ISSN 1995-4255, Contemporary Problems of Ecology, 2016, Vol. 9, No. 7, pp. 820–833. © Pleiades Publishing, Ltd., 2016.
Original Russian Text © T.V. Chernen'kova, O.V. Morozova, M.Yu. Puzachenko, S.Yu. Popov, N.G. Belyaeva, 2015, published in Lesovedenie, 2015, No. 5, pp. 323–338.

Composition and Structure of Spruce Forests of the Southwestern Part of Moscow Region

T. V. Chernen'kova[a], *, O. V. Morozova[b], M. Yu. Puzachenko[b], S. Yu. Popov[a, c], and N. G. Belyaeva[a]
[a]*Center of Forest Ecology and Productivity, Russian Academy of Sciences, Moscow, 117997 Russia*
[b]*Institute of Geography, Russian Academy of Sciences, Moscow, 119017 Russia*
[c]*Faculty of Biology, Moscow State University, 119991 Russia*
**e-mail: chernenkova50@mail.ru*
Received February 10, 2015

Abstract—Coenotic features of boreal, nemoral, and subnemoral spruce stands of the southwestern part of Moscow region have been studied using ground-based and remote sensing data. Despite significant modifications of the vegetation cover in the region due to human impacts, the species composition of the spruce communities still retains typical zonal features of the regional vegetation and is associated with certain landscape elements. Cartographic modeling has allowed us to identify the spatial distribution patterns for various spruce forest types and produce a series of geobotanical maps (scale 1 : 100000). The ecophytocoenotic approach was used for classifying the forest vegetation. An analysis of the spatial differentiation of the forest cover—using spruce forests with different species composition as an example—has confirmed the ecotonal structure of the study area demonstrated through a characteristic latitudinal distribution of geoecolological spectra of species.

Keywords: Spruce forest, southwest of Moscow region, coenotic diversity, mapping, classification, remote sensing

DOI: 10.1134/S1995425516070039

An assessment of the current forest-cover condition is important both for slightly disturbed and well-developed areas. Forest ecosystems of Moscow region have been impacted by deep anthropogenic transformations since the 16th century. Zonal broad-leaved–spruce forests had been replaced by secondary small-leaved stands, the biodiversity was affected, and the resistance of ecosystems against adverse exterior impacts has been reduced. The following factors are most typical for the region in the recent time: mass outbursts of the European spruce bark beetle in spruce stands, intense urban development, construction of cottage settlements, and recreation. As a result, the active economic activity, including silvicultural practices that are very common in this region, has considerably altered the ecocoenotic habitat area of zonal spruce and broad-leaved–spruce forest communities.

Processes developing in forest stands of natural and artificial origin are affected by the climate, because the climate is warming in the European part of Russia, especially since the end of the 1980s (Gruza and Ran'kova, 2001). According to Maslov (2012), the climate change has determined the increase of the share of nemoral shrub and tree species (common hazel and maple) and nemoral species in the lower layers of wood sorrel and nemoral–wood sorrel spruce forests. There is an opinion that boreal wood sorrel spruce forests represent a recovery stage of nemoral communities (*Lesa Severnogo*..., 1993; *Vostochnoevropeiiskie lesa*..., 2004).

The plant cover of Moscow region is researched well enough (Alekhin, 1947; Lyubimova, 1957; Kurnaev, 1968; *Lesa Vostochnogo*..., 1979; *Biogeotsenologicheskie osnovy*..., 1980; Il'inskaya et al., 1982; *Lesa Zapadnogo*..., 1982; Polyakova et al., 1983; *Lesa Yuzhnogo*..., 1985; Rysin et al., 2000; Nosova et al., 2009; Maslov, 2012). A vegetation cover map has been produced for Moscow region (1 : 200000, Ed. G.N. Ogureeva, 1966) based on forest taxation data and ground-based researches. Currently, the introduction of digital modeling and quantitative analysis techniques for processing field, remote sensing, and cartographic data allows one to reflect with great detail and accuracy the current condition of the forest cover and its individual parameters (Asner, 1998; Ustin et al., 2004; Puzachenko et al., 2006, 2014; McRober, 2006; Reese et al., 2008; Tomppo et al., 2008; Kryshen' and Litinskii, 2013; Chernen'kova et al., 2013). However, it is unfortunately impossible to use the data collected earlier for mapping purposes due to the absence of primary materials—geobotanical releves with coordinates of sample plots.

The complicated history of the forest-cover formation in Moscow region and the current condition of the

Moscow green belt leave many questions with regards to the assessment of forest condition and dynamics and the possibility of forecasting the ecological and recreational potential of forest stands of natural and artificial origin. The Norway spruce (*Picea abies* (L.) Karst.) is an indigenous species for Moscow region. Currently spruce forests occupy 23.5% of the total forest area in the region (*Lesnoi plan…*, 2010). According to our estimations, spruce forests with insignificant additions of pine, birch, aspen, and oak are the most common formation in the southwestern part of Moscow region and occupy some 22% of the total forest area.

The purpose of this study was to assess and analyze the composition and structure of spruce forests of the southwestern part of Moscow region on the basis of ground-based and remote sensing data using coenotic diversity classification and mapping techniques.

MATERIALS AND METHODS

Moscow region is located in the central part of the East European Plain. The relief is directly related to the geological structure, surface relief of primary rocks, and neotectonic movements (Spiridonov, 1971). The modern relief of the territory is defined by glacial and fluvioglacial relief forms formed in various glacial epochs and transformed by erosion–denudation processes to various extents (Kazakova, 1957). The border of the Moscow glaciation crosses the region from southwest to northeast (Smolensk–Moscow Upland); glacial–erosion forms with moraine ridges are common north of it, while erosion relief forms are common south of it. In the southwestern part of Moscow region, certain features of genesis and geological–morphological and structural characteristics allowed us to distinguish two large physiographic provinces (Annenskaya et al., 2001) roughly dividing the study territory into two halves: the Smolensk province in the western part and the Moskva–Oka province in the eastern part of the study area.

The primary base of the Smolensk physiographic province consists mostly of dolomitic–calcareous dense carbon rocks. Currently, this is the most elevated part of Moscow region (150–300 m a.s.l.). Moraine plains occupy a considerable part of it. The Moskva–Oka physiographic province is located in the interfluve of the Moskva and Oka rivers. The Prequaternary base of this area, consisting of carbon limestone, Jurassic clays, and Cretaceous sands, has an uneven erosion–residual relief with large elevation differences, which often reach 80–100 m. The soils are mostly sod–mesopodzolic, gleied in depressions, heavy–loamy, or clayey by texture (Gvozdetskii, 1963; Rysin, 2000).

On the schematic map of climatic regions and districts, Moscow region belongs to the East European district of the Atlantic–Continental region (Rysin, 2000). The continentality of the Moscow climate is 42% (Galakhov, 1947), while the continentality of the southwestern part of Moscow region is lower. Based on data provided by the Federal Service for Hydrometeorology and Environmental Monitoring (Rosgidromet), the gradient of average annual temperature and precipitation parameters in Moscow region, west-to-east, is 1°C and 100 mm respectively.

According to the existing geobotanical mapping schemes, borders of the south–taiga, broad-leaved–spruce, and broad-leaved subzones go through Moscow region, in particular, through its southwestern part (Alekhin, 1947; Smirnov, 1958; Petrov and Kuzenkova, 1968; Gribova et al., 1980; Morozova and Tikhonova, 2012). Many researches link the change of zones with changing geomorphological conditions due to the location of the area towards the Moscow glaciation border: slightly drained loamy plateaus on the west give place to well-drained eroded interfluves towards the east.

The study area is located in the southwestern part of Moscow region; it is a catchment basin in the upper stream of the largest rivers—Moskva and Nara. The area borders the Moscow Upland on the north and the Smolensk Upland on the west. The total area of the study territory is 4280 km^2. Forests cover 49% of the territory (Chernen’kova et al., 2012). Currently, no primary forests[1] remain in Moscow region. Conditionally primary forests—i.e., forests with the species composition of the tree layer and lower layers close to the primary forests, but considerably different from those by the age structure of the forest stands—are illustrative of zonal vegetation types and their association with certain landscapes. Both broad-leaved–coniferous and spruce subnemoral and boreal forests are typical for the study area, as well as broad-leaved forests whose distribution depends on the landscape structure of the territory (Ogureeva and Buldakova, 2006). Complex spruce forests and secondary birch forests predominate on watershed areas. Broad-leaved — oak and lime forests, genetically linked with complex spruce forests, grow on high plains, in richer forest growth conditions, and fragmentarily on hill and river terrace slopes. The widespread occurrence of European nemoral plant species—coedificators, dominants, or species distinctive for mixed forests—is distinctive. Almost everywhere, under the spruce cover, species typical for spruce forests are mixed with nemoral herbs. Boreal types of spruce forests are rare. Pine forests growing on water dividing ranges are mostly of artificial origin. In the valleys of the Moskva, Protva, Nara, and Isma rivers and their confluents, pine and complex spruce (with hazel and broad-leaved species) forests are growing.

[1] By primary forests we mean forests formed by tree species typical for the zone and developing without considerable anthropogenic and/or catastrophic natural impacts for periods of time comparable with the maximal biological longevity of these species or exceeding it (Sukachev, 1972).

In order to assess the current condition of the plant cover, an approach integrating ground-based and remote sensing information has been used. In this study we analyze spruce forests where the share of other species does not exceed 25% of the forest stand. Geobotanical releves (n = 193) have been produced for plant communities homogenous by their floristic composition, the composition of dominants in each layer, physiognomy (aspect and structure of communities), and habitat conditions on sample areas 10 × 10 and 20 × 20 m using GPS positioning. The distance between the sample areas was at least 200 m. Names had been assigned to syntaxonomic units taking into consideration the predominant parcel occupying at least 70% of the community area. The species saturation of plants in the ground layers—calculated as the average number of species per unit area—has been used to assess the species diversity. To produce ecocoenotic spectra, the system of ecocoenotic groups (ECG) by Smirnov et al. (2006) has been used.

Vascular plant names are provided in accordance with Cherepanov (1995) and moss names in accordance with Ignatov and Ignatova (2003, 2004). Moss species have been identified by E.A. Ignatova.

The FORDIV database (in Access database management system) (Certificate of State Registration no. 2014620979) was used to store and analyze materials of field geobotanical releves. Ordination of the communities has been performed using a multidimensional scaling method in the PC-ORD 5.0 package (McCune and Mefford, 2006) for transformed (square root) data.

The successful verification of remote sensing data (RSD) requires a special approach to the selection of an algorithm for the classification and confidence estimation of the distinction of classes. It is necessary to note that the use of RSD, on the one hand, expands the spectrum of possibilities to reflect the spatial irregularity of the plant cover, but on the other hand it imposes additional requirements to the identified classification units.

The need to adapt existing classification systems in accordance with specific conditions and user requirements is noted in the study by Kryshen' (2012). One such requirements—essential to reflect the plant community diversity when using satellite data—is the unambiguousness of their classification on the basis of the vegetation features.

An ecophytocoenotic approach was used for the classification of the forest vegetation. The identified units are consistent with categories of main classification types used by the domestic geobotanical school: type of vegetation—class of formations—group of formations—formation—class of associations—group of associations—association. In our case, the composition of a number of categories—by features and semantics of the classifiable subjects—has been specified. In particular, for better RSD distinction, the crown area and ratio of crowns of various tree species are being taken into account in the identification of the *class of formations*:

Dark Coniferous	—dark coniferous species (spruce) constitute at least 75% of the total crown area in the forest canopy.
Light Coniferous	—light coniferous species (pine) constitute at least 75% of the total crown area in the forest canopy.
Small-Leaved	—crowns of small-leaved tree species (birch, aspen, grey alder, and black alder) constitute at least 75% of the total crown area in the forest canopy.
Broad-Leaved	—crowns of broad-leaved tree species (oak, lime, maple, and elm) constitute at least 75% of the total crown area in the forest canopy.
Broad-Leaved–Coniferous	—at least 50–75% of broad-leaved species and 25–50% of coniferous species are present in the forest canopy.

At the formation level, the share of the edificatory species in the tree layer was also assessed by the crown density. Simple criteria have been used to assess shares of various species. Below are examples of names reflecting different shares of two species in the forest canopy of upper layers: *spruce forest* (spruce–100%, birch–0); *spruce forest with birch* (spruce–75%, birch–less than 25%); *birch–spruce forest* (spruce–60%, birch–40%); *spruce–birch forest* (spruce–40%, birch–60%); *birch forest with spruce* (spruce–less than 25%, birch–75%); and *birch forest* (spruce–0, birch–100%).

The identification of syntaxa in the *class of associations* rank was performed on the basis of the main predominant group of collective dominants[2] in the composition of the lower layer of ecologically similar communities (e.g. green moss spruce forests, herb spruce forests, and sphagnum spruce forests). *Groups of associations* were identified on the basis of the main groups of collective dominants in subordinate layers (e.g., shrub–green moss spruce forests, green moss–lichen spruce forests, etc.). For the more accurate division of a selection of releves into groups, their ordination in abstract variation axes and cluster analysis have been performed.

The group of association was the basic cartographic unit. The identified groups of associations have been used as a grouping variable or teaching selection during the multidimensional analysis of multispectral photo-

[2] For the purposes of this study, by collective dominants we, following Zaugol'nova and Morozova (2006), mean a group of species similar in their life form and/or belonging to the same systematic group.)

graphs. Information from satellites of the Landsat series (Landsat 5, 7, and 8) having a large number of spectral channels, high spatial resolution (30 m), and long period of photographing, was used as remote sensing data. Seven cloudless sceneries taken in the period of March–October in the last 10 years have been selected for the study territory. For more complete use of the information captured in the spectral channels, indexes have been calculated (NDVI, VI, NDWI, etc.) as differences and normalized differences between the spectral photography channels (Jackson and Huete, 1991). Information on the relief of the territory was obtained through digitization of hypsographic curves and height points on topographic maps with the scale 1 : 50000. A digital model with increments consistent with the RSD resolution has been produced on this basis. Relief parameters such as incline, curve, illumination intensity, etc., have been calculated on the basis of digital modeling of vegetation (DMV).

During the identification of cartographic units, the area for identifying typological units corresponded to the scale of cartographic presentation. The transition from the classification to a map legend is an element of scientific generalization, because there is no full analogy between the classification schemes and legends of geobotanical maps (Gribova and Isachenko, 1972). The use of quantitative criteria in the forest vegetation classification and unification of syntaxa contents have ensured certain correspondence between the typological and cartographic units.

A step-by-step discriminant analysis was used for the analysis of spatial data; it made it possible to define variables and divide the identified types of plant communities to the maximum extent (Puzachenko, 2004). Land categories missing in ground-based releves (fields, settlements, and water bodies) have been identified additionally on the basis of dichotomized clustering of the RSD according to the Euclidean metric. Multidimensional statistics techniques included into STATISTICA, SPSS, and Fracdim software packages have been used for data processing (parametric and nonparametric correlation analyses, regression analysis, variance analysis, discriminant analysis, cluster analysis, and multidimensional scaling).

At the final stage, a map of the vegetation cover (scale 1 : 100000) and a series of estimative (thematic) maps showing its individual parameters have been produced on the basis of the transformation of the study-class interpolation results into a vector format (ERDAS Imagine), including the filtration of items one or several pixels in size and legend design (ArcMap).

RESULTS AND DISCUSSION

The assessment of the forest-cover condition in the southwestern part of Moscow region, using ground-based and remote sensing data has made it possible to identify the composition and distribution areas of forests with various formational compositions. While the general forest coverage of the territory was 49%, the share of forests with predomination of spruce was 22%, that with the predomination of pine was 11%, with the predomination of broad-leaved species was some 2%, and the share of broad-leaved–spruce forests was 18% of the total forest area. Secondary spruce–small-leaved forests occupied 12%, while communities with the predomination of small-leaved species was 34%. The share of planted forests in the total forest area is significant. According to the forest survey of 2000, planted stands, mainly spruce, occupied almost one-third (27%) of the total area of a large forest massif in Naro-Fominsk forest district. It is characteristic that in the eastern sector (Moskva–Oka province), the area of spruce forests is twice as much as in the western sector (Smolensk province)—which confirms the opinion of Kuzenkova (1969) that the role of spruce increases on the border dividing the subzones: the coniferous–broad-leaved one and the broad-leaved one.

The forest-cover diversity assessment performed at a greater level of detail allowed one to analyze the distribution of 45 groups of associations of conditionally primary and secondary forests having various formational compositions. The relative quality of the discriminant analysis was 70%. The best relative quality of analysis was achieved using the residual dispersion method with *F*–inclusion/exclusion of 1 and 0.5 respectively.

Based on the field releves, a classification of forest communities in the study area has been performed. Below is a classification of dark coniferous forests with the predomination of spruce that are the subject of this study. These forests demonstrate maximal coenotic diversity and the full spectrum of communities in the transition from the boreal type to the nemoral one. Dominant species and species with high constancy class are provided in brackets for the identified typological units in the rank of groups of associations.

CLASSIFICATION OF SPRUCE FORESTS FOR THE SOUTHWESTERN PART OF MOSCOW OBLAST

SPRUCE FORESTS (*Picea abies*)

Boreal

1. Green moss spruce forests (*Picea abies*) with the addition of birch (*Betula pubescens* s. l., *B. pendula*).

1.1. Small herb (*Oxalis acetosela*, *Rubus saxatilis*, *Gymnocarpium dryopteris*, *Maianthemum bifolium*, *Orthilia secunda*)–green moss (*Pleurozium schreberi*, *Hylocomium splendens*, *Rhytidiadelphus triquetrus*) spruce forests.

2. Herb spruce forests (*Picea abies*) with the addition of pine (*Pinus sylvestris*), birch (*Betula pubescens* s. l., *B. pendula*), and rowan (*Sorbus aucuparia*).

2.1. Shrub–small herb (*Vaccinium myrtillus*, *Oxalis acetosela*, *Maianthemum bifolium*, *Gymnocarpium*

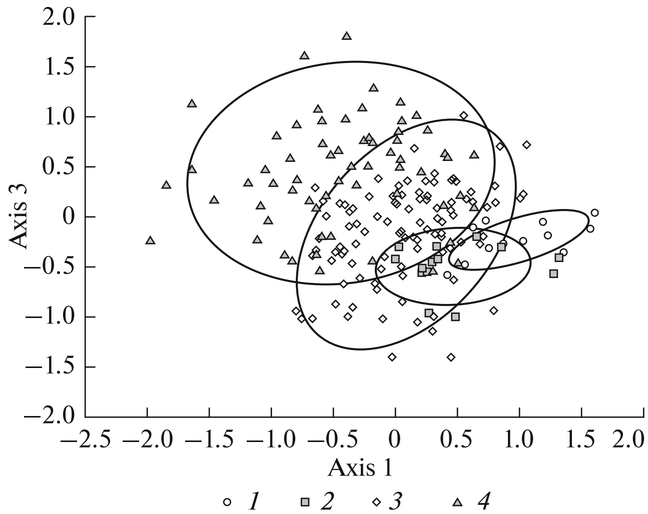

Fig. 1. Distribution of releves of spruce communities of the southwestern part of Moscow region on NMS ordination axes. Ellipses of 95% confidence regions for each group are shown. (*1*) Small-herb–sphagnum spruce forests; (*2*) small herb spruce forests; (*3*) small herb–broad herb spruce forests; (*4*) broad-herb spruce forests.

dryopteris, *Athyrium filix-femina*, *Pleurozium schreberi*, *Rhytidiadelphus triquetrus*, *Hylocomium splendens*) spruce forests.

2.2. Small herb (*Oxalis acetosela*, *Maianthemum bifolium*, *Rubus saxatilis*, *Gymnocarpium dryopteris*, *Athyrium filix-femina*, *Pleurozium schreberi*, *Rhytidiadelphus triquetrus*, *Hylocomium splendens*) spruce forests.

3. Sphagnum spruce forests (*Picea abies*) with the addition of pine and birch (*Pinus sylvestris* and *Betula pubescens* s. l., *B. pendula*).

3.1. Herb–polytric–sphagnum (*Carex globularis*, *C. lasiocarpa*, *C. cinerea*, *Eriophorum vaginatum*, *Polytrichum commune*, *Sphagnum squarrosum*, *S. girgensohnii*) spruce forests.

Subnemoral

4. Herb spruce forests (*Picea abies*) with addition of birch, lime, and oak (*Betula pubescens* s. l., *B. pendula*, *Tilia cordata*, and *Quercus robur*) and common hazel and rowan (*Corylus avellana* and *Sorbus aucuparia*).

4.1. Small herb–broad herb (*Oxalis acetosela*, *Gymnocarpium dryopteris*, *Rubus saxatilis*, *Maianthemum bifolium*, *Galeobdolon luteum*, *Convallaria majalis*, *Aegopodum podagraria*, *Eurhynchium angustirete*, *Rhytidiadelphus triquetrus*, *Hylocomium splendens*, *Atrichum undulatum*, *Plagiochilla porelloides*, *Pleurozium schreberi*) spruce forests.

4.2. Small herb–broad herb spruce forests with the addition of pine.

4.3. Small herb–broad herb spruce forests with the addition of birch and aspen.

4.4. Small herb–broad herb spruce forests with the addition of lime and oak.

Nemoral

5. Herb spruce forests (*Picea abies*) with the addition of pine, birch, lime, and oak (*Pinus sylvestris, Betula pubescens* s. l., *B. pendula*, *Tilia cordata*, and *Quercus robur*) and common hazel with fly honeysuckle and rowan (*Corylus avellana*, *Lonicera xylosteum*, and *Sorbus aucuparia*).

5.1. Broad herb (*Carex pilosa*, *Galeobdolon luteum*, *Ajuga reptans*, *Asarum europaeum*, *Pulmonaria obscura*, *Athyrium filix-femina*, *Ranunculus cassubicus*, *Aegopodium podagraria*, *Oxalis acetosella*, *Cirriphyllum piliferum*, *Atrichum undulatum*, *Rhytidiadelphus subpinnatus*) spruce forests.

5.2. Broad herb spruce forests with the addition of pine.

5.3. Broad herb spruce forests with the addition of lime and oak.

5.4. Moist herb (*Filipendula ulmaria*, *Athyrium filix-femina*, *Geum rivale*, *Lysimachia vulgaris*, *Lysimachia nummularia, Equisetum pratense, Aegopodium podagraria*, *Eurhynchium angustirete*, *Sciuro-hypnum curtum*, *Climacium dendroides*, *Cirriphyllum piliferum*) spruce forests with the addition of aspen and birch.

Ten cartographic units have been identified in forests with the predomination of spruce—i.e., the number of units interpreted on the basis of the remote sensing data was slightly less because some identified typological units (moist herb and sphagnum types) have been excluded from further analysis due to their rare occurrence and law quality of distinction. For the purposes of this study, the composition and structure of spruce forests had been researched on the basis of generalized selections, without taking their species composition into account. Ultimately, the releves of spruce communities have been divided into 4 groups: small herb–green moss spruce forests were represented by 12 releves, small herb spruce forests by 15 releves, small herb–broad herb spruce forests by 98 plots, and broad herb spruce forests by 68 plots; 11 releves in the last group pertained to spruce forests with the addition of oak and lime in the tree layer.

The position of ground layers of spruce forests in the rank of groups of associations on Nonmetric Multidimensional Scaling (NMS) ordination axes has demonstrated a pretty clear distinction of the identified groups of spruce forest associations (Fig. 1). The analysis has been performed for ground layers only, without considering the tree stand and shrub layer; square root of the coverage percentage was used for the assessment of species. The most lower right position on the diagram is occupied by small grass–green moss and small herb spruce forests. So-called 'complex' nemoral types of spruce forest, including those with the addition of oak and lime, are shown in the upper left part—these communities are transitional towards broad-leaved—spruce types. Communities classified as subnemoral small herb—broad herb spruce forests are shown in the middle; nemoral and boreal types of subordinate layers, including the moss cover, are equally presented in their composition.

The identified spruce forest groups differ by their structure. **Small herb—green moss** spruce forests have a forest stand consisting of two layers (at heights of 28 and 16 m); the 1st layer has an average crown density of 0.45, while the 2nd has one of 0.13. The forest consists of spruce with the insignificant addition of birch. The average age of spruce trees in the 1st layer is 90 years. The birch constitutes some 10% of the total canopy of the 1st layer in the forest stand (Table 1). The spruce is presented in the undergrowth by irregular groups (crown density is 0.1). The underwood layer is well-defined (projective cover is some 25%); common hazel, buckthorn, fly honeysuckle, and viburnum shrubs are presented with high constancy there. *Oxalis acetosella* (wood sorrel) predominates in the herb—shrub layer (projective cover is some 50%). Other boreal small herb species (*Rubus saxatilis*, *Gymnocarpium dryopteris*, *Pyrola rotundifolia*, and *Orthilia secunda*) are constant (constancy class is over IV) with the abundance of 3—10%, as well as nemoral herb species (*Convallaria majalis* and *Mycelis muralis*) with abundance less than 5%. The presence of young spruce individuals in the ground cover (11%) is characteristic. The general density of the moss cover is high enough—70%. Green mosses (*Pleurozium schreberi*, *Hylocomium splendens*, and *Rhytidiadelphus triquetrus*) clearly predominate in the moss layer. The species richness of the ground layers is relatively low—only 124 species. The average species saturation is 39 species; out of those, the number of species in the herb-shrub layer is 34.8 ± 6.2 and 4.6 ± 2.6 species in the moss layer.

The distribution of species in small herb—green moss spruce forests by ecocoenotic groups demonstrates the predominance of boreal accompanying plants in the ground layers (71%), while nemoral species constitute 17% (Fig. 2). The group of small herb—green moss spruce forests is represented by a sole association of wood sorrel—green moss spruce forests, considered by most authors a conditionally primary forest type and growing on slope parts of moraine residual hills with mesosod—mesopodzolic sandy—loamy soils with the groundwater level at the depth of 2—4 m (Rysin and Savel'eva, 2007). Amid the clear parceling of small herb—green moss spruce forests, areas with predominance of lady fern can be defined; however, the size of such areas (not exceeding 20%), located normally in windows in the forest canopy, did not allow one to distinguish the association of fern—wood sorrel—green moss spruce forests like was done in other works (Il'inskaya et al., 1982; *Karta rastitel'nosti*..., 1996).

Table 1. Abundance of constant species in main layers of small herb—green moss spruce forest types

Layer	Species	Projective cover, %
Tree	*Picea abies*	41.3
	Betula pendula	9.5
	Betula pubescens	2.3
Undergrowth	*Betula pendula*	1.3
	Picea abies	10.4
	Populus tremula	1.3
Underwood	*Corylus avellana*	6.0
	Frangula alnus	4.0
	Lonicera xylosteum	2.25
	Viburnum opulus	4.2
Herb—shrub	*Oxalis acetosella*	46.8
	Rubus saxatilis	9.6
	Athyrium filix-femina	6.8
	Dryopteris carthusiana	5.9
	Pyrola rotundifolia	5.3
	Gymnocarpium dryopteris	5.0
	Picea abies	5.0
	Deschampsia cespitosa	5.0
	Convallaria majalis	4.9
	Orthilia secunda	4.4
	Fragaria vesca	3.8
	Maianthemum bifolium	3.3
	Sorbus aucuparia	3.1
	Trientalis europaea	2.3
	Quercus robur	2.2
	Mycelis muralis	2.1
	Ajuga reptans	2.1
Moss	*Pleurozium schreberi*	19.4
	Rhytidiadelphus triquetrus	9.7
	Hylocomium splendens	5.0
	Sciuro-hypnum curtum	1.5

Based on the digital modeling of relief (DMR), spruce communities belonging to the small herb—green moss type (relative quality of discriminant analysis—58%) occupy a relatively small area. Their share in the total area of spruce forests is 12%. Analysis of distribution of small herb—green moss spruce forests shows their predomination in the western part of the territory corresponding to the broad-leaved—coniferous forest zone, as opposed to the eastern part corresponding to the broad-leaved forest zone (Fig. 3a). According to the Landscapes of Moscow region map (Annenskaya et al., 1997) most of those are associated with landscapes of moraine—fluvioglacial plains (Fig. 4a). Such landscapes have relatively poor drainage

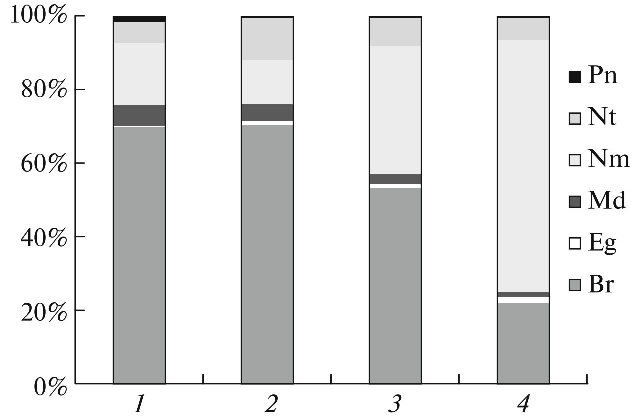

Fig. 2. Ecocoenotic spectrum of species in the herb–shrub and moss layers of the four groups of spruce forest associations assessed by the projective cover of the ecocoenotic groups: (Br) Boreal, (Pn) Pine Forest, (Md) Meadow–Steppe, (Nm) Nemoral, (Nt) Nitrophilous, and (Eg) Edge. Groups of associations: (*1*) small herb–green moss spruce forests, (*2*) small herb spruce forests, (*3*) small herb–broad herb spruce forests, and (*4*) broad herb spruce forests.

and flattened relief; they had been formed due to the overlapping of flat and undulating moraine plains with fluvioglacial sediments (Annenskaya et al., 1997).

Variance analysis of the distribution of the identified groups of spruce forest associations and relief characteristics has shown that the examined groups are statistically significantly determined by relief features. Small herb–green moss spruce forests occupy most lowered, plain, and low-inclined positions (Table 2).

Specific features of **small herb spruce forests** include an increase of the pine share in the tree layer, while in the ground layer they include an increase in the share of boreal mesophyllous small herbs, while the wood sorrel still remains the absolute dominant (55%), and a reduction of the moss share (some 30%). The assortment of other species present with high constancy in communities of this group is not different from that in small herb–green moss spruce forests (Table 3). The floristic similarity coefficient (Sørensen index) calculated for the small herb–green moss and small herb spruce forest groups was $Cs = 0.7$, which means that these belong to the same phytocoenotic complex. The species richness in the small herb group of spruce forests is higher in comparison with the small herb–green moss group and includes 141 species. The average species saturation is 37; out of those, the number of species in the herb–shrub layer is 32.1 ± 7.2 and the number of species in the moss layer is relatively low—4.9 ± 1.5.

The distribution of species in small herb spruce forests by ecocoenotic groups still demonstrates the predominance of boreal species in the ground layer (72%); the share of nemoral species is 12%; and the share of nitrophilous plants is almost twice as large as in the small herb–green moss group—11%, which indicates more favorable soil nutrition conditions (Fig. 2).

The group of small herb spruce forests includes **wood sorrel, wood sorrel–blueberry**, and **fern–wood sorrel spruce forests**, most of which are represented by 80-year-old planted stands. It is necessary to note that mature phytocoenoses of artificial origin formed to the present time are close to conditionally primary types of forest communities by their composition and structure (Nosova et al., 2009; Pesterova et al., 2012). The reduction of the edificatory function of the spruce canopy in 80- to 100-year-old monodominant communities is caused by the development of windfall windows in the process of forest-stand decay. As a result, the regime of permanent light suppression and increased dampness and precipitation suspension by the crowns are being lowered, while evapotranspiration increases. Lime, common hazel, and ferns appear in the windows; an invasive introduction and further expansion of nemoral broad herb species (*Paris quadrifolia*, *Mycelis muralis*, *Luzula pilosa*, *Circaea alpina*, *Actaea spicata*, and *Galium odoratum*) take place. The similarity of the species composition in spruce forests of artificial origin and in natural subnemoral broad-leaved–spruce communities ($Cs = 77\%$) (Pesterova et al., 2012) allows one to consider some small herb (wood sorrel) spruce forests their successional stage. Authors of the monograph *Forests of the Northern Part of Moscow region* (*Lesa Severnogo*..., 1993) also consider wood sorrel spruce forests growing on the Klin–Dmitrov ridge a stage of broad-leaved–spruce forests.

According to our assessment, the share of small herb spruce forests in the total spruce forest area on the study territory is also not too big—12%. The relative quality of discriminant analysis for this spruce forest group is considerably higher—93%. According to Rysin and Savel'eva (2007), communities included by the authors of this study into the group of associations of small herb boreal spruce forests are normally present on slightly inclined slopes of feebly marked hilly surfaces on fluvioglacial plains. Rysin and Savel'eva (2007) also note that spruce forests with addition of blueberry prefer better drained habitats in upper parts of moraine residual hills with mesopodzolic light-loamy soils and groundwater level deeper than 4 m. Analysis of the small herb spruce forests distribution shows their higher occurrence in the western sector of the study territory and lower occurrence on landscapes of moraine plains (Figs. 3b and 4b). Based on the variation analysis, communities classified as small herb spruce forests occupy most lowered and concave positions (Table 2).

In the next group—**small herb–broad herb spruce forests** with the average age of 100 years—the projective cover of the shrub layer is larger (some 50%). An increase in the common hazel abundance (25% on the average), which in some instances forms a canopy with

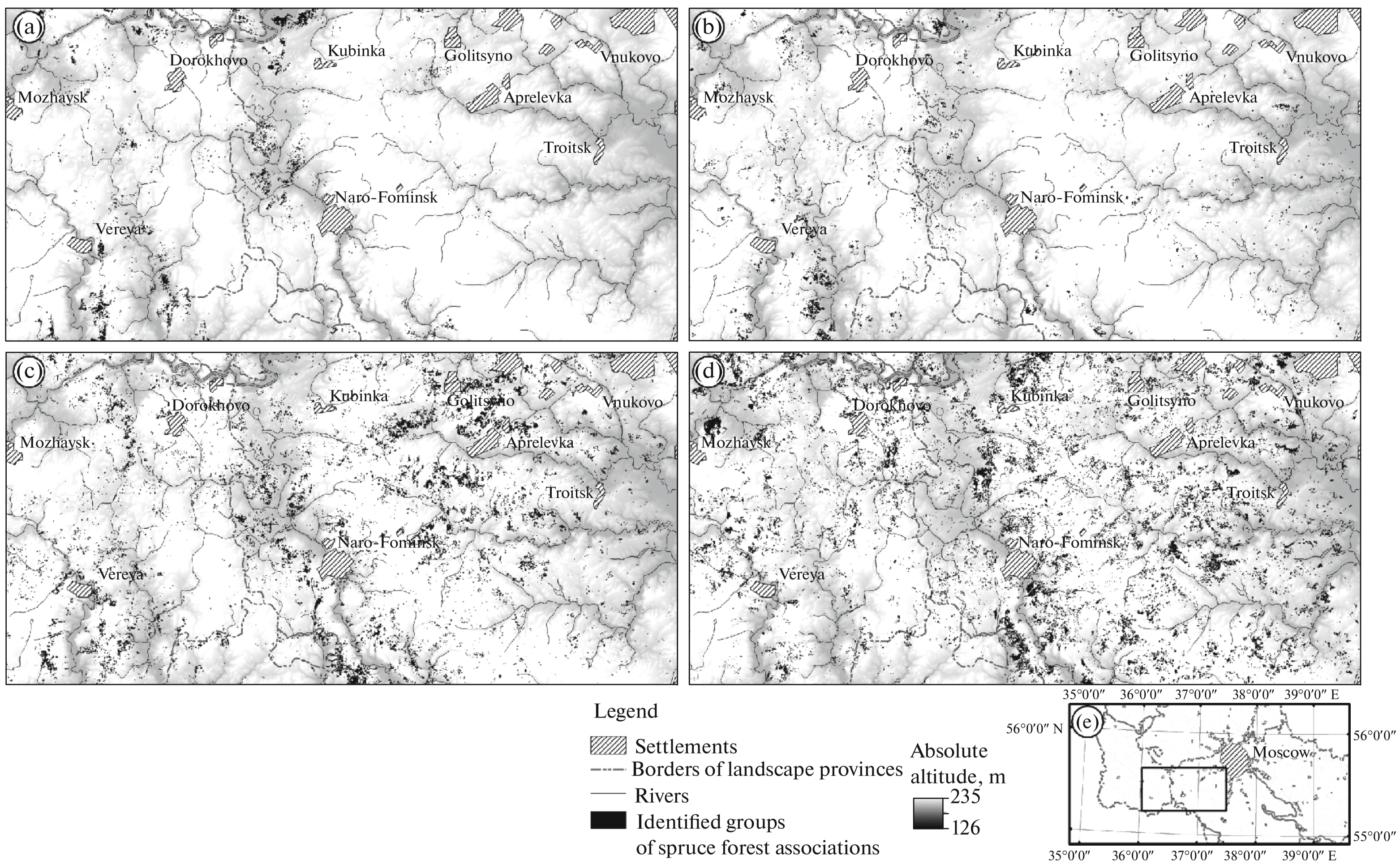

Fig. 3. Distribution of small herb (a), small herb–green moss (b), small herb–broad herb (c), and broad herb (d) spruce forests in the southwestern part of Moscow Region; (e) geographic location of the study territory.

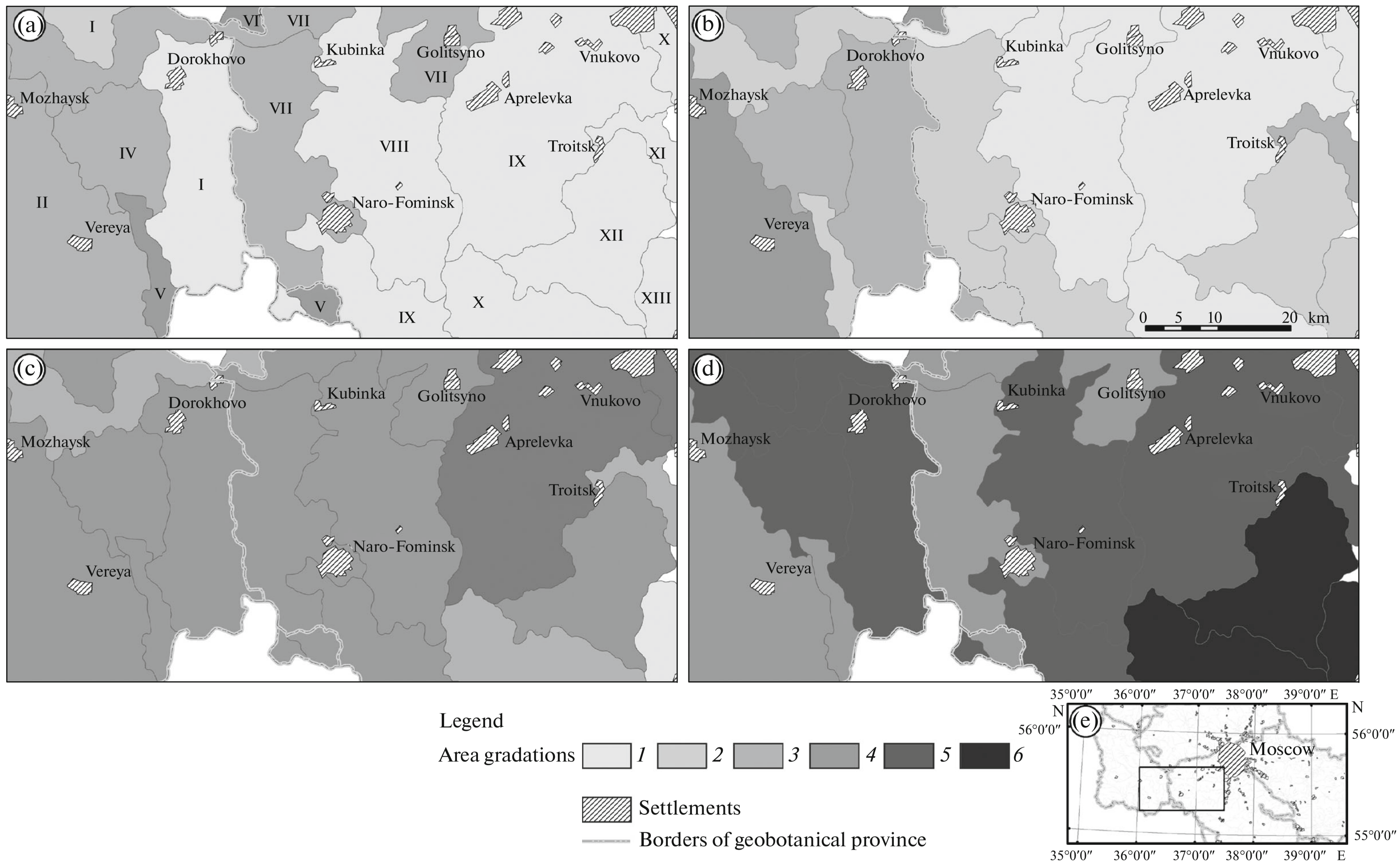

Fig. 4. Shares of areas covered by small herb (a), small herb–green moss (b), small herb–broad herb (c), and broad herb (d) spruce forests in the total area of all spruce forests in the landscape; (e) geographic location of the study territory. Gradations of the area shares: (*1*) less than 5%, (*2*) 5–10%, (*3*) 10–20%, (*4*) 20–40%, (*5*) 40–70%, and (*6*) over 70%. Landscapes of Smolensk province: I—moraine; II—moraine–water-glacial; III—moraine, water-glacial, and lake–water-glacial; IV—moraine and lake–water-glacial; V—ancient alluvial–water-glacial, ancient alluvial, and alluvial plains. Landscapes of Moscow province: VI—moraine and moraine–water-glacial plains. Landscapes of Moscow-Oka rivers province: VII—water-glacial; VIII—moraine and water-glacial; IX—moraine, water-glacial, and lake–water-glacial; X—moraine; XI—ancient alluvial –water-glacial, ancient alluvial, and alluvial; XII—lake–water-glacial; XIII—moraine and lake–water-glacial plains.

Table 2. Relation between the distribution of groups of spruce-forest associations and relief parameters

Group of associations	Altitude above sea level (m)	Laplacian*	Incline, degrees	Average curvature
Small herb–green moss spruce forests	188.82	0.0099	0.91	0.0014
Small herb spruce forests	184.80	0.1136	1.15	0.0051
Small herb–broad herb spruce forests	192.66	0.0908	1.13	0.0039
Broad herb spruce forests	194.80	–0.0947	1.44	–0.0088
F-criterion	4417.26	208.14	1090.70	1389.36

* Laplacian is a morphometric relief parameter (shape of surface) showing the intensity of "spreading and accumulation of flows" (Pu, 2000).

70% density, and rowan abundance (up to 10%) is especially significant. The share of boreal small herbs in the herb layer is sharply reduced; in addition to the wood sorrel, yellow archangel is also predominant (Table 4). There are no predominant species in the moss layer of small herb–broad herb spruce forests (projective cover is over 40%); the abundance of typical green mosses and nemoral mosses is approximately equal, but the species diversity of the second group is much higher in comparison with the first one.

In comparison with small herb spruce forests, the share of nemoral species is higher (36%), while the share of boreal species is lower (54%) (Fig. 2).

Because of the complex composition of the tree layer and combination of various dominant nemoral herb synusiae, high typological diversity is typical for this group, which has been mentioned in other studies as well (Il'inskaya et al., 1982; Ogureeva, 1996; Rysin and Savel'eva, 2007). The following associations have been described: *wood sorrel–yellow archangel*, *wood sorrel–hairy sedge* (*Carex pilosa*), *common hazel wood sorrel–hairy sedge*, and *common hazel wood sorrel–broad herb*. These associations are present on convex and flattened elements of water dividing plateaus with sod–mesopodzolic loamy, well-drained soils. The presence of oak and lime in the communities often indicates exposure of carbonate rocks and relative richness of the soil. The share of planted stands represented by monodominant spruce forests is high.

The species richness in the small herb–broad herb group of spruce forests is maximal and reaches 219 species; the species saturation of the herb-shrub layer is 29.7 ± 5.5, while the saturation of the moss layer is 6.1 ± 2.4 species.

The spatial distribution of small herb–broad herb spruce forests (relative quality of the discriminant analysis—67%) is different in many ways from the distribution of boreal forest communities (Figs. 3c and 4c). Firstly, their area is much larger—up to a quarter of the total spruce forest area on the study territory. Secondly, the area of their presence is dislocated eastward with the predomination of occurrence in the Moskva–Oka physiographic province, where small herb–broad herb spruce forests gravitate towards water dividing areas and moraine hilly surfaces and most frequently are located on slopes. The variation analysis has shown that small herb–broad herb spruce forests occupy elevated, slightly concave, and low-inclined surfaces (Table 2).

An increased share of nemoral species in all layers is characteristic for **broad herb spruce forests**. The lime and oak are always present in the 2nd tree layer, while the share of lime in the undergrowth is higher (some

Table 3. Abundance of constant species in main layers of small herb spruce forest types

Layer	Species	Projective cover, %
Tree	*Picea abies*	40.9
	Betula pendula	8.0
	Pinus sylvestris	7.2
	Populus tremula	4.8
Undergrowth	*Picea abies*	20.0
Underwood	*Corylus avellana*	10.0
	Sorbus aucuparia	4.6
Herb–shrub	*Oxalis acetosella*	54.8
	Athyrium filix-femina	12.7
	Picea abies	12.1
	Rubus saxatilis	10.4
	Gymnocarpium dryopteris	7.1
	Fragaria vesca	5.7
	Maianthemum bifolium	4.3
	Mycelis muralis	4.2
	Dryopteris carthusiana	3.8
	Orthilia secunda	2.2
	Luzula pilosa	2.2
	Convallaria majalis	2.1
	Ajuga reptans	2.1
	Urtica dioica	2.0
Moss	*Pleurozium schreberi*	7.4
	Rhytidiadelphus triquetrus	4.0
	Hylocomium splendens	2.0

Table 4. Abundance of constant species in main layers of small herb–broad herb spruce forest types

Layer	Species	Projective cover, %
Tree	*Picea abies*	70.0
	Betula pendula	12.0
	Populus tremula	6.6
Undergrowth	*Picea abies*	25.0
	Tilia cordata	7.8
Underwood	*Corylus avellana*	30.0
	Sorbus aucuparia	10.0
	Lonicera xylosteum	5.5
Herb–shrub	*Oxalis acetosella*	43.0
	Galeobdolon luteum	25.3
	Convallaria majalis	12.0
	Rubus saxatilis	10.0
	Stellaria holostea	8.2
	Gymnocarpium dryopteris	7.0
	Athyrium filix-femina	6.4
	Circaea alpina	6.0
	Dryopteris carthusiana	6.0
	Aegopodium podagraria	5.2
	Pulmonaria obscura	5.1
	Asarum europaeum	5.0
	Ajuga reptans	5.0
	Equisetum pratense	4.4
	Dryopteris filix-mas	4.0
	Fragaria vesca	4.0
	Picea abies	4.0
	Deschampsia cespitosa	3.3
	Galium odoratum	3.2
	Viburnum opulus	3.1
	Carex sylvatica	3.0
	Ranunculus cassubicus	3.0
	Geum urbanum	3.0
	Mycelis muralis	2.0
Moss	*Hylocomium splendens*	4.0
	Pleurozium schreberi	3.2
	Plagiomnium cuspidatum	3.0
	Rhytidiadelphus triquetrus	3.0
	Eurhynchium angustirete	2.3

10%) (Table 5). The share of spruce forests of artificial origin is also high in this type. According to Karpachevskii (1977), spruce stands planted in the end of the 19th century on arable lands in the estate of Earl Sheremetev have been transformed by the present time into oak–spruce hairy sedge forests typical for this zone. The crown density of spruce in the 2nd layer does not exceed 0.08, which indicates the predomination of even-aged (80 years) spruce forests with the perspective of their further decay and replacement by deciduous species. Common hazel, fly honeysuckle, and rowan are common in the underwood (24, 6, and 5% respectively). The herb layer includes individual boreal small herb species, but their abundance is low: in some communities, wood sorrel constitutes some 15%, common oak fern 4%, and stone bramble 5%. The moss cover demonstrates a high variability in abundance; its average coverage is 30%. Dominants can not be identified; nemoral moss species prevail.

The species richness is 182 species; the species saturation in the herb layer is minimal—25.8 ± 5.5; in the moss cover it is 6.6 ± 2.5. The similarity index (*Cs*) is maximal with the small herb–broad herb group—0.78—and minimal with the small-herb–green moss group—0.64. The share of the nemoral group in the ecocoenotic spectrum is expectedly higher (61%), the share of the boreal group is minimal (28%), and the share of nitrophilous plants is 9% in the four studied ecocoenotic groups (Fig. 2).

Forest community types differing by domination of individual species in the herb layer have been noted among broad herb spruce forests. Our observations are consistent with results of other researchers (Rysin and Savel'eva, 2007) who have noted the association of *hairy sedge spruce forests* with convex elements of water-dividing plateaus, while *yellow archangel spruce forests* occur more frequently on flattened parts of moraine hilly surfaces of water dividing plateaus on well-drained soils and *ground elder spruce forests* occur more frequently on lower parts of slopes.

The total area covered by broad herb spruce forests is maximal and equals the total area covered by all other abovementioned spruce forest groups together (i.e., more than half of the total area of forests with spruce predomination). The relative quality of the discriminant analysis for this group was 71%. A statistical analysis has shown that the broad herb spruce forests are associated with most elevated, convex, and inclined relief elements (Table 2). The broad herb spruce communities play a lesser role within the Smolensk province in comparison with the Moskva–Oka province, where broad herb forests occur on all landscapes and most frequently dominate among other spruce forest types (Figs. 3d and 4d). The maximal abundance of broad herb spruce forests in the landscape, assessed as the share of this community type in the total area covered by all spruce forest types in the landscape, is observed in most elevated natural–territorial complexes of landscapes of moraine plains (Fig. 4d). Habitats in these landscapes are characterized by a favorable combination of good drainage and high substrate trophicity (Annenskaya et al., 1997).

Table 5. Abundance of constant species in main layers of broad herb spruce forest types

Layer	Species	Projective cover, %
Tree	*Picea abies*	55.5
	Betula pendula	9.2
	Pinus sylvestris	11.2
Undergrowth	*Picea abies*	7.6
	Tilia cordata	9.7
Underwood	*Corylus avellana*	23.7
	Lonicera xylosteum	5.7
	Sorbus aucuparia	5.1
Herb–shrub	*Carex pilosa*	37.4
	Galeobdolon luteum	23.2
	Oxalis acetosella	11.6
	Ajuga reptans	6.8
	Athyrium filix-femina	6.7
	Pulmonaria obscura	5.9
	Asarum europaeum	5.7
	Ranunculus cassubicus	5.1
	Rubus saxatilis	4.8
	Dryopteris carthusiana	4.2
	Geum rivale	3.9
	Dryopteris filix-mas	3.6
	Picea abies	3.4
	Gymnocarpium dryopteris	2.7
	Urtica dioica	2.6
	Convallaria majalis	2.5
	Paris quadrifolia	1.9
Moss	*Plagiomnium undulatum*	7.1
	Plagiomnium affine	5.6
	Pleurozium schreberi	3.5
	Rhytidiadelphus triquetrus	3.1
	Eurhynchium angustirete	3.0
	Hylocomium splendens	2.5
	Atrichum undulatum	2.4
	Plagiochila porelloides	2.4
	Rhytidiadelphus subpinnatus	1.9

According to Alekhin (1947), broad-leaved forests, mostly oak forests, were growing there in the past.

CONCLUSIONS

The long history of economic development and complex landscape structure of the southwestern part of Moscow Region have determined high ecocoenotic diversity of the forest cover. The considerable transformation of the vegetation cover in the region—due to both forest felling with further plowing of lands and artificial forest cultivation—has resulted in the predomination of secondary types over conditionally primary ones. Nevertheless, the composition of the researched spruce communities reflects the zonal vegetation features of the study region and association with certain landscape elements.

On the basis of processing original materials, a classification of conditionally primary and secondary forest communities has been performed for the study area. The unification of the syntaxon composition and names ensured a certain conformity of the typological and cartographic units. An analysis of the four groups of spruce forest associations (small herb–green moss, small herb, small herb–broad herb, and broad herb) has revealed specific features of their species and coenotic diversity in the transition from the boreal to nemoral composition. In particular, in the course of the transition from the small herb–green moss group to the broad herb group, the share of boreal species in the ecocoenotic spectrum has decreased by 3.5 times, while the share of the nemoral group has respectively increased by 3 times. Spruce forests belonging to the boreal group (small herb–green moss and small herb ones) are represented by a relatively small number of syntaxa in the rank of groups of associations and associations, while the subnemoral (small herb–broad herb spruce forests) and nemoral (broad herb spruce forests) groups have a higher coenotic diversity—both due to a larger number of other tree species and the variety of combinations of species predominating in the ground cover.

A variation analysis of the links between the identified groups of associations and relief forms has demonstrated that these groups are statistically significantly determined by relief features. The most elevated, convex, and inclined areas are occupied by broad herb spruce forests, while small herb–broad herb spruce forests are associated with elevated, slightly concave, and low-inclined surfaces. Small herb–green moss spruce forests occupy most lowered, flat, and low-inclined positions. Small herb spruce forests are associated with most lowered and concave positions.

The application of cartographic modeling methods, using both ground-based and remote sensing data, has made it possible to present the spatial distribution of various forest community types on thematic maps, including their relation to the landscape structure of the territory. The analysis of the spatial differentiation of the forest cover—using spruce forests with different species composition as an example—has confirmed the ecotonal structure of the study area, resulting in a distribution gradient for spruce forests of various ecocoenotic spectra. Communities with boreal accompanying plant species predominated in the western part of the study territory (Smolensk province), while communities with nemoral accompanying plant species predominated in the eastern part (Moskva–Oka province). Overall, the total area of spruce forests is considerably increasing in the west-to-east direction.

ACKNOWLEDGMENTS

We thank G.N. Ogureeva, E.V. Tikhonova, O.A. Pesterova, N.G. Kadetov, D.A. Bykov, and many other colleagues for their participation in field studies and discussions of the results.

This study is part of the State Research Project "Spatiotemporal Organization of Forests and the Ways to Map," project no. 0110-2014-0007 of the Center of Forest Ecology and Productivity of the Russian Academy of Sciences, was supported by the Russian Foundation for Basic Research, project no. 11-04-01093, and the Russian Academy of Sciences Presidium program "Nature: Contemporary State and the Challenges of Development."

REFERENCES

Alekhin, V.V., *Rastitel'nost' i geobotanicheskie raiony Moskovskoi i sopredel'nykh oblastei* (Vegetation and Geobotanical Regions of Moscow and Adjacent Regions), Moscow: Mosk. O-vo Ispyt. Prir., 1947.

Annenskaya, G.N., Zhuchkova, V.K., Kalinina, V.R., Mamai, I.I., Nizovtsev, V.A., Khrustaleva, M.A., and Tsesell'chuk, Yu.N., *Landshafty Moskovskoi oblasti i ikh sovremennoe sostoyanie* (Landscapes of Moscow Oblast and Modern Status), *Smolensk*: Smolensk. Gos. Univ., 1997.

Asner, G.P., Biophysical and biochemical sources of variability in canopy reflectance, *Remote Sens. Environ.*, 1998, vol. 64, pp. 234–253.

Biogeotsenologicheskie osnovy sozdaniya prirodnykh zakaznikov (na primere zakaznika "Verkhnaya Moskva reka") (Biogeocenologic Principles of Organization of Natural Wildlife Sanctuaries by Example of Verkhnyaya Moskva-Reka Wildlife Sanctuary), Smagin, V.N., Ed., Moscow: Nauka, 1980.

Cherepanov, S.K., *Sosudistye rasteniya Rossii i sopredel'nykh gosudarstv* (Vascular Plants of Russia and Adjacent Countries), St. Petersburg: Mir i Sem'ya, 1995.

Chernen'kova, T.V., Levitskaya, N.N., Kozlov, D.N., Tikhonova, E.V., Ogureeva, G.N., and Pesterova, O.A., Assessment of status and dynamics of forest biological diversity in Moscow oblast using the land and remote analysis methods, in *Raznoobrazie i monitoring lesnykh ekosistem Rossii* (Diversity and Monitoring of Forest Ecosystems of Russia), Isaev, A.S., Ed., Moscow: KMK, 2012, book 1, pp. 316–370.

Chernen'kova, T.V., Puzachenko, M.Yu., Koroleva, N.E., and Basova, E.V., Assessment of forest spatial differentiation in Murmansk province using field surveys and remote sensing data, *Contemp. Probl. Ecol.*, 2013, vol. 6, pp. 738–746.

Galakhov, N.N., microclimate observations in Moscow region, *Tr. Inst. Geogr., Akad. Nauk SSSR*, 1957, no. 3, pp. 102–135.

Gribova, S.A. and Isachenko, T.I., Cartography of vegetation in survey scale, in *Polevaya geobotanika* (Field Geobotany), Leningrad: Nauka, 1972, vol. 4, pp. 137–330.

Gribova, S.A., Isachenko, T.I., and Lavrenko, E.M., *Rastitel'nost' evropeiskoi chasti SSSR* (Vegetation of European Part of Soviet Union), Leningrad: Nauka, 1980.

Gruza, G.V. and Ran'kova, E.Ya., Change of climate conditions in European part of Russia in the second half of 20th century, in *Vliyanie izmeneniya klimata na ekosistemy* (Influence of Climate Changes on Ecosystems), Moscow, 2001, pp. 13–36.

Gvozdetskii, N.A., *Fiziko-geograficheskoe raionirovanie Nechernozemnogo tsentra* (Physical-Geographical Zonation of Nonchernozem Central Region), Moscow: Mosk. Gos. Univ., 1963.

Ignatov, M.S. and Ignatova, E.A., *Flora mkhov srednei chasti evropeiskoi Rossii* (Moss Flora of the Central Part of European Russia), Moscow: KMK, 2003, vol. 1, pp. 1–608; 2004, vol. 2, pp. 609–960.

Il'inskaya, S.A., Matveeva, M.A., Rechan, S.P., Kazantseva, T.N., and Orlova, M.A., Forest types, in *Lesa Zapadnogo Podmoskov'ya* (Forests of the Western Part of Moscow Region), Moscow: Nauka, 1982, pp. 20–149.

Jackson, R.D. and Huete, A.R., Interpreting vegetation indices, *Prevent. Vet. Med.*, 1991, vol. 11, pp. 185–200.

Karpachevskii, L.O., *Pestrota pochvennogo pokrova v lesnom biogeotsenoze* (Motley Soil Cover in Forest Biogeocenosis), Moscow: Mosk. Gos. Univ., 1977.

Karta rastitel'nosti Moskovskoi oblasti. Masshtab 1 : 200000 (Map of Vegetation of Moscow Oblast, Scale 1 : 200 000), Ogureeva, G.N., Ed., Moscow: Ekor, 1996.

Kazakova, N.M., The key relief features of Moscow oblast, *Tr. Inst. Geogr., Akad. Nauk SSSR*, 1957, no. 71, pp. 5–15.

Kryshen', A.M., Systematization of habitats and forest dynamics in Eastern Fennoscandia, *Izv. Samar. Nauch. Tsentra, Ross. Akad. Nauk*, 2012, vol. 14, no. 1 (4), pp. 1033–1038.

Kryshen', A.M. and Litinskii, P.Yu., Comparison and reciprocal verification of geoinformation and ecological-dynamic models of diversity of forest ecosystems, *Tr. Karel. Nauch. Tsentra, Ross. Akad. Nauk*, 2013, no. 2, pp. 86–91.

Kurnaev, S.F., *Osnovnye tipy lesa srednei chasti Russkoi ravniny* (General Forest types of the Central Part of Russian Plain), Moscow: Nauka, 1968.

Kuzenkova, L.Ya., Vegetation of the Pakhra River basin, *Extended Abstract of Cand. Sci. (Biol.) Dissertation*, Moscow, 1969.

Lesa Severnogo Podmoskov'ya (Forests of Northern Part of Moscow Region), Rysin, L.P., Ed., Moscow: Nauka, 1993.

Lesa Yuzhnogo Podmoskov'ya (Forests of Southern Part of Moscow Region), Rysin, L.P., Ed., Moscow: Nauka, 1985.

Lesa Vostochnogo Podmoskov'ya (Forests of Eastern Part of Moscow Region), Rysin, L.P., Ed., Moscow: Nauka, 1979.

Lesa Zapadnogo Podmoskov'ya (Forests of Western Part of Moscow Region), Rysin, L.P., Ed., Moscow: Nauka, 1982.

Lesnoi Plan Moskovskoi oblasti (Forest Plan of Moscow Oblast), Moscow, 2010, book 1.

Lyubimova, E.L., Description of vegetation of natural areas of Moscow oblast, in *Ocherki prirody Podmoskov'ya* (Reviews of the Nature in Moscow Region), Moscow: Akad. Nauk SSSR, 1957, pp. 42–82.

Maslov, A.A., Fluctuations and successions in forest communities affected by climate change, *Izv. Samar. Nauch. Tsentra, Ross. Akad. Nauk*, 2012, vol. 14, no. 1 (5), pp. 1316–1319.

McCune, B. and Mefford, M.J., *PC-ORD. Multivariate Analysis of Ecological Data, Version 5*, Gleneden Beach, OR: MjM Software, 2006.

McRober, R.E., A model-based approach to estimating forest area, *Remote Sens. Environ.*, 2006, vol. 103, pp. 56–66.

Morozova, O.V. and Tikhonova, E.V., Differentiation of forest communities of the southwestern part of Moscow oblast, *Izv. Samar. Nauch. Tsentra, Ross. Akad. Nauk*, 2012, vol. 14, no. 1 (4), pp. 1073–1077.

Nosova, L.M., Ogureeva, G.N., Tikhonova, E.V., and Leonova, N.B., Dynamics of biological diversity in coniferous forests in the center of Russian Plain, *Lesovedenie*, 2009, no. 6, pp. 18–31.

Ogureeva, G.N. and Buldakova, E.V., Diversity of forests of the Klinsko-Dmitrovskaya Ridge related to landscape structure of the territory, *Lesovedenie*, 2006, no. 1, pp. 58–69.

Pesterova, O.A., Tikhonova, E.V., and Chernen'kova, T.V., Biological diversity of artificial green plantations in coniferous–broad-leaved forest subzone by example of southwest of Moscow region, *Vestn. Voronezh. Gos. Univ., Ser.: Khim., Biol., Farm.*, 2012, no. 2, pp. 189–196.

Petrov, V.V. and Kuzenkova, L.Ya., The western border of geobotanical region of the broad-leaved forests in Moscow oblast, *Vestn. Mosk. Gos. Univ.*, 1968, no. 3, pp. 59–69.

Polyakova, G.A., Malysheva, T.V., and Flerov, A.A., *Antropogennye izmeneniya shirokolistvennykh lesov podmoskov'ya* (Anthropogenic Changes in the Broad-Leaved Forests), Moscow: Nauka, 1983.

Pu, T., *Nelineinaya ekonomicheskaya dinamika* (Nonlinear Economic Dynamics), Moscow: Regulyarnaya Khaoticheskaya Dinamika, 2000.

Puzachenko, Yu.G., *Matematicheskie metody v ekologicheskikh i geograficheskikh issledovaniyakh* (Mathematical Analysis in Ecological and Geographic Studies), Moscow: Akademiya, 2004.

Puzachenko, Yu.G., Fedyaeva, M.V., Kozlov, D.N., and Puzachenko, Yu.M., Elementary geosystem processes, in *Sovremennye estestvennye i antropogennye protsessy v pochvakh i geosistemakh* (Modern Natural and Anthropogenic Processes in Soils and Geosystems), Moscow: Pochv. Inst. im. V.V. Dokuchaeva, 2006, pp. 13–52.

Puzachenko, Yu.G., Sandlersky, R.B., Krenke, A.N., and Puzachenko, Yu.M., Multispectral remote information in forest research, *Contemp. Probl. Ecol.*, 2014, vol. 7, no. 7, pp. 838–854.

Reese, H., Nilsso, M., Sandstro, P., and Olsso, H., Applications using estimates of forest parameters derived from satellite and forest inventory data, *Comput. Electron. Agric.*, 2002, vol. 37, pp. 37–56.

Rysin, L.P., Natural conditions in Moscow region, in *Dinamika khvoinykh lesov Podmoskov'ya* (Dynamics of Coniferous Forests in Moscow Region), Moscow: Nauka, 2000, pp. 5–21.

Rysin, L.P., Abaturov, A.V., Savel'eva, L.I., et al., *Dunamika khvoinykh lesov Podmoskov'ya* (Dynamics of Coniferous Forests in Moscow Region), Moscow: Nauka, 2000.

Rysin, L.P. and Savel'eva, L.I., *Kadastry tipov lesa i tipov lesnykh biogeotsnozov* (Inventories of Types of Forests and Forest Biogeocenosises), Moscow: KMK, 2007.

Smirnov, P.A., Flora of Prioksko-Terrasny Nature Reserve, *Tr. Prioksko-Terrasnogo Zapoved.*, 1958, no. 2.

Smirnov, V.E., Khanina, L.G., and Bobrovskii, M.V., Description of the system of ecological-coenotic groups of the plant species in the forest zone of European Russia based on ecological scales, geobotanical descriptions, and statistical analysis, *Byull. Mosk. O-va. Ispyt. Prir., Otd. Biol.*, 2006, vol. 111, no. 1, pp. 27–49.

Spiridonov, A.I., Geomorphology, in *Geologiya SSSR* (Geology of Soviet Union), Moscow: Nedra, 1971, vol. 4, pp. 679–706.

Sukachev, V.N., *Ozbrannye trudy. Tom 1. Osnovy lesnoi tipologii i biogeotsenologii* (Selected Research Works, Vol. 1: Principles of Forest Typology and Biogeocenology), Leningrad: Nauka, 1972.

Tomppo, E., Olsson, H., Stahl, G., Nilsson, M., Hagner, O., and Katila, M., Combining national forest inventory field plots and remote sensing data for forest databases, *Remote Sens. Environ.*, 2008, vol. 112, pp. 1982–1999.

Ustin, S.L., Roberts, D.A., Gamon, J.A., Asner, G.P., and Green, R.O., Using imaging spectroscopy to study ecosystem processes and properties, *BioScience*, 2004, vol. 54, pp. 523–534.

Vostochnoevropeiskie lesa: istoriya v golotsene i sovremennost' (East European Forests: History in Holocene and Present Time), Smirnova, O.V., Ed., Moscow: Nauka, 2004.

Zaugol'nova, L.B. and Morozova, O.V., Classification and characteristics of communities of boreal forests, in *Vostochnoevropeiskie lesa: istoriya v golotsene i sovremennost'* (East European Forests: History in Holocene and Present Time), Moscow: Nauka, 2006, book 2, pp. 298–330.

Translated by L. Emeliyanov