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GIS-based landscape classification and mapping of European Russia

E. Lioubimtseva[a,*], P. Defourny[b]

[a]School of Geography, Mansfield rd., Oxford OX1 3TB, United Kingdom
[b]Department of Environmental Sciences, Université Catholique de Louvain, Louvain-la-Neuve B-1348, Belgium

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Abstract

The landscape approach is widely recognised today as a powerful method of multidisciplinary environmental research. Integrating data both on natural geoecosystems and socio-economic impacts and their relationships, it offers an ideal frame of territorial sampling for evaluating, mapping and modelling environmental status and dynamics. This study is intended to compile a broad-scale environmental frame of European Russia, and to improve existing landscape classifications using GIS techniques. It also suggests a simple and efficient method of validation for broad-scale landscape maps by small-area 'maplets' generated from high-resolution remote sensing data. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Geographic information systems; Landscape mapping

1. Introduction

Both scientists and decision-makers need to be provided with complete and up-to-date information on various features of the environment and land use. In order to determine an adequate environmental policy and correctly evaluate its effects we must have a proper understanding of different features of the environment, such as land cover, soils, water resources, etc. (CORINE, 1994).

The landscape approach is widely recognised today as a powerful method of multidisciplinary environmental research. It provides a basis for the perception of the surface area as a system of interrelated territorial units with specific environmental characteristics. Integrating data both on natural geoecosystems and socio-economic impacts and their relationships, it offers an ideal frame of territorial sampling for evaluating, mapping and modelling environmental status and dynamics (Milanova et al., 1993).

There is a strong need to develop effective methods for generation and integration of national and regional data sets on land use and environment, and linking them to adequate frames of territorial sampling. These tasks may be solved only by Geographic Information Systems (GIS), which are capable of handling and manipulating considerable amounts of spatial data. Applications of GIS for small-scale environmental

*Corresponding author. Present address: UCL, 21 Rue de la Neuville, Louvain-la-Neuve, Belgium. Tel.: +32-104-78897; fax: +32-104-78898; e-mail: lioubimtseva@mila.ucl.ac.be

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mapping have been widely documented by many authors (Goodchild and Gopal, 1989; Bridgewater, 1993; Cousins, 1993; Haines-Young, 1992; Milanova et al., 1995). However, despite long traditions of hierarchical landscape mapping in Russia, no effort has been made until now to use GIS-based landscape classification and analyses.

Remote sensing which has proved a powerful tool for land-cover mapping (Tucker et al., 1984; Malingreau et al., 1989; Townshend et al., 1992), provides a lot of information on spectral properties of landscape and its spatial structure and mosaic. Using additional ancillary data, large-scale detailed landscape maps can be derived from satellite images classified for land cover.

These data are extremely useful for validation of broad-scale landscape data sets compiled from traditional maps, where validation by random sample points become unfeasible because of their large extent. Moreover, satellite images are a very valuable source of information on land cover where there are doubts or a lack of information from published maps and for mapping landscape change.

Because landscape aggregations show strong association between land cover and terrain characteristics, cover pattern derived from the satellite data is an important indicator for studying landscape structure. It is essential therefore to study relations between land cover and landscapes in order to improve existing methods of landscape interpretation, mapping and modelling.

2. Objectives

This study is intended to compile a broad-scale environmental frame of European Russia, which can be useful for a wide range of users, such as climate, socio-economic, or biodiversity modellers, land-use planners, students, etc. Its major goal is the compilation of a landscape database on the European part of Russia using Arc Info GIS. Besides purely practical issues of this study such as a computer-based small-scale-landscape database of the European part of Russia, we attempt to improve existing methods of GIS-integrated mapping in the following ways: (a) Developing methods of broad-scale landscape classification and mapping using Arc Info functions, and (b) developing methods of validating a broad-scale landscape database compiled from various sources, by small-area large-scale sample landscape 'maplets' generated from high- and medium-resolution remote sensing imagery and complementary ancillary data.

At the macroregional or subcontinental scale of this study large-area thematic maps included in the database are highly generalised, as far as details of classification and spatial resolution are concerned. Therefore their validation by traditional random point sampling based on in-field survey would be infeasible, because of the large extent of the study area. One of the goals of this study is to test an alternative procedure of map validation based on satellite imagery application.

3. Study area

The area covered by the small-scale landscape database is the entire European part of the Russian Federation (EPR). This extensive area features high environmental diversity and is well documented by traditional cartographic sources (Goudilin, 1980; Botanic Institute, 1987; Isachenko, 1978; Bazilevich, 1995; Glazovskaja, 1996). It stretches from the Barents and White seas on the north (68–70°N) to the Caucasus Mountains and the Caspian Sea (42–44°N) on the south and from the Russian border on the west (27–32°E) to the western slopes of the Ural mountains (55–60°E).

Several test areas characterised by significantly different environments were selected in different landscape zones in order to validate the consistency of the landscape database. Covered by high-resolution satellite imagery and well documented by local large-scale topographic and landscape maps, they would serve as references for the database evaluation. At present the methodology has been tested on three of them: Moscow region, Darwin reserve and Voronez region.

4. Small-scale database

4.1. Data sources and GIS environment

The initial phase of this study required assembling, storing and bringing to the same format various data on the landscape components of the EPR.

After analyses of relevant bibliographic and cartographic materials on the study area, we selected nine thematic maps as principal sources of basic information on the present day landscapes of European Russia. Climatic data were imported from the Global Climatic Database (Leemans and Kramer, 1994) and the hydrographic network from the Digital Chart of the World (1996). The most recently published maps of potential and present-day vegetation (1990; 1993), soils (1995) and land use (1992) of Russia were used for compilation of a small-scale landscape database. It would have been desirable to include a digital elevation model (DEM) in the GIS so that analysis of slope and elevation could be conducted. Unfortunately no DEM of adequate resolution was available. Alternatively contours of the relief classes identifiable according to altitude and geomorphologic processes, were digitised from the topographic map of the USSR (1987) as a compromise.

Building a landscape database required digitalisation and bringing to the same format data from thematic maps. The following thematic layers were created: climatic parameters; relief (six classes); typological subdivisions of climax vegetation (48 types); pedological types and genetic groups (41), phytomass (seven classes); mortmass (nine classes), vegetation production (seven classes); hydrological network; urban centres (five categories), transport network, and land-use categories (25). These primary data were necessary for capturing landscape classification criteria and form a core of information in the database.

In order to provide complete superimposition of all cartographic layers they were all uniformed to the same conic equidistant Nefedova projection – the most often used for mapping of the ex-USSR and Russia). Deformations, initially existing in thematic maps due to imperfect registration and geodetic control, were geometrically corrected by edgematching, and computing links for adjusting erroneous data using a considerable number of control points. All cartographic data were stored and processed in an Arc/Info GIS environment (ESRI, 1995).

The database structure meets the logic of landscape differentiation by various factors and includes a number of thematic coverages. Each coverage or directory includes subdirectories and files, describing thematic content, and geographical and topological references.

4.2. Criteria and variables in the landscape classification

Landscape is a system resulting from the interaction of natural and human-induced components. It is a synthetic complex, whose functioning and dynamics depend on its vertical and horizontal structure, rather than a simple sum of components. Different limitation factors and criteria, become apparent at different hierarchical levels of landscape aggregation (Table 1).

In the proposed classification the highest taxonomic level of landscape aggregation are system and subsystem, whose subdivision is based on climatic parameters. The latter are fundamental for determining the structure of natural landscape zones and sectors at the macroregional scale.

The next level in the classification is referred to as class and defined through landform and altitude. The principal criterion of landscape division into classes depends on the structure of geographical zones: horizontal – on plains, and vertical – in mountains. Class is further subdivided into subclasses according to the number of altitudinal vegetation bands on mountain slopes and genetic type of relief.

Subdivision of landscape types and subtypes depends on zonal features of vegetation and soils. Besides such qualitative criteria, as physiognomic and floristic features, quantitative parameters of vegetation cover such as annual production, standing phytomass and mortmass were considered. Distribution of these criteria is a good indicator of landscape structure and proves to show a high correlation with biogeochemical cycles and matter fluxes in landscapes (Bazilevich, 1995; Olson et al., 1983).

Zonal landscape types comprise a mosaic of ecosystems, which taxonomically correspond to genetic soil groups and vegetation formations or groups of vegetation associations. Landscape subdivisions at this subzonal level were referred to as landscape groups (subtypes). The last level of the landscape classification is referred to as an anthropogenic modification of the landscape and is defined by land use. Each hierarchical level of landscape classification corresponds to one or several criteria, which can be described by single, or several variables (Table 1; Fig. 1).

Table 1
Levels and variables of landscape differentiation

System	CLIMATE	R (kcal/cm^2) id{1,2,3} $R=10$ $10<R=45$ $R>45$	T_{jan} (°C) id{1,2,3} $T=-15$ $-15<T=-5$ $-5<T=+5$	T_{jul} (°C) id{1,2,3} $T=10$ $10<T=20$ $T>20$	AC id{1,2,3} Arct + Temp Temp Temp + Trop
Subsystem		P_a (mm) id{1,2,3,4} $P=700$ $500=P<700$ $300=P<500$ $P<300$	P/PET id{1,2,3,4} P/PET = 1 0.7 = P/PET < 1 0.2 = P/PET < 0.7 P/PET < 0.2		
Class	RELIEF	n id{1,2} $n=1$ $n>1$			
Subclass		ALT (m) (if $n=1$) id{1,2,3,4} ALT > 500 200 < ALT = 500 0 < ALT = 200 ALT = 0	n' (if $n>1$) id{1,2} $1<n'=3$ $n'>3$		
Type	ECOSYSTEM	PHYTO (t/ha) id{1–7} 2.5 = PHYTO = 5 5 < PHYTO = 12.5 12.5 < PHYTO = 25 25 < PHYTO = 50 51 < PHYTO = 150 150 < PHYTO = 300 300 < PHYTO = 400	MORT (t/ha) id{1–9} 2.5 = MORT = 5 5 < MORT = 12.5 12.5 < MORT = 25 25<MORT(50 51 < MORT = 150 150 < MORT = 300 300 < MORT = 400 400 < MORT = 500 MORT > 500	PRODUCT (t/ha/year) id(1–7) 1 = PRO = 2.5 2.5 < PRO = 4 4 < PRO = 6 6 < PRO = 8 8 < PRO = 11 11 < PRO = 16 16 < PRO = 30 PRO > 30	
Subtype (or group)		VEG id-p{1–48}	PED id-p{1–41}		
Modification	IMPACT	USE id{1–25}			

R is solar radiation balance; T_{jan} – mean temperature of January, T_{jul} – mean temperature of July; AC – dominant atmospheric circulation, Arct – arctic, Temp – temperate, Trop –tropical; P – annual sum of precipitation, P/PET coefficient of humidity, where PET is potential evapotranspiration; n, n' – number of altitudinal bands in vertical landscape stratification (n'– only in the mountains); ALT – altitude above the sea level; PHYTO – phytomass; MORT– mortmass; PRODUCT – annual production; VEG id – vegetation (sub) type; PED id – pedological (sub) type or group of soils; USE id – dominant type of land use.

4.3. Hierarchical landscape mapping

The proposed method of landscape mapping suggests the following steps:

1. topological overlay of thematic layers of landscape criteria, analyses of their resultant combinations, screening out polygons below the representative landscape level,
2. aggregating landscape polygons into groups corresponding to the higher hierarchical level,
3. linking legends of primary data and generating new landscape maps and legends.

This cycle of procedures is repeated at each hierarchical level of the classification.

Overlay function produces a considerable number of small polygons below the minimum-mapping unit. Their size is much smaller compared to the meaningful landscape polygons and they appear because of imperfect delineation of units on source maps, assumption on sharp polygon boundaries, difference

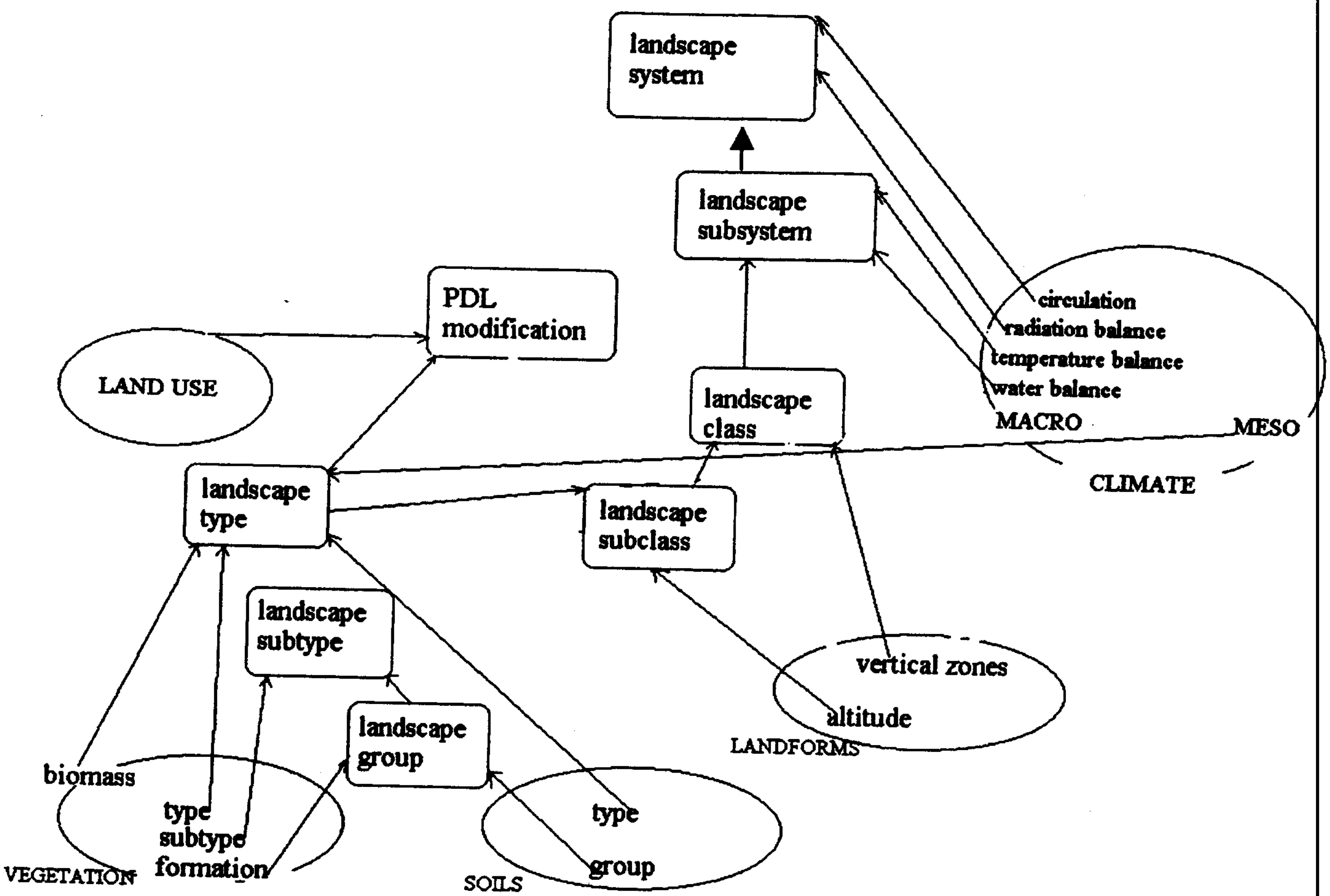

Fig. 1. Conceptual model of hierarchical aggregation of landscape components.

of mapping techniques and approaches used in the source maps.

Each overlay operation in the chain of generating landscape maps was accompanied by elimination of polygons with area below the minimum mapping unit of the database. The minimum mapping unit of 1 : 4 M source maps is 10 km^2. On 1 : 8 M source maps (biomass parameters) the minimum mapping unit is already 25 km^2. The accuracy decreases, however, with addition of errors brought by digitalisation and especially by superimposition of layers coming from different source maps. The reference scale of resultant landscape map is, therefore smaller than the source scale. However, elimination of such polygons does not affect precision of broad-scale landscape mapping because it is still lower than the minimum size of landscape polygon at the lowest level of suggested classification, which is about 100 km^2.

5. Large-scale datasets

5.1. 'Maplet' method and high-resolution data set

The 'maplet' method was suggested by Stoms (1996) as a development of idea an of Chrisman (1991), that validation of small-scale databases on extensive geographic areas by small-area datasets of higher resolution could be more effective than traditional random point validation. He pointed that the large number of classes on the small-scale large-area maps makes it almost unfeasible to validate by random sample points, because their number should be not less than 50 point per class to produce statistically sound measures of accuracy (Congalton, 1991; Stoms, 1996).

In contrast, the maplet method, although it suffers from generalisation and abstraction from field reality, can still provide a reasonably consistent but less

Table 2
Maplets sites supported by high-resolution satellite data

No.	Test site	Landscape zone	Latitude	Longitude	Status
1	Kola peninsula	Tundra, forest-tundra	67°30′N	34°40′E	planned
2	Karelian isthmus	Coniferous taiga	63°20′N	34°20′E	in progress
3	Darwin reserve	Mixed and coniferous taiga	57°96′N	38°04′E	completed
4	Moscow region	Mixed forest, urban-suburban	55°88′N	37°12′E	completed
5	Zagorsk region	Mixed forest, swamp	56° 10′N	38°15′E	planned
6	Kulikovo Pole	Forest-steppe, arable-pastoral	54° 30′N	38°20′E	planned
7	Voronez region	Forest-steppe, steppe, arable	51°76′ N	39°07′E	completed
8	Saratov region	Dry steppe, arable	50° 40′ N	44°10′E	planned
9	Krasnodar region	Steppe, arable	46° 20′N	40°20′E	planned
10	Baksan valley	High mountain	43°30′ N	44°10′E	planned
11	Kalmikija	Semi-desert, pastoral	45° 30′N	45°30′E	in progress

expensive way to capture the land cover and landscape pattern of the smaller-scale map.

The method proposed here of the small-scale landscape dataset validation suggests the generation of several randomly distributed small-area large-scale landscape maplets with compatible legends and their topologic comparison with respective fragments of the large-area small-scale dataset. These maplets were produced from independent sources of high spatial resolution.

Photographic imagery from the MK-4 camera onboard the Russian satellite RESURS-F of 25–35 m spatial resolution, together with large-and medium-scale ancillary data (1 : 200–1 : 500 K scale) were used for generating landscape maplets (Table 2).

5.2. Test sites

To validate the small-scale database 11 case studies are now chosen in significantly different landscape zones (Fig. 2; Table 2). At this stage the method was tested on three of them, where field experience of the author was a useful compliment to available satellite and cartographic data.

Darwin reserve (maplet no. 3). The case study belongs to the Upper Volga province of the Russian plain and is characterised by low accumulative relief (120–150 m alt.) and cool humid temperate climate. The area is dominated by spruce and spruce-hardwood forests (*Picea albies* × *P. obovata*) with a high proportion of birch and pine forests (*Betula czerepanovii, Pinus silvestris*) and meadows and peat bogs. Although the configuration and dynamics of the present-day landscapes are partly defined by the creation of the artificial Ribinsk water reservoir, a western part of the test area belongs to the Darwin reserve with quasi natural landscapes. Part of this area experiences agricultural and forestry impact, which is restricted to the coastal zone and to river valleys.

Moscow region (maplet no. 4) belongs to Smolensko-Moscovskaja province of the Russian plain and is characterised by hilly moraine relief with relatively high altitudes (220–310 m), temperate climate and rather contrasted potential landscapes. In the course of a long anthropogenic impact primary landscapes of coniferous and hardwood forests on sod-podzolic soils have been totally replaced by secondary birch and fir-birch forest. The major part of the test area is occupied by urban and rural lands with very dense built-up areas and infrastructure, and by arable lands, improved pastures, hay meadows and gardens.

Voronez region (maplet no. 7) is situated in the Oka-Don province. Flat relief on the forested eastern bank of the Voronez River (altitude 150–160 m) and typical gully relief, dendritic in plan, throughout the rest of the area characterise the test site. A subhumid temperate climate, often with droughts, has caused development of forest-steppe and steppe potential landscapes with hardwood forests on grey forest soils and meadow and typical chernozem steppe. However, almost the whole area is occupied nowadays by agricultural lands with the exception of the Voronez nature reserve with oak-lime forest. Gully valleys are occupied by *bairak*[1]

[1]Bairak (Turk-gully, ravine) is a dry gully overgrowing by hardwood, mainly oak wood. The term is widespread in southern Russia and the Volga basin.

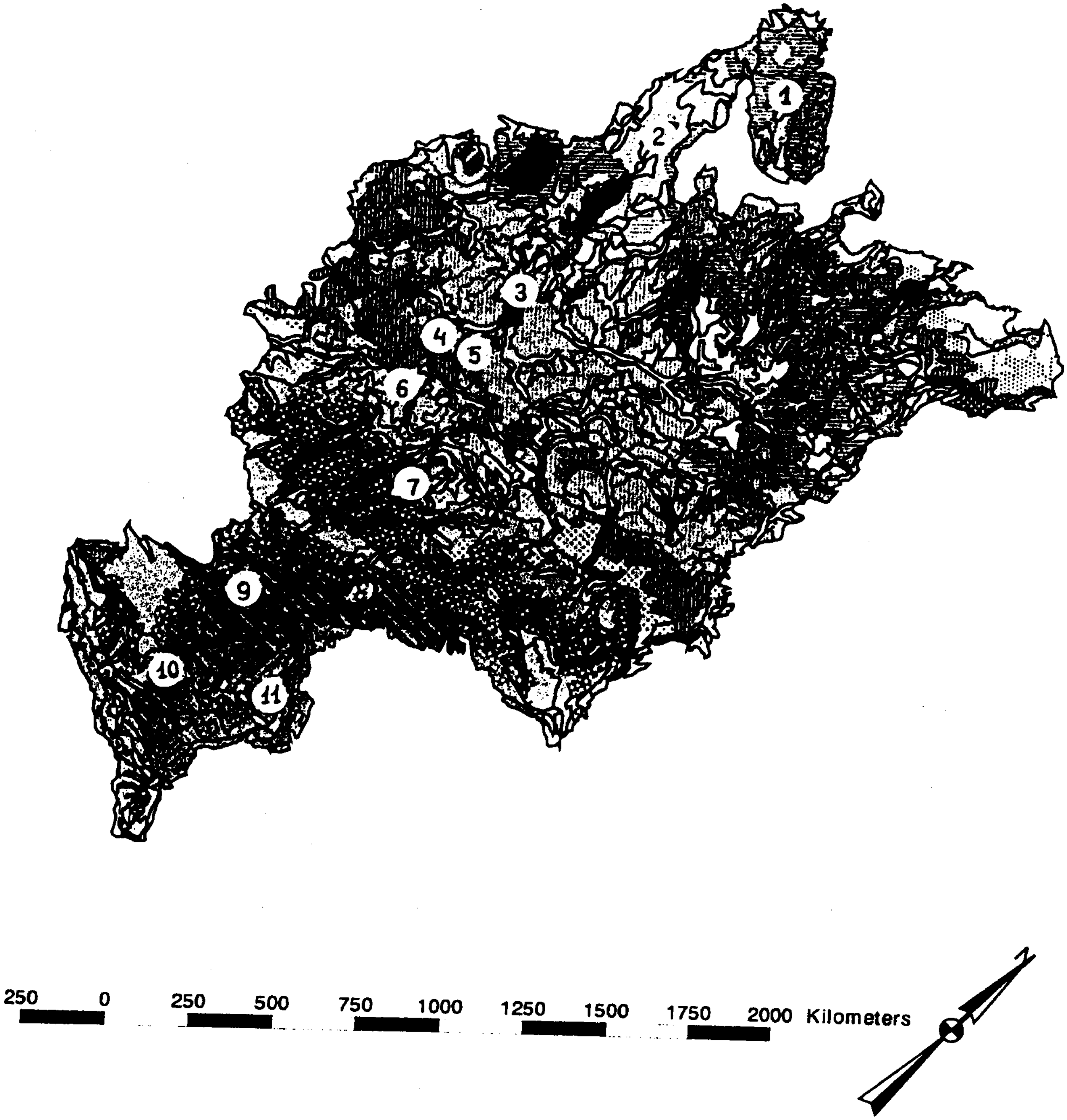

Fig. 2. Landscapes of Russia and maplet sites.

hardwood forests and shrubs. Agricultural lands are often protected by antierosional shelterbelts.

5.3. Image processing and land-cover classification

Satellite data from the RESURS-F/MK-4 instrument were spatially enhanced and corrected using the ERDAS Imagine processing system. In order to avoid the loss of information due to resampling and keep the spectral integrity of original data the images were first classified and only afterward rectified to the projection of the maps in the database. The nearest neighbour method was applied for rectification of the resultant thematic files to geographic co-ordinates of the database projection.

Maximum likelihood supervised classification with 8–10 training polygons per class and unsupervised Iterative Self-Organizing Data Analysis Tecnique

(ISODATA) were used for land-cover/land-use classification. Interpretation of classified scenes allowed the production of three small land-cover maplets, each with 4–7 land-cover types.

5.4. Landscape mapping

The next step of image interpretation was to derive the landscape information from the land-cover/use classification. Two groups of independent criteria were considered at this stage: landscape components (such as vegetation, soils, relief, and land use), and landscape pattern and texture. Interpretation of vegetation and land-use was based on classified images. Missing data on soil and topography were digitised from 1 : 200 K and 1 : 500 K scale topographic and soil maps.

The landscape pattern was then visually interpreted on the computer screen from the land-cover classified images so that each landscape type was identified as a particular patch-matrix-corridor combination (Forman and Gordon, 1986). In order to quantify the proportion of different land-cover types and the typical size of patches in each type of landscape pattern several simple landscape indices and Erdas analytical tools were used. Pattern analyses comprised detection of boundaries between classes, contiguity and diversity analyses. Landscape classes were identified according to both pattern and component criteria. Each maplet produced by this method has a legend compatible with the small-scale database but includes only 4–6 landscape categories against the small-scale database legend with 286 categories.

6. Small-scale database validation with large-scale 'maplets'

The database validation suggested topologic intersection of large-scale and small-scale maps and evaluation of their agreement. In order to evaluate the agreement between landscape categories produced by combining data from published small-scale maps, and those derived from imagery and large-scale maps, several simple techniques were applied.

First maplets were intersected with relevant fragments of the small-scale landscape map and agreement or disagreement between large-scale and small-scale landscape contours was evaluated for each map unit. As it could be expected very poor agreement was achieved because of different levels of heterogeneity of low and high-resolution maps.

The best agreement (70%) was a feature of relatively monotonous agricultural landscapes on the watershed plains in the forest-steppe zone (maplet no. 7, Fig. 2). Rather poor agreement was found between the broad-scale map and the maplet of Moscow region (no. 4) with its highly urbanised and very patchy mosaic of agricultural, forest and pastoral landscape combinations. However low agreement does not necessarily result from the poor quality of the broad-scale dataset or classification errors. Because the broad-scale map inherently represents a heterogeneous mosaic of patches captured by the high-resolution map, raw numbers of agreement should be expected to be low (Goodchild et al., 1996; Stoms, 1996). When the Moscow region and Darwin reserve maplets were aggregated to approximately 1 : 1 M scale, the same comparison with related broad-scale fragments showed much better agreement (68 and 82% respectively).

The second comparison looked at the total area of landscape types throughout each maplet area. This comparison, although it is unable to consider the landscape pattern of the compared maplets, was helpful to make a rough assessment if the area of some landscape types could be greatly over- or underestimated in the broad-scale database. This comparison made us suspect that the areal extent of secondary mixed forest landscape might be seriously overestimated in the Moscow region on the published broad-scale maps. However, we are not sure at this stage if this disagreement results from the rapid vegetation change around the Russian capital or from a vague forest definition in the legend of the 1 : 4 M map of vegetation of the USSR taken as a source for our database.

When maps of two different resolutions are compared they represent the landscape structure at two different levels of heterogeneity. Therefore, it was necessary first to assess if the labels of landscape units on the broad-scale map agree with the predominant patches of the maplets over the same area. If the label of the broad-scale map landscape unit agreed with the patches, which occupied more than 50% of the intersected area of the maplet, this unit was considered to be in agreement with the maplet. If the patches in agreement occupied less than 50% of the broad-scale landscape unit the maps were considered to disagree. This criterion is more correct than the overall agreement of total area of each class because two different maps may agree in the total area of landscape categories but do not necessarily depict their similar pattern.

The suggested comparison methods unfortunately could not capture quantitatively the impact of different levels of heterogeneity on agreement between broad- and high-resolution maps for landscapes with finer or coarser grain structure. Ideally, it would be interesting to compute the proportion of the mixed patches of the higher-resolution level for each landscape type on the broad-scale dataset. At this stage, however, only qualitative labelling of broad-scale landscape types as associations of finer-resolution landscape groups was undertaken. But it would be a challenge to apply further regression analyses to quantify the proportions of landscape patches at different scales changing with the level of landscape heterogeneity.

7. Results and discussion

The main output of this work is the broad-scale database and classification of Russian landscapes. Except for the recently available Land-Use Map of the USSR (CD-ROM based on Yanvareva, 1991) this is the first digital product of this scale covering the entire European Russia. As all GIS products it has many obvious advantages compared to existing hard-copy landscape maps (projection and scale flexibility, quick and efficient update and correction, statistics generation upon the selected criteria, etc.). The landscape database is an open system and in contrast with traditional landscape maps allows import and export of information, modification of classificatory principles and great flexibility in the use of spatial variables of interest. What is even more important is that the database can be extremely useful in serving as a territorial framework for broad-scale landscape and land-use modelling. Thematic information on landscape components organised as a multi-layer cartographic database proves useful for analysing not only horizontal spatial relationships between landscape polygons (such as neighbourhood, mosaic pattern, transitional zones and corridors) but also vertical links, mutual impacts and dependencies between landscape components.

Although the database is already available for users, several improvements should be foreseen in the near future: inclusion of DEM, which would enable analyses of slope and elevation on landscape pattern, instead of the currently used map of 'landform classes'; and increasing the range of climatic parameters, including mesoclimatic data.

Classification and analysis produced a hierarchy from which four levels (eight sublevels) of grouping were derived:

- Climatic level with three systems and seven subsystems;
- Landform level, which intersected with climatic level gives nine classes and 16 subclasses;
- Ecosystem level with 22 types and 68 subtypes;
- Human impacts level, where intersects of subtypes and groups with 25 land-use categories yield 286 different landscape units.

The proposed classification, however is far from being the first landscape mapping experience of this vast territory and partly borrowed its architecture from more or less intuitive landscape classifications implemented on Russian territory (Goudilin, 1980; Isachenko, 1978; Milanova et al., 1993). Its realisation was then filled with quantitative criteria, which allowed us to formalise the associations between different natural components into landscape categories. The landscape mapping unit is still quite a subjective object, at least while its representation strongly depends on the choice of criteria and decision rules of the classification. That is why it would not be effective to judge the quality of the proposed map on the basis of comparison with other landscape maps of Russia of broader or comparable scale. Although brief visual comparison with some of them shows rather good agreement of landscape pattern, such reference to other subjective broad-scale landscape maps could not be a satisfactory validation.

Traditional validation of the new cartographic product by random point validation would demand an unfeasibly great amount of field survey data and would be impossible for so broad a mapping area. To be a statistically consistent validation procedure through-

Table 3
Contingency tables between the small- and large-scale datasets – Darwin reserve, hectares Maplet 3

EPR map	1	2	3	4	total	% correct (user)
1	199015	11235	4328	6678	221256	89
2	13821	100379	12115	0	115523	86
3	2233	8984	31629	2003	44849	70
4	7536	2489	6583	115413	132021	87
Total	222611	123987	54655	124094	513649	
% correct, (producer)	89	80	57	93		

1 – Dark coniferous forest with peat bogs and small lakes.
2 – Birch-aspen secondary sparse woodland with swampy meadows.
3 – Arable-pastoral landscape with rural settlements.
4 – Water.

out such an extensive area classified into hundreds of mapping units would require several millions of testing points. That is why the 'maplet' method was chosen to test the validity of landscape database. Comparison of small fragments of the obtained broad-scale landscape map with a set of maplets, independently produced from high-resolution satellite imagery combined with large-scale ancillary data, is an attempt to overcome the subjectivity of a broad-scale mapping and to find agreement or disagreement between two different classifications. The results of the comparison vary from one site to another.

The best agreement appears in the sites with relatively homogenous landscapes (semi-natural landscapes in boreal forest zone and agricultural plain landscapes in the forest-steppe zone). In contrast poor agreement characterises mainly the highly heterogeneous sites with a complicated land-use pattern. Analysis of the Moscow site (maplet 4), for instance, shows a considerably less important extent of secondary mixed forest on the maplet than in the database. However, we do not know yet the reason of this disagreement. Meanwhile Tcherkashin and Milanova (1998), also recently reported a similar disagreement with published broad-scale maps based on analyses of NOAA AVHRR data. It is necessary to investigate if this overestimation of the mixed forest cover applies only to the Moscow region, or equally to a much bigger area. Maplet 5 to be taken also in the mixed forest zone but without big urban centres could help to answer this question. The general agreement or disagreement between the three maplets and the respective fragments of the broad-scale dataset are shown in Tables 3–5.

Table 4
Contingency tables between the small- and large-scale datasets – Moscow region, hectares Maplet 4

EPR map	1	2	3	4	5	6	total	% correct (user)
1	15308	22095	1253	344	0	525	39525	38
2	4958	78279	34121	10523	512	764	129157	61
3	808	33564	149956	23543	5535	2254	215660	70
4	1002	25315	72658	59213	234	2345	160767	37(!)
5	87	53	31253	8965	2629	6258	49245	6(!)
6	543	211	8748	214	46	24348	34110	71
Total	22706	159517	291989	102802	8956	36494	622464	
% correct, (producer)	67	49	51	58	29(!)	66		

1 – Urban built-up area.
2 – Agricultural-recreational highly fragmented. woodland-forest-meadow landscape around the city.
3 – Secondary mixed forest.
4 – Arable lands with fragments of forest and pasture meadows.
5 – Dark secondary coniferous forest.
6 – Water.

Table 5
Contingency tables between the small- and large-scale datasets – Voronez region, hectares Maplet 7

EPR map	1	2	3	4	total	% correct(user)
1	22126	1441	0	0	23567	94
2	37654	385975	2458	2548	428635	90
3	123	4323	132458	1427	138331	96
4	432	4500	1949	6237	13118	48(!)
Total	62335	396239	136865	10212	605657	
% correct, (producer)	35(!)	97	97	61		

1 – Urban built-up and suburban highly fragmented rural/agricultural landscape.
2 – Arable lands and plantations intersected by gully network.
3 – Broad-leaved primary forest;
4 – Water reservoir.

Because of the difference of scale of these two observations of the same sites two different levels of landscape heterogeneity were captured, and so it is normal to have relatively poor agreement between them. However, resampling of maplets to 1 : 1 M scale and filtering out tiny polygons allowed the achievement of much better agreement between the two datasets. Taking in account this difference of scales, it is important that even though there are quite many disagreements due to the different pattern representation on the broad-scale map and corresponding maplets, there is a good agreement between their landscape labelling. With a few exceptions all landscape labels present on the broad-scale fragments were recognised equally on the respective maplets. As far as the comparison of areal extent is concerned the best agreement was found for water, dark coniferous forest, and arable landscapes in the forest-steppe zone. There is a lot of confusion between mixed forest, woodland, pastoral and arable landscapes in all sites where these categories are present. This is most likely due to a different interpretation of the same areas on the referred broad-scale land-use map and in the image classification. Areas labelled as 'arable-pastoral' were sometime classified as grassland, sometimes as agricultural and sometime as woodland. Also a considerable part of 'mixed forest' was classified on the image as 'sparse woodland'. Such disagreements do not mean any error but in contrast may be considered as a good co-occurrence of similar landscape categories. It is also impossible make a proper comparison for urban landscapes except Moscow and St-Petersburg and to fully use maplet information because less important urban centres are mapped in the EPR dataset by spots.

There may be several reasons responsible for disagreement between the two datasets:

- Difference of landscape pattern heterogeneity captured at the lowest level of the broad-scale classification and on the maplets derived from the high-resolution imagery and large-scale maps;
- Difference of interpretation and labelling of the same landscape categories coming from the broad-scale source maps and from satellite data (not necessarily errors but difference of definitions of 'forest', 'pasture', urban land, etc in different sources);
- Errors in data co-registration and reclassification in the broad-scale dataset with consequent misinterpretation of resulting landscape units;
- Errors in the input of broad-scale data;
- Landscape change (or change of any landscape component) since the input data were acquired (broad-scale maps published in 90s generally depict the situation of the previous decade at best);
- Misclassification of landscapes on the high-resolution maplets due to errors in the image data calibration and interpretation.

Despite all these problems of assessing broad-scale data accuracy, the maplet approach is a much more efficient alternative to the traditional contingency table method based on random point sampling. With 286 landscape categories on the lowest level of suggested classification and the great extent of the study area, statistically meaningful assessment by random point sampling would require at least 14300 sampling points (minimum 50 points per category) (Congalton, 1991). It is obvious that collection of such an amount of field data is impossible. The maplet method suggested by Chrisman (1991) and first applied by Stoms (1996) provides an efficient and cheap alternative. Stoms developed the method using only one maplet to test the accuracy of the map of a 2240 km^2 area in San-Diego County and he used a very-high-resolution habitat map of less than 1 ha derived from the aerial photo. The scale and level of landscape aggregation of this study is much broader and suggests a dozen 3600 km^2 maplets needed for validation of a 3 335 605 km^2 area. After the generally successful application of the maplet method on the three above sites, the next step of our study will be to extend the assessment of the EPR landscape classification to another eight sites (Tables 3–5).

In many regions of the world, like in Russia, ready-to-use large-scale landscape maps are not available and their production by traditional field survey would be very expensive. Instead, satellite data may be directly used for maplet compilation. Detailed and up-to-date maplets can be also an efficient tool for finding areas or mapping categories, which need updating.

It can also help to analyse ecological nature of disagreement in the map legends caused by vagueness of class definitions or their different understanding by different disciplines, rather than traditional binary 'false/true' validation.

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