show a directed dependency on productivity and phytomass. Forest-related ES are determined by climatic factors of forest distribution and water-related ES by the distribution of precipitation and surface runoff over the territory. The ES of carbon storage is tied to the geographical distribution of chernozem soils and the ES of fodder production to the distribution of grassy ecosystems. Similarly, at this scale, these ES do not directly depend on the degree of plowing of the territory but only correlate with the geographical location of agricultural regions. A partial exception is the ES of wood production, which, in addition to climatic factors, depends on the area of forest and thus is negatively correlated with the degree of territory transformation.

The ES of crop pollination from the group of services provided in zones adjoining cities and farmlands (the second group in Table 4) is positively correlated with productivity and the degree of territory transformation. The pollination potential is derived from climatic factors and by considering the spatial mosaic of agricultural fields and natural ecosystems. The positive correlation is explained by the obvious fact that pollination primarily "operates" in agricultural regions. As with the ES of wood production, pollination depends on both climatic factors and the degree of territory plowing.

The considered ES correlate with biodiversity indicators in different ways. Wood production correlates positively with bird species richness, while water-related ES and fodder production are negatively correlated (Table 4, Figures 7d and 8c). The positive correlation with wood production and the negative correlation with fodder production are explained by the fact that the maximum number of birds was recorded in forest regions (Figure 7b), which have maximum phytomass and wood stocks along with minimum fodder production. The negative correlation with water-related ES is explained by a combination of negative correlation in the northern regions of European Russia and positive correlation in the southern regions, whereby the negative correlation is dominant and determines the total correlation for the whole of European Russia (Section 3.5, Figure 7d). A positive correlation between the ES of prevention of soil erosion and floristic diversity arises from the fact that the maximum diversity in flora is found in mountain regions (Section 3.5, Figure 9c), and the prevention of soil erosion is most important in the mountains due to their relief. The two considered ES from the second group—crop pollination and weekend recreation capacity—correlate positively with plant and bird species richness because of the simultaneous increase in species diversity, on the one hand, and in population density and cropland area, on the other hand, as climatic conditions improve from north to south. Therefore, these correlations do not imply that, in the case of increasing biodiversity, we can expect the ES of wood production, prevention of soil erosion, crop pollination, and recreation capacity to increase and the ES of runoff regulation and fodder production to decrease. These are not causal dependencies but the result of simultaneous changes in indicators in response to changes in geographical conditions over a wide area.

Table 6 shows that, in half of the cases, direct managerial interpretations of the revealed correlations turn out to be false and contradict the modern understanding of the relationships between services and ecosystem characteristics (“Wrong” in the last column). For example, prioritizing the conservation of less productive ecosystems does not enhance the ES of wood production and runoff regulation (interpretation number one in Table 6) but rather weakens them. In this case, the negative correlations between ecosystem productivity and indicators of these ESs are explained by counter-directional changes in indicators and a fundamental change in ecosystem structure on the wide gradients of geographic conditions. Productivity increases from north to south, while runoff and, thus, water-related ES decline. The maximum wood stock is typical for ecosystems of forest ecoregions and decreases in the southern herbaceous ecoregions, while productivity increases herbaceous ecoregions. Causal relationships within ecosystems of the same type of the same ecoregion can be opposite. For example, within forest zone, the most productive forests are most efficient in performing water regulating ES and have the largest wood stock. Thus, priority conservation of less productive forests within a forest region leads to declines in both wood stock and water-related ES. Similar to this example, the implementation of other false recommendations within certain regions leads to results opposite to revealed correlations. Interpretation number two for carbon storage is also false, since, in the northern regions, highly productive ecosystems are not the main carbon stores, which are concentrated in low-productive peat ecosystems. Implementation of the recommendation number four in non-forest regions leads to a negative result, namely a fall in both carbon storage and fodder production. The false nature of recommendations six and seven is obvious.

In half of the cases, the interpretation of correlations gave suitable recommendations (“Right” in the last column of Table 6). However, this can only be explained by the coincidence of changes in the indicators of services and ecosystems under geographic gradients over a vast territory. These recommendations are valid for ecosystems of the same type within the same region but not for different ecosystem types at the regional/national scale (see Section 4.2).

Therefore, correlations revealed at national/subnational scale should not be taken as a basis for decision-making. Nevertheless, such correlations are important for solving some tasks in the formation of SEEA-EA, namely to identify: (a) similarities and differences between regions of Russia when developing regionally differentiated approaches to ecosystem accounting; (b) groups of indicators that change in a similar way in response to certain factors; (c) trade-offs or synergies between ES as well as ES bundles, i.e., groups of mutually reinforcing ES [7].

4.4. *Consideration of Spatial Scales in Decision Making*

Correlations between indicators of ES and ecosystem assets can vary at different spatial scales, even changing sign. More specifically, when moving from a national or subnational scale (such as the European territory of Russia) to the scale of a group of ecoregions or individual ecoregions, positive correlations can become negative and vice versa. If correlations are absent at one scale, they may still reappear at another. For this reason, estimates and conclusions made at one scale cannot be directly transferred to other scales.

For example, the correlation between bird species richness and the ES of runoff regulation is slightly negative for the whole of European Russia (Figures 7c and 8c) but is positive within the group of southern ecoregions (forest-steppe, steppe, semi-desert) and more strongly negative within the group of northern, forest, and mountain ecoregions (Figure 7d). Another example is shown in Figure 10: for the whole of European Russia, the correlation between bird species richness and the degree of territory transformation is positive ($r_p = 0.8$, $p < 0.01$) for mean values per 50 km squares in ecoregions (Figure 10b), while this correlation disappears when considering real values for 50 km squares (Figure 10c, grey dotted line). Moreover, there is a clear positive correlation within the group of northern, forest, and mountain ecoregions but not within the group of southern regions (Figure 10c).

While not all correlations are statistically significant within individual ecoregions, there is a tendency towards explainable change in their slope (Figure 10d, see Section 3.5).

The results of the project showed that, at the national/subnational scale, correlations between indicators of ES and ecosystem assets generally do not reflect causality but rather the simultaneous response of indicators to changes in geographic conditions. However, at the local level, causal relationships can be at work; in particular, we can expect biodiversity to have an impact on ecosystem functioning and ES.

When assessing ES, scale and direction of their action should be considered. Our project showed that the value of ecosystem assets in providing local ES spatially linked to farmland and cities (e.g., pollination or air purification) may be relatively low at the national scale due to the limited area of action; yet, at local and regional scales, these ES can be crucially important for the well-being of the population.

4.5. Providing Ecosystem Accounting with Statistical and Cartographic Data

Currently, the lack of data is the main difficulty for the immediate start of ecosystem accounting in Russia. The available statistical data on ecosystem areas reflect only the most general land categories, such as forest, non-forest, agricultural, settlement, and industrial land. These data are insufficient for assessing biodiversity and ecosystem condition.

Data on rare and endangered species of plants and animals are available in the Red Data Books of the subjects of the Russian Federation. To use this data for ecosystem asset accounting, they must be converted into electronic form, indicating the coordinates or at least municipal districts of their findings. Indicators of species diversity are recorded only within federal PAs. There is no system for collecting data on species diversity in the rest of the country, for example, such as the Birds Directive, which provides a collection of bird data in the Member States' European territory [47]. In some regions of Russia, species diversity data are collected thanks to the enthusiasm of the scientific community and national or international projects. Now, the best coverage of the territory with regard to biodiversity indicators exists for the species richness of birds in the European part of Russia, for which data were collected within the project "Atlas of Breeding Birds of European part of Russia" [12]. However, these data are collected for a 50 $\times$ 50 km grid, which is significantly rougher than European data. For the Asian part of Russia, no such data are available. Nevertheless, TEEB-Russia 2 project showed the applicability and even the necessity of these data for assessing the condition of ecosystem assets in Russia. In the future, it is necessary to expand the collection of biodiversity data throughout the country and for other groups of organisms (plants, insects, mammals).

As stated in the Section 3.1, at the national (federal) level, data for quantification of only five out of 31 considered ES and nine of 27 quantitative ES indicators were directly obtained from open governmental statistics. An additional analysis carried out in 2020 showed that municipal districts are provided with statistical data on ecosystem accounting worse than the subjects of RF, since some indicators are not reflected in municipal statistics but are aggregated only at the federal level. This lack of data is a serious obstacle for the development of ecosystem accounting in Russia and its application for making decisions, many of which are taken at the municipal level.

Currently, given the lack of statistical data, the most important approach to ecosystem accounting is valuation of ES and ecosystem assets based on landcover and vegetation maps. The vegetation map of Russia derived from satellite images with a resolution of 250 m in a pixel [11] shows its applicability for these purposes. However, this map and its updated version [48] are not publicly available. The use of global landcovers is hampered due to the high degree of generalization of ecosystem types. For example, Copernicus Global Land Cover (https://land.copernicus.eu/global/products/lc (accessed on 7 June 2021), identifies ecosystems of tundra, steppe, and meadows as a single class of herbaceous vegetation. Furthermore, all coniferous forests are identified as one class without division into pine, spruce, fir, and larch forests, which is important for assessing ecosystems and biodiversity in Russia. Therefore, the most expedient way to help the development of ecosystem accounting in Russia, both at the federal and the municipal levels, is to resolve the issue of open access to Russian vegetation maps. It is also necessary to regularly update these data.

Remote sensing data are important for assessing indicators of conditions of ecosystem assets such as productivity and phytomass of ecosystems. In the TEEB-Russia project, we considered it possible to use previously compiled maps of productivity and phytomass from the DC resource for methodological purposes, although it is obvious that, in the future, it is necessary to include the actual values of these indicators in ecosystem accounting. In addition, remote sensing data are a valuable source of information for assessing biogeophysical climate-regulating ES (regulation of radiation balance between surface and atmosphere, atmospheric humidity, wind strength, etc.). Currently, the Russian scientific community has sufficient qualifications and technical capabilities to use remote sensing data for this purpose.

Remote sensing data, land cover, and ecosystem maps will help to estimate potential ES, which depends mainly on natural factors. To assess demanded and used ES, which are determined by socio-economic systems, it is necessary to supplement the Russian system for collecting statistical data with additional parameters.

5. Conclusions

Russia joined the process of developing national environmental-economic accounts in accordance with SEEA recommendations. Federal State Statistics Service started to fulfill the Instruction of the Deputy Prime Minister of the Russian Federation on the development of an action plan ("road map") for the implementation of priority accounts of the natural and economic accounting system (19 November 2019). The short-term work plan (2021–2025) includes the development of priority SEEA accounts, which do not require significant preparatory work. As is mentioned above (Section 4.5), the current system of state statistics does not collect enough data for a full-fledged ecosystem accounting. Thus, the issue of ecosystem accounts is included in a medium-term plan (2026–2028) aimed at developing accounts that require significant elaboration of both methodology and data provision [49].

The TEEB-Russia project passed the first step in this direction in advance. The first national assessment of ecosystem services showed that these are central to ensuring a healthy population and economy in Russia's regions (Section 3.2). The following main groups of indicators of ES and ecosystem assets were tested in the TEEB-Russia project and can be proposed as the basis for further ecosystem accounting research (Section 3.1):

- indicators of ES: ES provided by ecosystems (potential ES); ES required by the population and economy; ES consumed by the population and economy; degree of use of ES and satisfaction of demand (determined by the ratios of the provided, required and consumed ES);
- indicators of ecosystem assets: area of ecosystems; productivity and phytomass of ecosystems; indicators of biodiversity—plant and animal species richness, protective status of species (inclusion in red lists).

A general approach is also proposed for comparing ecosystem accounts of Russian regions and identifying regions—donors and consumers of ES (Section 3.3, Figure 6).

The analysis of correlations between indicators of ES and ecosystem assets showed that the national ecosystem accounting in Russia must have the following features:

- ecosystem accounting should be regionally differentiated so as to consider the regional specifics of natural conditions, the degree of anthropogenic transformation of ecosystems, and the socio-economic development of Russia's regions (Section 4.2, Figure 7c,d; Figure 9c; Figure 10);
- indicators and their managerial interpretation should consider the spatial scales of data (Section 4.4, Figure 7c,d; Figure 10);

- the managerial interpretation of indicator values should take into account the nature of correlations between these, namely whether they reflect causal relationships or are the result of simultaneous reaction of indicators to certain factors (Section 4.5).

Currently, the lack of data is the main difficulty for the immediate start of ecosystem accounting in Russia (Section 4.5). In the short term, the development of ecosystem accounting would be facilitated by the following measures:

- convert species finding data of Red Data Books of the subjects of the Russian Federation into electronic form, indicating the coordinates or at least municipal districts;
- support projects aimed at collecting data on plant and animal species diversity;
- provide open access to vegetation maps of Russia.

Current and future challenges to overcome crises (climate and land use changes, biodiversity loss, COVID-19) and transformations (conversion of society and economy to a "green" development, i.e., not harmful to nature and biodiversity and without fossil fuels) are only conceivable with adequate involvement of the Russian Federation in international activities. In this context, we started the preparation and the coordination of essential contents of a potential next project phase (TEEB-Russia 3) to further develop approaches and methods for ecosystem accounting as well as to draw up recommendations for a pilot regional implementation based on existing results of ecosystem/biodiversity assessments from the TEEB 1 and 2 studies. In addition, it is important that ecosystem accounting is not only dealt with in research projects in the future but is also included in governmental (statistical offices, economic, and welfare reports) and corporate balance sheets.

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