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Satellite Image Processing for Biodiversity Conservation and Environmental Modeling in Kyrgyz Republic National Park

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Satellite Image Processing for Biodiversity Conservation and Environmental Modeling in Kyrgyz Republic National Park

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by

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ABSTRACT

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There is a need for extensive surveys of living organisms at a global scale; digital data exchange and storage is an essential part of such studies. Biodiversity inventory of fungi, which play an essential role in the health of the mountainous conifer forests of a developing country – Kyrgyz Republic, was linked to the vegetation classification produced from the high-resolution satellite imagery. Terra ASTER and SRTM90 imagery was used as a base map for the ecosystem modeling of the species and habitat distribution and for the three-dimensional representation, especially valuable for the mountainous landscapes of the Ala Archa National Park. Image processing techniques with ER Mapper and ArcGIS/ArcInfo using ASTER bands and band ratios (NDVI, Brovey transform and 3/1, 4/3, 10/1) allowed distinguishing between vegetation community types and their complexes: mixed conifer and deciduous forests, dwarf juniper forests, cushion plants, shrublands, alpine grasslands, steppes, sagebrush semi-deserts, and complexes of grasslands and conifers.

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CHAPTER I. INTRODUCTION

Importance of biodiversity databases linked to the digital maps with Global Positioning System (GPS) coordinates as well as Internet access to such databases was recently emphasized by many researchers (Clarke, 2003; Choi, 2003; GISD, 2003; Peng & Tsou, 2003; Dietrich, 2002; Shekhar & Chawla, 2003). It is considered to be a priority for this type of regional studies (Ford, 2003; Millington et al. 2001; MEP, 1998) and global studies as well (Rock & Lawless, 1997 a&b). This study demonstrates how the use of satellite imagery processing and analysis together with the georeferencing techniques supports a regional biodiversity study of basidiomycete fungi in the Tien Shan Mountains. Fungi are the crucial component of forest biodiversity, largely responsible for ecosystem health through their mycorrhizal connections (Cibula et al., 1987). This explains a need for extensive surveys of macrofungi in Kyrgyz Republic and especially in its National Parks with intact natural conditions; investigation of their biodiversity holds answers to the successful conservation and sustainability of the forests. Mountain forests play a big role in economic development of Kyrgyz Republic not only as tourist attraction, but also as a sufficient natural resource.

Regional studies often lack proper geo-referencing, as was recently emphasized: "The Geographic Information for Sustainable Development (GISD) initiative is an international alliance of partners with a shared goal of realizing the potential of a new generation of geographic information technologies such as satellite data and computer software programs to help decision-makers meet a range of sustainable development challenges, including food security, sustainable agriculture, natural resource management, disaster mitigation, and poverty alleviation" (GISD, 2003). The problem of preserving the balance in ecosystems is directly linked to the conservation of local biological diversity; this directly concerns those groups of living organisms, which are consumed as a food product (Prikhodko & Mosolova, 2002). Currently, the list of all country's fungi includes 2,119 species. Out of almost 300 species of basidiomycete macrofungi (mushrooms) found in Kyrgyz Republic, many are of economic importance; 100 species are edible (Elchibaev, 1964, 1968; Prikhodko, 2000).

Objectives of the study included not only a survey of macrofungi but also a demonstration of mapping techniques that could apply to a wide variety of much needed global biotic studies of species in their native habitats. Vegetation complexity in the studied area is very high: conifer forests, riparian forests, scrublands, meadows, and semi-deserts are often formed by a mixture of several vegetation community types, especially at the medium elevations.

This mosaic creates a challenging task for image interpretation. The objectives of the satellite image processing were to explore the possibilities of identification and mapping vegetation community types or their combinations by finding processing algorithms and band combinations of the imagery.

Therefore there are three goals of the study:

- ✓ to compile a fungi database, which is linked to the map of vegetation community types or mapping units, and testing mycorrhizal connections with forest species
- ✓ to process satellite imagery for vegetation and non-vegetation feature extraction and for the three-dimensional (3D) display and analysis
- ✓ to make a vegetation classification map using results of the ground data survey, satellite image processing techniques and spatial analysis.

CHAPTER II. GEOGRAPHICAL SETTING

II.1. Biogeography and Economics

Kyrgyz Republic is a newly independent country with a population of 4.6 million, landlocked in the center of Eurasia. It borders Republic of China, Kazakhstan, Uzbekistan, and Tajikistan. Its small (198,500 km^2) territory is dominated by the Tien Shan Mountains (more than 90% of it lies above 1000 m above sea level). Kyrgyz Republic is located in the very center of Asia, north of China, within the mountain systems of Tien Shan and Pamiro-Alai (Fig.1).

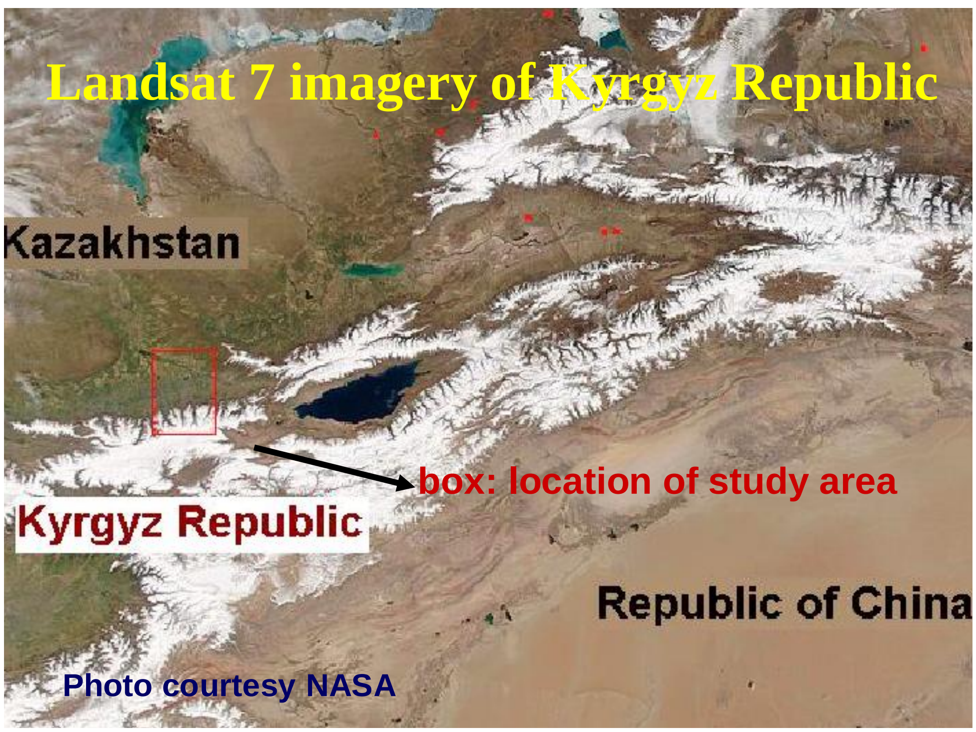


Figure 1. Geographic location of the Ala Archa National Park in Kyrgyz Republic.

The country is economically impoverished, and heavily depends on its forest resources and tourism for sustainable future. Historically, Kyrgyz Republic was at the crossroads of the Great Silk Road (Mandelbaum, 1994) and its future as a newly independent state depends on developing relationships with other countries of the world (Sanford, 1997). It is one of the important United States allies in this region of Central Asia.

Figure 2. Tien Shan mountains: steppe, spruce forest, and dwarf juniper plant communities (photo by Peter R. Klug).

Current environmental conditions, as stated in the country assessment reports (BIOFOR: Daviesson & Fet, 2001), are deteriorating and energy production shows insufficiency. The following problems are in the way of proper natural resources conservation. Kyrgyz Republic is undergoing a fuel crisis, which entails, among other things, the massive cutting of forests for firewood in the rural areas (Figs.2-4). At the same time, rich summer pastures in the remote highland regions are not currently used. Among the environmental consequences of the present economic situation are desertification, declining fertility of soils, increasing erosion, salinization of lands, deforestation and poaching. A decrease in species diversity has also been noted. Social destabilization and the lack of funds for biodiversity conservation make environmental control very difficult. A significant portion of the population still leads nomadic lifestyle.

Figure 3. Local shepherds move to the high mountains for the summer pastures; the “yurt” is a felt tent with a wood burning stove inside.

The territory of Kyrgyz Republic is one of the Global 200 Ecoregions identified by the World Wide Fund for Nature based on selection criteria such as species richness, levels of endemism, taxonomic uniqueness, unusual evolutionary phenomena, and global rarity of major habitat types (www.WWF.org). Kyrgyz Republic, sometimes called “Switzerland of Central Asia,” is a signatory to the International Convention on Biodiversity (1996), and takes a great pride in its natural resources and their conservation.

Figure 4. Local Kyrgyz selling edible mushrooms at the curbside of the road.

The fragile mountain ecosystems of Tien Shan (from 500 to 7,000 meters above sea level) support a unique assemblage of plants and animals and are notable for the rich and unique genetic resources of living organisms. Flora of Kyrgyzstan accounts for more than 4,500 species of higher plants. Vegetation of Tien Shan Mountains has been studied over a number of decades by numerous researchers who characterized in detail its diversity and complexity and suggested various ways of classification of plant communities (Korovin, 1934; Lavrenko & Sokolov, 1949; Bykov, 1950; Vykhodzev, 1956; Gan, 1970; Kamelin, 1971, 1975; Zlotin, 1975; Kotlyar, 1980; Ladygina & Litvinova, 1990; Pavlov, 1980; Roldugin, 1989; Golovkova, 1990; Shukurov, 1991; Ionov, 2001).

II.2. Fungi Role in Ecosystems

Preserving biodiversity is very important for stability of the ecosystems. Fungi play an important role in the forests due to their symbiotic mycorrhizal connections with tree species helping the trees to derive vital nutrients from the soil and increase their growth and resilience.

Forest conditions of the National Parks have been assessed using remote sensing techniques (Cibula & Nyquist, 1987). Several studies were dedicated to experimental fertilization of pine forests in Mississippi with mycorrhizal fungi (Cibula & Carter, 1987; Cibula et al. 1994). The fertilized forest plots showed increase in photosynthetic activity due to the ability of pine trees to derive more nutrients, and in a more available form, from the soil. Biodiversity of macrofungi, as a crucial component of the conifer forests, was drastically reduced in Czechoslovakia where decline of the forests was caused by the intensive high sulfur content coal burning; the condition of these forests was assessed with remote sensing (Cibula et al. 1994; Rock et al. 1994).

Forest ecosystems in Kyrgyz Republic house the maximal number of fungi species compared to other ecosystems: 146 in spruce forests; 86, in riparian forests; 66, in fruit-walnut forests (Prikhodko & Mosolova, 2002).

II. 3. Geology

The Kyrgyz Range, as well as the entire Tien Shan Mountains, is located in the territory of Lower Paleozoic folding, its relief is characterized by stair-like or folding vertical structure (Rezanov, 1977). Three mountain belts are well expressed: foothills, middle mountains, and high mountains.

An ancient glacial landscape characterizes the high mountain belt; the relief here is formed by prevailing wind and gravitational erosion processes (Agakhanyants, 1981). There are two annual floods in Ala Archa valley: one is caused by the melting of seasonal snow cover, and the second and larger one by the melting of glacial ice.

Figure 5. A typical erosion relief of the Kyrgyz Range mountain

As was determined from topographic and remotely sensed data, the Tien Shan glaciers have retreated about 3 kilometers during the last 40 years. Ala Archa glacier basin, which covers 36.31 km^2, has shrunk by 10.6% from 1977 to 2003 (Aizen et al., 2006).

The variety of relief-forming processes here is determined by a large range of altitudes, exposures, and by the climatic regime (Fig. 5). Melting water flow from the snow fields and glaciers at the higher elevations above 1600m (Figs. 6-7) can result in a considerable surface and ground water volumes entering through fractures into alluvial fans or apparently unstable quaternary deposits (Meleshko, 2000). Foothills and middle

Figure 6. A typical talus.

Figure 7. Mixed conifer forest: spruce, juniper, and dwarf juniper.

mountains are well differentiated (Zohary, 1973).

The National Park is located in the Ala Archa Valley, in the central portion of the northern macro slope of the Kyrgyz Range of Tien Shan Mountains, which stretches from east to west for 450 km. Ala Archa Valley is located in the highest part of the mountain range (Semenov-Tien-Shansky Peak, 4,875 m above sea level), and is a canyon-like ravine (50 to 100 m wide in its upper part, and up to 1,500 m in the foothills).

In the region of Ala Archa, considerable seismic activities, structural deformation of lithosphere, a number of land/rock slides have occurred in the Quaternary through recent periods (Burg et al., 2004). Landslides in the past century have impacted cultural facilities and human settlements with devastating effects.

II.4. Climate

The climate of Kyrgyz Republic is continental, which means hot summers and cold winters. Average number of days of sunshine per year: 322 (although in 1999 Bishkek received only 247). Maximum recorded temperature: 44° C at the Chuiskaya weather station. On 27th June 2000, Bishkek recorded the highest temperature in 100 years, 39.2° C. Minimum recorded temperature: -54° C at the Ak-Sai weather station, the average minimal temperature across the country: -24° C. The average annual rainfall is 380 mm, mostly falling in April. The highest recorded annual rainfall was at the Aktera-Gava weather station on the Western Ferghana range: 1,090 mm. The lowest annual rainfall was registered at Karakol, the western extremity of the Issyk-Kul basin: 144 mm.

Climate of the Ala Archa National Park is very diverse, which is explained by the large altitude range. The local climate is continental, with large annual and daily fluctuations of air temperature (Attachment I). The temperature regime in the park is moderate warm in summer and mild in winter. Annual air temperature is 2.5° C; average temperature of January is -9.4° C; average temperature of July is 13.5° C, and at the altitude 3,000 m it is 8.8° C. In the lower and middle parts of the valley the frostless period lasts about four months, and in its upper part is practically absent. The maximum of precipitation falls on spring-early summer and fall periods. Climate data were taken into consideration in the imagery selection process.

The movement of air masses is the major factor in the formation of precipitation. The mountain valley winds, with a regular daily change of direction, dominate the watershed of Ala Archa Valley. The upward valley wind starts in the morning and reaches its maximum by the noon. As higher air layers are warmed up, the valley wind decreases, and by the evening it disappears. At nighttime, the mountain wind is prevailing. In the side valleys the wind direction is determined by the valley direction. At the altitudes lower than 2,000-2,700 m, maximum precipitation falls on April-May, in the higher areas on May-June. Compared to other valleys of the Kyrgyz Range, the Ala Archa Valley has higher relative humidity. This factor determines a characteristic species composition of higher plants and fungi.

II.5. Vegetation and Soils

Vegetation of the study area was described by R.N. Ionov, T.V. Isakova, and L.P. Lebedeva (Ionov et al., 2001). The Ala Archa State National Park (42°33'N, 74°29'E) includes meadows, steppe, semi-desert, forest-meadow, subalpine and alpine vegetation zones. In the middle mountain zone, on the slopes of northwestern exposure above 1,600 m and higher, there are found fragments of steppe (grassland) with fescue (*Festuca sulcata*) and other grassland species – *Phleum phleoides, Bromus inermis, Poa pratensis, Achillea asiatica*. These steppe fragments are intermixed with juniper forests comprised of several species of junipers, some of which have a dwarf shrub-like growth form: *Juniperus semiglobosa, J. turkestanica, J. sabina*, and *J. pseudosabina.* Juniper forests and shrublands are distributed at the slopes of different exposures on naked rocks, stony screens, and along the valleys of the mountain rivers. Junipers forests (Fig. 8) often include a layer of shrubs of the genera *Berberis, Rosa, Cotoneaster* and others.

Spruce forests, formed by Schrenk's spruce (*Picea schrenkiana*), grow at elevations starting from 2,100 m, on the slopes of northern and similar exposures, at the Top-Karagai and Karagai-Bulak localities, along the right bank of the Ala Archa River, and along the valley of Ak-Sai River. At the lower boundary of their distribution, the spruce forests contact with juniper forests, meadows and shrublike forests ("shybliak"); at the higher boundary they border with dwarf junipers. Small fragments of deciduous forests with birch and willow are fond along the river valleys. Above the forest zone, steppe variants of subalpine meadows are found, and further up in the alpine zone – low-grass alpine meadows with *Alchemilla retropilosa, Cobresia capilliformis, Poa relaxa.*

Figure 8. Eastern slope of Ala Archa Valley: juniper trees and shrubs.

The soil cover of the Ala Archa National Park is characterized by the following soil types: mountain light chestnut and dark chestnut soils at the foothill zone of the Kyrgyz Range (1,000-2,000 m) and mountain meadow dark "chernozems" (2,000-2,500 m) of moderate thickness and high humus content. The soils of juniper and spruce forests and mountain meadows with a thicker soil horizon of subalpine chernozem-like soils occur at the altitudes of 2,500-3,000 m; and mountain meadow alpine soils, at 3,000-3,500 m and higher (Ionov et al., 2001).

Figure 9. Shrubs and dwarf junipers on the slopes of the lower Ala Archa.

CHAPTER III. METHODS AND TECHNIQUES

Different steps of the study, namely: field collection and description of the species at the sampling points (SP), georegistration, classification of the sampled vegetation community types, vegetation complexes assessment, and imagery classification and analysis, required the following methods.

III.1. Methods of Vegetation and Fungi Species Survey

A field survey with GPS Garmin Etrex unit was conducted in the summer of 2002 by the research team of mycologists from the Institute of Biotechnology of the Kyrgyz Academy of Sciences from Kyrgyz Technical University and Department of Autotransport of Kyrgyz Technical University. Garmin (Garmin, 2002) has an accuracy of about 20 meters, which is adequate for the macrofungi and habitat survey (Wood, 2000). Coordinates were converted into Universal Mercator Coordinate System (UTM) georeferencing with satellite imagery. Elevation measurements with 100 m accuracy are acceptable for the general habitats descriptions; they were calibrated by the weather permanent station of the Ala Archa Alpine Camp.

Herbaria collections were available for additional identification and verification in the laboratory. Mycologists and botanists from the Kyrgyz Academy of Scientists conducted species identification. Herbaria collections were available for additional identification and verification in the laboratory. Original photographs supported collections. Short geobotanical descriptions were provided for each of the 16 sampling points (SP). Dominant species of trees, shrubs and herbaceous layers were identified and recorded.

III. 2. Methods of Vegetation Classification and Mapping Units

Vegetation classification was based on physiognomic approach, i.e. growth type (tree, shrub, grass) of the dominant and co-dominant species of the plant communities (Lavrenko & Sokolov, 1949; Bykov, 1950; Ladygina & Litvinova, 1990; Shukurov, 1991; Ionov, 2001). Most frequently co-occurring species of each community type were grouped together in a table. These clusters of species characterize ecological conditions of each vegetation type and are essential for classification of the mixed units of the vegetation types (for example: juniper forest with a group of mesophytic shrubs, juniper forest mixed with deciduous trees, juniper forest mixed with xerophytic dwarf juniper shrublike forest, free-standing juniper trees in the mountain meadows).

III. 3. Methods of Image Processing

Image processing for identification features on the ground is based on amount of light reflected from their surface. Previous research (Jensen, 2005) established some of the correlations between the wavelengths and features recognized best within the certain band. Emission flux is measured by the sensors and converted to electronic signal with instantaneous field of view (IFOV) or spatial resolution, which in our case was or 15x15 m pixels resolution, or the size on the ground. “Digital remote sensor data are stored as a matrix (array) of numbers. A pixel is defined as a two-dimensional picture element that is the smallest non-divisible element of a digital image, each having an original brightness value (BV)” (Jensen, 2005, p.35). The brightness value at any point location is correlated with the energy emitted, reflected, or back-scattered from the objects and transformed to a “signature” in multiple bands of the electromagnetic spectrum available in digital format.

Spectral pattern recognition of one homogenous group of pixels representing certain feature with its unique spectral signatures is the essence of classification method. In the process of unsupervised classification, the computer program, rather than the investigator, generates the signatures that will be used to classify the scene with an algorithm. Classification results in a number of spectral classes, which the analyst must then assign to vegetation or non-vegetation classes (Jensen, 2005). This requires some knowledge of terrain present in the scene, vegetation types or complexes, as well as spectral characteristics of different surfaces.

Different spectral characteristics of visible, infrared and thermal bands allowed for vegetation and geomorphology feature extraction of the study area. Statistical analysis was used to separate each unit or consistently repeating pattern of complexity characterized by its spectral signature. Vegetation is one of the important features for imagery classification. Unsupervised and supervised classifications were performed to separate vegetation types and their complexes.

In the process of modeling natural environments, combinations of bands from the multispectral imagery enhance the features and allow their recognition: vegetation types, water, shale or rocky slopes, ice, snow, clouds, bare soil.

Digital imagery geodatasets were compiled using different band combinations of two types of imagery: Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Shuttle Radar Topography Mission (SRTM). Two scenes of the ASTER imagery of the different seasons of the year (winter and summer) and one

SRTM tile were acquired for the study (Attachment V). Image processing was done in several stages: selection of the imagery, corrections with real-time sun zenith and azimuth, altitude and projections, band combination overlay, band statistics, image enhancements for sharpness and intensity, image classification, mapping unit's statistics, reclassification, and three-dimensional displays. Several image-enhancing techniques were employed to sharpen the contour edges and texture: data fusion, filtering, and contrast stretch. For classification purposes original, unstretched imagery was used, because contrast stretching changes original pixel values. Stretching in our case was used only for a better contrast display and visualization of the features.

Feature extraction is spectrum (band) specific. Different band combinations could provide more information and feature resolution. Red and near infrared bands produce more vegetation information, red and thermal infrared carry more information for distinguishing water and geological features (Adams & Gillespie, 2006). Band combinations were used to outline the mapping units.

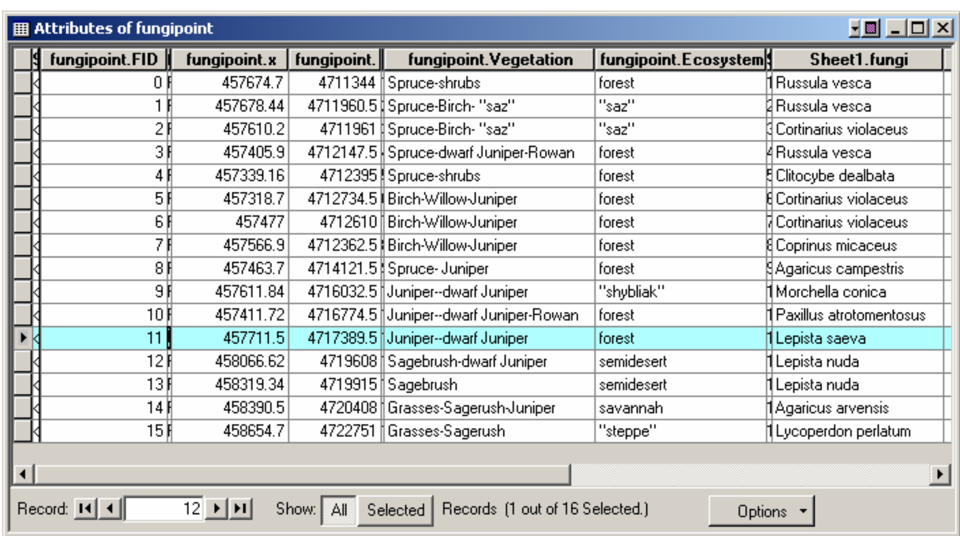
Digital elevation model (DEM) for 3D display could be produced in several ways: by contouring technique, using sampling points, elevations from a paper map, by processing of ASTER imagery (stereo bands 3) or by processing Shuttle Radar Topography Mission (SRTM) elevation tile as was done in this study. SRTM90 (GLCF, 2004) imagery was downloaded from the USGS website for this study. SRTM collected data using Synthetic Aperture Radar and is a joint project of the National Aeronautic Space Administration (NASA) and National Imagery and Mapping Agency (NIMA). SRTM data became available in 2004 with 1-arc second or 30m resolution for United States territory and in 3-arc seconds, 90 m for the world. ASTER image processing was performed with 6.4 and

SRTM with ArcInfo 9.1; statistics was calculated with ER Mapper, Excel and Sigmaplot. Model building elements in ArcGIS served as a supplementary tool.

CHAPTER IV. RESULTS AND DISCUSSION

IV.1. Fungi and Forest Species Database

Dominant vegetation species and fungi species were entered into Access and imported into ArcGIS geodatabase. Original 23 fungi species taxonomic descriptions from the field survey (out of the 50 species registered for the sampling plots), were translated from Russian into English (Attachment III), following the same terminology and style as in the standard macrofungi descriptions for North America (Kibby, 1996; McKnight & McKnight, 1998; Barron, 1999). Dominant species of trees, shrubs, and herbs from the 16 sampling points were grouped in a table according to their growth form and co-occurrence in forest types forming ecological groups helpful in forest identification. Vegetation and floristic descriptions followed the taxonomic nomenclature from several sources (Korovin, 1934; Kamelin, 1974; MEP, 1998).



Attributes of fungipoint

fungipoint.FID	fungipoint.x	fungipoint.	fungipoint.Vegetation	fungipoint.Ecosystem	Sheet1.fungi
0	457674.7	4711344	Spruce-shrubs	forest	Russula vesca
1	457678.44	4711960.5	Spruce-Birch- "saz"	"saz"	Russula vesca
2	457610.2	4711961	Spruce-Birch- "saz"	"saz"	Cortinarius violaceus
3	457405.9	4712147.5	Spruce-dwarf Juniper-Rowan	forest	Russula vesca
4	457339.16	4712395	Spruce-shrubs	forest	Clitocybe dealbata
5	457318.7	4712734.5	Birch-Willow-Juniper	forest	Cortinarius violaceus
6	457477	4712610	Birch-Willow-Juniper	forest	Cortinarius violaceus
7	457566.9	4712362.5	Birch-Willow-Juniper	forest	Coprinus micaceus
8	457463.7	4714121.5	Spruce- Juniper	forest	Agaricus campestris
9	457611.84	4716032.5	Juniper--dwarf Juniper	"shybliak"	Morchella conica
10	457411.72	4716774.5	Juniper--dwarf Juniper-Rowan	forest	Paxillus atrotomentosus
11	457711.5	4717389.5	Juniper--dwarf Juniper	forest	Lepista saeva
12	458066.62	4719608	Sagebrush-dwarf Juniper	semidesert	Lepista nuda
13	458319.34	4719915	Sagebrush	semidesert	Lepista nuda
14	458390.5	4720408	Grasses-Sagerush-Juniper	savannah	Agaricus arvensis
15	458654.7	4722751	Grasses-Sagerush	"steppe"	Lycoperdon perlatum

Record: 12 Show: All Selected Records (1 out of 16 Selected.) Options

Figure 10. Attribute table of the ArcGIS database;
sampling point #11 is highlighted.

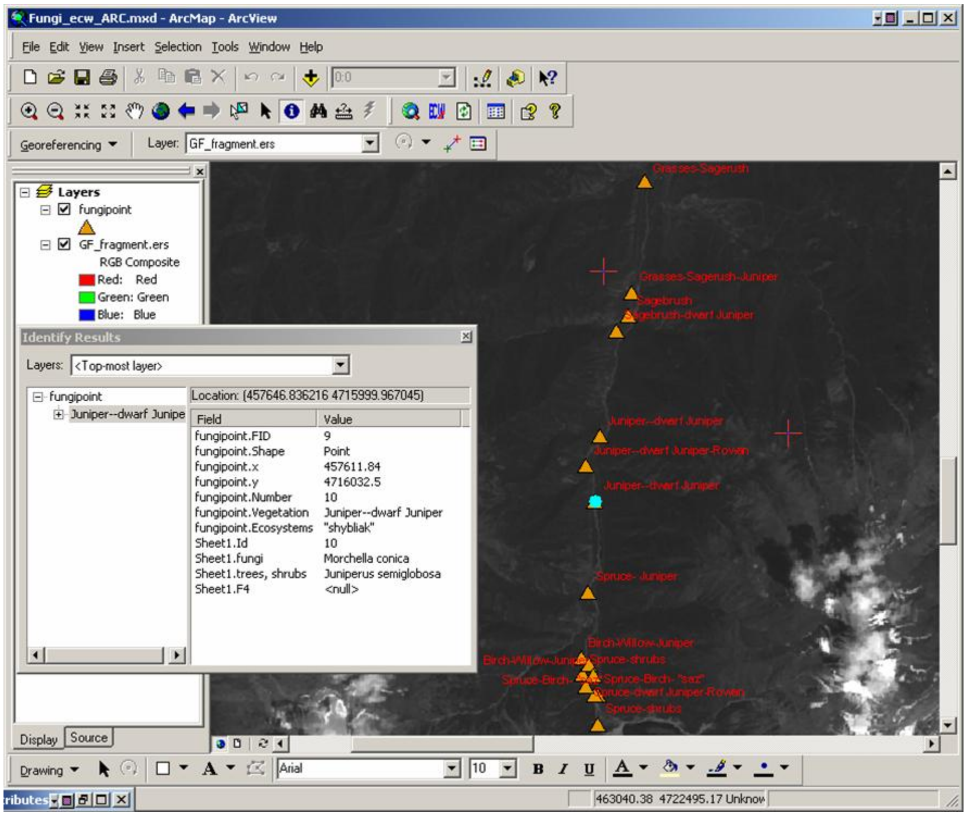


Figure 11. Sampling points query; sampling point #2 is highlighted.

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Figure 12. Sample of fungi photograph: Field Blewit (*Lepista saeva*).

Lepista saeva (Fr.) Orton - Field Blewit.
Cap: 5-7 cm, cushion-like, light brown with the edge folded inwards, smooth, shiny, cuticle not separated from flesh. Flesh: thick, meaty, light brown. Gills: attached, wide, same color as cap. Stem: 3-4 by 1-1.5 cm, light purple, cylindrical, widened downwards. Cap not separated from stem. Spores: 4-6 by 3-3.5 µm, ellipsoid, rarely almost round, colorless. EDIBILITY: edible. Sweet, nice taste. Widely consumed.

Figure 13. Sample of fungi species description.

Point 2
Altitude 2099
GIS N 423331.6
GIS E 74294.1

Russula vesca	*Hygrocybe conica*
Russula sp.	*Bovista sp.*
Leccinum scabrum	*Sarcodon sp.*
Lactarius deliciosus	*Cortinarius conica*
Agaricus silvaticus	*Pholiota squarrosa*

Figure 14. Sample of fungi community description.

Statistical analysis was performed in MS Excel to test the mycorrhizal connections between species of fungi and species of dominant trees. Correlation analysis on the sample of 136 species combinations or registered co-occurrences was conducted to determine mycorrhizal connections: whether certain species of fungi are correlated with forest dominant species. Statistical test and contingency table was created in Excel to calculate the co-occurrence probability (Attachment V). Correlation between the fungi and the tree species (mycorrhizal relationships) was not significant due to the small sample size compared to the biodiversity of species. Due to the limited amount of the data, χ^2 test did not show significant correlation. The test result of 0.47 determined a random distribution of species in this sample. A larger sample size should be used to study this type of correlation.

IV.2. Results of Vegetation Classification

Ecosystems representing habitat types or vegetation complexes in the territory of the Ala Archa National Park and the foothills are very rich in species and polydominant (dominated by a group of species occurring together, but not by one or two species), which makes their classification and mapping a rather challenging task. They belong to deciduous riparian forests, three distinctive types of conifer forests (with different dominant species of junipers and spruce), sagebrush desert, and several groups of grasslands, which may have sparse conifers in their composition. The mountain environment contributed to the complexity of forest vegetation. The elevation range of the study area (300 to 4,500 m), and the location of the valley being at 43^{o} north and running in the north-south direction result in a drastic contrast between its eastern and western slopes. At the mountain foothills, where availability of water is a limiting factor, vegetation types are less diverse and represented by arid vegetation with sagebrush and grassland semi-desert communities.

Several vegetation types and complexes of the studied area were outlined for further testing with satellite imagery recognition. Pure stands of conifer or deciduous forests are rare. On the slopes of the medium mountain belt, most often, it is a mixture of juniper forests with deciduous shrubs intermixed with mountain meadows or dwarf juniper shrublike forests. Thick stands of the tall juniper trees or its dwarf forms may occupy areas significant by size to be outlined as separate units. Pure stands of spruce occur at elevations higher than 1800 m. Riparian birch and maple forests at the bottom of the valley may have spruce and juniper trees in their composition or willows (in moist areas along the streams or near the springs).

Dry areas of the lower part of the valley or the mountain ridges have steppes or sagebrush semi-deserts with the patches of juniper trees forming savanna vegetation type. Dry cushion plants occupy the areas of the subalpine zone. Dry rocky slopes may be covered with mosses, lichens, ephemerous grasses or sedges, which have their growing season during the humid season of the year (winter or spring) making it difficult to distinguish them with satellite imagery from other sparsely vegetated slopes.

As a result of vegetation classification of sampled forest species data, eight major vegetation types were described for the sampling points at Ala Archa Valley. Dominant and co-dominant species in each classification category were assembled into a table which highlights ecological subgroups in each type (Table 1). These ecological subgroups form clusters of dominant and co-dominant trees, shrubs or herbs. The presence of characteristic ecological groups of species with different moisture content significantly affects discrimination of the forest types with remote sensing techniques.

The groups and subgroups of different types, including both conifer and deciduous trees, could be mixed in different proportion, and it is to the interpreter's judgment how to outline them on the map. Differentiating table served as a ground proof data; it outlines the ecological uniqueness of each of the eight habitat types for the sampled points. In addition to the eight vegetation units described for the sampling points, four more most commonly occurring vegetation units were added to the list to test their identification with the satellite imagery based on their reflectance signatures (patterns of clusters).

Table 1. Dominant vegetation and habitat types. Based on the sampling points descriptions in 2002.

DOMINANT SPECIES	forest	juniper shrubs	juniper forest	meadow "saz"	juniper savanna	juniper semidesert	semidesert	steppe
TREES	**CONIFER FOREST**		**DECIDUOUS AND CONIFER FOREST**		**SAVANNA WITH CONIFERS**			**STEPPE**
Picea shrenkiana	dominant	dominant	dominant	dominant				
Juniperus semiglobosa	co-dominant	dominant			co-dominant			
Juniperus turkestanica - dwarf		dominant	co-dominant			dominant	co-dominant	
Betula tianschanica			co-dominant	dominant				
Salix tianschanica			co-dominant					
SHRUBS								
Sorbus tianschanica		co-dominant						
Rosa albertii	co-dominant	co-dominant						
Cotoneaster melanocarpa	co-dominant	co-dominant						
Lonicera hispida	co-dominant							
Ribes meyeri	co-dominant							
Lonicera stenanta	co-dominant	co-dominant						
Lonicera tatarica		co-dominant						
Berberis intermedia			co-dominant					
Berberis heteropoda			co-dominant	co-dominant				
HERBACEOUS								
Rosa spinosissima		co-dominant						
Phlomis areolata		co-dominant						
Gallium verum		co-dominant						
Thalictrum minus		co-dominant						
Aconitum songoricum		co-dominant						
Myricaria squammosa			co-dominant					
Polygonum songoricum			co-dominant					
Epilobium palustris			co-dominant					
Potentilla orientalis			co-dominant	co-dominant				
Festuca valesiaca				co-dominant				dominant
Gentiana karelinii				co-dominant				
Fragaria vesca				co-dominant				
Poa pratensis				co-dominant	co-dominant		co-dominant	
Poa angustifolia					dominant		dominant	
SEMI-SHRUBS								
Artemisia santlinofilia					dominant	dominant	dominant	
Artemisia dracunculus					dominant	dominant	dominant	co-dominant
Ziziphora clinopodioides						co-dominant		

For the territory of the Ala Archa National Park, major ecosystems are mountainous forests and semi-deserts. Classification categories represent the following most often occurring vegetation types or complexes used as possible mapping units:

1. **Juniper forest**. Juniper forests dominated by the tall forms of *Juniperus semiglobosa* and *Juniperus turkestanica.*

2. **Spruce forest**. The dominant species is spruce or spruce fir *Picea schrenkiana.*

Figure 15. Spruce tree (left) and vegetation complex of the juniper forest and juniper savanna on the slope of the Ala Archa Valley.

3. **Complex: Spruce-juniper forest with shrubs**: spruce *Picea schrenkiana* with co-dominant tall growing junipers-- *Juniperus turkestanica* and *Juniperus semiglobosa* and shrubs: *Lonicera hispida, Lonicera stenantha, Berberis integerrima, Rosa spinosissima Rosa albertii*, *Ribes meyeri, Cotoneaster melanocarpa.* On the steep slopes of northern and northwestern exposures understory is often formed by rowan *Sorbus tianschanica.*

4. Complex of the Spruce and alpine grasslands: found at the upper forest boundary where spruce grows sparsely; the herbaceous cover is formed by the patches of meadow and forest grasses, herbs, and mosses: *Trisetum sibiricum, Carex dichroa, Silene graminigolia, Potentilla asiatica, Primula macrocalyx*.

5. Complex: "saz,"or spruce-birch forest with shrubs in the understory found in the habitats with surface hydrology and moist soils. This type of habitat is very distinct from the other forests; it is a combination of spruce-birch forest and moist meadow (Figure 17). It has a local classification name of "saz." Dominant species are: spruce *Picea schrenkiana* and birch *Betula tianschanica*, co-dominant shrubs *Berberis intermedia*, *Berberis heteropoda* and herbs *Poa pratensis, Festuca valesiaca, Gentiana karelinii, Fragaria vesca, Potentilla orientalis.*

Figure 16. Mixed spruce and juniper forest at the bottom of the valley.

6. Complex: Juniper-birch forest in association with numerous and diverse shrubs. Dominant species are: *Juniperus semiglobosa* and *Betula tianschanica*, with co-dominant *Berberis intermedia, Berberis heteropoda, Potentilla orientalis, Juniperus turkestanica, Salix tianschanica, Myricaria squamosa, Polygonum songoricum, Epilobium palustris.*

Figure 17. Birch and spruce forest in Ala Archa.

7. Dwarf juniper shrublike forests are formed by *Juniperus turkestanica* and usually found on the slopes at the upper forest boundary. They form pure communities at elevations of 2700-3000 m.

8. Mountain meadow: mesophytic grasslands at medium elevations with *Phlomis areolata, Gallium verum, Thalictrum minus, Aconitum songoricum.*

9. Dry grasslands and alpine meadows are formed by sparse herbaceous vegetation at high elevations on the rocky slopes, often with mosses of lichens.

10. Complex: Juniper and dwarf juniper forests with mountain meadows (Fig. 18)**.** Dominant species are junipers: *Juniperus turkestanica, Juniperus semiglobosa*, shrubs like rowan *Sorbus tianschanica,* roses *Rosa albertii*, *Rosa spinosissima, Cotoneaster melanocarpa,* hoheysuckle*s Lonicera stenanta, Lonicera tatarica* and herbs.

Figure 18. Complex of juniper forest, dwarf juniper, and mountain meadow.

11. Sagebrush semi-desert. This semi-desert is dominated by the sagebrushes *Artemisia santlinofilia* and *Artemisia dracunculus,* and occurs in the high mountain elevations or at the foothills. Sagebrush semi-desert in the foothills of the mountains has a grass layer of ephemeroids and ephemerous grasses like bluegrass *Poa pratensis.*

12. Steppe. An arid grassland with fescue grass and sagebrush. Dominant species are *Festuca valesiaca, Artemisia vulgaris.*

13. Complex: Sagebrush semi-desert with juniper stands. Dominant species are: *Juniperus turkestanica, Artemisia santlinofilia, Artemisia dracunculus*, with co-dominant *Ziziphora clinopodioidesm.*

14. Savanna or complex of steppe, sagebrush semi-desert with juniper stands. Dominant species: *Artemisia santlinofilia, Artemisia dracunculus*, *Poa angustifolia*, with co-dominant *Poa pratensis, Juniperus semiglobosa* (Figure 19).

Figure 19. Mountain meadow at the bottom of the valley;

savanna – grassland with juniper trees on the background.

IV.3. Results of SRTM Image Processing and 3D Modeling

Shuttle Radar Topography Mission imagery (SRTM) was processed with ArcInfo to obtain elevation contours with 18 natural breaks (Fig. 20). Derived contours were used as a base for the 3D display. Comparison of the SRTM90 contours (90 meters resolution) with existing map was conducted. Topographic contours from the digital geological map produced by digitizing the paper map (Burg, 2004) were well corresponding to the same elevation contours obtained with SRTM for the elevated portion and steep slopes of the valley, and not always corresponding at the lower elevations of the watershed (Fig. 21). Spatial analysis (slope, aspect) and 3D displays of the imagery band combinations (Fig. 22) were useful for assigning the units of vegetation on the imagery classification.

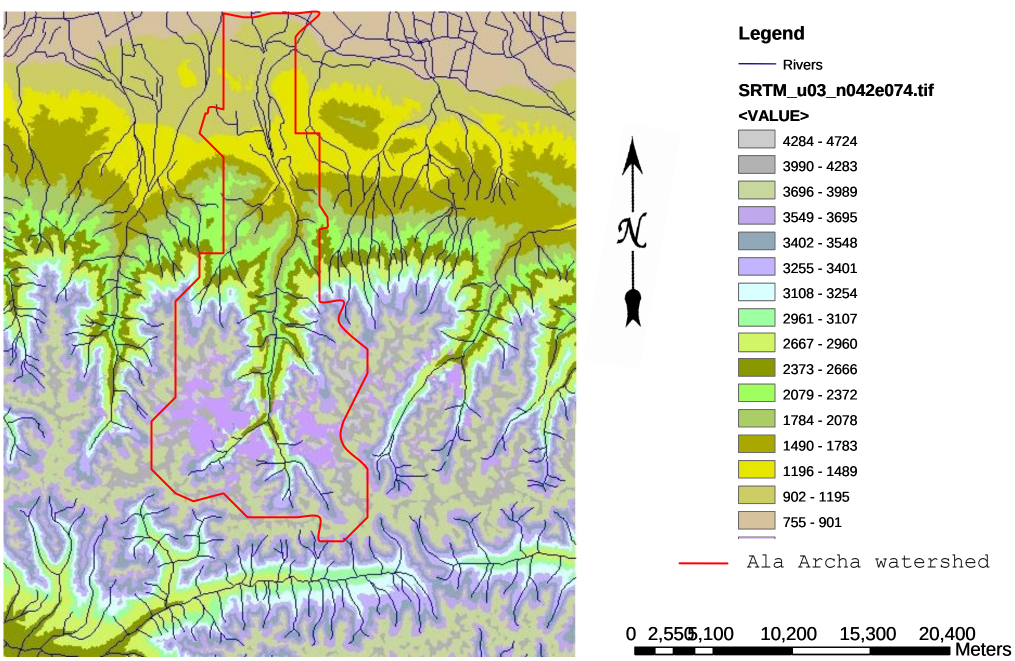

Figure 20. Elevation zones of the Ala Archa watershed based on SRTM.

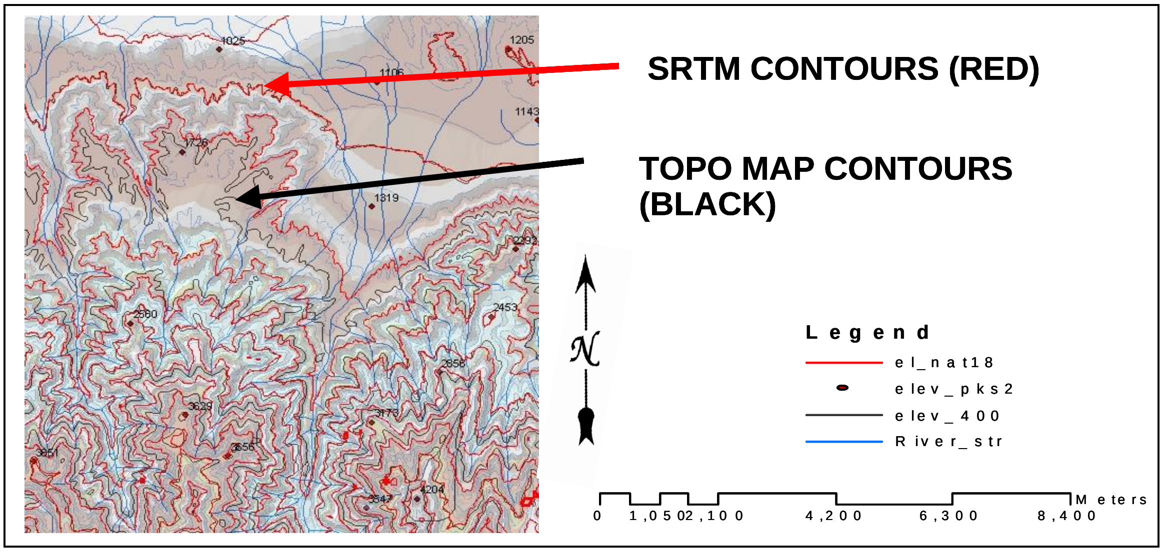

Figure 21. SRTM elevation contours comparison.

IV.4. Results of ASTER Imagery Classification

Several steps of the satellite imagery classification made it possible to outline the major vegetation types and complexes and to separate vegetation and non-vegetation sites. To outline on the imagery different features: variety of vegetation complexes, water, ice, rocks, shale, and bare ground, their reflectance or brightness value (BV) in different spectra (bands) was explored on the set of 15 ASTER bands. Different band combinations and band ratios were assembled for display and feature extraction. Band statistics calculations, cell value profiles, band combination displays were used for more detailed supervised image classification of the training area.

As a testing site, a 8x8 km set representing the area around Ala Archa tourist camp was selected. Vegetation complexity and absence of distinct boundaries between vegetation types create a difficulty in image interpretation. For example, reflectance values of the dry dwarf juniper stands are more similar to those of the dry shale slopes with cushion plants than to the tall growing forms of junipers.

Brovey Transform display of the bands increased the contrast of an image and highlighted the water and vegetation features in a natural-looking fashion. Brovey Transform is a ratio of ASTER bands: 4/431-3/431-1/431 with 15 m resolution (Fig. 22).

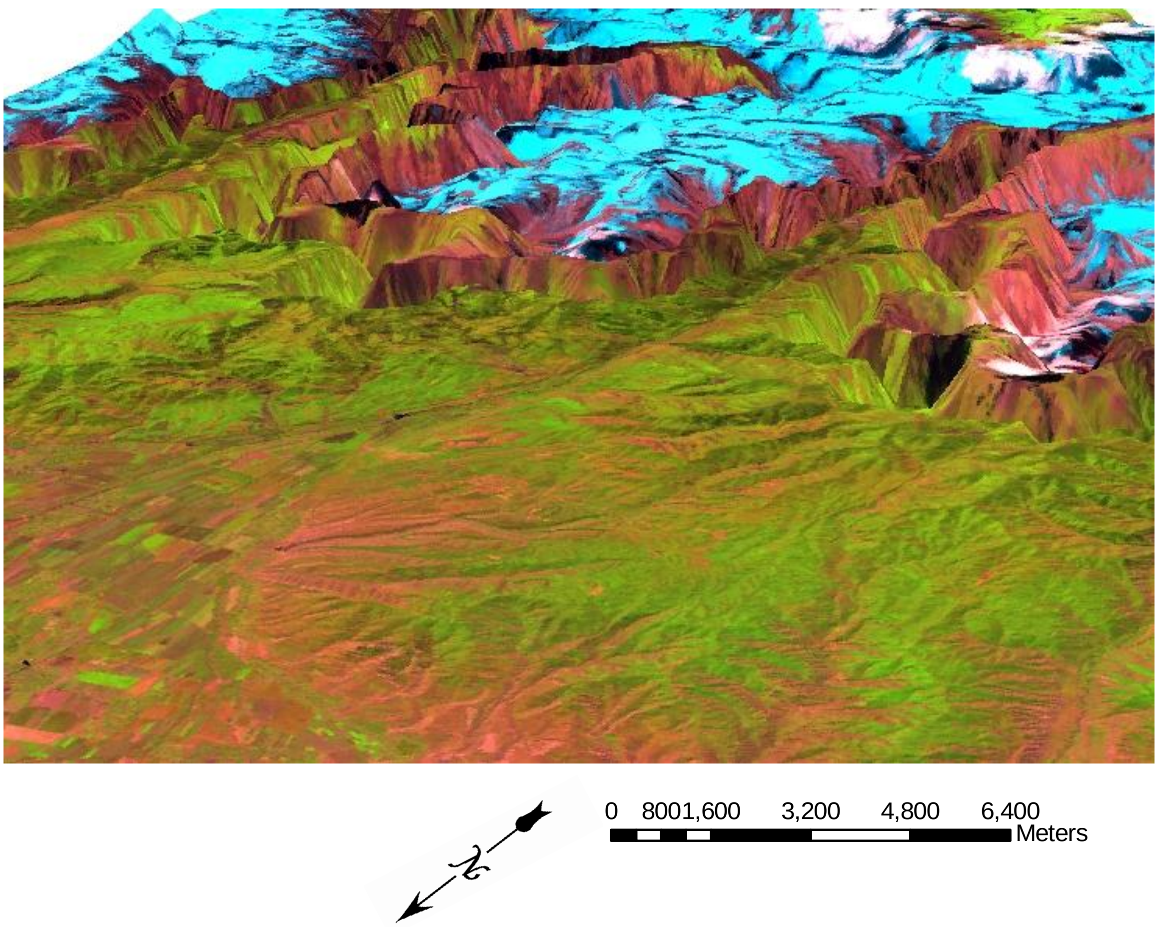

Figure 22. ASTER Brovey Transform in 3D display over SRTM; vertical exaggeration is 2. Entrance to the valley, view from the northwest. R (4/431), G (3/431), B (1/431).

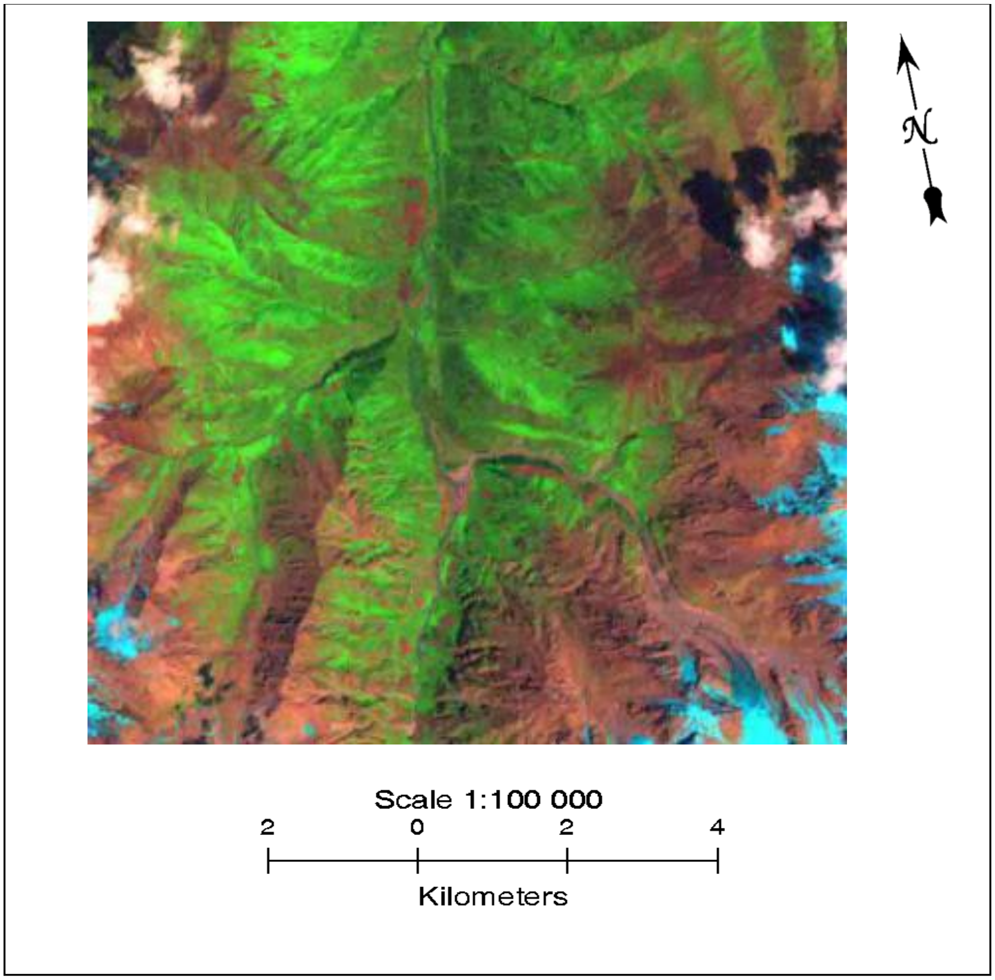

Figure 23. ASTER Brovey Transform of the training area.

Principal Component Analysis (PCA) with bands 1-2-3-4-5 is another enhancement technique used to display the image. By determining sets of correlated variables it allows to avoid the redundancy of information carried by the bands. The PCA Algorithm function in ER Mapper uses each image spectral band as a variable and rotates the multivariate axes around the statistical grand mean from the image data set to transform the data axes to maximize the variability. Statistically, this application of PCA displays the variability of each feature into the axis according to its variance and thereby behaves as a discriminate function in maximizing the ability to separate the features and enhance the pattern of the features in the image data set (ER Mapper, 2004). Clustering techniques and PCA proved to be the helpful tools in the analysis.

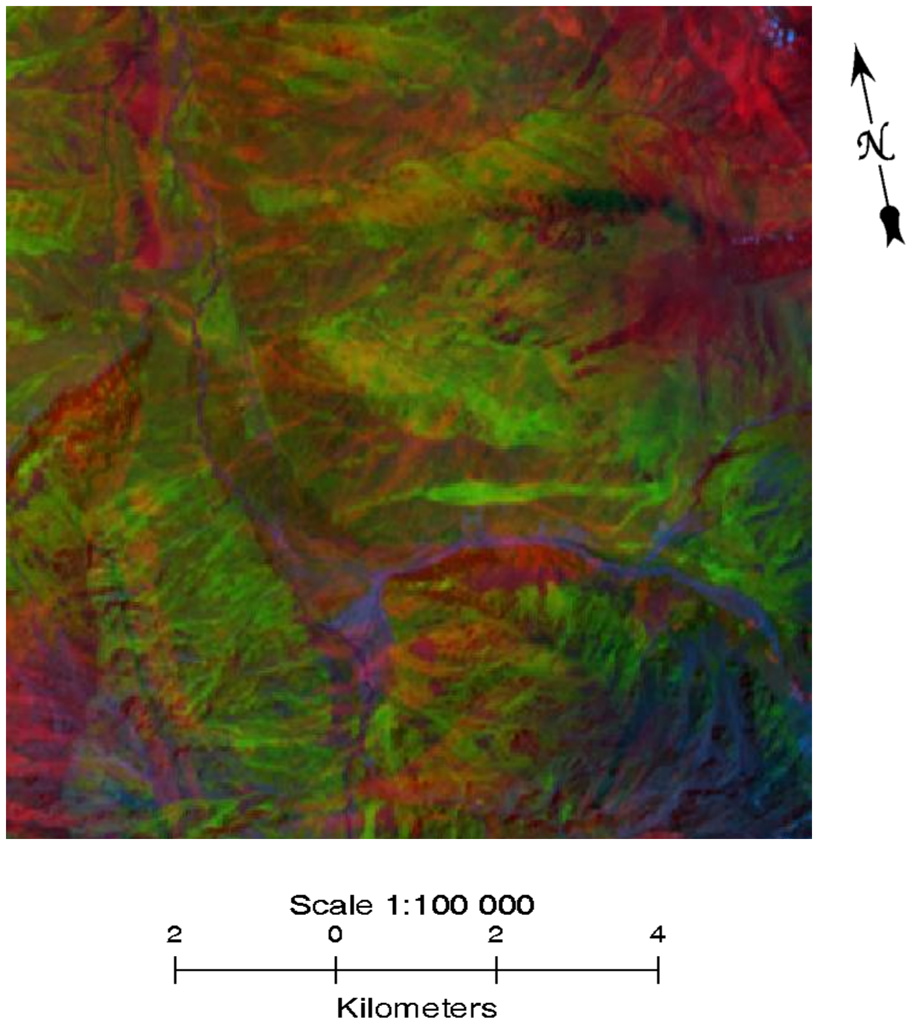

Figure 24. Principal Component Analysis (PCA) with bands 1-2-3-4-5.

The following combinations of bands were considered to be more informative than the others: 4-3-2-1-5-6 and 10. Thus combining visible near infrared (VISNIR), short wave infrared (SWIR), and thermal infrared band (TIR) it was possible to outline forest and grasslands vegetation units. Band ratio 3/1-4/3 -10/1 ASTER (Fig. 25) provided more details and allowed to outline vegetation units and complexes with conifers.

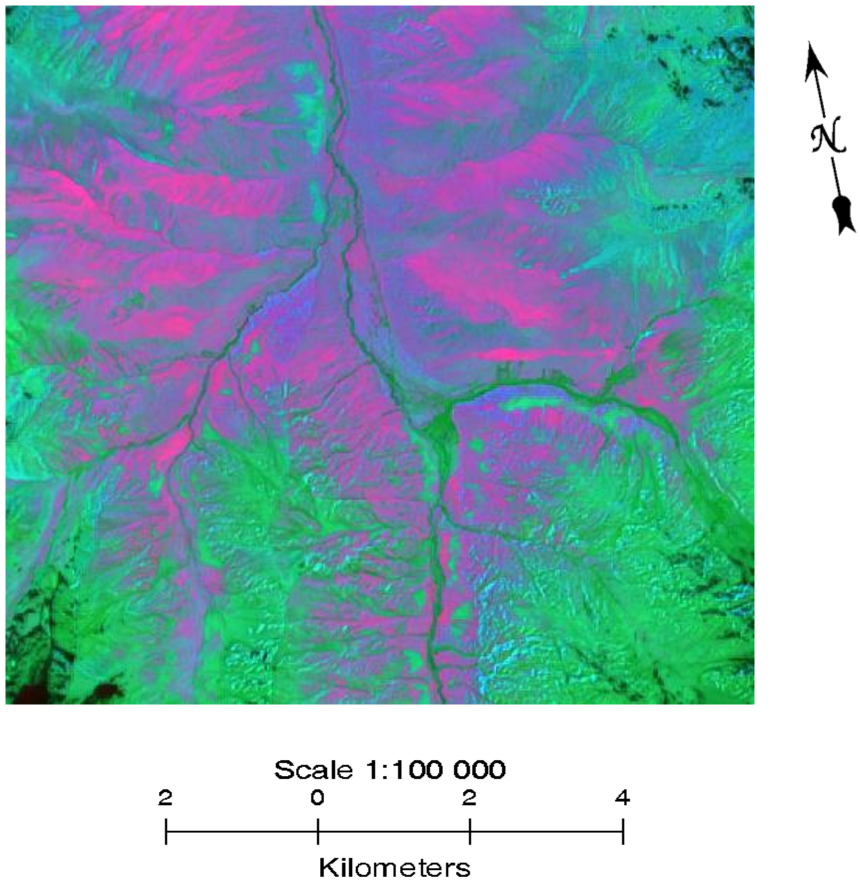

Figure 25. ASTER band ratio 3/1-4/3 -10/1.

Normalized vegetation index (NDVI) is often used to outline the areas with no vegetation. NDVI is a band ratio of near infrared and red bands: NDVI=NIR-R/NIR+R. It was calculated from the processed ASTER spring image and showed several units of vegetation density (Fig. 26). Rocky steep slopes of the valley covered with sparse vegetation: grasses, mosses and lichens showed lower brightness values of 51-157.

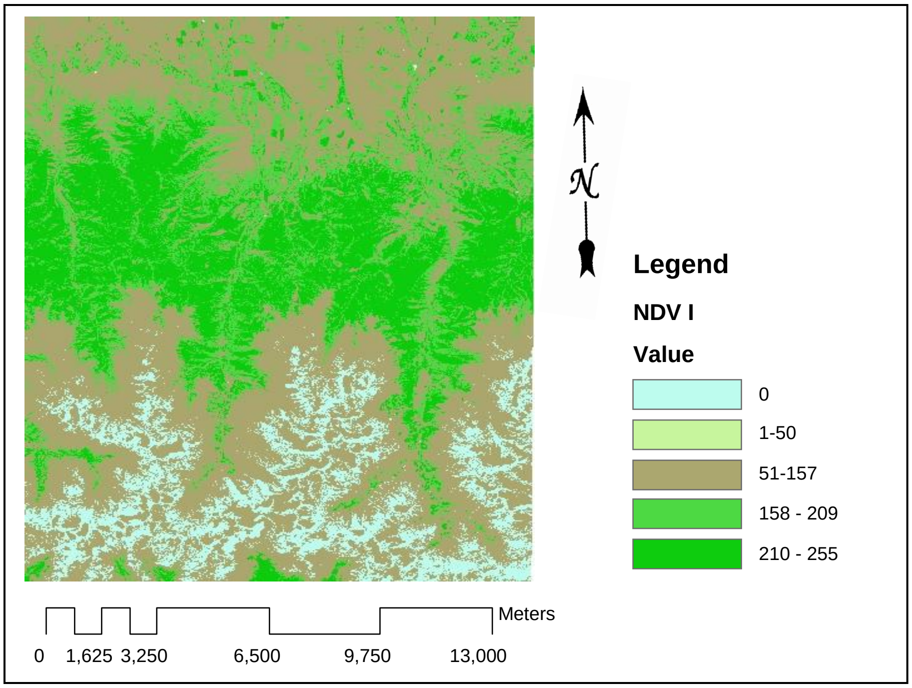

Figure 26. Normalized vegetation index (NDVI).

Clay/iron oxide index is a ratio of bands R (5/7), G (3/2), B (4/3), which highlights areas with vegetation in magenta and soil in green (Fig. 27).

Vegetation units on the slopes and the valley have conifers in their composition. Winter ASTER image (snow cover in March) of the training area was subjected to classification with 6 classes (bands 4, 1 and 10) to explore the possibility of outlining conifer trees (Fig. 28). Based on statistics for the median brightness values it was possible to outline contours with conifers, conifers and evergreens, shrubs and sparse winter vegetation on the steep slopes. Median brightness values in band 1 for contours with conifer trees were 74.1- 89.9 for mixed conifers, and higher for other evergreens.

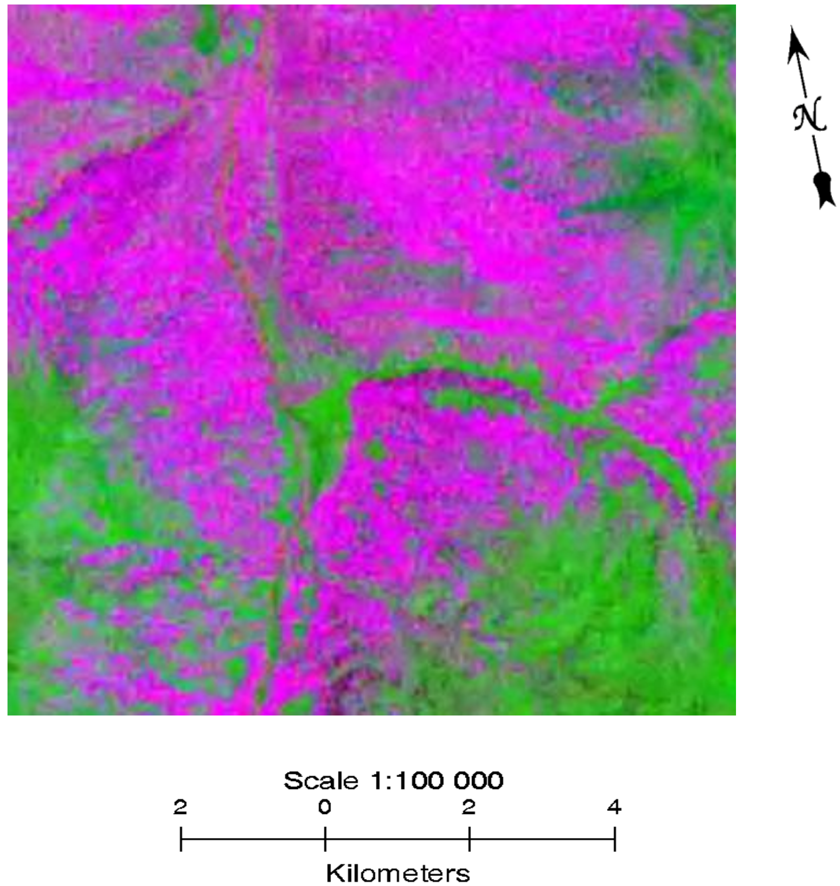

Figure 27. Clay/iron oxide/vegetation index display: R (5/7), G (3/2), B (4/3).

Band combination 6-5-3 highlighted geological features and made their extraction possible: rocks, disturbed soil, and bare land. It shows vegetation in green (band 6 helps to define moisture in vegetation and soil) and no vegetation features in magenta. With additional ground data proof data, bands 5 and 6 could be valuable for distinguishing between conifer types based on their water content. Statistics from the thermal bands 10 and 13 of the ASTER imagery also allowed detecting and excluding areas without vegetation presented by different geological materials.

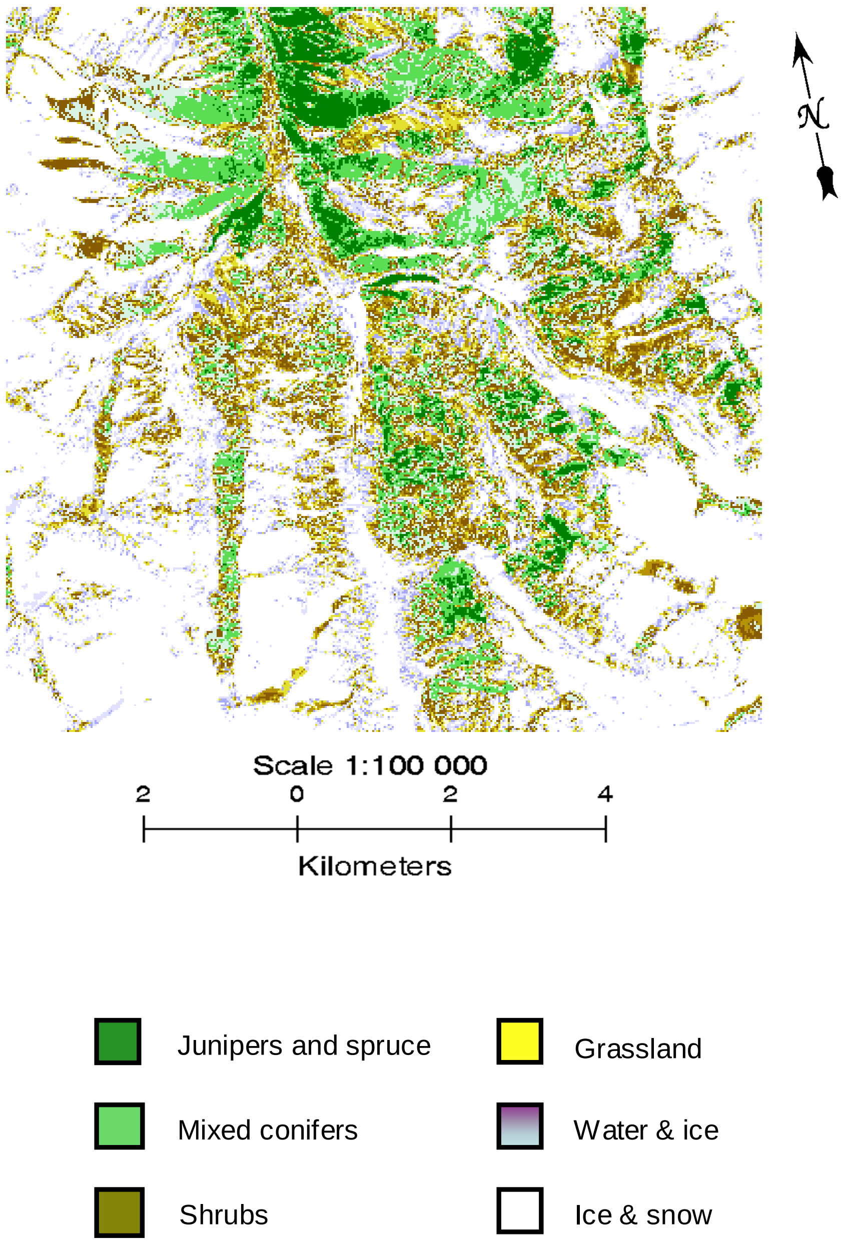

Figure 28. Conifers on processed winter ASTER imagery (bands 4-1-10).

Using classification algorithms in ER Mapper digital images of the area were split into clusters of pixels, characterized by brightness values (BV) and representing different categories of land features or classification categories. Iterative Self-Organizing Data Analysis Technique (ISODATA or clustering) was performed with ASTER band combinations to produce 6, 18, and 32 clusters.

Three ASTER band combinations of 4-3-2 (red, green, and blue) is most commonly used for land use, land cover classification. Unsupervised ISODATA classification for 32 classes with band combination 4-3-2 resulted in display of the homogenous group of pixels representing similar spectral patterns of the major vegetation and non vegetation complexes and was selected for further analysis. Knowledge of the units on the ground (sampling points, general description of the area, observations, and photographs) helped to select the band combinations in an optimal fashion to perform vegetation classification and recognition of its types. Sampling points, contours of known vegetation types (vector files created by editing tool), and SRTM elevation contours were displayed as transparent overlay with ASTER unsupervised classification for better feature recognition. Classification with 32 classes produced similar results with PCA (1-2-3-4-5) and Brovey Transform and band ratio: 3/1-4/3-10/1. Statistical tests for method comparisons were not conducted. Histogram analysis of bands 1 and 2 served as a tool to identify unknown features on the training area imagery display, for example, contours with sparse vegetation, shrubs, barren soil, rocks or shale.

Supervised classification was performed for the training area outlining the contours of the known locations of the mixed conifer and deciduous forests (Fig. 29). Band statistics results showed separability of the spruce and dwarf juniper forests in band 3 and band 4 of the spruce and mixed spruce-birch forests (Figs. 30-32). Scattergrams for the contours of vegetation types reflect the range of reflectance values in pairs of bands

(Figs. 31-32). Scattergrams are validating the training regions, show the correlation between two bands of the same image and illustrate ranges of brightness values for the forest types. Error statistics were not calculated due to the limited number of sampling points.

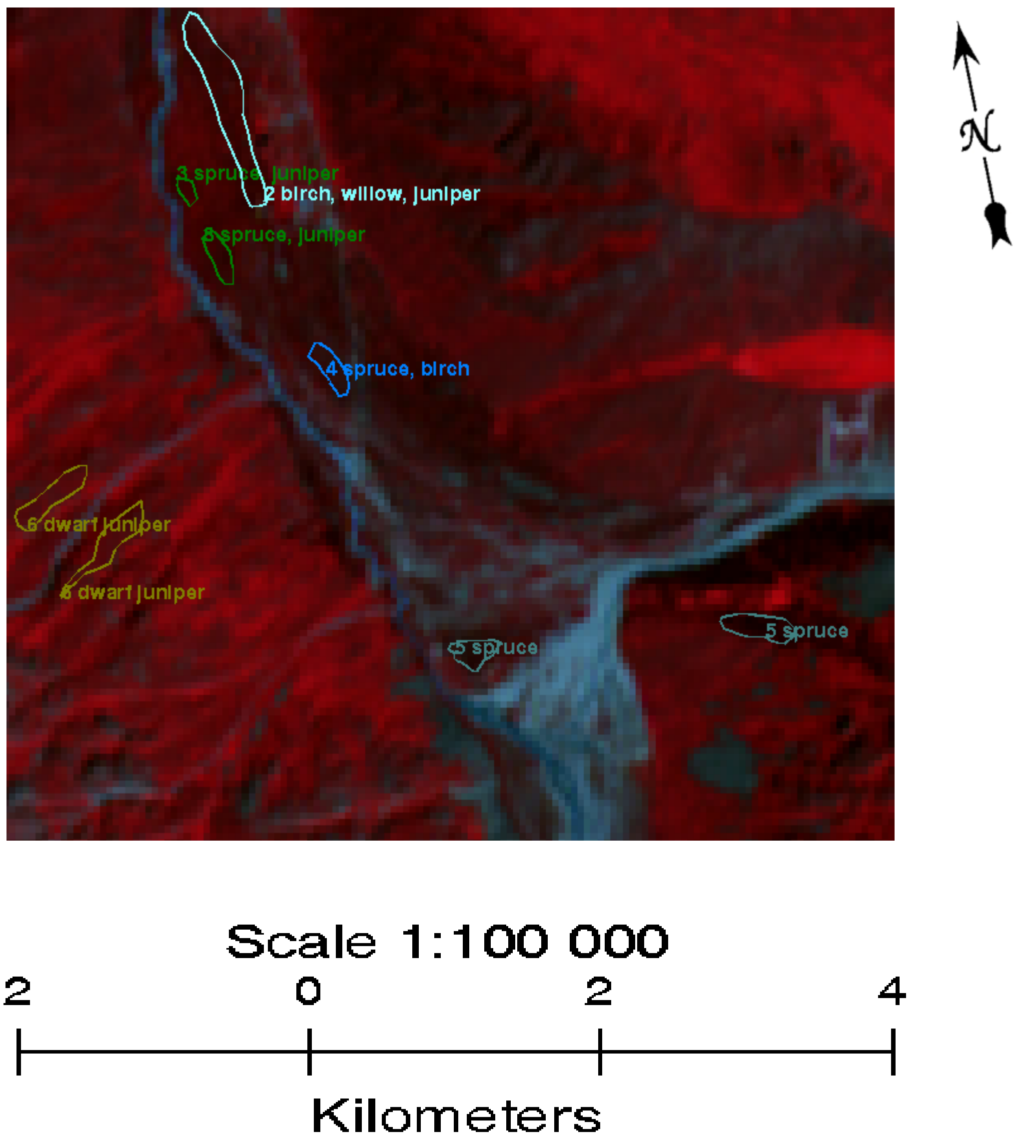

Figure 29. Supervised classification contours of the conifer forests.

Supervised classification of the watershed area produced a limited number of classes representing more generalized units: conifer forests, mixed conifer and deciduous forests, scrublands with cushion plants or dwarf conifers, complexes of conifers meadows and shrubs (savanna), dry grasslands, steppes and sagebrush deserts (Fig. 34). As a result, each class has a new range of spectral signatures that could be described in numeric values. Due to complexity of these classes, their values overlap and could only be associated not with individual forest types, but rather with a "mosaic" of different vegetation units.

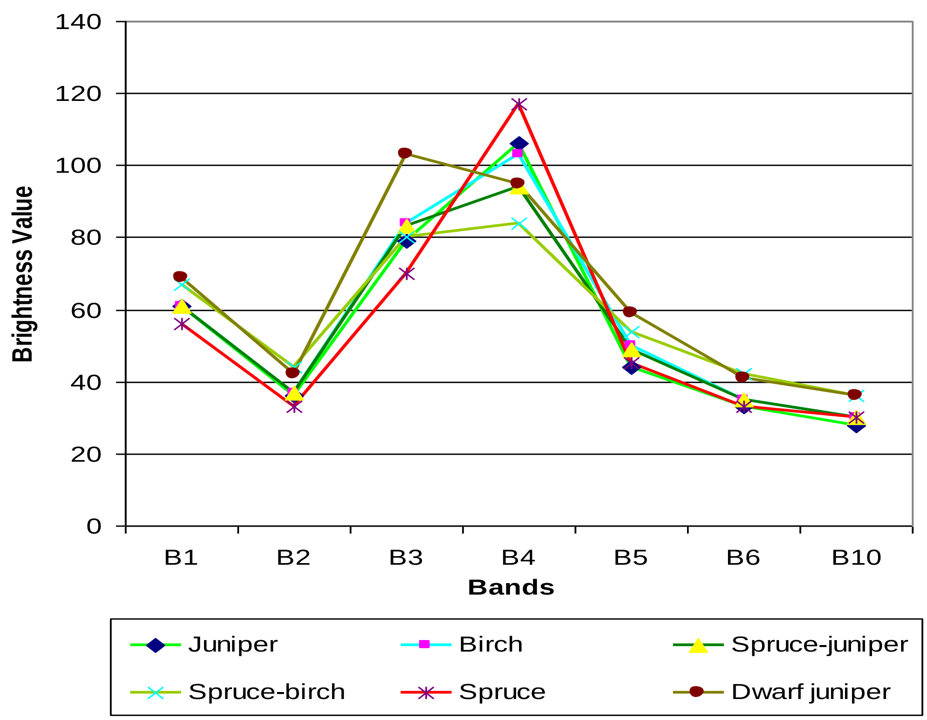

Figure 30. Brightness values of vegetation types in seven bands of ASTER.

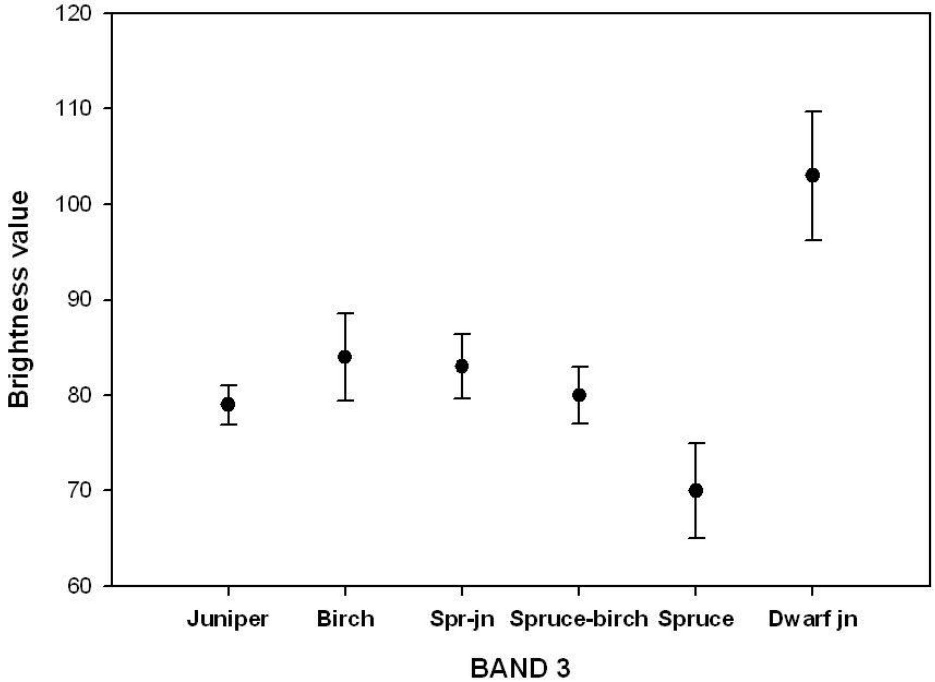

Figure 31. Brightness values of the vegetation units with conifers in band 3.

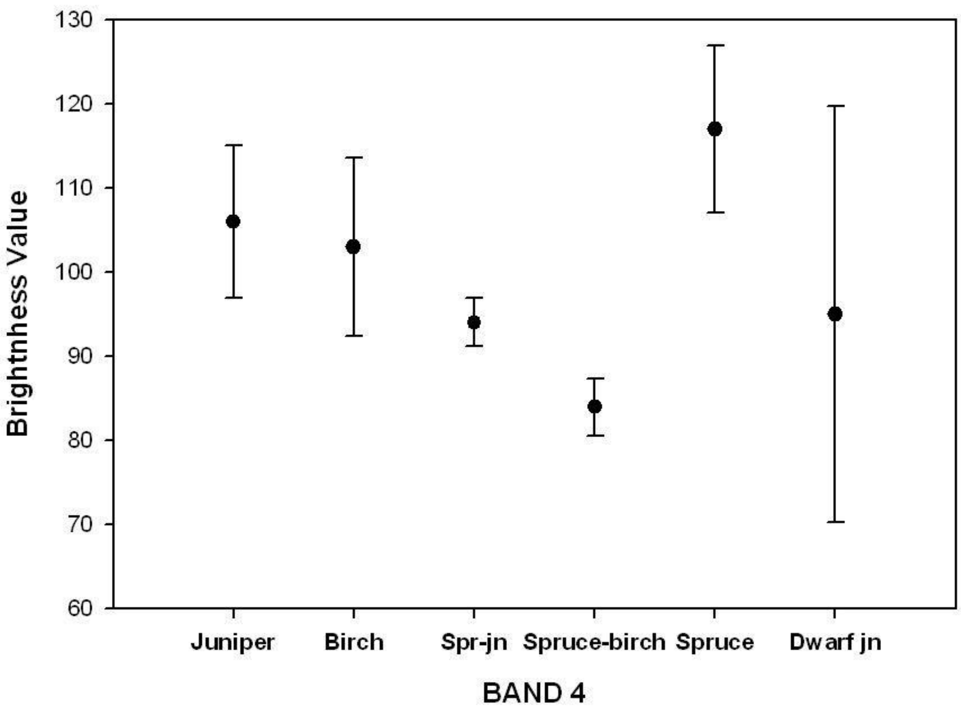

Figure 32. Brightness values of the vegetation units with conifers in band 4.

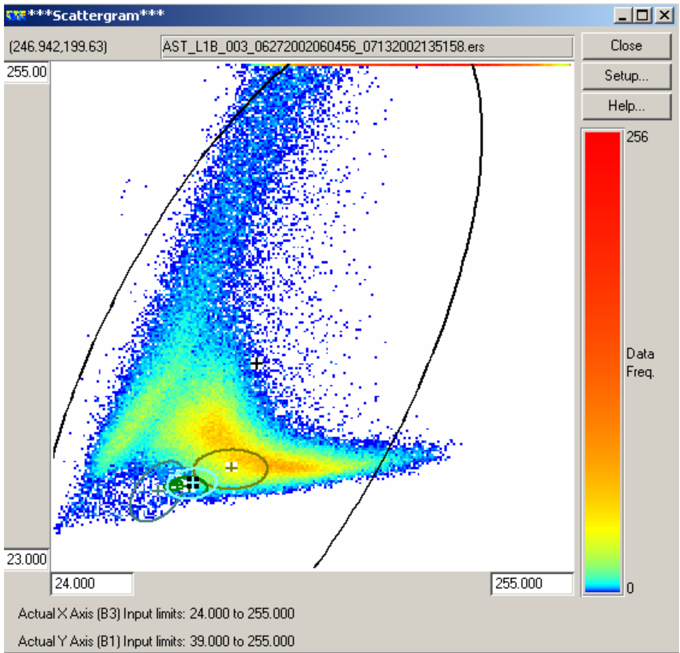

Figure 33. Ranges of brightness values of the conifer forest types in bands 3 and 1.

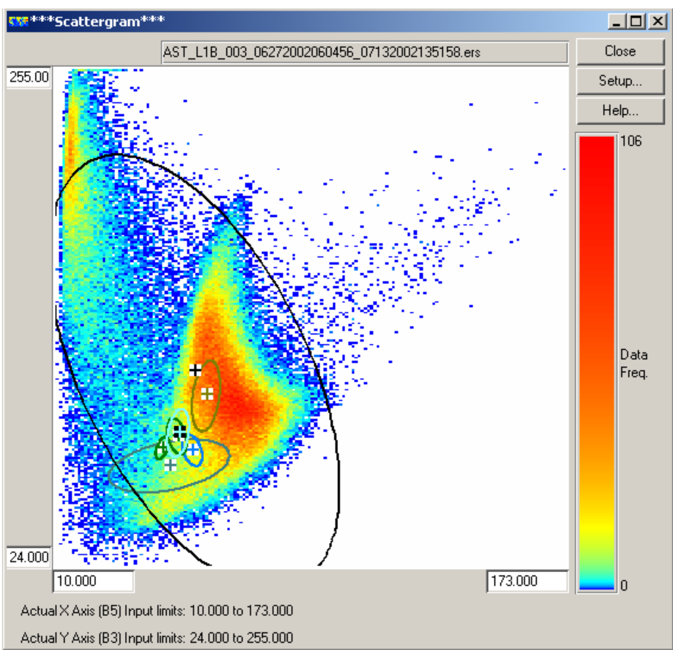

Figure 34. Ranges of brightness values of the conifer forest types in bands 3 and 4 (shown here as band number 5).

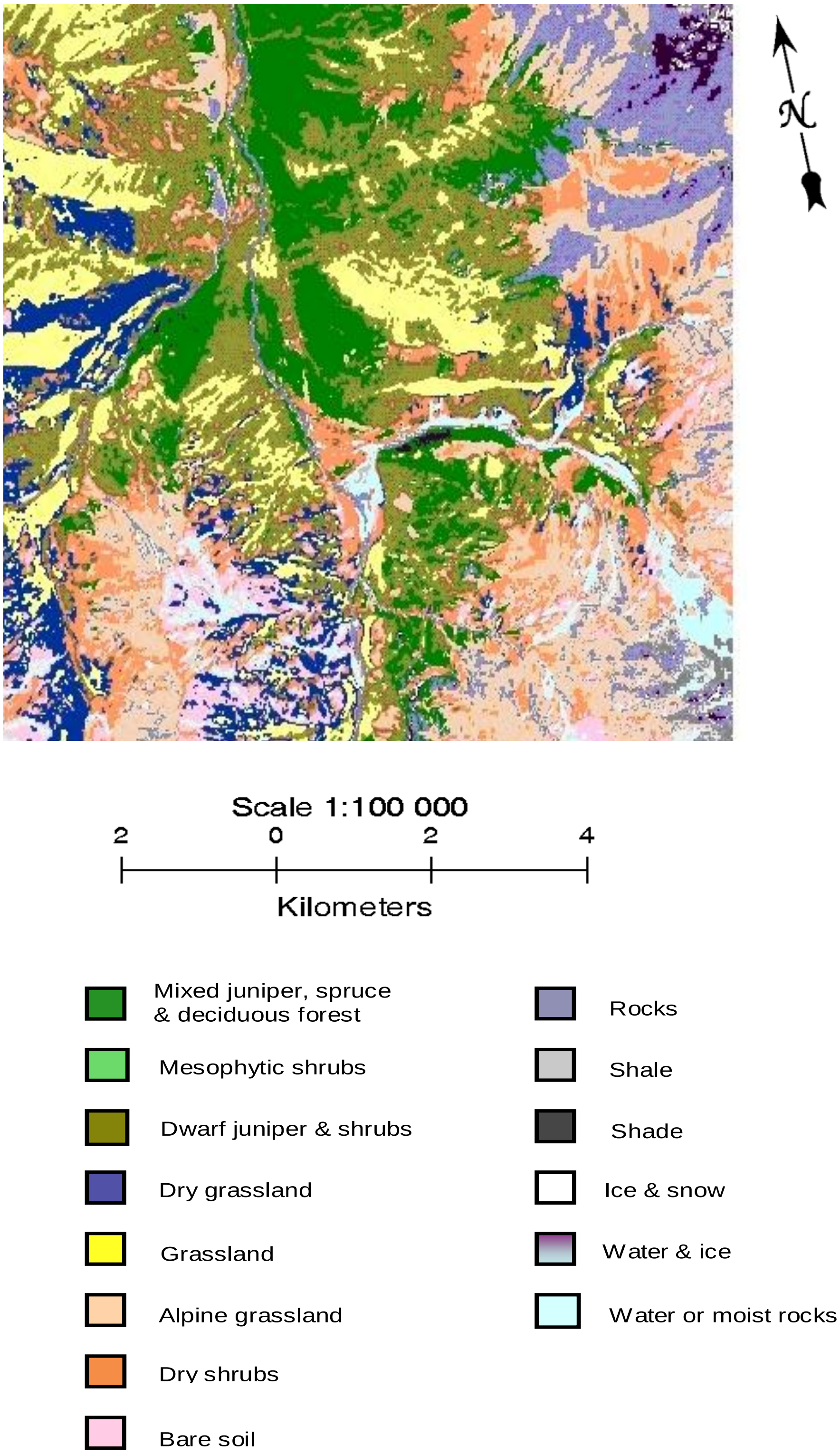

Figure 34. Vegetation classification of the training area.

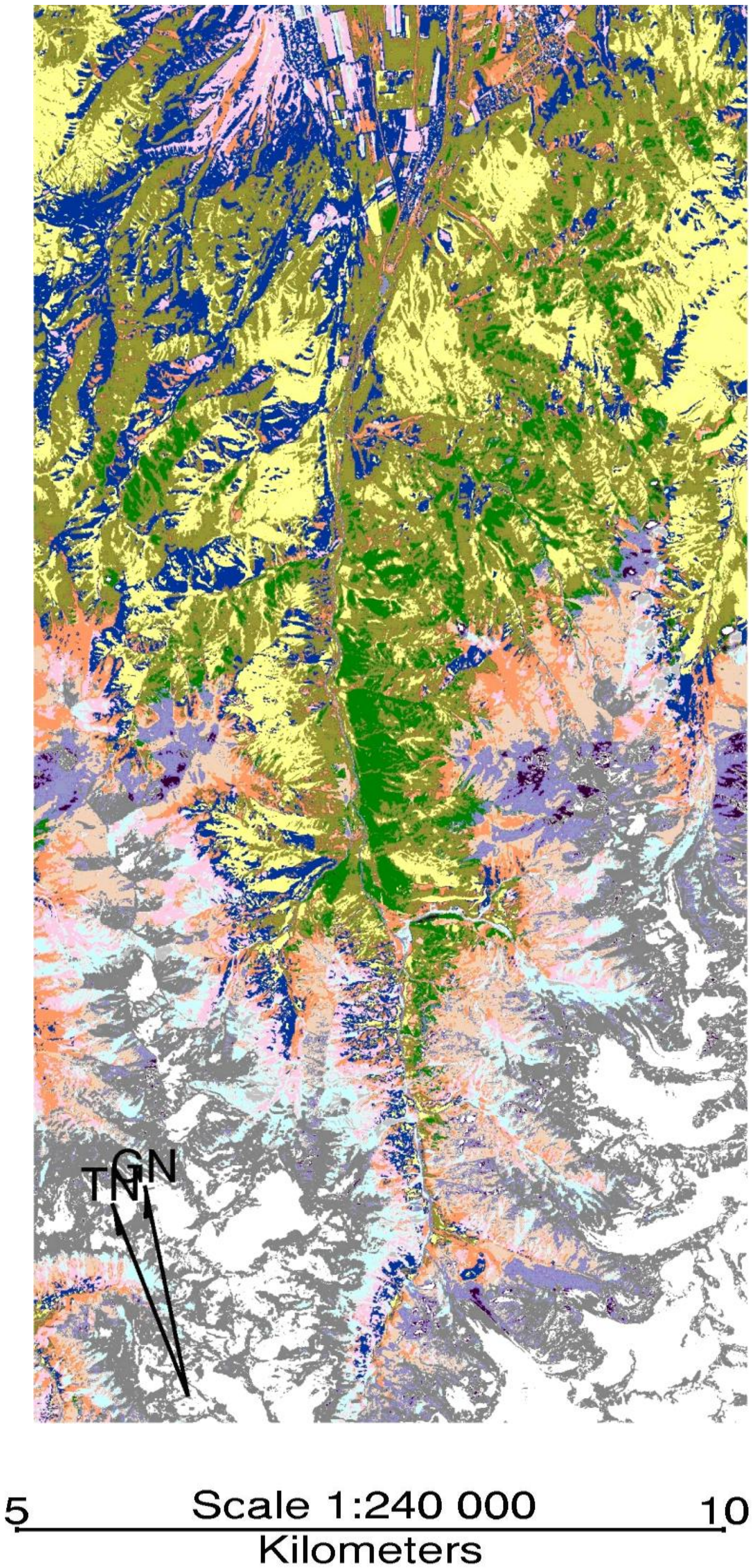

Figure 35. Vegetation classification of the Ala Archa watershed area.

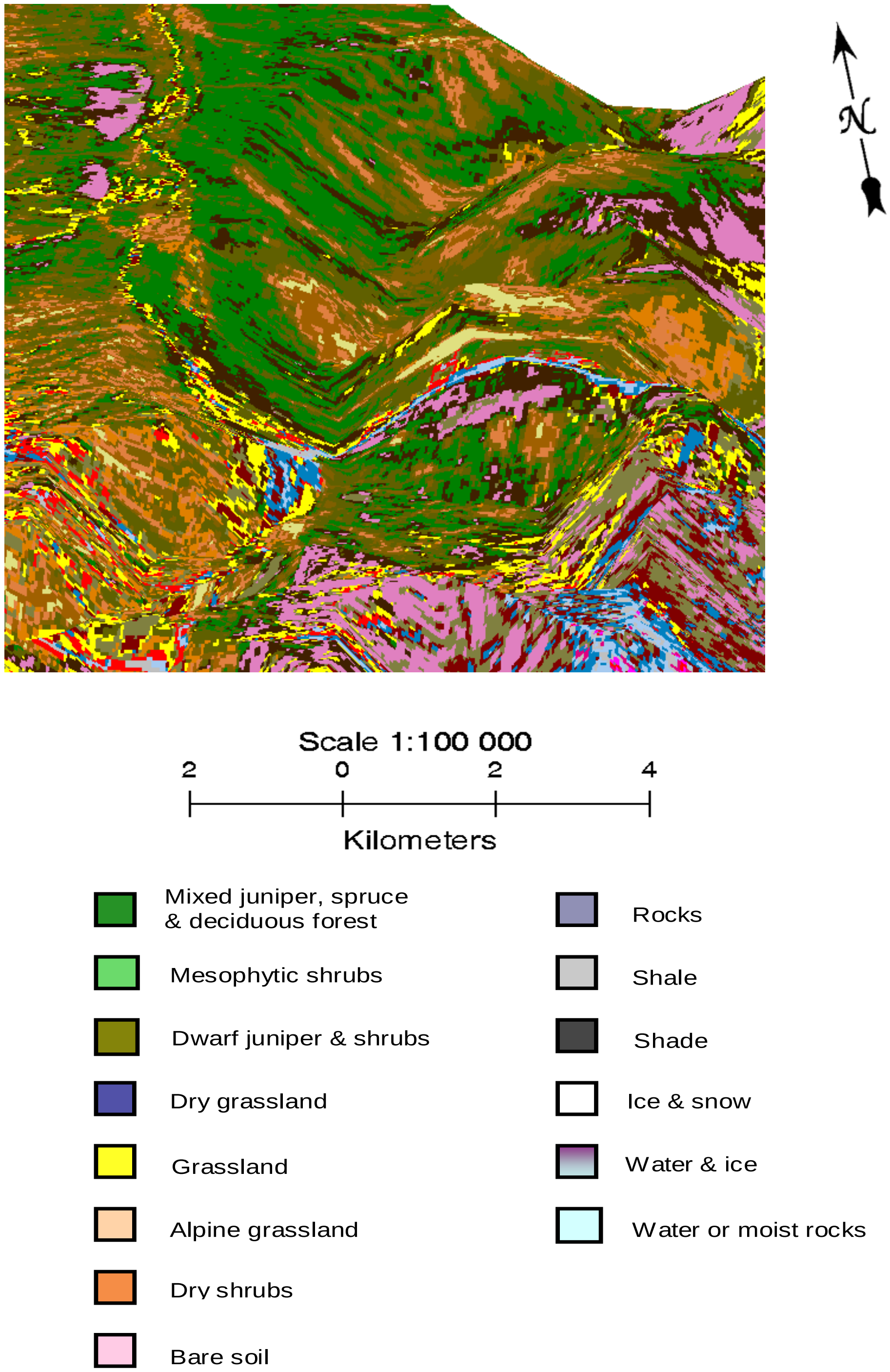

Figure 36. Classification 3D display of the training area.

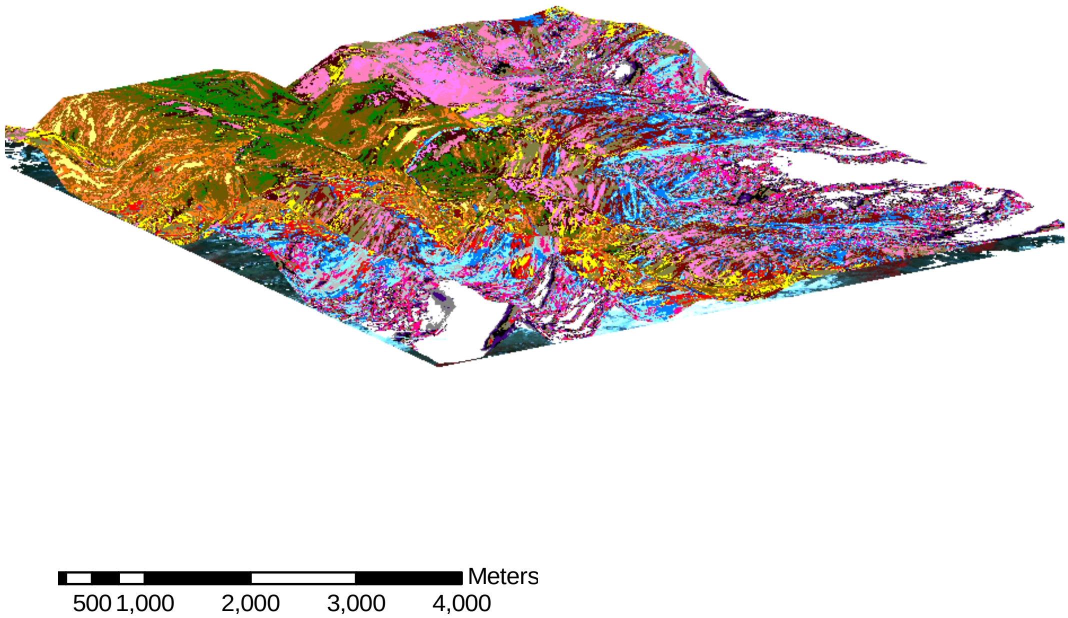

Figure 37. Classification 3D display of the Ala Archa watershed area, view from the south-west.

CHAPTER V. CONCLUSIONS AND FUTURE RESEARCH

Mountainous landscapes of Central Asia present a challenging task for biodiversity studies due to their high complexity and heterogeneity. The use of satellite imagery and the database approach in biodiversity conservation makes electronic inquiries and data sharing possible, this marks a new, modern level of biodiversity surveys. The territory of Ala Archa National Park in Kyrgyz Republic, selected for the study, is a part of Tien Shan Mountains known for their biodiversity and representing natural occurring forests and desert communities.

Satellite imagery of high resolution allowed for spatial analysis that provided correlation between the vegetation units and habitats. Through this use of image processing vegetation units were analyzed. Terra ASTER and SRTM90 Imagery was interpreted in order to produce a three dimensional base map of plant communities and their classification. Image processing techniques with ER Mapper and ArcGIS/ArcInfo using ASTER bands and band ratios (NDVI, Brovey transform, and 3/1, 4/3, 10/1) allowed distinguishing between several vegetation community types and their complexes.

Vegetation map of the most often occurring units of vegetation was accomplished through using high-resolution satellite imagery feature extraction techniques. Forests, semi-deserts, and meadows in this study represent polydominant communities often occurring as a “mosaic” of different vegetation types. These are complexes, rather than pure stands of a single forest type, were the units of our imagery classification. The following was accomplished in this study.

Macrofungi species inventory data base was created on the basis of field collections. Correlation between the specific fungi and the tree species (mycorrhizal relationships) was not significant due to the small sample size compared to biodiversity of fungi species. Species descriptions and photographs are part of the database linked to the habitat classification. Further statistical analysis requires more data sampling and will make it possible to provide correlation among the variables to establish suitability indices for fungi and forest species occurrences.

Ecological characteristics of species' habitats were described using relative abundance measurements of dominant species and supported by co-occurring clusters of ecological groups of species. A differentiating geobotanical classification table was compiled to illustrate the dominant and co-dominant assembly of the classification categories outlining the uniqueness of each community type. There are three distinctive groups of conifer forests with different dominant species of junipers and spruce, and also tree groups of grasslands and sagebrush desert ecosystems. Fourteen habitat types in the territory of the Ala-Archa National Park and the foothills where the survey was conducted were outlined.

An assessment of vegetation cover types was made with the satellite image processing. The geobiophysical modeling of the environmental parameters with statistical analysis and clustering techniques provided correlation between spectral signature and types of vegetation. Diversity and complexity of the studied mountain forests, where several species of trees are dominant or co-dominant, made the task of finding simple correlation difficult.

As a result, the major complexes of this polydominant vegetation that could be detected remotely for the study site were defined: mixed conifer and deciduous forests, dwarf juniper forests, cushion plants shrublands, alpine grasslands, steppes, sagebrush semi-deserts, and complexes of grasslands and conifers. Among the conifer forests, relatively pure stands of spruce and dwarf juniper were distinguished, while others represented mixed conifer and deciduous forests. The use of infrared and thermal bands of the Terra ASTER imagery allowed detection of areas with conifer forests and exclusion of the areas without vegetation, presented by different geological materials.

Producing three-dimensional classifications and displays (3D) using Shuttle Radar Topography Mission data (SRTM90) assisted in visualization of vertical distribution of vegetation types. Topographic contours derived from geological map were not always corresponding to elevation contours obtained with SRTM at the lower elevations, which may be explained by its low resolution of 90 meters.

Due to the lack of the detailed ground studies, the obtained results are considered to be a preliminary study demonstrating capabilities of the software and imagery analysis. Statistical analysis of the imagery showed the reflectance values associated with different land cover types: different types of vegetation, water, ice, bare rock, road, and urban features. Several image enhancement methods to emphasize the features were applied and proved to be useful for features' detection: contrast stretch, Fourier transform, band rationing, and filtering.

Unsupervised imagery classification resulted in producing the map contours that were then subjected to supervised classification which generalized the features, but failed to provide differences in details. Adding more sampling points in targeted areas will produce better identification of the features such as different types of juniper forests.

A digital elevation model will allow future modeling as more ground data will be collected. The future model of environmental parameters with spatial analysis and statistical analysis will provide correlation among the variables and could be used to establish indices of correlation. Further spatial analysis (slope, aspect) and 3D modeling requires more sampling points and could support the findings of correlation between vegetation types and their position in vertical profile in future studies. Slope-aspect correction method is needed to improve forest classification and to correct for the topographic effect, sun-facing slopes.

Limitations of the outcomes of study are attributed to the small sampling volume and could be considered as a pilot methodological study. An ability to synthesize all available data was constrained by the lack of large scale vegetation map of the area. More data is required for conducting statistical analysis of the correlations between species and between vegetation and geographic features such as elevations, slope and aspect. Further statistical analysis with a larger dataset will allow correlating clusters of fungi with different types of habitats outlined on a digital map: conifer forest, dwarf juniper forest, savanna, and sagebrush semi-desert.

The project demonstrated how the use of satellite imagery processing and analysis supports a regional biodiversity study of such economically important group as fungi as well as economically important forests of the region in a developing country that heavily depends on forestry and tourism. The study is beneficial for forestry applications and regional biodiversity studies of fungi, which play a key role in the health of the fragile mountain forest ecosystems. This investigation contributes to successful conservation of the forests and regional ecological monitoring. This model is valuable for park management and future tourism planning.

Accomplishing a task of detecting features useful for biodiversity conservation with satellite imagery and compiling digitally linked geodatabase of mushrooms (macromycete fungi) species was made possible by close cooperation with the scientists from Kyrgyz Republic Academy of Sciences who conducted the field survey in Ala Archa National Park. Our study demonstrated how the biodiversity species database could be linked to a digital map and could aid in much needed international information exchange on conservation issues and contributing to the novel approach to the natural resources conservation in the Kyrgyz Republic. The results of the study were presented at the annual conference of the American Association of Geographers, at SigmaXi conferences (Marshall University), at VWView Appalachian Remote Sensing Conference, and at ESRI Conservation GIS Conference.

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Attachment I. Climate of Ala Archa National Park

Verkhnyaya Ala Archa, Kyrgyzstan
Elevation: 2,717 feet Latitude: 42°49' N Longitude: 74°34'E

Average Temperature Years on Record: 94

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	50	26	28	39	51	62	69	75	71	62	50	35	28

Average High Temperature Years on Record: 53

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	60	35	37	48	62	73	80	87	84	75	62	46	37

Average Low Temperature Years on Record: 53

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	39	17	19	32	42	50	57	62	59	50	39	28	21

Average Precipitation Years on Record: 25

	YEAR	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
in	16.9	1	1.2	1.8	3	2.5	1.4	0.6	0.4	0.6	1.5	1.5	1.2

Source: http://www.weatherbase.com

Attachment II. List of Macrofungi Species Collected in Ala-Archa National Park

1. *Agaricus arvensis* Schaeff. ex Fr.
2. *Agaricus campestris* Fr.
3. *Agaricus silvaticus* Schaeff.
4. *Albatrellus ovinus* (Schaeff. ex Fr.) Murr.
5. *Bovista vassiagiana* Philimon. et Schwarzm.
6. *Clitocybe dealbata* (Fr.) Kumm.
7. *Coprinus micaceus* (Fr.) Fr.
8. *Cortinarius violaceus* (Fr.) Fr.
9. *Geastrum coronatum* Pers.
10. *Hygrocybe conica* (Fr.) Karst.
11. *Lactarius deliciosus* (Fr.) S.F.Gray
12. *Leccinum scabrum* (Bull. ex Fr.) Gray
13. *Lepista nuda* (Fr.) Cke.
14. *Lepista saeva* (Fr.) Orton
15. *Lycoperdon perlatum* Pers.
16. *Lycoperdon puriforme* Schaeff.ex Pers.
17. *Macrolepiota excoriata* (Fr.) Mos.
18. *Morchella conica* Fr.
19. *Morchella esculenta* St. Am.
20. *Paxillus atrotomentosus* (Fr.) Fr.
21. *Pholiota squarrosa* (Fr.) Kumm.
22. *Russula heterophylla* (Fr.) Fr.
23. *Russula vesca* (Fr.) Fr.
24. *Sarcodon imbricatus* (Fr.) Karst.
25. *Stropharia semiglobata* (Fr.) Quel.
26. *Suillus granulatus* (L.ex Fr.) O.Kunze
27. *Suillus luteus* (Fr.) S.E. Gray
28. *Albatrellus ovinus* (Schaeff. ex Fr.) Murr.

29. *Clitocybe dealbata* (Fr.) Kumm.

30. *Coprinus micaceus* (Fr.) Fr.

31. *Cortinarius violaceus* (Fr.) Fr.

32. *Geastrum coronatum* Pers.

33. *Hygrocybe conica* (Fr.)Karst.

34. *Lactarius deliciosus* (Fr.) S.F.Gray

35. *Leccinum scabrum* (Bull. ex Fr.) Gray

36. *Lepista nuda* (Fr.) Cke.

37. *Lepista saeva* (Fr.) Orton

38. *Lycoperdon perlatum* Pers.

39. *Lycoperdon puriforme* Schaeff.ex Pers.

40. *Macrolepiota excoriata* (Fr.) Mos.

41. *Morchella conica* Fr.

42. *Morchella esculenta* St. Am.

43. *Paxillus atrotomentosus* (Fr.) Fr.

44. *Pholiota squarrosa* (Fr.) Kumm.

45. *Russula heterophylla* (Fr.) Fr.

46. *Russula vesca* (Fr.) Fr.

47. *Sarcodon imbricatus* (Fr.) Karst.

48. *Stropharia semiglobata* (Fr.) Quel.

49. *Suillus granulatus* (L.ex Fr.) O.Kunze

50. *Suillus luteus* (Fr.) S.E. Gray

Attachment III. Taxonomic Descriptions of Macrofungi Found in Ala-Archa National Park (translated from Russian by Galina N. Fet)

1. Agaricus arvensis Schff. ex Fr. – Horse Mushroom

Cap: 6-8 cm broad, in young age semicircular, later convex with a small protuberance, cream-white, dry, smooth, silky with remainders of veil, later becomes yellowish at the edge. Gills: free, thin, dense, in young age white, later pink, at maturity dark-brown. Stipe: 4-5.5 cm tall, 1-1.5 cm thick, equal, at the base sometimes enlarged with flaky thin coating, hollow, same color as cap, at touch turns yellow. Annulus near the top, wide, white, with age turns yellow, from below with flaky thin coating. Flesh: white, thick. Spores: 7-8.5 x 5.5-6 µm, ovoid, with 1-2 oil drops, smooth, dark brown. Edibility: edible. Sweetish taste, pleasant odor.

2. Agaricus campestris Fr. – Meadow Mushroom, Champignon

Cap: 5.5-13.5 cm broad, in young age nearly spherical, then almost flat with the margin incurved, later white outstretched, when drying pale with feeble fibrous scales, silky, dry. Gills: broad, thin, dense, in young age white, later pink and at maturity almost black. Stipe: 4-9 cm tall, 1.2-3 cm thick, cylindrical, at the base broadened, white, fibrous, solid. Annulus membranous, thin, wide, receding at the mid-stem, white. Flesh: thick, white, dense. Spores: 6-7.5 x 4-5.5 µm, elliptical, smooth, dark brown. Edibility: edible. Pleasant taste and odor.

3. Albatrellus ovinus (Schaeff. ex Fr.) Murr. – Sheep's Head Polypore

Fruit body consists of a cap and a stump. Cap: round 5-10 cm broad, up to 1-2 cm thick, later flat, fleshy, elastic; fragile when dried. Surface white, grayish-yellow, slightly scaly. Edge laciniate, in young age incurved, then straight. Flesh: meaty, thick, lemon-yellow. Stump: central, short, at the base narrow and slightly bent, naked or with patina. Tubes: descending far down the stump, white with lemon-yellow patina. Pores: roundish with thin fringed edges, sometimes torn. Spores: spherical 3-4 x 3-3,5 µm, widened at base, smooth, whith one vacuolized drop. Edibility: edible. Pleasant taste and odor but tough.

4. Bovista vassjagiana Philimon.et Schwarzm. – Vasyagina's Puffball

Fruit body spherical or almost spherical, 2-3.5 cm cm broad, covered by peridium, sterile base absent. Peridium double-layered. Ectoperidium thin, white, falling off. Endoperidium thin, thick, pale-grayish, lustrous, opens with a hole on the top of fruit body, edge incurved. Flesh: light brown, soft, loose. Spores: 7-8.5 x 3.5-4.5 μm ellipsoidal, brownish, warty, with straight or curved remnant of sterigma, 7.5-10.5 x 1.0 μm. Capellicium strongly branched, colorless, without partitions and pores, side branches dichotomic.

5. Clitocybe candicans (Pers. ex Fr.) Kumm.

Cap: 1-3 cm broad, in young age convex, then impressed in the center, white, smooth with fluffy, light, silky thin coating. Gills: adnexed, notched, at maturity descending, thin, narrow, dense, white. Stipe: 1.5-3 tall, 0.2-0.3 cm, straight, slightly thickened, solid, later hollow, smooth, lustrous, white. Flesh: thin, whitish. Spores: 4.2-5.0 x 2.0-2.5 μm, elliptical, slightly rough, colorless. Edibility: poisonous. Taste sweetish, odorless.

6. Clitocybe dealbata (Sow. ex Fr.) Kumm. – Sweat Mushroom

Cap: 1.5-2 (up to 5) cm broad, cream-colored, almost white. Flat, impressed in center, dry, matte, wavy at the edge. Flesh: thin, whitish, thick. Gills: weakly descending, dense, in young age white then brownish-pink. Stipe: 2-3 cm tall, 0.5-0.7 cm thick, tapering toward the base. Spores: 4.5-5.0 x 2.5-3.5 μm, elliptical, yellowish. Edibility: poisonous. Odor weak, chalk-like.

7. Coprinus comatus (Fr.) S. F. Gray – Shaggy Inkcap

Cap: 2-7 cm broad, in young age narrow bell-shaped, ovoid, white, with densely scaled surface, white. Flesh: white, thin, rapidly darkening, slowly dissolves away from the margin upward so as to release the spore (autolysis). Gills: free, broad, white, pink at the edge, later become brown and black, in maturity disintegrate into ink-like drops.

Stipe: 6-15 cm tall, 1.5-3 cm thick, cylindrical, slightly enlarged toward the base, hollow, white, silky. Annulus mobile, disappearing. Spores: 7-11.5 x 5-7 μm, elliptical, sides unequal, black, thick-skinned. Edibility: edible when young.

8. Coprinus micaceus (Fr.) Fr. – Common Inkcap

Cap: 2.5-5.5 cm broad, bell-shaped, later flat, yellow-brown or light ochre, in the center more intensely colored, covered with lustrous whitish, rapidly disappearing flakes, when drying glimmering. Flesh: white. Gills: weakly adnexed, dense, later darkening with white edge. Stipe: 6-9 cm tall, 0.3-0.5 cm thick, equal, silky, lustrous, white with flakes. Spores: 7.5-10 x 4.5-5.5 μm, elliptical, grain-like, smooth, dark brown. Edibility: edible when young.

9. Cortinarius violaceus (Fr.) Fr. – Webcap

Cap: 4-10 cm broad, pillow-shaped, dark purple, matte, scaly, dry. Flesh thick, soft. Gills: adnexed, descending, notched, broad, sparse, dark purple. Stipe: 5-9 cm tall, 1-1.5 cm thick, club-shaped, tuberlike thickened at the base, dark purple, with fibrous scales. Young specimens often have weblike veil. Spores 9-13 x 5.5-7 μm, elliptical, verrucose, have unequal sides. Edibility: edible.

10. Lactarius deliciosus (Fr.) S. F. Gray – Saffron Milk Cap

Cap: 3.5-9.5 cm broad, first convex round, later wide funnel-shaped, orange, first with weakly incurved and later with a straight edge with dark orange concentric zones, wet, slightly sticky. Gills: adnexed or descending, dense, narrow, orange yellow, at the touch becoming greenish. Stipe: 1.5-5 cm tall, 0.7-1.3 cm thick, cylindric, smooth, hollow. Flesh: thick, white, under the cap’s cuticle orange, turning green when exposed to air. Latex orange yellow, turning green when exposed to air. Spores 7.0-11.3 x 5.5-8.5 μm, nearly spherical, spiny, colorless, as a mass yellowish. Edibility: edible. Taste sweetish, weakly sharp.

11. Leccinum scabrum (Bull. ex Fr.) Gray – Birch Bolete

Cap: 3.5-7.5 cm broad, first spherical, later pillow-shaped, smooth or very weakly creased, dry, oily at wet weather, very variable in color from whitish to grey and dark brown. Tubes narrow, open through uncovered small pores. Stipe: 8-12 cm tall, 2.5 cm thick, cylindrical, hollow, thick, white, with dark brown scales. Flesh: white, thick, with time becomes soft. Spores: 13-17 x 4-6.5 µm, spindle-shaped, with sharp tips, pale yellow. Edibility: edible. Pleasant taste and odor.

12. *Lepista nuda* (Fr.) Cke.

Cap: 3.5-11 cm broad, convex with incurved edge, later flat, blue-purple, fading, smooth, wet. Gills: adnexed, notched, broad, dense, violet. Stipe: 3-9 cm tall, 0.8-2.5 cm thick, equal, thick, at the base broadened, at the gills with flaky patina, first purple, then fading. Flesh: thick, soft, pale purple. Spores: 5.0-7.5 x 3.0-4.0 µm, elliptical, weakly roughened. Edibility: edible. Taste and odor as in a raddish.

13. Lepista saeva (Fr.) Orton – Field Blewit.

Cap: 5-7 cm broad, cushionlike, light brown with the edge folded inwards, smooth, shiny, cuticle not separated from flesh. Flesh: thick, meaty, light brown. Gills: adnexed, broad, same color as cap. Stipe: 3-4 cm tall, 1-1.5 cm thick, light purple, cylindrical, widened downwards. Cap not separated from stem. Spores: 4-6 x 3-3.5 µm, elliptical, rarely almost round, colorless. Edibility: edible. Sweet, nice taste.

14. Lycoperdon perlatum Pers. – Puffball

Fruit body globular, clublike, tapering downward, up to 8 cm high, 2-4 cm broad. Peridium (cover) first white, with detachable falling spines, later darkens up to dark brown. Flesh: white, fine, soft, at maturity becomes first yellow, later dark olive spore mass, which is coming out through a hole at the top. Mature spore mass is dispersed through the hole. Spore dust olive brown. Edibility: edible when young.

15. Lycoperdon pyriforme Schaeff.ex Pers. – Wolf-fart Puffball

Fruit body pyriform; up to 7 cm high, 3-4 cm in diameter. Peridium in young age white, with dense small warts. With maturity, changes color to brown. Flesh: in young age stays white and hard for a long time, then acquires yellow-brown color. At maturity, the mushroom spreads the brown dust of spores from a hole in the middle of its head. Spores 3-4.5 µm, globose, verrucose, olive brown. Edibility: edible when young.

16. Morchella conica Fr. – Morel

Cap: 2-4 cm broad, dark-brown, elongated-conical, hollow, at the edge attached to the stipe. Surface with ridges and elongated cells. Flesh: white, fragile. Stipe: 4-5 cm tall, 2-2.5 cm thick, enlarged toward the base, cylindrical, with grooves, with powdery surface, cream colored. Basidia cylindrical, with eight spores, with paraphyses. Spores: 18-22 x 12-15 µm, single-celled, colorless, positioned in a single row. Edibility: edible. Tasteless, odorless.

17. Morchella esculenta St. Am. – Yellow Morel

Cap: 3-4 cm broad, egg-shaped, at the edge attached to the stipe, grey-brown, with ridges and rounded cells. Flesh: thin, very fragile, light brown. Stipe: 5-6 cm tall, 2-2.5 cm thick, cylindrical, hollow, brownish or yellowish, with grooves. Basidia cylindrical, with eight spores, with paraphyses. Spores: 21-25 x 10-12 µm, elliptical, single-celled, smooth, colorless, as a mass yellowish. Edibility: edible. Tasteless and odorless. Sometimes considered conditionally edible.

18. Mycenastrum corium (Guers.) Desv. – Tough Puffball

Fruit body: spherical, 5-15 cm in diameter, sessile, with mycelial threads at the base. Exoperidium first white, later grey-white, matte or lustrous, smooth or cracking into small scaly strips, later falling off. Endoperidium thick, first fleshy, springy, white, later leathery, cracking into irregular fragments, later falling off. Flesh: first consists of chambers, then becomes porous, later falls apart forming dark brown powder. Spores: 7.5-9 µm, spherical, thinly verrucose, light brown. Capellitium arched, with simple spiny processes.

19. Russula heterophylla (Fr.) Fr.

Cap: 3-4 cm broad, at young age greenish, flat, dry with incurved edge; at maturity wide funnel-shaped, impressed in the center. Flesh: thick, fleshy, white, cuticle not easily detachable. Gills: adnexed, weakly descending, broad, simple. Same color as stipe, at young age white, later become brown. Stipe: 2-4 cm tall, 0.5-1.0 cm thick, cylindrical, thick, enlarged at the top, brown at the base. Spores: 5.5-7.5 x 7-8 µm, nearly spherical, verrucose. Spore dust white. Edibility: edible. Taste unclear, weak mushroomy odor.

20. Russula vesca Fr. – Bare-toothed Russula

Cap: 5-10 cm broad, convex, later concave with wavy edge, pink, dry, matte, fleshy. Flesh white, cuticle easily detachable. Gills: adnexed, simple, cream colored. Stipe: thick, equal, cylindrical, white, when broken does not change color. Spores: 9-10 x 7-8 µm, elliptical, verrucose, colorless. Spore dust white. Edibility: edible. Taste sweetish, with weak mushroomy odor.

21. Sarcodon imbricatus (Fr.) Karst.

Cap: 5-15 cm broad, 0.5-2.5cm thick, irregular in shape, slightly depressed in the center. Surface light brown, later darkening with large sharp-edged scales, positioned in a tile-fashion. Margin at first inrolled, later becoming decurved. Spines conical, sharp-edged, 2-7 mm long, 0.3-0.5 mm wide light brown, descending down the stipe. Stipe: 3.5-8 cm tall, 1-2.5 cm thick, enlarged at the base, smooth, solid, same color as cap. Flesh: slightly yellowish, thick, with bitter taste. Spores: 5.5-7 x 5-6 µm, spherical, verrucose, brown.

22. Suillus granulatus (L. ex Fr.) O.Kunze – Sticky Bun Bolete

Cap: 7-9.5 cm broad, yellow brown, first pillow-shaped, then more flat, slippery with mucus, later drying. Flesh: light yellow, water absorbing. Hymenophore descending, light yellow. Tubes yellow to ochre yellow, open through small rounded pores. Stipe: 3.5-2 cm tall, thick, cylindrical, equal, whitish at the top, with dark warts, without a ring. Spores: 7.5-9 x 2.5-3 µm, ovoid, with unequal sides, yellow, smooth. Edibility: edible. Pleasant taste and odor.

23. Suillus luteus (Fr.) S.F. Gray – Slippery Jack

Cap: 4-9 cm broad, first semispherical, then round convex with a small protuberance. Covered with a layer of brown mucus, later dry, lustrous, yellow-brown skin is easily detachable. Tubes lemon yellow, attached. Pores same color, narrow. Flesh: thick, dense, lemon colored. Stipe: 2-3 cm tall, 1.5 cm thick, short, cylindrical, enlarged toward the base, with remnants of filmy veil. The veil leaves a leathery brown annulus. Stipe above the annulus with light brown scales. Spore dust lemon yellow. Edibility: edible. Pleasant lemon taste.

Attachment IV. Correlation Table for Macrofungi and Tree Species

Species	*Betula*	*J. semi.*	*J. turk.*	*meadow*	*Picea*	*Salix*	*Sorbus*	Total
Agaricus arvensis	0.49	0.66	0.53	0.04	0.82	0.22	0.24	3
Agaricus campestris	1.62	2.21	1.76	0.15	2.72	0.74	0.81	10
Agaricus silvaticus	0.97	1.32	1.06	0.09	1.63	0.44	0.49	6
Albatrellus ovinus	0.97	1.32	1.06	0.09	1.63	0.44	0.49	6
Bovista vassiagiana	1.13	1.54	1.24	0.10	1.90	0.51	0.57	7
Clitocybe dealbata	1.46	1.99	1.59	0.13	2.45	0.66	0.73	9
Coprinus comatus	0.49	0.66	0.53	0.04	0.82	0.22	0.24	3
Coprinus micaceus	0.49	0.66	0.53	0.04	0.82	0.22	0.24	3
Cortinarius violaceus	1.46	1.99	1.59	0.13	2.45	0.66	0.73	9
Geastrum coronatum	0.16	0.22	0.18	0.01	0.27	0.07	0.08	1
Hygrocybe conica	0.97	1.32	1.06	0.09	1.63	0.44	0.49	6
Lactarius deliciosus	1.13	1.54	1.24	0.10	1.90	0.51	0.57	7
Leccinium scabrum	0.65	0.88	0.71	0.06	1.09	0.29	0.32	4
Leccinum scabrum	0.97	1.32	1.06	0.09	1.63	0.44	0.49	6
Lepista nuda	0.49	0.66	0.53	0.04	0.82	0.22	0.24	3
Lepista saeva	0.65	0.88	0.71	0.06	1.09	0.29	0.32	4
Lycoperdon perlatum	0.97	1.32	1.06	0.09	1.63	0.44	0.49	6
Lycoperdon pyriforme	0.49	0.66	0.53	0.04	0.82	0.22	0.24	3
Macrolepiota excoriata	0.16	0.22	0.18	0.01	0.27	0.07	0.08	1
Morchella conica	0.32	0.44	0.35	0.03	0.54	0.15	0.16	2
Morchella esculenta	0.32	0.44	0.35	0.03	0.54	0.15	0.16	2
Paxillus atrotomentosus	0.32	0.44	0.35	0.03	0.54	0.15	0.16	2
Pholiota squarrosa	0.32	0.44	0.35	0.03	0.54	0.15	0.16	2
Russula heterophylla	1.46	1.99	1.59	0.13	2.45	0.66	0.73	9
Russula vesca	2.26	3.09	2.47	0.21	3.81	1.03	1.13	14
Sarcodon imbricatus	0.49	0.66	0.53	0.04	0.82	0.22	0.24	3
Stropharia semiglobosa	0.32	0.44	0.35	0.03	0.54	0.15	0.16	2
Suillus granulatus	0.32	0.44	0.35	0.03	0.54	0.15	0.16	2
Suillus luteus	0.16	0.22	0.18	0.01	0.27	0.07	0.08	1
Total	22	30	24	2	37	10	11	136

Attachment V. Satellite Imagery, Maps and Software

Satellite Imagery:

AST_L1A_00303282004060325_20070425163320_6790
AST_L1B_00306272002060456_07132002135 158
SRTM_u03_n042e074
Projection: WGS_1984_UTM_Zone_43N

Maps:

Ala Archa Natural Park, Kyrgyz Mountain Range. Topographic Map 1 : 50,000. Goskartographia: Bishkek (Kyrgyz republic), 1999.

Plan of Ala Archa Camp 1 : 5,000

Digital Geological Maps of Kyrgyzstan (Burg et al., 2004). SNSF Project No7KSPJ065518.

Software:

MS Office 2000 Server
MS Windows Server 2002 operating system
MS Access 2003
MS Excel 5.0
ER Mapper 6.4
ArcGIS/ArcInfo 9.1 with Spatial Analyst and 3D Analyst

CURRICULUM VITAE

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Specialization and Summary of Professional Experience

Biodiversity conservation and environmental multidisciplinary studies: biotic, geotechnical, regulatory. Environmental assessments and surveys in USA, Russia, and Central Asia.

Major Accomplishments as Biologist and Long-term Projects

- 2001–2006, Environmental Scientist and Graduate Researcher. Conducted environmental and biodiversity assessments and report writing for applied Geographic Information Systems, wetlands studies and delineations for geotechnical and transportation companies, WV.
- 2004, Auditor/Evaluator of the UNDP/GEF Project in four Protected Areas and National Parks of Kamchatka, Far East, Russia. Interviewed stakeholders, NGOs, administration, local communities. Reviewed country's conservation laws and environmental regulations, NY.
- 2001, Biodiversity Reviewer/Writer, provided five regional biodiversity descriptions for World Ecoregions Mapping Project, World Wildlife Fund, Washington, DC.
- 2000, Biodiversity Specialist, conducted extensive field surveys and interviews, wrote five reports, reviewed bilingual documents on aspects of environmental protection, legal issues, land use, conducted assessment of NGO, scientific communities, National Parks in five Central Asian countries: Kazakhstan, Uzbekistan, Kyrgyz Republic, Turkmenistan, Tajikistan. USAID funded contract, Chemonics International, Washington, DC.
- 1997, Translator, GLOBE/NASA Educational Project for high schools, chapters on Biology, Soils and Remote Sensing, Arlington, VA.
- 1992–1996, Scientific co-editor of English translation of *Flora of the USSR*, Volumes 22-30, published by Smithsonian Institution, Washington, DC.
- 1992—1993, Teacher, Tulane and Loyola Universities: Ecology, Environmental Science.
- 1990–1993, Environmental Specialist, conducted environmental sampling and descriptions of vegetation, soils, and fungi for 30 rocket test site monitoring plots, Lockheed Co. and Sverdrup Intl., NASA Stennis Space Center, MS.
- 1978–1987, Plant Ecologist, accomplished large-scale map of plant communities of Synt-Khossardagh National Park, Turkmenistan, Central Asia (12,000 sq. miles, 1: 100 000).

Professional Societies Memberships:

American Association of Geographers; Society for Conservation GIS; Native Plants Society.

Relevant Recent Presentations:

Fet, G. N. 2006. ASTER image processing for forestry and biodiversity applications in Tien Shan Mountains. *NASA Land Cover Land Use Change Program*, College Park, MD.

Fet, G. N. 2006. Image processing for conifer forest detection in Tien-Shan Mountains. *WVView Forum and Workshops, Morgantown, WV.*

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Fet, G.N., Brumfield, J.O., Prikhodko, S.L. & Umralina, A.R. 2004. Fungi biodiversity geodatabase of the National Park in Central Asia. *Presented at the 7th Annual Meeting of Society for Conservation GIS, National Conservation Training Center, Shepherdstown, WV.*

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Balice, R. G., **Fet, G. N.** & King, C. W. 1993. *Species checklist of the monitoring plots of the Space Center, Mississippi.* Lockheed/ASRM Environmental Program documents.

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Shetler, S. G. & **G. N. Fet** (eds.). 1998. *Flora of the USSR*. Vol. XXVII, Tribes Echinopsideae and Cynareae. Smithsonian Institution Libraries, Washington, DC. xxxiv + 741 pp. [English translation from Russian of *Flora SSSR. XXVII.* (1962).]

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