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Rule-Based Land Cover Classification and Erosion Risk Assessment of the Krkonoše National Park, Czech Republic

Annika H Hyltén
&
Eva Uggla

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Department of Physical
Geography,
Lund University
Sölvegatan 13, S-221 00
Lund, Sweden

ABSTRACT

The Krkonoše National Park is located in the Sudetes mountain range at the Czech - Polish border. It is characterized by large variations in altitude and a mosaic vegetation pattern. The complex landscape raises the issues of appropriate classification techniques and scales. The first aim of this study is to produce a land cover map using 21 classes based on a rule-based classification system and to evaluate classifications based on this method and a maximum likelihood algorithm based on Landsat 7 ETM+ data. Ancillary data and prior probabilities are used in the rule-based system.

The rule-based classification (21 classes) yields an overall accuracy of 61.5%. A higher accuracy is reached if 11 land cover classes are used (overall accuracy: 74.9%). This indicates that the result of the accuracy assessment of the land cover map with 21 classes is strongly influenced by the rather low accuracy of the more infrequent and complex classes. Considering the differences in altitude, the mosaic vegetation and the large number of classes the result of the rule-based classification system is satisfactory, especially when the number of classes is reduced. This study shows that a rule-based classification system using ancillary data and prior probabilities clearly enhances a maximum likelihood classification based solely on spectral data. An interpretation of satellite data based exclusively on spectral information does not produce a satisfactory result for this region. To achieve an improved classification the use of ancillary data and prior probabilities in a rule-based classification system seem to offer a promising solution.

The second aim of this study is to assess the erosion risk in the National Park. Heavy air pollution has been deposited in this region during the last decades causing soil acidification, decreased biodiversity, deforestation and soil erosion. The erosion risk varies within the park and it is therefore essential to make an assessment of which areas are in danger of becoming eroded to prevent actual erosion. Two classes are used in the erosion risk assessment; erosion versus no erosion risk areas. It is based on statistical analyses of field data, consisting of GPS points including information on land cover and the presence of erosion /no- erosion, digital data on soil type, topographical form, slope gradient, aspect and altitude, and on literature studies. Accuracy assessments yield an overall accuracy of 86.4%. This indicates that assessments of this type can be made with satisfactory results.

Keywords: *GIS, Remote sensing, Rule-based systems, Land cover classifications, Prior probabilities, Erosion risk modelling*

SAMMANFATTNING

Krkonoše national park är beläget i Sudeterna vid gränsen mellan Tjeckien och Polen. Parken karakteriseras av stora variationer i altitud och ett mosaikliknande vegetationsmönster. Det komplexa landskapet medför svårigheter vid val av klassificeringsteknik och skala för produktion av tillförlitliga markanvändningskarteringar. Denna studie syftar i första hand till att producera en markanvändningskarta med 21 klasser baserat på ett regelbaserat klassificeringssystem samt att utvärdera klassificeringar baserade på denna metod och på en s.k. ”maximum likelihood” algoritm baserad på Landsat 7 ETM+ data. Komplement data och sannolikheter baserat på tidigare producerat material används i det regelbaserade systemet.

Den regelbaserade klassificeringen (21 klasser) uppnår en noggrannhet på 61,5 %. Högre noggrannhet uppnås om 11 markanvändningsklasser används (74,9 %). Detta indikerar att resultatet av noggrannhetsutvärderingen för markanvändningskartan med 21 klasser är starkt påverkad av den relativt låga noggrannheten hos de mindre och mer komplexa klasserna. Med hänsyn till skillnaderna i altitud, det mosaikliknande vegetationsmönstret samt det stora antalet klasser är resultatet av det regelbaserade klassificeringssystemet tillfredställande, speciellt om antalet klasser reduceras. Denna studie visar att ett regelbaserat system med komplement data otvivelaktigt förbättrar en ”maximum likelihood” klassificering baserad enbart på spektral data samt att ”maximum likelihood” klassificeringen ej är tillräcklig för detta område. För att uppnå en bättre klassificering framstår regelbaserade system med komplement data som en lovande metod för områden av detta slag.

Det andra syftet med studien är att uppskatta risken för erosion i national parken. Under de senaste decennierna har höga halter av luftföroreningar deponerats i denna region. Detta har medfört markförsurning, minskad biodiversitet, omfattande avverkning och jorderosion. Risken för erosion varierar inom parken, därav är det viktigt att uppskatta vilka områden som är i farozonen för att bli eroderade. Detta för att motverka reell erosion. Två klasser används i erosions riskuppskattningen; erosions- kontra icke erosions riskområden. Modellen baseras på statistiska analyser av fältdata, bestående av GPS punkter med information om markanvändning och förekomst av erosion, digital data över jordart, topografisk form, sluttningsgradient, sluttningsriktning och altitud, samt litteraturstudier. Noggrannhetsutvärderingen gav en noggrannhet på 86,4 %. Detta indikerar att uppskattningar av denna typ kan utföras med tillfredställande resultat.

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1 INTRODUCTION

The Krkonoše National Park is located at the border of the Czech Republic and Poland in the Krkonoše Mts. The Czech side of the park was established in 1963 and the Polish side, in 1959 (Stursa & Marková, 1999). The entire protected area on both sides of the Czech-Polish border was proclaimed a bilateral biosphere reserve of UNESCO in 1992, due to its unique biodiversity (Internet 3). The local administrations have since 1997 co-operated in the development and protection of the natural and cultural aspects of the park (Stursa & Marková, 1999).

The National Park is situated inside the "Black Triangle" where heavy air pollution from predominately Poland, Germany and the Czech Republic has been deposited during the last decades. The air pollution causes an increased stress situation for the ecosystems in the park and according to Schwartz (1998), 80 km^2 of forest have died off up to the present time and an additional 70 km^2 are endangered. Soil acidification, decreased biodiversity and deforestation are effects of the pollution load. This was the reason the World Conservation Union (IUCN) placed the Krkonoše National Park on the list of the most endangered protected areas of the world (Schwarts, 1998).

The air pollution in the region has also caused an increase in localities affected, or endangered, by erosion. The damage caused by the pollution and its accompanying phenomena leads to clear cutting of forests. This course of action leaves areas without a protective vegetation cover and might lead to irreversible loss of soil and development of non-reafforestable debris fields. In the Czech part of the Krkonoše Mts., 14% of the forest soil is endangered by erosion at present (Schwarts, 1998). It is therefore important to preserve a sufficient vegetation cover in these localities to protect the soil. The erosion risk varies within the park and it is therefore essential to make an assessment of which areas are in danger of becoming eroded to prevent actual erosion.

The landscape in the National Park is mountainous with a mosaic vegetation pattern. Land cover classifications of this region based on remote sensing techniques are naturally affected by these characteristics. Opportunities to incorporate ancillary data when classifying satellite data or to improve existing classification schemes exist today. Rule-based methods provide the possibility to integrate multisource data, prior probabilities and knowledge into a land cover classification. Classifications of complex landscapes, as the one in the Krkonoše National Park, raise the issues of appropriate techniques and scales. Can a satisfactory result be achieved using one data source or is it necessary and desirable to include multisource data in a rule-based classification system?

1.1 Aim

The main objective of this study is to produce a land cover map and to make an erosion risk assessment of the Krkonoše National Park. The following points specifies the aim and the intermediate goals:

I. To produce a land cover map of the National Park based on a rule-based classification system using ancillary data and prior probabilities, and to analyse the usefulness of a rule-based classification system compared to a maximum likelihood classification based solely on spectral characteristics.

II. To estimate the erosion risk, caused by running water, in the National Park at present based on statistical analyses of field data, digital data and on literature studies.

The land cover classification was made on assignment of and in co-operation with the Czech administration of the National Park. The assignment included classification of both sides of the National Park but with a focus on the Czech side of the park.

1.2 The study area

1.2.1 Location and topography

The National Park is located in the Krkonoše Mts. covering an area of approximately 600 km^2. These mountains are part of the Sudetes located at the border between Poland and the Czech Republic (figure 1). It is one of the highest mountain ranges in Central Europe north of the Alps, with the highest peak Snezka, 1 602 m a.s.l.

Figure 1. Overview of the Krkonoše National Park located at the border of the Czech Republic and Poland. The map is based on digital layers attained from the Administration of the National Park.

The Krkonoše Mts. stretch from northwest to southeast for almost 30 km. In the higher parts, two ridges are distinct. The highest ridge is located along the Czech-Polish border and the smaller ridge is located in Czech part of the park. Between the ridges valleys are abundant and there are also two high level plains located at Labská bouda and Lucní bouda. The Czech Krkonoše Mts. cover about 90% of the whole National Park and exhibit more extensive, broken and milder slopes than those in the northern Polish side, which are steep and short. In the park the elevation ranges from 400 to 1602 m a.s.l. (Stursa et al, 1996).

1.2.2 Climate

The climate is strongly influenced by the mountainous terrain and the predominating westerly humid oceanic winds. The annual precipitation varies with altitude and aspect from above 800 mm at the foothills to 1200-1600 mm on the ridges (Stursa et al, 1996). During the winter precipitation falls as snow and covers the ground from mid October till mid May with an average depth of 100-300 cm. The average annual temperature in the Krkonoše Mts. decreases with altitude from +6°C to 0°C (Stursa et al, 1996).

1.2.2.1 Anemo-orographic system

The prevailing western to southwestern winds in the Krkonoše Mts. combined with the long west-to-east stretched valleys support the occurrence of the so called anemo-orographic system. In the mountains, the valleys gather and streamline air currents from foothills up to the accelerating summit plateau, thus creating a “nozzle” between the two parallel ridges; to the east, southeast or northeast of each of these plateaus several leeward vortex cirques occur (figure 2) (Soukupová et al., 1997).

The anemo-orographic system affects rain, snowfall and the formation of avalanches which predominately occur on the leeward side of the ridges. The wind transports plant seeds, small animals and particles of soil that are deposited on the leeward side and thereby influence the composition, distribution and development of ecosystems (Stursa et al, 1996).

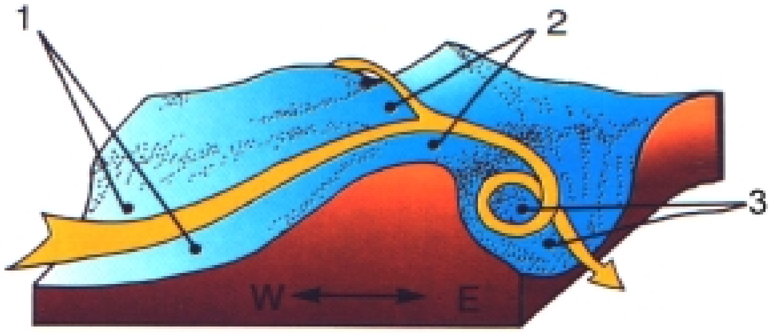


Figure 2. The anemo-orographic system is a natural phenomenon occurring in the Krkonoše Mts. It consists of 1) a windward funnel-shaped valley, 2) an acceleration summit plateau and 3) a fan of leeward slopes. The anemo-orographic system affects the topoclimate, soils, hydrology and overall life in the region (Soupková et al, 1997).

1.2.3 Geology and geomorphology

The bedrock consists mainly of acidic rocks (granites, phyllites, shists and gneisses), which are low in base elements (Emmer, 1996). The Polish side of the Krkonoše Mts. is primarily composed of granite (Stursa et al, 1996).

The Krkonoše Mts. belongs to a complex called Krkonossko-Jizerske crystallinicum created around one billion years ago. During the Mesozoic and Tertiary periods a significant denudation occurred creating an undulating landscape with rounded heights and wide valleys. Towards the end of older Tertiary the folding of the Alpine-Carphatian arch occurred causing an elevation of the Krkonoše Mts. During the Ice Age, in older Quaternary, the valleys were widened and deepened and became more U-shaped. The glaciers created moraine deposits and glacial lakes (Stursa et al, 1996).

At the end of the Ice Age, the climate became milder and water erosion was the most important type of denudation causing landslides and ravines to occur, which still is an ongoing process in the Krkonoše Mts. (Stursa et al, 1996). Other recent processes worth mentioning are rock falls, solifluction, avalanches and intra-skeletal erosion.

1.2.4 Soil types

Five major soil groups can be distinguished in the Krkonoše Mts.; Cambisols, Podzols, Histosols, Gleysols and Leptosols (Emmer, 1996). The five soil types will be described in detail in the sections below due to their influence on soil erosion.

- *Cambisols*
  Cambisols, commonly known as brown forest soils or brown earths, covers the largest area of the park and is found below 1100 m a.s.l. The cambisols in this region are slightly acid and have a high inherent fertility but with increasing altitude these become more podzolised. The cambisols in the Krkonoše Mts. can be divided into three sub-groups; Dystic Cambisols, Gleyic Cambisols and Spodi-Dystic Cambisols (Emmer, 1996). The most common vegetation on these soils is deciduous forest (Fitzpatrick, 1986).

- *Podzols*
  In the Krkonoše Mts. podzols are predominately located at altitudes between 1100 and 1400 m a.s.l. Podzol is an acid soil type with a low content of base-minerals. The main podzol types in the park are gleyic or haplic podzols. Due to sub-optimal drainage conditions and plentiful precipitation at these high altitudes the podzols in the Krkonoše Mts. often show gleyic properties (Emmer, 1996). Podzols have an extremely low potential for agriculture as heavy applications of lime and fertilisers are needed. Areas with a podzol soil type are often used for coniferous forestry or low volume grazing (Fitzpatrick, 1986).

- *Histosols*
  Histosols are organic, peaty soils. The organic matter accumulates due to wet conditions and the composition is determined by the nature of the plant material. In the Krkonoše Mts. highland blanket bogs with a peat depth of up to 3 m covering areas of several hectares occur in the high altitudes where slope angles are relatively small. Living bogs (Fibric Histosols), also present in the park, are supplied with water from brooklets and differ in their composition compared to highland blanket bogs (Emmer, 1996). Histosols can be drained and used for agricultural purposes with very good crop yields but with time they oxidised and shrinks (Fitzpatrick, 1986).

- *Gleysols*
  Gleysols are wet mineral soils common in depressions and in the vicinity of lakes and streams. These soils are poorly drained and normally used as meadows but if they are drained they can be used very successfully for agriculture (Fitzpatrick, 1986).

- *Leptosols*
  Leptosols are shallow mountain soils formerly known as Rankers, Rendzinas or Lithosols. Leptosols consist of loose unweathered boulders, which are formed by periglacial processes and transport. In the upper layer a fine organic earth is usually found around the boulders. The soil thickness ranges from less than 1 m to tens of metres. This soil type primarily exists above the timberline in the Krkonoše Mts. Exposed leptosols, especially lithic leptosols, are easily degraded. The thin organic material found between the boulders, the only nutrient source for the vegetation, is easily eroded when the soil is exposed (Emmer, 1996).

1.2.5 Vegetation

The Krkonoše Mts., in spite of their small area, are marked by an uncommon variety of mountain ecosystems. Mountain forests, flower rich mountain meadows, subarctic peat bogs and large tundras on the ridges, characterise the National Park. The altitude, air and earth temperatures, wind patterns, quantity of precipitation, geology and slope orientation influence the composition of the vegetation. In the Krkonoše Mts. there are four main altitude zones with different vegetation (figure 3).

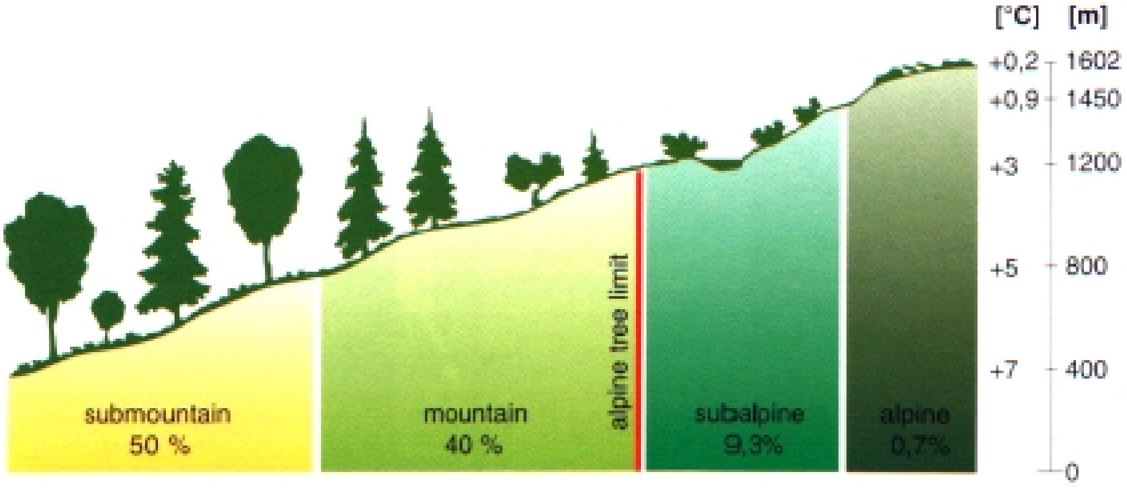


Figure 3. The Krkonoše Mts. have four main altitude zones characterised by different vegetation; 1) the submountain zone (400-800 m a.s.l.) characterised by meadows, cultivated fields, deciduous and spruce forests, 2) the mountain zone (800-1200 m a.s.l.) characterised by spruce forests, meadows and deciduous stands, 3) the subalpine zone (1200-1450 m a.s.l.) characterised by mountain pine, matt-grass meadows and peat bogs, 4) the alpine zone (1450-1602 m a.s.l.) characterised by stony debris, grassland and lichen vegetation (Stursa, 1999).

1.2.5.1 Submountain zone (400 – 800 m a.s.l.)

Cultivated fields, pastures and meadows characterise this zone at the foothills of the mountain. Broad-leaved and mixed forests, including mostly the European beech, sycamore, whitebarked fir, ash, grey alder but also spruce stands, are the dominating tree species (Stursa et al, 1996).

1.2.5.2 Mountain zone (800 – 1200 m a.s.l.)

Spruce forests prevail in the mountain zone but there are also numerous meadows, pastures and deciduous stands, but with a decreasing occurrence at higher altitudes (Stursa et al, 1996).

1.2.5.3 Subalpine zone (1200 – 1450 m a.s.l.)

Mountain pine stands, matt-grass meadows and subarctic peat bogs appear in the subalpine zone, concentrated mostly around the plateaux. The dwarf pine stands of the park’s two plateaux occasionally occur on peat bogs (Stursa et al, 1996).

1.2.5.4 Alpine zone (1450 – 1602 m a.s.l.)

This zone is situated at the highest peaks of the Krkonoše Mts. and is characterised by stony debris, grassland and lichen vegetation (Stursa et al, 1996).

The timberline in the Krkonoše Mts. forming the dividing line between the mountain and the alpine zones runs between 1200 – 1350 m a.s.l., but it is in general situated about 1250 m a.s.l. (Stursa et al, 1996).

1.2.6 History, problems and future plans

Since the fourteenth century humans have affected the ecosystems of the Krkonoše Mts. From the 16th to 18th century forests were cut down to provide metallurgy, glass-manufacture and agriculture with energy. The central and eastern parts were deforested in the late 16th century as a result of the demand for wood in the mines of Kutná Hora, this halted the clear-felling in 1609 (Internet 2). The western part was not affected until the beginning of the eighteenth century and in this part remnants of the original beech and mixed beech-spruce forests still exist. The extensive deforestation in the region resulted in artificial regeneration and plantation of spruce. The original forests were hence replaced with even aged, dense and unstable spruce stands, often of inappropriate origin. This increase in spruce stands led to an increase in needle litter, causing acidification of the soil and consequent leaching of essential nutrients (Internet 2). The plantation of spruce at lower altitudes led to podzolization of brown forest soils (Emmer et al., 1998).

In the 1950s large-scale industrialisation began in former Czechoslovakia, Eastern Germany and Poland. This led to an increase in emission of pollutants, which culminated in the late 1980s and has since then declined significantly. In what is known as the “Black Triangle”, an area along the Czech-German-Poland borders, some 800 km^2 of forest have died off during this period (Emmer et al., 1998). In the northern part of the Czech Republic 60% of all forests showed a decline in vitality. In the park some 80 km^2 of forest at higher altitudes have died off as a result of acid deposition and accompanying phenomena, such as wind and snow break, and insect plagues (figure 4) (Emmer et al., 1998). The present deforestation also enlarges the number of localities endangered by intra-skeletal erosion and consequently increases the development of non-reafforestable debris fields (Schwarz, 1998). In 1984 The World Conservation Union (IUCN) listed the Krkonoše National Park among the most endangered national parks of the world because of the acid atmospheric deposition (Internet 2).

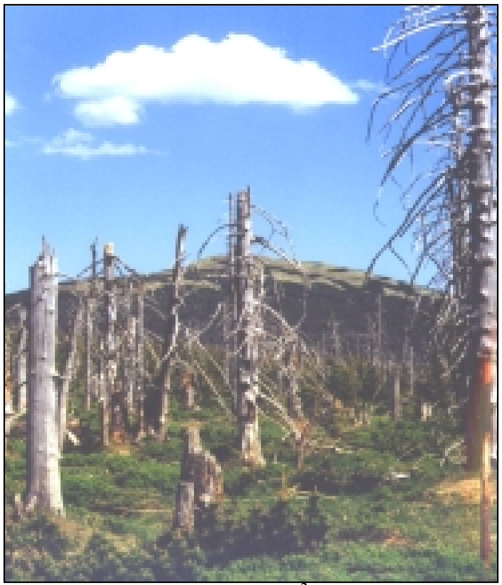


Figure 4. In the park 80 km^2 of forest have died off. Picture taken in the Krkonoše National Park by A. Hyltén, 2000-05-16.

After 1994, the aim of the Administration of the Krkonoše National Park has been to transform the spruce monocultures into forest ecosystems similar to the original ones, which are more resistant to pollution, insect pests and catastrophic wind-throw damages. To create forest stands similar to the natural forests in terms of species, age and spatial composition the percentage of deciduous stands has to increase. This action would subsequently lead to a decrease in soil acidification due to less needle litter, an increase in the biological activity in the soil, an increase in biodiversity and enhance the stability of the forest ecosystems (Internet 2). Attempts to regenerate areas affected or endangered by intra-skeletal erosion are also considered a vital part of the park’s management (Schwartz, 1998).

2 THEORETICAL BACKGROUND

2.1 Prior probabilities and rule-based classification systems

2.1.1 Prior probabilities

Classification of remotely sensed data can be enhanced through the use of prior probabilities based on independent knowledge, i.e. not based on the satellite data, concerning the area to be classified. The expected distribution (area) of classes in a final classification map is used as prior probabilities with the purpose to improve the classification accuracy. The use of prior probabilities in a classification system allow 1) prior weighting of output classes based on their anticipated sizes, 2) the merging of discrete collateral information datasets (e.g. soil type, rock type) with multispectral signatures and; 3) the construction of time-sequential classification systems in which an earlier classification modifies the outcome of a later one. Modifying the maximum likelihood decision rule incorporates prior probabilities and calculates *a posteriori* probability of class membership based both on spectral information and the estimated weight of the class (Strahler, 1980). This procedure increases the probability of a pixel to be incorporated in to a larger class and decreases the probability of a pixel to be assigned to a smaller class or, when using discrete collateral datasets it increases the accuracy of assignment since it “restrains” the numbers of classes that the pixel can be assigned to. For time-sequential classification, the prior probabilities indicate either the confidence of the investigator in the prior classification or the extent to which the prior class is likely to change during the time of interest.

In 1978, Strahler et al (from Strahler, 1980) performed a study involving classification of natural vegetation in a heavily forested area in northern California, U.S.A. The classification was based on Landsat MSS data, a digital elevation model and field points. The points were used both as basis for prior probabilities and for evaluation of the final classification map. The area was classified both with and without the use of prior probabilities. A classification accuracy of 58% was obtained using spectral data only, and assuming equal prior probabilities. In the second classification, three sets of prior probabilities for the forest types were used, each contingent on one of three elevation zones. This technique increased accuracy from 58% to 71% using 13 forest cover classes.

2.1.1.1 Review of maximum likelihood classification

Using the maximum likelihood classification, the algorithms are applied pixel by pixel and the classification is only dependent on class signatures and spectral properties of the data. In a satellite scene every pixel, i.e. every observation, consists of measurements on p channels. By distinguishing training areas, a set of observations is identified which correspond to a certain class. For these sets of observations, sample means and dispersion matrix are calculated describing the interrelationship among the measurement variables, which are characteristic of the class. When these measurements are known for each class it is possible to compute the set of probabilities that describe the likelihood of every pixel to belong to each class (Richards, 1990). The probability that an observation X will occur, given that it belongs to a class k, is given by the following function (Strahler, 1980);

$$\Phi_k(X_i) = (2\pi)^{-\frac{1}{2p}} \left|\sum\nolimits_k \right|^{-\frac{1}{2}} * e^{{}^{1}\!/_{2(\mathrm{X}-\mu\mathrm{k})'\Sigma_{\mathrm{k}}^{-1}\mathrm{X}-\mu\mathrm{k}}} \tag{1}$$

where

$\Phi_k(X_i)$: Probability density value associated with observation vector X_i, as evaluated for class *k*

p : Number of measurements variables used to characterise each observation

$\sum_k$: Parametric *p* by *p* dispersion (variance-covariance) matrix associated with the *k*-th class

X : A *p*-dimensional random vector, i.e. spectral characteristics of a specified pixel

μ_k : Parametric mean vector associated with the *k*-th class

Equation 1 calculates the probability that an observation is a member of each of *k* classes. The pixel is then assigned to the class with the highest probability (Strahler, 1980).

2.1.1.2 Incorporating prior probabilities in the decision rule

Prior probabilities are incorporated into the classification through manipulation of the Law of Conditional Probability (equation 2-8) (Strahler, 1980).

$$P\{\omega_k | X_i\} = {}^{P\{\omega_k, X_i\}}\!\big/_{P\{X_i\}} \tag{2}$$

where

$P\{\omega_k | X_i\}$: Probability that an observation is a member of class ω_k given that (pixel) X_i is observed

$P\{\omega_k\}$: The probability that an observation will be drawn from class ω_k, i.e. prior probability for class ω_k

$P\{X_i\}$: The probability that the observation (pixel) X_i will occur.

Modifying equation 2, the left-hand side of equation 3 describes the probability that a pixel from class ω_k exists at position $X_{i.}$

$$P\{X_i | \omega_k\} = {}^{P\{\omega_k, X_i\}}\!\big/_{P\{\omega_k\}} \tag{3}$$

$P\{X_i | \omega_k\}$ is acceptably estimated by $\Phi_k(X_i)$ and equation 3 can be rewritten as

$$\Phi_k(X_i) = P\{\omega_k, X_i\} \big/ P\{\omega_k\} \tag{4}$$

Rearranging equation 4 gives

$$P\{\omega_k, X_i\} = \Phi_k(X_i) P\{\omega_k\} \tag{5}$$

The numerator of equation 2 can therefore be evaluated as the product of the multivariate density function $\Phi_k(X_i)$ and the prior probability of occurrence of class ω_K.

The conditional probabilities for all *k* classes must sum to 1:

$$\sum_{K=1}^{K} P\{\omega_k | X_i\} = 1 = \sum_{K=1}^{K} \left(\frac{\Phi_k(X_i) P\{\omega_k\}}{P\{X_i\}} \right) \tag{6}$$

Therefore,

$$P\{X_i\} = \sum_{K=1}^{K} \Phi_k(X_i) P\{\omega_k\} \tag{7}$$

Substituting equation 5 and 7 into 2 gives,

$$\mathrm{P}\{\omega_\mathrm{k} | \mathrm{X_i}\} = \frac{\Phi_k(X_i) P\{\omega_k\}}{\sum_{K=1}^{K} \Phi_k(X_i) P\{\omega_k\}} \tag{8}$$

Equation 8 provides the basis for the decision rule, which includes prior probabilities. Since the denominator remains constant for all classes, the observation is simply assigned to the class for which the product of $\Phi_k(X_i)$ and $P\{\omega_k\}$ is a maximum (Strahler, 1980).

2.1.2 Knowledge-based classification systems

Development of knowledge-based systems, commonly known as expert systems, provides the opportunity to encapsulate knowledge in a computer system. These systems can be extensive and complex and for example be used to guide an unprofessional user through difficult analyses or they can be small and precise if designed to solve a particular task. Building knowledge-based systems are not a new idea and the earliest examples date from the 1960’s (Openshaw & Openshaw, 1997).

In the field of terrain and land use/land cover feature extraction in geographic information systems several expert systems/knowledge-based systems have been developed. In 1984 Palmer (from Robinson & Frank, 1987) used logic programming for analysis of terrain features. By using PROLOG valleys, streams and ridges were deduced. A Forestry Expert System (FES) was developed in 1984 by Goldberg et al (from

Robinson & Frank, 1987), to analyse multitemporal Landsat data for classification of land cover and identification of change for use by forest managers.

Cress and Deister (1990) developed a knowledge-based GIS to automate Geological Engineering Map (GEM) production, using the GoldWorks expert system shell. The development of the knowledge-based system included a decision tree translated into production rules. This knowledge-based system was thereafter used as an input to a conversion expert system, using FORTRAN code as output, in order to reduce production time.

In 1990, Srinivasan, developed a knowledge-based analysis system in order to analyse Landsat MSS and radar images jointly. The Landsat data is unable to distinguish between urban areas and areas cleared for development. Radar data on the other hand provides structural information of the area but does not provide information of the actual land cover type. A knowledge-based system was created to resolve classes confused in either the Landsat data or the radar data and a pixel–based approach was used in order to produce a land cover map. The results of using the knowledge-based scheme to classify the scene yielded an overall accuracy of 77.3% using 7 land cover classes.

In the area of remote sensing classification of satellite data based solely on spectral properties has for more than a decade been interpreted using well-established statistical techniques, where one of the most popular ones been the maximum likelihood classification technique discussed above. Nowadays we have the opportunity to work with multiple data sources when classifying satellite data. In order to process multiple data sets and to improve existing classification schemes using so called “ancillary” data sources, such as topographic information, existing maps, expert knowledge etc, knowledge-based methods are more often utilised in image interpretation and in GIS environments.

The interpreter’s success when classifying an image based on different kinds of data sources, lies within the interpreter’s knowledge – knowledge of spectral reflectance characteristics, how to combine information for example on soil and vegetation or altitude and vegetation etc. This knowledge is incorporated into the classification scheme by the usage of rules (Srinivasan, 1990).

2.1.2.1 Representation of knowledge: Rules

There are many ways that expert knowledge can be captured in a knowledge based system, but the most common way is the use of *rules* and it is therefore called *rule-based classification system* (Srinivasan, 1990).
These rules are of the form:

If condition **then** inference

The term *condition* is a logical expression that can be either true or false. If true then a certain inference follows otherwise there is another inference or a new rule. *Condition* can be a simple logic expression or it can be a compound logical statement combined by Boolean expressions such as *and, or, xor* and *not*. These rules need not to be conclusive, they may simply provide a degree of evidence that favour pixels to be classified according to a certain label. Occasionally a set of different rules is needed to satisfactory classify a group of pixels (Richards, 1993).

To exemplify the use of rules in a rule-based classification system, consider a land use planning-scheme. The rules used to achieve a satisfactory classification might be of the following kind;

A) **If** a slope is less than 10° **and** the altitude is less then 1000 m **and** the soil is good **then** land is suitable for arable farming

B) **If** a slope is more than 10° **and** the altitude is less then 1200 m **and** the soil is bad **then** land is suitable for meadows.

If every condition in rule A are true then the pixel under consideration is labelled "suitable for arable farming". If rule A is found to be false then rule B is considered, thereafter rule C and so forth until rule X is considered true.

The rules can provide a degree of justification of a particular labelling proposition and three types of rules are specified (Srinivasan, 1990):

Conclusive	If the condition is true then the evidence for the inference is absolute.
Prima Facie	If the condition is true then there is reason to believe that the inference is true. If the condition is false it can not be concluded in general that the inference is false. (There is another kind of Prima facie termed Criterion for which a false condition provides prima facie justification to disbelieve the inference.)
Contingent	If the condition is true then support is provided for other prima facie. A contingent reason can not, by itself, justify a belief in a proposition.

A rule is knowledge that is used to deduct new facts from existing facts. A fact is referred to as passive knowledge, whereas a rule is an active type of knowledge. Both facts and rules are important parts of a knowledge-based system. The mechanism that uses both rules and facts to derive new facts is called an inference mechanism (Usery et al, 1988). A simplified picture of the components of a rule-based classification system is illustrated in figure 5.

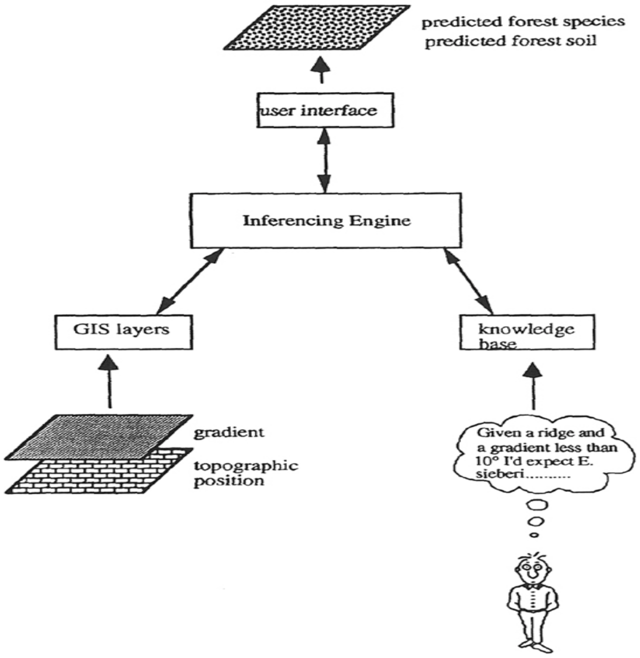


Figure 5. Components of a rule-based system where the GIS layers are passive knowledge and the knowledge base contain active knowledge (Skidmore et al, 1996).

The inference mechanism can be quite simple if the knowledge–based system is designed for a particular task; in this case, to find the most likely land cover type and to delineate new classes, or it can be very complicated when designing a general expert system. In a smaller, simpler application all the inference mechanism has to do is to check which rules that gives a positive response for all pixels in the image and label the pixel accordingly. In a larger, more complex general application the system has to keep track of all the rules that infer a particular cover type, along with those that infer that the pixel does not belong to a specific cover type and those that suggest other candidate classes that the pixel can be assigned to. Finally, in the end, the system has to choose which class the pixel should be assigned to by weighting all the evidence from the rules (Richards, 1993).

2.1.2.2 Handling multisource data

When constructing a knowledge-based system there are two different approaches that might be adopted;

1) a single knowledge base which contains all the rules necessary to process multisource data,
2) multisource data is handled in different analysis sets containing separate knowledge-bases and the results are combined in a separate module.

A single knowledge base is most frequently used when the analysis is strongly focussed on a particular application. The knowledge-based system consisting of smaller, separate systems is considered more practical when many sorts of multisource data is utilised in a complex and general expert system. The advantages of this approach are that the rule-sets are each focussed on a particular data source and the results are easier to update if or when new information becomes available (Richards, 1993).

A common approach used in a knowledge-based system is the creation of a *decision tree*. The decision tree demonstrates the structure of the production rules and is converted into If – Then rules. Each entry in the decision tree is a hypothesis, i.e. a set containing one or more classes. At the bottom level there are only individual sets, i.e. with one member; at the top there are the sets encompassing all the individual classes in the taxonomy (Wilkinson & Mégier, 1990). The decision tree approach minimises the search involved by considering only those factors needed to produce distinct results (Usery et al, 1988).

2.2 Introduction to erosion

Large areas in the Krkonoše National Park are affected by erosion. Much of the erosion is intra-skeletal erosion. This is defined as the loss of topsoil caused by water erosion, creating debris fields which are predominately occurring in areas with little or no vegetation (figure 6). In 1990, 5 to 10% of forest areas in Bohemia and Moravia, Czech Republic, were exposed to severe erosion and 11 to 47% were threatened by relatively severe erosion (Sach, 1990).

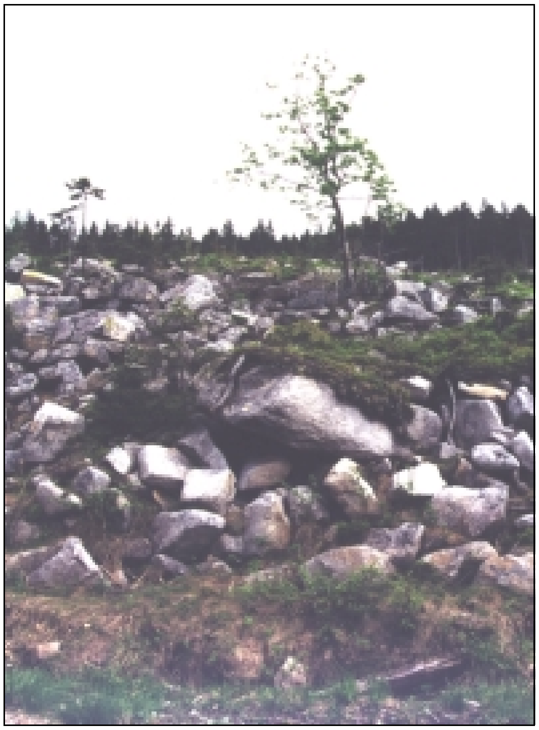


Figure 6. Intra-skeletal erosion creates large areas with non-reafforestable debris fields due to topsoil loss. The picture was taken at Špindlerův Mlýn in the Krkonoše National Park on the 18 May, 2000 by A. Hyltén.

2.2.1 Factors of Erosion

The main factors controlling soil erosion caused by water are: vegetation (the nature of the plant cover), climate (mainly the erosivity of the eroding agent), relief and area (primarly the slope and slope length), soil and rock type (mainly the erodibility of the soil), and human activities (presence or absence of conservation measures) (Pilesjö, 1992).

Erosion is a function of erosivity and erodibility (Selby, 1982).

Erosion = *f* (erosivity, erodibility)

Erosivity is the potential of raindrops, running water and sliding or flowing earth masses to cause erosion. Erodibility is the ability of a soil to erode. For given rainfall conditions soils erodibility can be compared quantitatively with another. This will create a numerical scale of erodibility for different soils (Selby, 1982). The erodibility of a soil is dependent upon the characteristics of the soil, physical and chemical composition, land use; cropping, forestry, grazing, etc. and management; use of fertilisers, cropping and harvesting (Selby, 1982).

According to Pilesjö (1992) precipitation, temperature, frost, snow and seasonality are climatic parameters that influence soil erosion. Precipitation is the most important of the climatic factors influencing the erosion rate. The erosion caused by rain is determined by the amount, intensity and duration of the rainfall (Selby, 1982). A higher intensity of the rain reflects a greater energy, causing increased detachment and run-off.

The two most frequently used topographical parameters in soil erosion modelling are slope gradient and slope length. The steeper the slope, the greater the erosion will be. The relationship between erosion and steepness of slope is not linear, but exponential. On a longer slope the surface runoff will increase and will thereby have a greater velocity and erosion potential (Pilesjö, 1992).

The soil erodibility depends on 1) the physical features of the soil, 2) the topographical position, 3) the steepness of the slope and 4) the management of the land. The physical feature of the soil is very important and erodibility varies with soil texture, aggregate stability, sheer strength, infiltration capacity and organic and chemical content (Morgan, 1986). Larger particles are more resistant to transport due to the greater force entailed to move them. However, in soils with particles finer than 0.06 mm, the erodibility is limited by the cohesiveness of the particles. The particles least resistant to erosion are silt and fine sand. Soil texture also influences the infiltration capacity. This is defined as the maximum sustained rate at which soil can absorb water and depends on pore size, pore stability and the form of the soil profile (Pilesjö, 1992). Water will have a higher infiltration upon permeable soils. These soils will experience less surface erosion since there will be lesser surface runoff (Selby, 1982).

Vegetation reduces the effects of the erosion factors. Selby (1982) concludes that the effects of vegetation can be divided into seven main categories: 1) the interception of rainfall by the vegetation canopy; 2) decreasing the velocity of runoff and hence reducing the cutting action of water and its capacity to entrain sediment; 3) roots increasing soil strength, granulation, and porosity; 4) biological activities associated with vegetative growth and their influence on soil porosity; 5) the transpiration of water, leading to the subsequent drying out of the soil; 6) insulation of the soil against high and low temperatures, which cause cracking or frost heaving and needle ice formation; and 7) compaction of underlying soil. The vegetation prevents runoff from becoming channelled and cutting into the soil and slows it down. The slowing down of the runoff gives it more time to infiltrate (Selby, 1982).

3 MATERIAL

In order to produce the land cover maps and the erosion risk assessment the following data were used:

- *Landsat 7 ETM+ scene (Enhanced Thematic Mapper plus)*
  The satellite data was registered on the 15th of September 1999 and has a spatial resolution of 30 m.

- *Digital black and white aerial orthophotos*
  These images were gathered in the spring of 1997 and have a spatial resolution of 1.1525 m. Images were only available for the Czech part of the National Park.

- *Digital forestry management plan*
  The forestry management plan was produced in 1990-1992 and was digitised from forestry maps (1:10 000). Forestry data is only available for the Czech part of the park. The forestry management plan includes age data of the stands and species composition.

- *Earlier digital land cover classification*
  This earlier land cover classification was based on interpretation of Landsat TM satellite data as of 1990. The classification does only cover the Czech part of the park.

- *Digital elevation model (DEM)*
  The data was digitised from topographic contour lines (1:10 000) and was produced in 1994-1997. The DEM has a spatial resolution of 30 m and covers the whole park, i.e. both Czech and Polish side.

- *Digital soil map*
  The digital soil map is included in the forestry management plan. It is dated 1994-1997 and derived (generalised) from the forestry maps (1:10 000).

- *Various digital vector layers*
  These digital vector layers include information on roads digitised from forestry maps (1:10 000), borders of the park digitised from 1:50 000 base maps and major streams in the park digitised from forestry maps (1:10 000).

- *Topographic paper maps*
  Paper maps were used for planning the fieldwork as well as for navigation in the park. The topographic paper maps are produced by Vojenský kartografický ustav, Hamanec, in 1999 and include topographic contours with an equidistance of 5 m in a 1:25 000 scale.

- *Collected field data*
  - GPS recordings. Magellan 320 with an accuracy of approximately 10-15 m (London, 2000 personal communication).
  - Land cover data
  - Estimation of erosion / no erosion

All digital data, except for the Landsat 7 ETM+ scene, were attained from the Administration of the Krkonoše National Park, KRNAP.

4 METHODOLOGY

4.1 Preprocessing

4.1.1 Geometric correction

The Landsat 7 ETM+ data was geometrically corrected using black and white aerial orthophotos registered over the National Park. The projection and coordination system of the orthophotos were in Transverse Mercator based on the Krassovsky ellipsoid. The correction was only performed over the National Park situated in the Czech Republic; the Polish side was not covered since aerial orthophotos over that area were missing. One ground control point (GCP) was registered per orthophoto and in total twenty GCPs were collected. In order to achieve a satisfactory geometric correction the points were dispersed over the National Park area. The registration was made with first order and nearest neighbour resampling. This resampling technique was chosen since the new image then consists of the original digital numbers, simply rearranged in position to give correct image geometry (Richards, 1986). The performed geometric correction was evaluated by objectively comparing vector layers containing roads and the resampled image.

4.1.2 Radiometric correction

The digital numbers in the satellite data were recalculated, using equation 9 (Pilesjö, 1992 from Markham & Baker, 1986), to spectral radiance. The values in equation 9 were retrieved from the World Wide Web (Internet 4).

$$L_i = L_{\min i} + \left(\frac{L_{\max i} - L_{\min i}}{DN_{\max}} \right) * DN \qquad (9)$$

L_i : Spectral radiance (i: band)
$L_{\min i}$: Minimum spectral radiance ($\mathrm{mWcm^{-2}sr^{-1}\mu m^{-1}}$)
$L_{\max i}$: Maximum spectral radiance ($\mathrm{mWcm^{-2}sr^{-1}\mu m^{-1}}$)
DN : Absolute calibrated digital numbers
$DN_{\max}$: Maximum digital number: 255

The park is characterised by a mountainous terrain. The differences in elevation and the orientation and steepness of the slopes affect the digital numbers recorded by the satellite sensor. In order to correct for the topographic differences in the park a Lambertian correction model was used (equation 10) (Ekstrand, 1996). This model transforms topographic surfaces into horizontal surfaces assuming that every pixels reflectance properties are half-sphereic. Thereafter the values were transformed to at satellite reflectance to correct for differences in sun angle and solar irradiance (Pilesjö, 1992 from Markham & Baker, 1986) (equation 11).

$$L_H(\lambda) = L_T(\lambda) * \cos z \big/ \cos i \qquad (10)$$

where

$L_H(\lambda)$: Radiance for a horizontal surface
$L_T(\lambda)$: Radiance for an inclined surface
z : Solar zenith angle
i : Incidence angle

$$\rho p\lambda = \left(P * L_i * d^2\right) \big/ \left(E_{suni} * \cos\Theta\right) \qquad (11)$$

$\rho p\lambda$: Unitless effective at-satellite reflectance
L_i : Spectral radiance ($mWcm^{-2}$ $sr^{-1}\mu m^{-1}$)
d : Earth-sun distance in astronomical units for the 15th of September 1999: 1.0058368 (Wall, 1999)
E_{suni} : Mean solar exoatmospheric spectral irradiance in $mWcm^{-2}$ $sr^{-1}\mu m^{-1}$ (table 1).
Θ : Solar zenith angle in degrees: 49.43

Table 1. Solar spectral irradiances ($mWcm^{-2}$ $sr^{-1}\mu m^{-1}$) for Landsat 7 ETM+ (Internet 1).

Landsat ETM7 Band	*1*	*2*	*3*	*4*	*5*	*7*
Solar Spectral Irradiance	197.0	184.3	155.5	104.7	22.71	8.053

4.2 Land cover classification

The land cover classification is based on Landsat 7 ETM+ data and a rule-based classification system using ancillary data and prior probabilities. The land cover classes were given as a proposal from the Administration of the Krkonoše National Park and the definitions of the classes are compromises of their definitions and ours. Twenty-one different classes were used (table 2).

Table 2. Land cover classes and number of evaluation points.

Land cover class	*Number of evaluation points*
Peat bog	4
Wet submountain meadow	4
Dry submountain meadow	11
Wet mountain meadow	4
Dry mountain meadow	28
Spruce forest – young	9
Spruce forest – mature	45
Mixed mountain pine and spruce stands	7
Mountain pine	8
Mixed deciduous & spruce forest	12
Deciduous forest	10
Acidophilus beech forest	9
Herb rich beech forest	1
Alderwoods	10
Cultivated fields	6
Subalpine/alpine grass & lichen vegetation	10
Clear cut	29
Rocky surfaces	10
Major settlements	10
Lakes & ponds	4
Nonclassified	—

A complete definition of the land cover classes can be found in appendix 1.

4.2.1 Maximum likelihood classification

The classification of the Landsat 7 ETM+ data was performed using PCI V6.3 software and a maximum likelihood algorithm. This procedure produces a classification exclusively based on spectral properties calculated on a pixel basis. The maximum likelihood classification algorithm requires training areas to be identified for every class. These training areas are chosen to represent the spectral behaviour within every class.

The training areas were located using black and white aerial orthophotos and the forest management plan for the Krkonoše National Park updated in 1990-1992. Training areas were taken for the following land cover classes: Spruce forest, deciduous forest, beech forest, alder and ash, meadows, mountain pine stands, subalpine/alpine grass and lichen vegetation, clear cut, mixed deciduous and spruce forest, pastures and cultivated fields. On an average seven training areas were identified for every class. Spectral signatures were generated based on the training areas for every class, the threshold and bias were put to 3 and 1 respectively. This means that every class is defined using a Gaussian threshold value expressed in standard deviation units for the radius of a hyperellipsoid surrounding the class mean and that no prior probabilities were used (PCI V6.3, on line Help manual). A maximum likelihood classification was performed using a null class, i.e. a class for non-classified pixels. A pixel is assigned to this class if it is not within the Gaussian threshold specified for any class. Lakes and ponds and major settlements were classified manually.

Twenty-two layers were produced with the maximum likelihood classification. These layers consisted of 11 thematic maps containing the most likely class, the second most likely class etc and 11 corresponding probability layers. Of these layers the first three layers, i.e. both thematic maps and probability layers, were used in the rule-based classification system.

4.2.2 Rule-based classification

A rule-based classification system was built to improve the maximum likelihood classification. The rule-based system was also constructed to enable the delineation of certain classes that could not be defined spectrally, i.e. peat bogs, wet and dry submountain and mountain meadows, young spruce forest, mixed mountain pine and spruce forest, acidophilus beech, herb rich beech and alderwoods along the major streams.

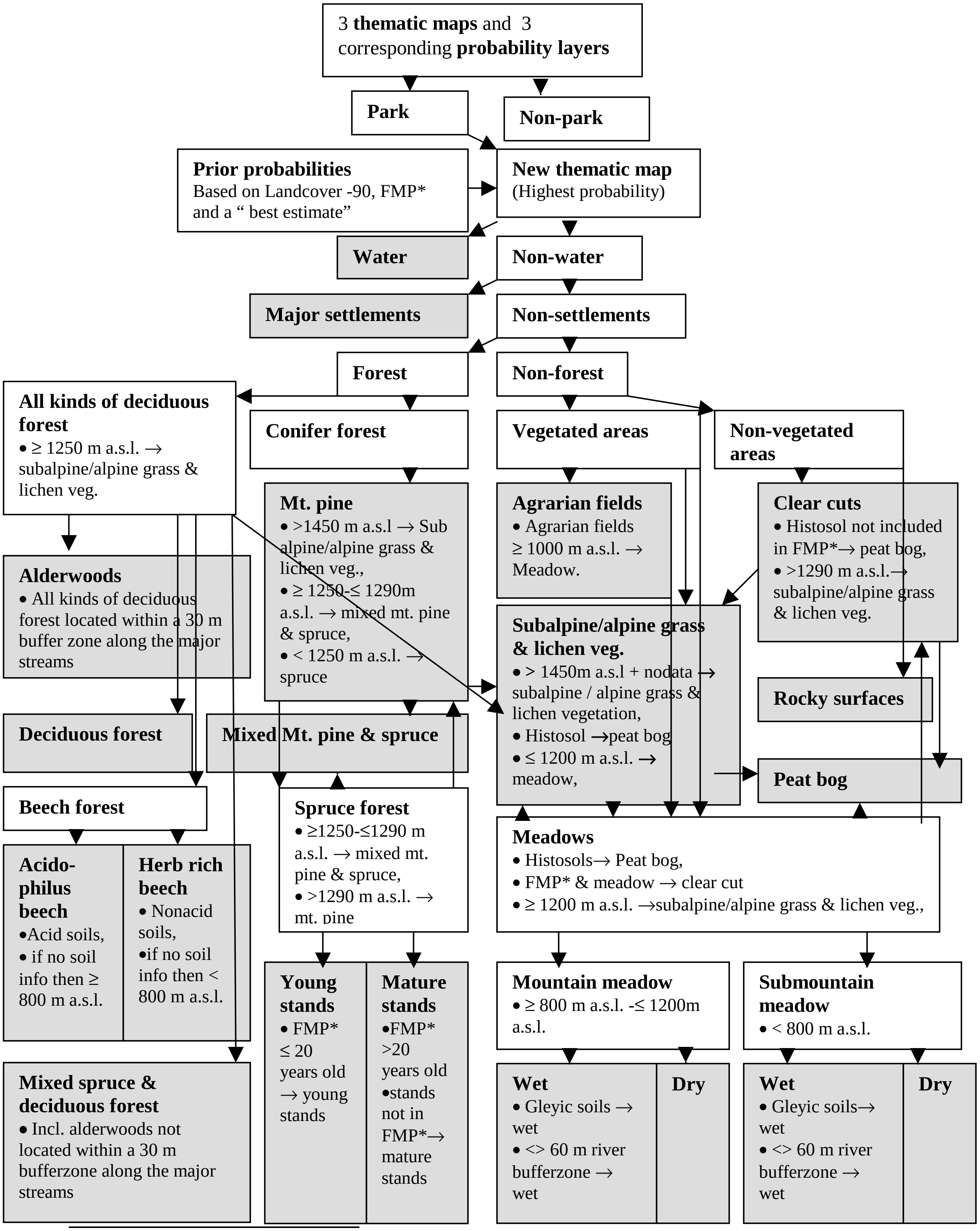
4.2.2.1 Construction

The design of this knowledge-based classification system was by intent simple to enable a quick but still satisfactory classification of the data. The classification system was constructed using a single knowledge base containing all the rules necessary to process the multisource data. This approach was chosen since the analysis is strongly focused on a particular application, which is the improvement of a land cover classification, and is not intended for any other purpose. The degree of justification of a particular labelling proposition provided by the rules was decided to be only of the *conclusive* order. The rules were applied using Avenue scripts in ArcView GIS 3.2 software, this software was chosen as this was the format of the multisource data.

A decision-tree was built containing the rules and the implementation order (figure 7). (A decision tree in pseudo code can be found in appendix 2, avenue scripts can be downloaded from the *.pdf version at Internet 6). The decision tree includes the following data:

1. Three thematic maximum likelihood maps and three corresponding *a posteriori* probability maps.
2. Forest soil type map
3. Forestry management map
4. Land cover classification from 1990
5. Vector data including rivers and borders
6. DEM.

The decision tree was converted into production rules of the IF – THEN type. To facilitate the description of the decision tree it will be described in the following order: prior probabilities, forest and non-forest.



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[*] FMP = Forestry Management Plan –90

Figure 7. The decision tree containing rules and implementation order. Grey boxes indicate final classes.

4.2.2.2 Prior probabilities

Vector data containing the borders of the park were used to exclude unnecessary data from the thematic maps and the corresponding probability layers. In order to estimate every land cover class' prior probability of occurrence a digital land cover classification from 1990, the forest management plan (1990-92) and a "best estimate" based on visual interpretation of the satellite data were used. The previous land cover classification and the forest management plan were divided into 4 altitude zones and prior probabilities were estimated for every class in these zones (table 3). The vegetation composition in these altitude zones differs and therefore prior probabilities contingent on these altitude zones were used. The extent of the zones is discussed in section 1.2.5.

In appendix 3 tables over prior probabilities retrieved from the previous land cover map and the forest management plan can be found. In order to avoid pixels to become unclassified the value zero was never used as a prior probability; these prior probabilities were instead given the value 0.00001.

Table 3. Prior probabilities for the land cover classes divided up into 4 altitude zones based on a previous land cover classification –90, the forestry management plan –90-92 and a " best estimate". The table also includes a referral to the data source, i.e. previous land cover: LC, forest management plan: FMP, best estimate: BE.

Land cover classes	*Submountain zone*	*Mountain zone*	*Subalpine zone*	*Alpine zone*	*Data source*
Spruce forest	0.367	0.648	0.326	0.005	LC, FMP, BE
Beech	0.05	0.035	0.000063	0.00001	(LC), FMP, BE
Mixed deciduous & spruce forest	0.049	0.023	0.012	0.0009	FMP, BE
Deciduous forest	0.09	0.06	0.022	0.001	(LC), FMP, BE
Mountain pine	0.00001	0.004	0.3	0.366	LC, BE
Clear cuts	0.01	0.15	0.086	0.05	LC, BE
Meadow	0.035	0.052	0.029	0.001	LC, BE
Subalpine/Alpine grass & lichen veg.	0.00001	0.002	0.13	0.47	LC, BE
Cultivated fields	0.093	0.001	0.00001	0.00001	LC, BE
Pasture	0.26	0.013	0.000076	0.00001	LC, BE
Alderwoods	0.015	0.006	0.00057	0.00001	FMP, BE
Rocky surfaces	0.00001	0.005	0.085	0.1	BE

Prior probabilities for spruce forest were based on the previously land cover map, the forest management plan and a "best estimate" procedure. Prior probabilities retrieved from the previous land cover map for beech forest and deciduous forest are in general much lower than the prior probabilities retrieved from the forest management plan. A visual interpretation of the satellite data indicates that prior probabilities based on the previously land cover map are too low and therefore prior probabilities for these two land cover classes are primarily based on the forest management plan and a "best estimate" procedure. Prior probabilities for clear cut, meadow, cultivated fields, pastures and subalpine/alpine grass and lichen vegetation were based on the previous land cover classification as they are not included in the forest management plan. Rocky surfaces are not represented in the above-mentioned digital maps and consequently the prior probabilities were estimated using a “best estimate” procedure. Manually classified classes, i.e. lakes and settlements, were not processed.

The prior probabilities were incorporated on a pixel basis by multiplication with the three probability layers according to equation 8 in the prior probability theory section 2.1.1.2. The land cover class possessing the highest *a posteriori* probability in one of the three layers was thereafter chosen and every pixel labelled accordingly. Pixels classified as either meadow or pasture were combined and labelled meadow.

The produced rectified map was thereafter searched for pixels classified as water excluding them from any further searches, thereby restricting the amount of data processed in the future. The same procedure was repeated for major settlements for the same reason, i.e. to limit the amount of data processed. The last major distinction was to determine areas of forest versus non-forest.

4.2.2.3 Forest

Forest data were searched for pixels classified as either spruce forest or mountain pine. Pixels belonging to either of these classes situated below 1250 m were classified as spruce forest. Between 1250 m and 1290 m a.s.l. spruce forest and mountain pine pixels were classified as mixed mountain pine and spruce based on the assumption that the timberline is situated about 1250 m a.s.l. (Stursa et al, 1996). According to Stursa (1999) mountain pine occurs approximately between 1250 m - 1450 m a.s.l. Spruce or mountain pine pixels located between 1290 m and 1450 m a.s.l. were hence labelled mountain pine. Any pixels spectrally classified as either spruce or mountain pine located above 1450 m a.s.l. were considered erroneous and labelled subalpine/alpine grass and lichen vegetation.

Areas with spruce forest were subdivided into young spruce forest and mature spruce forest based on the forest management plan updated in 1990-92. (To simplify the classification process the age of the forestry management plan was generalised to 10 years.) This causes the young spruce class to merely include trees aged 10-20 years old. The forest management plan includes only the Czech part of the National Park, pixels classified as spruce forest not included in the forest management plan were generalised as mature spruce. Spruce stands younger than 7-9 years old are spectrally classified as clear cut, stands aged around 7-9 years are (unfortunately) included in the class of mature spruce forest.

The data was further searched for pixels classified as beech forest, mixed deciduous and spruce forest, alderwoods or deciduous forest. Any of these classes situated above the timberline were classified as subalpine/alpine grass and lichen vegetation. This assumption was based on field studies indicating that minor stands of deciduous trees above 1250 m a.s.l. occasionally exist on grass vegetation and among sparse stands of mountain pine. Pixels classified as any kind of deciduous tree above this altitude are most likely mixed pixels and are therefore generalised as subalpine/alpine grass and lichen vegetation.

The seperability of the training areas' spectral signatures for beech forest, mixed deciduous and spruce forest and deciduous forest compared to alderwoods were respectively 0.52, 0.39 and 0.86 using the Bhattacharrya distance seperability measure. The seperability measures yield real values between 0 and 2, where values between 0 and 1 are considered as having very poor spectral seperability (PCI V6.3, on line Help manual). Alderwoods are therefore defined using all of the 4 above mentioned forest classes located within a 30 m buffer zone along the major streams. Pixels spectrally classified as alderwoods not located within the buffer zone are labelled mixed deciduous and spruce forest due to the low spectral seperability between the classes.

The data was thereafter searched for pixels classified as either mixed deciduous and spruce forest or deciduous forest to exclude them from any further searches. Areas classified as beech forest were subdivided into acidophilus beech and herb rich beech based on soil type where soil information was available otherwise it was based on altitude. Acid soil types indicate acidophilus beech stands (pH 3.5 ~ 5) and less acid or non-acid soil types indicates herb rich beech forest (pH 4.5 ~7) (Peters, 1997). A more detailed description of soil types used to divide the two beech classes can be found in appendix 1. If no soil information was available beech located above 800 m a.s.l. were labelled acidophilus beech and beech located below 800 m a.s.l. as herb rich beech (Stursa, 2000 personal communication).

4.2.2.4 Non-forest

Non-forest areas were searched for vegetated or non-vegetated identified pixels. Vegetated areas were then searched for pixels classified as cultivated fields. Visual interpretation of the satellite data indicated that cultivated fields only occur below 1 000 m a.s.l., therefore cultivated fields located above 1000 m a.s.l. were labelled meadow.

Pixels identified as subalpine/alpine grass and lichen vegetation located on organic soils, peat soils (histosols), were labelled peat bogs. This land cover class was further divided based on altitude. According to Stursa et al (1996), subalpine/alpine grass and lichen vegetation is mainly located above 1200 m a.s.l. Pixels identified as this class below 1200 m a.s.l. are therefore labelled meadows, due to similar vegetation. Non-classified pixels located above 1450 m a.s.l. were assigned to the subalpine/alpine grass and lichen vegetation class. This is the only class that generalised occurs above 1450 m a.s.l. except for the minor class rocky surfaces which predominately are located on peaks at this altitude.

Meadows located on histosols are assigned to the peat bog class. If pixels identified as meadows are included in the forest management plan these are assumed to be clear cut as they have been covered by forest 10 years ago. Above 1200 m a.s.l., meadows are labelled subalpine/alpine grass and lichen vegetation. Ancillary data consisting of soil types and streams were used to delineate the classes wet mountain meadow and wet submountain meadow. Meadows situated on gleysols or gleyic cambisols (see further appendix 1) or located within a 60 m buffer zone along the major streams were classified as wet mountain meadow (between 800-1200 m a.s.l.), or as wet submountain meadow (below 800 m a.s.l.). The remaining meadow areas were assigned to the class dry mountain meadow (between 800-1200 m a.s.l.) or to the class dry submountain meadow (below 800 m a.s.l.).

Non-vegetated areas were searched for pixels classified as clear cut. If located on histosols clear cut areas are assigned to the peat bog class. The distribution of clear cuts is limited to 1290 m a.s.l. based on the timberline location at 1250 m a.s.l. and the occurrence of mixed mountain pine and spruce stands (1250m – 1290 m a.s.l.). Clear cuts occurring above this limit are classified as subalpine/alpine grass and lichen vegetation due to similar vegetation.

The peat bog class is, as described in the above sections, a land cover class defined by organic and peaty soils, i.e. histosols. Only vegetation types with grass-like spectral behaviour are considered, other vegetation types existing on histosols are classified according to their vegetation. Most peat bogs in the National Park are of the subartic peat bog type predominately occurring in the subalpine zone. These peat bogs are occasionally hidden by mountain pine stands (Stursa et al, 1996), and will not be classified as peat bogs but are to remain as mountain pine.

The data is finally searched for pixels classified as rocky surfaces. Non-classified areas are if possible manually mapped based on black and white aerial orthophotos. Manually classified areas are not processed in the rule-based classification system.

4.3 Field measurements

Field measurements were conducted from the 15th of May until the 27th of May 2000. The measurements consisted of GPS recordings to evaluate the accuracy of the rule-based classifications and the maximum likelihood classification. The GPS points were further used for statistical analyses to assess the erosion risk in the area and to evaluate the same. 231 evaluation points were recorded using a road sampling technique. This technique was selected since an even distribution of the data was desired as well as representation of the whole Czech part of the park. The vast area to be covered and the limited amount of time available in the field had great impact on the chosen sample technique. The Polish side of the park was not covered during the field measurements. Figure 8 illustrates the position of the collected evaluation points, table 2 the number of evaluation points for every class.

GPS points were collected along most trafficable roads at every kilometre, if possible, but due to diverse obstacles the length between the evaluation points differ between 0.5 – 4 kilometres. At every recording the GPS points were sampled at a distance of approximately 50 m from the road to exclude any disturbances caused by the same. The effect of the roads is most likely small along the minor forest roads in the mountain zone, evaluation points were therefore recorded at the road. Areas not accessible by car were sampled by foot. At each location the position of the sample points was recorded using the WGS 84 map datum and the lat/long coordinate system and information on land cover and presence of erosion/no erosion were collected. The evaluation points were transformed to Transverse Mercator, Krassovsky ellipsoid.

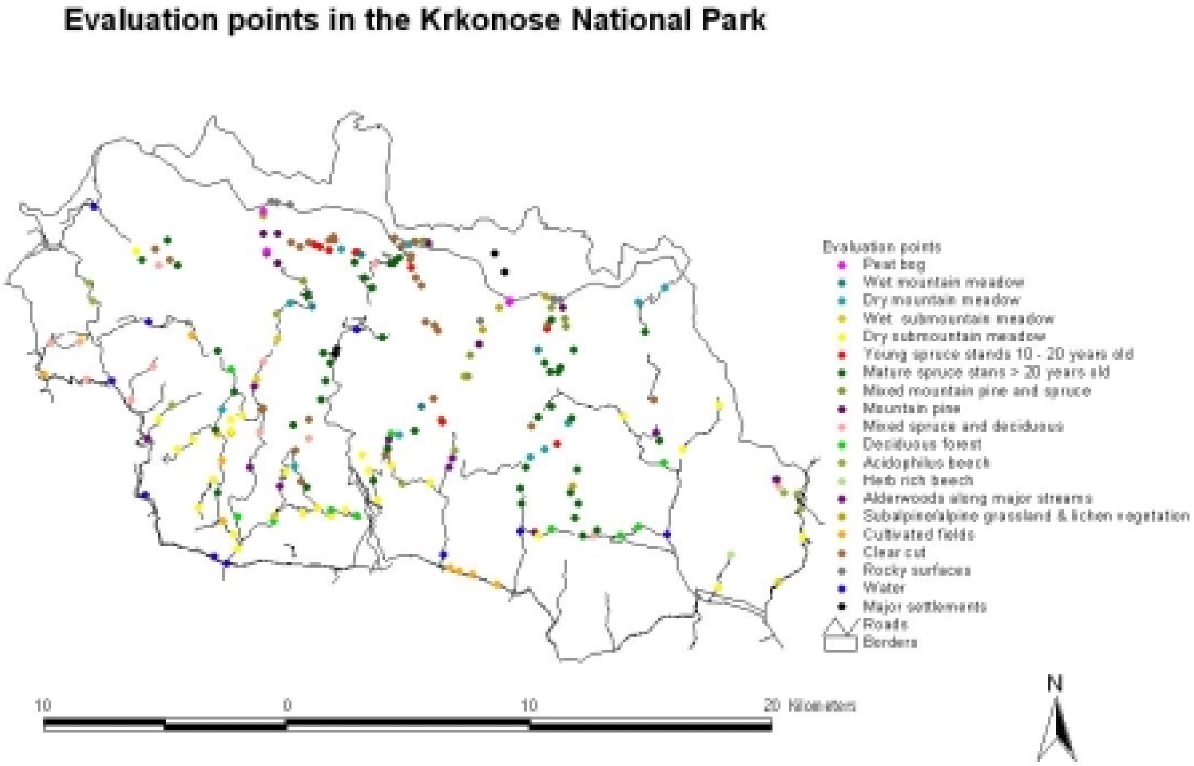

Figure 8. The location of the evaluation points collected in the Krkonoše National Park. All evaluation points were sampled at an interval of approximately 0.5 – 4 km, positioned 50 m away parallel to the roads to avoid any disturbances caused by the same. The Polish side of the park was not covered during the field measurements.

4.4 Erosion risk assessment

Topographical form, slope gradient, drainage direction and drainage area were assessed using software designed by P. Pilesjö at the department of Physical Geography, Lund University. Together with our land cover map, the soil type map and the DEM, an erosion model was made which divided the park into erosion risk areas and non erosion risk areas. Only annual precipitation data was available for the area, therefore the precipitation was set to one (1) in equation 18, assuming constant erosivity.

4.4.1 Estimation of slope gradient and aspect

Gradient is defined as the maximum rate of change in altitude. Aspect is the compass direction to the maximum rate of change. A third order finite difference method is being used for the application (Pilesjö, 1992). The first step in the algorithm is to calculate

$$\left[{}^{dz}\!/_{dx}\right]_{i,j} = \frac{\left[(z_i+1, j+1)+2(z_i+1, j)+(z_i-1, j+1)\right]-\left[(z_i-1, j+1)+2(z_i-1, j)+(z_i-1, j-1)\right]}{8DX} \tag{12}$$

and

$$\left[{}^{dz}\!/_{dy}\right]_{i,j} = \frac{\left[(z_i+1, j+1)+2(z_{i,j}+1)+(z_i-1, j+1)\right]-\left[(z_i+1, j-1)+2(z_{i,j}-1)+(z_i-1, j-1)\right]}{8DY} \tag{13}$$

where $z_{i,j}$ is the centre cell of a three-by-three moving window located at the ith row and jth column. DX is the spacing between points in the horizontal direction and DY is the distance in vertical direction (in this case DX=DY=pixel size). The gradient (G) is defined as

$$\tan G = \sqrt{\left[\left({}^{dz}\!/_{dx}\right)^2 + \left({}^{dz}\!/_{dy}\right)^2\right]} \tag{14}$$

the aspect (A) is defined as

$$\tan A = \sqrt{\left[\left({}^{dz}\!/_{dx}\right) + \left({}^{dz}\!/_{dy}\right)\right]} \tag{15}$$

Gradient and aspect are estimated for each cell in the DEM covering the area according to equations 12-15. Both gradient and aspect are given in degrees (°) (Pilesjö, 1992).

To be able to compare the different factors influence on erosion in the National Park they were divided into groups. This division was arbitrarily but to some extent based on literature, field studies and digital maps.

The gradient was divided into five groups (figure 9) and the aspect was divided into eight groups (figure 10).

4.4.2 Estimation of topographic form

By calculating the straight line between point *a* (the pixel above the centre pixel) and point *c* (the pixel below the centre pixel), and the line perpendicular to this line to point *b* (the centre pixel), the topographic form in the centre pixel can be estimated in a DEM. The length of the line *a-c* is called A and the length of the line between A and *b* is called B. The topographic form is estimated by:

$$Topographic\ form = {}^{B}\!/_{A}$$

B is negative if concave and positive if convex (Pilesjö & Ardö, 1995). The result was divided into four groups (figure 11).

4.4.3 Size estimation of drainage basins

This is done by examination of all the drainage directions ‘upslope’ from each cell in the DEM. The program starts with the drainage basin corresponding to the pixel with the lowest elevation in the DEM, continuing with the next lowest pixel and so forth (Pilesjö, 1992). The result was divided into six groups (figure 12).

4.4.4 Vegetation cover

The land cover map produced by us was divided into two groups, clear cuts and non vegetated areas, group 1 and the rest of the vegetation classes into group 2 (figure 13). This was made because of the high ability of areas with little or no vegetation cover to be eroded (Hudson, 1981).

4.4.5 Soil types

As described in section 1.2.4 the park has five main soil types: Cambisols, Podzols, Histosols, Gleysols and Leptosols (figure 14).

4.4.6 Altitude

The altitude is divided into four major altitude zones as described in 1.2.5.1-4, (figure 15).

4.4.7 Localizing areas with increased soil erosion risk

4.4.7.1 Histograms

To estimate which groups of the above described seven factors that have an impact on soil erosion in the Krkonoše Mountains, histograms were drawn for each group of the seven factors to visualize the distribution between the groups of every factor. These histograms are sub-results and displayed in figure 9-15.

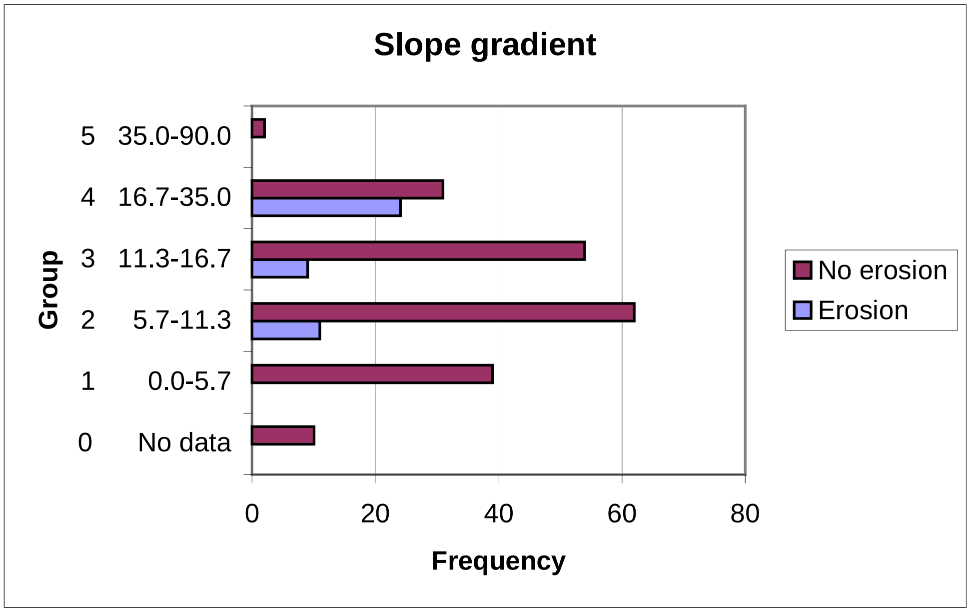

Figure 9. Histogram of the distribution of points between no erosion and erosion for every group. The group number is displayed as single numbers on the left side in the figure. The group extent is displayed in degrees.

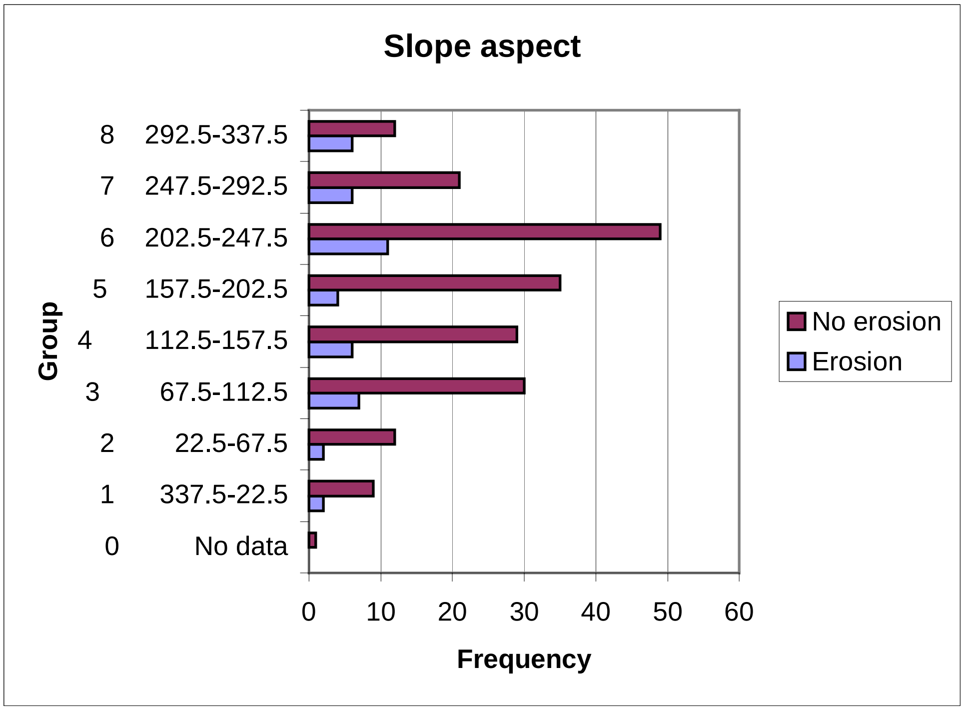

Figure 10. Histogram of the distribution of points between no erosion and erosion for every group. The group number is displayed as single numbers on the left side in the figure. The group extent is displayed in degrees.

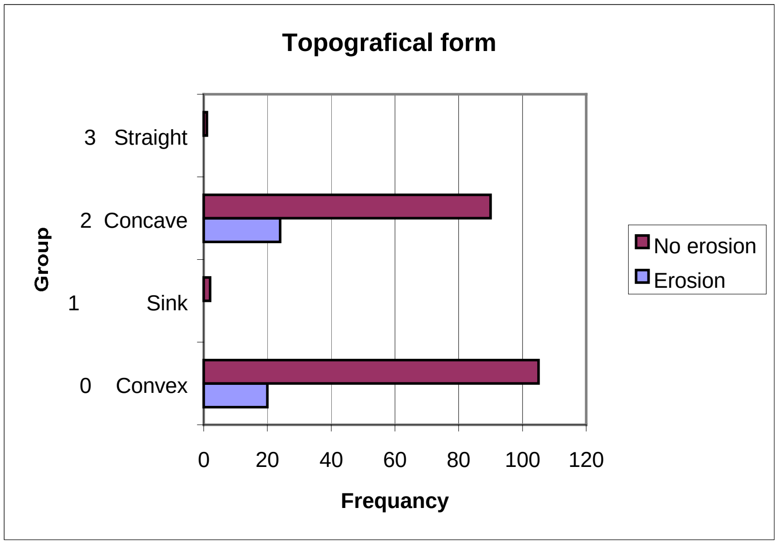

Figure 11. Histogram of the distribution of points between no erosion and erosion for every group. The group number is displayed as single numbers on the left side in the figure.

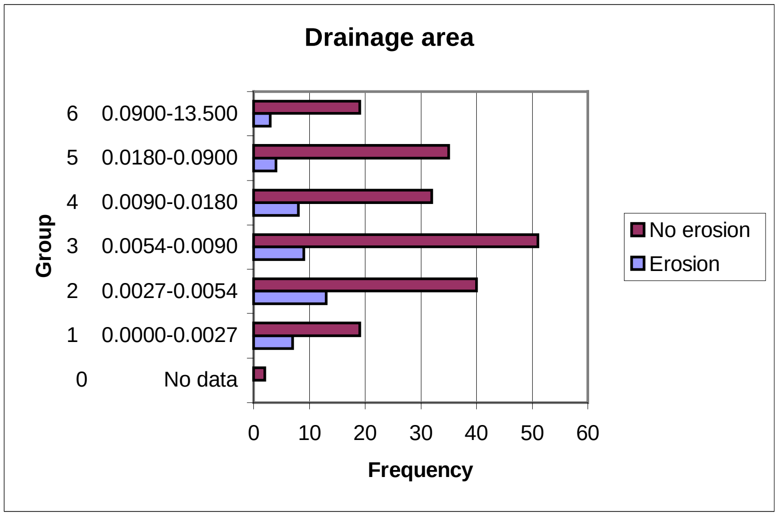

Figure 12. Histogram of the distribution of points between no erosion and erosion for every group. The group number is displayed as single numbers on the left side in the figure. The group extent is displayed in km^2.

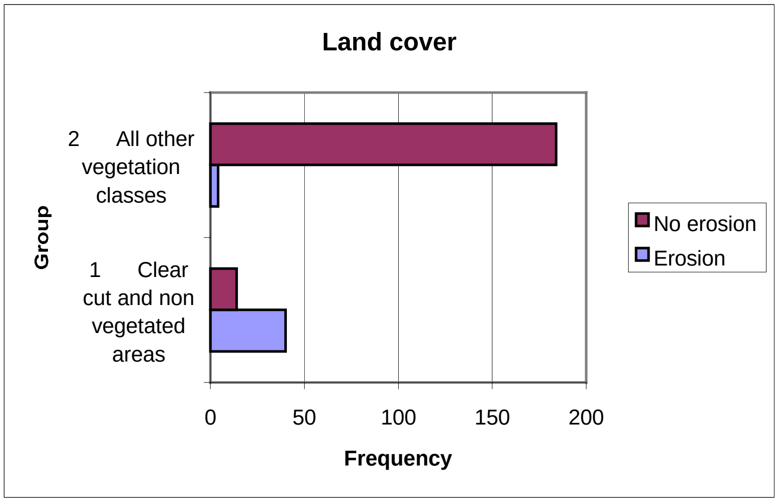

Figure 13. Histogram of the distribution of points between no erosion and erosion for every group. The group number is displayed as single numbers on the left side in the figure.

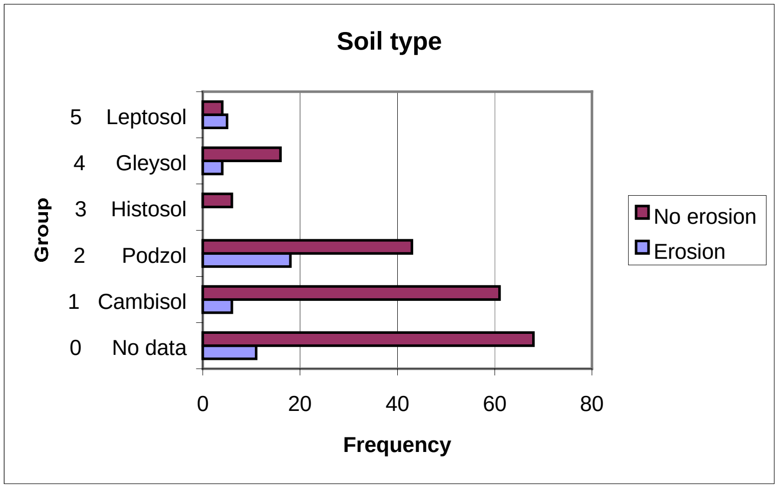

Figure 14. Histogram of the distribution of points between no erosion and erosion for every group. The group number is displayed as single numbers on the left side in the figure.

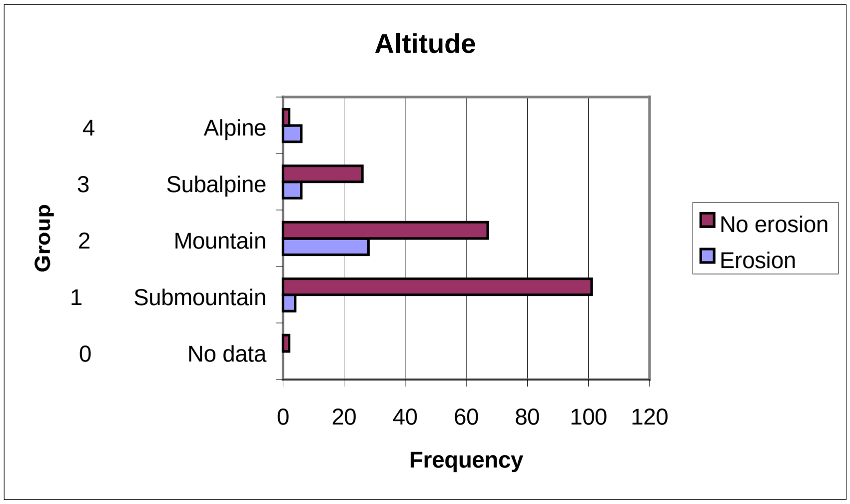

Figure 15. Histogram of the distribution of points between no erosion and erosion for every group. The group number is displayed as single numbers on the left side in the figure.

4.4.7.2 Nonparametric analysis

In addition to the histograms nonparametric analyses, Mann-Whitney U and Kruskal-Wallis tests (see further Pagano, 1994) were performed for the seven factors to examine if there were any significant differences between the factors of erosion and no erosion. In the Mann-Whitney U test we tested whether there was any significant difference between erosion points and the total number of evaluation points. In the Kruskal-Wallis test we tested the difference between erosion points and no erosion points for all of the groups. This was made for each of the seven groups (table 10-11).

Table 10. Mann-Whitney U test for the different factors of erosion and no erosion, 95.1% confidence interval.

Factor	*P-value*
Drainage area	0.1164
Topographical form	0.7916
Slope gradient	0.0003
Slope aspect	0.1024
Land cover	0.0000
Soil type	0.0132
Altitude	0.0000

Table 11. Kruskal-Wallis test for the different factors.

Factor	*P-value*
Drainage area	0.867
Topographical form	0.860
Slope gradient	0.006
Slope aspect	0.971
Land cover	0.000
Soil type	0.082
Altitude	0.000

4.4.8 Weighting of the different groups

From the results of the histograms and nonparametric analyses best estimate weights were assigned to the different groups according to how important they are to the arise of erosion. Calculus of the distribution expressed in percent between every group of every factor were estimated to determine how large impact every group has on erosion vs. no erosion, as shown in equation 16 and 17. Tables over these calculuses can be found in appendix 5.

$$X=F_i; G_j ;E_k / N(G_j) \tag{16}$$

and

$$Z= F_i ;G_j ;E_k /E \tag{17}$$

where:

X : Percentage of erosion/no erosion points of the total number of $N(G_j)$.
Z : Percentage of erosion/no erosion points of the total number of E.
F_i : factor 1-7
G_j : 1-j group for factor i
E_k : erosion or no erosion
$N(G_j)$: total amount of evaluation points (erosion/no erosion)
E : total amount of both erosion and no erosion points in group j

The factors where weighted and multiplied to create an erosion map.

The vegetation cover was considered to be the most important factor and therefore it was weighted high. The second most important factor was thought to be the slope gradient, thereafter soil and last the altitude. In table 12-15 the weights for the different factors are displayed.

Table 12. Land cover weights.

Weight	*Land cover*
10	Clear cuts and areas with no vegetation
1	All other land cover classes

Table 13. Slope gradient weights.

Weight	*Slope gradient (°)*
4	16.7-90
2	5.7-16.7
0.5	0-5.7

Table 14. Soil type weights.

Weight	*Soil type*
3	Leptosol
1	Podzol
0.5	Cambisol, Histosol and Gleysol

Table 15. Altitude weights.

Weight	*Altitude (m a.s.l.)*
2	1 450-1 602
1	800-1 450
0.5	400-800

4.4.9 Erosion risk equation

The erosion risk assessment is expressed using the following equation;

$$(\text{Land cover} * \text{Slope gradient} * \text{Soil type} * \text{Altitude} * \text{Precipitation}) \geq 10 \qquad (18)$$

The value of 10 was set by testing and evaluating different group values and product values.

4.5 Accuracy assessment

In order to assess the classification accuracy, confusion matrices were constructed for the performed classifications (table 16). Producer's accuracy and user's accuracy for every class, overall accuracy and a Kappa value were calculated and using the Kappa statistics we tested if there was a significant difference in the accuracy between the rule-based classification map and the maximum likelihood classification map using the same land cover classes. The statistical methods used to assess the accuracy are described below.

4.5.1 Theory

User's accuracy is the probability that a randomly chosen point in the map is correctly classified (Equation 19) (Cambell, 1996).

$$A_i = \left(P_{correct} / P_{map} \right) * 100 \qquad (19)$$

where

$P_{correct}$ is the total number of correct classified points for class *i* and
P_{map} is the total number of evaluation points for class *i* in the map

The "producer's accuracy" is the probability that a randomly chosen point in reality is correctly represented in the map (equation 20).

$$B_i = \left(P_{correct} / P_{evaluation} \right) * 100 \qquad (20)$$

where

$P_{evaluation}$ is the total number of evaluation points for class *i* in reality.

An overall accuracy is calculated by dividing the total number of correctly classified points with the total number of evaluation points. The product is multiplied by 100 and produces an estimation of the overall accuracy (Cambell, 1996).

To make an assessment of the overall agreement between image data and reference data, the Kappa or K value is used (equation 21) (Skidmore et al, 1996).

$$K = \frac{\theta_1 - \theta_2}{1 - \theta_2} \qquad (21)$$

where

$$\theta_1 = \sum_i pii \text{ and } \theta_2 = \sum_i p_{i+} p_{+i}$$

p_{i+} is the sum of the ith row and p_{+i} is the sum of the ith column. *pii* is the number of observations in row i and column i. The asymptotic variance of K is estimated by;

$$\sigma_\infty^2[K] = \frac{1}{N}\left\{\frac{\theta_1(1-\theta_1)}{(1-\theta_2)^2} + \frac{2(1-\theta_1)(2\theta_1\theta_2-\theta_3)}{(1-\theta_2)^3} + \frac{(1-\theta_1)^2(\theta_4-4\theta_2{}^2)}{(1-\theta_2)^4}\right\} \tag{22}$$

where

$$\theta_3 = \sum_i p_{ii}(p_{i+}+p_{+i}) \text{ and } \theta_4 = \sum_i p_{ij}(p_{i+}+p_{+i})^2$$

Kappa ranges in value from 0 (no association, i.e. any agreement between the two images equals chance agreement) to 1 (full association). Kappa can also be negative, which signifies less then chance agreement.

To test for a statistically significant difference between two produced maps the kappa values for map 1 and map 2 and their associated variance can be used to evaluate the normal curve deviate: i.e.,

$$z_t = \frac{K_1 - K_2}{\sqrt{\sigma_{K1}^2 + \sigma_{K2}^2}} \tag{23}$$

A null hypothesis can be set up to test whether the K values differ;

$H_0 : K_1 = K_2$

versus

$H_1: K_1 \neq K_2$

The null hypothesis is rejected using the normal curve deviate statistic (z) for α=0.05 if $z_t > 1.96$.

5 RESULTS

5.1 Land cover classification

The produced land cover maps over the Krkonoše National Park are shown in appendix 6 and allow a visual comparison of the two techniques. Four maps are included (table 16).

Table 16. In this study four maps were produced; (1) a rule-based classification with 21 land cover classes, (2) a rule-based classification with 11 merged, major classes, (3) a rule-based classification with 14 land cover classes comparable to the maximum likelihood classification. For these classifications the overall kappa and the overall accuracy were calculated.

Map	*Number of classes*	*Overall kappa*	*Overall accuracy (%)*
Rule-based classification (1)	21	0.58	61.5
Rule-based classification (2)	11	0.69	74.9
Rule-based classification (3)	14	0.63	67.3
Maximum likelihood classification	14	0.40	45.7

Table 17 to 20 presents confusion matrices and a summary of the accuracy results. The confusion matrix and the statistical analyses of accuracy for the rule-based classification map including 21 land cover classes are displayed in table 17.

Table 17. Confusion matrix and statistical analyses of accuracy for the rule-based map including 21 classes.

evaluation map	PB	WMM	DMM	WSM	DSM	SY	SM	MPS	MP	MDS	DF	AB	HRB	AW	AGL	CF	CC	RS	MS	W	Sum	User's Accu-racy (%)
NC*	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	2	0	0	0	6	0.0
PB	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	100.0
WMM	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	100.0
DMM	0	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	87.5
WSM	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.0
DSM	0	0	0	1	23	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	28	82.1
SY	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	66.7
SM	0	0	2	2	1	3	27	0	0	4	0	0	0	1	0	0	5	0	0	0	45	60.0
MPS	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	50.0
MP	1	0	0	0	0	0	1	4	6	0	0	0	0	0	0	0	0	0	0	0	12	50.0
MDS	0	0	0	0	0	1	0	1	0	2	0	1	0	1	0	0	0	0	0	0	6	33.3
DF	0	0	0	0	1	0	1	0	0	0	5	0	1	0	0	0	0	0	0	0	8	62.5
AB	0	0	0	0	0	0	10	0	0	3	2	8	0	3	0	0	0	0	0	0	26	30.8
HBR	0	0	0	1	0	0	1	0	0	1	2	0	0	0	0	0	0	0	0	0	5	0.0
AW	0	0	0	0	0	0	0	0	0	2	1	0	0	4	0	0	1	0	0	0	8	50.0
AGL	1	0	0	0	0	0	0	0	2	0	0	0	0	0	6	0	1	3	0	0	13	46.2
CF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	1	0	8	87.5
CC	0	1	2	0	0	3	0	0	0	0	0	0	0	0	0	0	20	0	0	0	26	76.9
RS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	7	100.0
MS	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	10	90.0
W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	100.0
Sum	4	4	11	4	28	9	45	7	8	12	10	9	1	10	6	10	29	10	10	4	231	
Producer's Accuracy (%)	50.0	50.0	63.6	0.0	82.1	22.2	64.3	16.7	75.0	16.7	50.0	88.9	0.0	40.0	100	70.0	74.1	70.0	90.0	100		

***** *For a complete list of the abbreviations, see appendix 4.*

Overall Kappa= 0.58 **Overall Accuracy**= 61.5%

The highest overall accuracy for the rule-based classification map was computed when more infrequent and complex classes were merged into 11 larger classes. The results are displayed in table 18.

Table 18. Confusion matrix and statistical analyses of accuracy for the rule-based classification using 11 merged, lager classes.

evaluation map	PB	CON	AD	M	AGL	CF	CC	RS	MS	W	Sum	User's Accuracy (%)
NC*	0	4	0	0	0	0	2	0	0	0	6	0
PB	2	0	0	0	0	0	0	0	0	0	2	100
CON	1	46	5	5	0	0	5	0	0	0	62	74.2
AD	0	14	36	2	0	0	1	0	0	0	53	67.9
M	0	0	1	36	0	3	0	0	0	0	40	90.0
AGL	1	2	0	0	6	0	1	3	0	0	13	46.1
CF	0	0	0	0	0	7	0	0	1	0	8	87.5
CC	0	3	0	3	0	0	20	0	0	0	26	76.9
RS	0	0	0	0	0	0	0	7	0	0	7	100
MS	0	0	0	1	0	0	0	0	9	0	10	90.0
W	0	0	0	0	0	0	0	0	0	4	4	100
Sum	4	59	42	47	6	10	29	10	10	4	221	
Producer's accuracy (%)	50.0	66.7	85.7	76.6	100.0	70.0	69.0	70.0	90.0	100		

*** *For a complete list of the abbreviations, see appendix 4.*

Overall Kappa= 0.69 **Overall Accuracy**= 74.9%

The maximum likelihood classification contains 14 land cover classes and to compare the two techniques the rule-based classification was reduced to 14 land cover classes comparable to the maximum likelihood classification. Results from the statistical analyses and a confusion matrix are shown in table 19.

Table 19. Confusion matrix and statistical analyses of accuracy for the rule-based classification map with classes comparable to the land cover classes of the maximum likelihood classification.

evaluation map	SF	MP	MDS	DF	BF	AW	M	AGL	CF	CC	RS	MS	W	Sum	User's Accuracy (%)
NC*	3	0	0	0	0	0	0	0	0	2	0	0	0	5	0.0
SF	34	0	4	0	0	1	5	0	0	5	0	0	0	49	69.4
MP	1	6	0	0	0	0	0	0	0	0	0	0	0	7	85.7
MDS	1	0	2	0	1	1	0	0	0	0	0	0	0	5	40.0
DF	1	0	0	5	1	0	1	0	0	0	0	0	0	8	62.5
BF	11	0	4	4	8	3	1	0	0	0	0	0	0	31	25.81
AW	0	0	2	1	0	4	0	0	0	1	0	0	0	8	50.0
M	0	0	0	0	0	1	36	0	3	0	0	0	0	40	90.0
AGL	0	2	0	0	0	0	0	6	0	1	3	0	0	12	50.0
CF	0	0	0	0	0	0	0	0	7	0	0	1	0	8	87.5
CC	3	0	0	0	0	0	3	0	0	20	0	0	0	26	76.9
RS	0	0	0	0	0	0	0	0	0	0	7	0	0	7	100
MS	0	0	0	0	0	0	1	0	0	0	0	9	0	10	90.0
W	0	0	0	0	0	0	0	0	0	0	0	0	4	4	100
Sum	54	8	12	10	10	10	47	6	10	29	10	10	4	220	
Producer's accuracy (%)	63.0	75.0	16.7	50.0	80.0	40.0	76.6	100	70.0	69.0	70.0	90.0	100		

*** *For a complete list of the abbreviations, see appendix 4.*

Overall Kappa= 0.63 **Overall Accuracy=**67.3%

The accuracy assessment and the confusion matrix for the maximum likelihood classification are shown in table 20.

Table 20. Confusion matrix and statistical analyses of accuracy of the maximum likelihood classification map.

evaluation map	SF	MP	MDS	DF	BF	AW	M	AGL	CF	CC	RS	MS	W	Sum	User's Accuracy (%)
NC*	3	1	0	0	0	0	0	0	1	3	5	0	0	13	0.0
SF	18	0	0	0	0	1	0	0	0	1	0	0	0	20	90.0
MP	10	5	0	0	0	0	3	0	0	4	0	0	0	22	22.7
MDS	3	1	1	1	1	1	1	0	0	1	0	0	0	10	10.0
DF	0	0	0	1	0	0	0	0	0	0	0	0	0	1	100
BF	15	0	8	4	3	4	3	0	0	0	0	0	0	37	8.1
AW	4	0	3	4	6	3	1	0	0	0	0	0	0	21	14.3
M	0	0	0	0	0	1	31	3	3	2	0	0	0	40	77.5
AGL	0	0	0	0	0	0	2	3	0	0	0	0	0	5	60.0
CF	0	0	0	0	0	0	4	0	6	5	0	1	0	16	37.5
CC	1	1	0	0	0	0	1	0	0	13	1	0	0	17	76.4
RS	0	0	0	0	0	0	0	0	0	0	4	0	0	4	100
MS	0	0	0	0	0	0	1	0	0	0	0	9	0	10	90.0
W	0	0	0	0	0	0	0	0	0	0	0	0	4	4	100
Sum	54	8	12	10	10	10	47	6	10	29	10	10	4	220	
Producer's accuracy (%)	33.3	62.5	8.3	10.0	30.0	30.0	66.0	50.0	60.0	44.8	40.0	90.0	100		

***** *For a complete list of the abbreviations, see appendix 4.*

Overall Kappa= 0.40 **Overall Accuracy**= 45.7%

The rule-based classification and the maximum likelihood classification (14 land cover classes) were tested for a statistical significant difference in accuracy. The test yielded a computed test statistic of z = 4.45 which is more than the critical z value of z = 1.96 for a 95 percent confidence interval. Thus, we reject the null hypothesis and conclude that there is significant difference between the accuracy of the two maps.

5.2 Erosion risk assessment

The erosion risk assessment map of the Krkonoše National Park is displayed in appendix 6. Statistical accuracy analyses were calculated for the erosion risk map (table 21). The erosion risk map is divided into two classes, (1) erosion and (2) no erosion.

Table 21. Statistical analyses of accuracy for the erosion risk assessment map.

evaluation map	1	2	Sum	User's Accuracy (%)
0	0	1	1	
1	27	15	42	64.3
2	17	182	199	91.5
Sum	44	198	242	
Producers accuracy (%)	61.4	91.9		

Overall Kappa= 0.54 **Overall Accuracy** =86.4%

6 DISCUSSION

6.1 Land cover classification

The accuracy evaluation for the rule-based classification map with 21 land cover classes yields an overall accuracy of 61.5% and an overall kappa of 0.58 (table 17). The number of evaluation points amounts to 231 and they differ considerably between the classes. According to Congalton (1991), a good rule of thumb is to collect a minimum of 50 samples for every land use or vegetation category. Fifty samples for every land cover class would mean a total number of 1000 sample points. This number was not obtained for every class and for 5 classes the number does not exceed 5 sample points (table 17). The low number of evaluation points for these classes yields unreliable accuracy assessments. To illustrate this, we can use the classes wet submountain meadow and herb rich beech which both have a producer's accuracy of 0.00% and 4 respectively 1 evaluation points. These two land cover classes are scarce and difficult to locate in the field. They are labelled based on certain vegetation characteristics (appendix 1) and our limited knowledge of these vegetation species and the mosaic vegetation pattern made it very difficult to find satisfactory evaluation areas.

Table 18 contains the confusion matrix and accuracy assessment for the rule-based classification using 11 classes. The overall accuracy for this map is 74.9% and the overall kappa 0.69. This indicates that the relatively low accuracy of the rule-based classification with 21 land cover classes partly is caused by the rather low accuracy of the more infrequent and complex classes. The production rules applied in the rule-based classification system attempting to locate these vegetation classes have not been all together successful. The most important reason for this result is probably that the definition of the more infrequent and complex land cover classes should have been based on statistical analyses of field work results, especially for mixed mountain pine and spruce stands, mountain pine, the two beech classes and for wet meadows. A better and a more accurate estimation of the cover, for example of mixed mountain pine and spruce, could have been obtained if extensive research on their living conditions had been performed in the field. Mixed mountain pine and spruce were encountered in the Krkonoše Mts. as far down as 1230 m a.s.l. up to 1390 m a.s.l. Instead of a generalised altitude zone independent of factors affecting growth conditions, a more flexible way of execution could have been applied by the production rules, where factors like slope, aspect and soil had been taken into account resulting in a more accurate classification.

Good results were reached for dry submountain meadow and dry mountain meadow, cultivated fields, clear cut and rocky surfaces that have both high user's and producer's accuracy and also for major settlements and lakes and ponds, which were manually classified. The accuracy of mature spruce forest, which covers a large part of the park, was surprisingly low (user's accuracy: 60.0%, producer's accuracy: 64.3%). We suspect that this result is caused by the fact that most evaluation points were sampled in the valleys where the roads are situated. The composition of the forest is predominately mosaic causing misclassifications in the valleys. The accuracy evaluation also indicates difficulties in separating young spruce stands from mature spruce and clear cuts. The main reason is probably the difficulty experienced in the field when determining the age of the stands. The age was determined by counting the circle of branches for each year on a tree. Theoretically this is an uncomplicated method but it is difficult in the field to determine an exact age of a spruce stand and this probably caused misclassifications of the evaluation points. Furthermore, the low accuracy number is most likely caused by the fact that stands aged 7-9 years old are label mature spruce stands since there was no alternative due to the age of the forestry management plan.

The accuracy of the five classes of different kinds of deciduous forest (table 2) does not ascent above 63% in either user's accuracy or producer's accuracy except for acidophilus beech, which has a producer's accuracy of 88.9%. Low spectral seperability between the classes probably causes this result. Mixed deciduous and spruce forest had the lowest accuracy for these five classes, except for herb rich beech, where the evaluation points for the class only resulted in two correctly classified points, four points were located in mature spruce forest and five points in beech forest and alderwoods.

A user's accuracy of 50.0% and a producer's accuracy of 40.0% were calculated for the alderwoods class. This result is satisfactory considering that this vegetation type grows alongside the streams and seldom has a width of more than 30 m. This causes not only mixed pixels to occur, but also since the definition of this class is based on its location near the streams the accuracy of the digital stream layer is a critical factor determining the accuracy of this class as well as the error factor of the GPS.

6.1.1 The rule-based classification system – an improvement?

There are obvious visual differences between the rule-based classification and the maximum likelihood classification using the same land cover classes (appendix 6). The test statistic for the kappa values reveals that there is a significant difference between the two maps. Thus, it appears that the rule-based classification system is an improvement. The use of ancillary data and prior probabilities clearly enhances the results of a classification based solely on spectral properties.

Even though the rule-based method resulted in the best classification accuracy, the 67.3% overall accuracy is still not remarkably high. There are several reasons for this result. First, a very undulating terrain characterises the National Park with a difference in altitude between the foothills to the mountain peaks of approximately 1200 m. The differences in altitude and aspect of the slopes create shadowing effects and differences in spectral behaviour. These effects are to some degree corrected for using various radiometric and topographic correction models, for example the Lambertian model used in this study. Some effects still exits after applying the correction models causing a greater variance in spectral behaviour within a class (Smith et al, 1980).

Secondly, the vegetation is heterogeneous, i.e. it grows in a mosaic manner, except for larger plantations of spruce in the mountain zone. This produces pixels with mixed information classes and may cause classification errors. The relative coarse spatial resolution of the satellite data, in this case 30 m, places a need of rather homogenous vegetation types in order for it to be correctly represented in the satellite data.

Comparing the producer's accuracy for these two maps reveal an increase in accuracy for every class in the rule-based classification map (excluding manually mapped classes, i.e. lakes and ponds and major settlements). The growth ranges from a 8.4 percentage points increase for the class mixed deciduous and spruce forest to a 50 percentage points increase for the classes beech forest and subalpine/alpine grass and lichen vegetation. The overall accuracy value of 67.3% can therefore, when taking into account the above stated, be considered satisfactory.

6.1.2 Problems and further improvements

The outcome of the maximum likelihood classification is heavily dependent on the quality of the training areas. Locating training areas in the field are in most cases the superior method, but the time frame and limited resources as well as the climate in this particular region during winter resulted in the use of black and white aerial orthophotos and a forest management plan. The proposed land cover classes contained several kinds of deciduous forest (table 2). Training areas for these classes could not solely be based on orthophotos, which resulted in training areas predominately based on the forest management plan from 1990-92. We suspect that a better classification could have been obtained if training areas had been collected in the field instead of been based on black and white aerial orthophotos and a ten year old forest management plan. Generalisations caused by the forest management plan could then have been avoided.

A null class was included in the maximum likelihood classification. Areas not classified cover a notable part of the National Park (8.7%). The main part of these areas are located on northern slopes which due to the Lambertian topographic correction model been overcompensated (Ekstrand, 1996) and therefore have not obtained a class label. The number of nonclassified pixels could have been decreased if a greater threshold had been used. This procedure would have forced more pixels to be classified according to the most likely class, but it would also increase the risk for a class to include incorrectly classified pixels.

An objection to the rule-based approach is that the result is categorical. Gradual variation and measurement errors in environmental data are ignored. Errors may be introduced into a GIS by incorrect input data, or from errors inherent in the analysis procedure used to produce the data. In a knowledge-based system errors may be introduced by the input data layers or through the production rules (Skidmore et al, 1996). For example, the digital soil map contain errors, both as a result of the generalisation of a continuous surface and the fact that the soil map is derived and generalised from the forestry management plan. A number of examples are apparent from this study where incorrect input data layers caused the wrong land cover class to be predicted by the rule-based classification system. The peat bog vegetation type is clearly associated with a histosol soil type. There is an area at Labska Loka classified as subalpine/alpine grass and lichen vegetation by the rule-based classification system but in field recognised as a peat bog. The discussed evaluation point is located on a podzol soil type instead of a histosol soil type in the digital soil map and is therefore not correctly classified.

To improve the rule-based classification system, multiple prior probabilities could be used. Vegetation and soil properties are closely related to each other. Certain vegetation types only grow on certain soil and the vegetation modifies the properties of the soil. This relationship can be used to estimate prior probabilities incorporated in a rule-based classification system.

6.1.3 Classification alternatives

The unique nature in the Krkonoše National Park inevitably causes problems with land cover classifications. The differences in altitude and the mosaic vegetation make it difficult to perform a high standard classification based on a satellite image.

So are rule-based land cover classifications of this particular area based on satellite images satisfactory? The answer to this question is of course depending on the requirements but as the results of the study discussed above show, the answer to this question is yes; -especially when larger, more generalised classes are used. Classifications based on satellite images provides a rather quick but, in most cases, still reliable classification, but they, of course, are more generalised than interpretations based on aerial photographs or for that matter in-field cartography. To achieve a more detailed classification these methods are to prefer but they are more time consuming and costly. To improve a classification based on satellite images, aerial orthophotos; preferably colour aerial orthophotos could be used as a compliment to locate smaller and more infrequent land cover classes. In-field cartography is probably the best way to map smaller classes since the field expert then considers not only the dominant vegetation type but also, for example, certain species of vegetation and soil moisture to conclude whether the area should be labelled wet meadow or dry meadow. To incorporate this kind of knowledge into a land cover classification of a satellite image, the use of a knowledge-based or rule-based classification system, combined with ancillary data in a GIS environment probably offers the best combination of cost efficiency and accuracy with the current technology.

6.2 Erosion risk assessment

The histograms (figure 9-15) showed that the distribution of evaluation points between different groups of drainage area, topographical form and slope aspect for erosion were similar to those taken for no erosion. The difference in distribution between the groups in land cover, slope gradient, soil type and altitude were much larger. The Mann-Whitney U test and the Kruskal-Wallis test for the seven factors (table 10-11) showed that there were no significant differences between the groups of drainage area, topographical form and slope aspect. Due to the results of the histograms and significance tests we decided not to use these factors in the erosion risk model, as they did not seem to affect the erosion risk in the park.

6.2.1 Significant factors

The performed Mann-Whitney U test and Kruskal-Wallis test (table 10-11) in addition to the produced histogram for the land cover factor indicate that this is the most important factor controlling erosion in the area. Due to air pollution much of the forests have been damaged. This makes them less resistant to insects, like the bark beetle (Internet 2). To control the bark beetle population large areas with decayed trees are being clear cut. In some areas above the timberline there are little or no vegetation cover to protect the soil and ground from erosion. Undisturbed forests and grass provides the best natural protection for soil from being eroded (Brady, 1996). The precipitation intercepts on leaves and stems and the energy of the precipitation is less direct to the soil. The root system mechanically strengthens the soil (Morgan, 1996) and hence lessens the erosion impact.

Erosion is expected to increase with the steepness of the slopes. The steeper and longer the slopes are the higher the velocity and volume of the surface runoff, and more soil will be eroded from the slopes (Morgan, 1996). In our analyses slope gradient showed the second lowest p-value, 0.0003 for the Mann-Whitney U test and 0.006 for the Kruskal-Wallis test. This result shows that this assumption is met in the Krkonoše Mts. where many slopes are very steep.

A soil with a relatively low erodibility factor may show signs of serious erosion when it occurs on long and steep slopes and soils with a much higher erodibility factor might show little or no erosion when occurring on short and gentle slopes (Wischmeier & Smith, 1978). Table 10 -11 indicates that this is a rather important factor in the area. We decided to use soil type as the third most important factor in the equation due to the fact that erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content (Morgan, 1996).

Both significance tests showed good seperability between the altitude zones. This is probably a result of the fact that much more forests are being cut down at higher elevations, slopes are steeper and for those reasons more erosion occur at higher altitudes. This indicates that altitude is a controlling factor in an area such as the Krkonoše Mts. with forests at high altitudes. Forests near the timberline at higher altitudes are both under climatic stress and anthropogenic stress due to air pollution, see 1.2.6.

The erosion risk assessment map for the Krkonoše Mts. has an overall accuracy of 86.4% and a Kappa value of 0.54 (table 21). Because of the large difference between the sizes of the evaluation points for each of the two classes, erosion and no erosion, the overall accuracy and the Kappa value in the erosion map disagree (Internet 5). The producer's accuracy, 61.4%, and user's accuracy, 64.3%, for erosion is rather low, compared with the accuracies for no erosion (producer's accuracy: 91.9%, user's accuracy: 91.5%).

The soil map and the DEM are not evaluated and the unknown accuracy influences the result. Preferably another set of GPS recordings should have been used to evaluate the erosion risk assessment to avoid any biases caused by the "training" set. This was however not possible due to the limited number of sample points attained in the field. Even though the erosion risk assessment map shows a high overall accuracy as a result of the high accuracy of no erosion. The National Park is about 600 km^2 and about 62 km^2 is affected or threatened by erosion.

6.2.2 Nonsignificant factors

The drainage area did not show any significant difference between the groups. It is thought of as being one of the main factors concerning erosion, since the length of slopes would increase the amount of water in the lower parts of a drainage area (Wischmeier & Smith, 1978). Usually an area that drains a larger area would be more sensitive to erosion than an area, which drains a smaller area. Our result might be an effect of the diversity of the terrain in the Krkonoše Mts. and the amount of precipitation. The slopes are broken up into smaller drainage areas, which of course are parts of larger ones. The undulation of the slopes makes it more difficult for sheet flows to erode the slopes.

Convex or straight slopes are more sensitive to erosion then concave slopes (Hudson, 1981) but the distribution between concave and convex slopes in our dataset are almost equal between erosion and no erosion. Therefore we cannot distinguish concave from convex slopes to be more or less easily affected by erosion. They appear to be equally sensitive to erosion.

The aspect of the slopes is not a predominant factor regarding the erosion in the Park. This factor had a p-value of 0.1024 in the Mann-Whitney test and 0.971 in the Kruskal-Wallis test.

6.3 Sampling strategy

The sampling strategy is most likely a factor influencing the result of this study. A disadvantage of the road sampling technique is that the distribution of the evaluation points is limited. The roads in this region is predominately located in the valleys that possesses a rather mosaic vegetation pattern. This means that a bias component is introduced into the data material. A better result of the land cover classification might have been achieved if another sampling strategy had been selected. According to Congalton (1988b) a stratified random sampling strategy is to recommend assessing the accuracy of classifications of remotely sensed data where a minimum number of samples are selected from each strata. Congalton (1988a) also states that perhaps some combination of random and systematic sampling would provide the best balance between statistical validity and practical application in places that are difficult to access. The limited amount of time available in the field and the difficulties of access presented by parts of the region made it difficult to apply the above discussed sampling methods.

Finally, the evaluation points were sampled in May 2000 approximately 8 months after the satellite data was recorded. In other words, the ground may change (i.e. cultivated fields are converted to temporary pastures etc) between the data registration and the accuracy assessment causing temporal problems and misclassifications.

7 GENERAL CONCLUSIONS

The classification produced by the rule-based system yields an overall accuracy of 61.5% and is the most reliable land cover map produced for this region to date. These numbers are relatively low but considering the differences in altitude, the mosaic vegetation pattern and the rather large number of land cover classes (21), the result is satisfactory, especially if the number of land cover classes is reduced. A higher accuracy is reached if only 11 major classes are used, yielding an overall accuracy value of 74.9%. This indicates that the relatively low accuracy of the land cover map with 21 classes is partly caused by the rather low accuracy of the more infrequent and complex classes.

This study shows that a rule-based classification system and ancillary data clearly enhances a maximum likelihood classification based solely on spectral data. The maximum likelihood classification yields an overall accuracy of 45.7% compared to 67.3% for the rule-based classification using the same land cover classes. Test statistics reveal a significant difference in accuracy between the two maps. Hence, an interpretation of satellite data based solely on spectral information does not produce a satisfactory result for this region. To achieve an improved classification the use of ancillary data and prior probabilities in a rule-based classification system seems to offer a promising solution.

The overall accuracy of 86.4% for the erosion risk map is satisfactory. The large difference between the numbers of evaluation points for the two classes makes the evaluation of the map difficult. The evaluation points for erosion only constitute of 18.2% of the total number and therefore the evalution points for no erosion dominates the accuracy assessment. A better reliability for areas susceptible to erosion could have been achieved if a more equally distributed set of evaluation points regarding erosion/no erosion had been collected using a different sampling method.

The weighing of the different factors is a very difficult task. In the field only the presence of erosion or no erosion was noted. To make the model more reliable more fieldwork should be performed estimating the magnitude of the different factors and their importance regarding erosion in the Krkonoše Mts. It should be stressed that the produced erosion model only points out areas susceptible to erosion and does not perform any grading of the erosion risk.

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APPENDIX 1: DEFINITION OF LAND COVER CLASSES

Land cover classes	*Definition and characteriztica*	*Altitude (m a.s.l.)*	*Soil definition used in the rule-based classification system*
Peat bogs	Peat bogs not covered with trees		Histosols
Wet submountain meadow	Wet pastures and meadows; Sedge (*Cyperaceae*), Meadowsweet (*Filipendula ulmaria*), sorrel (*Rumex acetosa*) and (*Petasites hybridus*)	< 800	• Gleyic Cambisols • Gleyic-Dystric Cambisol • Gleyic-Eutric Cambisol • Cambi-Dystric Gleysols • Stagni-Dystric Gleysols • Umbric Gleysols • Dystric Gleysols
Dry submountain meadow	Pastures and meadows, flower rich; buttercup (*Ranunculus acris*), red clover (*Trifolium pratense*), Cow parsley (*Anthriscus silvestris*), Wood cranesbill (*Geranium silvaticum*) and (*Melandrium rubrum*)	< 800	
Wet mountain meadow	Wet pastures and meadows; Sedge (*Cyperaceae*), Meadowsweet (*Filipendula ulmaria*), sorrel (*Rumex acetosa*) and (*Petasites hybridus*)	≥800 - ≤1200	• Gleyic Cambisols • Gleyic-Dystric Cambisol • Gleyic-Eutric Cambisol • Cambi-Dystric Gleysols • Stagni-Dystric Gleysols • Umbric Gleysols • Dystric Gleysols

Dry mountain meadow	Pastures and meadows, flower rich; buttercup (*Ranunculus acris*), red clover (*Trifolium pratense*), Cow parsley (*Anthriscus silvestris*), Wood cranesbill (*Geranium silvaticum*) and (*Melandrium rubrum*)	≥800 - ≤1200
Spruce forest – young stands	Norwegian spruce stands (*Picea abies*) aged between 10 to 20 years old	< 1250
Spruce forest – mature stands	Norwegian spruce stands (*Picea abies*) older than 20 years	< 1250
Mixed mountain pine and spruce stands	Approximately 50% Norwegian spruce (*Picea abies*) stands and 50% mountain pine (*Pinus mugo*) stands	≥1250 - ≤1290
Mountain pine	Stands of mountain pine (*Pinus mugo*) covering a minimum of appr. 70% of the area	>1290 - ≤1450
Mixed spruce and deciduous forest	Approximately 50% Norwegian spruce (*Picea abies*) stands and 50% deciduous stands	< 1250
Deciduous forest	All kinds of deciduous forest, (excluding major stands of beech and alderwoods growing along the major streams in the submountain zone). Mt ash (*Sorbus aucuparia*), aspen (*Populus tremula*), oak (*Querus robur*), maple (Acer platanoides, *pseudoplatanus*), birch (*betula verrucosa*), beech (*Fagus sylvatica*).	< 1250

Acidophilus beech forest	Beech forest (*Fagus sylvatica*). Very little or none understore vegetation.	< 1250	• Spodi-Dystric Cambisol • Gleyic-Dystric Cambisol • Dystric Cambisol • Haplic Podzol • Lithic Leptosols • Umbric Gleysols • Dystric Gleysols • Umbric Leptosols • Stagni-Dystric Gleysols • Cambi-Dystric Gleysols • Spodi-Umbric Leptosols • Gleyic Cambisols
Herb rich beech forest	Beech forest (*Fagus sylvatica*). Frequent herbs, rarely sedges or grasses	< 1250	• Gleyic-Eutric Cambisol • Eutric cambisol • Fibric Histosols • Eutri-Fibric Histosols
Alderwoods	Alder (*Alnus incana*) and ash (*Fraxinus excelsior*) stands along the major streams in submountain zone	< 800	
Cultivated fields	Cultivated fields	< 1000	
Subalpine/alpine grass and lichen vegetation	Mattgrass meadows, heather, shrubby, grassy and lichen vegetation	>1200	
Clear cut	Clear cut areas and young plantations approximately 1- 7 years old		
Rocky surfaces	Rocky surfaces and debris		
Major settlements	Larger villages and towns		
Lakes & ponds	Lakes & ponds		
Nonclassified			

APPENDIX 2: DECISION TREE PSEUDO CODE

Staring at level 4 (figure 7).

```
New Thematic map

Water?
Yes: → Water
No: Non-water

Major settlements?
    Yes: → Major settlements
    No: Non-settlements

Forest?
    Yes: Conifer forest?
                Yes: altitude?
                    <1250m a.s.l. → spruce forest
                    ≥1250m a.s.l. - ≤1290m a.s.l. → mixed mountain pine and
                        spruce
                    >1290m a.s.l. - ≤1450m a.s.l. → mountain pine
                    >1450m a.s.l. → Subalpine/alpine grass and lichen
                        vegetation
                   :Forestry management plan?
                    ≤20 years old and spruce → young spruce forest
                    > 20 years old and spruce → mature spruce forest
                  :Not covered by the forestry management plan?
                    → Mature spruce forest
                No: classified as deciduous forest or mixed deciduous and spruce
                 forest or beech forest or alderwoods?
                    Yes: Altitude?
                        ≥1250m a.s.l. → subalpine/alpine grass and
                            lichen vegetation
                        :buffer zone along the major streams?
                                <>30m: → alderwoods
                                No: alderwoods → Mixed deciduous
                                and spruce forest
                        : Forest type?
                        Mixed deciduous and spruce forest → mixed
                        deciduous and spruce forest
                        Beech
                            Yes: Soil?
                            Acid → Acidophilus beech
                            Non-acid → Herb rich beech
                         : Altitude and non-classified beech?
```

                >800m a.s.l. → Acidophilus beech
                ≤800m a.s.l. → Herb rich beech
            Deciduous forest → deciduous forest

No: Non-forest

Vegetated?
- Yes: Cultivated fields?
  - Yes: Altitude?
    - <1000m a.s.l. → Cultivated fields
    - ≥1000m a.s.l. → Meadow
  - No: Subalpine/alpine grass and lichen vegetation?
    - Yes: Altitude and no data?
      - > 1450m a.s.l. → Subalpine/alpine grass and lichen vegetation
    - :Soil?
      - Histosol → Peat bog
      - Non-histosol → Subalpine/alpine grass and lichen vegetation
    - : Altitude and Subalpine/alpine grass and lichen vegetation?
      - > 1200m a.s.l. → Subalpine/alpine grass and lichen vegetation
      - ≤ 1200m a.s.l. → Meadow

    - No: Meadow?
      - Yes: Soil?
        - Histosols → Peat bog
        - Non-histosols→ Meadow
      - :Forest management plan?
        - Meadow → clear cut
      - :Altitude?
        - >1200m a.s.l. → Subalpine/alpine grass and lichen vegetation
      - :Altitude and river buffert?
        - <>60m and >800m a.s.l. → Wet mountain meadow
        - <>60m and ≤800m a.s.l. → Wet submountain meadow
      - : Altitude and soil?
        - >800m a.s.l. and gleysols or gleyic cambisols → Wet mountain meadow
        - >800m a.s.l. → Dry mountain meadow
        - ≤800m a.s.l. and gleysols or gleyic cambisols → Wet submountain meadow
        - ≤800m a.s.l. → Dry submountain meadow

- No: Clear cuts?
  - Yes: Soils and not FMP?
    - Histosols→ Peat bog
    - Non-histosols→ Clear cut
  - : Altitude?
    - >1290m a.s.l. → subalpine/alpine grass and lichen vegetation
    - ≤1290m a.s.l. → Clear cut
  - No: Rocky surfaces?
    - Yes: →Rocky surfaces
    - No: → Peat bogs?
      - Yes: →Peat bogs
      - No: Nonclassified

APPENDIX 3: PRIOR PROBABILITIES

Table A. Prior probabilities based on a previous land cover classification (1990)

Land use class	*Submountain zone*	*Mountain zone*	*Subalpine zone*	*Alpine zone*
Spruce forest	0.434	0.679	0.326	0.005
Beech	0.019	0.009	0.000025	0
Mixed deciduous & spruce forest	0.049	0.028	0.017	0.002
Deciduous forest	0.048	0.008	0.017	0.002
Mt. Pine	0	0.004	0.334	0.368
Clear cuts	0.013	0.186	0.086	0.115
Meadow	0.031	0.056	0.029	0.001
Subalpine/Alpine grass & lichen veg.	0	0.001	0.121	0.480
Cultivated fields	0.093	0.001	0	0
Pasture	0.262	0.013	0.000076	0
Alderwoods	-	-	-	-
Rocky surfaces	-	-	-	-

Table B. Prior probabilities based on the forest management plan (1990-1992)

Land use class	*Submountain zone*	*Mountain zone*	*Subalpine zone*	*Alpine zone*
Spruce forest	0.190	0.582	0.277	0.036
Beech	0.047	0.040	0.000063	0
Mixed deciduous & spruce forest	-	-	-	-
Deciduous forest	0.090	0.064	0.023	0.001
Mt. Pine	-	-	-	-
Clear cuts	-	-	-	-
Meadow	-	-	-	-
Subalpine/Alpine grass & lichen veg.	-	-	-	-
Cultivated fields	-	-	-	-
Pasture	-	-	-	-
Alderwoods	0.015	0.006	0.00057	0
Rocky surfaces	-	-	-	-

APPENDIX 4: LAND COVER ABBREVIATIONS

NC	Nonclassified
PB	Peat bog
WMM	Wet mountain meadow
DMM	Dry mountain meadow
WSM	Wet submountain meadow
DSM	Dry submountain meadow
SY	Spruce – young stands 10-20 years old
SM	Spruce – mature stands >20 years old
MPS	Mixed mountain pine and spruce stands
MP	Mountain pine
MDS	Mixed deciduous and spruce forest
DF	Deciduous forest
AB	Acidophilus beech
HRB	Herb rich beech
AW	Alderwoods
AGL	Subalpine/alpine grass and lichen vegetation
CF	Cultivated fields
CC	Clear cut
RS	Rocky surfaces
MS	Major settlements
W	Lakes and ponds
CON	Spruce-young and mature stands, mixed mountain pine and spruce stands, mountain pine stands
AD	All kinds of deciduous forest, i.e. mixed deciduous and spruce forest, deciduous forest, alderwoods, beech forest
M	All kinds of meadow, i.e. wet mountain and submountain meadow, dry mountain and submountain meadow
BF	Beech forest - acidophilus beech, herb rich beech

APPENDIX 5: DISTRIBUTION CALCULESES OF EROSION VS. NO EROSION

Table C. Distribution calculus of drainage area.

Class	*Total amount of points*	*Erosion (n)*	*No erosion (n)*	*Result of equation 17, (%), erosion.*	*Result of equation 17, (%), no erosion.*	*Result of equation 16, (%), erosion.*	*Result of equation 16, (%), no erosion.*
0	2	0	2	0.0	100	0.0	1.0
1	26	7	19	27.0	73.0	15.9	9.6
2	53	13	40	24.5	75.5	29.5	20.2
3	60	9	51	15.0	85.0	20.5	25.8
4	40	8	32	20.0	80.0	18.2	16.2
5	39	4	35	10.3	89.7	9.1	17.7
6	22	3	19	13.6	86.4	6.8	9.6

Table D. Distribution calculus for aspect.

Class	*Total amount of points*	*Erosion (n)*	*No erosion (n)*	*Result of equation 17, (%), erosion.*	*Result of equation 17, (%), no erosion.*	*Result of equation 16, (%), erosion.*	*Result of equation 16, (%), no erosion.*
0	1	0	1	0.0	100	0.0	0.5
1	11	2	9	18.2	81.8	4.5	4.6
2	14	2	12	14.3	85.7	4.5	6.1
3	37	7	30	18.9	81.1	15.9	15.2
4	35	6	29	24.0	76.0	13.6	14.7
5	39	4	35	10.3	89.7	9.1	17.8
6	60	11	49	18.3	81.7	25.0	24.9
7	27	6	21	22.2	77.8	13.6	10.7
8	18	6	12	33.3	66.6	13.6	6.1

Table E. Distribution calculus for topographic form.

Class	*Total amount of points*	*Erosion (n)*	*No erosion (n)*	*Result of equation 17, (%), erosion.*	*Result of equation 17, (%), no erosion.*	*Result of equation 16, (%), erosion.*	*Result of equation 16, (%), no erosion.*
0	125	20	105	16.0	84.0	45.5	53.0
1	2	0	2	0.0	100	0.0	1.0
2	114	24	90	21.0	79.0	54.5	45.5
3	1	0	1	0.0	100	0.0	0.5

Table F. Distribution calculus for slope gradient.

Class	*Total amount of points*	*Erosion (n)*	*No erosion (n)*	*Result of equation 17, (%), erosion.*	*Result of equation 17, (%), no erosion.*	*Result of equation 16, (%), erosion.*	*Result of equation 16, (%), no erosion.*
0	10	0	10	0.0	100	0.0	5.0
1	39	0	39	0.0	100	0.0	20.7
2	73	11	62	15.0	85.0	25.0	33.0
3	63	9	54	14.3	85.7	20.5	28.7
4	55	24	31	43.6	56.4	54.5	16.5
5	2	0	2	0.0	100	0.0	1.1

Table G. Distribution calculus for land cover.

Class	*Total amount of points*	*Erosion (n)*	*No erosion (n)*	*Result of equation 17, (%), erosion.*	*Result of equation 17, (%), no erosion.*	*Result of equation 16, (%), erosion.*	*Result of equation 16, (%), no erosion.*
1	54	40	14	74.0	26.0	90.9	7.1
2	188	4	184	2.1	97.9	9.1	92.9

Table H. Distribution calculus for soil type.

Class	*Total amount of points*	*Erosion (n)*	*No erosion (n)*	*Result of equation 17, (%), erosion.*	*Result of equation 17, (%), no erosion.*	*Result of equation 16, (%), erosion.*	*Result of equation 16, (%), no erosion.*
0	79	11	68	14.0	86.0	25.0	34.4
1	67	6	61	9.0	91.0	13.6	30.8
2	61	18	43	29.5	70.5	40.9	21.7
3	6	0	6	0.0	100	0.0	3.0
4	20	4	16	20.0	80.0	9.0	8.1
5	9	5	4	55.6	44.4	1.1	2.0

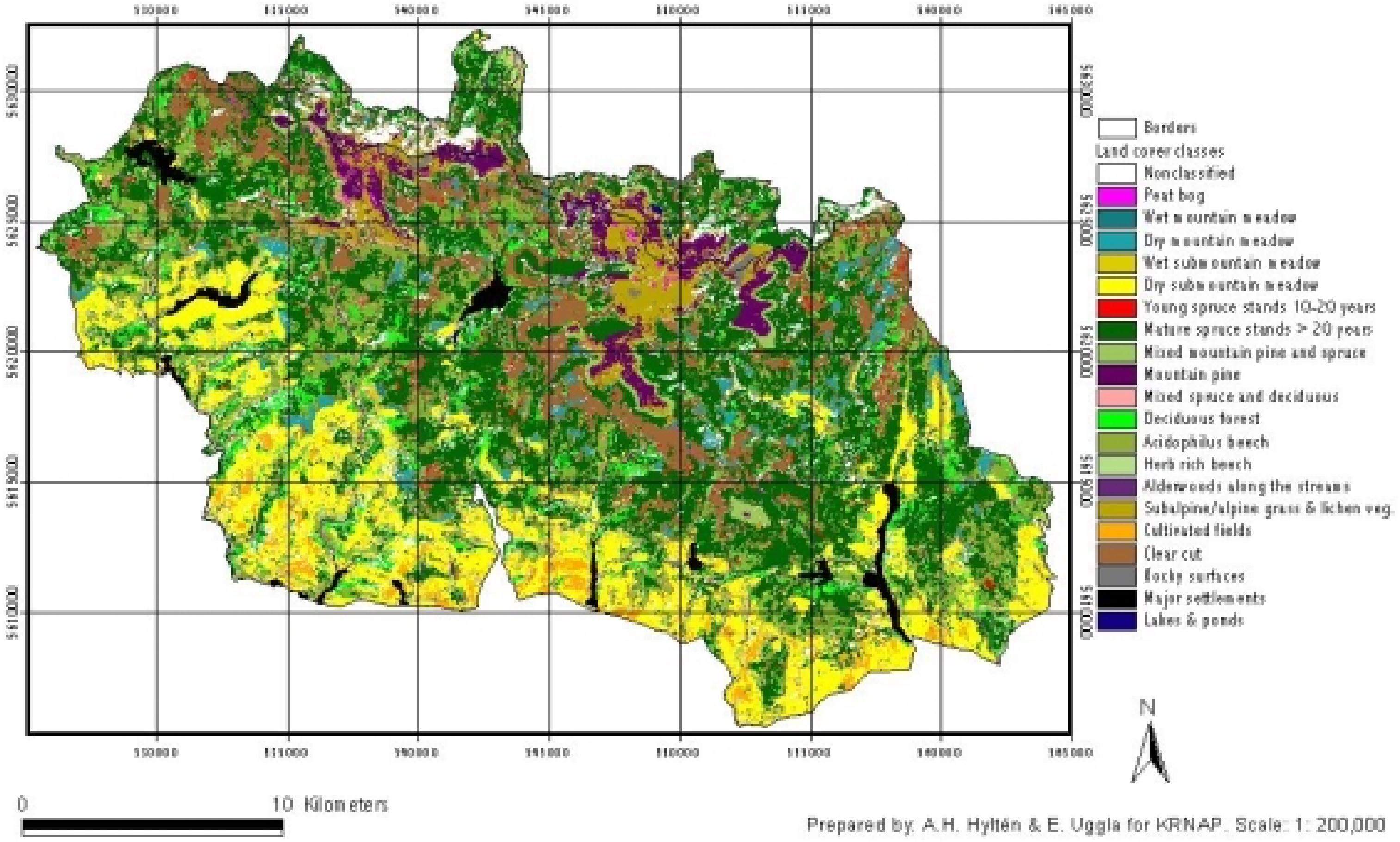
Table I. Distribution calculus for altitude.

Class	*Total amount of points*	*Erosion (n)*	*No erosion (n)*	*Result of equation 17, (%), erosion.*	*Result of equation 17, (%), no erosion.*	*Result of equation 16, (%), erosion.*	*Result of equation 16, (%), no erosion.*
1	105	4	101	3.8	96.2	9.1	51.5
2	95	28	67	29.5	70.5	63.6	34.2
3	32	6	26	18.8	81.2	13.6	13.3
4	8	6	2	75.0	25.0	13.6	1.0

APPENDIX 6: PRODUCED MAPS

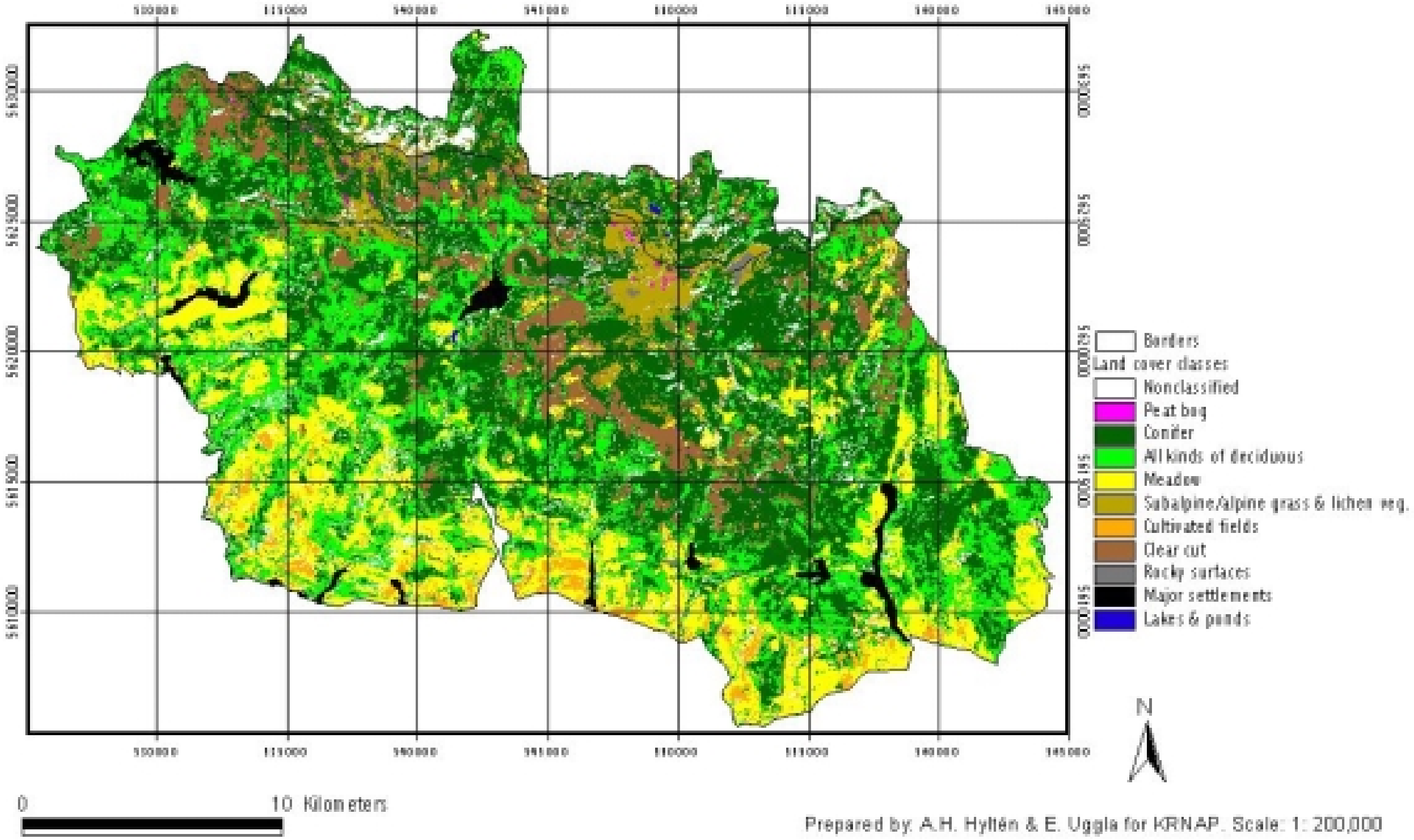
1) Rule-based land cover classification with 21 classes.
2) Rule-based land cover classification with 11 classes.
3) Rule-based land cover classification with 14 classes.
4) Maximum likelihood land cover classification with 14 classes.

Land cover classification of the Krkonose National Park (21 classes)



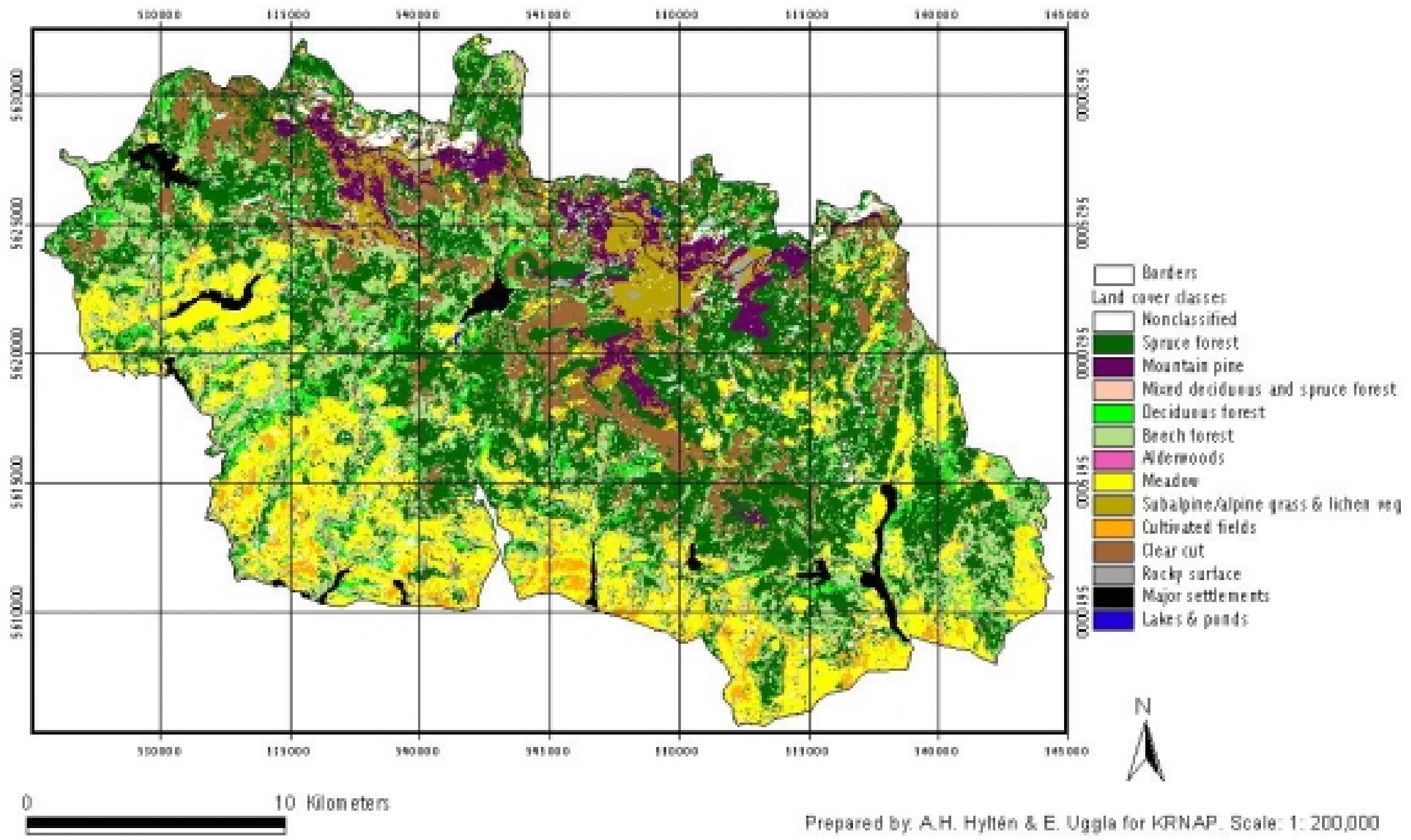
Prepared by: A.H. Hyltén & E. Uggla for KRNAP. Scale: 1: 200,000

Land cover classification of the Krkonose National Park (11 classes)



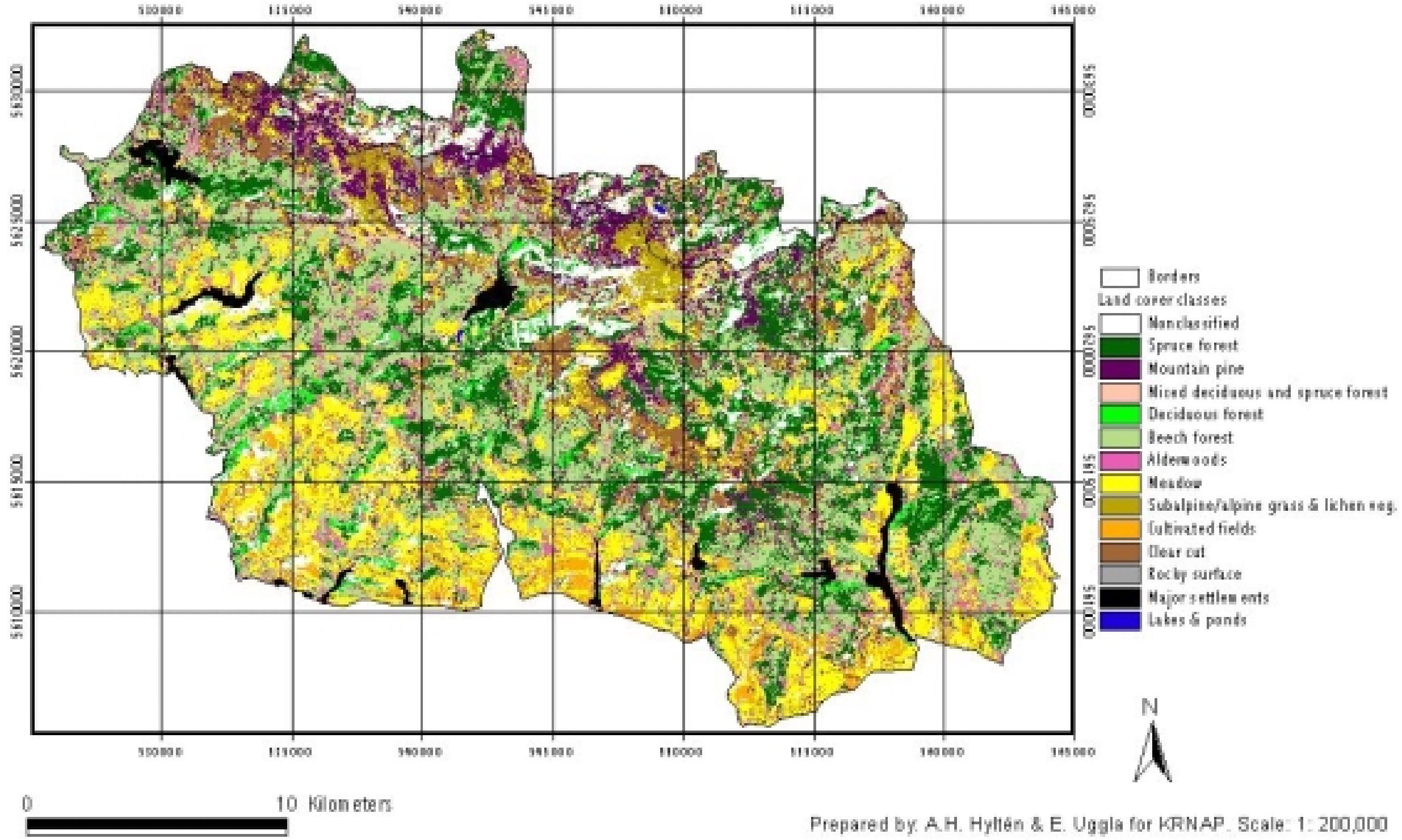
Prepared by: A.H. Hyltén & E. Uggla for KRNAP. Scale: 1: 200,000

Land cover classification of the Krkonose National Park (14 classes)



Prepared by: A.H. Hyltén & E. Uggla for KRNAP. Scale: 1: 200,000

Maximum likelihood classification of the Krkonose National Park (14 classes)



Prepared by: A.H. Hyltén & E. Uggla for KRNAP. Scale: 1: 200,000

APPENDIX 7: RULE-BASED CLASSIFICATION SYSTEM

```
theView=av.GetActiveDoc
theProbfirstTheme=theView.FindTheme("Prob1park")
theProbfirstGrid=theProbfirstTheme.GetGrid
theProbsecondTheme=theView.FindTheme("Prob2park")
theProbsecondGrid=theProbsecondTheme.GetGrid
theProbthirdTheme=theView.FindTheme("Prob3park")
theProbthirdGrid=theProbthirdTheme.GetGrid
theMlcfirstTheme=theView.FindTheme("Mlc1park")
theMlcfirstGrid=theMlcfirstTheme.GetGrid
theMlcsecondTheme=theView.FindTheme("Mlc2park")
theMlcsecondGrid=theMlcsecondTheme.GetGrid
theMlcthirdTheme=theView.FindTheme("Mlc3park")
theMlcthirdGrid=theMlcthirdTheme.GetGrid
'probability layer 1
'thematic layer 1
'making bitmaps of the prob layers out of every class in the MLC layer
theRockfirstGrid=(theMLCfirstGrid<>250.AsGrid).SetNull(theProbfirstGrid)
theConiferfirstGrid=(theMLCfirstGrid<>50.AsGrid).SetNull(theProbfirstGrid)
theBeechfirstGrid=(theMLCfirstGrid<>160.AsGrid).SetNull(theProbfirstGrid)
theRedfieldsfirstGrid=(theMLCfirstGrid<>210.AsGrid).SetNull(theProbfirstGrid)
theMountpinefirstGrid=(theMLCfirstGrid<>75.AsGrid).SetNull(theProbfirstGrid)
theBluefieldsfirstGrid=(theMLCfirstGrid<>200.AsGrid).SetNull(theProbfirstGrid)
theDecidouosfirstGrid=(theMLCfirstGrid<>150.AsGrid).SetNull(theProbfirstGrid)
theMixedForestfirstGrid=(theMLCfirstGrid<>130.AsGrid).SetNull(theProbfirstGrid)
theClearcutfirstGrid=(theMLCfirstGrid<>230.AsGrid).SetNull(theProbfirstGrid)
theMeadowfirstGrid=(theMLCfirstGrid<>180.AsGrid).SetNull(theProbfirstGrid)
theGrassfirstGrid=(theMLCfirstGrid<>190.AsGrid).SetNull(theProbfirstGrid)
theAlderfirstGrid=(theMLCfirstGrid<>170.AsGrid).SetNull(theProbfirstGrid)
'Dem is used to divide the bitmaps so different probabilities based on altitude can be used
theDemTheme=theView.FindTheme("Demb")
theDemGrid=theDemTheme.GetGrid
'every bitmap that has been made are multiplied with its prior probabilities
thenewRockfirstGrid=(theDemGrid<=800.AsGrid).Con(theRockfirstGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theRockfirstGrid*0.005.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theRockfirstGrid*0.085.AsGrid,theRockfirstGrid*0.01.AsGrid)))))
thenewConiferfirstGrid=(theDemGrid<=800.AsGrid).Con(theConiferfirstGrid*0.367.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theConiferfirstGrid*0.648.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theConiferfirstGrid*0.326400507.AsGrid,theConiferfirstGrid*0.005068791.AsGrid)))))
thenewBeechfirstGrid=(theDemGrid<=800.AsGrid).Con(theBeechfirstGrid*0.05.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theBeechfirstGrid*0.035.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theBeechfirstGrid*0.000063.AsGrid,theBeechfirstGrid*0.00001.AsGrid)))))
thenewRedfieldsfirstGrid=(theDemGrid<=800.AsGrid).Con(theRedfieldsfirstGrid*0.26.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theRedfieldsfirstGrid*0.013029247.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theRedfieldsfirstGrid*0.0000760456.AsGrid,theRedfieldsfirstGrid*0.00001.AsGrid)))))
thenewMountpinefirstGrid=(theDemGrid<=800.AsGrid).Con(theMountpinefirstGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMountpinefirstGrid*0.004429524.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMountpinefirstGrid*0.3.AsGrid, theMountpinefirstGrid*0.366.AsGrid)))))
thenewBluefieldsfirstGrid=(theDemGrid<=800.AsGrid).Con(theBluefieldsfirstGrid*0.093496.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theBluefieldsfirstGrid*0.001433287.AsGri
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d,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theBluefieldsfirstGrid*0.00001.AsGrid,theBluefieldsfirstGrid*0.00001.AsGrid)))))
thenewDecidouosfirstGrid=(theDemGrid<=800.AsGrid).Con(theDecidouosfirstGrid*0.09.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theDecidouosfirstGrid*0.06.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theDecidouosfirstGrid*0.022.AsGrid,theDecidouosfirstGrid*0.0014.AsGrid)))))
thenewMixedforestfirstGrid=(theDemGrid<=800.AsGrid).Con(theMixedforestfirstGrid*0.049424.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMixedforestfirstGrid*0.023.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMixedforestfirstGrid*0.012.AsGrid,theMixedforestfirstGrid*0.0009.AsGrid)))))
thenewClearcutfirstGrid=(theDemGrid<=800.AsGrid).Con(theClearcutfirstGrid*0.01.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theClearcutfirstGrid*0.15.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theClearcutfirstGrid*0.085716096.AsGrid,theClearcutfirstGrid*0.05.AsGrid)))))
thenewMeadowfirstGrid=(theDemGrid<=800.AsGrid).Con(theMeadowfirstGrid*0.035.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMeadowfirstGrid*0.052.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMeadowfirstGrid*0.02873257.AsGrid,theMeadowfirstGrid*0.001.AsGrid)))))
thenewGrassfirstGrid=(theDemGrid<=800.AsGrid).Con(theGrassfirstGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theGrassfirstGrid*0.001699619.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theGrassfirstGrid*0.13.AsGrid,theGrassfirstGrid*0.47.AsGrid)))))
thenewAlderfirstGrid=(theDemGrid<=800.AsGrid).Con(theAlderfirstGrid*0.015.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theAlderfirstGrid*0.0056.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theAlderfirstGrid*0.00057.AsGrid,theAlderfirstGrid*0.00001.AsGrid)))))
thenewRockfirstTheme=GTheme.Make(thenewRockfirstGrid)
thenewConiferfirstTheme=GTheme.Make(thenewConiferfirstGrid)
thenewBeechfirstTheme=GTheme.Make(thenewBeechfirstGrid)
thenewRedfieldsfirstTheme=GTheme.Make(thenewRedfieldsfirstGrid)
thenewMountpinefirstTheme=GTheme.Make(thenewMountpinefirstGrid)
thenewBluefieldsfirstTheme=GTheme.Make(thenewBluefieldsfirstGrid)
thenewDecidouosfirstTheme=GTheme.Make(thenewDecidouosfirstGrid)
thenewMixedforestfirstTheme=GTheme.Make(thenewMixedforestfirstGrid)
thenewClearcutfirstTheme=GTheme.Make(thenewClearcutfirstGrid)
thenewMeadowfirstTheme=GTheme.Make(thenewMeadowfirstGrid)
thenewGrassfirstTheme=GTheme.Make(thenewGrassfirstGrid)
thenewAlderfirstTheme=GTheme.Make(thenewAlderfirstGrid)
'all the class grids defining the new probability layer are put together to one  probability grid
theGridList={thenewConiferfirstGrid,thenewBeechfirstGrid,thenewRedfieldsfirstGrid,thenewMountpinefirstGrid,thenewBluefieldsfirstGrid,thenewDecidouosfirstGrid,thenewMixedforestfirstGrid,thenewClearcutfirstGrid,thenewMeadowfirstGrid,thenewGrassfirstGrid,thenewAlderfirstGrid}
theNewProb1Grid=thenewRockfirstGrid.Merge(theGridList)
theNewProb1Theme=GTheme.Make(theNewProb1Grid)
'every probability layer is divided up into 12 different classes making bitmaps
'probability layer 2
'thematic layer 2
'making bitmaps of the prob layers out of every class in the MLC layer
theRocksecondGrid=(theMLCsecondGrid<>250.AsGrid).SetNull(theProbsecondGrid)
theConifersecondGrid=(theMLCsecondGrid<>50.AsGrid).SetNull(theProbsecondGrid)
theBeechsecondGrid=(theMLCsecondGrid<>160.AsGrid).SetNull(theProbsecondGrid)
theRedfieldssecondGrid=(theMLCsecondGrid<>210.AsGrid).SetNull(theProbsecondGrid)
theMountpinesecondGrid=(theMLCsecondGrid<>75.AsGrid).SetNull(theProbsecondGrid)
theBluefieldssecondGrid=(theMLCsecondGrid<>200.AsGrid).SetNull(theProbsecondGrid)
theDecidouossecondGrid=(theMLCsecondGrid<>150.AsGrid).SetNull(theProbsecondGrid)
theMixedForestsecondGrid=(theMLCsecondGrid<>130.AsGrid).SetNull(theProbsecondGrid)
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theClearcutsecondGrid=(theMLCsecondGrid<>230.AsGrid).SetNull(theProbsecondGrid)
theMeadowsecondGrid=(theMLCsecondGrid<>180.AsGrid).SetNull(theProbsecondGrid)
theGrasssecondGrid=(theMLCsecondGrid<>190.AsGrid).SetNull(theProbsecondGrid)
theAldersecondGrid=(theMLCsecondGrid<>170.AsGrid).SetNull(theProbsecondGrid)
'every bitmap that has been made is multiplied with its prior probabilities
thenewRocksecondGrid=(theDemGrid<=800.AsGrid).Con(theRocksecondGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theRocksecondGrid*0.005.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theRocksecondGrid*0.085.AsGrid,theRocksecondGrid*0.01.AsGrid)))))
thenewConifersecondGrid=(theDemGrid<=800.AsGrid).Con(theConifersecondGrid*0.367.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theConifersecondGrid*0.648.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theConifersecondGrid*0.326400507.AsGrid,theConifersecondGrid*0.005068791.AsGrid)))))
thenewBeechsecondGrid=(theDemGrid<=800.AsGrid).Con(theBeechsecondGrid*0.05.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theBeechsecondGrid*0.035.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theBeechsecondGrid*0.000063.AsGrid,theBeechsecondGrid*0.00001.AsGrid)))))
thenewRedfieldssecondGrid=(theDemGrid<=800.AsGrid).Con(theRedfieldssecondGrid*0.26.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theRedfieldssecondGrid*0.013029247.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theRedfieldssecondGrid*0.0000760456.AsGrid,theRedfieldssecondGrid*0.00001.AsGrid)))))
thenewMountpinesecondGrid=(theDemGrid<=800.AsGrid).Con(theMountpinesecondGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMountpinesecondGrid*0.004429524.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMountpinesecondGrid*0.3.AsGrid,theMountpinesecondGrid*0.366.AsGrid)))))
thenewBluefieldssecondGrid=(theDemGrid<=800.AsGrid).Con(theBluefieldssecondGrid*0.093496.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theBluefieldssecondGrid*0.001433287.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theBluefieldssecondGrid*0.00001.AsGrid,theBluefieldssecondGrid*0.00001.AsGrid)))))
thenewDecidouossecondGrid=(theDemGrid<=800.AsGrid).Con(theDecidouossecondGrid*0.09.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theDecidouossecondGrid*0.06.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theDecidouossecondGrid*0.022.AsGrid,theDecidouossecondGrid*0.0014.AsGrid)))))
thenewMixedforestsecondGrid=(theDemGrid<=800.AsGrid).Con(theMixedforestsecondGrid*0.049424.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMixedforestsecondGrid*0.023.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMixedforestsecondGrid*0.012.AsGrid,theMixedforestsecondGrid*0.0009.AsGrid)))))
thenewClearcutsecondGrid=(theDemGrid<=800.AsGrid).Con(theClearcutsecondGrid*0.01.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theClearcutsecondGrid*0.15.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theClearcutsecondGrid*0.085716096.AsGrid,theClearcutsecondGrid*0.05.AsGrid)))))
thenewMeadowsecondGrid=(theDemGrid<=800.AsGrid).Con(theMeadowsecondGrid*0.035.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMeadowsecondGrid*0.052.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMeadowsecondGrid*0.02873257.AsGrid,theMeadowsecondGrid*0.001.AsGrid)))))
thenewGrasssecondGrid=(theDemGrid<=800.AsGrid).Con(theGrasssecondGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theGrasssecondGrid*0.001699619.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theGrasssecondGrid*0.13.AsGrid,theGrasssecondGrid*0.47.AsGrid)))))
thenewAldersecondGrid=(theDemGrid<=800.AsGrid).Con(theAldersecondGrid*0.015.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theAldersecondGrid*0.0056.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theAldersecondGrid*0.00057.AsGrid,theAldersecondGrid*0.00001.AsGrid)))))
thenewRocksecondTheme=GTheme.Make(thenewRocksecondGrid)
thenewConifersecondTheme=GTheme.Make(thenewConifersecondGrid)
thenewBeechsecondTheme=GTheme.Make(thenewBeechsecondGrid)
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thenewRedfieldssecondTheme=GTheme.Make(thenewRedfieldssecondGrid)
thenewMountpinesecondTheme=GTheme.Make(thenewMountpinesecondGrid)
thenewBluefieldssecondTheme=GTheme.Make(thenewBluefieldssecondGrid)
thenewDecidouossecondTheme=GTheme.Make(thenewDecidouossecondGrid)
thenewMixedforestsecondTheme=GTheme.Make(thenewMixedforestsecondGrid)
thenewClearcutsecondTheme=GTheme.Make(thenewClearcutsecondGrid)
thenewMeadowsecondTheme=GTheme.Make(thenewMeadowsecondGrid)
thenewGrasssecondTheme=GTheme.Make(thenewGrasssecondGrid)
thenewAldersecondTheme=GTheme.Make(thenewAldersecondGrid)
'all the class grids defining the new probability layer are put together to one  probability grid
theGrid2List={thenewConifersecondGrid,thenewBeechsecondGrid,thenewRedfieldssecondGrid,thenewMountpinesecondGrid,thenewBluefieldssecondGrid,thenewDecidouossecondGrid,thenewMixedforestsecondGrid,thenewClearcutsecondGrid,thenewMeadowsecondGrid,thenewGrasssecondGrid,thenewAldersecondGrid}
theNewProb2Grid=thenewRocksecondGrid.Merge(theGrid2List)
theNewProb2Theme=GTheme.Make(theNewProb2Grid)
'every probability layer is divided up into 12 different classes making bitmaps
'probability layer 3
'thematic layer 3
'making bitmaps of the prob layers out of every class in the MLC layer
theRockthirdGrid=(theMLCthirdGrid<>250.AsGrid).SetNull(theProbthirdGrid)
theConiferthirdGrid=(theMLCthirdGrid<>50.AsGrid).SetNull(theProbthirdGrid)
theBeechthirdGrid=(theMLCthirdGrid<>160.AsGrid).SetNull(theProbthirdGrid)
theRedfieldsthirdGrid=(theMLCthirdGrid<>210.AsGrid).SetNull(theProbthirdGrid)
theMountpinethirdGrid=(theMLCthirdGrid<>75.AsGrid).SetNull(theProbthirdGrid)
theBluefieldsthirdGrid=(theMLCthirdGrid<>200.AsGrid).SetNull(theProbthirdGrid)
theDecidouosthirdGrid=(theMLCthirdGrid<>150.AsGrid).SetNull(theProbthirdGrid)
theMixedForestthirdGrid=(theMLCthirdGrid<>130.AsGrid).SetNull(theProbthirdGrid)
theClearcutthirdGrid=(theMLCthirdGrid<>230.AsGrid).SetNull(theProbthirdGrid)
theMeadowthirdGrid=(theMLCthirdGrid<>180.AsGrid).SetNull(theProbthirdGrid)
theGrassthirdGrid=(theMLCthirdGrid<>190.AsGrid).SetNull(theProbthirdGrid)
theAlderthirdGrid=(theMLCthirdGrid<>170.AsGrid).SetNull(theProbthirdGrid)
'Dem is used to divide the bitmaps so different probabilities based on altitude can be used
'every bitmap that has been made is multiplied with its prior probabilities
thenewRockthirdGrid=(theDemGrid<=800.AsGrid).Con(theRockthirdGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theRockthirdGrid*0.005.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theRockthirdGrid*0.085.AsGrid,theRockthirdGrid*0.01.AsGrid)))))
thenewConiferthirdGrid=(theDemGrid<=800.AsGrid).Con(theConiferthirdGrid*0.367.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theConiferthirdGrid*0.648.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theConiferthirdGrid*0.326400507.AsGrid,theConiferthirdGrid*0.005068791.AsGrid)))))
thenewBeechthirdGrid=(theDemGrid<=800.AsGrid).Con(theBeechthirdGrid*0.05.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theBeechthirdGrid*0.035.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theBeechthirdGrid*0.000063.AsGrid,theBeechthirdGrid*0.00001.AsGrid)))))
thenewRedfieldsthirdGrid=(theDemGrid<=800.AsGrid).Con(theRedfieldsthirdGrid*0.26.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theRedfieldsthirdGrid*0.013029247.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theRedfieldsthirdGrid*0.0000760456.AsGrid,theRedfieldsthirdGrid*0.00001.AsGrid)))))
thenewMountpinethirdGrid=(theDemGrid<=800.AsGrid).Con(theMountpinethirdGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMountpinethirdGrid*0.004429524.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMountpinethirdGrid*0.3.AsGrid,theMountpinethirdGrid*0.366.AsGrid)))))
thenewBluefieldsthirdGrid=(theDemGrid<=800.AsGrid).Con(theBluefieldsthirdGrid*0.093496.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theBluefieldsthirdGrid*0.001433287.AsG
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rid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theBluefieldsthirdGrid*0.00001.AsGrid,theBluefieldsthirdGrid*0.00001.AsGrid)))))
thenewDecidouosthirdGrid=(theDemGrid<=800.AsGrid).Con(theDecidouosthirdGrid*0.09.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theDecidouosthirdGrid*0.06.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theDecidouosthirdGrid*0.022.AsGrid,theDecidouosthirdGrid*0.0014.AsGrid)))))
thenewMixedforestthirdGrid=(theDemGrid<=800.AsGrid).Con(theMixedforestthirdGrid*0.049424.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMixedforestthirdGrid*0.023.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMixedforestthirdGrid*0.012.AsGrid,theMixedforestthirdGrid*0.0009.AsGrid)))))
thenewClearcutthirdGrid=(theDemGrid<=800.AsGrid).Con(theClearcutthirdGrid*0.01.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theClearcutthirdGrid*0.15.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theClearcutthirdGrid*0.085716096.AsGrid,theClearcutthirdGrid*0.05.AsGrid)))))
thenewMeadowthirdGrid=(theDemGrid<=800.AsGrid).Con(theMeadowthirdGrid*0.035.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theMeadowthirdGrid*0.052.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theMeadowthirdGrid*0.02873257.AsGrid,theMeadowthirdGrid*0.001.AsGrid)))))
thenewGrassthirdGrid=(theDemGrid<=800.AsGrid).Con(theGrassthirdGrid*0.00001.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theGrassthirdGrid*0.001699619.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theGrassthirdGrid*0.13.AsGrid,theGrassthirdGrid*0.47.AsGrid)))))
thenewAlderthirdGrid=(theDemGrid<=800.AsGrid).Con(theAlderthirdGrid*0.015.AsGrid,(((theDemGrid<=1200.AsGrid)and(theDemGrid>800.AsGrid)).Con(theAlderthirdGrid*0.0056.AsGrid,(((theDemGrid<=1450.AsGrid)and(theDemGrid>1200.asGrid)).Con(theAlderthirdGrid*0.00057.AsGrid,theAlderthirdGrid*0.00001.AsGrid)))))
thenewRockthirdTheme=GTheme.Make(thenewRockthirdGrid)
thenewConiferthirdTheme=GTheme.Make(thenewConiferthirdGrid)
thenewBeechthirdTheme=GTheme.Make(thenewBeechthirdGrid)
thenewRedfieldsthirdTheme=GTheme.Make(thenewRedfieldsthirdGrid)
thenewMountpinethirdTheme=GTheme.Make(thenewMountpinethirdGrid)
thenewBluefieldsthirdTheme=GTheme.Make(thenewBluefieldsthirdGrid)
thenewDecidouosthirdTheme=GTheme.Make(thenewDecidouosthirdGrid)
thenewMixedforestthirdTheme=GTheme.Make(thenewMixedforestthirdGrid)
thenewClearcutthirdTheme=GTheme.Make(thenewClearcutthirdGrid)
thenewMeadowthirdTheme=GTheme.Make(thenewMeadowthirdGrid)
thenewGrassthirdTheme=GTheme.Make(thenewGrassthirdGrid)
thenewAlderthirdTheme=GTheme.Make(thenewAlderthirdGrid)
'all the class grids defining the new probability layer are put together to one  probability grid
theGrid3List={thenewConiferthirdGrid,thenewBeechthirdGrid,thenewRedfieldsthirdGrid,thenewMountpinethirdGrid,thenewBluefieldsthirdGrid,thenewDecidouosthirdGrid,thenewMixedforestthirdGrid,thenewClearcutthirdGrid,thenewMeadowthirdGrid,thenewGrassthirdGrid,thenewAlderthirdGrid}
theNewProb3Grid=thenewRockthirdGrid.Merge(theGrid3List)
theNewProb3Theme=GTheme.Make(theNewProb3Grid)
'modifies the cells with the value of No Data to a value of 0 for every new probability layer
theModprob1Grid=theNewprob1Grid.IsNull.Con(0.AsGrid,theNewprob1Grid)
theModprob2Grid=theNewprob2Grid.IsNull.Con(0.AsGrid,theNewprob2Grid)
theModprob3Grid=theNewprob3Grid.IsNull.Con(0.AsGrid,theNewprob3Grid)
theModProb1Theme=GTheme.Make(theModProb1Grid)
theModProb2Theme=GTheme.Make(theModProb2Grid)
theModProb3Theme=GTheme.Make(theModProb3Grid)
'the classes with the highest prob is shown here
'creation of a new thematic map over the park
theThematictestGrid=((theModprob1Grid>theModprob2Grid)and(theModprob1Grid>theModprob3Grid)).Con(theMLCfirstGrid,(((theModprob2Grid>theModprob1Grid)and(theModprob2Grid>theModprob3Grid))
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.Con(theMLCsecondGrid,(((theModprob3Grid>theModprob1Grid)and(theModprob3Grid>theModprob2Grid)).Con(theMLCthirdGrid,0.AsGrid)))))
theThematictestTheme=GTheme.Make(theThematictestGrid)
'the new thematic map is divided up into water and not water using the manually classified water bitmap
theWaterTheme=theView.FindTheme("Waterny")
theWaterGrid=theWaterTheme.GetGrid
theNonWaterGrid=(theWaterGrid=1.AsGrid).Con(0.AsGrid,theThematictestGrid)
'the new thematic map is divided up into settlements and not settlements using the manually classified settlements bitmap
theSettlementsTheme=theView.FindTheme("Settlementsny")
theSettlementsGrid=theSettlementsTheme.GetGrid
theNonSettlementsGrid=(theSettlementsGrid=1.AsGrid).Con(0.AsGrid,theNonWaterGrid)
'the Non Settlements theme is divided up into forest versa non forest
theForestGrid=(theNonSettlementsGrid<=170.AsGrid).Con(theNonsettlementsGrid,0.AsGrid)
theNonforestTempGrid=(theNonSettlementsGrid>170.AsGrid).Con(theNonsettlementsGrid,0.AsGrid)
theNonforestGrid=(theNonforestTempGrid=210.AsGrid).Con(180.AsGrid,theNonforestTempGrid)
'a thematic map showing only conifer species eg mountain pine and conifer forest
TheConiferTotalGrid=((theForestGrid=50.AsGrid)or(theForestGrid=75.AsGrid)).Con(theForestGrid,0.AsGrid)
'spruce and mt pine divided into classes based on altitude
theGrassTemp1Grid=((theConiferTotalGrid>=50.AsGrid)and(theDemGrid>1450.AsGrid)).Con(190.AsGrid,0.AsGrid)
theTemp1Grid=((theConiferTotalGrid>=50.AsGrid)and(theDemGrid>1450.AsGrid)).Con(0.AsGrid,theConiferTotalGrid)
theMtpineGrid=((theTemp1Grid>=50.AsGrid)and(theDemGrid>1290.AsGrid)).Con(75.AsGrid,0.AsGrid)
theTemp2Grid=((theTemp1Grid>=50.AsGrid)and(theDemGrid>1290.AsGrid)).Con(0.AsGrid,theTemp1Grid)
theMixedpinespruceGrid=((theTemp2Grid>=50.AsGrid)and(theDemGrid>=1250.AsGrid)).Con(65.AsGrid,0.AsGrid)
theTemp3Grid=((theTemp2Grid>=50.AsGrid)and(theDemGrid>=1250.AsGrid)).Con(0.AsGrid,theTemp2Grid)
theSpruceGrid=((theTemp3Grid>=50.AsGrid)and(theDemGrid<1250.AsGrid)).Con(50.AsGrid,0.AsGrid)
theGrassTemp1NodataGrid=(theGrassTemp1Grid=0.AsGrid).SetNull(theGrassTemp1Grid)
theMtpineNodataGrid=(theMtpineGrid=0.AsGrid).SetNull(theMtpineGrid)
theMixedpinespruceNodataGrid=(theMixedpinespruceGrid=0.AsGrid).SetNull(theMixedpinespruceGrid)
theSpruceNodataGrid=(theSpruceGrid=0.AsGrid).SetNull(theSpruceGrid)
theGrassTemp1NodataTheme=GTheme.Make(theGrassTemp1NodataGrid)
theMtpineNodataTheme=GTheme.Make(theMtpineNodataGrid)
theView.AddTheme(theMtpineNodataTheme)
theMtpineNodataTheme.SetName("Mt pine")
theMtpineNodataTheme.SetVisible(true)
theMixedpinespruceNodataTheme=GTheme.Make(theMixedpinespruceNodataGrid)
theView.AddTheme(theMixedpinespruceNodataTheme)
theMixedpinespruceNodataTheme.SetName("Mixed Mt pine & Spruce")
theMixedpinespruceNodataTheme.SetVisible(true)
theSpruceNodataTheme=GTheme.Make(theSpruceNodataGrid)
'young spruce and mature spruce stands based on the forest management plan stands not located under the fmp are classified as mature stands
'divides forestry2 into conifer and non-conifer
theNewforestryTheme=theView.FindTheme("Forestry2")
theNewforestryGrid=theNewforestryTheme.GetGrid
theConiferGrid=(theNewforestryGrid=1.AsGrid).Con(1.AsGrid,0.AsGrid)
theConifer1Grid=(theConiferGrid=0.AsGrid).SetNull(theConiferGrid)
'increases forestryage with 10 years
theNewforestryageTheme=theView.FindTheme("Forestryage")
theNewforestryageGrid=theNewforestryageTheme.GetGrid
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theAgeGrid=(theNewforestryageGrid+10.AsGrid)
'distinguishes age pixels with conifer from age pixels with non-conifer
theNewConiferageGrid=((theConifer1Grid=1.AsGrid).Con(theAgeGrid,0.AsGrid))
theNewConiferagenodataGrid=(theNewConiferageGrid=0.AsGrid).SetNull(theNewConiferageGrid)
'distinguishes age pixels with conifer from our conifer map from age pixels with conifer in our map but with no age
theConiferagemapGrid=((theSpruceNodataGrid=50.AsGrid).Con(theNewConiferagenodataGrid,0.AsGrid))
theConiferagemapnodataGrid=(theConiferagemapGrid=0.AsGrid).SetNull(theConiferagemapGrid)
'divides theConiferagemapnodataGrid into young=1 and mature stands=2
theConiferage3Grid=(theConiferagemapnodataGrid<=20.AsGrid).Con(52.AsGrid,((theConiferagemapnodataGrid>20.AsGrid).Con(54.AsGrid,0.AsGrid)))
theConiferage3NodataGrid=theConiferage3Grid.IsNull.Con(0.AsGrid,theConiferage3Grid)
'adds pixels which are classified as conifer by us, but aren´t in the young and mature stands, to mature stands
theOurconiferGrid=((theSpruceNodataGrid=50.AsGrid)and(theConiferage3NodataGrid=0.AsGrid)).Con(54.AsGrid,0.AsGrid)
theOurConiferNodataGrid=(theOurconiferGrid=0.AsGrid).SetNull(theOurconiferGrid)
'merges our mature stands to the mature stands in the young and mature stands map
theNodataConiferage3Grid=(theConiferage3NodataGrid=0.AsGrid).SetNull(theConiferage3NodataGrid)
theGrid4List={theOurConiferNodataGrid}
theNewmatureconiferGrid=theNodataConiferage3Grid.Merge(theGrid4List)
theNewmatureconiferTheme=GTheme.Make(theNewmatureconiferGrid)
theView.AddTheme(theNewmatureconiferTheme)
theNewmatureconiferTheme.SetName("Spruce mature and young stands")
theNewmatureconiferTheme.SetVisible(true)
'all kinds of deciduous forest based on the forest theme but all kinds of deciduous forest located above 1250m asl are classified as alpine grass
theDeciduoustempGrid=(theForestGrid>=130.AsGrid).Con(theForestGrid,0.AsGrid)
theAlpineGrasstemp2Grid=((theDeciduoustempGrid>=130.AsGrid)and(theDemGrid>1250.AsGrid)).Con(190.AsGrid,0.AsGrid)
theAlpineGrasstemp2NodataGrid=(theAlpineGrasstemp2Grid=0.AsGrid).SetNull(theAlpineGrasstemp2Grid)
theAlpineGrasstemp2NodataTheme=GTheme.Make(theAlpineGrasstemp2NodataGrid)
theDeciduousGrid=((theDeciduoustempGrid>=130.AsGrid)and(theDemGrid<=1250.AsGrid)).Con(theDeciduoustempGrid,0.AsGrid)
'Alderwoods classified based on all kinds of deciduous, beech, alder and ash, deciduous, mixed spruce and deciduous within a 30m buffer zone along the major streams
theRivbuffTheme=theView.FindTheme("Rivbuff30")
theRivbuffGrid=theRivbuffTheme.GetGrid
theRivbuffNullGrid=theRivbuffGrid.IsNull.Con(0.AsGrid,theRivbuffGrid)
theAlderwoodsGrid=((theRivbuffNullGrid=30.AsGrid)and(theDeciduousGrid>=130.AsGrid)).Con(170.AsGrid,0.AsGrid)
theAlderwoodsNodataGrid=(theAlderwoodsGrid=0.AsGrid).SetNull(theAlderwoodsGrid)
theAlderwoodsNodataTheme=GTheme.Make(theAlderwoodsNodataGrid)
theView.AddTheme(theAlderwoodsNodataTheme)
theAlderwoodsNodataTheme.SetName("Alderwoods")
theAlderwoodsNodataTheme.SetVisible(true)
theNewDeciduous1Grid=((theRivbuffNullGrid=30.AsGrid)and(theDeciduousGrid>=130.AsGrid)).Con(0.AsGrid,theDeciduousGrid)
theNewDeciduous2Grid=(theNewDeciduous1Grid=170.AsGrid).Con(130.AsGrid,theNewDeciduous1Grid)
theMixedGrid=(theNewDeciduous2Grid=130.AsGrid).Con(130.AsGrid,0.AsGrid)
theMixedNodataGrid=(theMixedGrid=0.AsGrid).SetNull(theMixedGrid)
theMixedNodataTheme=GTheme.Make(theMixedNodataGrid)
theView.AddTheme(theMixedNodataTheme)
theMixedNodataTheme.SetName("Mixed deciduous and spruce forest")
theMixedNodataTheme.SetVisible(true)
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theDeciduousGrid=(theNewDeciduous2Grid=150.AsGrid).Con(150.AsGrid,0.AsGrid)
theDeciduousNodataGrid=(theDeciduousGrid=0.AsGrid).SetNull(theDeciduousGrid)
theDeciduousNodataTheme=GTheme.Make(theDeciduousNodataGrid)
theView.AddTheme(theDeciduousNodataTheme)
theDeciduousNodataTheme.SetName("Deciduous forest")
theDeciduousNodataTheme.SetVisible(true)
'divides  beech into acidophilus and herb rich based on soils acid=1 and non-acid=2
theSoilacidTheme=theView.FindTheme("acid vs. nonacid soils")
theSoilacidGrid=theSoilacidTheme.GetGrid
theSoilacidNullGrid=theSoilacidGrid.IsNull.Con(0.AsGrid,theSoilacidGrid)
'shows only beech
theBeechGrid=(theNewDeciduous2Grid=160.AsGrid).Con(160.AsGrid,0.AsGrid)
theBeechNodataGrid=(theBeechGrid=0.AsGrid).SetNull(theBeechGrid)
'Divides beech into acidophilus = 164 and herb rich = 168 based on soil properties and beech stands with no soil information are classified by altitude herb rich beech <=800m asl and acidophilus beech >800m asl.
theAcidHerbBeech1Grid=((theBeechNodataGrid=160.AsGrid)and(theSoilacidNullGrid=1.AsGrid)).Con(164.AsGrid,(((theBeechNodataGrid=160.AsGrid)and(theSoilacidNullGrid=2.AsGrid)).Con(168.AsGrid,0.AsGrid)))
theHeightbeech1Grid=((theBeechNodataGrid=160.AsGrid)and(theSoilacidNullGrid=0.AsGrid)).Con(169.AsGrid,0.AsGrid)
theHeightbeech2Grid=((theHeightbeech1Grid=169.AsGrid)and(theDemGrid<=800.AsGrid)).Con(168.AsGrid,(((theHeightbeech1Grid=169.AsGrid)and(theDemGrid>800.AsGrid)).Con(164.AsGrid,0.AsGrid)))
theAcidHerbBeech1NodataGrid=(theAcidHerbBeech1Grid=0.AsGrid).SetNull(theAcidHerbBeech1Grid)
theHeightbeech2NodataGrid=(theHeightbeech2Grid=0.AsGrid).SetNull(theHeightbeech2Grid)
theGrid5List={theHeightbeech2NodataGrid}
theAcidHerbBeechNodataGrid=theAcidHerbBeech1NodataGrid.Merge(theGrid5List)
theAcidHerbBeechNodataTheme=GTheme.Make(theAcidHerbBeechNodataGrid)
theView.AddTheme(theAcidHerbBeechNodataTheme)
theAcidHerbBeechNodataTheme.SetName("Acidophilus Beech and Herb Rich Beech")
theAcidHerbBeechNodataTheme.SetVisible(true)
'divides the map into vegetated and nonvegetated areas
theVegetatedGrid=((theNonforestGrid>=180.AsGrid)and(theNonforestGrid<=200.AsGrid)).Con(theNonforestGrid,0.AsGrid)
theNonvegetatedGrid=(theNonforestGrid>200.AsGrid).Con(theNonforestGrid,0.AsGrid)
'map showing agrarian fields with an altitude limit of 1000m asl based on visual interpretation of the satellite scene
theAgrarianfieldsGrid=((theDemGrid<1000.AsGrid)and(theVegetatedGrid=200.AsGrid)).Con(200.AsGrid,0.AsGrid)
theTempMeadow1Grid=((theDemGrid>=1000.AsGrid)and(theVegetatedGrid=200.AsGrid)).Con(180.AsGrid,0.AsGrid)
theAgrarianfieldsNodataGrid=(theAgrarianfieldsGrid=0.AsGrid).SetNull(theAgrarianfieldsGrid)
theAgrarianfieldsNodataTheme=GTheme.Make(theAgrarianfieldsNodataGrid)
theView.AddTheme(theAgrarianfieldsNodataTheme)
theAgrarianfieldsNodataTheme.SetName("Agrarian fields")
theAgrarianfieldsNodataTheme.SetVisible(true)
theTempMeadow1NodataGrid=(theTempMeadow1Grid=0.AsGrid).SetNull(theTempMeadow1Grid)
theTempMeadow1NodataTheme=GTheme.Make(theTempMeadow1NodataGrid)
'pixels that are situated above 1450m asl and are nonclassified (nodata) will be classified as subalpine and alpine grassland
thetempNonclassGrid=((theNonforestGrid=0.AsGrid)and(theforestGrid=0.AsGrid)).Con(1.AsGrid,0.AsGrid)
thetempNonclassGrassGrid=((theDemGrid>1450.AsGrid)and(thetempNonclassGrid=1.AsGrid)).Con(190.AsGrid,0.AsGrid)
thetempNonclassGrassNodataGrid=(thetempNonclassGrassGrid=0.AsGrid).SetNull(thetempNonclassGrassGrid)
theAlpinegrassGrid=(theVegetatedGrid=190.AsGrid).Con(190.AsGrid,0.AsGrid)
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theAlpinegrassNodataGrid=(theAlpinegrassGrid=0.AsGrid).SetNull(theAlpinegrassGrid)
theGrid6List={thetempNonclassGrassNodataGrid,theGrassTemp1NodataGrid,theAlpineGrasstemp2NodataGrid}
theTotal1GrassGrid=theAlpinegrassNodataGrid.Merge(theGrid6List)
thesoilTheme=theView.FindTheme("Soil")
thesoilGrid=thesoilTheme.GetGrid
theSoil0Grid=thesoilGrid.IsNull.Con(0.AsGrid,thesoilGrid)
thePeatTemp1Grid=((theTotal1GrassGrid=190.AsGrid)and(thesoil0Grid=3.AsGrid)).Con(10.AsGrid,0.AsGrid)
thePeatTemp1NodataGrid=(thePeatTemp1Grid=0.AsGrid).SetNull(thePeatTemp1Grid)
thePeatTemp1NodataTheme=GTheme.Make(thePeatTemp1NodataGrid)
theTotal2GrassGrid=((theTotal1GrassGrid=190.AsGrid)and(thesoil0Grid=3.AsGrid)).Con(0.AsGrid,theTotal1GrassGrid)
'map showing alpine grass situated above 1200m asl alpine grass situated below this zone are classified as meadow
theTotal3GrassGrid=((theDemGrid>1200.AsGrid)and(theTotal2GrassGrid=190.AsGrid)).Con(190.AsGrid,0.AsGrid)
theTotal3GrassNodataGrid=(theTotal3GrassGrid=0.AsGrid).SetNull(theTotal3GrassGrid)
theMeadowTemp2Grid=((theDemGrid<=1200.AsGrid)and(theTotal2GrassGrid=190.AsGrid)).Con(180.AsGrid,0.AsGrid)
theMeadowTemp2NodataGrid=(theMeadowTemp2Grid=0.AsGrid).SetNull(theMeadowTemp2Grid)
theTotal3GrassNodataTheme=GTheme.Make(theTotal3GrassNodataGrid)
theMeadowTemp2NodataTheme=GTheme.Make(theMeadowTemp2NodataGrid)
'meadow makes 0 into no data
theMeadowTemporaryGrid=(theVegetatedGrid=180.AsGrid).Con(180.AsGrid,0.AsGrid)
theMeadowTemporaryNodataGrid=(theMeadowTemporaryGrid=0.AsGrid).SetNull(theMeadowTemporaryGrid)
theMeadowTemporaryNodataTheme=GTheme.Make(theMeadowTemporaryNodataGrid)
'meadows and temporary themes showing meadows put together in one map
theMeadowList={theTempMeadow1NodataGrid,theMeadowTemp2NodataGrid}
theMeadow1tempGrid=theMeadowTemporaryNodataGrid.Merge(theMeadowList)
theMeadow1tempNodataGrid=(theMeadow1tempGrid=0.AsGrid).SetNull(theMeadow1tempGrid)
theMeadow1tempNodataTheme=GTheme.Make(theMeadow1tempNodataGrid)
'peat bogs based on histosols and meadow
thePeatTempGrid=((theMeadow1tempNodataGrid=180.AsGrid)and(thesoil0Grid=3.AsGrid)).Con(10.AsGrid,0.AsGrid)
thePeatTempNodataGrid=(thePeatTempGrid=0.AsGrid).SetNull(thePeatTempGrid)
thePeatTempNodataTheme=GTheme.Make(thePeatTempNodataGrid)
theMeadowTemp4Grid=((theMeadow1tempNodataGrid=180.AsGrid)and(thesoil0Grid=3.AsGrid)).Con(0.AsGrid, theMeadow1tempNodataGrid)
theMeadowTemp4NodataGrid=(theMeadowTemp4Grid=0.AsGrid).SetNull(theMeadowTemp4Grid)
theMeadowTemp4NodataTheme=GTheme.Make(theMeadowTemp4NodataGrid)
'pixels classified as forest in the forestry map and classified as meadow in the rule based classification system
theAllskogTheme=theView.FindTheme("Forestry2")
theAllskogGrid=theAllskogTheme.GetGrid
theAllskogNullGrid=theAllskogGrid.IsNull.Con(0.AsGrid,theAllskogGrid)
theClearcutTempGrid=((theAllskogNullGrid>=1.AsGrid)and(theMeadowTemp4NodataGrid=180.AsGrid)).Con(230.AsGrid,0.AsGrid)
theClearcutTempNodataGrid=(theClearcutTempGrid=0.AsGrid).SetNull(theClearcutTempGrid)
theMeadowTemp5Grid=((theAllskogNullGrid>=1.AsGrid)and(theMeadowTemp4NodataGrid=180.AsGrid)).Con(0.AsGrid,theMeadowTemp4NodataGrid)
theMeadowTemp5NodataGrid=(theMeadowTemp5Grid=0.AsGrid).SetNull(theMeadowTemp5Grid)
theClearcutTempNodataTheme=GTheme.Make(theClearcutTempNodataGrid)
theMeadowTemp5NodataTheme=GTheme.Make(theMeadowTemp5NodataGrid)
```

```
'Total Meadow Temp 5 is divided up into mt meadow and submt meadow and they are divided up into dry and wet meadow and pixels with no soil information and classified as meadow located within a 60m bufferzone along the rivers are classified as wet meadow.
thesoil1Theme=theView.FindTheme("Gleyic soils")
thesoil1Grid=thesoil1Theme.GetGrid
theSoil1nullGrid=thesoil1Grid.IsNull.Con(0.AsGrid,thesoil1Grid)
theRiverbuffertTheme=theView.FindTheme("Riverbuffert")
theRiverbuffertGrid=theRiverbuffertTheme.GetGrid
theRiverbuffert0Grid=theRiverbuffertGrid.IsNull.Con(0.AsGrid,theRiverbuffertGrid)
theAlpinegrassTemp4Grid=((theMeadowTemp5NodataGrid=180.AsGrid)and(theDemGrid>1200.AsGrid)).Con(190.AsGrid,0.AsGrid)
theAlpinegrassTemp4NodataGrid=(theAlpinegrassTemp4Grid=0.AsGrid).SetNull(theAlpinegrassTemp4Grid)
theAlpinegrassTemp4NodataTheme=GTheme.Make(theAlpinegrassTemp4NodataGrid)
theMeadowTemp6Grid=((theMeadowTemp5NodataGrid=180.AsGrid)and(theDemGrid>1200.AsGrid)).Con(0.AsGrid,theMeadowTemp5NodataGrid)
theMtmeadowGrid=((theMeadowTemp6Grid=180.AsGrid)and(theDemGrid>800.AsGrid)).Con(20.AsGrid,0.AsGrid)
theMtmeadowNodataGrid=(theMtmeadowGrid=0.AsGrid).SetNull(theMtmeadowGrid)
theTempGrid=((theMeadowTemp6Grid=180.AsGrid)and(theDemGrid>800.AsGrid)).Con(0.AsGrid,theMeadowTemp6Grid)
theSubMtmeadowGrid=((theTempGrid=180.AsGrid)and(theDemGrid>0.AsGrid)).Con(30.AsGrid,0.AsGrid)
theSubMtmeadowNodataGrid=(theSubMtmeadowGrid=0.AsGrid).SetNull(theSubMtmeadowGrid)
theMtmeadowwetTempGrid=((theMtmeadowNodataGrid=20.AsGrid)and(thesoil1nullGrid=1.AsGrid)).Con(24.AsGrid,theMtmeadowNodataGrid)
theMtmeadowwettemp2Grid=((theRiverbuffert0Grid=60.AsGrid)and(theSoil1nullGrid=0.AsGrid)).Con(1.AsGrid,0.AsGrid)
theMtmeadowwetGrid=((theMtmeadowwettemp2Grid=1.AsGrid)and(theMtmeadowNodataGrid=20.AsGrid)).Con(24.AsGrid,theMtmeadowwetTempGrid)
theMtmeadowdrywetGrid=(theMtmeadowwetGrid=20.AsGrid).Con(28.AsGrid,theMtmeadowwetGrid)
theMtmeadowdrywetTheme=GTheme.Make(theMtmeadowdrywetGrid)
theView.AddTheme(theMtmeadowdrywetTheme)
theMtmeadowdrywetTheme.SetName("Wet and dry Mt Meadow")
theMtmeadowdrywetTheme.SetVisible(true)
theSubMtmeadowwetTempGrid=((theSubMtmeadowNodataGrid=30.AsGrid)and(thesoil1nullGrid=1.AsGrid)).Con(34.AsGrid,theSubMtmeadowNodataGrid)
theSubMtmeadowwettemp2Grid=((theRiverbuffert0Grid=60.AsGrid)and(theSoil1nullGrid=0.AsGrid)).Con(1.AsGrid,0.AsGrid)
theSubMtmeadowwetGrid=((theSubMtmeadowwettemp2Grid=1.AsGrid)and(theSubMtmeadowNodataGrid=30.AsGrid)).Con(34.AsGrid,theSubMtmeadowwetTempGrid)
theSubMtwetdrymeadowGrid=(theSubMtmeadowwetGrid=30.AsGrid).Con(38.AsGrid,theSubMtmeadowwetGrid)
theSubMtwetdrymeadowTheme=GTheme.Make(theSubMtwetdrymeadowGrid)
theView.AddTheme(theSubMtwetdrymeadowTheme)
theSubMtwetdrymeadowTheme.SetName("Wet and dry SubMt Meadow")
theSubMtwetdrymeadowTheme.SetVisible(true)
'all clear cut areas put together
theClearcutTemporaryGrid=((theNonvegetatedGrid=0.AsGrid)or(theNonvegetatedGrid=250.AsGrid)).SetNull(theNonvegetatedGrid)
theClearcutTemporaryTheme=GTheme.Make(theClearcutTemporaryGrid)
theGrid7List={theClearcutTempNodataGrid}
theClearCutTemp2Grid=theClearcutTemporaryGrid.Merge(theGrid7List)
theClearCutTemp2Theme=GTheme.Make(theClearcutTemp2Grid)
'peat bog based on clear cuts not covered by the forestry management plan
theForestryTheme=theView.FindTheme("Forestry2")
```

```
theForestryGrid=theForestryTheme.GetGrid
theforestry0Grid=theForestryGrid.IsNull.Con(0.AsGrid,theForestryGrid)
theTemppeatGrid=((theClearcutTemp2Grid=230.AsGrid)and(theForestry0Grid>=1.AsGrid)).Con(0.AsGrid,theClearcutTemp2Grid)
theHistclearcutGrid=((theTemppeatGrid=230.AsGrid)and(thesoil0Grid=3.AsGrid)).Con(10.AsGrid,0.AsGrid)
theHistclearcutNoDataGrid=(theHistclearcutGrid=0.AsGrid).SetNull(theHistclearcutGrid)
theHistclearcutNodataTheme=GTheme.Make(theHistclearcutNodataGrid)
theClearCuttemp3Grid=((theHistclearcutGrid=10.AsGrid)and(theClearcutTemp2Grid=230.AsGrid)).Con(0.AsGrid,theClearcutTemp2Grid)
theClearCut3NodataGrid=(theClearCuttemp3Grid=0.AsGrid).SetNull(theClearCuttemp3Grid)
theClearCut3NodataTheme=GTheme.Make(theClearcut3NodataGrid)
'the class is created using a zone based on the Dem containing clear cut found in this zone and they are put into the subalpine and alpine grassland and lichen vegetation class
'making a bitmap out of the DEM selecting only pixels situated between 1250m asl - 1290m asl the timberline 1250m asl
theDemnullGrid=theDemGrid.IsNull.Con(0.AsGrid,theDemGrid)
theTempGrass5Grid=((theClearcut3NodataGrid=230.AsGrid)and(theDemnullGrid>1290.AsGrid)).Con(190.AsGrid,0.asGrid)
theTempGrass5NodataGrid=(theTempGrass5Grid=0.AsGrid).SetNull(theTempGrass5Grid)
theTempGrass5NodataTheme=GTheme.Make(theTempGrass5NodataGrid)
theClearcut4Grid=((theClearcut3NodataGrid=230.AsGrid)and(theDemnullGrid>1290.AsGrid)).Con(0.AsGrid,theClearcut3NodataGrid)
theClearcut4NodataGrid=(theClearcut4Grid=0.AsGrid).SetNull(theClearcut4Grid)
theClearcut4NodataTheme=GTheme.Make(theClearcut4NodataGrid)
theView.AddTheme(theClearcut4NodataTheme)
theClearcut4NodataTheme.SetName("Clear cut")
theClearcut4NodataTheme.SetVisible(true)
'shows only rocky surfaces
theRockysurfacesGrid=(theNonVegetatedGrid<=230.AsGrid).SetNull(theNonVegetatedGrid)
theRockysurfacesTheme=GTheme.Make(theRockysurfacesGrid)
theView.AddTheme(theRockysurfacesTheme)
theRockysurfacesTheme.SetName("Rocky Surfaces")
theRockysurfacesTheme.SetVisible(true)
'all temporary alpine grass grids put together, Total Grass Temp 3, Grass Temp 4 and Grass Temp 5
theGrid8List={theAlpinegrassTemp4NodataGrid,theTempGrass5NodataGrid}
theAlpineGrassGrid=theTotal3GrassNodataGrid.Merge(theGrid8List)
theAlpineGrassTheme=GTheme.Make(theAlpineGrassGrid)
theView.AddTheme(theAlpineGrassTheme)
theAlpineGrassTheme.SetName("Subalpine and alpine grass and lichen vegetation")
theAlpineGrassTheme.SetVisible(true)
'peat bogs put together
theGrid9List={thePeatTemp1NodataGrid,thePeatTempNodataGrid}
thePeatGrid=theHistclearcutNodataGrid.Merge(theGrid9List)
thePeatTheme=GTheme.Make(thePeatGrid)
theView.AddTheme(thePeatTheme)
thePeatTheme.SetName("Peat bog")
thePeatTheme.SetVisible(true)
'all final themes put together
theDeciduousfinalTheme=theView.FindTheme("Deciduous forest")
theDeciduousfinalGrid=theDeciduousfinalTheme.GetGrid
theAlderwoodsfinalTheme=theView.FindTheme("Alderwoods")
theAlderwoodsfinalGrid=theAlderwoodsfinalTheme.GetGrid
thePeatbogsfinalTheme=theView.FindTheme("Peat bog")
thePeatbogsfinalGrid=thePeatbogsfinalTheme.GetGrid
theAlpinegrassfinalTheme=theView.FindTheme("Subalpine and alpine grass and lichen vegetation")
```

```
theAlpinegrassfinalGrid=theAlpinegrassfinalTheme.GetGrid
thediffbeechfinalTheme=theView.FindTheme("Acidophilus Beech and Herb Rich Beech")
thediffbeechfinalGrid=thediffbeechfinalTheme.GetGrid
theMixedfinalTheme=theView.FindTheme("Mixed deciduous and spruce forest")
theMixedfinalGrid=theMixedfinalTheme.GetGrid
theSubMtwetdryfinalTheme=theView.FindTheme("Wet and dry SubMt Meadow")
theSubMtwetdryfinalGrid=theSubMtwetdryfinalTheme.GetGrid
theConiferfinalTheme=theView.FindTheme("Spruce mature and young stands")
theConiferfinalGrid=theConiferfinalTheme.GetGrid
theMtwetdrymeadowfinalTheme=theView.FindTheme("Wet and dry Mt Meadow")
theMtwetdrymeadowfinalGrid=theMtwetdrymeadowfinalTheme.GetGrid
theClearcutfinalTheme=theView.FindTheme("Clear cut")
theClearcutfinalGrid=theClearcutfinalTheme.GetGrid
theSettlementsfinalTheme=theView.FindTheme("Settlementsny")
theSettlementsfinalGrid=theSettlementsfinalTheme.GetGrid
theAgrarianfieldsfinalTheme=theView.FindTheme("Agrarian fields")
theAgrarianfieldsfinalGrid=theAgrarianfieldsfinalTheme.GetGrid
theWaterfinalTheme=theView.FindTheme("Waterny")
theWaterfinalGrid=theWaterfinalTheme.GetGrid
theRockysurfacesfinalTheme=theView.FindTheme("Rocky Surfaces")
theRockysurfacesfinalGrid=theRockysurfacesfinalTheme.GetGrid
theMixedpineconiferfinalTheme=theView.FindTheme("Mixed Mt pine & Spruce")
theMixedpineconiferfinalGrid=theMixedpineconiferfinalTheme.GetGrid
theMtPinefinalTheme=theView.FindTheme("Mt pine")
theMtPinefinalGrid=theMtPinefinalTheme.GetGrid
'themes with the same value are converted to new values
theSettlementsnewGrid=(theSettlementsfinalGrid=1.AsGrid).Con(252.AsGrid,0.AsGrid)
theWaternewGrid=(theWaterfinalGrid=1.AsGrid).Con(254.AsGrid,0.AsGrid)
' themes with a null class are converted to no data
theSettlementsfinalNodataGrid=(theSettlementsnewGrid=0.AsGrid).SetNull(theSettlementsnewGrid)
theWaterfinalNodataGrid=(theWaternewGrid=0.AsGrid).SetNull(theWaternewGrid)
'make grid list
theGrid10List={theAlderwoodsfinalGrid,thePeatbogsfinalGrid,theAlpinegrassfinalGrid,thediffbeechfinalGrid,theMixedfinalGrid,theSubMtwetdryfinalGrid,theConiferfinalGrid,theMtwetdrymeadowfinalGrid,theClearcutfinalGrid,theRockysurfacesfinalGrid,theSettlementsfinalNodataGrid,theAgrarianfieldsfinalGrid,theWaterfinalNodataGrid,theMixedpineconiferfinalGrid,theMtPinefinalGrid}
theRulebasedthematicmapGrid=theDeciduousfinalGrid.Merge(theGrid10List)
theRulebasedthematicmapTheme=GTheme.Make(theRulebasedthematicmapGrid)
'manually classified areas are put into the rule based Thematic map
theManuallyclassificationTheme=theView.FindTheme("Manually classification")
theManuallyclassificationGrid=theManuallyclassificationTheme.GetGrid
theFinalThemmapGridList={theRulebasedthematicmapGrid}
theFinalThemmapGrid=theManuallyclassificationGrid.Merge(theFinalThemmapGridList)
theFinalThemmapTheme=GTheme.Make(theFinalThemmapGrid)
theView.AddTheme(theFinalThemmapTheme)
theFinalThemmapTheme.SetName("Final Thematic Map")
theFinalThemmapTheme.SetVisible(true)
theView.Invalidate
```

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