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An approach for mapping Northern Fennoscandian forests at different scales

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ABSTRACT

Assessment of the diversity of forests throughout their distribution range poses a major challenge for researches because it involves a significant effort of collecting and analyzing heterogeneous information. Our approach to mapping and analyzing the present-day spatial diversity of forests in European Russia was based on a multi-parametric analysis of the chart community characteristics obtained by ground surveys, remote sensing data, and morphometric parameters of the relief. The main steps of methodology were: a) ground-based in a test region selected to represent the main zonal divisions of forest cover, b) development of uniform forest classification, c) mapping at local (large) scale, d) mapping at regional (small) scales. Forest classification was based on the relative availability of ecological and morphological groups of plant species in syntaxa and included seven hierarchical units. Two types of forest cover maps for Northern Fennoscandia are presented as examples at regional and local scales.

Keywords: dominant classification, boreal forest, cartographic modeling, statistical methods, GIS, hierarchical legend

РЕЗЮМЕ

Черненькова Т.В., Пузаченко М.Ю., Морозова О.В., Огуреева Г.Н., Куперман Р.Г. Подход к картографированию лесов северной Фенноскандии в разных масштабах. Оценка разнообразия лесов на протяжении их ареала представляет собой большую проблему, которая требует приложения значительных усилий по сбору и анализу разнородного материала. Представлен подход для картографирования и оценки современного пространственного разнообразия лесов европейской части России в различных масштабах. Он основан на многопараметрическом анализе характеристик растительных сообществ, полученных при наземных обследованиях, данных дистанционного зондирования (ДДЗ) и морфометрических параметрах рельефа. Основными этапами нашей методологии являются: а) наземные исследования в тестовой области в соответствии с основными зональными подразделениями лесного покрова, б) разработка единой классификации лесов, в) картографирование на локальном уровне в крупном масштабе, г) картографирование на региональном уровне в мелком масштабе. Лесная классификация основана на учете экологических и морфологических групп видов растений в синтаксонах и включает семь иерархических единиц: тип растительности, подтип растительности, класс формаций, формация, класс ассоциаций, группа ассоциаций и ассоциация. В качестве примера представлены два типа карт лесного покрова для локального и регионального уровня северной части Фенноскандии.

Ключевые слова: доминантная классификация, бореальные леса, картографическое моделирование, статистические методы, ГИС, дистанционная информация

Nomenclature: Cherepanov (1995) for vascular plants, Ignatov et al. (2006) for mosses, Konstantinova & Bakalin (2009) for liverworts, Santesson et al. (2004) for lichens.

INTRODUCTION

Exploration of the spatial differentiations of boreal forests at multiple structural levels is among pressing research needs for the vegetation science. Meaningful mapping of vegetation cover can reveal ecogeographic patterns in forest distributions and their regional specificity, as well as the role of anthropogenic factors in the formation of contemporary biodiversity.

Numerous survey maps have been developed for the European part of Russia. These maps were created using a variety of methodological approaches and principles for preparing the legends. Specific information on the Eastern-European forests can be found at regional and general maps: "Map of the vegetation of European part of the former USSR and the Transcaucasia" (Lavrenko 1976); "Map of Reconstructed vegetation of Central and Eastern Europe" (Gribova & Neuhäusl 1989); "Map 'Vegetation of the USSR" (Belov et al. 1990) and "Map of the Natural vegetation of Europe" (Bohn et al. 2004). These maps provide information on restored, or potential vegetation cover, and other important background scientific information. However, they may contain outdated information, including plant communities composition representative of the 1960-1970s, and do not accurately depict the present condition of the vegetation.

A more accurate representation of the spatial distribution of contemporary forest cover can be achieved by means of digital maps based on remote sensing information. One of the first successful products of digital cartography was the map "Vegetation of Russia" (scale 1:7,500,000) that was developed on the basis of satellite images SPOT-Vegetation with a spatial resolution of 250 m (Bartalev et al. 2003, 2011). However, the legend of this map lacks the necessary details and provides only general information on the composition of present-day forests. Only large formation groups, such as Evergreen Dark Needle-leaf Forest, Evergreen Light Needle-leaf Forest, Deciduous Broadleaf Forest, Needleleaf with Broadleaf Forest, Mixed Forest, Broadleaf with Needleleaf Forest, Deciduous Needle-leaf Forest, and Sparse Deciduous Needle-leaf Forest, can be distinguished on this map. Notwithstanding these limitations, this map very accurately depicts the current forestland cover, possible disturbances (e.g., burned areas in the last few years), thus represents a phase in operative mapping on a small scale required for forest monitoring.

Recently, a mapping method that is based on combination of remote sensing and ground-based sources of information has gained a widespread acceptance (McRober 2006, Tomppo et al. 2008, Puzachenko & Chernenkova 2012, Kravtzova 2013, Puzachenko et al. 2014, Roelofsen et al. 2014). This method is commonly used to create regional and local maps. However, cartographic information on the current vegetation and on the diversity of forest cover is not available for most regions of the European part of Russia. Another problem is the lack of uniform classification for the Russian forests, which would allow to compare the forests from different part of their range and evaluate their diversity (Zaugolnova & Morozova 2006). Study of the vegetation diversity at either large or small geographical scales is closely related to classification of plant communities (Walker 1999, Rodwel et al. 2002, Rysin & Savelyeva 2007). Finally, development of a common methodology is needed to identify the factors that affect the forest diversity at different scales.

To fill the current methodological gaps, a team of experts from different research centers (Center for Productivity of Forests and Institute of Geography of the Russian Academy of sciences, Geography Department of Moscow State University) is assessing current plant diversity of the Eastern European boreal and hemi-boreal forests, including their regional specificity and distribution. An effort to map the forest vegetation for the Eastern European part of Russia at different scales was among the objectives of this team. This paper discusses the methodology for detecting a spatial diversity of forests by using remote sensing technology in order to create maps at large and small scales using northern part of Fennoscandia as an example.

METHODS AND DATA

Present study developed and utilized methodology and methods for cartographic modeling of vegetation at different spatial scales (Fig. 1). It was based on multiparametric analysis of the characteristics of plant communities obtained by ground surveys, remote sensing data (RSD), and morphometric parameters of the ground surface. We conducted field survey within test area and stored geobotanical features into database for further analyses in the form of classification units to create maps, design a map legend, and assess a forest diversity. These data can be utilized in large- or medium-scale maps at scales ranging between 1:50,000 and 1: 200,000 to show a current diversity of vegetation. The results of the local assessment of the vegetation surveys were used to map the structure of the vegetation cover at the regional level and for the creation of small-scale map within a corresponding zonal division.

Study area and field data

The large scale study area is located in the central part of the Kola Peninsula (67°50'N, 32°35'E) and belongs to the northern taiga subzone (Fig. 2). Total area of this model territory is approximately 8400 km^2. It covers the Lake Imandra basin, which includes the territory of the Lapland Nature Reserve and a large part of Khibiny mountains area with mining and ore enrichment plants (Kola Mining and Metallurgical Company). The territory is characterized by a complex, rugged relief, the altitudes range from 100 to 1200 m a.s.l.

Geobotanical data of plant communities were obtained on sampling plots (size 20 × 20 m) with exact geographical positions determined by GPS. The sampling plots were selected on basis of preliminary analysis of RSD, digital elevation model (DEM), topographic and forest inventory maps and to be representative of regional diversity of forest communities and their anthropogenic modifications. In addition, non-forest vegetation was examined. As many as 500 geobotanical plots were sampled in the model study area. These plots were selected to be representative of the majority of vegetation diversity in the region. Different types of land cover and water bodies that are not represented in the sample plots were determined from all available spatial information (280 points).

At small-scale (1:2,000,000), the vegetation map is represented by a fragment of Fennoscandia region with total area about 540,000 km^2, which includes North Scandinavia and the Kola Peninsula.

Forest classification

A uniform eco-phytocoenological forest classification was developed to assess the typological diversity of forests. This forest classification was based on the relative presence of ecological and morphological groups of plant species in syntaxa (Zaugolnova & Morozova 2006, Chernenkova et al. 2012). A hierarchical classification included the following units: vegetation type, vegetation subtype, formation class

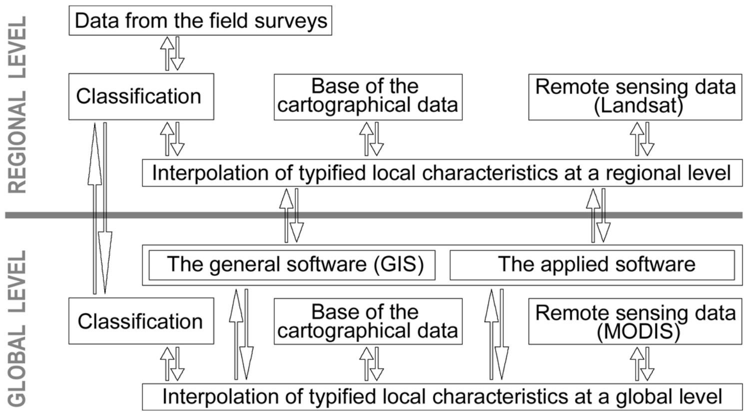

Figure 1 The main stages of forest mapping at different scales

shed information on the vegetation of different regions (Bohn at al. 2004, Saucier et al. 2013). At large and medium scales (from 1:50,000 to 1:200,000), the main mappable units for forest vegetation were groups of association for zonal communities, and classes of association for azonal vegetation types (e.g., wetlands, meadows). Units of lower level were identified on the basis of diagnostic or indicator species that revealed the regional specificity of communities. Association class and formation class were the base units for mapping at a small scale.

(group), formation, association class, association group, and association. Vegetation type was based on a biomorphic type; subtype was based on floristic and phylogenetic commonality (Sochava 1964, Lavrenko 1968). Formation class was determined on the basis of the predominant life form of tree species (e.g., dark coniferous, light coniferous forests). Formation group was based on genera of the dominant tree species (e.g., spruce, pine forests). Formation was determined by predominant species of tree stand. Association class was characterized by both composition of tree stand edificators and composition of the predominant ecological and morphological groups of understory species. The association group was characterized by dominant species groups at main layers of forest community.

The development of forest classification involved both the analyses of field data and the review of available publi-

Vegetation mapping at large scale

Each sample plot was correlated with association group for forests communities and association class for non-forest vegetation. Other land cover classes (e.g., water bodies, settlements) were determined from topographic maps and RSD.

The basis for large-scale interpolation of vegetation classes were Landsat 5, 7, 8 and relief data. Landsat data for analysis are presented by images for the last 10–15 years and for different seasons. Both the brightness values of channels as well as the derived 24 indices (NDVI, VI, RVI, QRVI, DVI, TSA, R/G, TVI, GNDVI, TNDVI, NDWI, NDSI, SAVI and etc.) were used in analysis. Model area covers several Landsat scenes that required mosaicking images. This was accomplished by using ErdasImagine mosaicking with histogram correction. As a result, seamless mosaics of Landsat images were obtained from May to October.

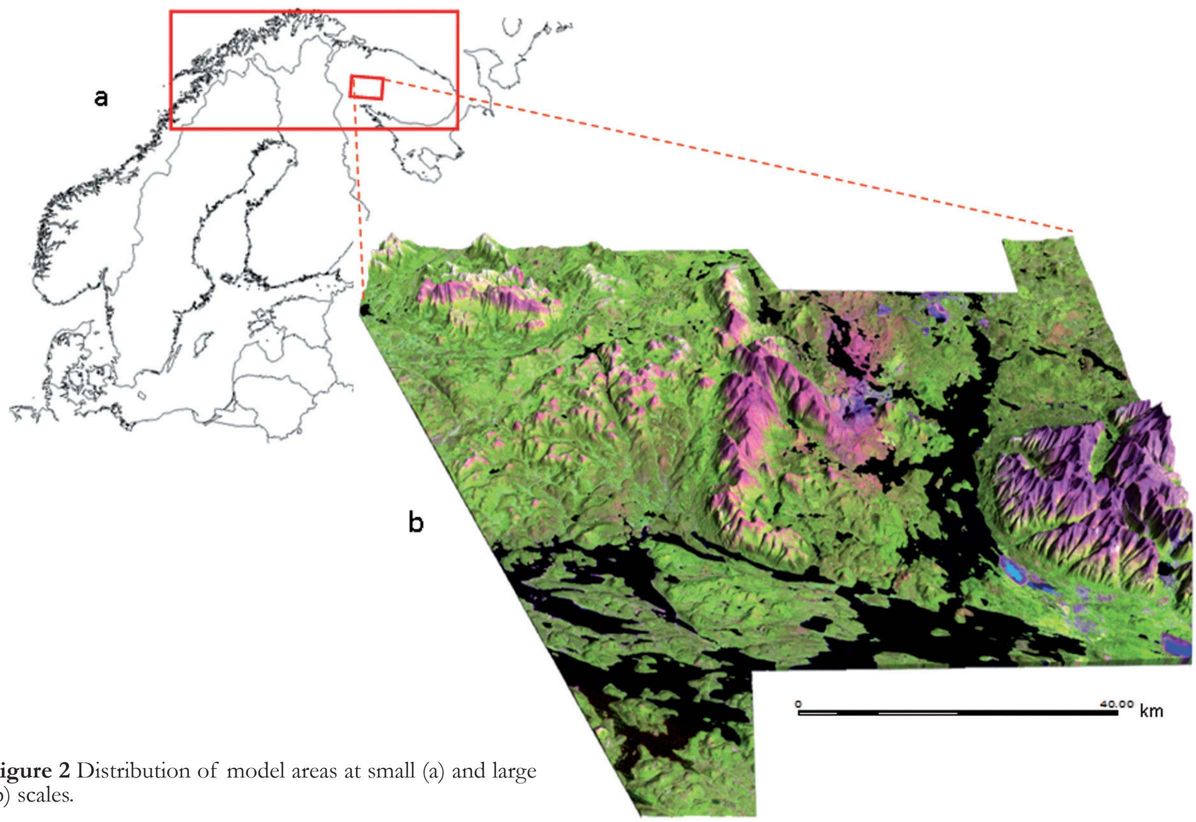

Figure 2 Distribution of model areas at small (a) and large (b) scales.

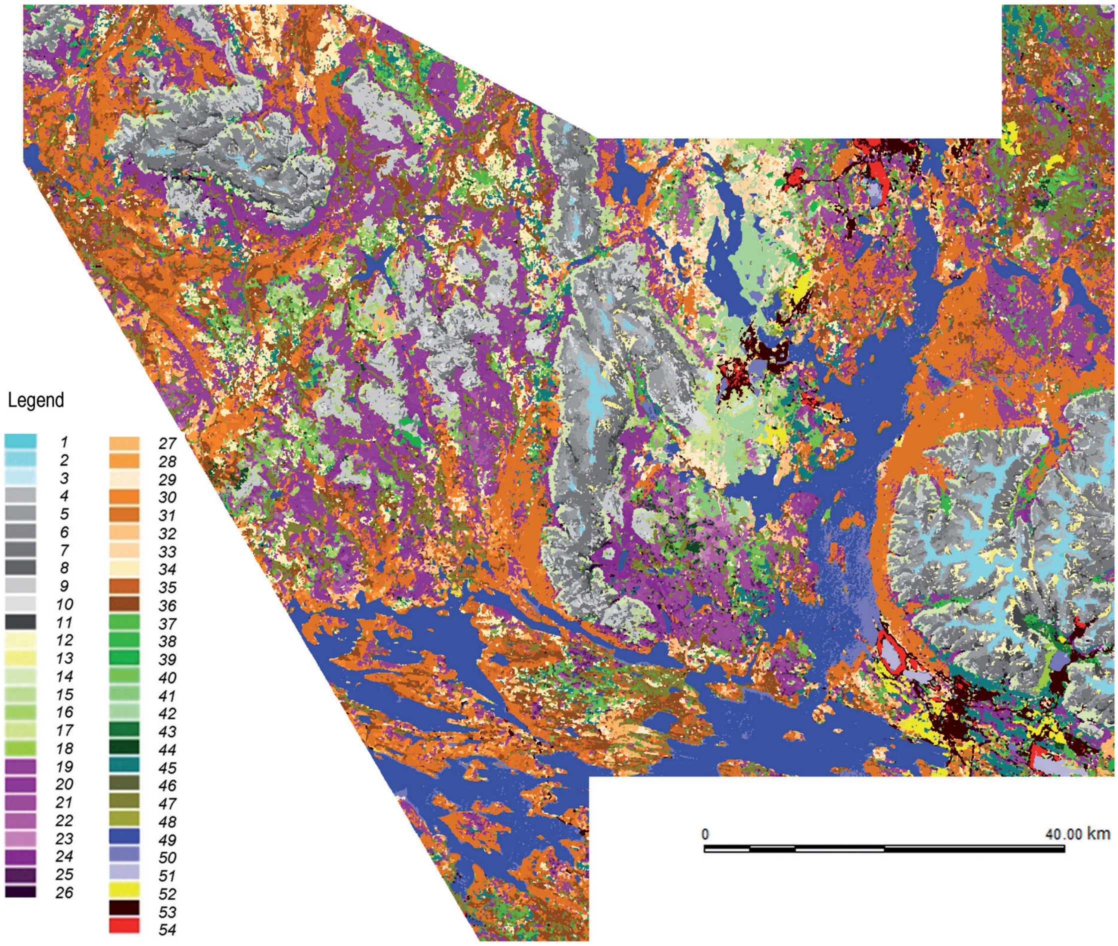

Figure 3 Vegetation map of model area at large scale, for legend see Table 1

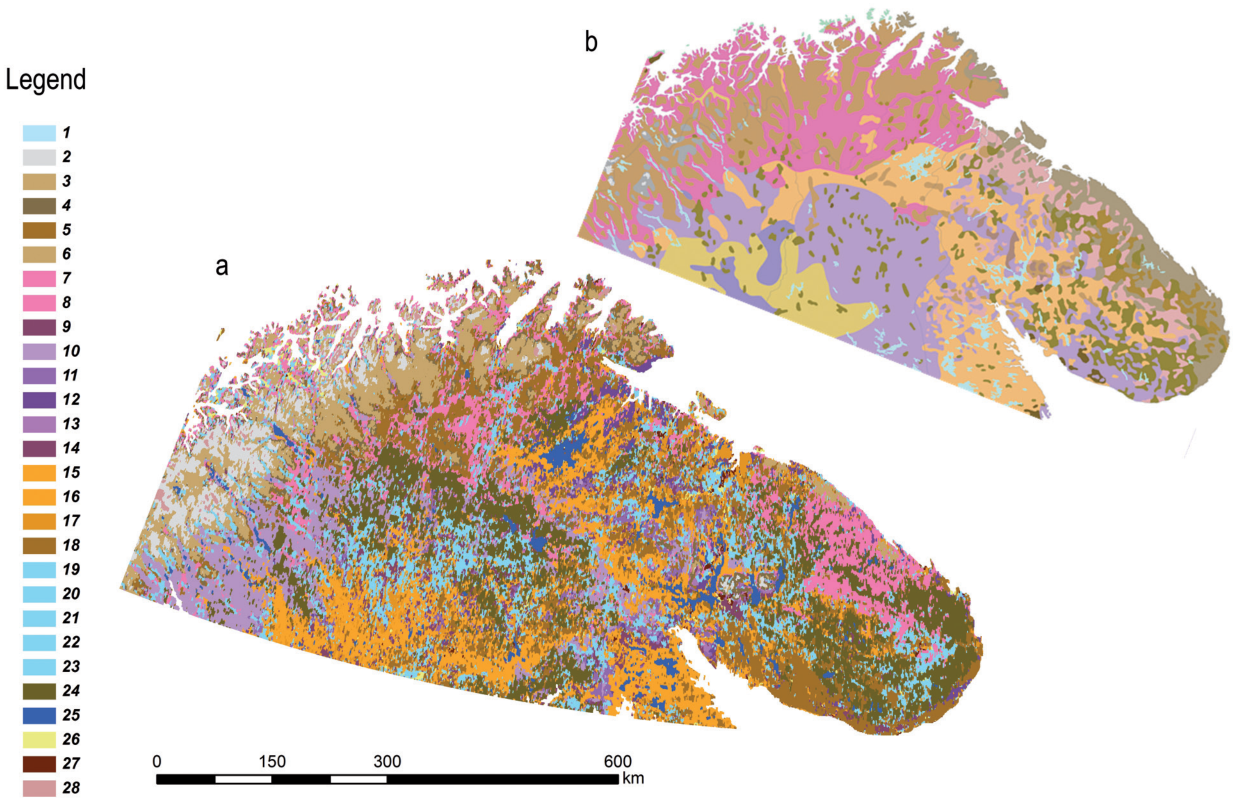

Figure 4 Vegetation map of the Northern Fennoscandia at small scale: a – the present effort version of the vegetation map for association classes, for legend see Table 1; b – fragment of the Natural vegetation European Map (Bohn et al. 2000)

Table 1. Classification scheme for vegetation of the northern part of Fennoscandia. Secondary vegetation types are marked with asterisks; numbers in arabic mark association classes on the small scale maps and association groups – on large scale maps

Vegeta-tion type	Formation class	Association class	Association group
Nival area	Nival area	1. Nival area	1. Nival area
Tundra	Stone golsty barrens	2. Barren landscapes with very sparse, very low plant cover (<10 %) with scattered crustose and fruticose lichens, dwarf shrubs and herbs	2. Stone golsty barrens and sparse epilitic/crustose lichens (*Rhizocarpon geographicum, Umbilicaria spp., Arctoparmelia centrifuga*) tundra
			3. Sparse fragments of dwarf shrubs (*Silene acaulis, Empetrum hermaphroditum*), grass (*Juncus trifidus, Festuca ovina, Carex bigelowii*) and lichens (*Flavocetraria nivalis, Alectoria ochroleuca, Cetraria islandica*)
	Sparse tundra with epilithic lichen communities	3. Sparse tundra vegetation (10–30 %) of flat tops and crests. Prostrate lichens, mosses-lichen and dwarf shrub–lichen groups	4. Sparse dwarf shrub (*Empetrum hermaphroditum, Saxifraga oppositifolia, Dryas octopetala, Loiseleuria procumbens, Diapensia lapponica*) with mosses (*Racomitrium lanuginosum*) and lichens *(Flavocetraria nivalis, Alectoria ochroleuca, Cetraria islandica)* tundra
	Dense lichen tundras	4. Dense (> 30 %) lichen vegetation on the tops and slopes of mountains with dwarf shrub-moss complexes	5. Lichen-rich (*Cladonia stellaris, C. arbuscula, Alectoria ochroleuca, Cetraria islandica, Flavocetraria nivalis*) tundra
			6. Dwarf shrub (*Empetrum hermaphroditum, Arctous alpina, Betula nana, Carex bigelowii*) with lichens (*Cladonia stellaris, C. arbuscula, Flavocetraria nivalis, Cetraria islandica*) tundra
			7. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium myrtillus, Betula nana*) with mosses (*Pleurozium schreberi, Ptilidium ciliare, Barbilophozia* spp.*, Pohlia nutans*) and lichens (*Cladonia stellaris, Cladonia arbuscula, Cetraria islandica, Orthocaulis* spp.) tundra
	Dense dwarf shrub, shrub and partly mosses tundras	5. Dense (> 30 %) vegetation on the tops and slopes of mountains with dwarf shrubs and shrubs	8. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium myrtillus, Dryas octopetala, Loiseleuria procumbens*), shrub (*Salix* spp., *Betula nana*), sedge (*Carex bigelowii)* and partly with mosses (*Pleurozium schreberi, Racomitrium lanuginosum*) tundra
			9*. Dwarf shrub (*Betula nana, Vaccinium uliginosum, Vaccinium vitis-idaea*), herb (*Avenella flexuosa, Deschampsia caespitosa, Chamaenerion angustifolium*) fragments of vegetation
			10. Herb (*Carex bigelowii, Juncus trifidus)* with lichens *(Umbilicaria* spp., *Stereocaulon alpinum*) tundra
			11. Dense shrub (*Betula nana, Salix lapponum, S. glauca*), dwarf shrub (*Empetrum hermaphroditum, Vaccinium myrtillus*) and partly with mosses (*Hylocomium splendens, Pleurozium schreberi*) meadow community
	Herbs communites in depressions and meadow azonal tundra's complexes	6. Meadow complexes in valley of streams and on moist gentle slopes and dwarf–small herb groups	12. Small herb, grass (*Anthoxanthum alpinum, Avenella flexuosa, Nardus stricta*) meadow
			13. Willow (*Salix phylicifolia, Salix lapponum, Salix glauca, Betula nana*), dwarf shrub (*Empetrum hermaphroditum, Vaccinium myrtillus*), herb (*Saxifraga stellaris, Oxyria digyna*) with mosses tundra in depressions and meadow complexes with herbs (*Anthoxanthum alpinum, Geranium sylvaticum, Trollius europaeus*)
Forest-tundra	Northeast European subalpine prostrate birch stands (krummholz) and forest-tundras	7. Subalpine prostrate birch woodlands (krummholz) (*Betula pubescens* subsp. *czerepanovii*) partly with *Picea obovata* and *Pinus sylvestris,* with dwarf shrubs and lichens	14. Dwarf shrub (*Empetrum hermaphroditum, Arctostaphylos uva-ursi, Betula nana, Calluna vulgaris*) with lichens (*Flavocetraria nivalis, Cladonia stellaris, C. arbuscula, Cetraria islandica*); Dwarf shrub (*Empetrum hermaphroditum, Vaccinium myrtillus, V. vitis-idaea, Betula nana*) with mosses (*Pleurozium schreberi, Hylocomium splendens*) and lichens (*Cladonia stellaris, Cetraria islandica, Flavocetraria nivalis*) prostrate birch woodlands
		8. Subalpine prostrate birch woodlands (krummholz) (*Betula pubescens* subsp. *czerepanovii*) with *Picea obovata* and *Pinus sylvestris,* with dwarf shrubs and partly with lichens	15*. Dwarf shrub (*Empetrum hermaphroditum, Arctostaphylos uva-ursi*) prostrate birch woodlands
			16*. Dwarf shrub (*Empetrum hermaphroditum, Arctous alpina, Vaccinium myrtillus),* herb *(Carex bigellowii, Juncus trifidus, Avenella flexuosa*) with crustose lichens (*Trapeliopsis granulosa, Cladonia deformis*) prostrate birch woodlands
			17*. Sparse dwarf shrub and mosses (*Pohlia nutans*) prostrate birch woodlands
		9. Subalpine prostrate birch woodlands (krummholz) (*Betula pubescens* subsp. *czerepanovii*) with *Picea obovata* and *Pinus sylvestris,* with dwarf shrubs and herbs	18. Dwarf shrub (*Vaccinium myrtillus*), herb (*Chamaepericlymenum suecicum, Chamaenerion angustifolium, Geranium sylvaticum*) prostrate birch woodlands
Dark coniferous forest	Northeast European open spruce forests	10. Spruce forests (*Picea abies* × *Picea obovata, P. obovata*) with *Pinus sylvestris, Betula pubescens, B. pubescens* subsp. c*zerepanovii,* with dwarf shrubs, mosses and lichens	19. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium myrtillus, Ledum palustre*) with mosses (*Pleurozium schreberi, Hylocomiun splendens)* and lichens (*Cetraria islandica, Cladonia* spp.) spruce forest
		11. Spruce forests (*Picea abies* × *Picea obovata, P. obovata*) with *Pinus sylvestris, Betula pubescens, B. pubescens* subsp. *czerepanovii*, with dwarf shrubs, herbs and mosses	20. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium uliginosum, V. myrtillus, V. vitis-idaea*), herb (*Chamaepericlymenum suecicum, Gymnocarpium dryopteris, Avenella flexousa*) with mosses (*Pleurozium schreberi, Hylocomiun splendens*) spruce forest

Table 1. Continued

Vegetation type	Formation class	Association class	Association group
Dark coniferous forest	Northeast European open spruce forests	12. Spruce forests (*Picea abies* × *Picea obovata, P. obovata*) with *Pinus sylvestris, Betula pubescens, B. pubescens* subsp. *czerepanovii*, with dwarf shrubs, partly with mosses and lichens	21*. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium myrtillus*), with liverworts (*Barbilophozia* spp., *Lophosia* spp., *Orthocaulis* spp.) and partly with lichens (*Cetraria islandica, Cladoni*a spp.) spruce forest
			22*. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium uliginosum, V. myrtillus*), herb (*Avenella flexuosa*) spruce forest
			23*. Dwarf shrubs with crustose lichens (*Trapeliopsis granulosa, Cladonia deformis*) spruce forest
		13. Spruce forests (*Picea abies* × *Picea obovata, P. obovata*) with *Betula pubescens,* with herb and tall-forb	24. Herb (*Chamaepericlymenum suecicum, Gymnocarpium dryopteris, Avenella flexousa),* tall-forb *(Cicerbita alpina, Geranium sylvaticum)* spruce forest
		14. Spruce forests (*Picea obovata),* with herb and sedges, and peat mosses	25. Dwarf shrub (R*ubus chamaemorus, Vacciniun myrtillus, V. uliginosum, Empetrum hermaphroditum*) with peat mosses (*Sphagnum girgensohnii*) spruce forest
			26. Herb and sedges (*Carex nigra, Carex rostrata, Equisetum palustre, Eriophorum vaginatum*) with peat mosses (*Sph. girgensohnii, Sph. russowii, Sph. angustifolium)* spruce forest
Northern light coniferous forest	Pine forests	15. North European open pine forests (*Pinus sylvestris*) with *Betula pubescens,* with dwarf shrubs and lichens	27. Lichens (*Cladonia stellaris, C. arbuscula, C. rangiferina*) open pine forest
			28. Dwarf shrub (*Calluna vulgaris, Arctous alpina, Vaccinium myrtillus, V. vitis-idaea, Empetrum hermaphroditum)* with lichens (*Cladonia stellaris, C. arbuscula, C. rangiferina*) open pine forest
			29*. Dwarf shrub with crustose lichens (*Trapeliopsis granulosa*) open pine forest
		16. North European open pine forests (*Pinus sylvestris*) with *Betula pubescens,* with dwarf shrubs and mosses	30. Dwarf shrub (*Vaccinium vitis-idaea, V. uliginosum, Empetrum hermaphroditum)* with mosses (*Dicranum majus, Pleurozium schreberi, Polytrichum juniperinum*) and lichens (*Cetraria islandica, Cladonia stellaris, C. arbuscula, C. rangiferina*) open pine forest
			31. Dwarf shrub (*Vaccinium myrtillus, V. vitis-idaea, Empetrum hermaphroditum, Ledum palustre, Betula nana*) with mosses (*Dicranum majus, Pleurozium schreberi, Polytrichum juniperinum*) open pine forest
		17. North European open pine forests (*Pinus sylvestris*) with *Betula pubescens*, with dwarf shrubs and partly with mosses	32*. Dwarf shrub (*Vaccinium myrtillus, V. vitis-idaea, V. uliginosum, Calluna vulgaris, Avenella flexuosa*), partly with liverwort mosses (*Barbilophozia* spp., *Orthocaulis* spp.) open pine forest
			33*. Dwarf shrub (*Ledum palustre, Vaccinium vitis-idaea, Calluna vulgaris*) with fragments of moss cover (*Pohlia nutans*) open pine forest
			34*. Dwarf shrub (*Vaccinium myrtillus, Empetrum hermaphroditum, Calluna vulgaris*) with mosses (*Polytrichum* spp.) open pine forest
		18. Northeast European open hygrophilous pine forests (*Pinus sylvestris*) with herbs, sedges and peat mosses	35. Dwarf shrub (*Vaccinium uliginosum, Andromeda polifolia, Chamaedaphne calyculata, Ledum palustre*), herb and sedge (*Carex spp., Eriophorum vaginatum, Molinia coerulea, Baeothyon cespitosum*) with peat mosses *(Sph. magellanicum, Sph. russowii)* open pine forest
			36. Herb *(Molinia coerulea, Baeothyon cespitosum*), sedge (*Carex* spp., *Eriophorum vaginatum*) with peat mosses *(Sph. magellanicum, Sph. russowii)* open pine forest
Northern small-leaved forest	Birch forests	19. Northeast European open birch woodlands (*Betula pubescens* subsp. *czerepanovii*), partly with *Picea obovata, Pinus sylvestris*) with dwarf shrubs and lichens	37. Dwarf shrub (*Ledum palustre, Vaccinium myrtillus*) with lichens (*Cladonia stellaris, C. arbuscula, C. rangiferina, C. cenotea, C. deformis*) open birch woodland
		20. Northeast European open birch woodlands (*Betula pubescens*), partly with *Picea obovata* and *Pinus sylvestris*, with dwarf shrubs, herbs and green mosses	38. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium uliginosum, V. myrtillus, V. vitis-idaea*) with mosses (*Pleurozium schreberi, Hylocomiun splendens*) open birch woodland
			39. Dwarf shrub (*Empetrum hermaphroditum, Vaccinium uliginosum, V. myrtillus, V. vitis-idaea*), herb (*Chamaepericlymenum suecicum, Avenella flexousa*) with mosses (*Pleurozium schreberi, Hylocomiun splendens*) open birch woodland
		21. Northeast European open birch woodlands (*Betula pubescens*), partly with *Picea obovata* and *Pinus sylvestris*, with dwarf shrubs	40*.Dwarf shrub (*Vaccinium myrtillus, Empetrum hermaphroditum*), herb (*Avenella flexuosa, Chamaepericlymenum suecicum*) open birch woodland
			41*. Dwarf shrub with crustose lichens (*Trapeliopsis granulosa*) open birch partly with willow woodland
			42*. Sparse dwarf shrubs with mosses (*Pohlia nutans*) open birch partly with willow woodland
		22. Northeast European birch woodlands (*Betula pubescens*) with *Picea obovata* with dwarf shrubs, with tall herbs partly with mosses	43. Herb (*Chamaenerion angustifolium, Geranium sylvaticum, Equisetum palustre*), dwarf shrub *(V. myrtillus, V. vitis-idaea*), tall herb (*Chamaenerion angustifolium, Geranium sylvatica, Equisetum palustre)* partly with mosses (*Pohlia nutans, Polytrichum spp.*) open birch woodland

Table 1. Continued

Vegetation type	Formation class	Association class	Association group
Northern small-leaved forest	Birch forests	23. Northeast European open hygrophilous birch woodlands (*Betula pubescens*) with *Picea obovata,* with dwarf shrubs, herbs, sedges and mosses	44. Dwarf shrub (*Betula nana, Rubus chamaemorus, Ledum palustre*), herb (*Equisetum palustre*) with peat mosses (*Sphagnum girgensohnii*) open birch woodland
			45*. Dwarf shrub (*Vaccinium myrtillus, Empetrum hermaphroditum*), herb (*Avenella flexuosa, Chamaepericlymenum suecicum*) aspen woodland
Mire	Mires	24. Bogs	46. Herb (*Eriophorum vaginatum, Carex rotundata, C. rariflora*) with peat mosses bog (*Sph. compactum, Sph. fuscum*)
			47. Dwarf shrub (*Ledum palustre, Rubus chamaemorus, Andromeda polifolia*) with peat mosses (*Sph. fuscum, Sph. russowii*)) bog
			48. Dwarf shrub, herb with peat mosses (*Sph. fuscum*) aapa-complex
Not vegetation categories of legend			
		25. Lakes and rivers	49. Lakes and rivers
			50. Polluted waters
			51. Waters for sedimentation
		26. Farmlands	52. Farmlands
		27. Settlements	53. Settlements
		28. Mining dumps and open pits	54. Mining dumps and open pits

The DEM of model area was obtained from topographic maps (1:50,000) by contour lines digitizing, followed by non-linear interpolation in ErdasImagine. The DEM cell size was determined to be 60 m, which corresponds to the scale of topographic maps and multiple to Landsat scenes cell size. Morphometric characteristics of the relief forms were calculated for different sizes of the moving window, thus allowing to take into account the relief structure (Puzachenko et al. 2002). The seven levels of relief structures were determined with linear sizes from 180 to 3300 m. Morphological characteristics of relief were estimated in program complex Environment for visualizing images (ENVI).

For interpolation of vegetation classes, the sample plots were merged with RSD and DEM in GIS. Interpolation of vegetation classes were based on the stepwise discriminant analysis (Kim et al. 1989, Puzachenko 2004, Kozlov et al. 2008). Statistically significant relationships among vegetation classes and "external" variables (RSD, DEM) were used for interpolation of the investigated classes for the entire model area. Furthermore, it allowed us to understand better spatial variation in vegetation classes in relation to various factors (characteristics of the terrain, natural and anthropogenic disturbances, etc.). Assessments of interpolation significance were based on probabilities of class attribution for each grid cells and relative quality of the discriminant analysis. Single cells were removed from grid of interpolated classes and replaced by the neighboring cells. After that, grid of vegetation classes in association group rank was converted to vector format for editing and making a final map.

Vegetation mapping at small scale

The small-scale vegetation maps were obtained on the basis of interpolation of the large-scale vegetation maps. The external variables for interpolating of regional vegetation maps to small-scale maps were MODIS multispectral data MCD43B4 (NASA LP DAAC) for May, June, July, September and October with delivered indices and Global Digital Elevation Model (GTOPO30) with morphometric characteristics (Fig. 1). The seven levels of relief structures were determined with linear sizes ranging from 1.8 km to 35 km.

At this resolution scale, the association groups on large-scale maps were aggregated to association classes for small-scale interpolation. Subsequently, vector-formatted large-scale maps were reproject from UTM to Geographic coordinate system and converted to the grid format according to the small-scale grid of external variables (0.008333 dd or ~460×930 m per pixel). As the result, large-scale map was represented by 24642 points in small-scale grid. Interpolations of the small-scale maps of association classes were based on the stepwise discriminant analysis, as was done for large-scale mapping.

RESULTS AND DISCUSSION

At large scale, we mapped 54 typological units, which characterized 47 association groups of forest and non-forest vegetation types and 7 land cover types of areas without vegetation cover (Table 1). The relative quality of discriminant analysis was 71.5 %. The accuracy was over 75 % for 23 units, varied between 50 % and 74 % for 23 units, between 26 % and 49 % for 6 units, and was equal 25 % for 2 units. Large scale vegetation map (Fig. 3) of the model area in the central part of the Kola Peninsula shows that plain areas, as well as the lower and mid-slope areas (200–350 m a.s.l.) are covered by coniferous forests – spruce forests (*Picea obovata*) with pine (*Pinus sylvestris*), and birch (*Betula pubescens*), dwarf shrubs (*Empetrum hermaphroditum, Vaccinium* spp., *Ledum palustre*), green mosses (*Pleurozium schreberi, Hylocomiun splendens*), and lichens (*Cetraria islandica, Cladonia* spp.). On the plains and mountain valleys (180–250 m a.s.l.) pine forests (*Pinus sylvestris*) with birch (*Betula pubescens*), dwarf shrubs (*Vaccinium vitis-idaea, V. uliginosum, Empetrum hermaphroditum*), green mosses (*Pleurozium schreberi, Polytrichum juniperinum*) and lichens (*Cetraria islandica, Cladonia* spp.) are also common. Low-lands, lake basins, and river valleys are covered by marshes. Higher elevations (350–450 m a.s.l.) are covered by mountain birch forests and open forests (*Betula pubescens* ssp. *czerepanovi*) sometimes mixed with spruce (*Picea obovata*) and pine (*Pinus sylvestris*), dwarf shrubs (*Empetrum hermaphroditum, Betula nana, Calluna vulgaris*), green mosses (*Pleurozium schreberi, Hylocomiun splendens*) and lichens (*Cladonia* spp., *Cetraria islandica, Flavocetraria nivalis*).

On the upper slopes and hilltops (400–800 m a.s.l.), the belt of "warped" birch is replaced by tundra: first, shrub-moss; then, shrub-lichen tundra. Areas of even higher elevation are covered by epilithic lichen communities with small contribution by mosses, growing on the surfaces of stones and rocks substrata, and isolated vascular plants (occasional small fragments of tundra communities) – dwarf shrubs (*Silene acaulis, Empetrum hermaphroditum*) and herbs (*Juncus trifidus, Festuca ovina, Carex bigelowii*). Epilithophytic lichen vegetation (*Rhizocarpon geographicum, Umbilicaria spp., Arctoparmelia centrifuga*) and fruticose lichens (*Flavocetraria nivalis, Alectoria ochroleuca, Cetraria islandica*), occupy stone outcrops and rocks. Bare rocks and nival areas are found on some mountain ranges at altitude over 1200 m a.s.l.

Analyses of spatial distribution of plant communities using field data, RSD, DEM, and statistical methods made it possible to depict their composition and structure with consideration of successional status and anthropogenic impacts. Altitudinal gradient of mountain ranges, anthropogenic disturbance, and the natural dynamics of plant communities at different successional stages are the main factors affecting spatial differentiation of vegetation cover in Khibiny model area. Fires and air pollution emissions from smelter are among the types of anthropogenic impacts that prevail in this region (Chernenkova et al. 2011). The cartographic depiction of the anthropogenic succession units depends largely on the scale, and is least challenging for a large-scale map. Understanding information contained in these units allows to assess the intensity of impact. For example, the presence of Spruce forest with birch dwarf shrub-liverwort mosses (*Barbilophozia* spp., *Orthocaulis* spp., *Lophozia* spp.) and sparse lichens (*Cetraria islandica*, *Cladonia* spp.) in the vicinity of metallurgical plant may indicate a 10–50 fold increase in heavy metal content in soils, compared with natural background metal concentrations. Presence of Spruce forest with birch dwarf shrub-corticulous lichens (*Cladonia deformis*, *Trapeliopsis granulosa*) may indicate even greater contamination level (e.g., 50–100 fold increase compared with background) (Chernenkova & Kuperman 1999, Chernenkova et al. 2011). Analysis of the map showed that approximately 23 % of the study area is covered by anthropogenically-modified vegetation.

The 54 mappable units of large-scale map were aggregated to the 28 units for small-scale mapping. The legend for the small-scale map reveals the composition of vegetation types (Table 1), and is analogous with the thematic classes of vegetation map of Europe (Bohn et al. 2004). The legend also reveals the secondary character of forest vegetation, thus takes into account an anthropogenic disturbance of the current vegetation cover in Europe.

The overall relative quality of the discriminant analysis in this case was 52.1 %. The accuracy was over 75 % for 6 classes, ranged from 50 % to 74 % for 10 classes, and from 25 % to 49 % for 12 classes.

Transition to smaller scale maps requires a certain degree of generalization in the allocation and depiction of classification units, including adjustments in impact factors and vegetation units.

Analysis of mapping units of vegetation and land cover types at small-scale (Fig. 4 a) revealed that approximately 48 % of total area belongs to forests, including pine forests – 25 % (16 % of which are modified types), spruce forests – 11 % (20 % – modified types), and small-leaved forests –12 % (26 % – modified types). Barrens cover 3.3 %, tundra – 16 %, forest-tundra and elfin birch forests – 11 %, and the marshes – 17 %. Surface water covers approximately – 3.5 % of the territory. Farmlands, settlements, tailings and open pits are about 1 % of total area. Secondary successional communities identified for Fennoscandia at a small scale represent more general types of communities with strongly modified structure and composition due to compounded effects of anthropogenic factors (Table 1). Overall, approximately 19 % of the forest cover within this area is covered by such type of derivative forests.

There is an insufficient availability of small-scale maps that are based on satellite data for northwestern Europe. A single map is available for area of northern parts of Finland, Sweden and adjacent territories of Norway and Kola Peninsula (Johansen & Karlsen 2008). Based on the visual comparison, the map developed in the present project is in good agreement with the map developed by the Norwegian researches. Small differences may be related to direct vegetation classifications that underlie each map product.

Substantial differences were revealed when comparing maps developed in the present study with the previously developed map of natural vegetation of Europe (Bohn et al. 2004) (Fig. 4 a, b). A clear disparity is manifested not only in the more precise contours of all selected groups, but also in the distribution of pine and spruce forests in Karelia, Finland and Sweden. Such differences may be related to different classification approaches in the national classification systems used in different countries. Based on the dynamic classification, originally developed by Cajander (1926), spruce forests represent potentially climax communities in the considerable part of Finland and Sweden. Our present map shows widely spread pine forests derived from spruce forests in Fennoscandia.

CONCLUSIONS

The present studies developed the methodology and methods for cartographic modeling of vegetation at different spatial scales. Results of the study allowed to start a comparative analysis of the boreal forest ecosystem diversity at the regional level in natural regions of Eastern European part of Russia. Empirical data on the composition and structure of forest communities of Northern Kola Peninsula allowed us to assess coenotic diversity, identify trends in diversity changes, and evaluate the role of different factors in differentiation of forest cover, all in relation with both natural characteristics of the territory, as well as with human impact.

In our study a method for constructing large- and small-scale maps of vegetation cover was affirmed. This method is based on analysis of the characteristics of vegetation obtained by ground surveys, remote sensing data, and morphometric parameters of the relief. This investigation also revealed spatially explicit patterns in structure of forest diversity in the model regions. An assessment of coenotic diversity and the development of maps for different regions were accomplished using consistent approach to vegetation classification. The proposed methodology for describing and mapping vegetation types at different spatial scales has proven to be effective because it is based on uniform hierarchical classification. The integrated hierarchical approach was successful in mapping vegetation in northern Alaska (Walker 1999), Italian landscapes (Blasi et al. 2000, 2011), Canada (Saucier et al. 2013), natural vegetation of Europe (Bohn et al. 2004). In addition to the typological diversity of forests, map developed in the present project reveals ecological specificity and the dynamics of forest communities in relation to their disturbance and successional stage.

Regional maps developed in this investigation can be used for further mapping and synthesis of Eastern European regional components of the country with the aim of developing small-scale maps of the present-day diversity of boreal and hemi-boreal forests. This map depicts the most common forest types (mountain birch forests and open forests, spruce and pine forests), as well as their derivative modifications, including characterization of the dominant species of ground cover.

Results of the analyses of the spatial diversity of Eastern European boreal forests were harmonized with the typological units of vegetation classification and phytogeographical subdivisions of the boreal forest biome within the framework of international project developing circum-boreal vegetation maps (Circum-Boreal Vegetation Mapping, CBVM).

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