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Spatial Modeling of Vegetation Units for GIS-based Terrestrial Carbon Accounting in the Siberia-II Study Region

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Contents

Abstract

This study dealt with the development of spatial methods for generating a land cover database over the Siberia-II study region in Central Siberia, for the purpose of full terrestrial carbon accounting. Hierarchical decision rules were developed specifically for this boreal region to indicate vegetation distribution and relied mainly on satellite derived datasets such as land cover, digital elevation models, Vegetation Continuous Fields, and a disturbance dataset, as well as a soil database. The resulting spatially-based description consists of vegetation units, which are homogenous in vegetation composition and stand conditions and therefore in above-ground carbon content (living biomass) and rates of CO_2-absorption (Net Primary Production—NPP). This spatial vegetation model is part of a regionalization system for IIASA’s Geographic Information System (GIS)-based landscape ecosystem model for full terrestrial greenhouse gas accounting.

Traditionally, satellite-based approaches to vegetation classification over large areas rely upon one main input dataset, and the use of trained algorithms for classification. Results from this study indicate that an automated approach, which combines a priori information specific to a region, greatly enhances the value of the final result. Results from this study could be applied to other large boreal regions with modifications, and the techniques developed here could be further tested.

Acknowledgments

This work was carried within the Forestry Program as part of IIASA's Young Scientists Summer Program (YSSP) in 2005. The author is grateful to her supervisor Anatoly Shvidenko, who provided her with the needed scientific information and helped her with the development of the decision rules. Additionally, the author would like to thank Ian McCallum for his help with respect to technical questions concerning GIS (Geographic Information System).

About the Author

Daniela Knorr graduated in July 2002 from the Friedrich-Schiller-University in Jena, Germany in geography. Her main fields of scientific interest include remote sensing and Geographic Information System (GIS) and their application in climate change research. Her research project during the YSSP 2005 was embedded in her Ph.D. project in the framework of the EU-project SIBERIA-II at the Friedrich-Schiller-University in Jena, Germany with the topic “Application of Spatial Modelling Techniques in an Ecosystem GIS for Improved Greenhouse Gas Accounting in Boreal Ecosystems”.

Spatial Modeling of Vegetation Units for GIS-based Terrestrial Carbon Accounting in the Siberia-II Study Region

Daniel Knorr

1 Introduction

A major requirement of the Kyoto Protocol is the development of a comprehensive and consistent system to measure sources and sinks of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The development, evaluation and implementation of such a global scale mapping and monitoring system is one of the major challenges for the science community and particularly within the field of geography. The investigations have to focus on the development of appropriate methods for detailed and accurate acquisition and assessment of spatial characteristics in GHG sinks and sources. In that context, the combined application of remote sensing, spatial analysis and spatial modeling represents one of the most important methodological frameworks. Currently, remote sensing is the only method for the derivation of spatial data with appropriate spatial and temporal resolution and consistency. The reasonably priced and detailed remote sensing data open up new views to climatic process research for the observation of large parts of the earth's surface and atmosphere.

The EU-funded project SIBERIA-II—Multi-Sensor Concepts for Greenhouse Gas Accounting of Northern Eurasia—uses both satellite based remote sensing and in-situ measurements in order to derive land surface parameters for GHG accounting. These parameters are transferred to both, Dynamic Global Vegetation Models (e.g., LPJ-Model of the Potsdam Institute of Climate Impact Research) and a Geographic Information System (GIS)-based landscape ecosystem model by IIASA. The latter is an empirical model, which provides diagnostic predictions of the carbon storage and GHG fluxes in the study region. GIS serves as a medium for preprocessing the input data, management of the data sets, building a database holding all parameters needed for the model, and cartographic and visual display, as well as spatial analysis of the model results. The model itself is a specifically developed C-program consisting of empirical regression equations and runs outside the GIS. The IIASA model for a terrestrial biota full GHG account consists of a combination of two major approaches. The pool-based approach accounts for the carbon stored in live biomass (phytomass), dead biomass (litter), below and above ground, respectively; henceforth called Full Carbon Account (FCA). The flux-based approach accounts for Net Primary Production (NPP), fluxes due to natural and human induced parameters and transport of carbon to lithosphere and hydrosphere. The input parameters for the IIASA model include the detailed description of ecosystems on a polygon level, numerous sets of empirical models for estimating major components of the FCA (NPP, Heterotrophic Respiration, etc.) and other auxiliary information (Shvidenko, 2005). A technical description of the GHG model can be found in the SIBERIA-II internal Deliverable 66 by Nilsson *et al*. (2004a).The base year for the calculations is 2003.

Since some of the needed crucial input parameters are available from remote sensing, the idea arose to develop a methodology for parameterization of the IIASA model with remote sensing products. Within the presented research project, the potential of remote sensing data for mapping the strongest and most rapidly changing component of the terrestrial carbon cycle, namely vegetation, is investigated.

2 Objectives

IIASA's model input data set is a polygon based vegetation map with an attributive database holding all information needed for the calculation of GHG fluxes and carbon pools. This map was delineated by Russian regional vegetation experts. By manual digitizing in ArcMap (ArcGIS 8.3) they identified and delineated homogenous polygons based on a variety of information sources (field data, forest inventory, topographic maps and remote sensing data). As an additional source, the SIBERIA-II land cover dataset produced by the University of Wales, Swansea (UWS) (Skinner and Luckman, 2003) has been used for initial separation between forested and non-forested areas. The vegetation attributes for polygons were taken from aggregated forest inventory maps at the scale of 1:100.000 to 1:300.000 and databases (both digital and hardcopy) and manually assigned to each polygon (Nilsson *et al*., 2004b). Although this procedure is very accurate it has several disadvantages:

- The approach is very labor and time consuming.
- In order to receive a manageable number of polygons for the big study area, the data is strongly aggregated.
- The practical implementation of the delineation and aggregation rules is not completely clear, as a huge amount of expert knowledge was incorporated. Thus, the estimation of uncertainties of the process of delineation is not possible.
- Forest inventory, the most important information source for this product, is only conducted every 10 to 15 years and also only in the forested middle and southern parts of the study region. For the remote northern parts for which data from different inaccurate and obsolete inventories were available, the updating was provided based on air photography and partially by using LANDSAT imagery.

- The result presented by IIASA's vegetation map is a snapshot land cover description for 2003. An extension of the above mentioned points to other years is not possible.

Since vegetation is the strongest and fastest changing component of the terrestrial biosphere and therefore the most important part in the GHG balance, it is necessary to observe it continuously. Only an automated method using strict algorithms and data retrieved continuously in time can provide the needed temporal resolution for the IIASA model for full GHG accounting.

The only cost effective data source offering the needed temporal resolution comes from remote sensing. Especially in terms of change detection and mapping disturbances, such as fire or logging, remote sensing can help to observe vegetation. Unfortunately, remote sensing data lacks the required depth of information about vegetation classes, dominant species in forests, etc., which are needed for accounting major components of a FCA and resulting exchange of CO_2 between atmosphere and biosphere. The SIBERIA-II land cover product, which was retrieved from the MODIS/TERRA sensor with a spatial resolution of 500 meters (m) contains only 16 classes, which represent superordinated vegetation classes, such as evergreen needleleaf forest or wetland. However, the IIASA model differentiates between single tree species, types of wetlands etc., because there are significant differences in the rates of respiration and assimilation between different species.

To fulfill the requirements of the vegetation database needed by the IIASA model, namely yearly information on vegetation distribution and high classification depth down to species level, a synthesis between both approaches is needed. With a combination of remote sensing and inventory data a relevant bottom-up/top-down approach could be developed.

Therefore, the objective of this research is the development of an automated method for the derivation of a vegetation map, which can be used as a substantial part of the input data set for the IIASA model for FCA. The input data for this vegetation map comes from both remote sensing and ground data. For the classification of these data into the needed vegetation classes, rules have to be developed. The technical environment for this method is GIS, because of its strength in managing different spatial data sources and the large number of tools for combining, overlaying and analyzing spatial data. With this exercise the potential of remote sensing data for mapping the vegetation will be evaluated.

3 State of Science

A full carbon account must include all land cover and land use types and requires therefore a holistic view of the environment and an integration of all relevant information sources (on-ground, remote sensing data and appropriate regional ecological models) (Nilsson *et al*., 2004a). This concept represents the basic idea of landscape ecology, which studies the individual elements of a landscape (soil, relief, vegetation, hydrosphere, etc.), in contrast to traditional ecology, not separated from each other, but as a whole (Naveh and Lieberman, 1994). Additionally, landscape ecology is interested in the effect of geographic location on and spatial interactions between the different landscape elements and species (Johnston, 1998).

3.1 The Russian Landscape Concept

Trying to divide the vast territory of Russia in bio-, soil-, or climate-ecological zones, landscape ecology played and still plays an important role as an approach for regionalization in Russia's schools of natural science. Putting the emphasis on different landscape elements (e.g., soils by Dokuchaev, vegetation types by Tanfilyev, or relief by Polynov) different regionalization concepts were developed. Nevertheless, all ideas about landscape zonation have two aspects in common: first, a division in natural complexes which are homogenous in zonal and azonal aspects regarding several environmental parameters and second, a hierarchy of classification levels from superordinated zones, for example, macroclimatic zones to subordinated parts of landscapes, e.g., vegetation (Gudilin, 1987; Rojkov *et al*., 1996).

Regionalization in means of landscape ecology, the so-called landscape approach, plays a crucial role in different fields of science, nature reserve, planning and management in Russia, such as forest inventory and forest management (Rojkov *et al*., 1996).

Rojkov *et al*. (1996) applied landscape ecology for the development of a classification scheme of Siberian landscapes and the derivation of a digitized map of Siberian landscapes at the scale of 1:1 million. It represents five different levels from geological megastructures, over macroclimate, geomorphology and soil characteristics to vegetation type. This map serves as a basis for the evaluation of biodiversity and bioproductivity and for forecasting the dynamics and development of the landscapes under conditions of natural and anthropogenic disturbances.

3.2 Predictive Vegetation Mapping

Another application of landscape ecology, enabled by the technology of GIS, is spatial modeling of different landscape components, such as vegetation. Vegetation patterns are determined by environmental factors, such as the climate, topography, soil, as well as human disturbances. As soon as information about a region is poor or not available because the study region is too big or inaccessible to be mapped in situ, predictive vegetation mapping—an application of spatial modeling—is needed. This is an approach, which uses relationships between vegetation distribution and already mapped physical data to predict vegetation composition across the landscape (Vogiatzakis, 2003).

Plant growth and species composition of vegetation depend on ecological site factors, such as elevation and slope aspect, which have an influence on temperature, as well as slope and slope curvature, which influence the flow direction and allocation of water (Pfeffer *et al*., 2003).

GIS can be used to derive primary topographic parameters, such as elevation, slope and aspect, as well as secondary topographic parameters, for example, potential solar radiation or topographic wetness index from **digital elevation models** (DEMs). The use of topographic attributes derived from DEMs is among the most common variables employed in predictive vegetation mapping (Vogiatzakis, 2003). Pfeffer *et al*. (2003) used for elevation, slope, curvature and wetness index derived from a 10 m resolution DEM together with vegetation sampling plots to map alpine vegetation in Tyrol/Austria on a local scale. By using cluster analysis the authors found linear regressions between sampled vegetation and topographic attributes, which where then used to model the distribution of vegetation species with GIS.

Moore *et al*. (1993) used two sophisticated models to calculate the spatial distribution of annual short-wave radiation, annual net radiation, average minimum monthly temperature, annual evapotranspiration and soil water content from a 20 m DEM to characterize the fine-scale environmental heterogeneity and environmental domain of the five forest types in the sub-alpine study area of Brindabella Range in south-eastern Australia.

Bolstad *et al*. (1998) studied the relationships between mapped forest composition in the Southern Appalachian Mountains/USA, elevation and terrain curvature calculated from a 30 m and a 80 m DEM. Producing vegetation maps applying four different geostatistical methods to elevation and curvature derived from the DEMs, and comparing it with the on-ground mapped vegetation, they observed strong relationships between some tree species and the terrain parameters. Additionally, they found that regression and mosaic diagram mapping approaches had significantly higher mapping accuracies than kriging and co-kriging, as well as that DEMs with a finer resolution produce more accurate vegetation predictions.

Remote sensing data is also often used as initial information about the distribution of vegetation pattern. One example for the application of GIS and remote sensing data for predictive vegetation mapping is given by Ohman and Gregory (2002), who presented a GIS-based gradient analysis and nearest neighbor method for predicting forest composition and structure in the Oregon coastal province. Using multiple vegetation attributes from georeferenced forest inventory plots, mapped environmental data (climate, topography, geology), and land cover classification from Landsat TM imagery, they received good to moderate accuracy for predicted tree species occurrence and several measures of vegetation structure and composition.

Another study by Kharuk *et al*. (2003), conducted in the SIBERIA-II study region, used NOAA AVHRR data for forest mapping along the Yenisey River. An attempt to classify the entire 1000 kilometers (km) × 3000 km transect at once turned out to be too general to map the different landscapes along this vast area. The classification was improved using a landscape-ecological approach, by segmentation of the transect into ecological regions. Using this approach AVHRR data were found to be adequate for small scale mapping at the level of vegetation types or plant formations. A comparison of the classification results for mountainous regions showed that AVHRR-derived maps were more detailed than existing landscape maps, and larger scale forest management maps of softwood and hardwood forests.

The **combination of remote sensing data and digital terrain analysis** has also been proven a practicable method for predictive vegetation mapping. Dirnböck *et al*. (2003) employed topographical variables (elevation, slope, aspect and curvature derived from a 50 m DEM) reflecting relief properties as surrogates for environmental conditions in combination with spectral band values from high-resolution infrared air-photography to map dominant plant communities of an alpine area in the north-eastern Alps in Austria. Since different plant communities often show similar spectral responses, their specific topographical location could help to separate them from each other. Whereas the correlation between topography and plant species distribution was particularly significant for mapping alpine grasslands, spectral texture measures proved to be of major importance in discriminating between pioneer communities. The overall accuracy was 69.4%. Inaccuracy resulted from confounding effects of additional controls like land use history, which could not be accounted for by topographic descriptors.

Kuzmenko (2003) used MK-4 space-borne remote sensing data and information about elevation, soil and geomorphology coming from existing maps, to produce a map of the forest vegetation in the south-eastern part of the Angara-Yenisey region in Siberia, especially considering anthropogenic disturbances.

4 Description of the Study Region

4.1 Geographic Location

The study region of the Siberia-II project is located in central Siberia/Russia spanning from 85° to 115° east and from 52° to 75° north. It covers a total area of 328 million hectares (ha), limited by borders of six administrative regions of the Russian Federation: *Krasnoyarsk kray, Autonomous Republic (AR) Khakassia, Taimir* and *Evenkia Autonomous Okrugs (AO)*, and *Irkutsk oblast*, including *Ust'-Ordinsky (AO)* (Nilsson *et al*., 2002). Figure 1 shows the location of the study region in Eurasia with its six administrative regions.

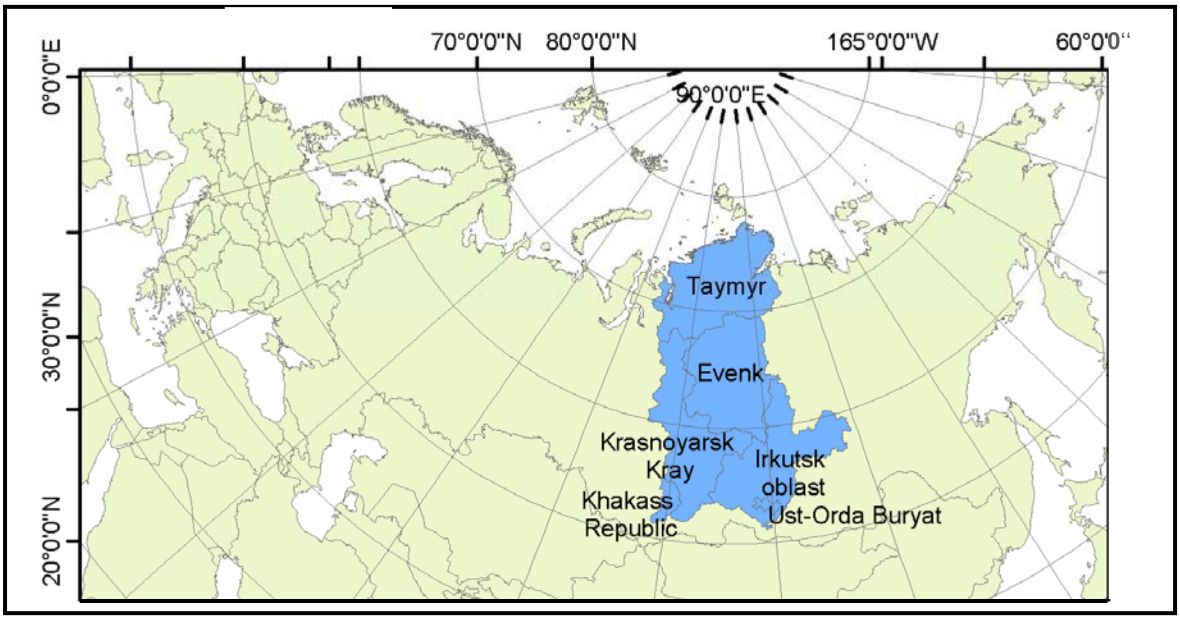

Figure 1: Location of Siberia-II study region and administrative regions.

4.2 Climate

The climate of the study region is very diverse, because of its vast north-south extension of about 2500 km. It is characterized by latitudinal caused increases of temperature from north to south as well as by increasing continentality from west to east. The average annual air temperature varies from –17°C in the north to 0°C in the south-west of the region. Differences of maximum and minimum temperatures during the year reach about 60 to 70°C. Precipitation is more influenced by increasing continentality and decreases more from west to east. The ranges of annual precipitation are very high. While some north-eastern parts are limited to 250 millimeters (mm), some altitudinal belts of the West Sayan Mountains in the south-west of the study region receive 1500 mm (Lucht *et al*., 2003; Rojkov *et al*., 2003).

The length of the growing season increases from north to south and fluctuates between 60 and 140 days. The warmest July temperatures range from 17°C in the north to 24°C in the south (Kashtanov, 1983). Lower temperatures and fewer days above 10°C in the north result in a lack of trees, whereas the south is characterized by higher temperatures and distinct tree growth (Lucht *et al*., 2003).

4.3 Landscapes and Topography

Resulting from the diverse climate and relief the landscapes of the region are very diverse. The Arctic shore is a low-altitude plain. In the center of the Taimir peninsula are the relatively low mountains of Byranga (the highest peak is at 1146 m). Both regions are barely covered by arctic tundra (Gudilin, 1987).

To the south, the vast North Siberian plain stretches to 71° N. Bearing more vegetation than the Arctic areas this region is covered by subarctic tundra and a narrow belt of forest tundra at the transition zone to the South following the vast territory of the Middle Siberian Plateau. This stretches to the line Krasnoyarsk-Ust'-Ilimsk-Mirny. The plateau is dominated by hilly terrain and low mountains including a number of smaller plateau areas: The Putorana (up to 1700 m above sea level—asl), and Anabarskoe (up to 905 m asl) are covered by forest tundra and sparse taiga. The Siverma (up to 942 m asl) is covered by middle taiga, mostly larch forests. Finally, the lower Viljuiskoe, Prilenskoe and Central-Tungusskoe plateaus are covered by vast areas of continental low-productive larch forests (Pleshnikov, 2002; Rojkov *et al*., 1996, 2003).

To the west, the Yeniseisky *krjag* (range) forms the right bank of the Yenisey River between the mouth of Podkamennaja Tungusska (Stony Tunguska) and Krasnoyarsk (Rojkov *et al*., 2003: 55). Further west on the left bank of the Yenisey River, the West Siberian Lowland—a neotectonic depresssion—stretches to the Ural (Treter, 1993). Although both sides are covered by taiga forests, they are substantially different. While the West Siberian Lowland are flat and rich in wetlands and dark coniferous forests, the Yeniseisky *krjag* is hilly with elevations up to 500 to 600 m and covered mostly by fir and cedar forests further to the East.

The southern part of the region is basically formed by the mountain systems of East and West Sayan with mountain southern taiga forests (Rojkov *et al*., 1996). In the transition zone between the taiga forests and the Sayan Mountains, on both sides of the Yenisey River, there are relatively small areas of steppe and forest steppe.

4.4 Soil, Permafrost and Wetlands

When the annual mean temperature is mostly below 0°C, permafrost—permanently frozen ground—appears. Almost the entire study region (except for the territories to the west of the Yenisey River below 65° N) shows permafrost in different characteristics (sporadic, discontinuous, continuous). The southern border of continuous permafrost reaches to 65° N. Permafrost plays a crucial role for soil formation in this environment (Walter and Breckle, 1994).

Because weather conditions for most of the year are cold and wet and the coniferous needles and ericoid leaves of many dwarf shrubs are persistent, the decomposition of dead organic matter is very slow. As a result, huge litter layers are formed especially in the boreal forest region. Since there is little evaporation and water cannot infiltrate the permafrost in almost the whole study region, water logging leads to the formation of peat or raw humus. Especially in the North of the study region and western side of the Yenisey River, extended bogs and marshes constitute in depressions (Schultz, 1995). The western side of the Yenisey belongs to the Western Siberian Lowlands, comprising the Ob-Irtiysh Basin, which represents the largest bog region on earth. Since this territory was never glaciated in the Pleistocene, alluvial clay could be sedimented. Together with the permafrost and flat relief this led to water logging. The development of bogs started 10 to 12 thousand years ago, and is still continuing. Today, about 40% of the entire peat deposits on earth are located in this region (Walter and Breckle, 1994, 1999).

4.5 Hydrology

The density of rivers is usually high (Schultz, 1995). The biggest rivers in the study region are the Yenisey and its largest tributaries Angara (the outlet of Lake Baikal), Stony Tunguska, and Lower Tunguska. The longest river is the Yenisey with a total length of more than 4,000 km, running from the Sayan Mountains in the south straight northwards between the peat basin of the West Siberian Lowland and the plateaus to the Kara sea (Brissette *et al*., 2000).

Extreme runoff peaks occur in April and May, when all the snow melts within a few weeks. In the beginning of the thaw period the river beds are still frozen and therefore overflowed by the melting water. Because of this and the non-cohesive material of the river banks which crumbles easily when it is undercut, the rivers often change their courses, forming braided streams on broad valley floors (Schultz, 1995).

Besides the dense river network, lakes and wetlands are conspicuously numerous in the study region, especially in the tundra and on the western side of the Yenisey.

4.6 Vegetation Pattern

As a result of the diverse climate, vegetation differs extremely from north to south. In the most northern part of the study region, arctic deserts can be found which account for only 2% of the entire study area. Slightly to the south, the region is covered by tundra, which accounts for about 30% of the entire study area. With about 60% of the study region, the boreal zone of coniferous forests (taiga) with its subzones of sparse taiga, northern taiga, middle and southern taiga is the main vegetation type (Pleshikov, 2002; Zhukov, 1969; Rojkov *et al*., 2003). The transition zone between tundra and taiga is called forest tundra. In the dry south-west of the study region, there are some small steppe and forest steppe regions. Like the arctic deserts, these ecozones also cover only 2% of the region (see Figure 2).

Due to the low nutrient supply of the soils and the short growing season, agriculture does not play an important role in the study region. Agricultural areas, which are mainly pastures (Walter and Breckle, 1994), covered in the 1990s only 3.2% of the entire study region (10.2 million ha) (Rojkov *et al*., 2003). Currently this area is constantly decreasing due to abandonment of agricultural land (Kejuev, 2001).

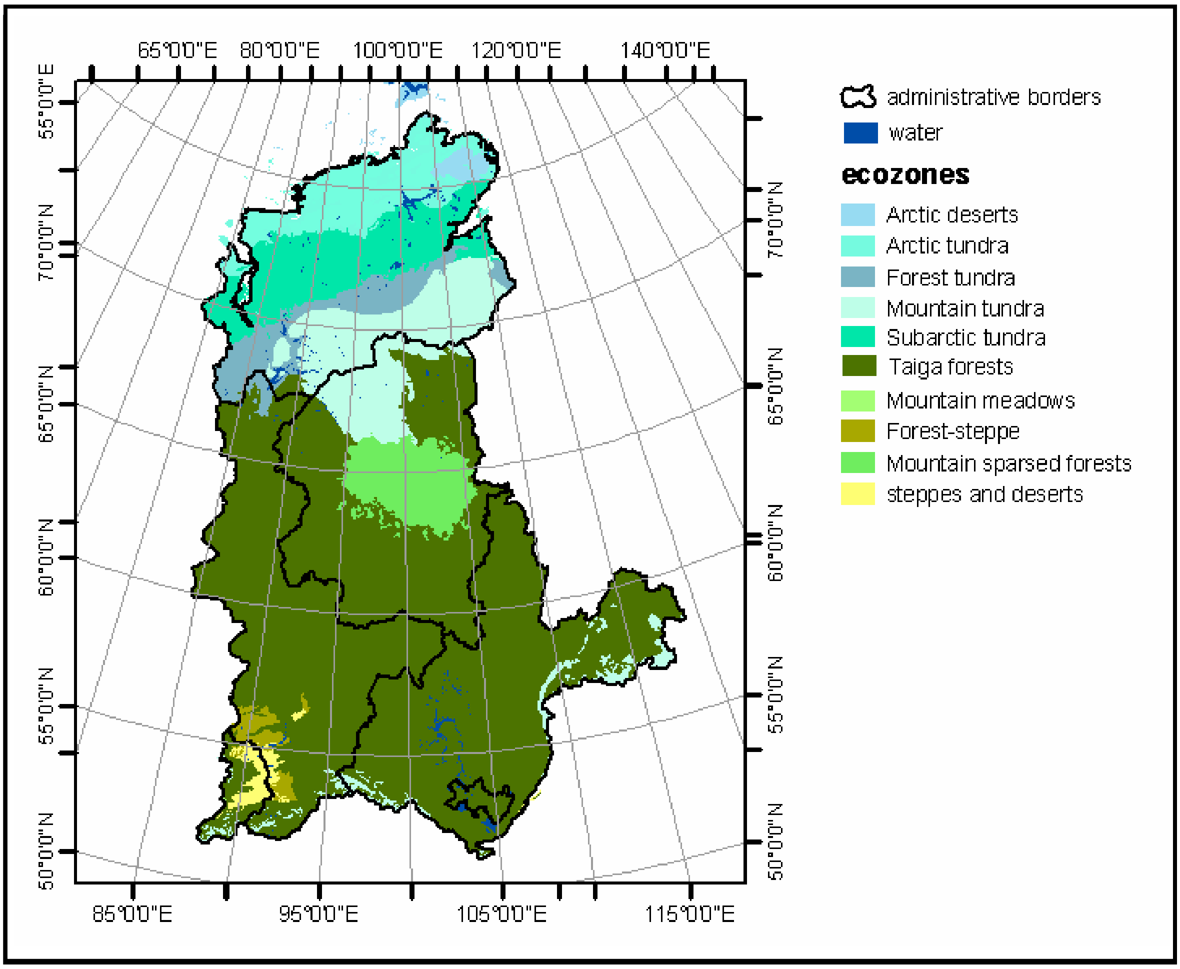

Figure 2: Ecozones of the Siberia-II study region (data by IIASA).

4.6.1 Tundra

The tundra zone has three subzones in the study region. The **arctic tundra** shows dwarf shrub-herb-lichen-moss and herb-lichen-moss polygonal spotted vegetation communities (basically small shrubs, like *Salix polaris, Dryas punctata, Saxifraga hieracifolia, Deshampia borealis,* etc.) and sedge-grass-moss mires. The **typical tundra** is represented by hemiprostrate dwarf shrub-lichen-moss, tussok and low shrub tundras (*Cassiope tetragona, Dryas, Empetrum subholarcticum, Vacinium uliginosum, V. vitis-ideaa, Ledum decubens*) and polygonal herb-dwarf shrub-lichen-moss mires. The **southern tundra** is basically generated by shrub and tussok tundras (*erniki*-generated by *Betula exilis, B.nana*), willow (*Salix alaxensis, S. glauka, S. lanata* and others), alder (*Alnus fruticosa*), tussok tundra with *Eriophorum vaginatum,* grasses-low shrubs with sedges (*Ledum, Vaccinium, Dryas, Cassiope tetragona*) and polygonal herb-dwarf shrub-lichen-moss mires (Rojkov *et al*., 2003).

The southern border of the tundra region against the boreal forest zone is represented by the forest tundra, a belt of about 100 km width, where coniferous forest (mainly larch) and tundra gradually merge into one another (see Figure 3). This transition zone runs along 72° N following the 10°C July isotherm and the polar tree line. Reasons for the development of a tree line are freeze dryness and permafrost, which decreases the space for roots (Grabherr, 1997; Schultz, 1995).

Figure 3: Typical tundra with open water bodies (Source: http://www.arctic photo.co.uk/gallery2/arctic/landscape/tundra/tundra.htm).

4.6.2 Boreal Forest (Taiga)

A major part of the study region belongs to the typical boreal forest zone. It stretches from 72° N to 50° N, where it borders the steppe, and has the most southern extension of the entire boreal zone (Walter and Breckle, 1994).

Compared to the boreal forest in North America and Eastern Asia, the boreal forest in Siberia has a limited diversity of tree species (Shvidenko and Nilsson, 2003; Walter and Breckle, 1999). Only five dominant coniferous species (pine, spruce, fir, larch and cedar) cover 71.1% of the total forested area in Russia. By adding the two deciduous species—birch and aspen—the coverage is 87.4% (Shvidenko and Nilsson, 2003).

As a result of the vast north-south expanse of the boreal zone, significant differences in climate cause a regional deviation in different taiga zones (Walter and Breckle, 1994).

Forest tundra and sparse taiga cover the southern part of the North Siberian plain and the major part of the plateaus, Putorana and Anabarskoe. The climate of these zones is extremely severe and continental with a growth period of only 87 to 92 days, and a frost-free period of only 44 to 67 days. The total forested area is 14.7 million ha, of which 94% is covered by coniferous and 6% by soft wood leaved species. Significant areas are covered by mires (4.3 million ha), ravines and steep slopes (about 1.5 million ha) and water (about 0.5 million ha). Forests are represented by larch (basically *Larix gmelini*), with bog blueberry (*Vaccinium uliginosum),* crowberry *(Empetrum subholarcticum),* birch *(Betula exilis),* green mosses and lichens. Spruce (*Picea obovata*) occurs only in the extreme west and south-western parts. Relative stocking is low (0.2–0.4 in the north and 0.5–0.6 in the south), as well as growing stock (40–60 m^3/ha in the south and 20–30m^3/ha in the north) (Abaimov *et al*., 1997; Zhukov, 1969; FFR, 1999).

The subzones of the middle and southern taiga occupy the major part of the study region. Vegetation is represented by typical boreal forests. The percentage of forest cover reaches 60–70%. Forests are basically formed by larch (*Larix gmelini* with *Picea obovata, Pinus sibirica* and *Abies sibirica*) and pine (*Pinus sylvestris)* (Rojkov *et al*., 2003). Understory is very low with a herb layer mainly consisting of blueberry *(Vaccinium myrtillus*), lowbush cranberry *(Vaccinium vitis-idaea),* and erica *(Calluna vulgaris) and* a dense lichen carpet. Wetlands are represented by moss mires with birches (*Betula fruticosa)* and *Sphagnum* (Rojkov *et al*., 2003; Walter and Breckle, 1994).

The middle taiga shows two different faces. On the western side of the Yenisey River, which belongs to the Western Siberian Lowlands, climatic conditions are more favorable for tree growth (see Figure 4). The forest comprises dense stands of pine (*Pinus obovata*) as the dominant species together with cedar (*Pinus sibirica*) and spruce (*Abies sibirica*) which forms the dark taiga. However, the dark taiga comprises only 40% of the forested area. The remaining part is represented by peatbogs and forest highmoors, which still expand at the expense of the forest. The forest of the dark taiga appears only as islands between the bogs and as stripes along the rivers (Treter, 1993).

In contrast, at the eastern side of the Yenisey River, the Middle Siberian Mountains rise up. Here the climate becomes extreme continental and the permafrost continuous. Due to dropping its needles and frost resistance only larch (basically *Larix gmelini*) has adapted to these unfavorable climate conditions and forms pure larch stands, called light taiga (Treter, 1993; Walter and Breckle, 1999).

The southern taiga of non-mountain regions begins along 60° N, and is represented by pine (*Pinus sylvestris)*, larch (*Larix sibirica)*, and spruce-fir (*Abies sibirica, Picea obovata*) forests with admixture of deciduous species (*Betula pendula, B. pubescens, Populus tremula*), basically small shrub-grass-green moss and bog blueberry (*Vacinium uliginosum)* and rhododendron (*Rhododendron dahuricum)* forest types. Pine and larch forests cover approximately two-thirds of the forested areas. Larch usually dominates in northern regions but is present in all forest formations. Spruce (*Picea sibirica*) grows in river valleys and on watersheds higher than 400–500 m asl. Cedar (*Pinus sibirica*) is a typical dominant of "mist" forests and occupies high plateaus. The major type of wetlands is sedge-gypnum mires with birch (*Betula exilis)* (Rojkov *et al*., 2003).

Figure 4: Middle taiga in the region of Zotino (60°N, 90°E) (Photo: H. Förster, 2002).

The most southern part of the study region belongs to the Sayan Mountains and, due to its relief, shows a multitude of vegetation communities: larch forests interspersed with birch and aspen, dark coniferous forest consisting of pine, spruce, cedar, and fir, subalpine meadows, and mountain steppes (see Figures 5 and 6). Forested areas cover 60% in this territory. Because of the relief-based site conditions a zonal vegetation classification is not possible in this mountain and basin landscape. The distribution of coniferous forests is mainly defined by altitudinal belts (Treter, 1993). Beginning with pine and spruce at the foothill, dark coniferous forests dominated by cedar follows from 600 m above sea level and changes to sparse sub-alpine forests with larch, sub-alpine meadows and at 1300 to 1500 m above sea level to mountain tundra (Rojkov *et al*., 2003).

Due to site factors like coldness, low nitrogen levels and permafrost, the productivity of boreal forest is low (Treter, 2000), but it increases from the north to the south. Growing stock volume of mature forests is approximately 150 $m^3 \cdot ha^{-1}$ in the middle taiga and 230–250 $m^3 \cdot ha^{-1}$ in the southern taiga. A major part of the forests is represented by mature forests (more than 60% for large regions) (Rojkov *et al*., 2003).

Figure 5: Closed cedar (*Pinus sibirica*) forest in southern mountain taiga of Eastern Sayan mountains near Ermakovskaya (52,5°N, 92,5°E) (Photo: D. Knorr, 2004).

Figure 6: Typical landscape with sparse forest, alpine meadow and bare rocks in top altitudinal belts in Eastern Sayan mountains (around 52,5°N, 92,5°E), the flower (*Epilobium*) in the foreground indicates post fire vegetation (Photo: D. Knorr, 2004).

4.6.3 Steppe and Forest Steppe

In the southern part of the Krasnoyarsk Kray and the eastern part of the Republic Khakassia, enclosed by the high mountains of East and West Sayan, a relatively small area of steppe and forest steppe vegetation is located (see Figure 7). Secondary deciduous forests, dominated by birch and aspen, as well as pine forest are common in the forest steppe region. According to the Siberian steppe classification (Kuminova, 1976), five steppe types from moist meadow steppes, true steppes (tall and short bunchgrass), dry steppes to desertificated steppes can be found in this region. Approximately two-thirds of this area is transformed to agricultural land, mainly cultivated pastures and arable lands.

Figure 7: Steppe vegetation in Khakassia (Photo: D. Knorr, 2004).

4.7 Disturbances

In the boreal forest, the most important types of disturbances are fire, outbreaks of insects and diseases, and harvest. Furthermore, some regions are impacted by air pollution (Shvidenko, 2000). This is also reflected in the study region. The most disturbed and altered forests are distributed around cities and industrial centers, like Krasnoyarsk, Irkutsk, Norilsk, and Bratsk. Regeneration of forests after disturbances (in particular, after clear cut harvests and fire) usually goes through a change of species, which explains the large areas of birch and aspen forest (Pleshikov, 2002; Zhukov, 1969).

Causes of natural fires are lightning but, especially in the southern forests, anthropogenic induced fires are becoming increasingly important and account already for 75% of all fires in this area (Schulze *et al*., 2002).

According to official FAO (Food and Agriculture Organization of the United Nations) data, about 20,000 to 40,000 forest fires occur each year involving a total area of about 4–5 million ha in the entire boreal zone. But these data are only from protected areas, which comprises only a third of the whole area. Only expert estimates of forest fires for the total boreal forest exist, which are about 25–30% higher in comparison with data for protected areas (Shvidenko, 2000). In Siberia, specific climatic conditions of the last decade caused the unprecedented fires in 1998 and 2003. The area affected by fires in 2003 in the SIBERIA-II region amounts to more than 3 million ha (Nilsson *et al*., 2005).

There are different types of fire: ground fires which are more frequent and rare crown fires. Pine stands are resistant against the first type, because of their thick bark. In contrast, young sprouting spruces and understory are destroyed by such fires which even favor pine. On light sand soils, ash after a fire is immediately washed out by rain. An increase of soil alkalinity does not occur and pines grow immediately on the burned area. This explains the high portion of pine in the northern taiga (Walter and Breckle, 1994).Damages caused by insects and diseases are estimated to be as large as forest fire damages in the boreal countries. The last outbreak of Siberian Moth (*Dendrolimus superans sibiricus*) in Krasnoyarsk Kray between 1994–1996 damaged forests on an area of more than 1 million ha, including 0.5 million ha where more than 51% was destroyed (Shvidenko, 2000).

The largest human-induced disturbance in boreal forests is harvesting. Between the 1980s and the 1990s, the annual removal in Russia was between 400 and 450 million m^3 growing stock volume. During the last decade, total harvest decreased to about 150 million m^3, of which about 35 million in 2004 have been harvested in the SIBERIA-II study region (database of Siberia-II Project).

Air pollution has a clearly expressed contagious distribution and is limited to several industrial centers in Russia. However, affected areas are significant. In 1993, the area of dead forest tundra landscape due to industrial emissions around Norilsk in the northern part of the Krasnoyarsk Kray reached 2.1 million ha including 0.6 million ha forested area. The official statistics of areas disturbed by this phenomenon in the region are incomplete (Shvidenko, 2000).

5 Methodology

5.1 Concept

As already shown in Section 3.2, the distribution of vegetation communities is a result of the interaction of different environmental factors, especially elevation, which influences temperature, and the shape of relief, soil texture and in higher latitudes permafrost, which have an impact on the distribution and availability of water. Additional influences on the ecosystem are natural and anthropogenic induced disturbances, such as fire, diseases, wind-throw or logging, which change the potential vegetation to the actual vegetation. Figure 8 shows the interactions between the mentioned environmental indicators for vegetation distribution.

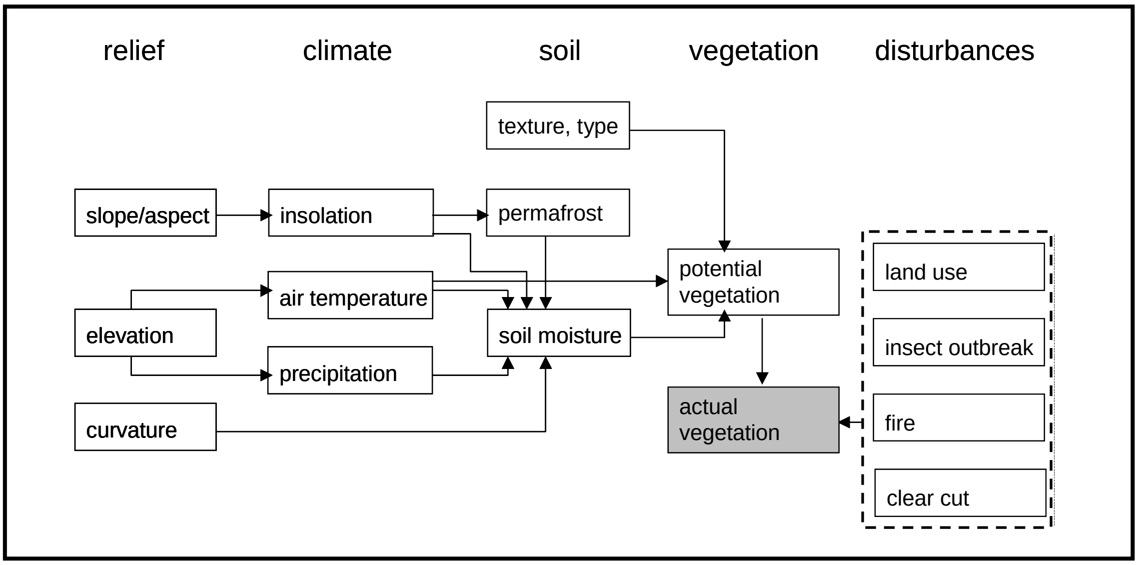

Figure 8: Environmental processes controlling vegetation structure (Source: Modified after Bonan, 1988).

Having a remote sensing-based land cover product with information about the distribution of vegetated and not vegetated areas and superimposed vegetation types, such as needleleaf forest, deciduous forest, grassland, etc., information about the mentioned environmental indicators could help to improve the land cover product and derive a digital map of the actual vegetation distribution in the study region. Information about the environmental indicators is available from Digital Elevation Models (DEM), digitized soil maps, and a wide suite of remote sensing data. By combining the datasets in the GIS using specified rules, it should be possible to develop an automated method for producing a digital vegetation map with a classification depth appropriate for IIASA's FCA.

5.2 Data Sources

From the SIBERA-II project a wide variety of remote sensing-based maps of land surface parameters as well as inventory-based digital maps from IIASA's existing GIS are available for developing decision rules and as input data sets.

5.2.1 SIBERIA-II Land Cover Product

In the framework of SIBERIA-II, land cover maps for the years 2000 to 2003 have been produced by the University of Wales, Swansea (UWS). The primary data source for this product was from the MODIS sensor, with a spatial resolution of 500 m. This land cover product contains 16 classes, as shown in Figure 9 and Table 1. Training data were 40 Landsat ETM scenes covering most of the southern study region and the Global Land Cover 2000 map (GLC2000).

The vast majority of homogeneous patches in the study region are below 300 m^2. Consequently, most of the pixels from 500 m resolution imagery contain a mixture of land cover types in these areas. This has significant implications if a hard classification is to be derived from such data sets (George *et al*., 2004).

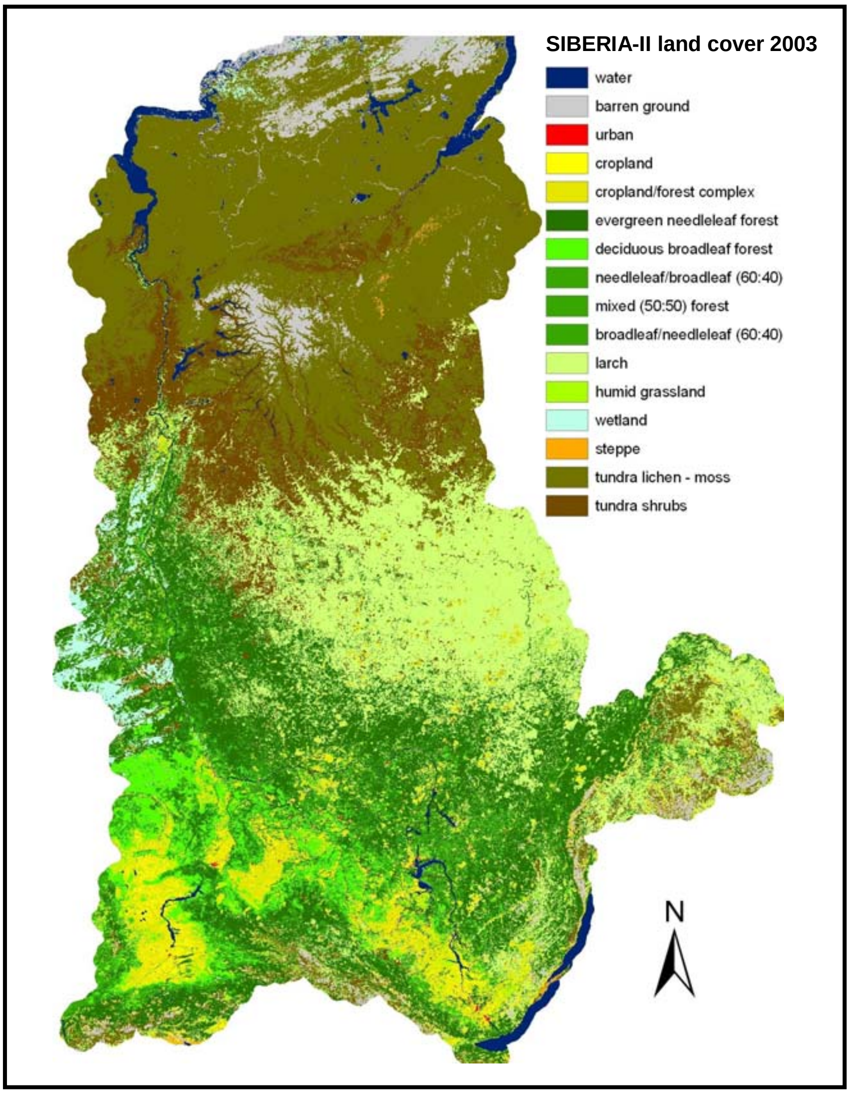

Figure 9: SIBERIA-II land cover product for 2003.

Table 1: Land cover classes of SIBERIA-II land cover and training data (Courtesy of R. Gerlach, FSU).

No.	Class Name	Training Data	Description	No. of Samples
1	Water	Landsat and MODIS	All water bodies including rivers, lakes and open sea	2038
2	Barren	Landsat and MODIS	Areas where bare ground or rock is exposed throughout the spring and summer	5241
3	Urban	Landsat only	Urban areas as identified from Landsat imagery	130
4	Cropland	Landsat and GLC2000	Agricultural land following bare soil, crop cover, harvest, bare soil cycle, geometrically identified using Landsat	719
5	Forest/Cropland Complex	Landsat and GLC2000	Areas of mixed cropland, forest and grassland	2321
6	Evergreen Needleleaf Forest[a]	GLC2000	<GLC2000 def.> >15% tree cover where either spruce, fir, pine or cedar dominate with a coverage >80%	1052
7	Deciduous Broadleaf Forest[a]	GLC2000	<GLC2000 def.> >15% tree cover where either birch or aspen dominate with a coverage >80%	1052
8	Needleleaf/ Broadleaf Forest[a]	GLC2000	<GLC2000 def.> >15% tree cover with 60–80% needleleaf and 20–40% broadleaf forest	1052
9	Mixed Forest[a]	GLC2000	<GLC2000 def.> >15% tree cover with ~50% broadleaf and ~50% needleleaf forest	1052
10	Broadleaf/ Needleleaf Forest[a]	GLC2000	<GLC2000 def.> >15% tree cover with 60–80% broadleaf and 20–40% needleleaf forest	1052
11	Deciduous Needleleaf Forest[a]	GLC2000	<GLC2000 def.> >15% tree cover where larch is dominating with a coverage >80%	1052
12	Humid Grassland	GLC2000	<GLC2000 def.> Herbaceous vegetation with a growing season of >5 months and shrub cover <20%	1758
13	Wetland	GLC2000	<GLC2000 def.> sphagnum moss and lichens or rushes and sedges are dominant	3980
14	Steppe	GLC2000	<GLC2000 def.> Herbaceous vegetation with a growing season <3 months	2016
15	Tundra—Lichem Moss[b]	GLC2000	<GLC2000 def.>Dry to wet barren regions with sparse lichens, mosses and scattered herbs	1751
16	Tundra—Heath[b]	GLC2000	<GLC2000 def.> Tundra regions dominated by erect shrubs mostly 40 cm tall	3660

[a] Total extent of forest area defined by initial classification scheme is retained and new classes have been defined only within the total forest area.

[b] The two tundra classes adopted from GLC2000 have been substituted by four tundra classes in the final version of GLC2000; this change has not been accounted for in the SIBERIA-II products.

5.2.2 SIBERIA-II Disturbance Product

The disturbance product of SIBERIA-II was developed by the Center of Ecology and Hydrology, Monks Wood, UK (CEH) (see Figure 10). Because of the large uncertainties and incompleteness in current fire statistics for the study region, burnt area and approximate date of fire events are estimated between 1992 and 2003. Monthly data are available for 2002 and 2003, and annual data for the years before 2002 (Nilsson *et al*., 2005). George *et al*. (2003) used two approaches to detect fire scars. The Normalised Differenced Shortwave Infrared index (NDSWIR = (NIR-SWIR)/NIR +SWIR), retrieved from SPOT-VGT and MODIS data, was used to map old fire scars, due to differences in the canopy moisture content. With additional data about thermal anomalies, coming from AVHRR, ATSR and MODIS data, a decade of fire history could be constructed. For the 2003 fire season, they used the Normalised Difference Vegetation Index (NDVI). The final product consists of a GIS vector data set, converted from 1 km resolution pixel data.

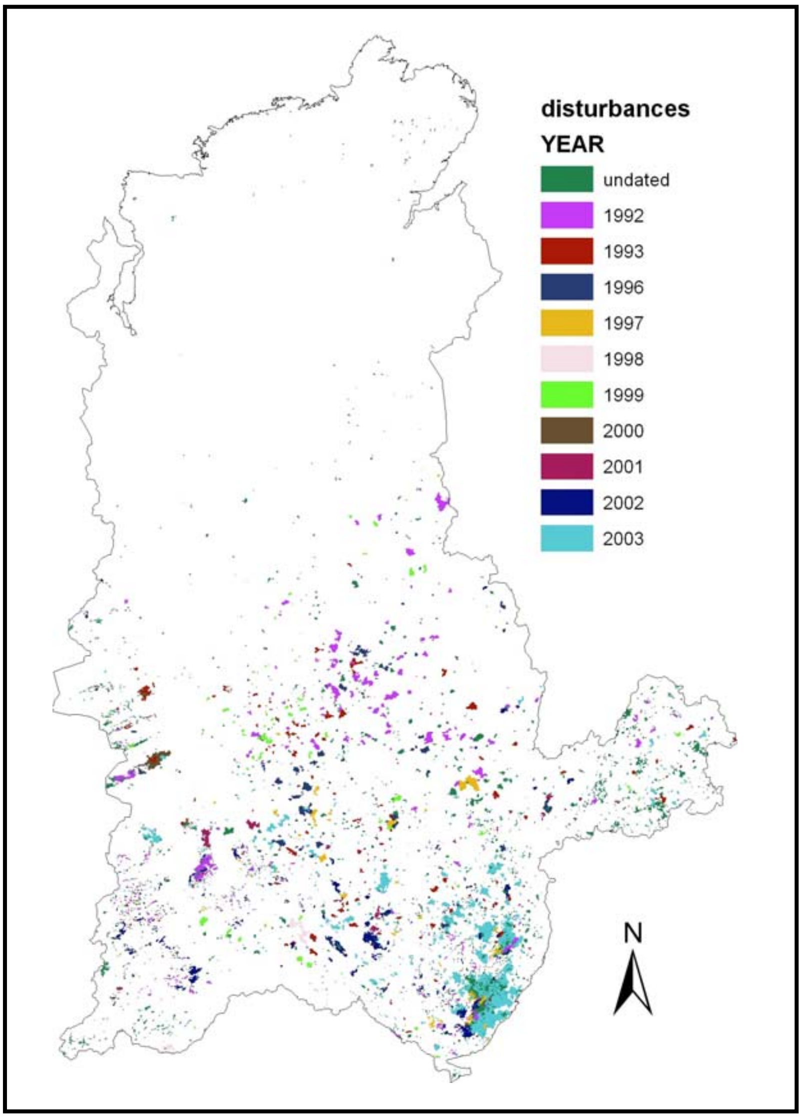

Figure 10: SIBERIA-II disturbance product for 1992 to 2003.

5.2.3 SIBERIA-II ASAR Water Bodies

The Institute for Photogrammetry and Remote Sensing (IPF) of the University of Technology in Vienna produced a map of permanent open water bodies from ENVISAT ASAR Wide Swath data for the years 2003 and 2004, with a spatial resolution of 150 m. Using only data from the summer months they avoided to map the temporary water surfaces during the spring thaw period (Bartsch *et al*., 2007). Figure 11 shows a part of the Taimyr peninsular, which is covered by a vast amount of small water bodies. These water bodies, which are related to extensive polygon mire systems, are too small to be identified by the MODIS land cover product (LeToan *et al*., 2004). Also some parts of the river systems are not detected by the MODIS sensor and thus misclassified in the SIBERIA-II land cover. This shows the importance of this product for refinement of the SIBERIA-II land cover product.

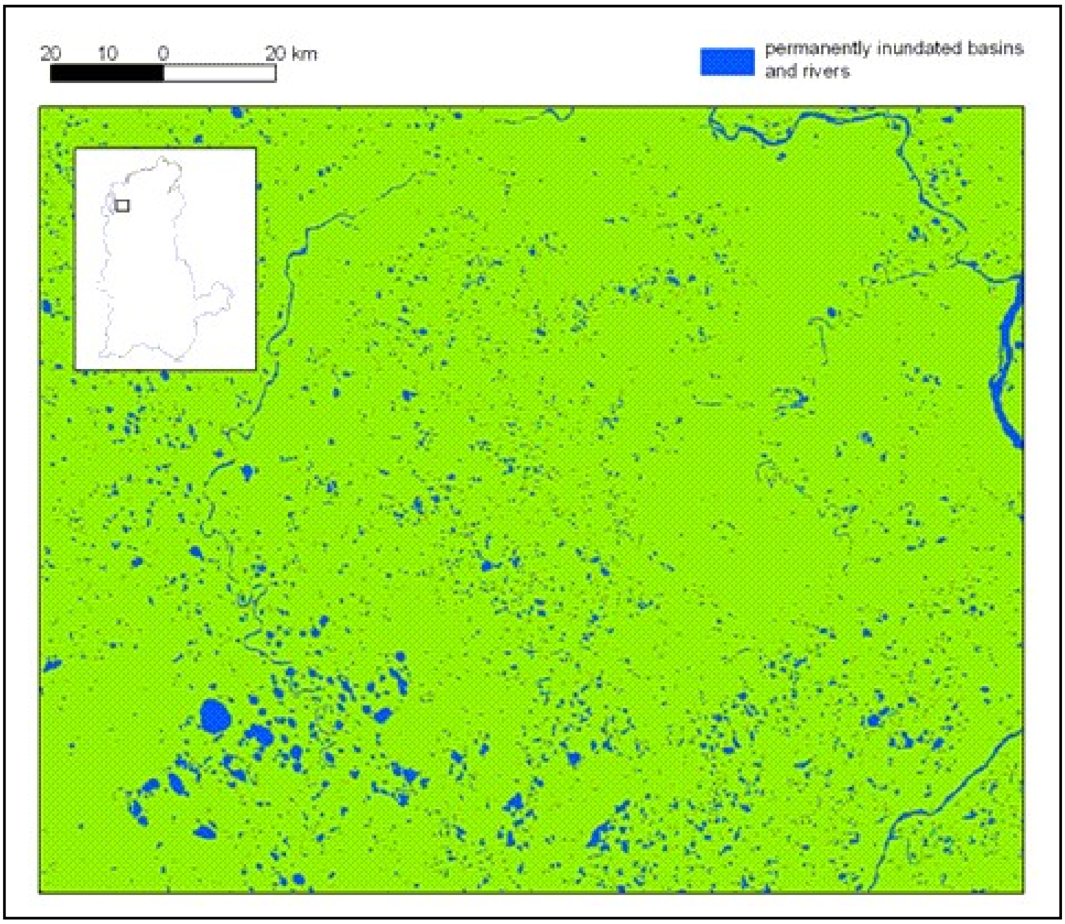

Figure 11: Permanently open water bodies the western Taimyr tundra based on summer acquisitions in 2003 (Source: LeToan *et al*., 2004).

5.2.4 *MODIS and AVHRR Vegetation Continuous Fields (VCF)*

Continuous fields of land surface properties offer advantages over traditional discrete classifications. By presenting each pixel as a percent coverage, areas of heterogeneity are better represented (Hansen *et al*., 2002). Currently, there are two global continuous field products for vegetation cover available:

- the prototype VCF product derived from NOAA AVHRR data acquired in 1992/93 at a spatial resolution of 1 km (DeFries *et al*., 2000), and
- a newer VCF product derived from MODIS data from 2001 with a higher resolution of 500 m (Hansen *et al*., 2003).

The AVHRR product contains five layers, representing the overall percentage of tree cover, the percentage of trees with a special leaf longevity (evergreen and deciduous) and a special leaf type (needleleaf and broadleaf), estimated for each 1 km pixel. Each pixel has a value between 10% and 80%. This product was developed using a linear mixture model applied to the 1 km AVHRR data. Training data were a set of Landsat TM data, which were used to define end members for the un-mixing of the spectral response of the AVHRR data. A separate model was developed for each continent to determine mixtures of broadleaf evergreen, broadleaf deciduous, needleleaf evergreen, and needleleaf deciduous woody vegetation, depending on representative forest types of each continent (DeFries *et al*., 2000; http://glcF.umiacs.umd.edu/data/treecover/description.shtml). The AVHRR VCF data set is available through the Global Land Cover Facility at the University of Maryland at http://glcF.umiacs.umd.edu/data/treecover/.

Concerning spatial resolution, algorithm and resulting accuracy, an improved VCF product was generated from monthly composites of all seven MODIS bands. Compositing was based on the second darkest albedo to remove clouds and cloud shadow. This product represents the percentage of tree cover, barren soil and herbaceous vegetation per 500 m MODIS pixel in three separate layers (see Figure 12). This information was estimated using a supervised regression tree algorithm (Hansen *et al*., 2003, http://glcf.umiacs.umd.edu/data/modis/vcf/description.shtml). A big improvement of the MODIS VCF is the application of continuous training data over the whole range of tree cover in contrast to the AVHRR trainings data, which were developed for the discrete classification system of the International Geosphere-Biosphere Programme (IGBP) land cover map (Hansen *et al*., 2002).

First results show that MODIS data yield greater spatial detail in the characterization of tree cover compared to past efforts using AVHRR data. Initial validation efforts show a reasonable relationship between the MODIS-estimated tree cover and tree cover from validation sites (Hansen *et al*., 2003, http://glcf.umiacs.umd.edu/data/modis/vcf/description.shtml).

The MODIS VCF product for 2001 is also freely downloadable from the University of Maryland at http://glcf.umiacs.umd.edu/data/modis/vcf/index.shtml. Data for the following four years are expected to be available early in 2006.

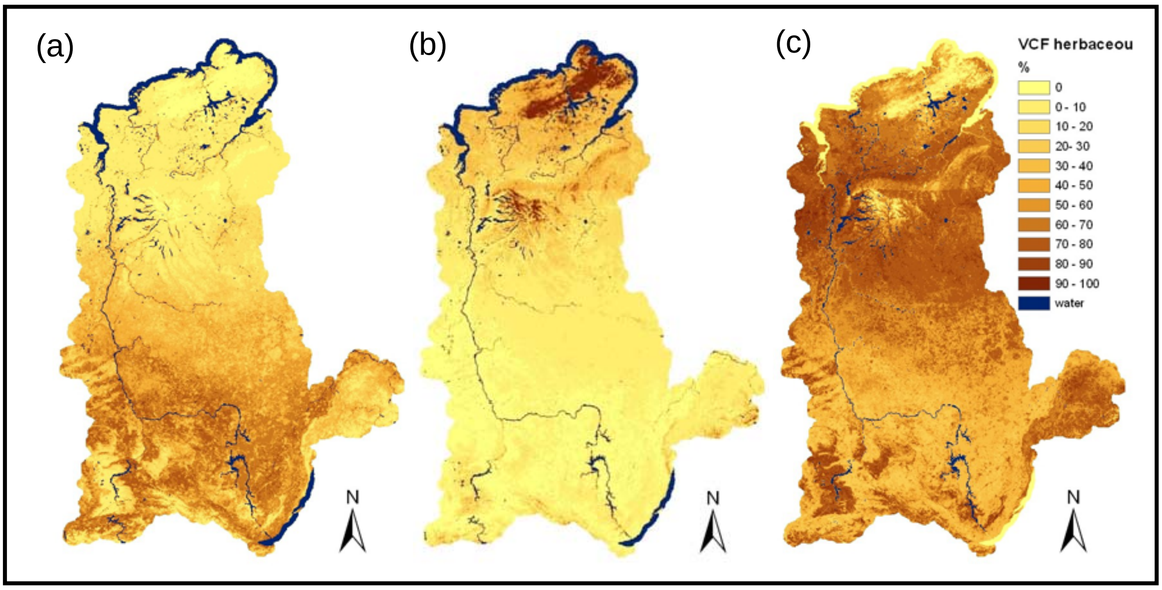

Figure 12: MODIS VCF for 2001, (a) tree cover, (b) barren ground, (c) herbaceous vegetation (in percent) (Source: Hansen *et al*., 2003).

5.2.5 Digital Elevation Model

In November 2003, NASA and NIMA (National Imagery and Mapping Agency) released the Shuttle Radar Topography Mission Digital Elevation Model (SRTM-3-DEM) for Europe and Asia. These preliminary elevation data between latitudes 60°N and 57°S are posted at three arc seconds in latitude and longitude (approximately 90 m) with an absolute vertical accuracy of 16 m. For the test area part up to 60°N it is freely available.

Another freely available DEM is the global GTOPO'30 from the USGS (http://edcdaac.usgs.gov/gtopo30/gtopo30.asp). It has a grid spacing of 30 arc seconds in latitude and longitude (i.e., roughly 1 km) and a vertical accuracy of ±30 m (Distributed Active Archive Center, 2004).

To meet the requirements of SIBERIA-II, Gamma Remote Sensing Research and Consulting AG generated a single DEM based on both DEMs, the SRTM-3 DEM, available for the latitudes below 60° North and the GTOPO-30 DEM for the areas above 60°N. In the combination of SRTM-3 and GTOPO-30 conditioned DEMs are used. In the conditioning of the SRTM-3 DEM the original DEM tiles were integrated into a single mosaic.

In the combination of the two DEMs of different spatial resolution, three zones are distinguished. To get a homogeneous transition between the two DEMs at different spatial resolution and to avoid any kind of local height offsets, a linear feathering between the SRTM-3 DEM and the GTOPO-30 DEM is done to for a transition zone (59.5°N < latitude < 60°N).

The GTOPO-30 DEM was also conditioned and interpolated to the same sampling as the SRTM-3 DEM, i.e., three arc seconds (approximately 90 m). The merging of the DEMs was done in geographic coordinates (latitude/longitude). The merged DEM was then converted to Albers projection.

For the southern part, which completely includes the area covered by the SRTM DEM, the combined DEM is provided initially at 100 m sampling, using short integers for the height values. For the use of the whole area, the combined DEM was resampled to 500 m resolution (Figure 13).

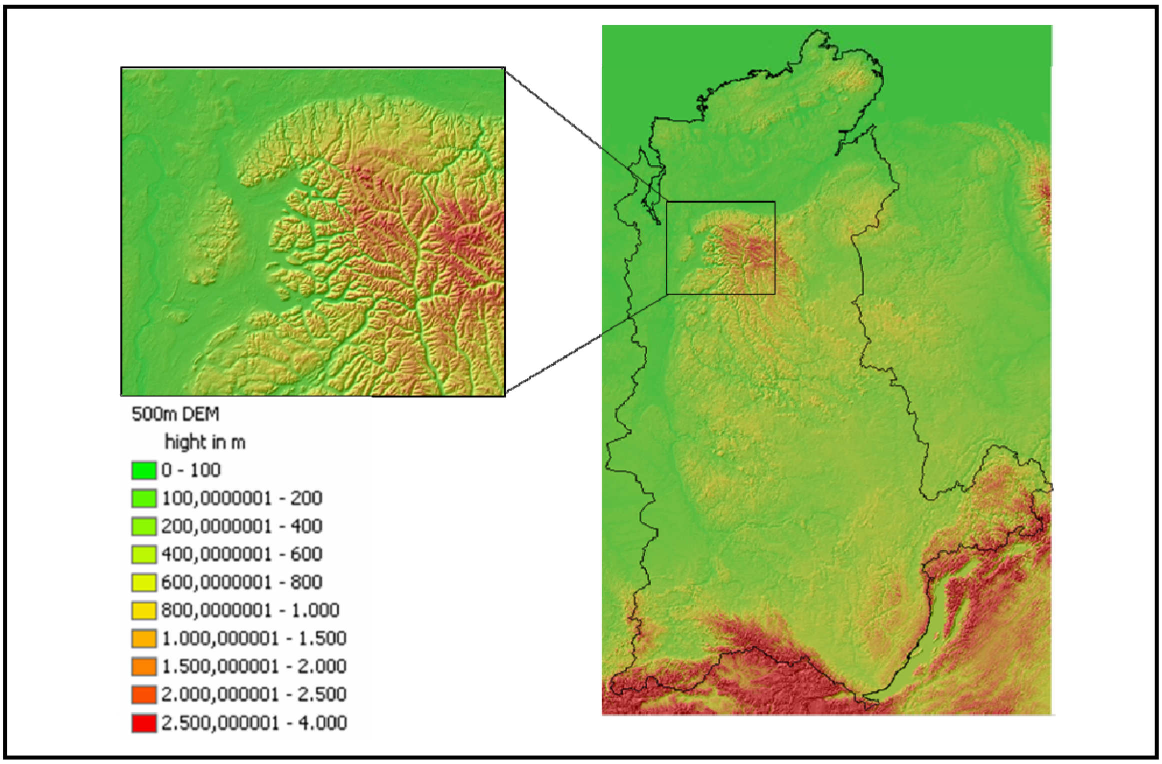

Figure 13: SIBERIA-II Digital Elevation Model (SRTM and GTOPO-30), 500 m resolution.

5.2.6 IIASA's Soil Map

Based on the 1:2.5 million paper soil map of Russia, edited by V. Fridland in 1989, the Dokuchaev Soil Institute (Moscow, Russia) and IIASA generated a digitized map and corresponding databases in the same scale. For the Siberia-II region, a 1:1 million soil coverage has been produced based on this 1:2.5 million soil coverage of Russia, using the identical database structure, with an intensified spatial resolution (Rojkov *et al.*, 2003). This transition was based on a simple adjustment of the geometry of polygons for relatively homogeneous territories. For mountainous and very heterogeneous areas a relevant clarification of polygon boundaries was provided by using sheets of the State soil map of the former USSR at scale 1:1 million, remote sensing images, more precise topographical basis, and different maps (climate, vegetation, geomorphology and geology, etc., Figure 14) (Nilsson *et al*., 2004c).

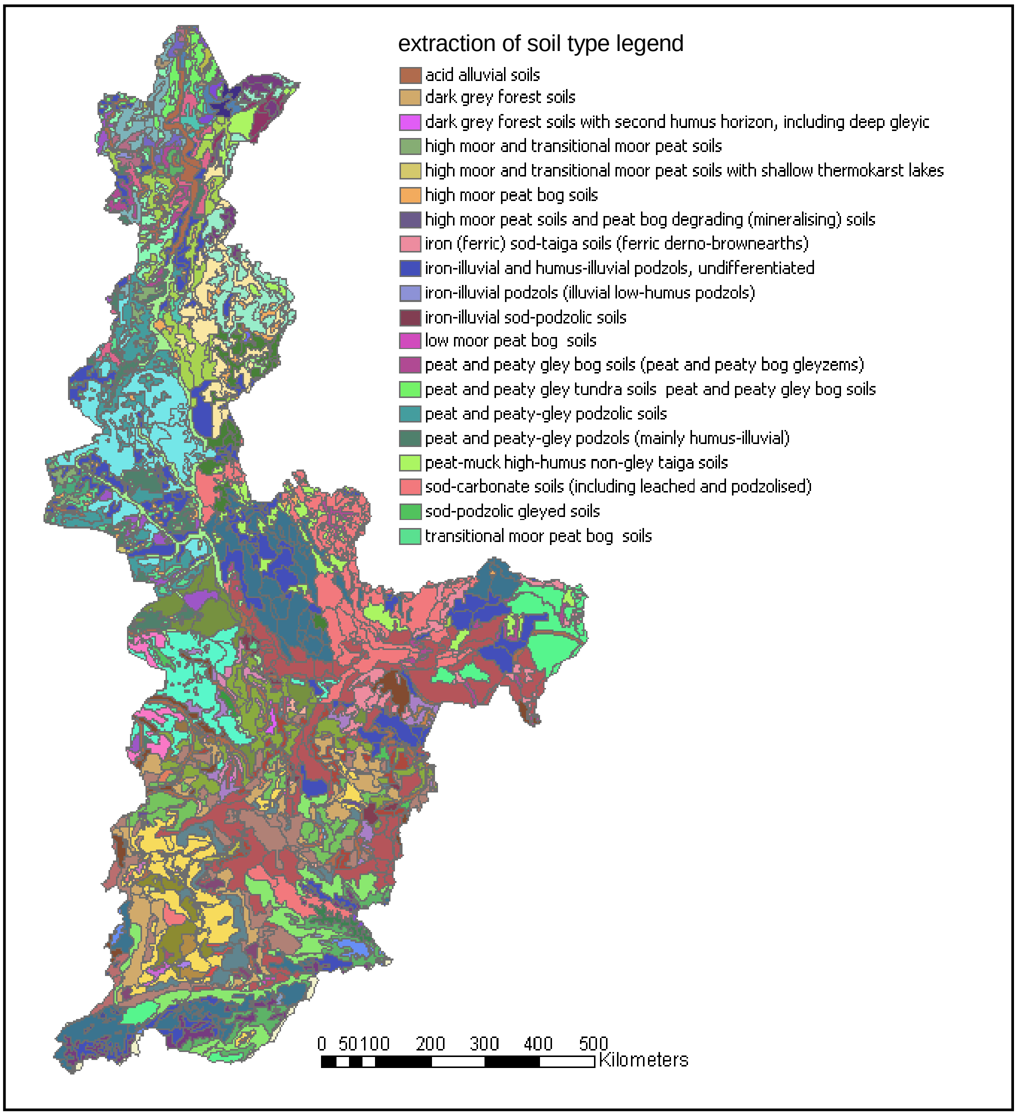

Figure 14: Soil layer for Krasnoyarsk Kray and Khakassia (legend contains only a small extract of the 115 soil types).

The soil database has been generated based on the measurement results of several thousand soil profiles and contains the maximum amount of available information possible. However, due to the high variability of indicators, the maximal and minimal values (corresponding approximately to 10% and 90% of the reciprocal distribution) are presented in the database (Nilsson *et al*., 2004c).

The soil layer contains a total of 5,039 polygons with an average size of 61,611 ha, linked to a related database. The coverage is stored in Arc/Info format in double precision and contains complete polygon topology (Rojkov *et al*., 2003).

5.2.7 IIASA's Vegetation Map and Forest Inventory Data

As already mentioned in Section 2, IIASA exploited several sources of data for the compilation of the vegetation database, which is used as parameter input for IIASA's terrestrial biota full GHG accounting model. The map at scale 1:1 million consists of 30,497 polygons, which are more or less highly aggregated based on the requirements of the Russian forest inventory manual (FFR, 1995). This implies that in each polygon those tree species are indicated that are forest economically most important. In the case of a mixed forest consisting of birch and conifers, the dominant conifer species is indicated, e.g., if Siberian cedar is present with 30–50% of the species composition (Shvidenko, 2005). In areas without forest, such as steppe or tundra, vegetation classes were separated based on major types of vegetation (Glebov, 1969; Oguzeeva, 2001). For the case of mixed vegetation classes in one polygon, the map is split into three separate data layers, representing three different levels of dominant species. The first level data set represents the land cover class with the highest area share, the second level data set the land cover class with the second highest area share, and the third level data set with the third highest area share. In this way, mixed land cover definitions are avoided.

In order to provide ground truth data for validation, verification and calibration of the remote sensing products of the SIBERA-II project and detailed ground data of the project region for the GIS, IIASA established a ground truth net of 29 test territories, each representing an area of 1–3 million ha, and consisting of up to five test areas with 30,000 to 300,000 ha (Nilsson *et al*., 2003). In total, there are 73 test areas of which 50 are updated test areas developed by the SIBERIA-I project and 23 are newly developed test areas, in order to cover the extended area of the SIBERIA-II region. Of the latter, seven test areas present remote northern territories outside of regions of on-ground forest inventories, and 16 test areas are developed on recently inventoried (mostly) forest territories (Figure 15) (Balzter *et al*., 2003).

Due to their remoteness and limited available sources of information, the seven test areas of the remote northern territories have databases with individual structures due to substantially diverse land cover at a coarser scale of 1:100,000 to 1:200,000. The other test areas, called in the following test areas of the first type, are based on forest inventory data and initial forest maps at a scale of 1:50,000 and have uniform data base structures (Balzter *et al*., 2003; Nilsson *et al*., 2003).

All test territories—updated and newly developed—are presented in the project's database by their state by early June 2003. However, a catastrophic fire situation took place in Irkutsk Oblast during 2003. Due to labor and financial constraints, a repeated reconsideration of the impacted territories is impossible, which means that changes of the land surface by disturbances during 2003 are not presented in the test site database (Balzter *et al*., 2003). In contrast, the final IIASA vegetation map at the scale 1:1 million has been compiled in the fall of 2003 and includes the areas disturbed by fire in 2003.

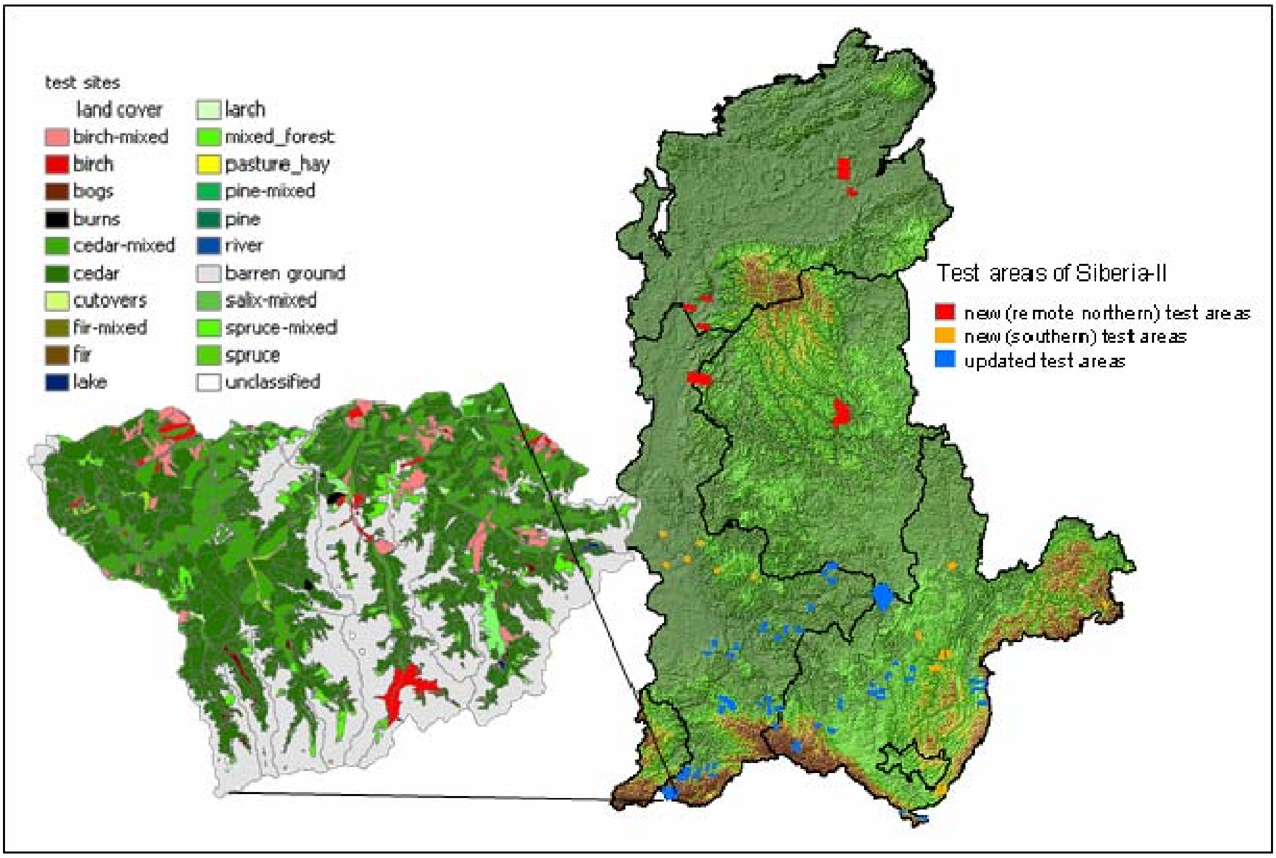

Figure 15: Test areas of SIBERIA-II.

5.2.8 Agreement Between Data Sets

A cross comparison of the disturbance product and the land cover product showed that the highest percentage of burnt area is found in the crop and grassland classes. This represents very probably the fire scars after 1992, identified as a crop/grass class in the land cover product. The spectral responses in optical wave-lengths of burnt areas can be close to that of low vegetation like crops or grass even after 10 years, given the slow regeneration after fires in Siberia (LeToan *et al*., 2004).

The ASAR water bodies map agrees well with the land cover. All water bodies detected using MODIS at 500 m resolution are well identified by ASAR at 75 m resolution, whilst ASAR detects a large number of small water bodies in addition. The water bodies of the size less than 1 km^2, not detected by MODIS, represent 24.2% of the total area of water bodies. Among this 24.2% the largest proportion is located in tundra. Much lower percentages are found in the soil/rock class, followed by forest classes. A marginal percentage of water bodies is found in the wetland and humid grassland classes. This is understandable since the ASAR water bodies retrieval algorithm does not detect inundated vegetation cover (LeToan *et al*., 2004).

A comparison on a pixel basis of the land cover product and the IIASA vegetation map showed that the numerical indicators on the consistency of land classes derived from the RS product and those identified on the IIASA map are underestimated. The reason is the heterogeneity of the aggregated polygons of the IIASA map on the scale 1:1 million. The underestimation depends on land cover specifics and could be estimated on average at 30–40% of the calculated values for the southern part of the region with a fragmented land cover, at 10–20% for northern taiga and forest tundra regions, and less towards the tundra (Nilsson *et al*., 2004b).

5.3 Decision Rules for Delineating Vegetation Classes and Implementation

The whole process of producing the vegetation map was pixel based using the SIBERIA-II land cover map as initial raster data set, whose cells were reclassified successively following specific decision rules. Input for the rules came from the above mentioned datasets, which were combined in a specific order. Before combining, they had to be rasterised in cases of vector data sets or simply resampled to the cell size of the land cover product, so that the cells of the different raster data sets match exactly with the cells of the land cover raster data set. After each combination the specific decision rules for this level were applied for each cell. The resulting land cover classes are adopted from the classification scheme of IIASA's vegetation map and can be found in Appendix A. Caused by problems of separation, some of IIASA's classes were aggregated, such as "water", "agriculture", "urban territories" and "dark coniferous forests". Additionally, some new classes were introduced for mixed classes, such as forest steppe, and several tree species combinations (e.g., birch-aspen with larch). Figure 16 shows schematically the order of data set combination and applied rules, as well as three examples. The data set requirements and the decision rules itself can be found in Appendices B and C. In the following, the decision rules and the necessary preprocessing steps for the data sets are explained.

Since the study region covers a vast area of about 3 million km^3, the landscapes in this region are very different. Influenced by different climatic and insolation conditions and topography, the vegetation is very diverse throughout the entire study region, as already shown in Section 4. Therefore, it is practical to split the region into smaller subregions and to develop different rule sets for each of them. These subregions were adopted from already existing ecoregions from IIASA's vegetation map, which are based on administrative, bioclimatic, topographic and floristic criteria. For simplification, these 23 ecoregions were aggregated to seven ecoregions, as shown in Figure 17. The criteria for this aggregation were the more or less homogeneous vegetation patterns tundra and forest tundra, northern taiga, middle taiga, southern taiga, mountain middle taiga, mountain southern taiga, steppe and forest steppe, which have been already described in Section 4.6.

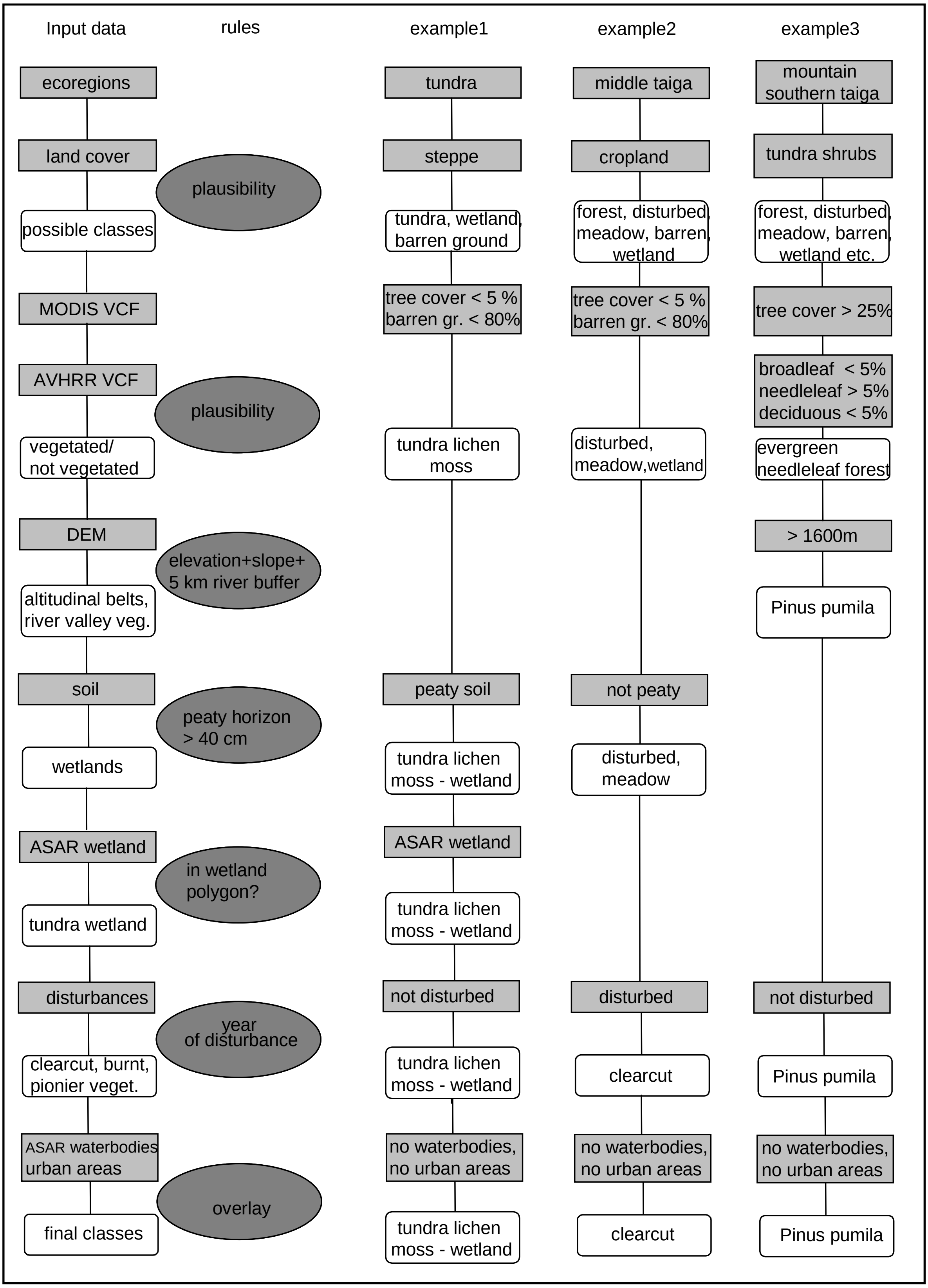

Figure 16: Schematic diagram of data set combination and application of decision rules.

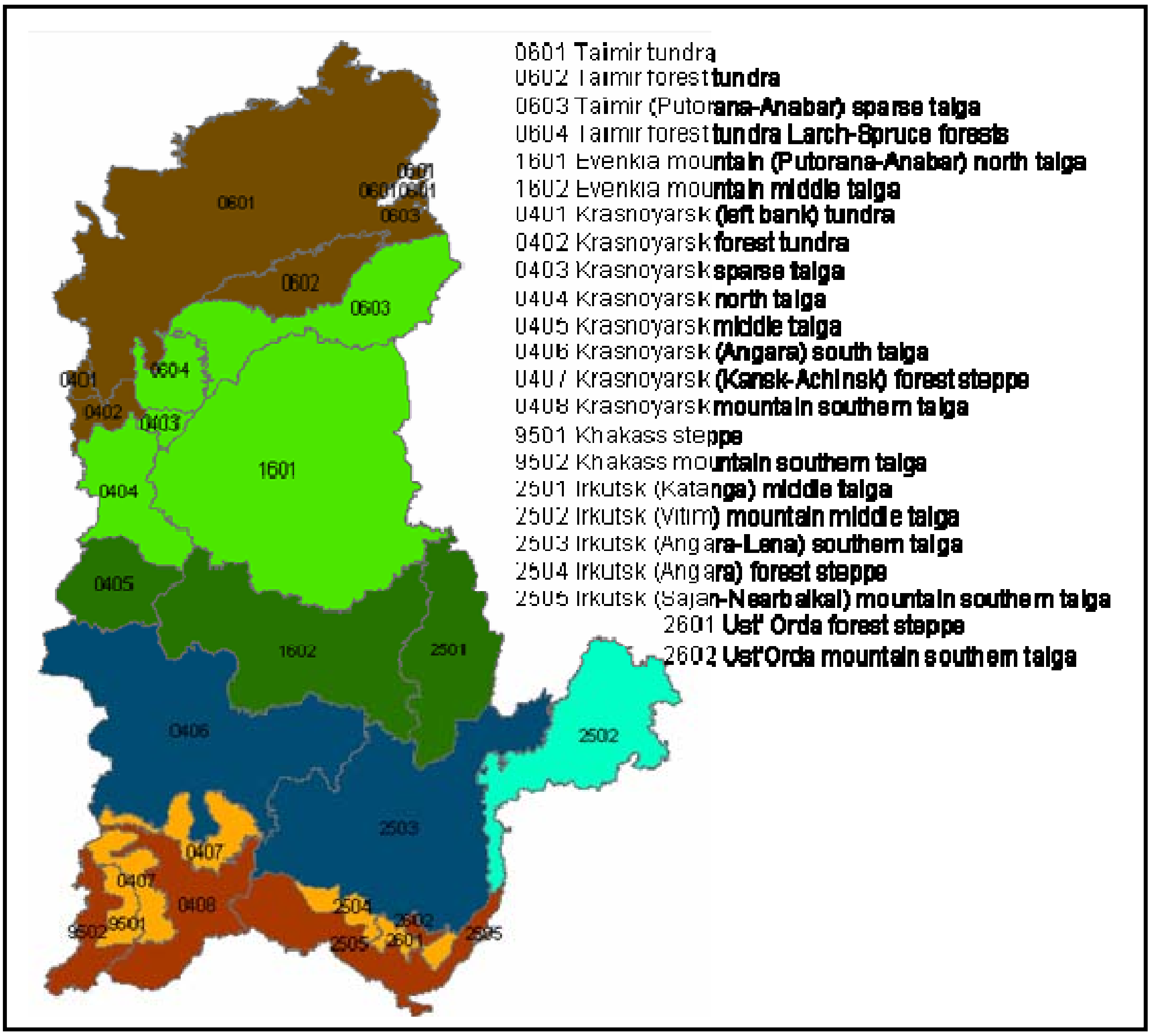

Figure 17: Aggregated ecoregions for vegetation group delineation.

Based on these ecoregions, it was possible to check the SIBERIA-II land cover product for obvious misclassifications and to reclassify the relevant pixels after plausibility rules. For example, if pixels that are located in the tundra ecoregion, are classified as agriculture, steppe or deciduous broadleaf forest, they are obviously misclassified. In such cases these pixels are assigned to new classes, which are more plausible for the specific ecoregion. Since in all cases there is more than one possible class, the assignment to one class followed exclusion principles in the next classification levels.

The second classification level used information from the vegetation continuous fields products from MODIS and AVHRR. Depending on the initial land cover class and the values of the MODIS VCF tree cover and barren ground, the pixels were reclassified. The thresholds “5% to 25%” tree cover for sparse and “>25%” for closed forest definitions came from the IIASA vegetation map definitions. Other thresholds, such as 30% tree cover for the separation of wetlands from surrounding forests in ecoregions 3 and 4 came from visual comparisons with the IIASA vegetation map. The percentage of the MODIS VCF barren ground was only needed for defining the land cover class “barren ground”. All cells in all ecoregions, no matter which initial class they belong, having a MODIS VCF tree cover value <5% and barren ground value >80% were assigned to the class “barren ground”. Only pixels with the initial land cover class “barren ground” could have a lower proportion of MODIS VCF barren ground of >40% to be kept as “barren gound”. In this way, initial land cover classes received a higher weight. Pixels with an initial land cover class differing from forest and shrub classes (e.g., tundra shrubs), but a MODIS VCF tree cover value above 25%, and 30% respectively for initial wetlands in ecoregions 3 and 4, were assigned as “forest”. To define the forest type of these pixels, the AVHRR VCF was used. If the coverage of AVHRR VCF broadleafed trees was higher than 5% and of AVHRR VCF needleleafed trees was lower than 5%, the pixel is assigned to “deciduous broadleaf forest”. If it is vice versa, the pixel is assigned to “needleleaf forest” and the coverage of the AVHRR VCF deciduous trees is used with the same threshold to define, if it is “deciduous needleleaf forest”, namely larch, or “evergreen needleleaf forest”. Returning to the exclusion principles mentioned before and the example of misclassified “steppe” in the tundra ecoregion, this second level of decision rules helps to decide, whether this pixel is “barren ground”, “larch forest” or “wetland/tundra”. In the latter case, further rules have to be applied for the decision between “wetland” or “tundra”.

The third level of decision rules is the topographical location of the pixels in means of elevation, slope and neighborhood to rivers. Elevation is derived from the SRTM-DEM, which was filtered twice with a 3 × 3 low pass filter to smooth the inhomogeneities resulting from the receiving process by radar. There are two concepts behind the application of elevation. The first is the altitudinal zonation of vegetation in mountains applied to ecoregion 5 (Pribaikal) and 7 (Sayan Mountains). The vegetation composition of the different altitudinal belts is taken from literature (Abaimov *et al*., 1997; Buzikin, 1977; FAO, 2001, Polykarpov *et al.,* 1986; Popov, 1982; Semechkin, 1985; Zhukov, 1969). The elevations for the belts were received from visual comparison of the polygon borders of specific vegetation classes in the IIASA map and the DEM. The second application scheme of elevation information is the separation of regions inside the ecoregions, which have different tree species or types of wetlands. In this way it was possible to separate the region on the left side of the Yenisey river, which belongs to the West Siberian Lowlands from the Krasnoyarsk Kraj on the right side of the river in the ecoregions 2 (northern taiga), 3 (middle taiga) and 4 (southern taiga). For the latter ecoregion, elevation was not enough to separate all different subregions. Here, slope, derived from the DEM with a threshold of 1°, was used in combination with elevation and some specific soil types for the separation of pine, fir and cedar.

For assigning riparian vegetation to pixels along rivers, a 5 km wide river buffer was applied to the ASAR water bodies map. Since the ASAR water bodies map contains not only—for this purpose—interesting big rivers but also small rivers and hundreds of lakes, it was necessary to reduce the information content. After buffering the remaining big rivers, the new data set was converted to a raster dataset with only two values, 1 for the reparian areas and 0 for the matrix. Depending on the ecoregion, different vegetation communities of river valleys and riparian areas could be assigned. One example is the 5 km wide stripe of larch trees along the rivers in the tundra region, which can be defined the width of the buffer. According to IIASA's vegetation map, this river buffer was also useful for separating some wetland types or defining agricultural areas, which can be found only along rivers in ecoregion 4 (middle taiga).

After the topographical criteria comes the application of information about the distribution of peaty soils for the detection of peatlands as a level of decision rules. This information descends from IIASA's digital soil map. Using IIASA's vegetation map again as training data, it was found that those polygons indicated as "peat" or "peaty" soil types and with a soil thickness of more than 40 cm best represent the amount and location of wetlands in the IIASA vegetation map. For the combination with the other data sets, a new data set had to be created by selecting the specific polygons in the polygon soil map and converting it to a raster data set, which contains only two grid values, 1 for peaty soil and 0 for areas that are not peaty. Depending on ecoregion and topographical location, all land cover classes besides the forest classes and wetlands were assigned to specific wetland types, if they coincide with value 1. The specific wetland types for each ecoregion were adopted from the IIASA vegetation map and separated from each other by topographical location.

For the tundra ecoregion another rule for wetland detection was applied. One problem here is the vast amount of small and shallow lakes in this region (about 26,000 water bodies of a size between 2 ha and 30 ha, and 150,000 bigger than 2 ha), of which a huge part is not represented in the 500 m resolution of MODIS and therefore in the resulting vegetation map. Since these lakes are crucial for the methane budget they should not be ignored. Permanent water bodies below a size of 8 ha in the subarctic regions indicate tundra wetland according to the Ramsar classification scheme (Bartsch *et al*., 2007). To keep these lakes in the raster vegetation map with a resolution of 500 m, these lakes and the tundra land between them were aggregated to one polygon indicated as tundra wetland. This was done by Bartsch *et al*. (2007), separating these lakes from their ASAR water bodies product (Bartsch *et al*., 2007) and performing a density analysis with a search radius of 50 km and a density threshold of 5000 m^2/km^2 of water surface area.

By overlaying the resulting polygon, the pixels indicated as "tundra shrubs" and "tundra lichen moss" received the new classes "tundra-wetlands shrubs with small lakes" and "tundra-wetlands lichen moss with small lakes", which are not indicated in the IIASA classification.

The next step in the classification process is the identification of disturbed areas. For this rule set, the disturbance product with information about the period 1992 to 2003 is used. In the initial SIBERIA-II land cover product, there is no class definition for burnt or logged areas. This means that these areas are assigned to one of the 16 classes, and probably not to one of the forest classes.

So, all pixels in the reclassified land cover map, except those initially assigned as forest classes in the SIBERIA-II land cover, that coincide with pixels of the disturbance map are assigned as “burnt area” if the MODIS VCF tree cover is lower than 5%. If it is higher than 5%, it could mean that the vegetation cover changed due to disturbances after 2001, the year of the MODIS VCF. In such cases, the year of the disturbances is applied: Only disturbances after 2001 lead to the class “burnt area”. Pixels with newly (not in SIBERIA-II land cover) assigned forest classes that were disturbed before 2001 receive the class “birch” as pioneer plant after fire. A second exception for these rules are those pixels belonging to the initial land cover class “cropland”, which receive the class “clear cut” if they coincide with pixels of the disturbance map.

Since the classification of croplands is based on the recognition of rectangular shapes that do not appear in nature and in the ecoregions 1, 2, 3 and 5 agriculture is not possible; it is probable that in these ecoregions the cropland areas are misclassified clear cut areas. Checking of these areas with Landsat data showed that this suggestion was right. If the logging was before 1992, it is not registered in the disturbance map. To classify these areas a second rule set for disturbances is applied: A MODIS VCF tree cover higher than 5% means that these areas are covered with pioneer species of secondary forest, which is in the tundra ecoregion larch and in all other ecoregions birch. This simple rule cannot be applied to ecoregion 4, where agriculture and logging is possible. Since agriculture is only located in river valleys in this ecoregion, the usage of the river buffer helps to separate clear-cut from real cropland.

The last step in assigning classes to the pixels was the overlay of the water bodies map derived from ASAR data and settlements from digital topographical maps to get more detailed information about the position of rivers, lakes and settlements, than MODIS is able to derive.

The whole reclassification process of the initial SIBERIA-II land cover to the final vegetation map using the information of the different data sets under application of the explained decision rules has been run in ArcInfo, the workstation tool of ArcGIS by ESRI (Environmental System Research Institute, Inc.). Here, the combination of the raster data sets has been performed in the module GRID and the reclassification applying the decision rules in the module TABLE, which allows editing the attribute Table of the raster data set. The process is automated by a macro written in ArcInfo’s Macro Language (AML).

5.4 Encountered Problems

The described model for automatic derivation of a remote sensing based vegetation map shows two types of problems, one is connected to the availability of data for the desired period of time and the other to the derivation of decision rules.

The first one refers to the availability of recent VCF data. Currently, the MODIS VCF product is only available for the year 2001. Changes in the tree cover due to disturbances since this time are not detected. The same is the case for the AVHRR product, which represents the forest distribution of 1992/93. In the decade between the acquisition of these data and the target year 2003 for the vegetation map, a significant change in the distribution of tree types could have occurred. For future attempts at producing such a vegetation map the new MODIS VCF products for the years 2002 to 2005 are expected to be available early in 2006. There are also layers for the proportion of leaf types and leaf longevity announced, which will replace the AVHRR VCF.

The second type of problems results from some cases in which it was not possible to derive decision rules for separating initial land cover classes in vegetation classes. For example, in ecoregion 4 (southern taiga) the big areas of cedar forest on the left bank of the Yenisey river could not be separated from the initial class “evergreen needleleaf” and is misclassified as “pine”.

Under these current problems the resulting product is expected to have some inaccuracies and has to be considered critically, but keeping in mind, that the application of new data sets could improve the result.

6 Results and Discussion

The produced remote sensing-based vegetation map, in the following referred to as RS map, is presented in Figures 18 and 19 in comparison with the IIASA vegetation map. It is represented in the form of a raster dataset with 500 m pixel size and contains 80 classes, which are explained in Appendix A. These classes are adopted from IIASA’s vegetation map and slightly changed to meet the possibilities of the vegetation differentiation using the described method:

- There are two new classes for the tundra wetlands in the tundra ecoregion,
- one new class for “forest steppe”, and
- new classes for mixed forests, such as “birch/aspen” or “birch/pine”, or for areas where a species separation was not possible, such as “dark coniferous forest”.
- All forest classes were separated in open and closed forests depending on MODIS VCF tree cover.
- Some IIASA classes do not exist in the RS map, due to problems in separation between types of vegetation classes, especially some tundra, wetland and shrub types.

For validation, the RS map was compared with the IIASA vegetation map in three different representations, considering different aspects:

1. A visual comparison of the location of vegetation patterns is shown in Figures 18 and 19.
2. For the comparison of the spatial agreement between the two products on pixel level, a confusion matrix—a cross tabulation of all classes of both

products—has been created. It shows the amount of pixels of each class of the RS map occurring in the classes of the IIASA map.

3. Concerning the carbon accounting, the area of the different vegetation classes is most important. Therefore, also the area of the different classes has been compared.

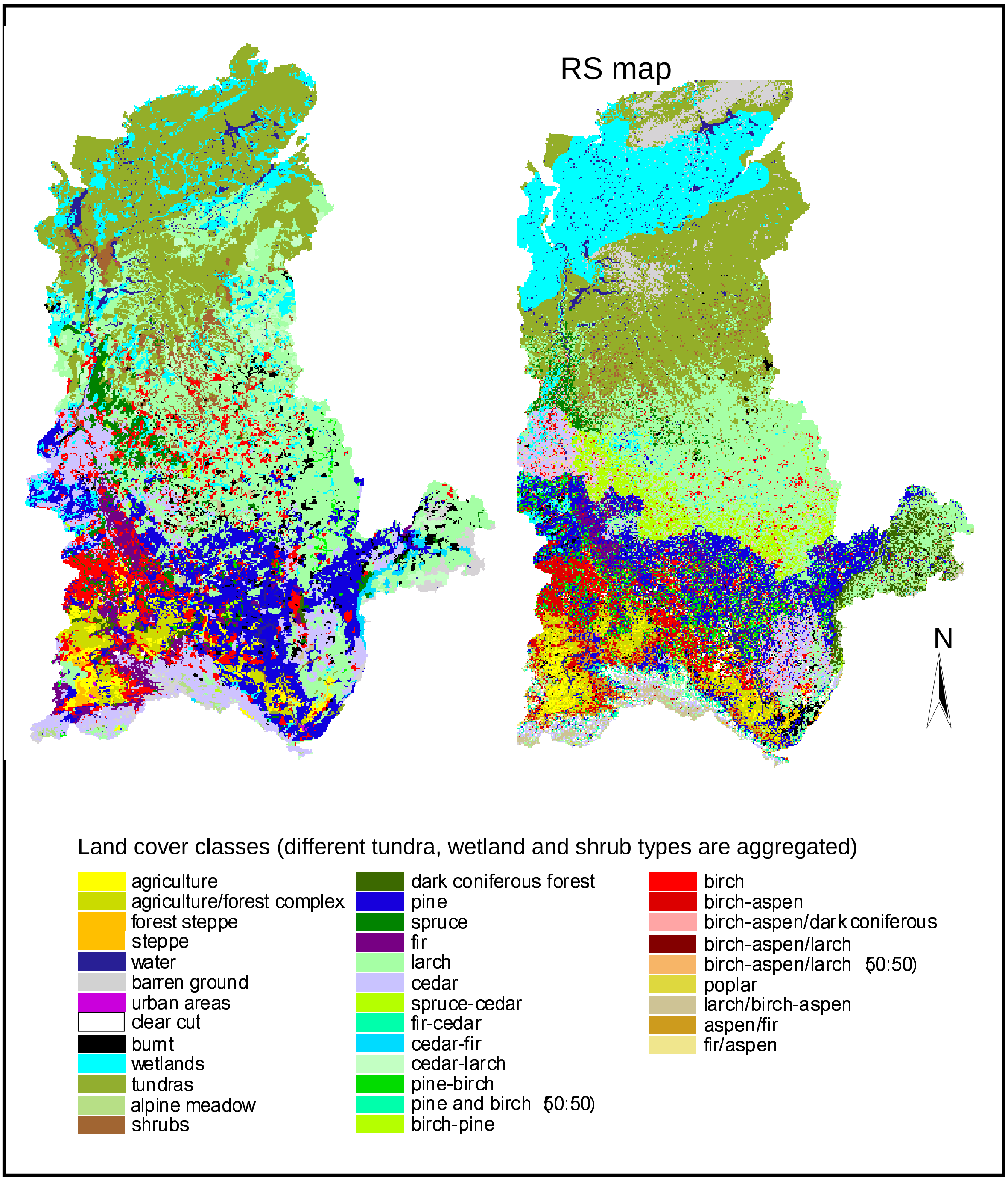

Figure 18: IIASA vegetation (polygon) map and remote sensing-based vegetation (raster) map.

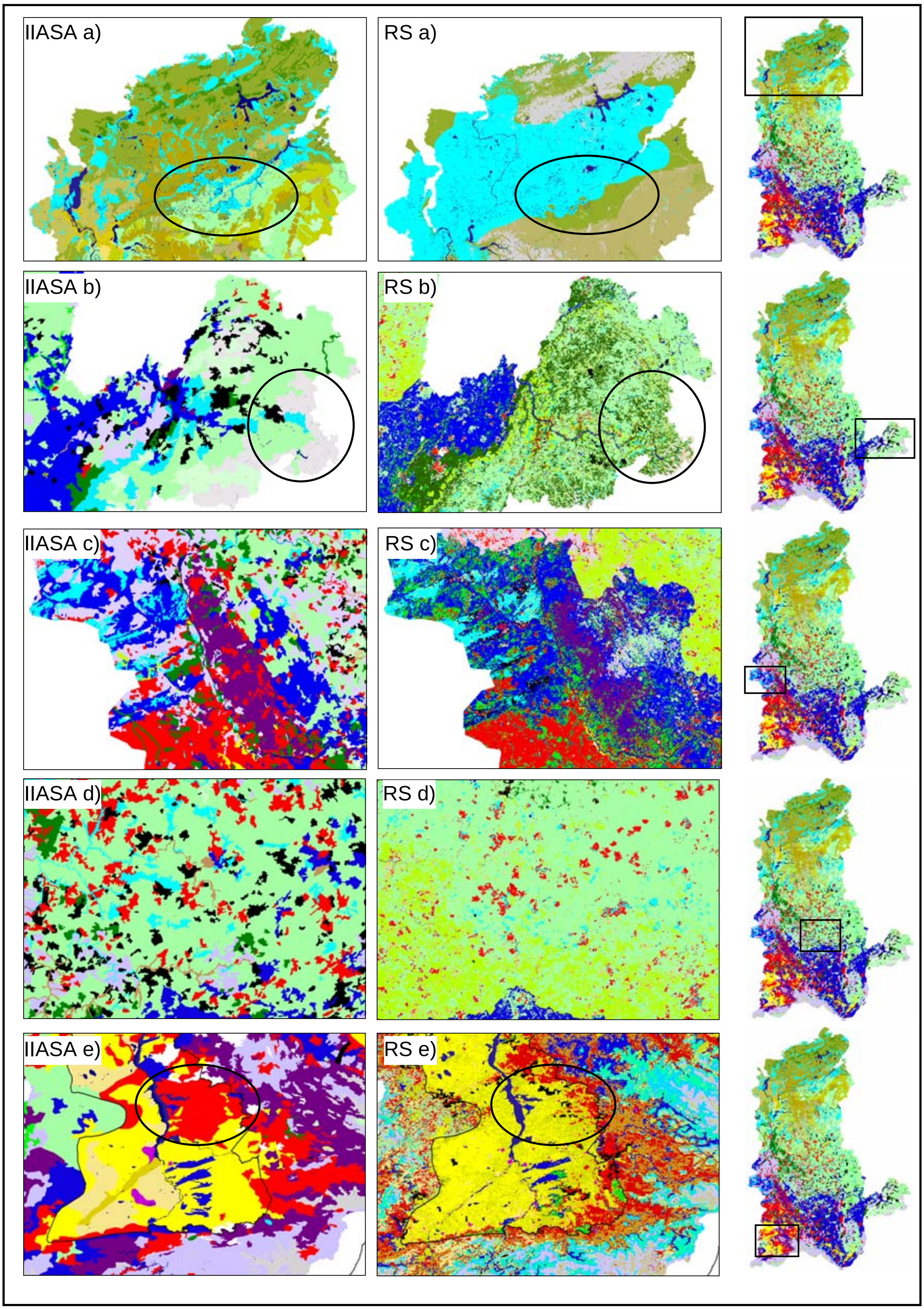

Figure 19: a)–e) Comparison of IIASA vegetation map and remote sensing-based vegetation map.

Since both products are derived using different methodologies and are presented in different data representations, their comparison is problematical. Strongly aggregated polygons of the IIASA map have to be compared with scattered pixels of the RS map. To make the two products generally comparable, the IIASA map was rasterised to 500 m to match the RS map. Additionally, both products had to be reclassified to comparable classes by aggregating some classes.

The visual comparison of the RS map and the IIASA map of the entire study region in Figure 18 shows an overall agreement of the vegetation patterns. However, the northern part shows a prominent difference between both maps. In the IIASA map, it is mainly covered by tundra and shows only patches of wetlands. In contrast, in the RS map it is almost completely covered with one connected wetland. This is the result of the overlay with the tundra wetland polygon and is justifiable because of the already mentioned reasons. More problematical is the much higher ratio of larch forest in the IIASA map in the northern taiga. These forests are the most northern boreal forests in the world, consisting of sparse growing larch trees with a very small basal area and low crown closure (Shvidenko, 2005). These forests are probably so sparse that they are transparent for satellite remote sensing with a relatively low spatial resolution, such as MODIS, and are not detectable. The underlying ground vegetation is detected instead and classified as tundra. Figure 19a) shows in more detail the northern part of the study region and the problem of underestimation of the sparse larch forest in this area.

Another problem is the different estimation of barren ground. Looking in more detail at Figure 19a), it can be seen that in the northern part of the Taymir peninsula the RS map shows unvegetated areas (gray), whereas the IIASA map does not. Again, this is a result of different aggregation and class definition. This area is indicated as spotty tundra in the IIASA map, which means that only some spots are covered with tundra vegetation and the predominant rest is barren ground. After the definition of the RS map, regions with less than 20% vegetation cover were classified as barren ground. In ecoregion 5, Pribaikal, (shown in Figure 19b) it is exactly the opposite. Applying the same thresholds for vegetation cover, the RS map shows much less barren ground here than the IIASA map. In this case, the difference can not be explained but only assumed to be caused by the strong aggregation in the IIASA map. Also other classes, such as “burnt area” (black) are represented by big polygons compared to the RS map and endorse this assumption.

Figure 19c) shows a known misclassification of the RS map. In the southern taiga, on the left bank of the Yenisey river (West Siberian Lowlands) there are regions covered by cedar forest (light violet), that can not be separated from the other evergreen needleleaf trees using the described decision rules and data sets, and is therefore misclassified as pine forest.

Figure 19d) shows a region in the middle and southern taiga, which is strongly disturbed by fires. While the IIASA map indicated areas that were disturbed by fires (black) some years ago, the RS map shows the vegetation cover of 2003 when the disturbed areas, according to the MODIS VCF, are already recovered by the pioneer tree species birch (red). The light violet areas in the IIASA map are indicated as cedar forest, surrounded by larch (light green). This agrees with the yellow green pixels in the RS map, which are indicated as the mixed forest class “cedar with larch”. Also the blue patch at the southern border of the window, representing pine forest agrees well in both products.

The best agreement between the vegetation patterns is given in the southern part of the study region. An example is given in Figure 19e). Agricultural land (yellow), cropland/forest complexes (greenish yellow), and birch stands (red) agree well. Differences are resulting from strong aggregations of the heterogeneous vegetation cover in the southern mountain taiga to big polygons. Additionally mixed forests, such as “pine/birch” (green), are under-represented in the IIASA map, resulting from the forest inventory manual, and often assigned to single economically valuable species.

The pixel based comparison between the IIASA map and the RS map shows relatively low spatial agreement. Only 22.94% of all pixels have the same class definition in both products. Table 2 shows the rates of corresponding pixels for each ecoregion. Especially in the tundra and forest tundra ecoregion there is almost no agreement, because of the already discussed tundra wetland classification. The general low agreement between pixels can be explained by the two different characters of the products. The RS product is speckled because of heterogeneous landscapes, whereas the IIASA map consists of polygons, in which smaller areas of different land covers are aggregated to a bigger matrix, and is so more generalized and homogeneous.

A polygon based comparison in the meaning of a statistical analysis of the pixels in each polygon of IIASA’s vegetation map, shows a slightly better agreement. In Table 2, the percent of area is shown, where the majority of pixels belong to the same land cover class like the corresponding polygon of IIASA’s map.

Table 2: Percent of pixels with the same class definition in the IIASA map and the RS map.

Ecoregion No.	Ecoregion Name	Percent of Agreeing Pixels	Percent of Agreeing Area (polygon based)
1	Tundra and forest tundra (Taymir)	5.9	7
2	Northern taiga	23.09	25.9
3	Middle taiga	40	46.4
4	Southern taiga	25.7	34
5	Mountain middle taiga (Pribaikal)	26.02	44.7
6	Steppe and forest steppe	34.03	45
7	Mountain southern taiga (Sayan)	14	18.6
	Entire Region	***22.94***	***26.7***

For a more detailed evaluation of the classification accuracy of the RS map, a confusion matrix was produced, which shows how many pixels per land class of the RS product coincide with the different classes of the IIASA product. An extract of the matrix, showing the occurrence frequency in percentage of the forest classes (3100–3191), disturbed areas (323, 324), agricultural classes (2, 24), water (11), barren ground (12) and urban areas (13), is given in Table 3. The red marked values in the cross tabulation represent the proportion of the pixels in the RS map that are assigned to the same classes in the IIASA map. The blue marked values identify the classes with the highest frequency in other classes. The highest pixel-based agreement exists for the water class (11) with 90.9%, the lowest for disturbed areas with 0.4% and 8.6%, forest steppe (57) with 0.8% and alpine meadow (58) with 0.6%. The low values for disturbed areas can be explained by the already mentioned fact that the RS map represents the vegetation in 2003. Formerly disturbed areas that are covered again with trees are assigned to the class “birch” (24) and not to “burnt” or clear cut”, as in the IIASA map. This is why, 15.9% of pixels of the class “burnt area” (324) are classified as “birch in the RS map. The low value for “forest steppe” is also understandable, since this class does not exist directly in the IIASA vegetation map. It was derived by combining all three levels of the IIASA map and assigning those polygons with different vegetation types in the different levels to this new class. Since this was also the case for the class “cropland/forest complex” (24) and both classes are very similar, it is not astonishing that the highest proportion of class 57 in the RS map coincides with class 24 in the IIASA map.

Considering the forest classes, 72% to 98% of the pixels assigned to one of the forest classes in the RS map are also classified as forest in the IIASA map. This proportion decreases, if the classes are separately compared. The best agreement shows cedar (3105) with 62.1% and larch (3104) with 67%. The mixed forest classes (3107 to 3136) are scattered over the full range of forest classes in the IIASA map, but still with emphasis on the tree species that are contained in this class. For example, the “pine/birch” classes (3121, 3122, 3123) in the RS map coincide with the highest frequency with the classes “pine” (3101) and “birch” (3124) in the IIASA map, the “cedar/fir” classes (3108, 3109) and “cedar/larch” class (3110) in the RS map coincide with 60% to 77.1% with the class “cedar” (3105) in the IIASA map. The reason for the relatively high proportion of mixed forest classes in the RS map coinciding with the according single tree species class in IIASA’s vegetation map is, as already mentioned, the class assignment of the polygons to the economically most valuable tree species in a mixed stand.

Table 3: Extract of confusion matrix of RS map against IIASA vegetation map: Values are in % of all pixels of one class of RS map coinciding with pixels in IIASA map (further explanation in text).

Classes of RS Map	Classes of IIASA Vegetation Map																
	2	**11**	**12**	**13**	**24**	**57**	**58**	**323**	**324**	**3101**	**3102**	**3103**	**3104**	**3105**	**3124**	**3125**	**3191**
2	**44.0**	0.9	0.2	1.1	**36.4**	3.8	0.0	0.1	0.4	5.4	0.2	0.2	1.5	0.3	5.4	0.2	0.0
11	0.5	**90.9**	0.1	0.0	0.4	0.0	0.0	0.0	0.2	2.2	0.5	0.2	3.6	0.7	0.6	0.0	0.0
12	1.5	18.8	**43.9**	0.3	0.3	0.0	4.8	0.0	0.2	0.8	0.1	0.0	20.1	0.6	0.1	0.0	8.7
13	**29.2**	4.4	0.1	**21.2**	**22.9**	2.4	0.0	0.0	0.0	12.4	0.3	0.7	3.3	0.7	2.1	0.2	0.1
24	**23.0**	0.4	0.2	0.6	**41.8**	0.9	0.0	0.3	0.4	20.1	0.5	1.0	3.1	0.9	6.3	0.5	0.0
57	26.6	0.6	0.5	0.6	**44.6**	**0.8**	0.0	0.0	0.0	9.7	0.1	0.0	1.5	0.1	14.3	0.5	0.0
58	0.9	0.6	**32.2**	0.0	0.1	0.0	**0.6**	0.0	13.3	6.4	0.8	2.4	17.0	13.1	2.5	0.0	10.0
323	14.9	0.3	0.0	0.0	10.9	0.0	0.0	**0.4**	15.0	**23.3**	0.7	4.3	13.2	4.3	11.3	1.6	0.1
324	11.7	0.2	1.4	0.2	8.7	0.0	0.0	1.0	**8.6**	**34.3**	0.5	0.6	20.4	6.0	5.9	0.3	0.2
3101	0.7	0.4	0.1	0.0	1.0	0.0	0.0	0.3	1.3	**41.9**	4.8	8.0	17.0	17.9	5.6	0.6	0.3
3102	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	**30.4**	0.0	**46.5**	11.1	10.9	0.0	0.0
3103	0.3	0.1	0.0	0.0	0.2	0.0	0.0	0.2	0.7	**39.0**	4.7	**24.1**	15.1	7.3	7.4	1.0	0.0
3104	0.1	0.2	1.0	0.0	0.1	0.0	0.0	0.1	5.4	7.6	3.8	0.2	**67.0**	4.5	9.1	0.0	0.9
3105	0.0	0.2	3.7	0.0	0.0	0.0	0.5	0.0	1.2	8.3	2.2	2.6	15.6	**62.1**	3.2	0.3	0.1
3107	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	3.2	7.8	9.5	0.0	**54.8**	17.1	7.0	0.0	0.2
3108	0.1	0.0	0.7	0.0	0.1	0.0	0.1	0.0	0.4	9.9	0.1	18.9	7.1	**60.0**	2.6	0.0	0.0
3109	0.1	0.0	2.2	0.0	0.1	0.0	0.1	0.0	0.1	2.5	0.0	15.7	6.0	**71.1**	1.7	0.0	0.4
3110	0.1	0.1	10.2	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.4	10.6	**77.1**	0.1	0.0	0.0
3121	0.4	0.1	0.0	0.0	1.0	0.0	0.0	0.3	0.5	**44.0**	5.2	10.2	8.2	11.1	16.8	2.1	0.0
3122	0.5	0.1	0.0	0.0	1.1	0.0	0.0	0.3	0.7	**36.5**	2.7	6.9	11.9	9.1	27.8	2.2	0.1
3123	1.3	0.2	0.0	0.0	3.4	0.0	0.0	0.3	0.6	**50.0**	3.1	6.8	5.2	3.0	22.9	3.0	0.1
3124	4.5	0.2	0.0	0.0	4.4	0.0	0.0	1.2	15.9	**27.2**	1.9	2.4	15.0	5.3	**20.5**	1.5	0.1
3126	1.7	0.1	0.4	0.0	7.2	0.0	0.0	0.4	0.3	22.3	2.5	7.3	6.7	4.8	**41.4**	4.7	0.2
3127	0.2	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.7	24.0	5.5	1.0	**32.2**	19.5	14.9	1.6	0.0
3128	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.6	7.3	7.4	0.2	**32.2**	28.7	22.9	0.4	0.0
3129	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.6	17.1	7.3	1.2	28.7	**34.8**	8.9	1.1	0.0
3130	0.0	0.1	1.5	0.0	0.0	0.0	0.0	0.0	0.4	5.6	15.6	0.2	**43.1**	16.9	7.5	0.0	9.2
3133	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.2	1.8	13.9	0.0	**55.5**	7.7	17.3	0.0	3.2
3134	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.4	9.5	**32.1**	0.4	**31.0**	14.8	6.0	0.0	4.7
3135	0.5	0.0	0.1	0.0	3.4	0.0	0.0	1.2	0.0	20.8	1.4	**25.0**	4.1	14.5	23.1	5.8	0.0
3136	0.1	0.0	1.1	0.0	0.2	0.0	0.1	0.0	0.0	16.5	0.2	21.5	12.1	**40.4**	7.6	0.2	0.0

The comparison of the areas of the different classes between both vegetation maps is presented in Tables 4 and 5. Since the most northern part of the study region is missing in the RS map, because of acquisition restrictions of the MODIS sensor above 75° N, the total area differs a bit between both maps. The area of the RS map is therefore not 100% of area of the IIASA map, but only 97.4%. Considering the entire study region, water, urban, tundra and forest areas are comparable between both maps. Barren ground, meadow and clear cut areas are between two and five times bigger in the RS map, whereas burnt and shrub areas cover only half of the area they cover in the IIASA map. The reason for the lower proportion of burnt areas in the RS map was already explained above. The lower proportion of shrubs can be explained with the introduction of the open forest classes. A high proportion of the shrub areas in the IIASA map are assigned to open forest classes, which also explains the much higher proportion of sparse forest in the RS map. Areas of agricultural land and steppe in the RS map are less than half of the areas in the IIASA map. Adding the mixed classes "cropland/forest" and "forest steppe" to these classes, the areas become comparable and even a bit bigger than in the IIASA map. The area surplus is probably imputable to the proportion of trees in the mixed classes, which are missing the pure forest classes.

Table 4: Area of vegetation land cover types for the RS vegetation map and IIASA vegetation map.

Land Cover Class (code)	Area [ha] RS Map	Area [ha] IIASA Map	% of IIASA Area
Agriculture (2)	3040400	7657820	39.70
Forest/cropland (24)	7745825		
Water (11)	5098850	6229738	81.85
Barren ground (12)	10404725	4784977	217.45
Urban areas (13)	165275	134835	122.58
Forest steppe (57)	748550		
Steppe (571, 572)	381750	1103289	34.60
Meadow (561)	4003575	698987	572.77
Clear cut (323)	1090225	406244	268.37
Burnt area (324)	2999350	5451825	55.02
Wetlands (411–491)	41767850	28169059	148.28
Tundra (511–562)	63198950	70423271	89.74
Shrubs (611–641)	3014525,00	8370958	36.01
Forest total (3100–3236)	163415950	181766783	89.90
Sparse forest (3200–3236)	53331125	8933.1	597005.8
Total	***307075800***	***315197790***	***97.4***

Table 5: Area of vegetation land cover types for each ecoregion for the RS vegetation map and IIASA vegetation map.

Ecoregion	Land Cover Class	Area [ha] RS Map	Area [ha] IIASA Map	% of IIASA Area
1	water	2369300	2983690	79
	barren ground	6996500		
	urban areas	2475	73	3390
	burnt area	13800	96811	14
	wetlands	37453300	16124779	232
	tundra	13538000	49631183	27
	shrubs	0	1154354	0
	forest total	272975	7943967	3
	sparse forest	106500		
2	water	1181325	1546010	76
	barren ground	3018325	8678	34779
	urban areas	1250	3299	37
	burnt area	416700	998388	41
	wetlands	1563975	7434404	21
	tundra	47508425	20470321	232
	meadow	68425		
	shrubs	2946075	6204658	47
	forest total	22237150	35663364	62
	sparse forest	7700000		
3	water	103075	162470	63
	barren ground	2275		
	clear cut	35025		
	burnt area	47150	2721551	2
	wetlands	1501150	2497855	60
	meadow	231000	3862	5981
	shrubs	68450	764219	9
	forest total	44131475	39969914	110
	sparse forest	6489500		
4	water	1021000	1059441	96
	barren ground	9000	16360	55
	urban areas	39400	1298	3035
	forest/cropland	695650		
	agriculture	335825	1134203	30
	clear cut	1055200	285892	369
	burnt area	1061975	1486947	71
	wetlands	1218000	1793847	68
	meadow	260400	180858	144
	shrubs	0	155064	0
	forest total	61688175	61042506	101
	sparse forest	**33653950**	**1580**	2129997
5	water	22775	41249	55
	barren ground	252075	2962521	9
	urban areas	1325	225	589
	burnt area	115550	1318513	9
	wetland	22100	6373	347
	meadow	2135500		
	tundra	106025		
	forest total	13172125	10478992	126
	sparse forest	4397775		
6	water	287800	299694	96
	barren ground	4075		407500
	urban areas	82150	70104	117
	agriculture	2457600	5530030	44
	cropland/forest	5488325		
	forest steppe	737425		
	clear cut	0	4148	0
	burnt area	783725	18051	4342
	wetlands	0	61801	0
	steppe	337325	1103289	31
	shrubs	0	65408	0
	forest total	3046500	6058105	50
	sparse forest	186075		
7	agriculture	246975	993587	25
	forest/cropland	1561850		
	water	113575	137183	83
	barren ground	122475	1797416	7
	urban areas	38675	59836	65
	forest steppe	11125		
	clear cut	0	116203	0
	burnt area	676000	130076	520
	wetlands	9325	249998	4
	meadow	1308250	514267	254
	tundra	2046500	321766	636
	steppe	44425		
	shrubs	0	27251	0
	forest total	18867550	20609933	92
	sparse forest	797325	7353	10843

Much higher differences in the areas of the several classes are identifiable, if single ecoregions are considered, as shown in Table 5. The already mentioned underestimation of the sparse larch forest in ecoregion 1 (Taymir peninsula) accounts for 97%. In contrast, the area of wetlands is twice as high as in the IIASA map, resulting from the aggregation of small open water bodies to one wetland polygon, whereas IIASA excludes all open water bodies from the wetland classification. In ecoregion 2, almost all classes have a smaller area proportion in the RS map for the benefit of the classes “barren ground” and “tundra”. Especially in the Putorana Plateau, a much higher area proportion was classified as barren ground instead of “mountain stony tundra”, which is an aggregation of bare rocks with some spot of tundra vegetation. The higher proportion of tundra and lower proportion of forest in the RS map is again the result of the sparse larch forest, which is probably not detectable with MODIS 500 m resolution. The differences in the other ecoregions were already explained in the area consideration of the entire study region.

7 Conclusions and Further Work

This work demonstrated a method for a fully automated derivation of a raster based vegetation map using mainly remote sensing data and herewith globally available information sources. Since this study represented only the first attempt of developing such a system, it still bears some known problems, such as obsolete data sources or missing information. Nevertheless, expecting newer remote sensing products in the near future, this method has potentials for improvement. Comparison with the IIASA vegetation map, which is expected to be the currently most accurate available representation of the land cover in Siberia, showed an overall agreement of the spatial vegetation patterns, but revealed considerable differences especially in the area distribution of the land cover classes. Some are definitely explainable by the inadequatenesses of decision rules or input datasets, but others result from the strong aggregation of polygons of the IIASA map and different priorities in class definitions.

Regarding the cost and labor intensity of the different derivation processes, the proposed remote sensing-based method represents a more comprehensible and faster technique to derive information about the vegetation distribution than the IIASA method. Additionally, it produces a more detailed representation of the vegetation cover than currently available remote sensing-based land cover products. Such a method could be especially interesting for studies, which investigate large or/and inaccessible regions with no possibilities of continuous ground surveys and a need for vegetation monitoring in short time intervals.

This point leads back to the idea behind the attempt to produce this vegetation map, namely a full carbon account using the IIASA model. Considering this objective, this work represents only an initial step in this framework. To calculate the amount of carbon stored in the terrestrial vegetation and exchanged with the atmosphere by processes of respiration and photosynthesis, the productivity of the derived vegetation groups has to be estimated. This could also be realized using remote sensing products. For example, the length of the growing season can be retrieved from remote sensing-based datasets of phenology for deciduous species and freeze/thaw data of the surface for evergreen species. Both products are available from the SIBERIA-II project. Under consideration of the above mentioned limitations, relative stocking of the forested areas could be replaced by canopy closure coming from the MODIS VCF. Information about other important indicators for vegetation productivity, such as site index and stand age are difficult to derive independently from forest inventory. Currently, there are only initial attempts to derive stand age from satellite remote sensing (e.g., Cohan and Spies, 1992; Sabol *et al*., 2002). Especially in this field, further research is needed.

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Appendix A: Codes for Land Classes

Land classes and class codes were adopted from IIASA vegetation map.

Group	Code	Class	Explanation
Unproductive lands	11	water	rivers, lakes
	12	barren ground	areas without vegetation cover
	13	urban areas	settlements
Agriculture lands	2	agricultural land	arable lands, cultivated pastures and hay lands, perennial vegetation
	24	cropland/forest complex	mixed class of agricultural land with patches of undefined forest
Forested areas	3100	closed dark coniferous forest	forest with >25% crown closure consisting of cedar, fir and/or spruce
	3101	closed pine	Pine forest with >25% crown closure
	3102	closed spruce	Spruce forest with >25% crown closure
	3103	closed fir	Fir forest with >25% crown closure
	3104	closed larch	Larch forest with >25% crown closure
	3105	closed cedar	Cedar forest with >25% crown closure
	3107	closed dark coniferous forest (spruce/cedar)	dark coniferous forest with spruce and cedar dominating with >25% crown closure
	3108	closed dark coniferous forest (fir with cedar)	dark coniferous forest with fir dominating and admixture of cedar, crown closure >25%
	3109	closed dark coniferous forest (cedar with fir)	dark coniferous forest with cedar dominating and admixture of fir, crown closure >25%
	3110	closed cedar with larch	forest dominated by cedar with admixture of larch, crown closure >25%
	3121	closed pine with birch	mixed forest of pine and birch with ratio 60:40, crown closure >25%
	3122	closed birch and pine	mixed forest of pine and birch with ratio 50:50, crown closure >25%
	3123	closed birch with pine	mixed forest of pine and birch with ratio 40:60, crown closure >25%
	3124	closed birch	Birch forest with crown closure >25%
	3126	closed birch with aspen	Forest dominated by birch with admixture of aspen, crown closure >25%
	3127	closed birch with aspen—dark coniferous	mixed forest dominated by birch and aspen with admixture of dark coniferous trees (60:40)
	3128	closed birch with aspen and dark coniferous	mixed forest of birch/aspen and dark coniferous trees (50:50), crown closure >25%
	3129	closed dark coniferous with birch with aspen	mixed forest dominated by dark coniferous trees with admixture of birch and aspen (60:40)
	3130	closed birch-aspen with larch	mixed forest dominated by birch and aspen with admixture of larch (60:40), crown closure >25%
	3133	birch-aspen and larch	mixed forest of birch/aspen and larch (50:50), crown closure >25%
	3134	larch with birch-aspen	mixed forest dominated by larch with admixture of birch/aspen (60:40), crown closure >25%
	3135	aspen with fir	mixed forest dominated by aspen with admixture of fir, crown closure >25%
	3136	fir with aspen	mixed forest dominated by fir with admixture of aspen, crown closure >25%
	3191	closed dwarf pine (Pinus pumila)	Dwarf pine (Pinus pumila) with crown closure >25%
	3200–3291	open forest classes	Same class definitions as for closed forests but with only 5–25 % crown closure
Disturbed areas	323	clear cut areas	deforested areas by logging
	324	burnt areas	areas that burned between 1992 and 2003

Group	Code	Class	Explanation
Wetlands	411	arctic tundra wetland	Sedge-hypnum mosses, sedge-cotton (*Eriophorum*) and cereals-sedge bogs
	422	over-moisture sites of river valleys in subarctic tundra	Series of over-moisture sites of river valleys (hypnum-sedge bogs, marshy sedge meadows with swampy *ernic* and *ol'khovnik* tundras
	423	tundra-wetlands shrubs with small lakes	small flat lakes with only 500 to 1500 m land, covered with shrubs between them
	424	tundra-wetlands lichen moss with small lakes	small flat lakes with only 500 to 1500 m land, covered with lichen moss between them
	441	Grass-green moss-lichen and sedge-sphagnum bogs (often with larch and other species)	
	452	Small-shrub-dicranum-lichen-sedge-hypnum and sedge-cotton grass-sphagnum large bumpy complex bogs	
	453	Small shrub-sphagnum and grass-moss *grjadovo-mochazhinnie* aapa-bogs	
	461	Sphagnum small shrub oligotrophic convex bogs (often with Pine)	
	462	Big-bumpy bogs of valley and river terraces	
	463	Bumpy-lake upper bogs	
	471	Sphagnum with pine and sphagnum oligotrophic convex bogs with secondary small lakes and meso-evtrophic *grjadovo-mochazhinnie topi*	
	472	Different types of bogs of river valley of southern taiga	
	473	Different types (sphagnum, small shrubs, green moss) of bogs of terraces of southern taiga	
Tundra	512	Moss-lichen polygonal tundras	
	513	Coastal salinity cereal-sedge swampy meadows	
	514	Tundras in river valley: cereals-sedge-mosses	
	521	Small shrub-moss-sedge tundras	
	531	Ernic-willow low shrubs tundras	
	543	Mountain small shrub green moss tundra	
	562	Mountain tundras of forest zone	
Steppe	57	Forest steppe	steppe grassland with trees (mainly birch and pine)
	571	steppe	motley grass-cereal meadow steppe and stepisized meadow
	572	steppe	motley grass-sod-cereal steppe
Humid grassland	58	alpine meadows	
	561	(plain) meadow	
Shrubs	632	Alder shrubbery subalpine	
	641	Shrub-forest vegetation of river valleys (alder-willow-birch)	

APPENDIX B: Data Set Requirements

Needed input data	Source	Value range	Unit	Classification code
land cover	SIB-II LC	1–16		
tree cove r	MODIS VCF	0–100	%	251 and 253 = water, urban, transportation
barren ground	MODIS VCF	0–100	%	251 and 253 = water, urban, transportation
broadleaf tree cover	AVHRR VCF	0–80	%	
needleleaf tree cover	AVHRR VCF	0–80	%	
deciduous tree cover	AVHRR VCF	0–80	%	
DEM	SRTM	0–4000	m	
slope	SRTM DEM	0–45	degree	1 <= 1° and 2 > 1° (reclassification is included in aml)
5 km river buffer	ASAR water bodies	0; 1		0 = not in buffer, 1 = 5km buffer along rivers
soil	IIASA soil map	0; 1; 2		1 = peaty soil ticker than 50, 2 = soils 136, 230 and 278, 0 = all other soils
disturbances	SIB-II disturbance map	0; 1; 1992–2003	year	0 = no disturbance, 1 = undated disturbance, 1992–2003 = year of disturbance
wetland	ASAR water bodies distance analysis	0; 1		0 = not tundra wetland, 1 = tundra wetland
water bodies	ASAR water bodies	0; 1		0 = no water, 1 = water
settlements	topographic maps	0; 1		0 = no settlement, 1 = settlement

All files have to be converted into grids with 500 m resolution and stored in one directory. The river buffer, soil, disturbances, wetland, water bodies and settlement grids must have a matrix with 0 values. This can be realized by a union of the source coverage files with the boundary of the study region before converting it into grid.

Appendix C: Decision Rules

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Tundra (Taimir tundra, Taimir forest tundra, Krasnoyarsk tundra, Krasnoyarsk forest tundra) (1)	tundra–shrubs (16)	/	≤5%	>80%	/	barren ground (2)								
				<81%		tundra–lichen moss (15)								
			6–25%	/	/	/	upland	tundra shrubs	/	/	/	/	yes	tundra shrubs wetland (423)
													no	dry tundra–small shrub-moss-sedge (521)
							5 km river buffer	over-moisture sites of river valleys (422)						
			>25	/	/	tundra shrubs on uplands or larch forest along river (70)	upland	tundra–shrubs (521)						
							5 km river buffer	closed larch forest (3104)						
	tundra–lichen moss (15)	/	≤5%	>80%	/	barren ground (2)								
				<81%	/	/	upland	tundra–lichen moss	/	/	/	/	yes	tundra–lichen moss wetland (424)
													no	dry tundra–lichen moss (512)
							5km river buffer	over-moisture sites of river valleys (422)						
			6–25%	/	/	tundra–shrubs (16)								
			>25		/	tundra shrubs on uplands or larch forest along river (70)								
	evergreen needleleaf (6)	/	≤5%	>80%	/	barren ground (2)								
				<81%	/	tundra– lichen moss (15)								
			6–25%	/	/	open spruce forest (3202)								
			>25%	/	/	closed spruce forest (3102)								
	deciduous broadleaf (7)	tundra–shrubs (16)												

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Tundra (cont.)	larch (11)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra– lichen moss								
			6–25%	/	/	open larch forest (3204)								
			>25%	/	/	closed larch forest (3104)								
	mixed forest (8, 9, 10)	evergreen needleleaf (6)												
	steppe (14), cropland (4), cropland\forest complex (5)	tundra–shrubs (16)												
	wetland (13), humid grassland (12)	/	≤5%	/	/	Sedge-hypnum mosses, sedge cotton and cereals-sedge bogs (411)	/	/	/	/	/		/	Sedge-hypnum mosses, sedge cotton and cereals-sedge bogs (411)
			>5%	/	/	tundra–shrubs (16)								
	barren ground (2), water (1), urban (3)	/	≤5%	>40%	/	(1), (2), (3)	/	/	/	/	/		/	(11), (12), (13)
				<41%	/	wetland or tundra–lichen moss (59)	/	/	peat soil >40 cm	sedge cotton and cereals-sedge bogs (411)				
									not peaty	tundra–lichen moss (512)				
			>5%	/	/	tundra–shrubs or larch forest (70)								

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Northern Taiga (Taimir sparse Taiga, Taimir forest tundra larch-spruce forest, Krasnoyarsk sparse taiga, Krasnoyarsk north taiga, Evenka mountain north taiga) (2)	tundra–shrubs (16)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss (15)								
			6–25%	/	/	/	<250 m	ernic willow (531)	/	/	burnt	burnt area (324)		
											not burnt	ernic willow (531)		
							>250 m	tundra–shrubs (543)	/	/	burnt	burnt area (324)		
											not burnt	tundra–shrubs (543)	yes	tundra–lichen moss wetland (441)
													no	dry tundra–shrubs (543)
			>25	/	/	tundra shrubs on uplands or larch forest along river (in valley) (70)	<250 m	ernic willow (531)						
							>250 m	alder shrubery (632)						
							5 km buffer along river	closed larch forest (31041)	/	/	burnt	burnt area (324)		
											not burnt	closed larch (3104)		
	tundra–lichen moss (15)	/	≤5%	>80%	/	barren ground								
				<81%	/	/	/	tundra lichen (543)	/	/	not burnt	tundra–lichen moss (543)	yes	tundra– lichen moss wetland (441)
													no	dry tundra–lichen moss (543)
											burnt after 2001	burnt area (324)		
			6–25%	/	/	tundra–shrubs (16)								
			>25	/	/	tundra–shrubs on uplands or larch forest along river (70)								
	evergreen needleleaf (6)	/	≤5%	>80%	/	barren ground								
			6–25%	/	/	open spruce forest (3202)								

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Northern Taiga (cont.)	evergreen needleleaf (6)	/	≤5%	>80%	/	barren ground								
			6–25%	/	/	open spruce forest (3202)								
	deciduous broadleaf trees (7) (birch with aspen)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss (15)								
			6–25%	/	/	open birch with aspen (3226)	/	/	/	/	burnt	open birch (3224)		
											not burnt	open birch with aspen (3226)		
			>25%	/	/	closed birch with aspen (3126)	/	/	/	/	burnt	closed birch (3124)		
											not burnt	closed birch with aspen (3126)		
	larch (11)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss								
			6–25%	/	/	open larch forest (3204)								
			>25%	/	/	closed larch forest (3104)								
	mixed forest (8, 9, 10)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss								
			6–25%	/	/	open broadleaf-needleleaf (39)	<100 m	open birch-aspen with dark coniferous (3227)						
							>100 m	open birch-aspen with larch (3230)						
						open mixed forest (40)	<100 m	open birch-aspen and dark coniferous (3228)						
							>100 m	open birch-aspen and larch (3233)						
						open needleleaf-broadleaf (41)	<100 m	open dark coniferous with birch and aspen (3229)						
							>100 m	open larch with birch and aspen (3234)						
			>25%	/	/	closed broadleaf-needleleaf (43)	<100 m	closed birch-aspen with dark coniferous (3127)						
							>100 m	closed birch-aspen with larch (3130)						
						closed mixed forest (44)	<100 m	closed birch-aspen and dark coniferous (3128)						
							>100 m	closed birch-aspen and larch (3133)						

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Northern Taiga (cont.)	mixed forest (cont.)	/	>25%	/	/	closed needleleaf-broadleaf (45)	<100 m	closed dark coniferous with birch and aspen (3129)						
							>100 m	closed larch with birch and aspen (3134)						
	steppe (14), cropland (4), cropland\ forest complex (5)	tundra–shrubs (16)												
	wetland (13)	/	≤30%	/	/	wetland (13)	<200 m	small shrub-sphagnum and grass-moss aapa-bogs (453)						
							>200 m or in 5 km river buffer	small shrub bumpy complex bog (452)						
			>30%	/	broadleaf	closed birch with aspen	/	/	/	/	burnt before 2001	closed larch (3104)		
					evergreen needleleaf	closed spruce					burnt after 2001	burnt area (324)		
					larch	closed larch					not burnt	forest (3126, 3102, 3127, 3128, 3129, etc.)		
					mixed	like mixed forest	<100 m	with dark coniferous						
							>100 m	with larch						
	humid grassland (12)	/	<5%	/	/	humid grassland (561)	/	/	/	/	burnt	burnt area (324)		
											burnt before 2001	plain meadow (561)		
											not burnt			
			5–30%	/	/	tundra or wetland (65)	<200 m	(6501)	peat soil >40 cm	small shrub-sphagnum and grass-moss aapa-bogs (453)	burnt before 2001	aapa-bogs (453)		
											burnt after 2001	burnt area (324)		
											not burnt	aapa-bogs (453)		
							<200 m		not peaty	tundra–shrubs (531)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Northern Taiga (cont.)	humid grassland (cont.)	/	5–30%	/	/	tundra or wetland (cont.)	>200 m or in 5 km river buffer	(6502)	peat soil >40 cm	small shrub bumpy complex bog (452)	like (453)			
									not peaty	tundra–shrubs (543)				
			>30%	/	broadleaf	closed birch with aspen								
					evergreen needleleaf	closed spruce								
					larch	closed larch								
					mixed	closed mixed forest								
	barren ground (2), water (1), urban (3)	/	≤5%	>55%	/	/	/	/	/	/	burnt	burnt area (324)		
											not burnt	(11), (12), (13)		
				<56%	/	wetland or tundra -lichen moss (59)	<200 m	(59)	peat soil >40 cm	aapa-bogs (453)				
									not peaty	tundra–lichen moss (531)				
							>200 m or in 5 km river buffer	(591)	peat soil >40 cm	small shrub bumpy complex bog (452)				
									not peaty	tundra–lichen moss (543)				
			>5%	/	/	tundra shrubs on uplands or larch forest along river (in valley) (70)								

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (Evenka mountain middle taiga, Irkutsk middle taiga, Krasnoyarsk middle taiga) (3)	tundra–shrubs (16), tundra–lichen moss (15)	meadow or forest or burnt area (60)												
	evergreen needleleaf (6)	/	≤5%	>80%	/	barren ground								
				<81%	/	meadow or wetland (60)	<220 m	(6001)	peat soil >40 cm	bumpy-lake upper bogs (463)				
									not peaty	meadow (561)	burnt	burnt area (324)		
											not burnt	meadow (561)		
							in 5 km river buffer	(6002)	peat soil >40 cm	big bumpy-bogs of valleys and river terraces (462)				
									not peaty	meadow (561)				
							>220 m	(6003)	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs (461)				
									not peaty	meadow (561)				
			6–25%	/	/	open evergreen forest (24)	<220 m	open dark coniferous forest (cedar dominated) (3205)						
							>220 m	open dark coniferous (spruce and cedar) (3207)						
			>25%	/	/	closed evergreen forest with shrub understory (28)	<220 m	closed dark coniferous forest (cedar dominated) (3105)						
							>220 m	closed dark coniferous (spruce and cedar) (3207)						
	deciduous broadleaf trees (7)	/	≤5%	>80%	/	barren ground								
				<81%	/	meadow (561)								
			6–25%	/	/	open birch with aspen (3226)	/	/	/	/	burnt	open birch (3224)		
											not burnt	open birch with aspen (3226)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (cont.)	deciduous broadleaf trees (cont.)		>25%	/	/	closed birch with aspen (3126)	/	/	/	/	burnt	closed birch (3124)		
											not burnt	closed birch with aspen (3126)		
	larch (11)	/	≤5%	>80%	/	barren ground								
				<81%	/	meadow (561)								
			6–25%	/	/	open larch forest (3204)								
			>25%	/	/	closed larch forest (3104)								
	mixed forest (8, 9, 10)	/	≤5%	>80%	/	barren ground								
				<81%	/	meadow (561)								
			6–25%	/	/	open birch-aspen with dark coniferous (3227)								
					/	open birch-aspen and dark coniferous (3228)								
					/	open dark coniferous with birch and aspen (3229)								
			>25%	/	/	closed birch-aspen with dark coniferous (3127)								
					/	closed birch-aspen and dark coniferous (3128)								
					/	closed dark coniferous with birch and aspen (3129)								
	steppe (14)	meadow or forest or burnt area (60)	≤5%	>80%	/	barren ground								
				<81%	/	meadow, wetland or burnt area (80)	<220 m	8001	peat soil >40 cm	bumpy-lake upper bogs or burnt area (4631)	burnt area	burnt area (324)		
											not burnt	bumpy-lake upper bogs (463)		
									not peaty	meadow or burnt area (82)	burnt	burnt area (324)		
											not burnt	meadow (561)		
							in 5 km river buffer	(8002)	peat soil >40 cm	big bumpy-bogs of valleys or burnt area (4621)	like (4631)			
									not peaty	meadow or burnt area (82)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (cont.)	steppe (cont.)	meadow or forest or burnt area (cont.)	<5%	<81%	/	meadow, wetland or burnt area (cont.)	in 5 km river buffer	(8002)	peat soil >40 cm	big bumpy-bogs of valleys and river terraces or burnt area (4621)	like (4631)			
									not peaty	meadow or burnt area (82)				
							>220 m	(8003)	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs or burnt area (4611)	like (4631)			
									not peaty	meadow or burnt area (82)				
			5–30%	/	broadleaf	open broadleaf forest or wetland or disturbed area	<220 m	open birch with aspen or wetland or disturbed area	peat soil >40 cm	bumpy-lake upper bogs or burnt area (4632)	burnt before 2001 or not burnt	bumpy-lake upper bogs (463)		
											burnt after 2001	burnt area (324)		
									not peaty	open birch with aspen				
							in 5 km river buffer	shrub-forest of river valleys or wetland or disturbed area	peat soil >40 cm	big bumpy-bogs of valleys and river terraces or burnt (4622)	like (4632)			
									not peaty	shrub-forest of river valleys or burnt (6411)				
							>220 m	open birch with aspen or wetland or disturbed area	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs or burnt (4612)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (cont.)	steppe (cont.)	meadow or forest or burnt area (cont.)	5–30%	/	broadleaf (cont)	open broadleaf forest or wetland or disturbed area (cont.)	>220 m	open birch with aspen or wetland or disturbed area (cont.)	not peaty	open birch with aspen	burnt before 2001	open birch (3224)		
											burnt after 2001	burnt area (324)		
											not burnt	open birch with aspen (3226)		
					evergreen needleleaf	open evergreen needleleaf forest or wetland or disturbed area	<220 m	open dark coniferous forest (cedar dominated) or wetland or disturbed area	peat soil >40 cm	bumpy-lake upper bogs or burnt area (4632)				
									not peaty	open dark coniferous forest (cedar dominated) (32058101)	like (32078103)			
							in 5 km river buffer	shrub-forest of river valleys (641)	peat soil >40 cm	big bumpy-bogs of valleys and river terraces or burnt (4622)				
									not peaty	shrub-forest of river valleys or burnt (6411)				
							>220 m	open dark coniferous (spruce and cedar) or wetland or disturbed area	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs or burnt (4612)				
									not peaty	open dark coniferous (spruce and cedar) (32078103)	burnt before 2001	open birch (3224)		
											burnt after 2001	burnt area (324)		
											not burnt	open dark coniferous (spruce and cedar) (3207)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (cont.)	steppe (cont.)	meadow or forest or burnt area (cont.)	5–30%	/	larch	open larch forest or wetland or disturbed area	<220 m	open larch forest or wetland or disturbed area	peat soil >40 cm	bumpy-lake upper bogs or burnt area (4632)				
									not peaty	open larch				
							in 5 km river buffer	shrub-forest of river valleys (641)	peat soil >40 cm	big bumpy-bogs of valleys and river terraces or burnt (4622)				
									not peaty	shrub-forest of river valleys or burnt (6411)				
							>220 m	open larch forest or wetland or disturbed area	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs or burnt (4612)				
									not peaty	open larch	burnt before 2001	open birch (3224)		
											burnt after 2001	burnt area (324)		
											not burnt	open larch(3204)		
					mixed	open mixed forest or wetland or disturbed area	<220 m	open mixed forest or wetland or disturbed area	peat soil >40 cm	bumpy-lake upper bogs or burnt area (4632)				
									not peaty	open mixed forest	like (32..8103)			
							in 5 km river buffer	shrub-forest of river valleys (641)	peat soil >40 cm	big bumpy-bogs of valleys and river terraces or burnt (4622)				
							in 5 km river buffer	shrub-forest of river valleys (641)	not peaty	shrub-forest of river valleys or burnt (6411)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (cont.)	steppe (cont.)	meadow or forest or burnt area (cont.)	5–30%	/	mixed (cont.)	open mixed forest or wetland or disturbed area (cont.)	>220 m	open mixed forest or wetland or disturbed area	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs or burnt (4612)				
									not peaty	open mixed (32..8103)	burnt <2001	open birch (3224)		
											burnt after 2001	burnt area (324)		
											not burnt	open mixed (3227/28/29)		
			>30%	/	broadleaf	closed birch with aspen (312648)	in 5 km river buffer	shrub-forest of river valleys (64148)	/	/	burnt <2001	closed birch (3124)		
											burnt after 2001	burnt area (324)		
											not burnt	shrub-forest of river valleys (641)		
							/	/	/	/	burnt < 2001	closed birch (3124)		
											burnt after 2001	burnt area (324)		
											not burnt	closed birch with aspen (3126)		
					evergreen needleleaf	closed evergreen (2848)	<220 m	closed dark coniferous forest (cedar dominated) (310548)	/	/	burnt before 2001	closed birch (3124)		
											burnt after 2001	burnt area (324)		
											not burnt	closed dark coniferous forest (cedar dominated) (3105)		
							in 5 km river buffer	shrub-forest of river valleys						

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (cont.)	steppe (cont.)	meadow or forest or burnt area (cont.)	>30%	/	evergreen needleleaf (cont.)	closed evergreen (cont.)	>220 m	closed dark coniferous (spruce and cedar)	/	/	like 310548			
					larch	closed larch (310448)								
					mixed	like mixed forest (312748)	like 312648							
	cropland (4), cropland\forest complex (5)	meadow, wetland or forest or clear cut (62)	≤5%	>80%	/	barren ground								
				<81%	/	meadow or clear cut area (83)	<220 m	8301	peat soil >40 cm	bumpy-lake upper bogs or clear cut (4633)	burnt	clear cut (323)		
											not burnt	bumpy-lake upper bogs (463)		
									not peaty	meadow or clear cut (83)	burnt	clear cut (323)		
											not burnt	meadow (561)		
							in 5 km river buffer	8302	peat soil >40 cm	big bumpy-bogs of valleys and river terraces or clear cut (4623)	like (4631)			
									not peaty	meadow or clear cut (83)				
							>220 m	8303	peat soil > 40 cm	oligotrophic convex bogs or burnt area (4613)	like (4631)			
									not peaty	meadow or clear cut (83)				
			5–30%	/	/	open forest or clear cut (248)	/	/	/	/	burnt after 2001	clear cut (323)		
											burnt 2001 or not burnt	open birch (3224)		
						closed forest or clear cut (448)	/	/			burnt before 2001 or not burnt	closed birch (3124)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle Taiga (cont.)	cropland, cropland\forest complex (cont.)	meadow, wetland or forest or clear cut (cont.)	>30%	/	/	closed forest or clear cut (448)	/	/			burnt before 2001 or not burnt	closed birch (3124)		
											burnt after 2001	clear cut (323)		
	wetland (13)	/	≤30%	/	/	wetland (13)	<220 m	Bumpy-lake upper bogs (463)						
							in 5 km river buffer	big bumpy-bogs of valleys and river terraces (462)						
							>220 m or in 5 km river buffer	Sphagnum small shrub oligotrophic convex bogs (often with Pine) (461)						
			>30%	/	broadleaf	closed broadleaf forest (312648)								
					evergreen needleleaf	closed evergreen needleleaf (2848)								
					larch	closed larch (310448)								
					mixed	closed mixed forest (..48)								
	humid grassland (12)	/	<5%	/	/	humid grassland (561)	/	/	/	/	burnt after 2001	burnt area (324)		
											burnt before 2001	plain meadow (561)		
											not burnt			
			5–30%	/	broadleaf	forest or wetland or grassland or burnt (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									
			>30%		broadleaf	closed forest (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									
	barren ground (2), water (1), urban (3)	/	≤5%	>40%	/	/	/		/	/	burnt	burnt area (324)		
											not burnt	(11), (12), (13)		
				41%	/	wetland or meadow (soil) (80)								

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Middle taiga (cont.)	barren ground, water, urban (cont.)		5-30%	/	broadleaf	forest or wetland or grassland or burnt (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									
			>30%		broadleaf	closed forest (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									
Southern Taiga (Krasnoyarsk south taiga, Irkutsk southern taiga) (4)	tundra–shrubs (16), tundra–lichen moss (15)	meadow, wetland or forest (60)												
	evergreen needleleaf (6)	/	≤5%	>80%	/	barren ground								
				<81%	/	meadow (561)								
			6–25%	/	/	open evergreen forest (24)	<470 m and slope >1°	open fir (3203)	soil type = 278, 136 or 230	open fir (3203)				
									other soil types	open pine (3201)				
							>600 and slope >1°	open cedar (3205)						
							470–600 m	open pine (3201)						
			>25%	/	/	closed evergreen forest (28)	like open forest							
	deciduous broadleaf trees (7)	/	≤5%	>80%	/	barren ground (2)								
				<81%	/	meadow (561)								
			6–25%	/	/	open birch with aspen (322425)	/	/	/	/	burnt	open birch (3224)		
											not burnt	open birch with aspen (322425)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	deciduous broadleaf trees (cont.)	/	>25%	/	/	closed birch with aspen (3126)	/	/	/	/	burnt	closed birch (3124)		
											not burnt	closed birch with aspen (3126)		
	larch (11)	/	≤5%	>80%	/	barren ground								
				<81%	/	meadow (561)								
			6–25%	/	/	open larch forest (3204)								
			>25%	/	/	closed larch forest (3104)								
	mixed forest (8, 9, 10)	/	≤5%	>80%	/	barren ground								
				<81%	/	meadow (561)								
			6–25%	/	/	open broadleaf-needleleaf	<600 m	open birch with pine (3223)						
							>600 m	open decid. Br. with cedar-spruce-fir (3227)						
					/	open mixed forest	<600 m	open birch and pine (3222)						
							>600 m	open decid. Br. and cedar-spruce-fir (3228)						
					/	open needleleaf-broadleaf	<600 m	open pine with birch (3221)						
							>600 m	open cedar-spruce-fir with decid. Br. (3229)						
			>25%	/	/	closed broadleaf needleleaf	<600 m	closed birch with pine (3123)						
							>600 m	closed decid. Br. with cedar-spruce-fir (3127)						
					/	closed mixed forest	<600 m	closed birch and pine (3122)						
							>600 m	closed decid. Br. and cedar-spruce-fir (3128)						
					/	closed needleleaf-broadleaf	<600 m	closed pine with birch (3121)						
							>600 m	closed cedar-spruce-fir with decid. Br. (3129)						
	steppe (14),	meadow, wetland or forest (60)	≤5%	>80%	/	barren ground								
				<81%	/	meadow or wetland or burnt area (60)	<200 m or in 5 km buffer	6001	peat soil > 40 cm	oligotrophic convex bogs with mosses and pine (471)	burnt	burnt area (324)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	steppe (cont.)	meadow, wetland or forest (cont.)	≤5%	<81%	/	meadow or wetland or burnt area (cont.)	<200 m or in 5 km buffer	6001	peat soil >40 cm	oligotrophic convex bogs with mosses and pine (cont.)	not burnt	oligotrophic convex bogs with mosses and pine (471)		
									not peaty	plain meadow (561)	burnt	burnt area (324)		
											not burnt	plain meadow (561)		
							201–450	6002	peat soil >40 cm	motley grass, sedge, shrub bogs (472)	like (471)			
									not peaty	plain meadow (561)				
							>450 m	6003	peat soil > 40 cm	shrub, moss bogs (473)	like (471)			
									not peaty	plain meadow (561)				
			5–30%	/	broadleaf	broadleaf forest or wetland or burnt area	<200 m or in 5 km buffer	(32268101)	peat soil > 40 cm	oligotrophic convex bogs with mosses and pine (471)				
									not peaty	open broadleaf forest (32266401)	burnt	burnt area (324)		
											not burnt	open birch with aspen (3226)		
							201–450	(32268102)	peat soil >40 cm	motley grass, sedge, shrub bogs (472)				
									not peaty	open broadleaf forest (32266401)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	steppe (cont.)	meadow, wetland or forest (cont.)	5–30%	/	broadleaf	broadleaf forest or wetland or burnt area (cont.)	>450 m	(32268103)	peat soil >40 cm	shrub, moss bogs (473)				
									not peaty	open broadleaf forest (32266401)				
					evergreen needleleaf	evergreen needleleaf forest or wetland or burnt area	<200 m or in 5 km buffer	(246401)	peat soil >40 cm	oligotrophic convex bogs with mosses and pine (471)				
									not peaty	open pine forest (32016401)	burnt	burnt area (324)		
											not burnt	open pine (3201)		
							201–450	(246402)	peat soil >40 cm	motley grass, sedge, shrub bogs (472)				
									not peaty	open pine forest (32016401)				
							>450 m	(246403)	peat soil >40 cm	shrub, moss bogs (473)				
									not peaty	open dark coniferous (32006403)	burnt	burnt area (324)		
											not burnt	open dark coniferous (3200)		
					larch	larch forest or wetland or burnt area	<200 m or in 5 km buffer	(32046401)	peat soil >40 cm	oligotrophic convex bogs with mosses and pine (471)				
									not peaty	open larch (32046401)	burnt	burnt area (324)		
											not burnt	open larch (3204)		
							201–450 m	(32046402)	peat soil >40 cm	motley grass, sedge, shrub bogs (472)				
									not peaty	open larch (32046401)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	steppe (cont.)	meadow, wetland or forest (cont.)	5–30%	/	larch	larch forest or wetland or burnt area (cont.)	>450 m	(32046403)	peat soil >40 cm	shrub, moss bogs (473)				
									not peaty	open dark coniferous (32046401)				
					mixed	mixed forest, wetland or burnt area (3981)	<200 m or in 5 km buffer	(396401)	peat soil >40 cm	oligotrophic convex bogs with mosses and pine (471)				
									not peaty	open birch with pine (322364)	burnt	burnt area (324)		
											not burnt	open birch with pine (3223)		
							201–450 m	(396402)	peat soil >40 cm	motley grass, sedge, shrub bogs (472)				
									not peaty	open birch with pine (322364)				
							>450 m	(396403)	peat soil >40 cm	shrub, moss bogs (473)				
									not peaty	open decid. Br. With cedar-spruce-fir (322764)	burnt	burnt area (324)		
											not burnt	open dec. with cedar-spruce-fir (3227)		
						mixed forest, wetland or burnt area	<200 m or in 5 km buffer	(406401)	peat soil >40 cm	oligotrophic convex bogs with mosses and pine (471)				
									not peaty	open birch and pine (322264)	burnt	burnt area (324)		
											not burnt	open birch and pine (3222)		
							201–450 m	(406402)	peat soil >40 cm	motley grass, sedge, shrub bogs (472)				
									not peaty	open birch and pine (322264)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	steppe (cont.)	meadow, wetland or forest (cont.)	5–30%	/	mixed	mixed forest, wetland or burnt area (cont.)	>450 m	(406403)	peat soil >40 cm	shrub, moss bogs (473)				
									not peaty	open decid. Br. and cedar-spruce-fir (322864)	burnt	burnt area (324)		
											not burnt	open dec. and cedar-spruce-fir (3228)		
						mixed forest, wetland or burnt area (4181)	<200 m or in 5 km buffer	(416401)	peat soil >40 cm	oligotrophic convex bogs with mosses and pine (471)				
									not peaty	open pine with birch (322164)	burnt	burnt area (324)		
											not burnt	open pine with birch (3221)		
							201–450 m	(416402)	peat soil >40 cm	motley grass, sedge, shrub bogs (472)				
									not peaty	open pine with birch (322164)				
							>450 m	(416403)	peat soil >40 cm	shrub, moss bogs (473)				
									not peaty	open cedar-spruce-fir with decid. Br. (322964)	burnt	burnt area (324)		
											not burnt	open cedar-spruce-fir with decid. Br. (3229)		
			>30%	/	broadleaf	broadleaf forest, wetland or burnt area (312648)	/	/	/	/	burnt	burnt area (324)		
											not burnt	closed birch with aspen (3126)		
					evergreen needleleaf	evergreen needleleaf, wetland or burnt area (2848)	<600 m	closed pine (310148)	/	/	burnt	burnt area (324)		
											not burnt	closed pine (3101)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	steppe (cont.)	meadow, wetland or forest (cont.)	>30%	/	evergreen needleleaf	evergreen needleleaf forest, wetland or burnt area (2848)	<470 m and slope >1°	closed fir (310348)	soil type = 278, 136 or 230	open fir (310348)	burnt	burnt area (324)		
											not burnt	closed fir (3103)		
									other soil types	open pine (310148)	burnt	burnt area (324)		
											not burnt	closed pine (3101)		
							>600 and slope >1°	closed cedar (310548)	/	/	burnt	burnt area (324)		
											not burnt	closed cedar (3101)		
							470–600 m	closed pine (310148)						
					larch	larch forest, wetland or burnt area (310448)	/	/	/	/	burnt	burnt area (324)		
											not burnt	cl. larch (3104)		
					mixed	mixed forest, wetland or burnt area (4348), (4448), (4548)	<600 m	closed birch/pine (312348), (312248), (312148)	/	/	burnt	burnt area (324)		
											not burnt	cl. birch/ pine (3123, 3122,3121)		
							>600 m	closed birch/larch (313048), (313348), (313448)	/	/	burnt	burnt area (324)		
											not burnt	cl. birch/ larch (3130,3134		
	cropland (4), cropland\forest complex (5)	/	<10%	/	/	cropland (4)	<210 m or in 5 m buffer	perennial vegetation (231)	/	/	burnt	clear cut (323)		
											not burnt	per. veg. (231)		
							>210	arable land (211)	/	/	burnt	clear cut (323)		
											not burnt	arable land (211)		
			10–25%	/	/	cropland\forest complex or clear cut or secondary open forest (5)	in 5 m buffer	perennial vegetation/ forest complex (24)	/	/	burnt	clear cut (323)		
											not burnt	cropland/ forest complex (24)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	cropland, cropland\forest complex (cont.)	/	10–25%	/	/	clear cut or secondary open forest (cont.)	not in buffer	logged area or (323)	/	/	burnt after 2001	clear cut (323)		
											burned before 2001 or not burnt	open birch (3224)		
			>25%	/		clear cut or secondary closed forest (51)	in 5 km buffer	perennial vegetation/ forest complex (24)	/	/	burnt	clear cut (323)		
											not burnt	perennial vegetation/ forest complex (2313)		
							not in buffer	/	/	/	burnt after 2001	clear cut (323)		
											burned before 2001 or not burnt	open birch (3224)		
	wetland (13)	/	<30 %	/	/	/	<200 m or in 5 km buffer	oligotrophic convex bogs with mosses and pine (471)						
							201–450	motley grass, sedge, shrub bogs (472)						
							>450 m	shrub, moss bogs (473)						
			>30%	/	like steppe									
	humid grassland (12)	/	<5%	/	/	humid grassland (561)	/	/	/	/	burnt after 2001	burnt area (324)		
											burnt before 2001 or not burnt	plain meadow (561)		
			5–30%	/	broadleaf	forest or wetland or grassland or burnt (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									
			>30%	/	broadleaf	closed forest (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Southern Taiga (cont.)	barren ground (2), water (1), urban (3)	/	≤5%	>40%	/	(1), (2), (3)	/		/	/	burnt	burnt area (324)		
											not burnt	(11), (12), (13)		
				<41%	/	wetland or meadow (soil) (60)								
			5–30%	/	broadleaf	forest or wetland or grassland or burnt (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									
			>30%		broadleaf	closed forest (like steppe)								
					evergreen needleleaf									
					larch									
					mixed									
Pribaikalie (Irkutsk mountain middle taiga,) (5)	tundra–shrubs (16)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss or meadow (54)								
			6–25%	/	/	tundra shrubs or open forest (72)	<600 m	open pine (301)	/	/	burnt <2001	open larch (3204)		
											burnt after 2001	burnt area (324)		
											not burnt	open pine (3201)		
							600–1600 m	open dark coniferous (302)	/	/	burnt <2001	open larch (3204)		
											burnt after 2001	burnt area (324)		
											not burnt	open dark coniferous (3200)		
							>1600 m	mountain tundra of forest zone (562)	/	/	burnt before 2001	mountain tundra of forest zone (562)		
											burnt after 2001	burnt area (324)		
			6–25%	/	/	tundra shrubs or open forest (cont.)	>1600 m	mountain tundra of forest zone (cont.)			not burnt	mountain tundra of forest zone (562)		
			>25%	/	/	/ or closed forest (73)	<600 m	closed pine (311)	/	/	like (301)			
							600–1600 m	closed dark coniferous (312)	/	/	like (302)			
							>1600 m	mountain tundra of forest zone (562)						

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Pribaikalie (cont.)	tundra-lichen moss (15)	/	≤5%	>80%	/	barren ground								
				<81%	/	/ or meadow (54)	<1600 m	alpine meadow (58)						
							>1600 m	mountain tundra (562)						
			6–25%	/	/	tundra–shrubs or open forest (72)								
			>25%	/	/	tundra–shrubs or closed forest (73)								
	evergreen needleleaf (6)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss or meadow (54)								
			6–25%	/	/	open evergreen forest (24)	<300	pine (3201)						
							300–600 m	open dark coniferous (3200)						
							600–900 m	open spruce-cedar (3207)						
							>900 m	open shrubs (pinus pumila) (3291)						
			>25%		/	closed evergreen forest (28)	see open forests (24)							
	deciduous broadleaf trees (7)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss or meadow (54)								
			6–25%	/	/	open birch with aspen (3226)	/	/	/	/	burnt <2001	open birch (3224)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Pribaikalie (cont.)	deciduous broadleaf trees (cont.)	/	6–25%	/	/	open birch with aspen (cont.)					not burnt	open birch with aspen (3226)		
			>25%	/	/	closed birch with aspen (3126)	/	/	/	/	burnt <2001	closed birch (3124)		
											not burnt	closed birch with aspen (3126)		
	larch (11)		≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss or meadow (54)								
			6–25%	/	/	open larch forest (3204)								
			>25%	/	/	closed larch forest (3104)								
	mixed forest (8, 9, 10)	/	≤5%	>80%	/	barren ground								
				<81%	/	tundra–lichen moss or meadow (54)								
			6–25%	/	/	open broadleaf-needleleaf	<600	open birch-aspen with pine (3223)						
							>600	open birch-aspen with larch (3230)						
						open mixed forest	<600	open birch-aspen and pine(3222)						
							>600	open birch-aspen and larch (3233)						
						open needleleaf-broadleaf	<600	open pine with birch-aspen (3221)						
							>600	open larch with birch-aspen (3234)						
			>25%	/	/	closed broadleaf-needleleaf	<600	closed birch-aspen with pine (3123)						
							>600	close birch-aspen with larch (3130)						
						closed mixed forest	<600	closed birch-aspen and pine (3122)						
							>600	closed birch-aspen and larch (3133)						
						closed needleleaf-broadleaf	<600	closed pine with birch-aspen (3121)						
							>600	closed larch with birch-aspen (3134)						

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Pribaikalie (cont.)	steppe (14), cropland (4), cropland\forest complex (5)	meadow or disturbed area (50.)	<5%	>80%	/	barren ground								
			5–30%	/	/	/	<600 m or in 5 km buffer	meadow (561)	/	/	burnt before 2001	meadow (561)		
											burnt after 2001	burnt area (324)		
											not burnt	meadow (561)		
							600–1600m	alpine meadow (58)	/	/	burnt before 2001	alpine meadow (58)		
											burnt after 2001	burnt area (324)		
											not burnt	alpine meadow (58)		
							>1600m	mountain tundra of forest zone (562)						
			>30%	/	/	tundra shrubs or closed forest (73)								
	wetland (13), humid grassland (12)	/	≤30%	/	/	wetland or meadow (soil) (60)	<600 m or in 5 km buffer	6001	peat soil >40 cm	Big-bumpy bogs of valley and river terraces(462)	burnt before 2001	Big-bumpy bogs of valley and river terraces(462)		
											burnt after 2001	burnt area (324)		
											not burnt	Big-bumpy bogs of valley and river terraces(462)		
									not peaty	meadow (561)	burnt <2001	meadow (561)		
											burnt after 2001	burnt area (324)		
											not burnt	meadow (561)		
							60–1600 m	6002	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs (461)	like (462)			
									not peaty	alpine meadow (58)				

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Pribaikalie (cont.)	wetland, humid grassland (cont.)	/					>1600 m	6003	peat soil >40 cm	spagnum small shrub oligotrophic convex bogs (461)				
									not peaty	mountain tundra of forest zone (562)				
			>30%	/	/	tundra shrubs or closed forest (73)								
	barren ground (2), water (1), urban (3)	/	≤5%	>40%	/	/	/	/	/	/	burnt	burnt area (324)		
											not burnt	(11), (12), (13)		
				<41%	/	wetland or meadow (soil) (60)								
			6–25%	/	/	tundra or open forest (72)								
			>25%	/	/	tundra or closed forest (73)								

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Mountain Southern Taiga (Ust'Orda mountain southern taiga, Irkutsk mountain southern taiga, Krasnoyarsk mountain southern taiga, Khakass mountain southern taiga) (7)	tundra–shrubs (16), tundra–lichen moss (15)	alpine or mountain tundra (55)	>100%	>100%	/	water or alpine mountain tundra (74)	<630 m	river (11)						
							630–1600 m	alpine meadow (58)						
							>1600 m	alpine mountain tundra (562)						
			<5%	>80%	/	barren ground								
				<81%	/	alpine mountain tundra (562)	<1600 m	alpine meadow (58)						
							>1600 m	alpine mountain tundra (562)						
			6–25%	/	/	alpine mountain tundra–shrubs or open forest (72)	<800 m	open pine (301)	/	/	burnt <2001 burnt after 2001	open birch (3224) burnt area (324)		
											burnt after 2001	burnt area (324)		
											not burnt	open pine (3201)		
							800–1000 m	open fir with aspen (302)	/	/	like (301)			
							1000–1200 m	open cedar-fir (303)	/	/				
							1200–1600	open cedar (304)	/	/				
							>1600 m	alpine mountain tundra–shrubs (562)						
			>25%	/	/	alpine mountain tundra–shrubs or forest (73)	<800 m	open pine (311)	/	/	like (301)			
							800–1000 m	open fir with aspen (312)	/	/				
							1000–1200 m	open cedar-fir (313)	/	/				
							1200–1600	open cedar (314)	/	/				
							>1600 m	alpine mountain tundra - shrubs (562)						
	evergreen needleleaf (6)	/	>100%	> 100 %	/	water or alpine mountain tundra (74)								
			<5%	> 80%	/	barren ground								
				< 81%	/	alpine mountain tundra–lichen moss or meadow (581)	<1600 m	alpine meadow (58)						
							>1600 m	alpine mountain tundra–lichen (562)						
			6–25%	/	/	open evergreen forest (24)	<800	open pine (3201)						
							800–1000 m	open fir with cedar (3208)						
							1000–1200	open cedar-fir (3209)						
							1200–1600	open cedar (3205)						
							1600–1700	open cedar-larch (3210)						

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Mountain Southern Taiga (cont.)	evergreen needleleaf (cont.)	/	6–25%	/	/	open evergreen forest (cont.)	>1700	pinus pumila (3206)						
			>25%	/	/	closed evergreen forest (28)	like open evergreen forest							
	deciduous broadleaf trees (7)	/	<5%	>80%	/	barren ground								
				<81%	/	alpine mountain tundra–lichen moss or meadow (elevation) (581)								
			6–25%	/	/	open birch with aspen (3226)	/	/	/	/	burnt	open birch (3224)		
											not burnt	open birch with aspen (3226)		
			>25%	/	/	closed birch with aspen (3126)	/	/	/	/	burnt	closed birch (3124)		
											not burnt	closed birch with aspen (3126)		
	larch (11)	/	<5%	>80%	/	barren ground								
				<81%	/	alpine mountain (581)								
			6–25%	/	/	open larch forest (3204)								
			>25%	/	/	closed larch forest (3104)								
	mixed forest (8, 9, 10)	/	<5%	>80%	/	barren ground								
				<81%	/	alpine mountain tundra–lichen moss or meadow (581)								
			6–25%	/	/	open mixed forest (40)	<800 m	open aspen with fir (3235)						
							>800 m	open fir with aspen (3236)						
			>25%	/	/	closed mixed forest (44)	<800 m	closed aspen with fir (3135)						
							>800 m	closed fir with aspen (3136)						

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Mountain Southern Taiga (cont.)	steppe (14)	/	<5%	>80%	/	barren ground								
				<81%	/	steppe (14)	/	/	/	/	burnt <2001	steppe (571)		
											burnt after 2001	burnt area (324)		
											not burnt	steppe (571)		
			>5%	/	/	forest steppe (57)	/	/	/	/	burnt <2001	forest steppe (57)		
											burnt after 2001	burnt area (324)		
											not burnt	forest steppe (57)		
	cropland (4)	/	<5%	/	/	cropland (4)	<800 m	cropland (2)	/	/	burnt <2001	cropland (2)		
											burnt after 2001	burnt area (324)		
											not burnt	cropland (2)		
							800–1600 m	alpine meadow (58)						
							>1600 m	alpine mountain tundra (562)						
			>5%	/	/	cropland\ forest complex (cont.)	<800 m	cropland/forest complex (24)	/	/	burnt before 2001	like cropland		
											burnt after 2001			
											not burnt			
							800–1600 m	alpine meadow (58)						
							>1600 m	alpine mountain tundra (562)						
	cropland\forest complex (5)	/	<5%	/	/	cropland (4)								
			>5%	/	/	cropland\forest complex (5)								
	wetland (13)	/	≤30%	/	/	/	<800 m	different types of bogs (472)	/	/	burnt before 2001	different types of bogs (472)		
											burnt after 2001	burnt area (324)		
											not burnt	different types of bogs (472)		
							>800	alpine meadow (58)	/	/	burnt before 2001	alpine meadow (58)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Mountain Southern Taiga (cont.)			≤30%	/	/	/	>800	alpine meadow (cont.)	/	/	burnt after 2001	burnt area (324)		
											not burnt	alpine meadow (58)		
			>30%	/	/	alpine mountain tundra–shrubs or forest (73)								
	humid grassland (12)	alpine or mountain tundra (55)												
	barren ground (2), water (1), urban (3)		≤5%	>40%	/	/	/		/	/	burnt	burnt area (324)		
											not burnt	(11), (12), (13)		
				<41%	/	alpine mountain tundra (562)								
			6–25%	/	/	tundra or open forest (72)								
			>25%	/	/	tundra or closed forest (73)								

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Forest Steppe and Steppe (Krasnoyarsk forest steppe, irkutsk forest steppe, Ust'Orda forest steppe, Khakass steppe) (6)	tundra–shrubs (16)	steppe (14)												
	tundra–lichen moss (15)													
	evergreen needleleaf (pine) (6)	/	≤5%	>80%	/	barren ground (2)								
				<81%	/	steppe (14)								
			6–25%	/	/	open pine forest (3201)								
			>25%	/	/	closed pine forest (3101)								
	deciduous broadleaf (7)	/	≤5%	>80%	/	barren ground								
				<81%	/	steppe (14)								
			6–25%	/	/	open birch with aspen (3226)	/	/	/	/	burnt before 2001	open birch (3224)		
											not burnt	open birch with aspen (3226)		
			>25%	/	/	closed birch with aspen (3126)	/	/	/	/	burnt before 2001	closed birch (3124)		
											not burnt	closed birch with aspen (3126)		
	larch (11)	evergreen needleleaf (6)	≤5%	>80%	/	barren ground								
				<81%	/	steppe (14)								
			6–25%	/	/	open birch with pine (3223)								
						open birch and pine (3222)								
						open pine with birch (3221)								
			>25%	/	/	closed birch with pine (3123)								
						closed birch and pine (3122)								
						closed pine with birch (3121)								
	steppe (14)	/	>5%	<81%	/	steppe (14)	/	/	/	/	burnt <2001	steppe (572)		
											burnt after 2001	burnt area (324)		
											not burnt	steppe (572)		
				/	/	forest steppe (57)	/	/	/	/	burnt <2001	forest steppe (57)		
											burnt after 2001	burnt area (324)		
											not burnt	forest steppe (57)		

Ecoregion	Land cover class	Reclass 1	Tree cover (VCF)	Barren ground (VCF)	AVHRR – VCF	Reclass 2	Relief position	Reclass 3	Soil	Reclass 4	Disturb	Reclass 5	Water bodies	Final vegetation group
Forest Steppe and Steppe (cont.)	cropland (4)	/	<5%	/	/	cropland (4)	/	/	/	/	burnt <2001	cropland (2)		
											burnt after 2001	burnt area (324)		
											not burnt	cropland (2)		
			>5%	/	/	cropland\forest complex (5)	/	/	/		burnt <2001	cropland\ forest complex (24)		
											burnt after 2001	burnt area (324)		
											not burnt	cropland\ forest complex (24)		
	cropland\ forest complex (5)	/	<5%	/	/	cropland (4)								
			>5%	/	/	cropland\forest complex (5)								
	wetland (13), humid grassland (12)	steppe (14)												
	barren ground (2), water (1), urban (3)	/	≤5%	>40%	/	(1), (2), (3)	/	/	/	/	burnt	burnt area (324)		
											not burnt	(11), (12), (13)		
				<41%	/	steppe (14)								
			>5%	/	/	forest steppe (57)								

APPENDIX D: Extract of AML Source Code for Combining Data Sets and Classifying Pixel (Example Ecoregion 4)

```
/* setting the input files to variables for multiple using

&setvar ecoregion = [response 'enter ecoregion file']
&setvar landcover = [response 'enter land cover file']
&setvar treecov = [response 'enter MODIS VCF tree cover file']
&setvar barren = [response 'enter MODIS VCF barren ground file']
&setvar broad = [response 'enter AVHRR VCF broadleaf file']
&setvar needle = [response 'enter AVHRR VCF needleleaf file']
&setvar decid = [response 'enter AVHRR VCF deciduous file']
&setvar elevation = [response 'enter DEM file']
&setvar buffer = [response 'enter river buffer file']
&setvar soil = [response 'enter soil file']
&setvar disturbances = [response 'enter disturbances file']
&setvar wetland = [response 'enter ASAR wetland file']
&setvar waterbodies = [response 'enter ASAR waterbodies file']
&setvar urban = [response 'enter topographic file']

/* setting the analysis window and cell size to initial MODIS land
cover

grid
setwindow %landcover%
setcell %landcover%


/* --------- combining land cover with ecoregions -------------

vegetation_n = combine (%ecoregion%, %landcover%)

q

Tables
additem vegetation_n.vat reclass1 2 2 int # %landcover%


/* --------- reclassifying original land cover regarding plausibility
-

select vegetation_n.vat
calculate reclass1 = %landcover%

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res %landcover% = 14 or %landcover% = 15 or %landcover% = 16
calculate reclass1 = 60

q

/*----------  combining new land cover with VCF   -----------------

grid

setwindow %landcover%
setcell %landcover%
```

```
vegetation_n2 = vegetation_n.reclass1

kill vegetation_n

vegetation_n = combine (%ecoregion%, vegetation_n2, %treecov%,
%barren%)

kill vegetation_n2

q

Tables
additem vegetation_n.vat reclass2 8 8 int # %barren%


/*-------- reclassifying 2nd level land cover regarding tree cover ---
-

select vegetation_n.vat
calculate reclass2 = vegetation_n2


/*---- evergreen needleleaf -----------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 6
res %treecov% < 6 and %barren% < 81 or %barren% > 100
calculate reclass2 = 561

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4 or %ecoregion% = 5 or
%ecoregion% = 7
res vegetation_n2 = 6
res %treecov% > 5 and %treecov% < 26
calculate reclass2 = 24

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4 or %ecoregion% = 5 or
%ecoregion% = 7
res vegetation_n2 = 6
res %treecov% > 25 and %treecov% < 101
calculate reclass2 = 28

/*---- deciduous broadleaf -----------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 7
res %treecov% < 6 and %barren% < 81 or %barren% > 100
calculate reclass2 = 561


/*---- larch ------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 11
res %treecov% < 6 and %barren% < 81 or %barren% > 100
```

```
calculate reclass2 = 561

select vegetation_n.vat
res %ecoregion% = 1 or %ecoregion% = 2 or %ecoregion% = 3 or
%ecoregion% = 4 or %ecoregion% = 5 or %ecoregion% = 7
res vegetation_n2 = 11
res %treecov% > 5 and %treecov% < 26
calculate reclass2 = 3204

select vegetation_n.vat
res %ecoregion% = 1 or %ecoregion% = 2 or %ecoregion% = 3 or
%ecoregion% = 4 or %ecoregion% = 5 or %ecoregion% = 7
res vegetation_n2 = 11
res %treecov% > 25 and %treecov% < 101
calculate reclass2 = 3104


/*---- mixed forest --------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 8 or vegetation_n2 = 9 or vegetation_n2 = 10
res %treecov% < 6 and %barren% < 81 or %barren% > 100
calculate reclass2 = 561

select vegetation_n.vat
res %ecoregion% = 2 or %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 8
res %treecov% > 5 and %treecov% < 26
calculate reclass2 = 41

select vegetation_n.vat
res %ecoregion% = 2 or %ecoregion% = 5 or %ecoregion% = 4
res vegetation_n2 = 9
res %treecov% > 5 and %treecov% < 26
calculate reclass2 = 40

select vegetation_n.vat
res %ecoregion% = 2 or %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 10
res %treecov% > 5 and %treecov% < 26
calculate reclass2 = 39

select vegetation_n.vat
res %ecoregion% = 2 or %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 8
res %treecov% > 25 and %treecov% < 101
calculate reclass2 = 45

select vegetation_n.vat
res %ecoregion% = 2 or %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 9
res %treecov% > 25 and %treecov% < 101
calculate reclass2 = 44

select vegetation_n.vat
res %ecoregion% = 2 or %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 10
res %treecov% > 25 and %treecov% < 101
```

```
calculate reclass2 = 43


/*---- 60 ------------------------------

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 60 or vegetation_n2 = 12
res %treecov% > 5 and %treecov% < 31
calculate reclass2 = 81

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 60 or vegetation_n2 = 12 or vegetation_n2 = 13
res %treecov% > 30 and %treecov% < 101
calculate reclass2 = 48


/*----- wetland, meadow ----------------------------

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 3
res vegetation_n2 = 12
res %treecov% < 6 or %treecov% > 100
calculate reclass2 = 561


/*----- barren ground ----------------------------

select vegetation_n.vat
res vegetation_n2 > 3
res %treecov% < 6 and %barren% > 80
calculate reclass2 = 2

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 1 or vegetation_n2 = 2 or vegetation_n2 = 3
res %treecov% < 6 and %barren% < 41
calculate reclass2 = 60

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 1 or vegetation_n2 = 2 or vegetation_n2 = 3
res %treecov% > 5 and %treecov% < 31
calculate reclass2 = 81

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 1 or vegetation_n2 = 2 or vegetation_n2 = 3
res %treecov% > 30 and %treecov% < 101
calculate reclass2 = 48


/*----- cropland ----------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4
res %treecov% > 10 and %treecov% < 26
```

```
calculate reclass2 = 5

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4
res %treecov% > 25 and %treecov% < 101
calculate reclass2 = 51

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 5
res %treecov% < 11 or %treecov% > 100
calculate reclass2 = 4

q


/*---------- combining new land cover with AVHRR VCF ---------------

grid

setwindow %landcover%
setcell %landcover%

vegetation_n2 = vegetation_n.reclass2

kill vegetation_n

vegetation_n = combine (%ecoregion%, vegetation_n2, %broad%, %needle%)

kill vegetation_n2

q

Tables
additem vegetation_n.vat reclass8 10 10 int # %needle%

select vegetation_n.vat
calculate reclass8 = vegetation_n2

/* ---- steppe -------------------------

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 81
res %broad% < 6 and %needle% > 5           /* needleleaf
calculate reclass8 = 100

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 81
res %broad% > 5 and %needle% < 6           /* broadleaf
calculate reclass8 = 322681

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 48
res %broad% < 6 and %needle% > 5
calculate reclass8 = 200
```

```
select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 48
res %broad% > 5 and %needle% < 6
calculate reclass8 = 312648

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 81
res %broad% > 5 and %needle% > 5 and %broad% < %needle%
calculate reclass8 = 3981

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 81
res %broad% > 5 and %needle% > 5 and %broad% > %needle%
calculate reclass8 = 4181

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 81
res %broad% > 5 and %needle% > 5 and %broad% = %needle%
calculate reclass8 = 4081

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 48
res %broad% > 5 and %needle% > 5 and %broad% > %needle%
calculate reclass8 = 4348

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 48
res %broad% > 5 and %needle% > 5 and %broad% < %needle%
calculate reclass8 = 4548

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 48
res %broad% > 5 and %needle% > 5 and %broad% = %needle%
calculate reclass8 = 4448


q

/*------ combining new land cover with AVHRR VCF deciduous ---------

grid

setwindow %landcover%
setcell %landcover%

vegetation_n2 = vegetation_n.reclass8

kill vegetation_n

vegetation_n = combine (%ecoregion%, vegetation_n2, %decid%)

kill vegetation_n2
```

```
q

Tables
additem vegetation_n.vat reclass9 10 10 int # %decid%

select vegetation_n.vat
calculate reclass9 = vegetation_n2

/* ---- steppe ------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 100
res %decid% < 6
calculate reclass9 = 2481

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 100
res %decid% > 5
calculate reclass9 = 320481

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 200
res %decid% < 6
calculate reclass9 = 2848

select vegetation_n.vat
res %ecoregion% = 3 or %ecoregion% = 4
res vegetation_n2 = 200
res %decid% > 5
calculate reclass9 = 310448

q


/*-----  combining new land cover with DEM, slope and river buffer----
-


grid

slope_rec = reclass (%slope%, reclass_files/slope_reclass.txt)

setwindow %landcover%
setcell %landcover%

vegetation_n2 = vegetation_n.reclass9

kill vegetation_n

vegetation_n = combine (%ecoregion%, vegetation_n2, %elevation%,
%buffer%, slope_rec)

kill vegetation_n2

q
```

```
Tables
additem vegetation_n.vat reclass3 8 8 int # slope_rec

select vegetation_n.vat
calculate reclass3 = vegetation_n2


/*---- evergreen needleleaf -----------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 2481
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 248101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 2481
res %elevation% > 200 and %elevation% < 451 and %buffer% = 0
calculate reclass3 = 248102

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 2481
res %elevation% > 450 and %buffer% = 0
calculate reclass3 = 248103

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 24
res %elevation% < 471 and slope_rec = 2
calculate reclass3 = 3203

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 24
res %elevation% > 600 and slope_rec = 2
calculate reclass3 = 3205

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 24
res slope_rec = 1
calculate reclass3 = 3201

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 24
res %elevation% > 470 and %elevation% < 601
calculate reclass3 = 3201

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 28
res %elevation% < 471 and slope_rec = 2
calculate reclass3 = 3203

select vegetation_n.vat
res %ecoregion% = 4
```

```
res vegetation_n2 = 28
res %elevation% > 600 and slope_rec = 2
calculate reclass3 = 3205

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 28
res slope_rec = 1
calculate reclass3 = 3201

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 28
res %elevation% > 470 and %elevation% < 601
calculate reclass3 = 3201

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 2848
res %elevation% < 471 and slope_rec = 2
calculate reclass3 = 310348

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 2848
res %elevation% > 600 and slope_rec = 2
calculate reclass3 = 310548

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 2848
res %elevation% > 470 and %elevation% < 601 and slope_rec = 2
calculate reclass3 = 310148

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 2848
res slope_rec = 1
calculate reclass3 = 310148


/*---- broadleaf forest ------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322681
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 32268101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322681
res %elevation% > 200 and %elevation% < 451 and %buffer% = 0
calculate reclass3 = 32268102

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322681
res %elevation% > 450 and %buffer% = 0
```

```
calculate reclass3 = 32268103


/*---- larch forest -------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 320481
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 32048101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 320481
res %elevation% > 200 and %elevation% < 451 and %buffer% = 0
calculate reclass3 = 32048102

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 320481
res %elevation% > 450 and %buffer% = 0
calculate reclass3 = 32048103


/*---- mixed forest -------------------------------

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 39
res %elevation% < 601
calculate reclass3 = 3223

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 39
res %elevation% > 600
calculate reclass3 = 3226

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 40
res %elevation% < 601
calculate reclass3 = 3222

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 40
res %elevation% > 600
calculate reclass3 = 3228

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 41
res %elevation% < 601
calculate reclass3 = 3221

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 41
```

```
res %elevation% > 600
calculate reclass3 = 3229

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 43
res %elevation% < 601
calculate reclass3 = 3123

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 43
res %elevation% > 600
calculate reclass3 = 3127

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 44
res %elevation% < 601
calculate reclass3 = 3122

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 44
res %elevation% > 600
calculate reclass3 = 3128

select vegetation_n.vat
res %ecoregion% = 4 or %ecoregion% = 5
res vegetation_n2 = 45
res %elevation% < 601
calculate reclass3 = 3121

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 45
res %elevation% > 600
calculate reclass3 = 3129

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 3981
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 398101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 3981
res %elevation% > 200 and %elevation% < 451 and %buffer% = 0
calculate reclass3 = 398102

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 3981
res %elevation% > 450 and %buffer% = 0
calculate reclass3 = 398103

select vegetation_n.vat
res %ecoregion% = 4
```

```
res vegetation_n2 = 4081
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 408101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4081
res %elevation% > 200 and %elevation% < 451 and %buffer% = 0
calculate reclass3 = 408102

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4081
res %elevation% > 450 and %buffer% = 0
calculate reclass3 = 408103

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4181
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 418101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4181
res %elevation% > 200 and %elevation% < 451 and %buffer% = 0
calculate reclass3 = 418102

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4181
res %elevation% > 450 and %buffer% = 0
calculate reclass3 = 418103

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4348
res %elevation% < 601
calculate reclass3 = 312348

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4348
res %elevation% > 600
calculate reclass3 = 313048

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4448
res %elevation% < 601
calculate reclass3 = 312248

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4448
res %elevation% > 600
calculate reclass3 = 313348
select vegetation_n.vat
res %ecoregion% = 4
```

```
res vegetation_n2 = 4548
res %elevation% < 601
calculate reclass3 = 312148

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4548
res %elevation% > 600
calculate reclass3 = 313448


/*---- 48, 81 ------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 81 or vegetation_n2 = 48
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 811

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 81 or vegetation_n2 = 48
res %elevation% > 200 and %elevation% < 451
calculate reclass3 = 812

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 81 or vegetation_n2 = 48
res %elevation% > 450
calculate reclass3 = 813


/*---- wetlands, grasslands ----------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 13
res %elevation% < 201 or %buffer% = 1
calculate reclass3 = 471

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 13
res %elevation% > 200 and %elevation% < 451
calculate reclass3 = 472

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 13
res %elevation% > 450
calculate reclass3 = 473

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 60
res %elevation% < 201 or %buffer% = 0
calculate reclass3 = 6001
select vegetation_n.vat
res %ecoregion% = 4
```

```
res vegetation_n2 = 60
res %elevation% > 200 and %elevation% < 451
calculate reclass3 = 6002

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 60
res %elevation% > 450
calculate reclass3 = 6003


/*---- cropland ----------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4
res %elevation% < 211 or %buffer% = 1
calculate reclass3 = 231

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 4
res %elevation% > 210
calculate reclass3 = 211

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 5 or vegetation_n2 = 51
res %buffer% = 1
calculate reclass3 = 24

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 5
res %buffer% = 0
calculate reclass3 = 323

q


/*--------- combining new land cover with soil ---------------------

grid

setwindow %landcover%
setcell %landcover%

vegetation_n2 = vegetation_n.reclass3

kill vegetation_n

vegetation_n = combine (%ecoregion%, vegetation_n2, %soil%)

kill vegetation_n2

q

Tables
additem vegetation_n.vat reclass4 8 8 int # %soil%
```

```
select vegetation_n.vat
calculate reclass4 = vegetation_n2


/* ---- evergreen needleleaf ------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 3203
res %soil% = 0
calculate reclass4 = 3201

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 3103
res %soil% = 0 or %soil% = 1
calculate reclass4 = 3101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 310348
res %soil% = 0 or %soil% = 1
calculate reclass4 = 310148


/* ---- wetland, grassland ---------------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32268101 or vegetation_n2 = 6001 or vegetation_n2
= 248101 or vegetation_n2 = 32048101 or vegetation_n2 = 398101 or
vegetation_n2 = 408101 or vegetation_n2 = 418101 or vegetation_n2 =
811
res %soil% = 1
calculate reclass4 = 471

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32268102 or vegetation_n2 = 32268103
res %soil% = 0 or %soil% = 2 or %soil% = 2
calculate reclass4 = 32268101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 248101 or vegetation_n2 = 248102
res %soil% = 0 or %soil% = 2
calculate reclass4 = 32016401

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 248103
res %soil% = 0 or %soil% = 2
calculate reclass4 = 32006403

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 398101 or vegetation_n2 = 398102
res %soil% = 0 or %soil% = 2
calculate reclass4 = 322364
```

```
select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 398103
res %soil% = 0 or %soil% = 2
calculate reclass4 = 322764

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 408101 or vegetation_n2 = 408102
res %soil% = 0 or %soil% = 2
calculate reclass4 = 322264

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 408103
res %soil% = 0 or %soil% = 2
calculate reclass4 = 322864

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 418101 or vegetation_n2 = 418102
res %soil% = 0 or %soil% = 2
calculate reclass4 = 322164

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 418103
res %soil% = 0 or %soil% = 2
calculate reclass4 = 322964

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32048103 or vegetation_n2 = 32048102
res %soil% = 0 or %soil% = 2
calculate reclass4 = 32048101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 811 or vegetation_n2 = 812
res %soil% = 0 or %soil% = 2
calculate reclass4 = 32018101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 813
res %soil% = 0 or %soil% = 2
calculate reclass4 = 32048101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32268102 or vegetation_n2 = 6002 or vegetation_n2
= 248102 or vegetation_n2 = 32048102 or vegetation_n2 = 398102 or
vegetation_n2 = 408102 or vegetation_n2 = 418102 or vegetation_n2 =
812
res %soil% = 1
calculate reclass4 = 472

select vegetation_n.vat
res %ecoregion% = 4
```

```
res vegetation_n2 = 32268103 or vegetation_n2 = 6003 or vegetation_n2
= 248103 or vegetation_n2 = 32048103 or vegetation_n2 = 398103 or
vegetation_n2 = 408103 or vegetation_n2 = 418103 or vegetation_n2 =
813
res %soil% = 1
calculate reclass4 = 473

q

/*--------- combining new landcover with disturbances ----------------
-

grid

setwindow %landcover%
setcell %landcover%

vegetation_n2 = vegetation_n.reclass4

kill vegetation_n

vegetation_n = combine (%ecoregion%, vegetation_n2, %disturbances%)

kill vegetation_n2

q

Tables
additem vegetation_n.vat reclass5 8 8 int # %disturbances%

select vegetation_n.vat
calculate reclass5 = vegetation_n2


/* ---- evergreen needleleaf --------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32018101
res %disturbances% > 0
calculate reclass5 = 324

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32018101
res %disturbances% = 0
calculate reclass5 = 3201

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32016401
res %disturbances% = 0
calculate reclass5 = 3201

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32006403
res %disturbances% = 0
calculate reclass5 = 3200
```

```
select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 310148
res %disturbances% = 0
calculate reclass5 = 3101

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 310148
res %disturbances% > 0
calculate reclass5 = 324

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 310048
res %disturbances% = 0
calculate reclass5 = 3100


/* ---- deciduous broadleaf --------------------------------

select vegetation_n.vat
res vegetation_n2 = 3226
res %disturbances% > 0
calculate reclass5 = 3224

select vegetation_n.vat
res vegetation_n2 = 3126
res %disturbances% > 0
calculate reclass5 = 3124

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32268101 or vegetation_n2 = 32016401 or
vegetation_n2 = 32006403 or vegetation_n2 = 312648 or vegetation_n2 =
31148 or vegetation_n2 = 310048
res %disturbances% > 0
calculate reclass5 = 324

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32268101
res %disturbances% = 0
calculate reclass5 = 3226

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 312648
res %disturbances% = 0
calculate reclass5 = 3126


/* ---- larch --------------------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32048101 or vegetation_n2 = 31044801 or
vegetation_n2 = 310448
res %disturbances% > 0
```

```
calculate reclass5 = 324

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32048101
res %disturbances% = 0
calculate reclass5 = 3204

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 32044801 or vegetation_n2 = 310448
res %disturbances% = 0
calculate reclass5 = 3104

/* ---- mixed forest ---------------------------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322364 or vegetation_n2 = 322764 or vegetation_n2
= 322264 or vegetation_n2 = 322864 or vegetation_n2 = 322164 or
vegetation_n2 = 322964 or vegetation_n2 = 312348 or vegetation_n2 =
312248 or vegetation_n2 = 312148 or vegetation_n2 = 313048 or
vegetation_n2 = 313348 or vegetation_n2 = 313448
res %disturbances% > 0
calculate reclass5 = 324

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322364
res %disturbances% = 0
calculate reclass5 = 3223

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322764
res %disturbances% = 0
calculate reclass5 = 3227

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322264
res %disturbances% = 0
calculate reclass5 = 3222

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322864
res %disturbances% = 0
calculate reclass5 = 3228

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322164
res %disturbances% = 0
calculate reclass5 = 3221

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 322964
```

```
res %disturbances% = 0
calculate reclass5 = 3229

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 312148
res %disturbances% = 0
calculate reclass5 = 3121

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 312248
res %disturbances% = 0
calculate reclass5 = 3122

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 312348
res %disturbances% = 0
calculate reclass5 = 3123

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 313048
res %disturbances% = 0
calculate reclass5 = 3130

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 313348
res %disturbances% = 0
calculate reclass5 = 3133

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 313448
res %disturbances% = 0
calculate reclass5 = 3134


/* ---- meadow, steppe, wetland -----------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 471 or vegetation_n2 = 561 or vegetation_n2 = 472
or vegetation_n2 = 473
res %disturbances% > 0
calculate reclass5 = 324


/* ---- cropland -------------------------

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 231 or vegetation_n2 = 211 or vegetation_n2 = 24
res %disturbances% > 0
calculate reclass5 = 323

select vegetation_n.vat
```

```
res %ecoregion% = 4
res vegetation_n2 = 323 or vegetation_n2 = 51
res %disturbances% < 2001
calculate reclass5 = 3224

select vegetation_n.vat
res %ecoregion% = 4
res vegetation_n2 = 51
res %disturbances% > 2000
calculate reclass5 = 323

q

/*--------------- adding ASAR water bodies and topographic data -----

grid

setwindow %landcover%
setcell %landcover%

vegetation_n2 = vegetation_n.reclass6

kill vegetation_n

vegetation_n = combine (vegetation_n2, %waterbodies%, %urban%)

kill vegetation_n2

q

Tables
additem vegetation_n.vat reclass7 8 8 int # %urban%

select vegetation_n.vat
calculate reclass7 = vegetation_n2

select vegetation_n.vat
res %waterbodies% = 1
calculate reclass7 = 11

select vegetation_n.vat
res %urban% = 1
calculate reclass7 = 13

q

grid

veget_final = vegetation_n.reclass7

q

&return
```