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Pan-Siberian Forest Biodiversity: Identifying Sustainable Forest Management Practices

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Pan-Siberian Forest Biodiversity:

Identifying Sustainable Forest Management Practices

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Foreword

This report is the second attempt to try to illustrate how new mathematical tools can be used to better understand the issue of biodiversity. The first report (IIASA IR 98-106; Wilk et al., 1998) outlined the analytical framework in the case study of the biodiversity of the Siberian forests. This report, produced by Matti Flinkman, attempts to link this analytical framework with forest management and protection practices for sustainable development of the Siberian forest ecosystems.

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Pan-Siberian Forest Biodiversity:
Identifying Sustainable Forest Management Practices

Matti Flinkman

1. Introduction

The Russian Forest Study (FOR) was initially launched at IIASA in 1992 in cooperation with the Russian Academy of Sciences, and the Russian Federal Forest Service, following the agreements with the Russian Ministry of the Environment and Natural Resources signed in 1992 and 1994. The FOR involves an integrated analysis of the study's cornerstone areas, including biodiversity and landscapes, greenhouse gases, environmental status, non-wood products and functions, forest resources and utilization, transport infrastructure, forest industry and markets, and socio-economics. Building on the analysis of these areas, the ultimate goal of the FOR is to identify possible policy options for the further development, in a sustainable manner, of the Russian society and its vast forest resources.

In such an integrated study, context it is necessary to develop and implement analytical approaches which facilitate understanding of the complex interactions within and between cornerstone areas such as biological diversity, environmental status and non-wood products and functions, etc.. These interactions have to be scrutinized in a holistic manner taking into account ecological as well as socio-economic aspects. This report describes the results of an analytical approach to identify SFM practices specific to biodiversity.

The paper is organized as follows. The next section states the specific objectives of our work and incorporates the major issues associated with assessment of biological diversity and other forest characteristics. Section 3 describes the overall methodology for this study. Section 4 deals with presentation of the initial results from the descriptive data analysis while section 5 exemplifies how the results of this study can be used to develop SFM practices.

2. Study Approach: Analyzing Biological Diversity and other Forest Characteristics in the Context of Dynamic Ecosystem Functioning

This work seeks its idealistic starting-point from the Statement of Principles on Sustainable Forest Management (SFM) at the 1992 UN Conference on Environment and Development (UNCED, 1992) in Rio. The focus of the statement is on developing principles for forest management from the point of view of sustainability and conservation. The entry point for this process is a broad one taking into account all ecological, economic, social and even cultural aspects of forestry and related socio-economic aspects. In that sense the statement harmonizes with the objectives of the Russian Forest Study (FOR).

The UNCED approach consists of a number of theme areas for each of which specific criteria and indicators have been suggested. Following theme areas are proposed:

- Global carbon cycles
- Health and Vitality
- Wood and Non-Wood productive functions
- Biological diversity[1]
- Protective functions as regard soils and waters
- Socio-economic functions and conditions

In this discussion, “biodiversity” appears as a component together with some others in attempts to develop principles of the SFM. Biodiversity and other incorporated theme areas thus create a toolbox for gathering and assessing environmental (forest management) and socio-economic information for policy decisions on the sustainable development of the forest resources. The implementation of this descriptive and assessable framework for decision making is, so far, under way and is not practically implemented. Despite the comprehensive nature of this approach, its principal shortcoming is that the theme areas, and performance indicators, are treated in isolation rather than in a holistic manner (Nilsson, 1997).

On the other hand, the set of the theme areas calls for consideration of the ecosystem as a living organism interacting with enclosed entities “within its boundaries at different levels” and surrounding abiotic and biotic conditions. The theme areas such as Global carbon cycles, Health and Vitality, Wood and Non-wood functions, Biological diversity etc. could be regarded as examples of some interacting main components (functions) of the (forest) ecosystem to be analyzed. Especially those theme areas (functions) related to biogeophysical phenomena could, and also should, primarily be utilized to increase the understanding of the dynamic functioning of ecosystems and biosphere.

The biosphere containing all the existing life forms is just a thin cover (layer) around the Earth’s surface; some kilometers above the ground and even less under the ground.

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[1]The biological diversity, biodiversity, of the forest resources has become a worldwide concern in the environmental debate in the recent years, actually since the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro. The contents of ”biodiversity” is, however, still a very indistinct matter in the forestry debate, as it is in every other environmental context too, even if the subject has been debated a lot. A mainstream of the debate (originating from the Convention on Biological Diversity at UNCED) has mainly been focused on the ”biodiversity of populations” on various levels; e.g. one talks about genetic diversity, species diversity and ecosystem diversity. Further, the question arises about how one should describe the ”degree” of biodiversity on the different levels. Also the concern about ecosystem boundaries is arisen and consequently what is the appropriate scale of the ecosystem studied in order to be a reasonable unit for such biodiversity descriptions and analyses. In this connection the ”landscape approach” (Noss, 1990) has been introduced as an attempt to find a solution for the scale problems but still the question of what kind of explanatory framework should be used remains.

All life and the life supporting activities take place within the biosphere and are dependent on solar radiation and green plants' assimilation ability. We view biological diversity not as end in itself but as a component, among others, for explaining the dynamics of ecosystem functioning. This perspective can be used as a starting-point for the further development and analysis of the SFM practices including conservation activities; i.e. the adaptation of the anthropogenic influence on the ecosystem functioning.

The objectives of this study are (i) describe some biological diversity aspects and other characteristics of the forests in Siberian ecoregions[2] in order to (ii) identify of the dominant ecoregion conditions, and subsequently (iii) link these conditions to SFM practices.

3. Methodology

3.1. Description of biological diversity aspects and other characteristics

The (i) *the description of biological diversity aspects and other characteristics* comprised a broad review of natural and human related conditions in Siberia. The data[3] was organized into the following groups: (1) description of various biogeophysical conditions at the landscape and ecoregion level, and for descriptions of (2) anthropogenic "transboundary" impacts and (3) anthropogenic "direct" impacts. These groups organized and illustrated potential descriptors associated with the theme areas proposed in the UNCED statement for principles on SFM (UNCED, 1992), as well as for the cornerstones of the FOR. The sub-groupings 1 and 2 attempted to capture, in a holistic manner, potential descriptors for functions such as Global carbon cycles, Health and Vitality, Wood/Non-wood functions, Biological diversity and parts of Protective functions as presented in the UNCED approach. This concept was considered as an effort to scrutinize and highlight a number of aspects relating to "dynamic ecosystem functioning".

In step 3, the "direct" impacts of anthropogenic origin, were regarded as an attempt to cover the theme areas incorporating the "direct" interactions between human activities and the ecosystem resources; i.e. Socio-economic functions and conditions.

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[2] In Siberia, we have used 65 ecoregions (and 360 landscapes) based on the premises that the area of an ecoregion (and a landscape) should allow a reasonably homogenous evaluation of a biosphere conditions as regard vegetation, climate, soils, and biogeophysical processes within each ecoregion (Nilsson, *et al* 1996).

[3]This data set contains a sample of original abiotic and biotic attributes and attributes for human induced conditions extracted from the Siberian database. Also, for each ecoregion a number of modified attributes describing the structure of certain distributions, e.g. age distribution of forested area, *etc*., have been developed. Moreover, for illustration and assessment of diversity aspects so called SHDI-descriptors were also included. The calculation of SHDI-descriptors is based on Shannon Diversity index formula (Shannon and Weaver, 1962). The SHDI-descriptor illustrates the degree of diversity of the attribute being considered. The actual distribution of values for an attribute with few dominating classes generates low diversity value of the SHDI-descriptor, while an evenly distributed share is coded as a high value.

The descriptive part of the sub-study, (i) "*the description of biological diversity aspects*", is presented in the form of a comprehensive set of GIS maps which are available upon request from IIASA.

3.2. Ecoregion Characteristics

The resulting descriptions at the ecoregion level (1,2,3) were also considered as the baseline presentation and review of the input data and potential variables for (ii) *the identification of dominant ecoregion conditions*.

Due to the large amount of possible variables to available, it was necessary to review attributes describing various conditions for forest ecosystems, and to select those with the best descriptive powers according to statistical analysis. The reduced set of the attributes was used in a process of identifying forestry parameters of specific interest for developing SFM practices.

The requirements of this analysis closely followed a data mining principle. A review of knowledge discovery and data mining utilizing many methodological approaches yielded with no clear indication of the most suitable one for a specific decision situation. However, Slowinski (1992) demonstrated that the Rough Sets (RS) analysis can be a very useful tool for solving problems related to identification of certain descriptive components within a large number of attributes. Following this finding the RS analysis was used to analyze and to identify important characteristics contributing to a better understanding of how forest management practices affect the functioning of ecosystems (EF).

Rough Sets analysis was used to identify ecosystem conditions from the abiotic, biotic and human condition information existing in the Siberian Ecoregion Database of IIASA. In other words, to identify the "most contributing" attributes, which adequately describe fundamental functions for the ecosystem dynamics.

The initial analysis applying Rough Sets Theory is given in Wilk, *et al*. (1998) which mainly deals with the methodology applied for identification of appropriate indicators.

3.3. Linkage to SFM practices

We linked the driving forces identified about conditions to SFM practices required to maintain or modify these conditions. The identification was based on the following general reasoning:

- First, the “sustainable” functioning[4] of the (forest) ecosystem in general was considered the main objective in order to also achieve (relative) sustainability for “underlying” functions such as biological diversity, wood and non-wood functions, biogeophysical cycles, etc. The main concern focused on the sustainable functioning of ecosystem(s) as a whole while considering the extremely complicated interactions between other crucial functions.

- Second, the ecosystem and its individual entities (plants, mammals etc.) was seen as a body interacting with abiotic factors (climate, soils, etc.) and with each other at different levels of aggregation; from genetic up to landscape, region, continent and “global” levels. This “scale factor” or “vertical dimension” brings still another extent not taken into account in this analysis.

The linkage of ecoregion conditions to SFM practices was based upon the interactions between indicator(s) of ecosystem functioning and the factors affecting them. The analysis of interactions between descriptors for ecosystem dynamics at the ecoregion level attempted to distinguish those parameters that were the most appropriate for the construction and structuring of interactions within the “overall” analytical framework. The explanatory parameters represented forest ecosystem abiotic and biotic factors, and factors indicating human impact on the ecosystem. They described a set of ecosystem conditions regarding the structure and variety of land-uses, vegetation types, and other pure forest conditions, e.g. forest density, site index, age, and different aspects of human activities. They provided a consistent description of interactions, and thus enabled identification of a set of appropriate indicators to be used for drawing conclusions with respect to desirable and/or SFM practices.

4. Results

4.1. Description of biological diversity aspects and other characteristics

The review of the data on the biogeophysical and anthropogenic transboundary conditions, as well as anthropogenic “direct” impacts, was carried out as a visual analysis of a set of GIS-shade and/or pie maps, mainly at the ecoregion level. Different explanatory variables according to the proposal for criteria and indicators (UNCED, Helsinki process etc.) were used to illustrate the “degree” or “extent” of specific ecosystem phenomena. For example, extent of the area of natural, virgin and managed forests of the total forested area, extent of area by site class, by density class, by age class relative to total forested area, occurrence of threatened, extinct, endangered, vulnerable and rare species was used as descriptive “profiles” (distributions) of current ecoregion conditions. Moreover, by applying a set of indicators, we accomplished a

[4] From the anthropogenic point of view, the ”sustainable” ecosystem functioning could be considered as a delivery of ecosystem services that may involve (Cairns, 1997): (1) Capture of solar energy and conversion into biomass that is used for food, building materials and fuels, (2) Breakdown of organic wastes and storage of heavy metals, (3) Maintenance of gas balance in the atmosphere that supports human life: absorption and storage of carbon dioxide and release of oxygen for breathable air, (4) Regeneration of nutrients in the form essential to plant growth, e.g. nitrogen fixation and movement of those nutrients.

visual evaluation of the influence of the present and past human activities on the forest ecosystem.

The descriptive "profiles" were aggregates of landscape data (e.g. soil, vegetation and relief types, fragmentation of landscapes within ecoregions) and ecoregion data (land-use, phytomass productivity, site class, etc.). Also, a diversity measure, denoted as a SHDI-descriptor, was calculated, applying Shannon diversity index formula (Shannon and Weaver, 1962) to the data distributions, and illustrated in GIS-maps. The SHDI-descriptor illustrates the degree of diversity of the attribute being considered. The actual distribution of values for an attribute with few dominating classes generated a low diversity value of the SHDI-descriptor, while an evenly distributed share was coded as a high value.

4.2 Biogeophysical Conditions, and "Transboundary" Impacts of Anthropogenic Origin

As an introduction to the biogeophysical conditions in Siberia, the distribution of geo-subzones by ecoregions is given in the view figure A2 (figures with an A are located in Appendix 5). This view also contains a map of ecoregion and landscape boundaries illustrating the degree of landscape fragmentation (Geoghegan *et al.*, 1997) within ecoregions respectively. The degree of fragmentation within ecoregions calculated by the SHDI descriptor tended to be highest in the western and southwestern part of Siberia, but also the ecoregions adjacent to the Pacific Ocean show a high fragmentation rate. The third map[5] indicates a relatively high degree of vegetation diversity (indicated by the dark color) among ecoregions but less diversity (indicated by the light color) within ecoregion boundaries as expressed by Shannon Diversity Index for vegetation types. A list of single vegetation communities occurring in Siberia is provided in Appendix 1. The low diversity ecoregions had some dominating vegetation type(s) covering relatively large part(s) of the ecoregion area thus resulting in a low value for the diversity index. The fourth map illustrates then the share of the Forested Area of the total ecoregion area.

The spatial frequency of the rare and medical plant species are highlighted in figure A3 as a part of the biological diversity conditions. The highest aerial densities of rare plants were recorded in the southeastern part of Far East Siberia where the southern tip of Sachalin forms the densest habitat for about 20 rare plant species. Altogether about 160 single rare plant species were identified from the Siberian database (see Appendix 3). On the other hand, the occurrence of medical plants occurred across a zone through the whole of Siberia in a southeastern-northwestern direction, and thus clearly associated with Middle Taiga and Southern Taiga regions. The highest aerial densities (50-60 species) of medical plant species occurred within this area. Appendix 3 lists the habitats of roughly 110 single medical plant species recorded in the database.

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[5] The numbering of the maps in a view follows the scheme from left top (map 1) to right top (map 2 or 3) and then from left bottom (map 3 or 4) to right bottom (map 4, 5 or 6).

The overall functional land use pattern is introduced in figure A4. The first map deals with the different categories of land uses divided into Forest Land, Non-Forest Land and Land for long-term lease. As a sub-division, the second map gives the distribution of various land use types within Non-Forest Land while the third one illustrates the area of Forest Land distributed by Forested Area and Unforested Area. In the fourth map the annual Net Primary Production of Phytomass per ha according to Bazilevich (1993) is illustrated in four productivity levels in order to give an overview of the phytomass production conditions in Siberia, also indicating land use potentials in different parts of the vast Siberian territory.

Figure A5 completes functional land uses by showing a map of Forest Land distributed by Forested Area and Unforested Area (left top) and a corresponding calculation of Shannon Diversity index for these sub-land use types (left bottom). Similarly on the right side the maps illustrate the distribution and diversity of Unforested Land by sub-types such as Sparse forests, Burnt and dead areas, Unforested cutting areas and Grassy glades. The two maps in the middle give the distribution and diversity of Forested Area by Virgin, Natural and Anthropogenic forests.

Focusing on the Forest Land in figure A6 the first map shows the share of plantations of the total Forested Area whereas the second map gives the distribution of Unforested Land by sub-land use types. In the third one the relative distribution of coniferous, deciduous hardwoods and deciduous softwoods is illustrated. The occurrence of the species is also a result of, among other things, growing conditions that are highlighted in the fourth map showing the distribution of the relative area of different site classes within each ecoregion.

Some general climate conditions in Siberia are illustrated in figures A7 and A8 comprising maps for average air temperature, average soil temperature, total precipitation, duration of the vegetation period with a temperature higher than 5 degrees Celsius, average wind speed, the number of snow cover days in a year, permafrost and relief[6] conditions.

The spatial occurrence the actual number of identified “rare” animals within certain areas is summarized in figure A3. (For a list of individual animal species see Appendix 4).

Figure A8 illustrates the transportation possibilities in order to describe transboundary impacts. The first map gives the relative distribution of transport alternatives in km distributed by roads, railways and waterways within ecoregions, whereas the maps 2 to 4 illustrate the density of the transportation network by the type of transport means. The third map in figure A10 shows the network for roads, railways and waterways. Consequently, the population density of the Siberian ecoregions is illustrated in the first map and the main cities in the map 2 whereas the map 4 specifically highlights the location of cities in the central Siberia. Other transboundary effects of human activities are emissions. In figure A11, the two maps show the relative distribution of emissions

[6] Regarding the map of relief conditions, the legend ”no data” indicates mountain areas in the Far East, adjacent to the Pacific Ocean.

distributed by solid and gaseous and liquid substances and the gaseous and liquid substances distributed by the type of emission.

4.3. Anthropogenic “Direct” Impacts on Forests

The following anthropogenic “direct” impacts are typically pure man made and mostly local; i.e. ecoregional, and “direct” impacts on the forest ecosystem. They strengthen the more overall descriptions developed in the preceding stages.

The focus of the review of the “direct” impacts is mainly on the Forested Area and on the distinctions between exploitable and non-exploitable forests as illustrated figure A12 where the first map gives the Forested Area distributed by exploitable and non-exploitable forests. The three other maps are dealing with age distribution of the total Forested Area, exploitable and non-exploitable Forested Area respectively. Figure A13 then completes the previous picture showing again the age distributions of the total Forested Area, exploitable and non-exploitable forests in conjunction to the Shannon diversity measures respectively.

Similarly, figure A14 first exposes the distribution of Growing Stock on exploitable and non-exploitable stock while the remaining three maps then highlight the age distribution of the total Growing Stock, the exploitable and non-exploitable Growing Stock respectively. Figure A15 completes the picture comprising the age distributions of the total Growing Stock, exploitable and non-exploitable Growing Stocks with respect to the Shannon diversity measures respectively.

Figure A16 and A17 illustrate the distribution of the forested area for all age classes (i.e. for all forest stands within an ecoregion), young stands, middle aged stands, immature stands, and mature and overmature stands into density classes, completed with the Shannon diversity measure for each age class.

Following the approach for the density description, figure A18 and A19 highlight the distribution of the forested area into site index classes comprising all forest stands and the sub-groups for young stands, middle aged stands, immature stands, and mature and overmature stands respectively. For each of them the Shannon diversity index is also calculated and illustrated in the maps.

Figure A20 shows the distribution of protected areas into groups I, II and III (Figure 1), and in particular within the forests classified into Group I the nature (distribution) of the protected areas into watershed forests, environmental protection forests, nature reserves etc. (Figure 2). Furthermore, the maps 3 to 5 show the share of the exploitable area of the total forested area for each protection group.

4.4. Identification of dominant ecoregion conditions

In this we use the description of some biological diversity aspects and other characteristics of the forests in Siberian ecoregions to identify the dominant ecosystem conditions (see for more thorough explanation of the applied methodology Wilk *et al.*, 1998). The practices derived from this analysis can be described as follows:

- From the Siberian Database (IIASA 1998) a set of descriptive attributes was compiled. Moreover, the Net Primary Production of phytomass (NPP attribute) was used to classify the ecoregions into three categories Low (L), Medium (M) and High (H). In the following the focus of the presentation is, however, on the occurrence of high NPP classes in Siberia. Originally the high class was assigned to 16 ecoregions (Figure 1). The categorizing of the (decision) attribute NPP into L, M and H was assumed to act as a proxy for the degree of ecosystem functioning; thus high class should indicate a "good" or "desirable" functioning from an anthropogenic point of view (see footnote no 4). The Rough Set (RS) methodology was implemented for the reduction of a large number of descriptive (condition) attributes; i.e. for the identification of an appropriate set of indicators that could enable conclusions with respect to desirable and/or SFM practices.

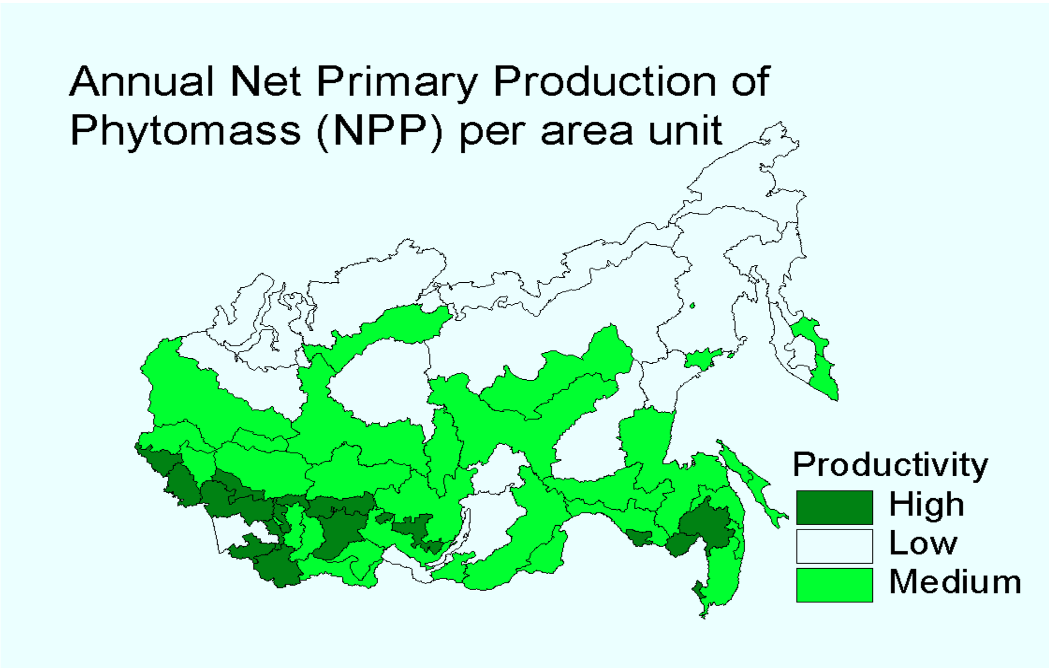

Figure 1. Net Primary Production of Phytomass (NPP) of the Siberian ecoregions in categories High, Medium and Low.

1. Through the RS analysis an original set of 31 attributes was significantly reduced, and the following reduced set was identified:
   - Relief conditions (MOUNTAN)
   - Snow cover conditions (SNOW-COVER)
   - Share of forested area of total ecoregion area (FA/Area),
   - Forest Fund profile consisting of Forest land, Non-forest land and Lease (FF-Code)
   - Age profile of growing stock consisting of 5 age class categories (AgVo-Code)
   - Density of railway network (Railw/sqkm)

Table 1. *Interesting rules* for the NPP classification problem[7]

Rule	Decision attr.	Selected Condition Attributes					
No.	NPP Class	AgVo-Code	FA/Area	FF-CODE	MOUNTAN	Railw/sq km	SNOW_COVER
1	L	AABAF					
4	L		0				1
5	L			ECA	1		1
6	L			ECA			1
7	M	ABDBC			1		
8	M	AABBE			2		
9	M	ABDBC	1				
10	M		1	ECA		1	
11	M		1	GAA		0	
12	M	AACBD	1			1	
13	M		1	FBA	2		0
14	M		1		2	0	0
15	M			FBA	2	0	0
16	H		0	FBA	2		
17	H			FBA	2	1	
18	H		0	FBA		1	

2. By using an algorithm proposed by Mienko, *et al.* (1996) the *interesting rules* were generated for the reduced set of attributes and organized into a table format (Table 1).

[7] Values 0 and 1 in columns FA/Area and Railw/sqkm indicate either first or second interval generated by automatic discretization of a continuous attribute. All other attributes were discretized through expert discretization.

3. Using the *interesting rules* new knowledge was derived about linkages between ecosystem functioning and certain (forest) characteristics of the ecoregions. This new knowledge was created through interpreting the *interesting rules* at different approximation levels.

4. Depending on the mode of approximation it was possible to develop various (forest) descriptions of the ecoregions considered as "good" ones from the perspective of ecosystem functioning (EF). The impact of the mode of approximation on the interpretation of rules is illustrated below using three modes denoted as the "lower" (A), "mechanical" (B) and "upper" (C) approximation of knowledge.

A. The "lower" approximation method for "good" ecosystem functioning is characterized by the attributes (and their values) FF-Code = FBA, Railw=1 and Mountan=2.

This is interpreted as a specific distribution of Forest Fund (FF-code=FBA)[8], a "high" degree of development (Railw=1) occurring on plain areas (Mountan=2) impliing good ecosystem functioning. There are 4 ecoregions that satisfy this characterization (Figure 2).

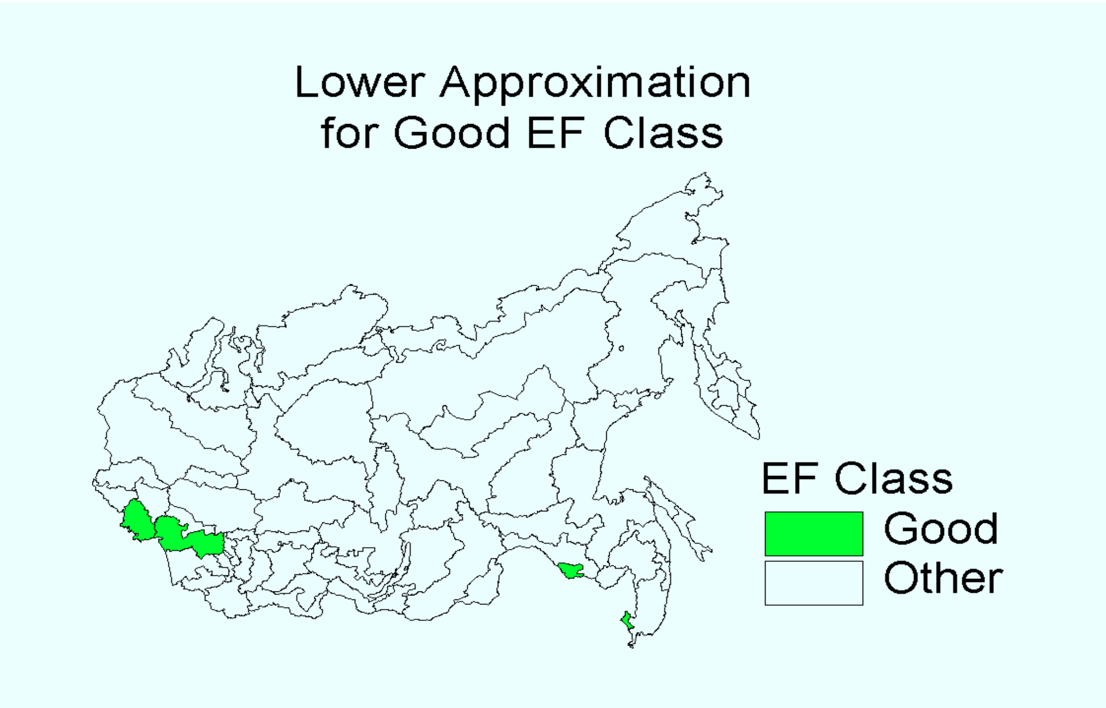

Figure 2. The "lower" approximation method for Good Ecosystem Functioning.

[8] The share of Forest Land is 80-95 % (indicated by F) of the total ecoregion area, while Non-Forest Land counts for 5-20 % (indicated by B), and the land for Long-term lease for less than 5 % (indicated by A).

In general, ecoregions having a dominant part of Forest Fund as forest land, a developed infrastructure and plain relief conditions, were characterized by "good" (NPP class H) ecosystem functioning. Moreover, one can state that a typical feature of the ecoregions established using the "lower" approximation method have a relatively high share of forest land of the total Forest Fund is that the forests at the same time cover just a minor part of the selected ecoregions' total area. This implies that "good" ecosystem functioning (i.e. high NPP) mainly depends on life forms other than forests. A common characteristic of the forests in these ecoregions is a relative large share of growing stock in the fast growing, middle age classes, resulting in a relatively high productivity in the forests. In addition, the "lower" approximation clearly includes the ecoregions that originally were defined as high NPP class ecoregions (see Figure 1), but also which show the absolutely highest NPP among all the Siberian ecoregions.

B. The "mechanical" approximation utilizes the attributes (and their values) FA/Area=0, FF-Code=FBA, Railw=1 and Mountan=2.

The analysis of this approximation mode implies that a typical feature for ecoregions classified as "good" EF classes have a low share of the land mass covered by forested area (Figure 3). The existing Forest Fund within these ecoregions, however, consists of mainly forest land and, to a lesser extent, non-forest land. Ecoregions seem to have a well developed infrastructure and the climate conditions appear also to be relatively favorable for a good EF.

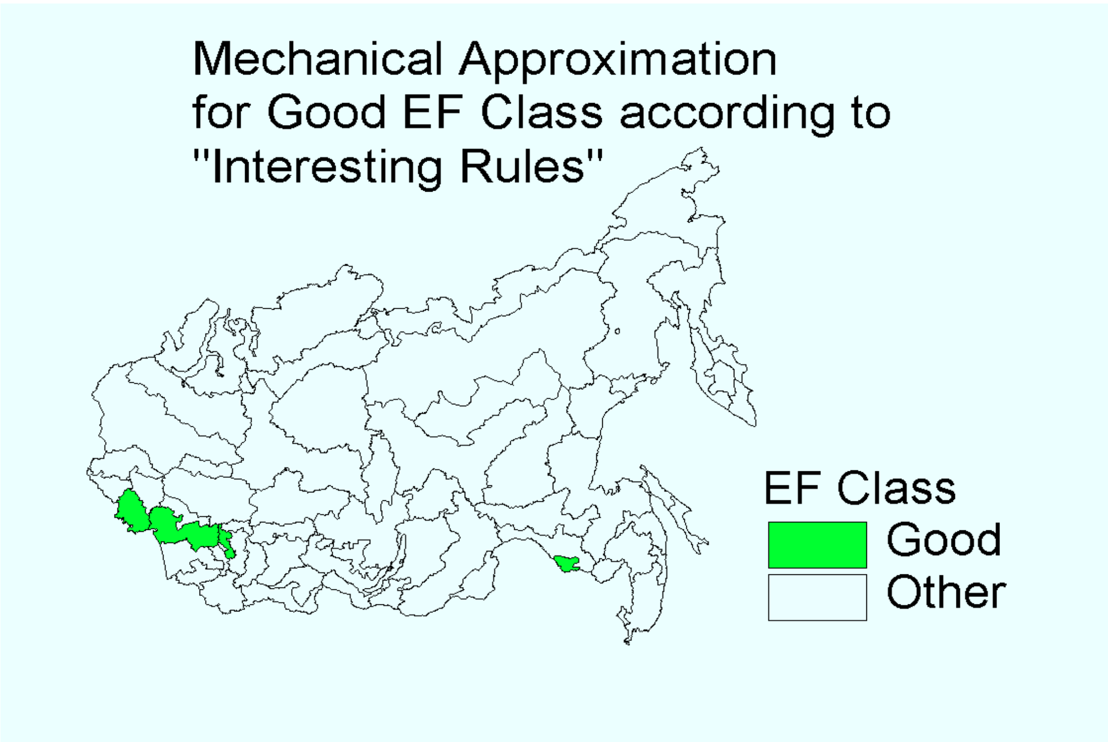

Figure 3. "Mechanical" approximation for Good Ecosystem Functioning.

In other words, the interpretation here is rather similar to the one presented for the "lower" approximation method with three ecoregions selected by both methods. The ecoregion in the Far East selected by the "lower" approximation is now replaced by another one in an immediate proximity to the three ones located in the western part of Siberia. The similarities are most likely due to the restrictive character of the FBA value for the FF-code. The FF-code=FBA together with the attribute FA/Area=0 constitutes a strong constraint for which ecoregions can be included in the EF class "good". Excluding the FF-code=FBA while maintaining FA/Area=0 gives "more relaxed" restrictions that is illustrated by the "upper" approximation method (Figure 4).

C. The "upper" approximation method involves the attributes (and their values) FA/Area=0, Railw=1 and Mountan=2.

The application of "upper" approximation method involves "low" proportion of forested area covering the ecoregion area (FA/Area=0), a "high" development degree (Railw=1) and plain areas (Mountain=2) as characteristic of "good" class in choosing 9 ecoregions of which four are also identified in the "lower" approximation. The associated knowledge statement can be: In general, ecoregions having a low share of forested area and a developed infrastructure and plain relief conditions, are characterized by a "good" ecosystem functioning.

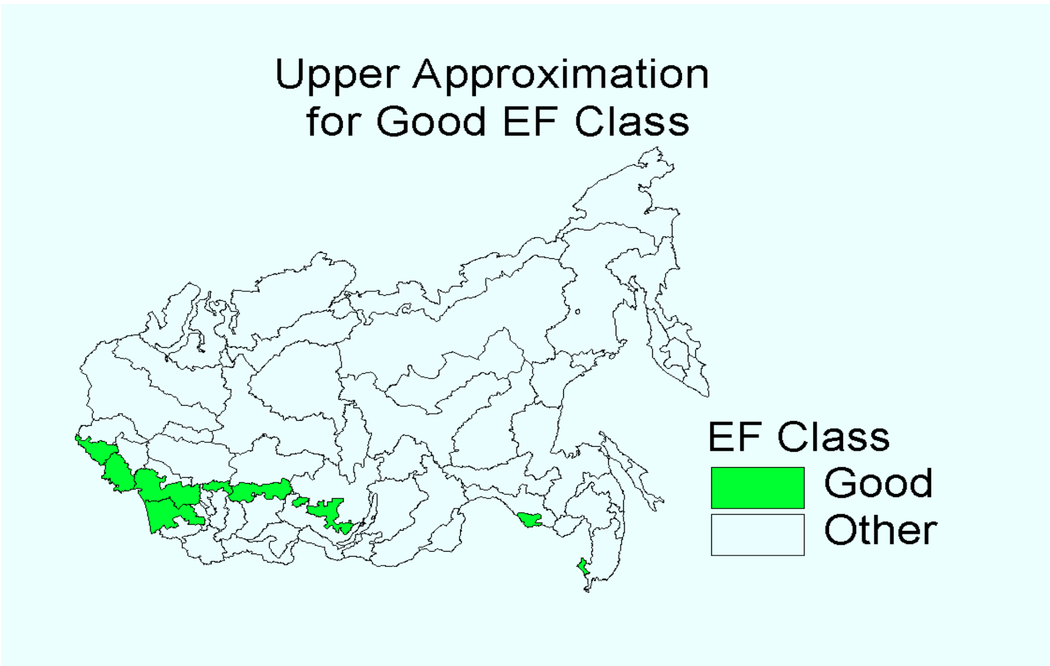

Figure 4. "Upper" approximation method for Good Ecosystem Functioning.

In addition, one can say that a typical feature for the "upper" approximation method is that the share of forested area of the total ecoregion area is, in average, clearly higher in the ecoregions selected here than in the former "lower" category. In general, this implies that "good" ecosystem functioning (or high NPP) of these ecoregions mainly depends on the role of forests. The exception being the four ecoregions which were selected also according to the “lower” approximation method and where the share of forest fund (and forested area) of the total ecoregion area was assumed to be of minor importance for these ecoregions’ EF. In addition, we see that those ecoregions identified by all approximation methods have high vegetation community diversity and medical plant density.

The role of the forests in the context of ecosystem functioning is not straightforward. The relatively “high” share of forested areas can be advantageous in promoting EF. One the other hand, these ecoregions have a relative large share of the growing stock is in the immature and mature & overmature age classes implying that the productivity of these forests could be increased through more intensive forest management. Specifically, the 5 ecoregions with a less favorable age structure which were identified as “good” ones here but were not so if the “lower” approximation method was used, represent potential to increase NPP, and ecosystem functioning, through implementation of more efficient forest management practices.

4.5. Linkage to SFM practices

The previous section claimed that it was possible, depending on the mode of interpretation of the interesting rules, to link a specific set of dominant characteristics to the ecoregions considered as “good” ones from the point of view of ecosystem functioning. As shown above, the broad interpretation of the rules has resulted in the identification of several (9) ecoregions as characterized by “good” ecosystem functioning. In other words, we could identify specific (forest) characteristics, e.g. distribution of growing stock into various age classes in the ecoregions selected, and thus from this kind of patterns. In this section, we recognize the potential of the forests to enhance ecosystem functioning by implementing alternative forest management practices. We linked a subset of the dominant ecoregion conditions to alternative forest management practices to do this.

We used an “extended” approximation method to examine the potential contribution of forests to enhance ecosystem functioning. In this context, it is of interest to distinguish ecoregions with “desirable” forest structure (FS) originating from a specific type of forest management practices and/or natural disturbances from those having “undesirable” FS due to less sustainable management practices and/or the lack of natural disturbances in the past. In the following example, the subset of attributes from the reduced set is used to discover directions for alternative forest management practices.

The “desirable” FS should:

a. Be characterized by relatively low snow coverage of the land mass (SNOW-COVER=0), *b*. Have greater than 60 % of the Forest Fund of the ecoregion as forest land. Specifically, in the FF-code attribute, the first element (X**) should have values G, F or E. (G, F and E express the extent of forest land, from 95-100 %, 80-95% and 60-80% respectively, of the total area of an ecoregion). So the code will have the values G**, F** or E**.

c. Have up to 60 percent of forest area in the "mature and overmature" and less than 60 % in the immature age class. In the AgVo-code attribute, the focus is on the two last elements (***xx), denoted xx. We state that the fourth element, ***X*, is allowed to have values A, B, C or D expressing the relative extent of the volume of growing stock in "immature" age class. In other words, it should not be more than 60% (D indicates from 40-60%). Similarly we state for the fifth element, ****X, that the share of "mature and overmature" could be up to D as a maximum.

In general, the interpretation of selected attributes for the "desirable" FS pattern will comprise ecoregions having favorable growing conditions; "Southern location" indicated by low snow cover and "productive forests" indicated by AgVo-code where the share of forest growing stock in immature, and mature & overmature age classes is relatively low. All the other ecoregions not exhibiting the above characteristics would have the "undesirable" FS pattern. Such broad interpretation also means that the "desirable" FS probably could contain, in addition to those ecoregions belonging to the NPP class H, those classed as the NPP classes M or L.

By considering the forest structure, one evaluates ecoregions based on the degree of forest management impacts on the overall EF (not just the EF class "good" in this "extended" case). In the ecoregions with the "desirable" FS the "existing" potential to improve EF through forest management practices is lower than those with the "undesirable" FS. In the latter, there might be "more" potential to increase EF by implementing different forest management actions for the change of the present "undesirable" forest structures towards more "desirable" ones; e.g. through a reduction of the share of old growth forests. We consider this a management that uses "good" EF as a target *and* provides possibilities for humans to steer it by means of forest management. So, now the forest structure patterns termed as "desirable" or "undesirable" are not expressing just the degree of EF, but also include other dimensions such as the potential for forest management actions for enhancing the productivity of the forests and thereby the ecosystem functioning.

Having distinguished "desirable" from "undesirable" ecoregions we suggest that "desirable" FS is managed, to some extent, by man or natural disturbances that produce a relatively low share of growing stock in "immature" and "mature and overmature" age classes, less potential to increase their productivity (NPP), and EF. This might allow us to examine alternative forest management practices of ecoregions with the "desirable" FS and apply them to those ecoregions with "undesirable" FS pattern. The underlying assumption being that ecoregions with "undesirable" FS pattern are mismanaged by humans and/or the occurrence of natural disturbances have been minimal resulting in the extremely high share of growing stock in "immature" and "mature & overmature" age classes. In other words, ecoregions with "undesirable" FS have a lot of old growth forests and thus may have much potential to increase their productivity through improved forest management activities.

Figure 5 includes the ecoregions satisfying the requirements for the "desirable" FS. Compared with the Map 1 obviously some ecoregions in NPP classes M and even L are now in fact classified as having the "desirable" FS according to "extended" approximation. Moreover, these selected ecoregions have a relatively low share of growing stock in "immature" and "mature and overmature" ages thus having "less" potential to increase their productivity (NPP), and thus EF, even if more effective forest management was applied. In other words, these ecoregions are relatively well managed in terms of forest productivity.

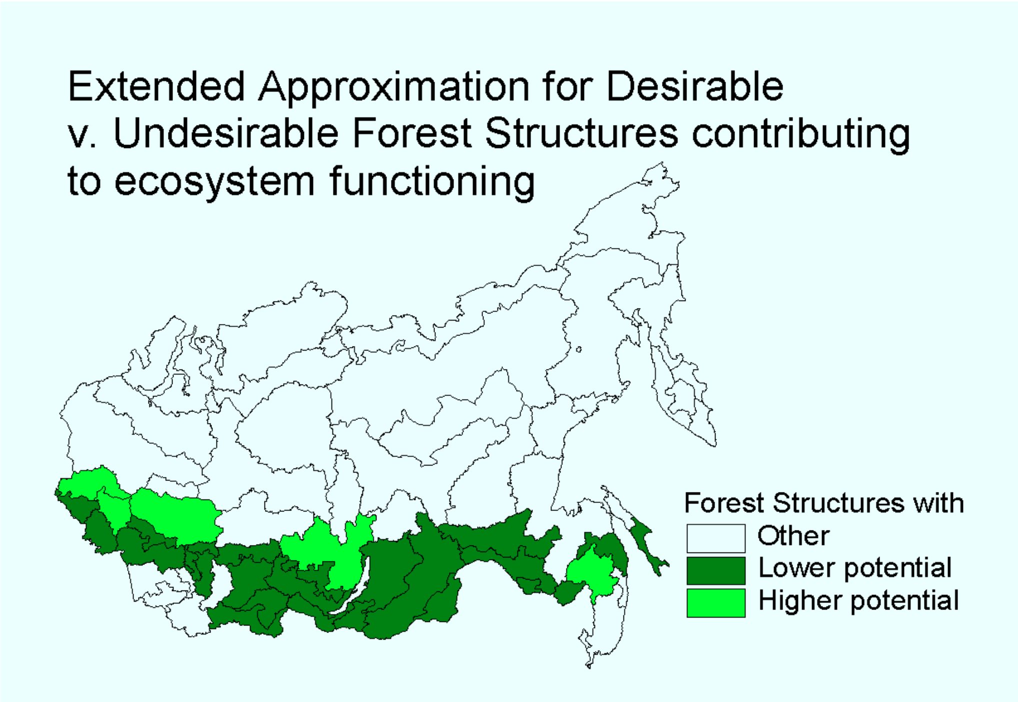

Figure 5.Extended approximation method for identification of desirable and undesirable forest structures of ecoregions with respect to ecosystem functioning.

The ecoregions with the "undesirable" FS pattern are allowed to have a relatively high share of growing stock in "immature" and "mature and overmature" age classes, thus having "more" potential to increase their productivity (NPP) and EF, through more effective forest management practices. In other words, these ecoregions are considered to be unsatisfactory managed from the point of view of forest productivity because a considerable share of the forested area consists of unproductive old growth forests.

5. Concluding Remarks

This study proposed forest ecosystems should be treated in conjunction with other important ecosystem processes and evaluated in the context of an overall ecosystem functioning. We analyzed interactions between dynamic ecosystem functioning and biotic-, abiotic- and human-induced conditions according to the following simplified framework:

- A broad description of the "natural" and human induced conditions of Siberian ecological regions in the form of comprehensive GIS maps,
- The analysis of a large number of potential descriptors resulting in a dominant set of ecosystem conditions,
- The development of forest management practices that may enhance a sustainable and desirable ecosystem functioning from the point of view of anthropogenic aspects.

The development of the integrated framework was based on the working hypothesis, tested through statistical analysis, that the categorizing of ecoregions' NPP into levels high, medium or low could be considered as a proxy for the ecosystem functioning.

A rough evaluation of potentially "interesting" forest-related descriptors contributed to the evaluation of the current forest management practices in the context of ecosystem functioning. Furthermore, the results were used to develop SFM practices for the ecoregions based on NPP production classes. These practices include re-direction and improvement of the current forest management practices (Figure 5) with respect to a sustainable and desirable ecosystem functioning.

The approach that was proposed in this paper appears to be promising. It also constitutes a first effort to develop a research tool to deal with issues of holistic understanding of various environmental and socio-economic aspects of interest by using the IIASA FOR databases (IIASA 1998). Apart from further analyses of other 'dimensions' on the ecoregion level, as indicated in section 2, additional research is needed to address the vertical 'dimension' (ecoregion to landscape, forest enterprise and ultimately individual forest stands). In order to improve the accuracy of the research outputs one might consider relying on more comprehensive and systematically collected data preferably coming both from field surveys and through remote sensing.

References

Bazilevich, N. I. (1993). Biological Productivity of Ecosystems of Northern Eurasia (in Russian). Nauka. Moscow.

Cairns, J. Jr. (1997). Protecting the delivery of Ecosystem Services, *Ecosystem Health*. Vol.3 No.3, September 1997.

Geoghegan, J., L. A. Wainger and N. E. Bockstael. (1997). Spatial Landscape Indicies in a Hedonic Framework: An Ecological Economics Analysis using GIS. *Ecological Economics* 23, pp. 251-264.

IIASA. (1998). IIASA Forest Database.

See description at URL: http://www.iiasa.ac.at/Research/FOR/dbdoc/index.html

Mienko, R., J. Stefanowski, K., Tuomi, D. Vanderpooten. (1996). Discovery-oriented Induction of Decision Rules. *Cahier du LAMSADE*, No.141.

Nilsson, S., A. Shvidenko and K. Blauberg. Small Siberian Forest Atlas. IIASA Working Paper 96-151. International Institute for Applied Systems Analysis. Laxenburg.

Nilsson, S. (1997). Challenges for the Boreal Forest Zone and IBFRA. A Key Note Paper for IBFRA Conference.

Noss, R.F. (1990). “Indicators for Monitoring Biodiversity. A Hierarchical Approach”. *Conservation Biology* No. 4, pp. 355-363.

Shannon, C.E and W. Weaver (1962). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.

Slowinski R. (ed.) (1992). *Intelligent Decision Support. Handbook of Applications and Advances of the Rough Set Theory*. Kluwer Academic Publishers, Dordrecht.

UNCED, (1992). The Global Partnership for Environment and Development. United Nations, Geneva.

Wilk, S., M. Flinkman, W. Michalowski, S. Nilsson, R. Slowinski and R. Susmaga. (1998). Identification of Biodiversity and Other Forest Attributes for Sustainable Forest Management: Siberian Forest Case Study. IIASA Interim Report 98-106. International Institute for Applied Systems Analysis. Laxenburg. Austria.

APPENDIX 1: Vegetation communities occurring in Siberia

This is a complete list of the vegetation communities used in the study, Figure A1 shows a summary map of this database.

1. Open (unclosed) aggregations of lichen (Pertusaria Ochrolechia), moss (Ditrichum flexicaule, Bryum, Pohlia) and arctic species of flowering plants
2. Grass-moss and low bush-grass-moss
3. Grass-moss and low bush-moss with Carex ensifolia ssp.arctisibirica, species: Betula, Salix glauca, S.lanata
4. Low bush-moss (Dryas punctata, Cassiope tetragone, species Aulacomnium, enthypnum nitens, Hylocomium splendens var. alaskanum with Betula exilis, Salix pulchra, S.lanata)
5. Small willow stand (Salix glauca, S.reptans)
6. Cotton grass and moss (species Aulacomnium, Hylocomium splendens var.alaskanum, Eriophorum vaginatum) hummocky
7. Shrubbery grass-low bush-moss
8. Low bush-cotton grass-moss (Ledum decumbens, Eriophorum vaginatum, species: Sphagnum, Aulacomnium) together with Betula exilis, Salix pulchra, in some places Duschekia fruticosa
9. Open (unclosed) aggregations of crustaceous and foliose lichen (species such as Rhizocarpon, Lecanora,Lecidea, Umbilicaria, Gyrophora), moss (species of Rhacomitrium), arctic-alpine species of flowering plants
10. Low bush-moss, grass-low bush-moss and lichen (Novosieversia glacialis, species Dryas)
11. Low bush-lichen and low bush-moss in combination with shrubs and sparse etation among rock streams
12. Sparse communities of subnival plants, scree and rock etation
13. Herb (middle grass) meadows and umbelliferous plants
14. Sedge, Cobresia apline, herb (short grass) meadows
15. Spruce forest (Picea obovata) with mosaic low shrub-spruce cover, including
16. Larch forest with low bush-lichen-spruce cover
17. Spruce thin forest with Betula nana in low bush-lichen-grass undergrowth
18. Larch-spruce-cedar thin forest (Pinus sibirica, Picea obovata, Larix sibirica) with low bush-lichen cover
19. Pine thin forest with low bush-grass-lichen cover
20. Larch thin forest with low bush-moss and low bush-lichen cover
21. Spruce and fir-spruce forest with low bush-spruce and short grass cover
22. Spruce-cedar and cedar-spruce forest (Pinus sibirica, Picea obovata) with grass-low bush-spruce cover cover

23. Pine forest with low bush-spruce and lichen cover
24. Larch forest
25. Spruce, fir-spruce and spruce-fir forest with mosaic grass-low bush and grass-spruce cover
26. Cedar-spruce-fir forest (Abies sibirica, Picea obovata, Pinus sibirica) with mosaic short grass-spruce cover
27. Pine (Pinus sylvestris) and larch-pine forest with grass-spruce and low bush-lichen-spruce cover
28. Larch (Larix gmelinii) and pine-larch forest with low bush-grass cover
29. Dark coniferous forest with admixture of broad-leaved one (undergrowth and cover of nemorose species), broad-leaved and dark coniferous forest
30. Pine forest (Pinus sylvestris) with grass cover, frequently forest with pine and meadow-steppe species (southern bor)
31. Larch forest (Larix gmelinii) with Quercut mongolica, Betula davurica and other grass species
32. Aspen-birch forest (Populus tremula, Betula pendula) with grass cover, Tilia cordata, predominated in Pre-Ural region, birch-aspen forest with nemorose species in the region of Kuznetsk Alatau
33. Pine forest (Pinus sylvestris) with steppe grass cover
34. Aspen-birch and birch-aspen forest with steppe grass cover
35. Dark coniferous forest with low bush-moss-lichen cover
36. Larch forest with low bush-moss-lichen cover
37. Communities with Pinus pumila in combination with larch open woodland and tundra
38. Cedar-spruce and fir-spruce forest
39. Spruce-fir and cedar-fir forest with grass-low bush cover
40. Cedar and fir-cedar forest (Pinus sibirica, Abies sibirica, Larix sibirica, Picea obovata) with low bush-short grass-spruce cover
41. Spruce-fir, cedar-fir, fir-spruce forest with nemorose elements
42. Pine forest (Pinus sylvestris)
43. Larch forest
44. Birch forest (Betula lanata) with high grass cover
45. Oak-hornbeam, hornmeam forest (Carpinus betulus, Quercus robur) with Acer pseudoplatanus, Cerasus aviumm
46. Oak forest
47. Cedar and broad-leaved forest (Quercus mongolica, Tilia taquetii, Pinus koraiensis) with ferns and high grasses
48. Broad-leaved and oak forest

49. Cedar-broad leaved forest (Quercus mongolica, Betula costata, Pinus koraiensis) high grassy
50. Herb-grass and grass-herb (Festuca valesiaca, species Stipa, Bromopsis, Carex, Helictotrichon, Phleum, Poa, Filifolium sibiricum mesophyye and xeromesophyte herbs) meadow steppe and steppe meadows in combina- tion with forests (forest-steppe)
51. Herb (xeromesophytic herbs) and bunchgrass steppe
52. Herb (mesoxerophytic herbs), bunchgrass and bunchgrass herbs
53. Northern dry bunchgrass and rootstock (rhizome) grasses
54. Meadow and herb-bunchgrass steppe (Festuca valesiaca, species: Stipa, Helictotrichon, Carex, Phleum, mesophytes, xerophytes and petrophytes) in combination with shrubs
55. Shrub communities (species Caragana, Amygdalus, Spiraea, Rosa) in combination with meadow steppes
56. Herb-bunchgrass and bunchgrasses (species: Stipa, Koeleriam Festuca valesiaca, mesoxerophytes and petrophytes) in combination with shrubs
57. Short bunchgrasses (Agropyron cristatum, Stipa krylovii)
58. Halfshrub-bunchgrass desertified and desert steppes
59. Grass and hypnum grass bogs
60. Grass-subshrub-lichen-moss complex polygonal bogs
61. Grass-subshrub-lichen-moss palsa bogs
62. Grass-hypnum-sphagnum aapa with ridges and pools
63. Hepatic-lichen-sphagnum high bog with ridges and pools
64. Sphagnum highland bogs with ridges and pools
65. Grass-sphagnum and subshrub-grass-sphagnum transitional bogs
66. Wooded swampy fens
67. Shrub communities
68. Herb and grass halophytic meadows
69. Ecological rows of perennial and annual saltworts, halophytic grasses, halophytic subshrubs, halophytic shrubs in combination with bare solonchaks
70. Meadow-bog-shrub sequence with an admixture of willow stand and yernik tundra
71. Sor (Arctophila fulva, Agrostis stolonifera)-meadow (Carex aquatilis, Calamagrostis langsdorfii)-small leaved (Betula pendula)-coniferous sequence
72. Shrub-coniferous sequence
73. Shrub-small leaved (Populus suaveolens, Chosenia arbutifolia)-coniferous (Larix gmelinii, Picea obovata) sequence
74. Shrub-broad leaved forest sequence

75. Shrub-small leaved forest sequence (Betula pendula, Populus tremula, P.nigra, P.alba)
76. Shrub-small leaved forests and steppe meadows sequence
77. Meadow sequence
78. Reed brakes in plavni (long time flooded areas with Phragmites in river deltas and bottomlands) and lake kettle depressions

APPENDIX 2: List of Siberia rare plants used in analysis

Abies Mayrana

Abies Mayriana

Abies Sachalinensis

Aconitum Tanguticum

Actinidia Giraldii

Adenophora Jacutica

Allium Microbulbum

Amanita Caesarea

Amanita Caesarea

Ampelopsis Japonica

Anemone Baikalensis

Aralia Cordata

Arabidopsis Tschuktschorum

Archidium Alternifolium

Aristolochiaceae Manshuriensis

Artemisia Senjavinensis

Asahinea Scholanderi

Asparagus Brachyphyllus

Astragalus Olchonensis

Belamcanda Chinensis

Betula Maximowicziana

Betula Maximowicziana

Betula Schmiditii

Bothrocaryum Controversum

Brachanthemum Baranovii

Brunner Sibirica

Campylium Krylovii

Cardiocrinum Glehnii

Caryopteris Mongholica

Cardamine Sphenophylla

Cephalanthera Longibracteata

Cetraria Komariovii

Chrysosplenium Rimosum

Cladonia Graciliformis
Clavariadelphus Pistillaris
Cladonia Vulcani
Coccocarpia Cronia
Coccocarpia Erythroxili
Coleanthus Subtilis
Coleanthus Subtilis
Coriscium Viride
Cotoneaster Lucidus
Cypripedium Calceolus
Cypripedium Calceolus
Cypripedium Macranthon
Daphniphyllum Humile
Dendranthema Sinuatum
Desmodium Oldhamii
Deschampsia Turczaninowii
Deschampsia Turczaninowii
Deutzia Glabrata
Dictyophora Duplicata
Dictyophora Duplicata
Eleorchis Japonica
Eleorchis Japonica
Eleorchis Japonica
Ephippianthus Sachalinensis
Epipogium Aphyllum
Epipogium Aphyllum
Erythronium Japonicum
Erythronium Japonicum
Eutrema Cordifolium
Festuca Bargusinensis
Frangula Grandifolia
Gastrodia Elata
Gastrolychnis Soczaviana
Glossodium Japonicum

Grifola Fondosa
Halosciastrum Melanotilingia
Hedysarum Ussuriense
Hedysarum Zundukii
Hericium Coralloides
Hydrangea Petiolaris
Hypogymnia Hypotrypella
Ilex Rugosa
Ilex Sugerokii Maxim
Iris Laevigata
Iris Tigridia
Isoetes Asiatica
Isoetes Berigensis
Juglans Ailanthifolia
Juniperus Rigida
Juniperus Sargentii
Juniperus Sargentii
Kalopanax Septemlobus
Lagopsis Eriostachya
Larix Olgensis
Larix Olgensis
Larix Olgensis
Leiospora Exscapa
Lepiota Lignicola
Lespedeza Cyrtobotrya
Lespedeza Tomentosa
Lilium Callosum
Lilium Cernuum
Lobaria Amplissima
Lilium Pseudtigrinum
Lobaria Pulmonaria
Macropodium Pterospermum
Macrolepiota Puellaris
Macrolepiota Puellaris

Megadenia Bardunovii
Microbiota Decussata
Mutinus Caninus
Mutinus Caninus
Myosotis Czekanowskii
Myrmechis Japonica
Neottia Ussuriensis
Oplopanax Elatus
Orchis Militaris
Orchis Militaris
Osmundastrum Claytonianum
Oxytropis Sublongipes
Oxytropis Todomoshiriensis
Paeonia Oreogton
Panax Ginseng
Papaver Walpolei
Parmelia Borisorum
Parthenocissus Tricuspidata
Peganum Nigellastrum
Picea Glehnii
Pinus Densiflora
Platanthera Camtschatica
Poa Radula
Pogonia Japonica
Polygonum Amgense
Populus Balsamifera
Primula Beringensis
Prinsepia Sinensis
Pseudocolus Fusiformis
Pueraria Lobata
Pryethrum Kelleri
Pyrrosia Lingua
Quercus Crispula
Quercus Crispula

Quercus Dentat
Quercus Dentat
Redowskia Sophiifolia
Rhododendron Fauriei
Rhododendron Redowskianum Maxim
Rhododendron Schlippenbachii Maxim
Rhododendron Sichotense
Rhododendron Tschonoskii
Ribes Ussuriense
Sanguisorba Magnifica
Saussurea Sovietica
Schizophragma Hydrangeoises
Scilla Scilloids
Sparassis Crispa
Sparassis Crispa
Stereocaulon Saviczii
Stipa Consanguinea
Taxus Cuspidata
Teloschistes Flavicans
Thladiantha Dubia
Trapa Natans
Trapa Natans
Tridactylina Kirilowii
Umbilicaria Esculenta
Valerinana Ajanensis
Viburnum Edule
Viola Incisa

APPENDIX 3: List of Siberian medical plants used in analysis

Abies Sibirica

Achellea Millefolium

Achillea Setacea

Acorus Calamus

Actinidia Arguta

Actinidia Kolomikta

Alnus Incana

Altheae Officianalis

Aralia Elata

Aralia Mandshcrica

Aralia Schmidtii

Artemisia Absinthium

Bergenia Crassifolia

Bergenia Pacifica

Betula Mandshurica

Betula Pendula Roth

Betula Platyphylla

Betula Pubescens

Bidens Tripartita

Bupleurum Multinerve

Capsella Bursa-Pastoris

Carum Carvi

Cetraria Islandica

Chelidonium Majus

Cimicifuga Dahurica

Convallaria Keiskei

Crataegus Dahurica

Crataegus Sanguinea

Datura Stramonium

Dioscorea Nipponica

Dryopteris Crassirhizoma

Echinops Ritro

Eleutherococcus Senticosus

Equisetum Arvense
Crysimum Cheiranthoides
Erysimum Diffusum
Frangula Alnus
Glycyrrhiza Uralensis
Haliaeetus Pelagius
Helichrysum Arenarium
Hippophae Rhamnoides
Huperzia Selago
Hyoscyamus Bohemicus
Hypericum Perforatum
Juniperus Communis
Lamium Album
Larix Gmelinii
Larix Sibricica
Ledum Palustre
Leonurus Cardiaca
Lycopoduim Clavatum
Melilotus Officinalis
Menyanthes Trifoliata
Oplopanax Elatus Nakai
Origanum Vulgare
Padus Avium
Paeonia Anomala
Panax Ginseng
Phellondendron Amurense
Phlojodicarpus Sibiricus
Pinus Sylvestris
Plantago Major
Polygonum Aviculare
Polygonum Bistorta
Polemonium Coeruleum
Polygonium Hydropiper
Polygala Sibirica

Potentilla Erecta
Rhaponticum Corthanoides
Ribes Nigrum
Rosa Davurica
Rosa Rugosa
Rubus Idaeus
Rubus Sachalinensis
Rumex Confertus
Sanguisorba Officianalis
Schinsandra Chinensis
Scutellaria Baicalensis
Sorbus Sambucifolia
Sorbus Sibirica
Tanacetum Boreale
Tanacetum Vulgare
Tatazacum Officianal
Thalictrum Foetidum
Thermopsis Lanceolata
Thymus Marschallianus
Thymus Serpyllum
Tilia Amurensis
Tilia Cordata
Tilia Mandshurica
Tussilago Farfara
Urtic Angustifolia
Urtica Dioica
Usnea Longissima
Vaccinium Myrtillus
Vaccinium Vitis-Idaea
Valeriana Alternifolia
Valeriana Dubia Bunge
Valeriana Fauriei
Valeriana Rossica
Valeriana Transjenisensis

Veratrum Dahuricum
Veratrum Lobelianum
Veratrum Oxysepalum
Verbascum Thapsus
Viburnum Opulus
Viola Arvensis
Viscum Album

Figure A1. Vegetation map of Russia.

APPENDIX 4: List of Siberian rare animals used in analysis

Accipiter Soloensis

Aix Galericulata

Bradypterus Taczanowskius

Castor Fiber Pohlei

Castor Fiber Tuvinicus

Cervus Nippon Hortulorum

Elaphe Japonica

Emberiza Godlewskii

Emberiza Jankowskii

Erinaceus Dauricus

Eumeces Latiscutatus

Falcipennis Falcipennis

Felis Euptilura

Felis Manual

Grus Monacha

Haliaeetus Albicilla

Ketupa Blakistoni

Mergus Squamatus

Moschus Moschiferus

Nemorhaedus Caudatus

Ninox Scutulata

Numenius Minutus

Ovis Nivicola Koriakorum

Ovis Nivicola Borealis

Panthera Pardus Orientalis

Panthera Tigris Altaica

Parus Varius Temmnick

Passer Rutilans

Prunella Rubida

Sorex Mirabilis

Sphenurus Sieboldii

Terpsihone Paradisi

Uncia Uncia

Ursus Thibetanus

Zosterops Japonica

APPENDIX 5: Descriptive Views

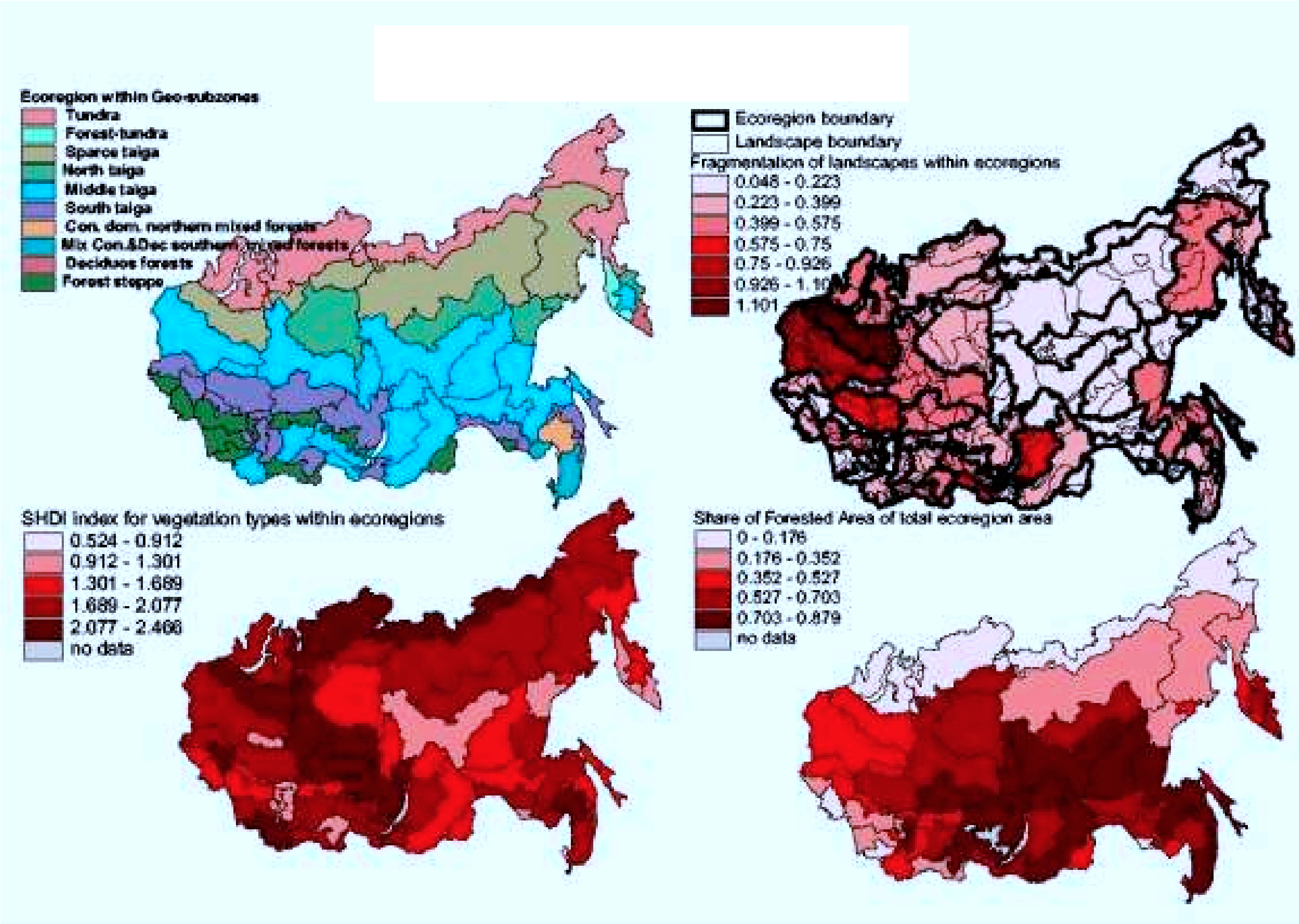

Figure A2. Geo-subzones, vegetation type diversity and landscape fragmentation within ecoregions.

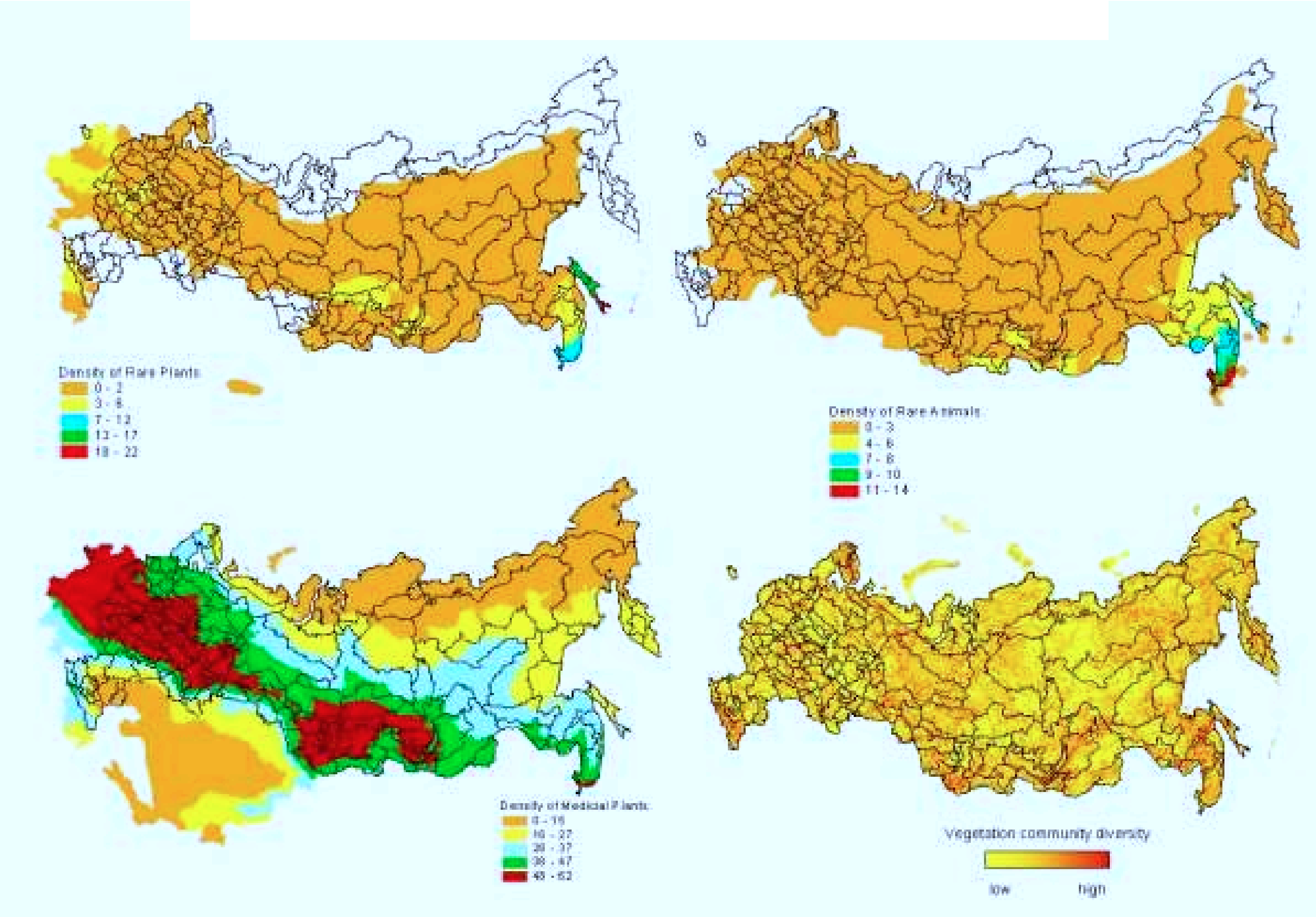

Figure A3. Number of rare plants, rare animals, medical plants and diversity of vegetation communities.

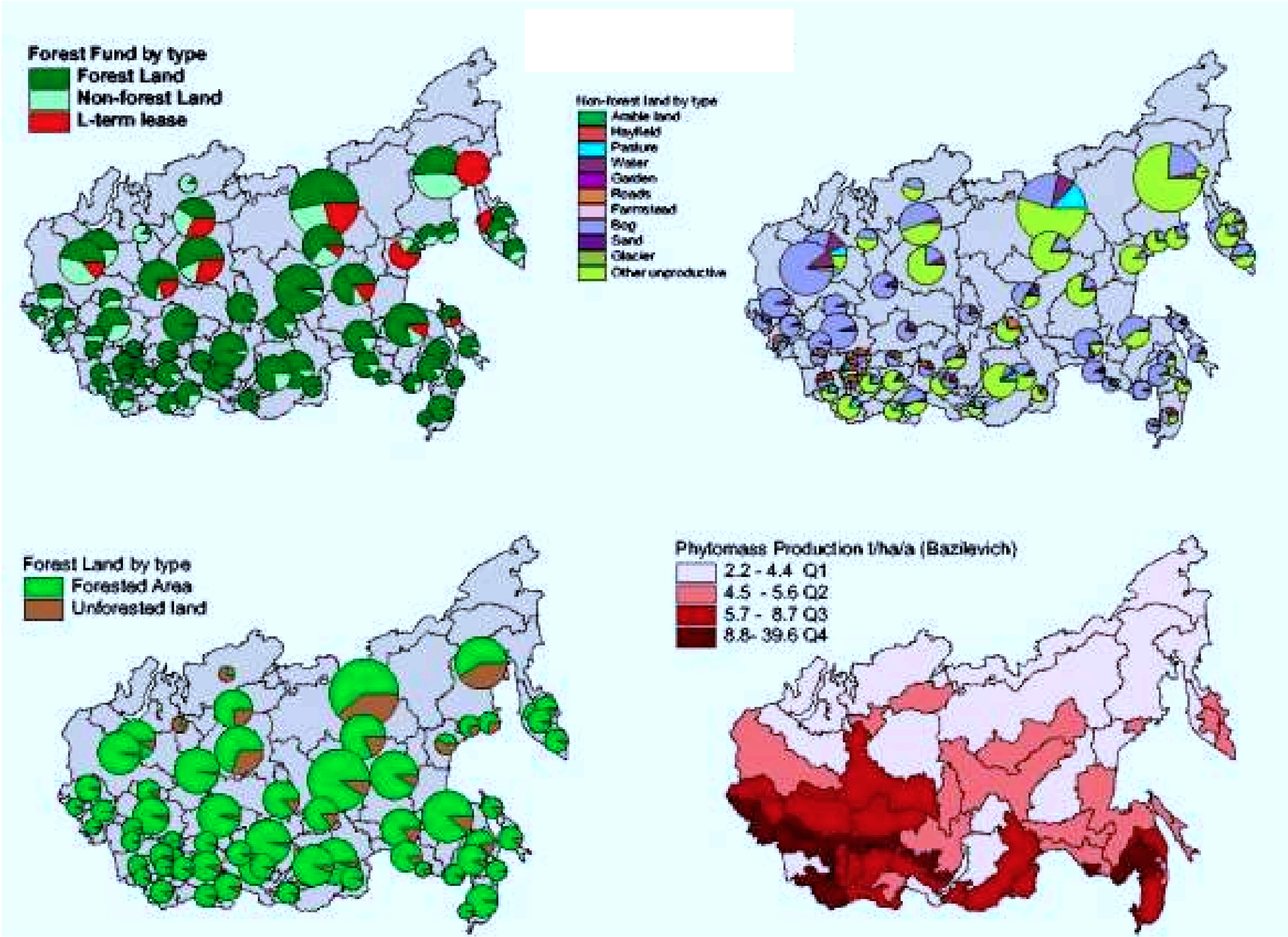

Figure A4. Forest fund type, non-forest land use, state of forest land and phytomass production.

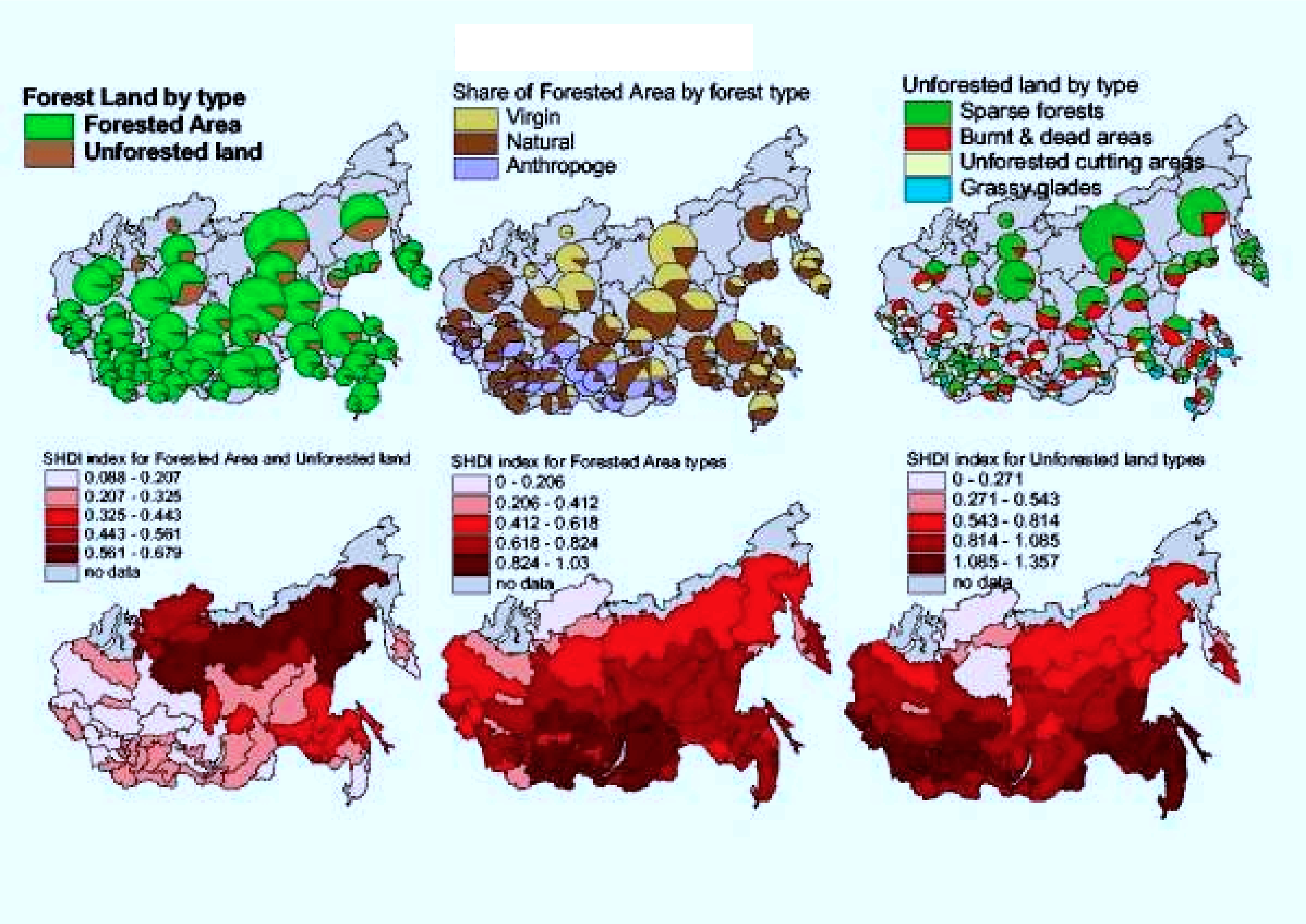

Figure A5. State of forest land, share of forest area by forest type, un-forested land by type, SHDI indices by forest types.

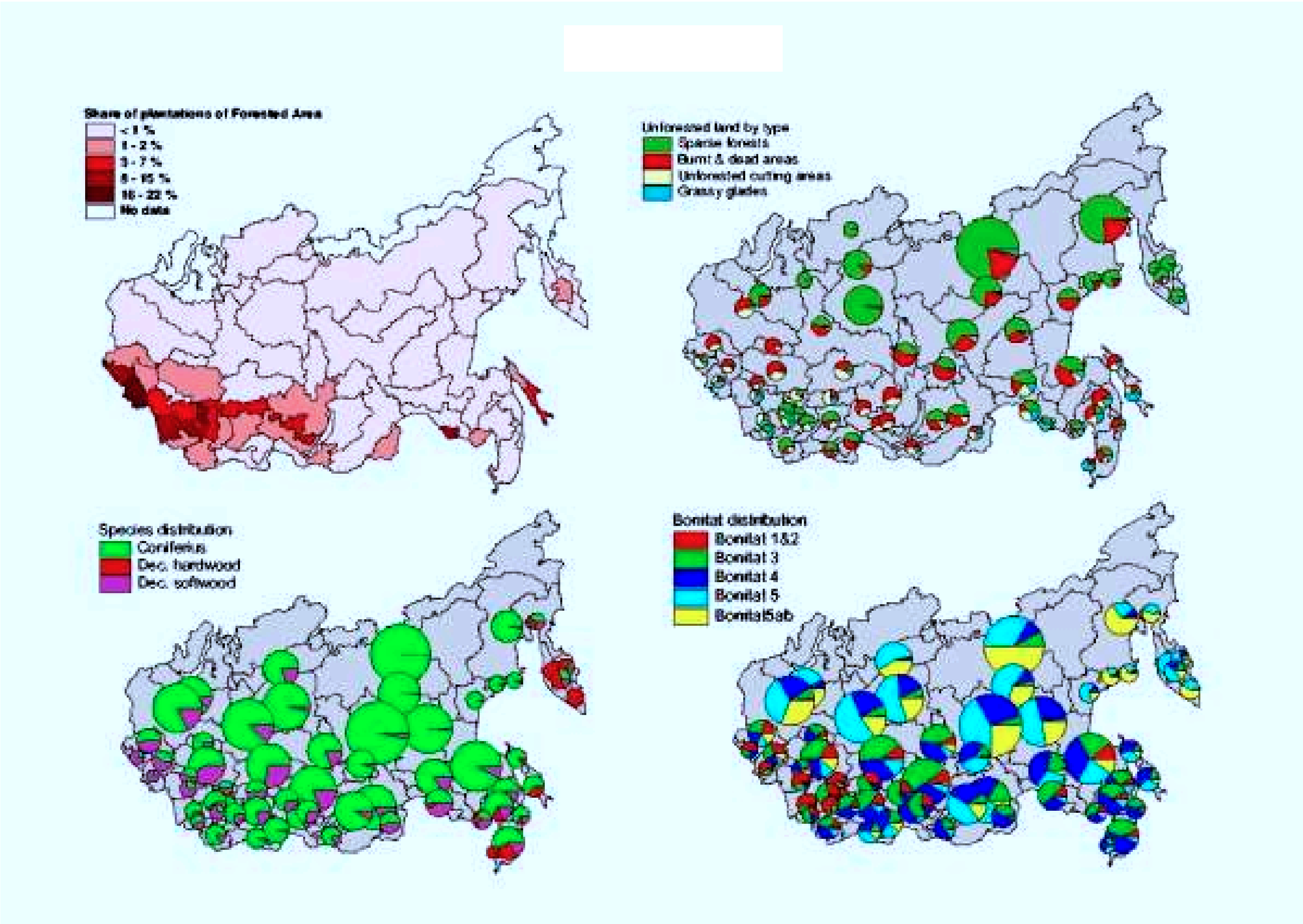

Figure A6. Share of plantations of forested areas, un forested land by type, species distribution and bonitat distribution.

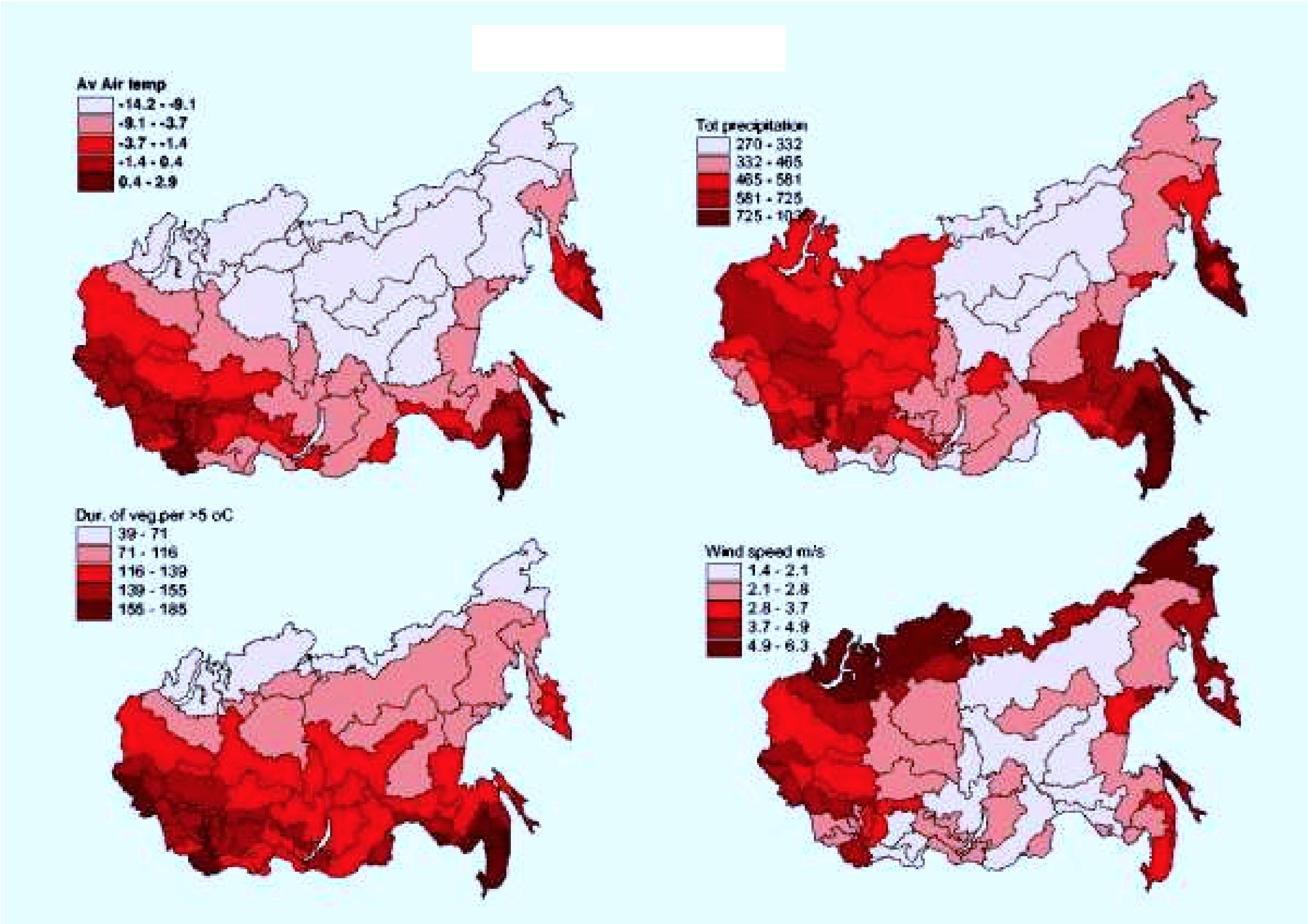

Figure A7. Average air temperature (°C), total precipitation (mm), duration (days) of vegetation period above 5°C and wind speed.

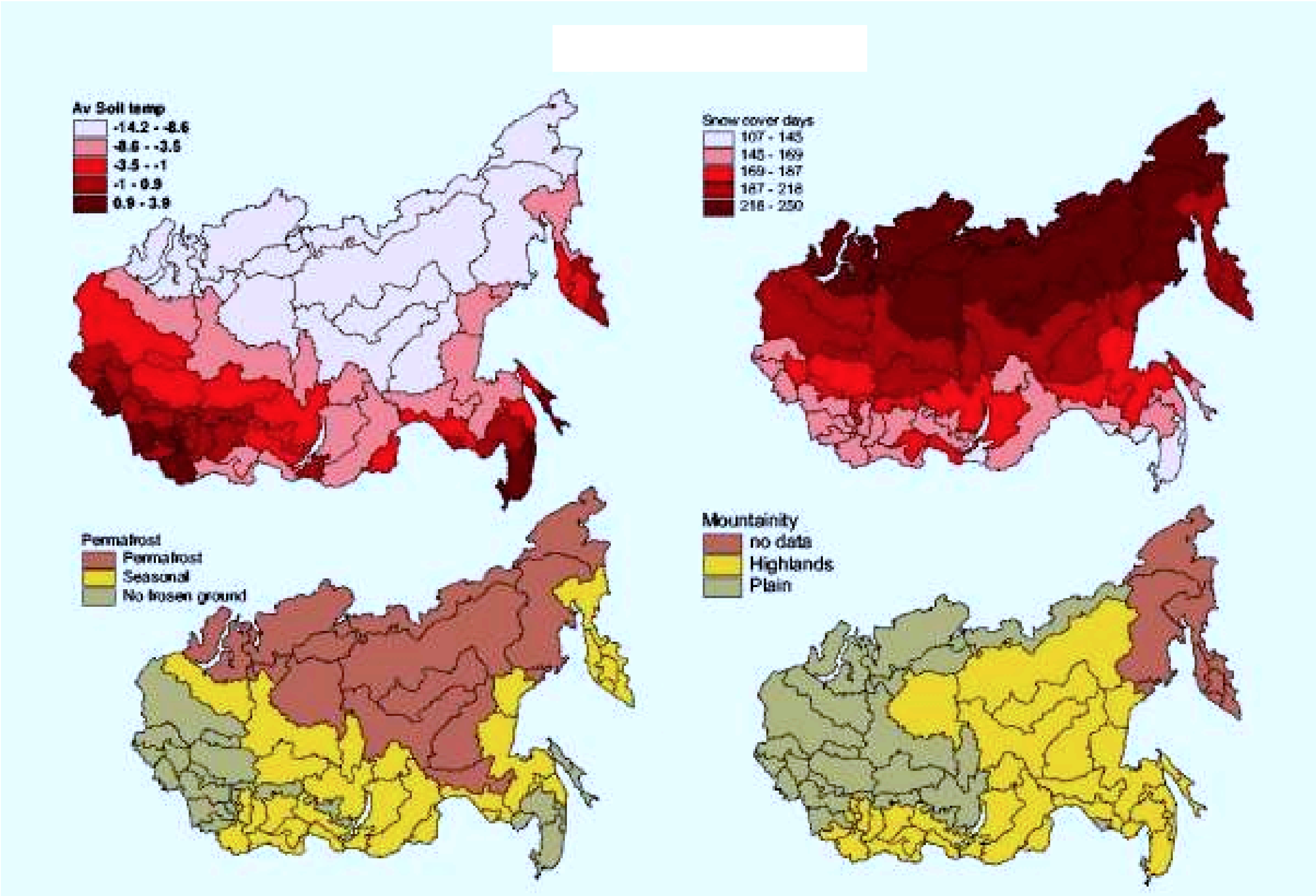

Figure A8. Average soil temperature (°C), snow cover days, permafrost and topography.

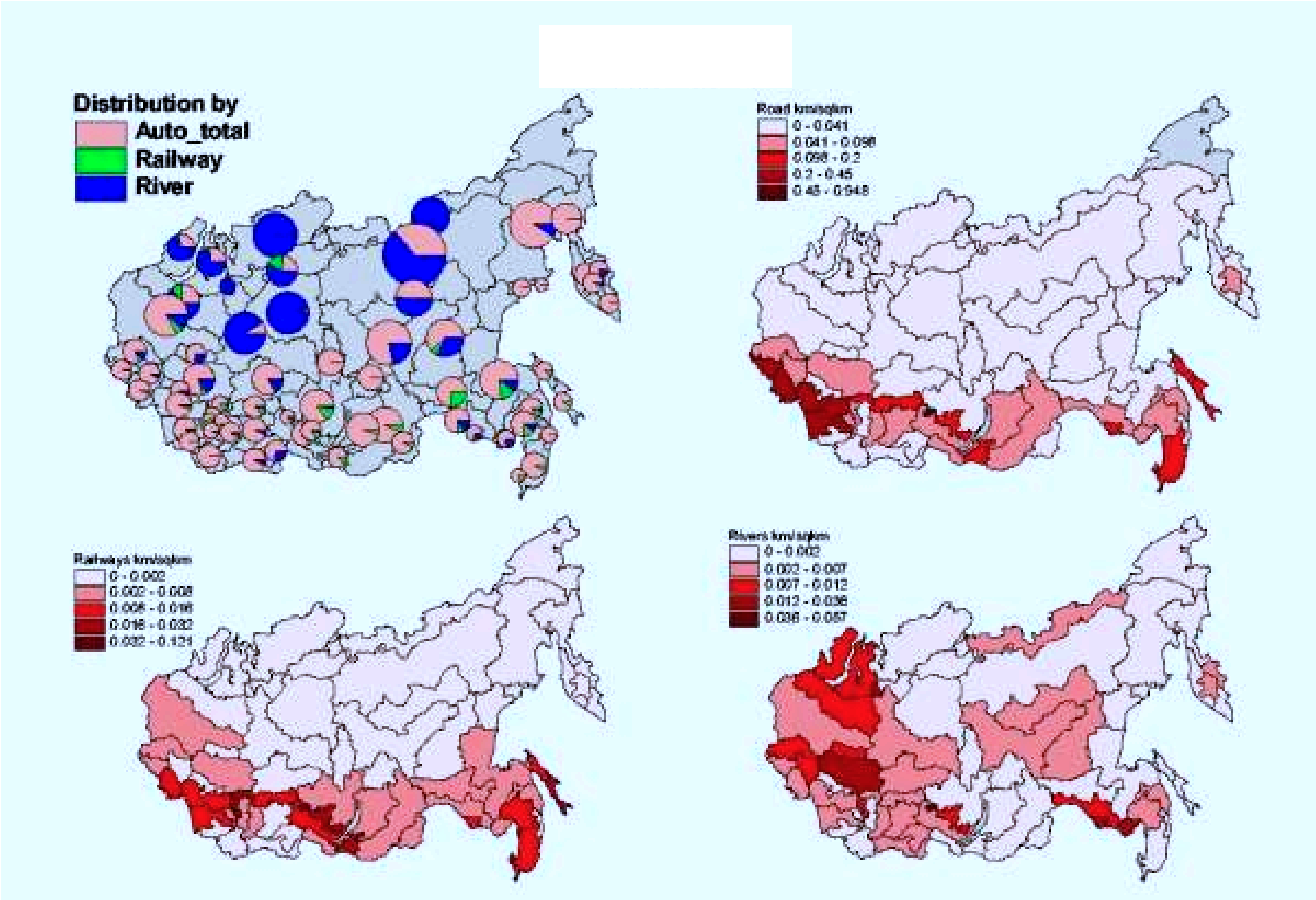

Figure A9. Transportation means, road, railway and navigable river density (km/km^2).

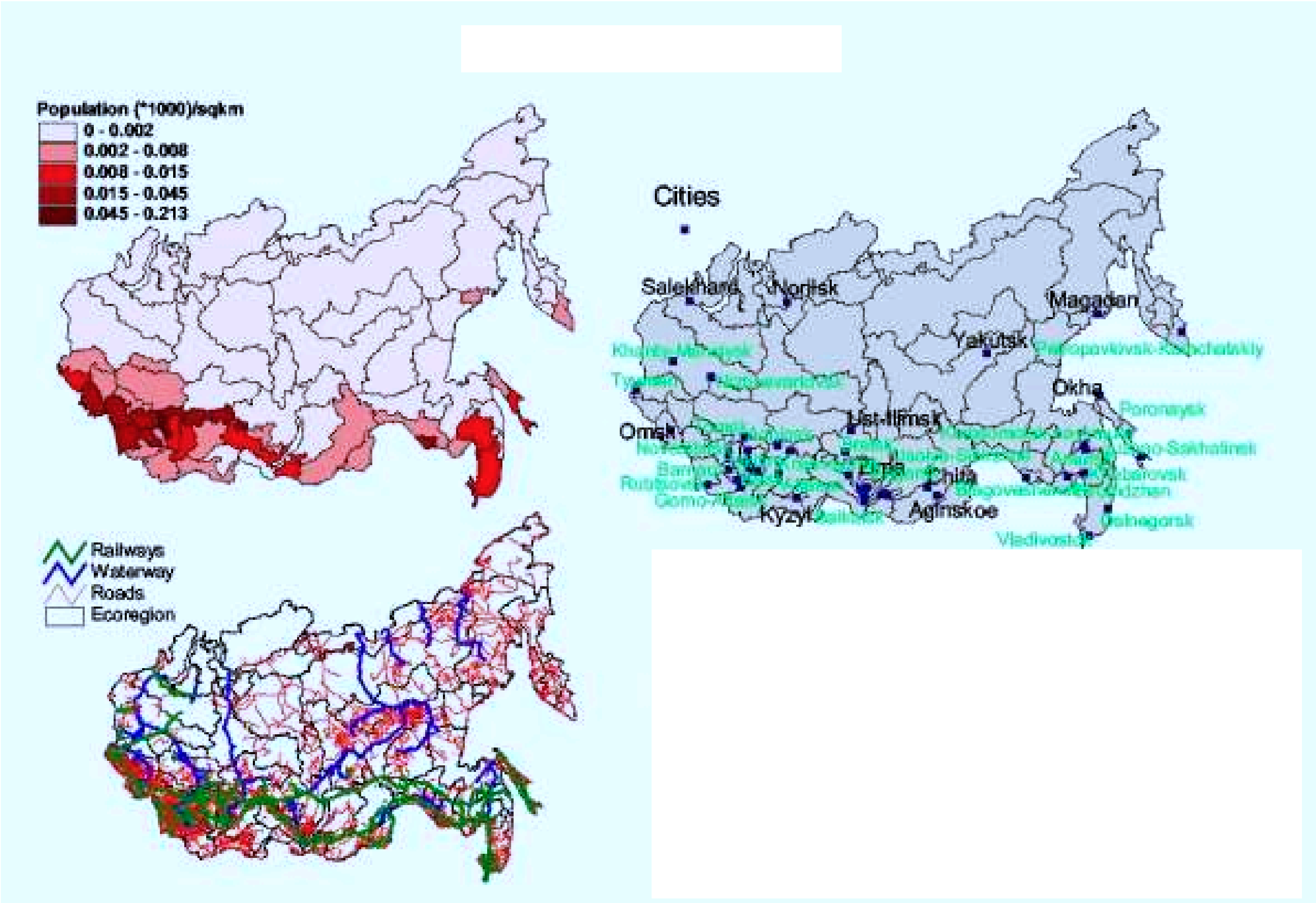

Figure A10. Anthropogenic impacts on ecosystem function: Population density (1000/ km^2), City locations and transportation network.

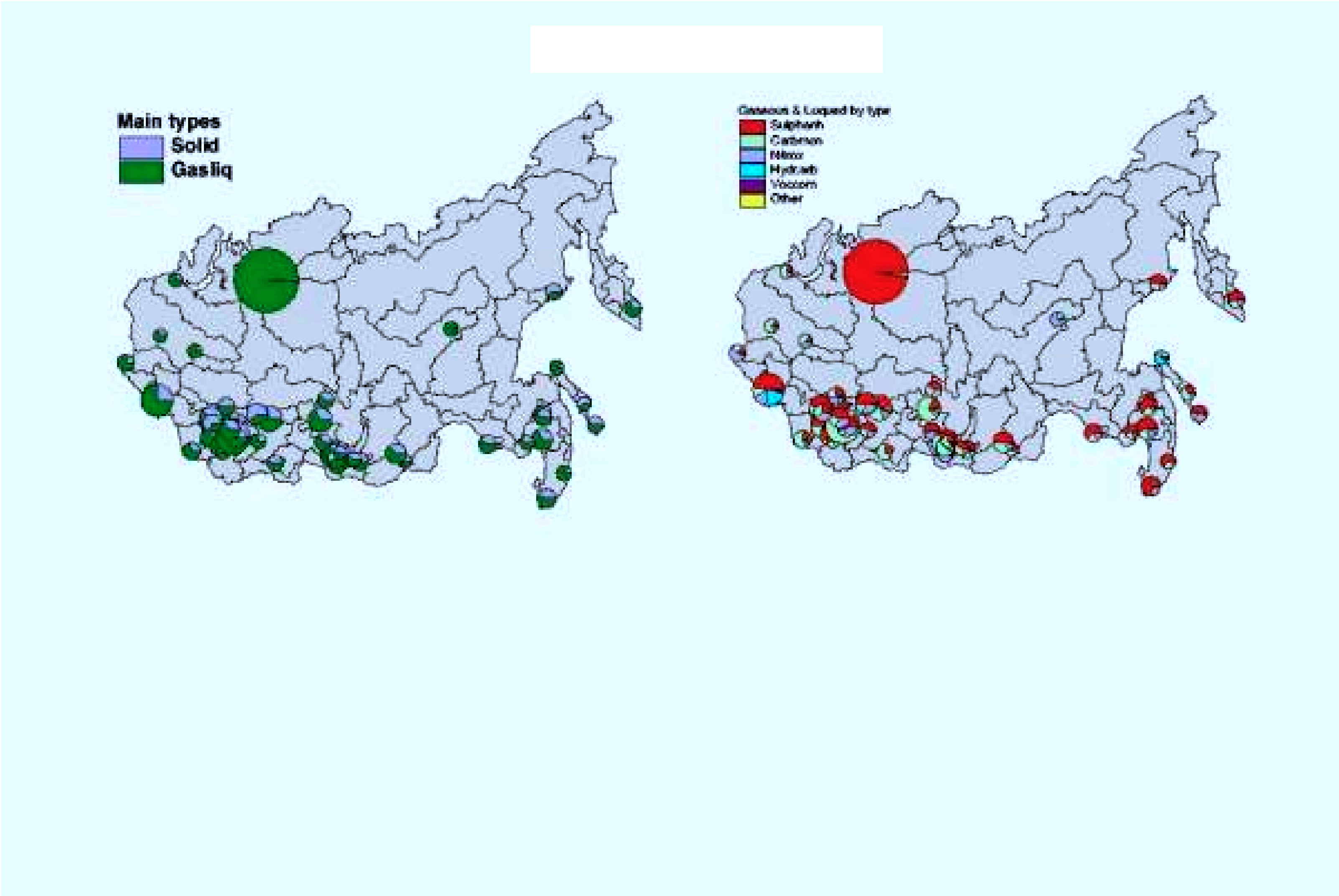

Figure A11. Types of Transboundary emissions.

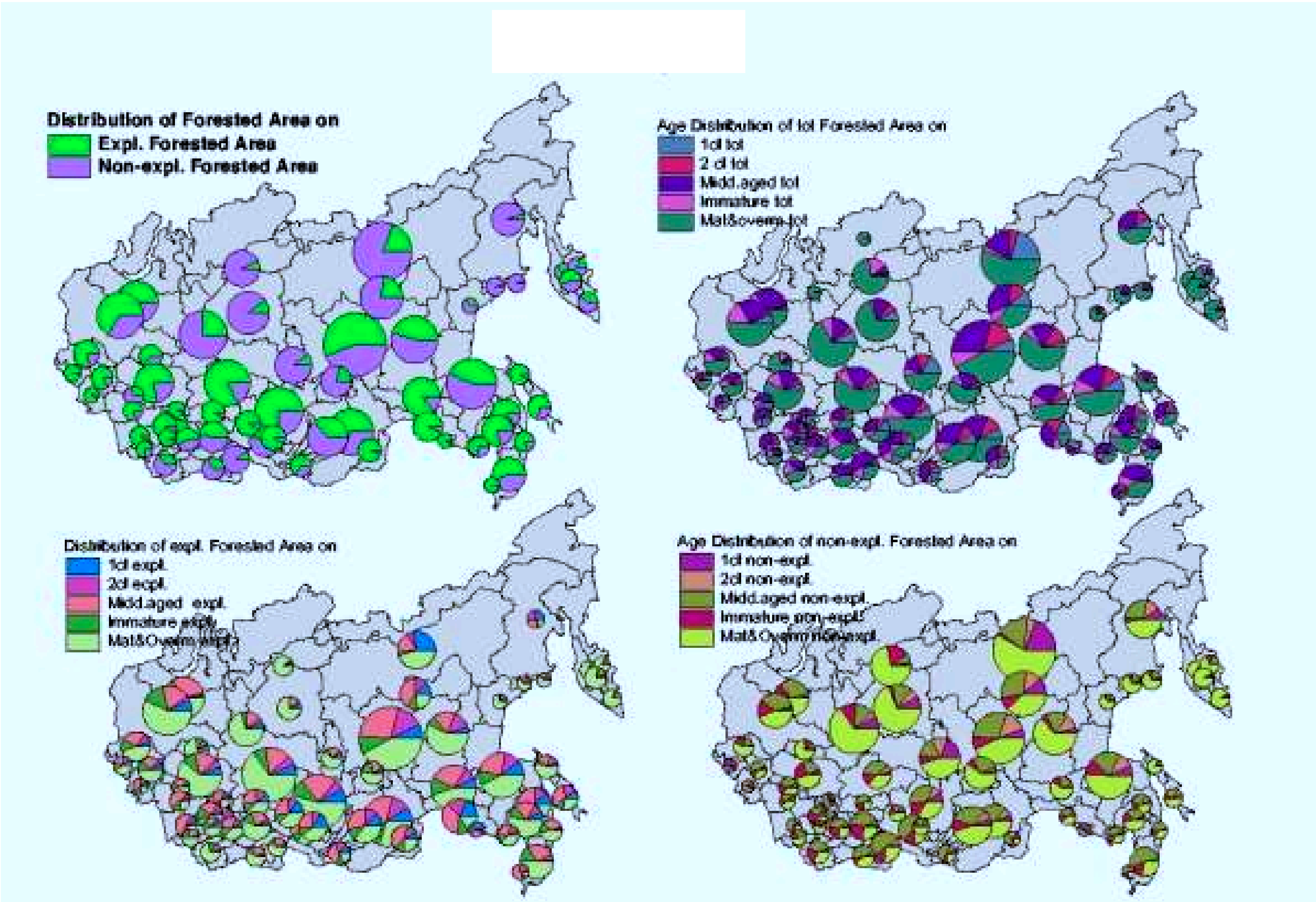

Figure A12. Forest exploitation, all forest, exploited and non-exploited forested area age class distribution.

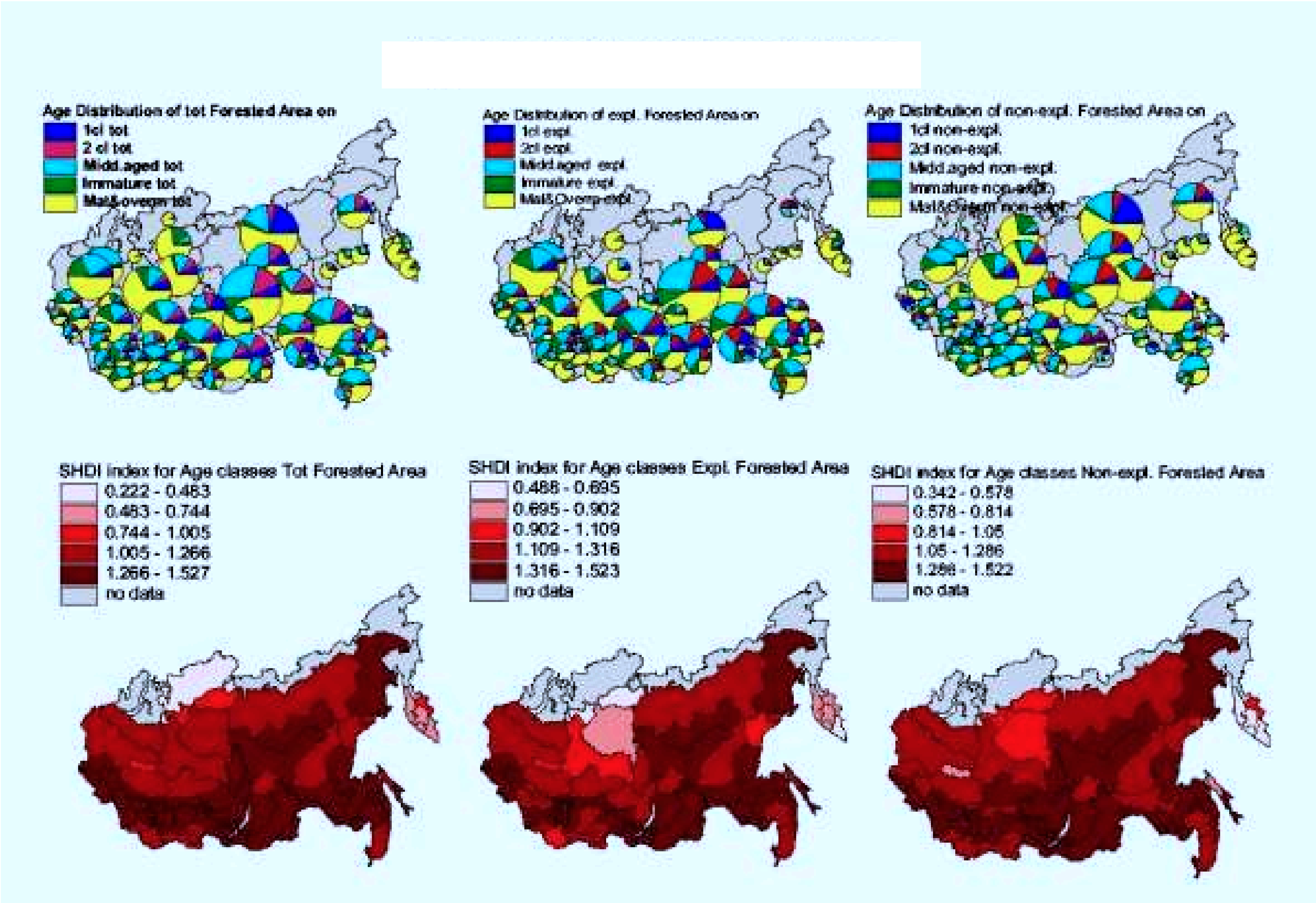

Figure A13. Total forested area, exploited forest area and non-exploited forest area age class distribution and diversity (SHDI).

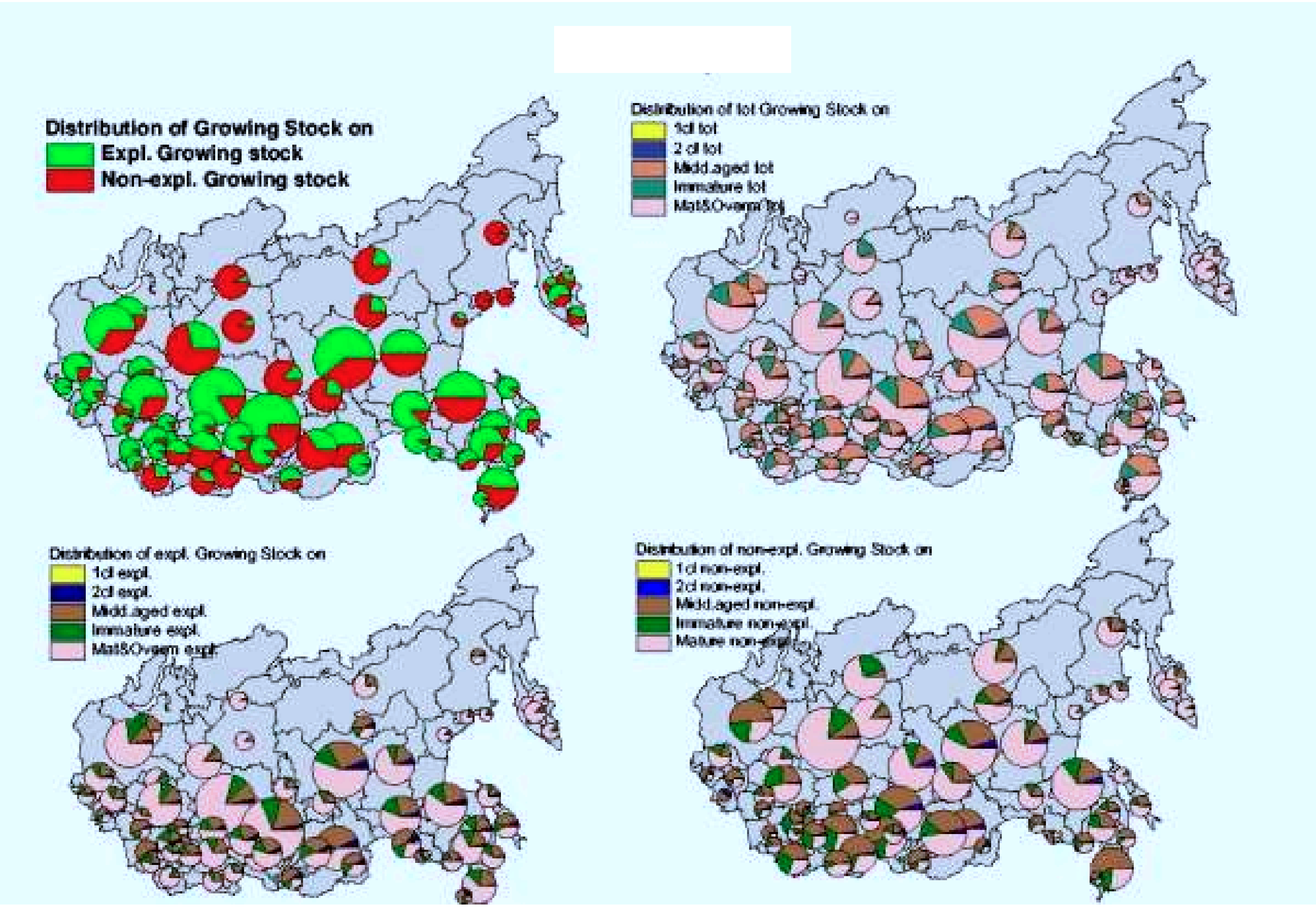

Figure A14. Growing stock distribution by forest exploitation and age class.

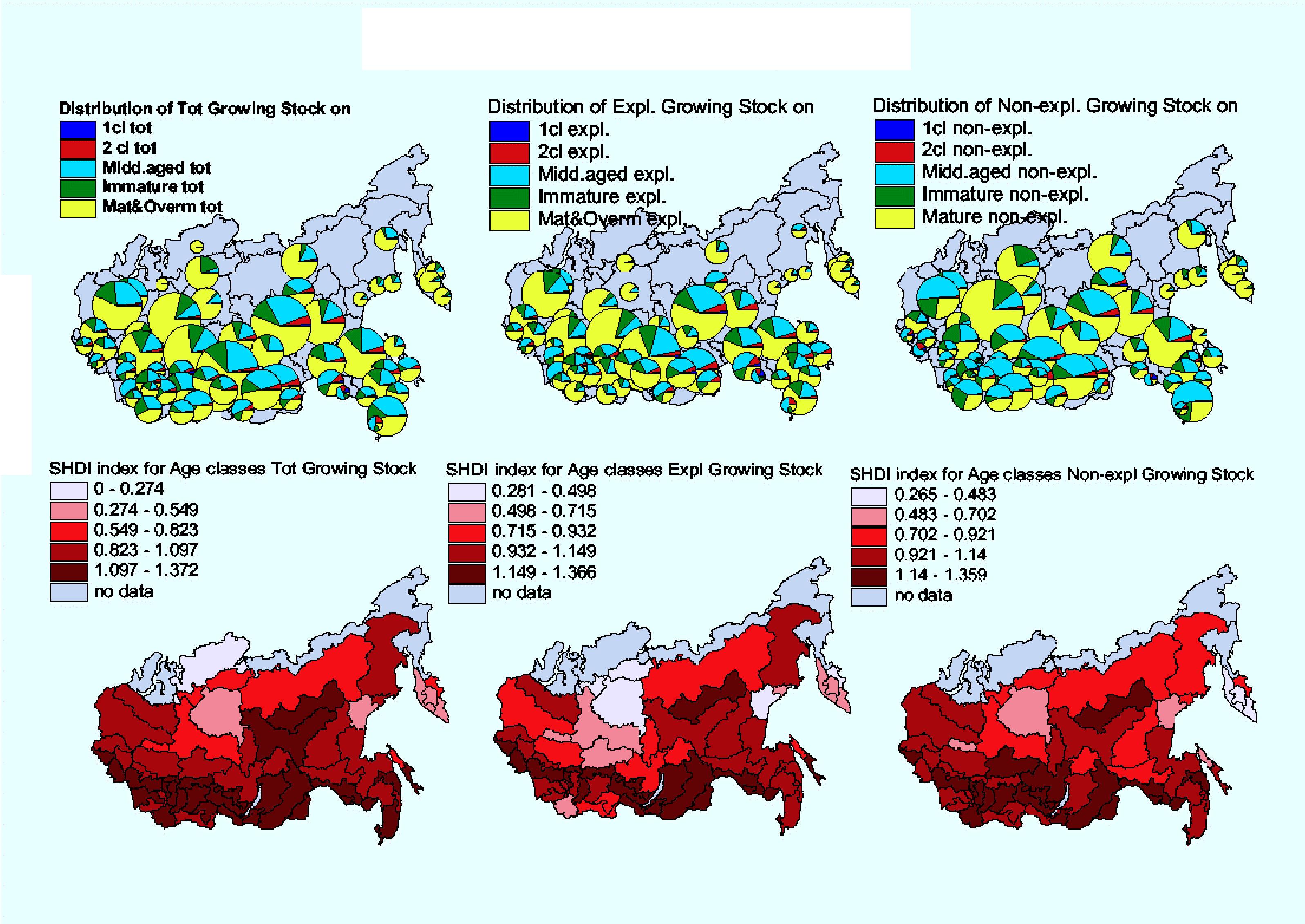

Figure A15. Age class and diversity (SHDI) by growing stock.

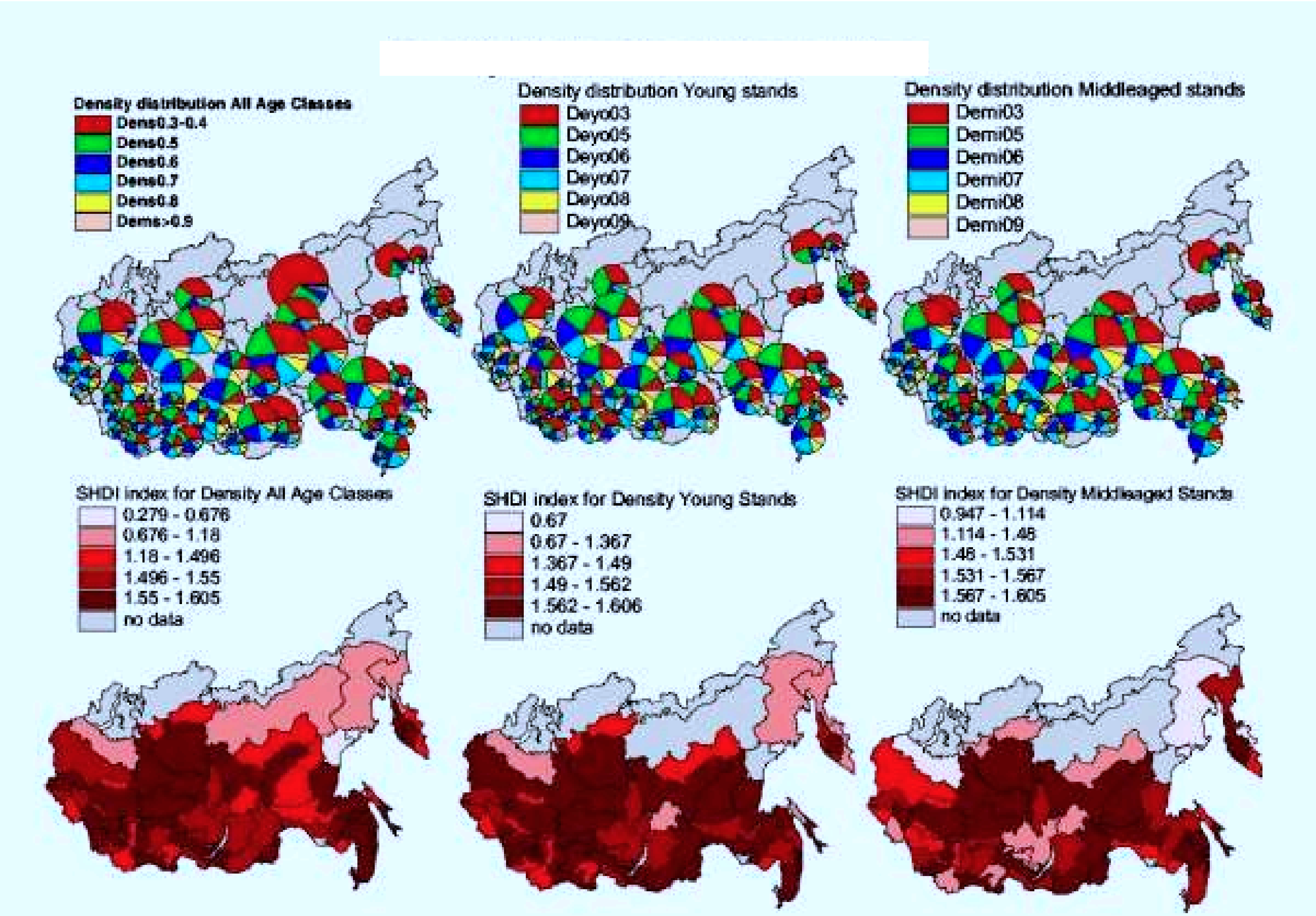

Figure A16. Density distribution and diversity index (SHDI) of forested areas.

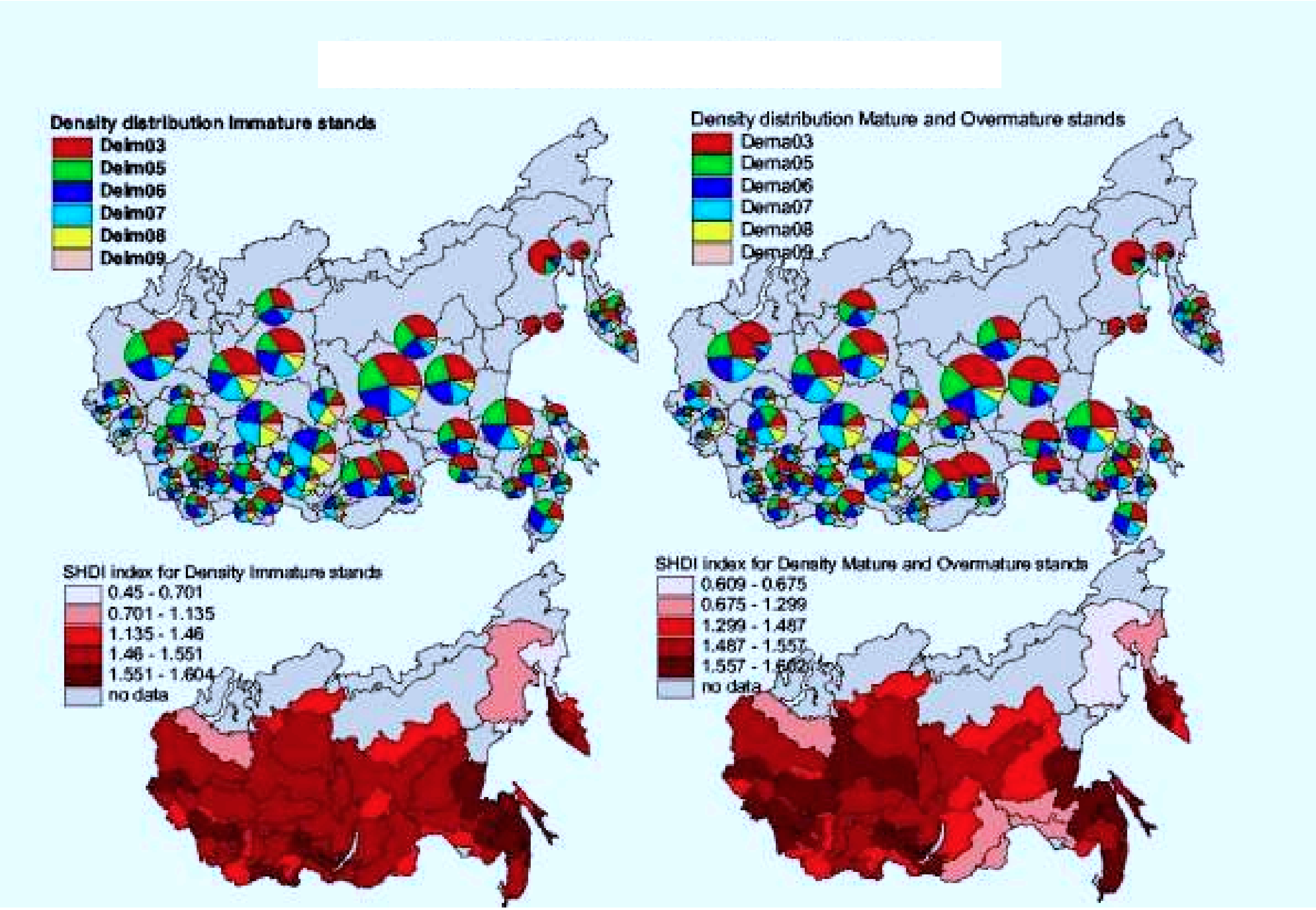

Figure A17. Density distribution and diversity index (SHDI) of forested areas.

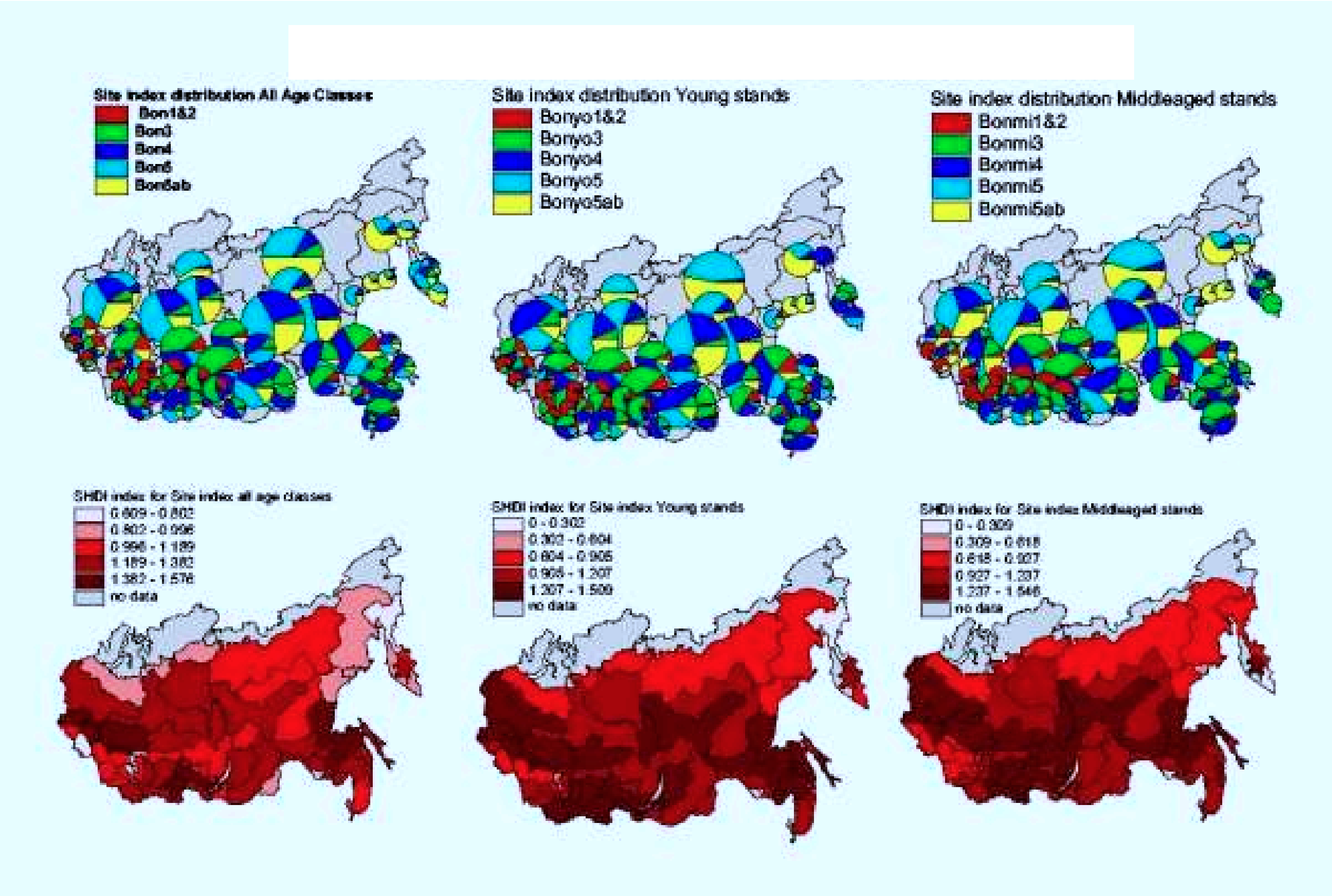

Figure A18. Site index (boniteat) distribution and diversity index (SHDI) of forested areas.

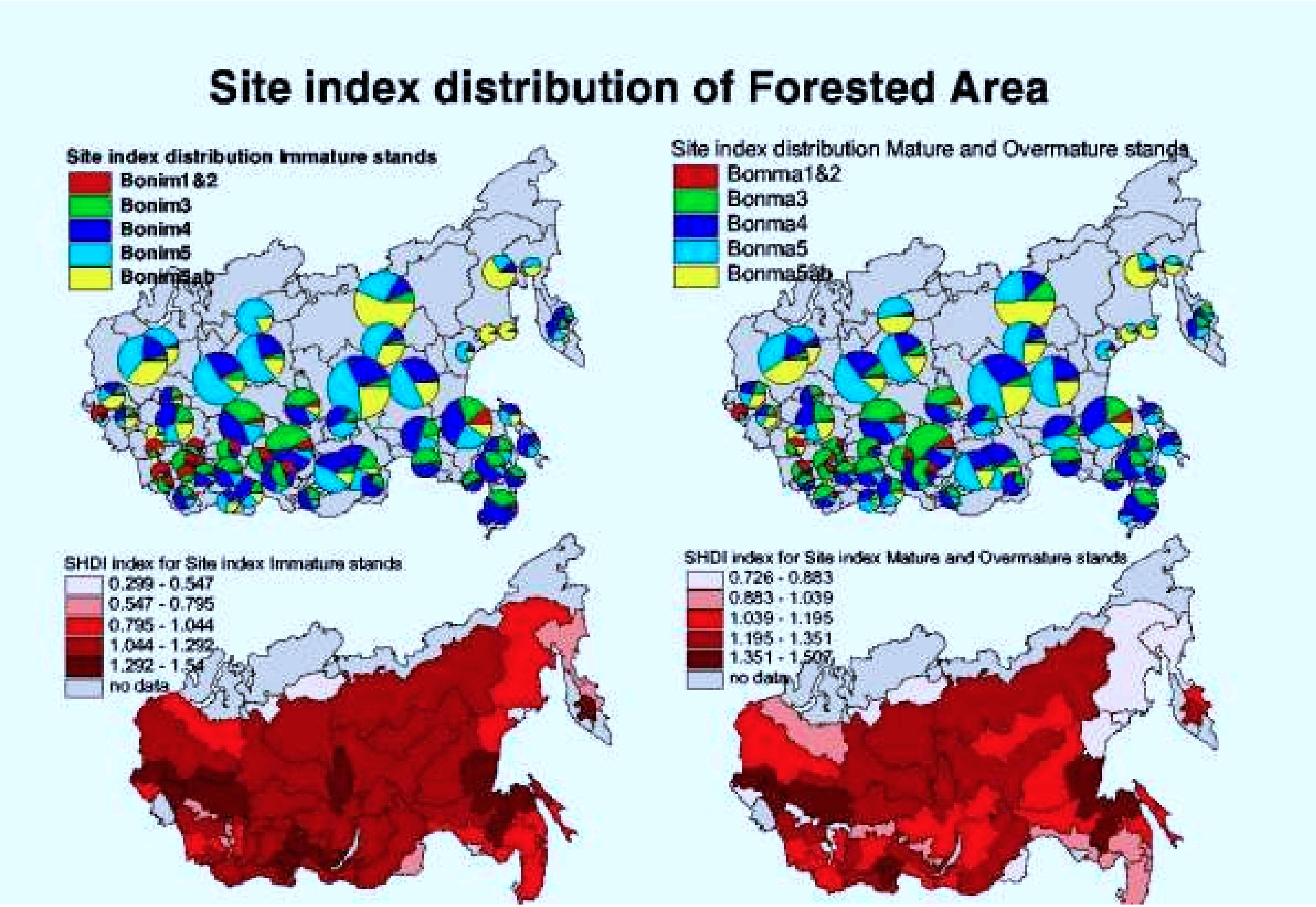

Figure A19. Site index (boniteat) distribution and diversity index (SHDI) of forested areas.

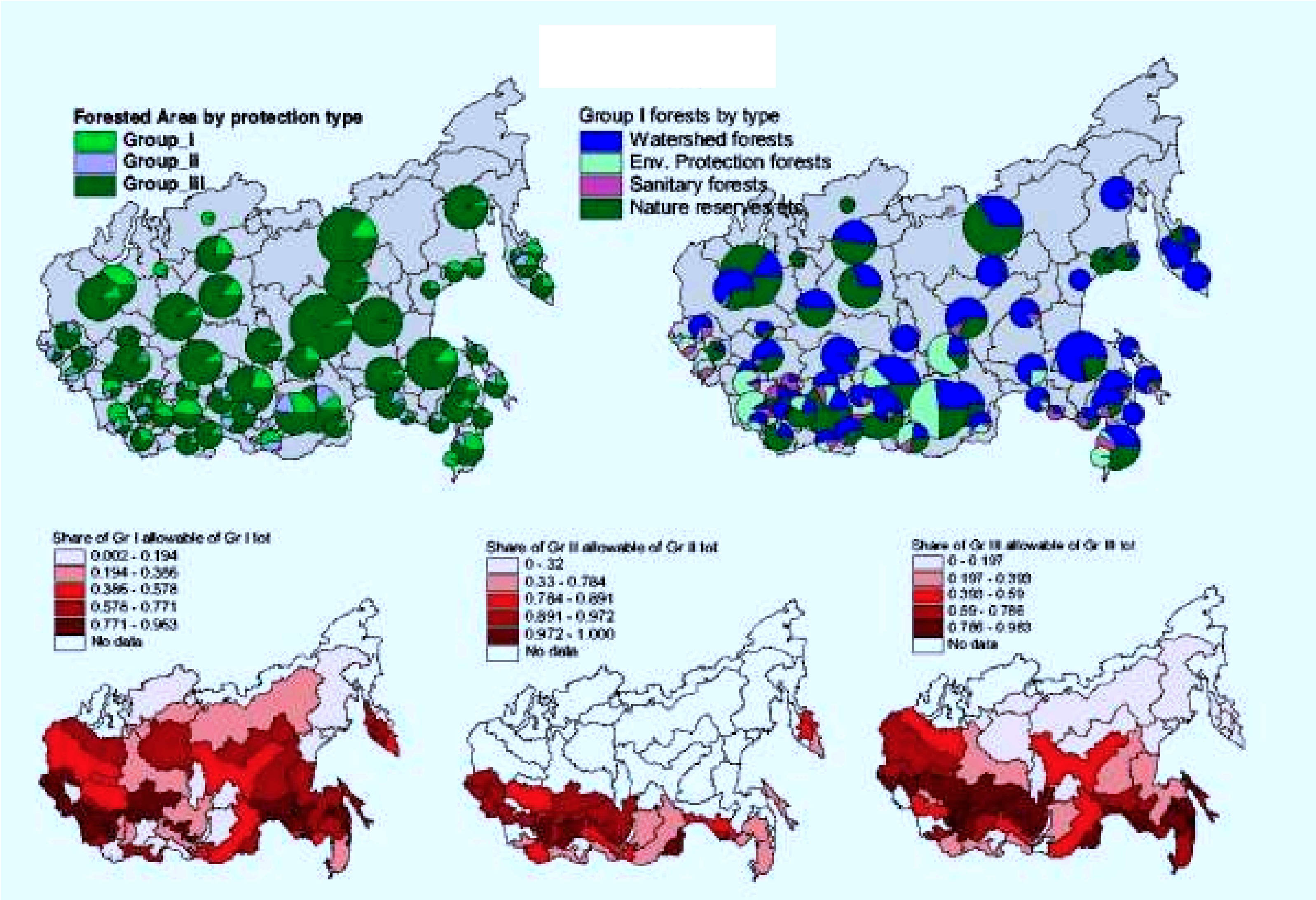

Figure A20. Forest protection types, group I forest by type and proportions.