DISCRIMINATION OF PEATLANDS AND MINERAL SOIL LANDS USING MULTISOURCE REMOTE SENSING DATA

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ABSTRACT

The discrimination of peatlands and mineral soil lands and different peatland canopy types was studied using Landsat TM-, Landsat MSS-, NOAA AVHRR-images, aerogeophysical data and data derived from a digital terrain model. The study area, centered at 63° 28' N, 26° 14' E was located in the Middle Finnish Boreal forest. The field data were 2126 temporary sample plots of the National Forest Inventory. The analysis methods were discriminant and clustering analysis and Tukey's studentized range tests. The classifications, based on discriminant analysis (maximum likelihood classification) were tested using external ground truth data.

Peatlands and mineral soil lands were separated in an accuracy of 76.6 percent. The best image variables to discriminate peatlands and mineral soil lands were geophysical variables (Gamma ray intensity of Potassium (K^{40}) and out-of-phase component of electromagnetic data). Without geophysical data the classification accuracy was more than 10 percent lower. Open bogs and poor mineral soil lands were separated well but the peatlands and mineral soil lands with abundant growing stock were mixed. The subgroups of peatlands were separated best using Landsat images only. The proportion of correctly classified field plots was 70 percent. Open bogs and spruce dominated peatlands were separated best. The percentage of correctly classified pixels was 67.4 percent, when peatlands were discriminated on basis of peat type (*Sphagnum*, *Carex*). The discrimination accuracy of peatlands on basis of ditching stage was 63 percent.

Keywords: Remote sensing, forests, satellite image, interpretation, peatlands

INTRODUCTION

About one fourth of the world's forested area, 1000 million hectares, is Boreal forests. It has been estimated that the carbon storage of trees in Boreal forests is 31 000 000 million kg. But when the carbon content of undergrowth vegetation, of the humus in mineral soil lands, and of peat is taken into account, the total amount of carbon stored in Boreal forests raises up to 400 000 000 million kg (Kuusela 1990).

There are no good statistics about the area of peatlands in the Boreal forest zone. It can be estimated from various sources that about one third, i.e. 300 million hectares of the area of Boreal forests is peatlands (Kivinen and Pakarinen 1981). Thus, about two thirds of world's peatlands is located in Boreal forests. The carbon storage of peatlands is not known, either. It may be larger than the storage of carbon of mineral soil lands.

In global scale, information about the boundaries of peatlands is needed for carbon cycle studies. Locally, this information is needed for operational forest management and silviculture as well as road network planning and construction.

The objective of this study is find out: 1) how reliably peatlands and mineral soil lands can be separated from each other using multisource remotely sensed and map data, and 2) what are the opportunities to separate different peatland canopy types within the category of peatlands. The study is restricted to Boreal coniferous forest zone.

The definition of mineral soil lands and peatlands used in Finnish forestry is applied: the site is considered mineral soil land if more than of 75 percent of the ground is covered with species typical to the undergrowth vegetation of the mineral soil lands (e.g. *Vaccinium sp.* dwarf shrubs, *Pleurozium* and *Hylocomium* mosses). If more than 75 percent of the ground is covered with species typical to peatlands (*Sphagnum* mosses, *Carex* sedges), the site is considered peatland despite the thickness of the peat layer. If the proportion of peatland species is between 25 and 75 percent the site is considered a paludifying forest (Lehto 1978). In this study those areas are assigned to mineral soil lands.

MATERIALS

The study area, centered at 63° 28' N, 26° 14' E, was located in Middle Finland. Its dimensions were 70 km in eastward direction and 60 km in northward direction. The most common tree species were Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* Karst.). Also birches (*Betula sp.*) were common. The mean age of the trees was 57 years. The proportion of peatlands was 20 percent in the topographical map. In the national forest inventory data, 39.4 percent of the plots on forestry land were classified as peatlands.

The ground truth data consisted of 2126 temporary sample plots of the 7th National Forest Inventory of Finland. The National Forest Inventory uses a systematic cluster sampling design. In the 7th inventory, each cluster, having the form of letter L, had 41 sample plots. The distance of the corners of the clusters was 8 km both in East-West and North-South direction.

The ground measurements had been carried out during 1980-82. Only plots falling on the forestry land were accepted. Of the 2126 plots, 1292 (60.8 percent) were on mineral soil land and 834 (39.2 percent) on peatland.

The image variables were:

1) - 4)	Landsat MSS channels 1-4
5)	Ratio MSS3/MSS2 (MSS32)
6)	Ratio MSS1/MSS2 (MSS12)
7) - 8)	The 1st and the 2nd principal components of the four MSS channels
9) - 15)	Landsat TM-channels 1-7
16)	Ratio TM4/TM3 (TM43)
17)	Ratio TM2/TM3 (TM23)
18) - 20)	The first three principal components of the seven TM channels
21) - 24)	NOAA AVHRR channels 1-4
25)	Normalized Difference Vegetation Index (NOAA2-NOAA1)/(NOAA2+NOAA1) (NDVI)
26)	Terrain elevation (Elev)
27)	Local terrain elevation calculated from (26)
28)	Terrain slope in eastward direction calculated from (26)
29)	Terrain slope in northward direction calculated from (26)
30)	Gamma ray intensity from isotope K^{40} (Potassium) using airborne measurements (GammaK)
31)	Out-Of-Phase component of electromagnetic airborne measurements (O-O-P)

All image variables were rectified to the uniform coordinate system which is a Finnish coordinate system in Transverse Mercator (Gauss-Krueger) projection. The applied pixel size was 100 m × 100 m except for Landsat TM-image it was 30 m × 30 m. The selected pixel size was a compromise that corresponded the true spatial resolution of most of the image variables.

The date of Landsat TM-image acquisition was June 20, 1990 and NOAA AVHRR-image was acquired in May 21, 1984. Landsat MSS-image was a combination of several images. The majority of images was acquired in June 17, 1986. In all images the study area was cloud free.

Terrain elevation was acquired from a digitized topographic map, scale 1:200 000 and contour interval 20 meters, through interpolation. The topographical data were therefore quite coarse. Local terrain elevation was defined as the elevation at a pixel minus the average elevation in an 11 by 11 pixels (1100 m by 1100 m) neighborhood of the central pixel. Terrain slope in eastward direction was computed as the derivative of terrain elevation in that direction. The northward slope was computed similarly. Both derivatives were estimated as simple differences in a 3 by 3 pixels window (Häme et al. 1991).

The aerogeophysical data (variables 30 and 31) were acquired using low-altitude (30-50 m) airborne measurements. The distance between parallel flight lines had been 200 m and the distance between the measurement points had been approximately 50 m. The measurement results were interpolated to raster format.

The gamma ray data were measured from the emittance range of the K^{40} isotope. K^{40} is the most prominent source of gamma radiation in ground. The registered radiation originates from the top layer of the ground. Wet and moist areas have usually low gamma ray intensities because water absorbs gamma radiation very effectively (Kuittinen 1988).

The out-of phase component of the electromagnetic data reflects the electrolytic conductivity of the soil. The conductivity improves as the moisture content of the soil increases. The texture of soil also affects the conductivity. Fine textures have better conductivity than coarse textures. The peat has better conductivity than typical Finnish mineral soil, fine sand moraine.

ANALYSIS

Discrimination of the following categories was studied:

1) Peatland - Mineral soil land
2) Subgroup of peatland (Spruce dominated peatlands - Pine dominated peatlands - Open bogs)
3) Peat type of peatland (*Sphagnum* dominated peat - *Carex* dominated peat)
4) Ditching stage of peatland (virgin - ditched)

The principal components that were used in addition to the original Landsat MSS and Landsat TM channels, were computed from the four MSS channels and seven TM channels using the correlation matrix of the channels. The first two components of the MSS channels and the first three components of the TM channels were further analyzed. The ratios MSS3/MSS2, MSS1/MSS2, TM4/TM3, and TM2/TM3 and the normalized difference vegetation index from the NOAA AVHRR channels NOAA1 and NOAA2 were also computed.

The intensity values of all image variables were selected for ground sample plots by means of the map coordinates of the plots.

The statistical analysis methods were Tukey's studentized range tests, and discriminant and clustering analyses. The SAS statistical software package was used. The depended variables were the canopy types listed above. The independent variables were the image variables. In discriminant analysis, two procedures of SAS were used. The best discriminating image variables were selected using the STEPDISC-procedure (SAS Institute Inc. 1988). The final discriminant models were computed using the DISCRIM procedure since separate covariance matrices were used for image variables. Half of the ground truth data was used for model construction and the other half for testing in discriminant analyses.

The FASTCLUS procedure that places observations into clusters on the base of the Euclidean distances, was used in clustering experiments. The image variables were clustered and the content of the clusters was obtained using the ground truth data. The data set was divided into ten clusters in all analyses. The amount of clusters was selected basing on preliminary clustering analyses. The input image variables both in discriminant and clustering analyses were standardized to same mean and standard deviation before performing the analysis.

The Tukey's tests and discriminant analysis could be used to select the best independent image variables. However, the accessibility of the image variables varies. Therefore discriminant models were also computed and tested for image variable sets where the image variables had been selected on the base of their accessibility. First, only NOAA data were used. In final phase, the aerogeophysical variables were taken to the model.

RESULTS

Peatland - Mineral soil land

Gamma radiation was superior to the other image variables to separate mineral soil lands and peatlands. The intensities of gamma radiation were, on average, lower from peatlands than from the mineral soil lands (Fig. 1). The other image variables, significant with the 1 percent significance level, were: out-of-phase component of the electromagnetic measurements, ratio TM2/TM3, and absolute elevation. The intensities of the out-of-phase component indicated a higher electrolytic conductivity on peatlands than on the mineral soil lands. The ratio green light/red light (TM2/TM3) was lower on the peatlands and the peatlands were on average located on higher elevations than the mineral soil lands. The differences in the intensities of the Landsat TM channels were very small in this test where all mineral soil lands were in one category and all peatlands in another category.

The ground truth plots were also divided into three coarse biomass classes (Häme 1991) using the intensities of the Landsat TM channel 3, the red light channel:

1) Mineral soil lands, TM3 < 21
2) Mineral soil lands, 21 <= TM3 < 31
3) Mineral soil lands, TM3 => 31
4) Peatlands, TM3 < 21
5) Peatlands, 21 <= TM3 < 31
6) Peatlands, TM3 => 31

After this deviation could be seen that in categories with tree cover (classes 1, 2, 4, and 5) the intensities of mineral soil lands and peatlands are very similar (Fig. 2). The open mineral soil lands and peatlands (classes 3 and 6) differ more from each other. The result was confirmed in discriminant and clustering analyses: peatlands with tree cover were mixed with the mineral soil lands, but open bogs could be separated using Landsat TM data only. The open bogs had lower near infrared intensities but higher middle infrared intensities than open mineral soil lands.

When a discriminant model was computed and tested using best nine image variables, GammaK, O-O-P, NOAA2, Elev, MSS32, TM43, TM23, TM3 and MSS2, the percentage of correctly classified ground plots of the external test data set was 74.1 percent. Figure 3 shows the classification result and Figure 4 the peatland mask of the topographical map 1 : 100 000. The discriminant model was also computed using variables GammaK and O-O-P only. The proportion of correctly classified ground plots was even slightly better (76.6 percent). If the image variables were TM channels only, the percentage of correctly classified plots was 62.9. The clustering also showed that geophysical variables prevent treeless mineral soil land sites mixing with poor and treeless peatlands.

The discriminant analysis was also carried out so that only the unditched or virgin peatlands represented the peatland category. The purpose was to find out whether the ditching had an effect on discrimination. Virgin open bogs and pine dominated peatlands were separated very well from the mineral soil lands while spruce dominated peatlands were mixed with mineral soil lands. Most of the virgin peatlands in the study area were rich spruce dominated forests.

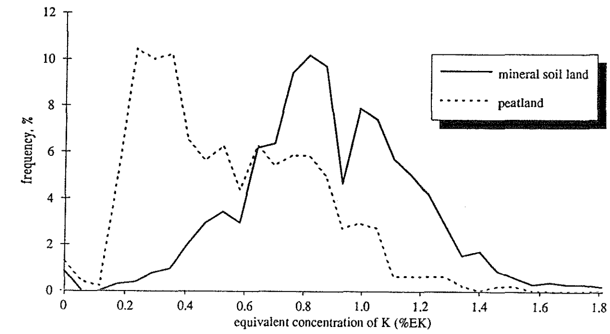

Fig. 1. The frequency distribution of gamma ray intensities in mineral soil lands and peatlands.

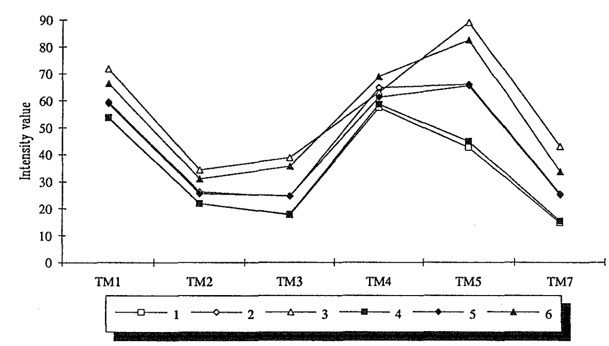

Fig. 2. The Landsat TM intensities by mineral soil land and peatland classes that are formed using the red light channel of TM.

Figure 5 indicates how the classification performance greatly improved when geophysical variables are included.

Discrimination of subgroups of peatlands

The best variables to separate the three peatland canopy types or peatland subgroups were TM43, TM3, TM5, TM23 and MSS32. Those spectral features were also significant with 1 percent significance level to separate all subgroup combinations in Tukey's tests. The red light and middle infrared intensities were higher on open bogs than on peatlands with tree cover. The pine dominated peatlands were separated best from the spruce dominated peatlands particularly due to their lower near infrared intensities and higher visible and middle infrared intensities. This was caused by the lower tree biomass on pine dominated peatlands (visible and middle infrared) and higher proportion of deciduous trees on spruce dominated peatlands (near infrared). The gamma radiation data (GammaK) was very useful to separate spruce dominated forests from pine dominated forests and open bogs.

In classifications to the three peatland subgroups, based on discriminant analysis, the overall performance was 70 percent (Table 1). Both discriminant and clustering analysis indicated that spruce dominated peatlands and open bogs were separated quite well while pine dominated peatlands were mixed mainly to spruce dominated peatlands.

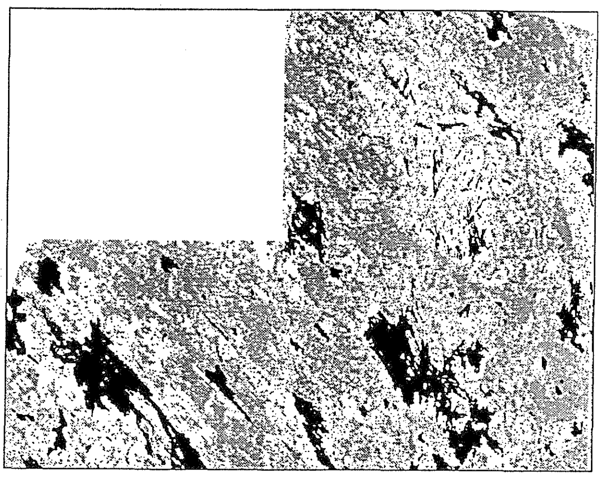

Fig. 3. Maximum likelihood classification of the 70 km by 60 km study area to peatlands (grey) and mineral soil lands (white) using best nine image variables. Waters are black.

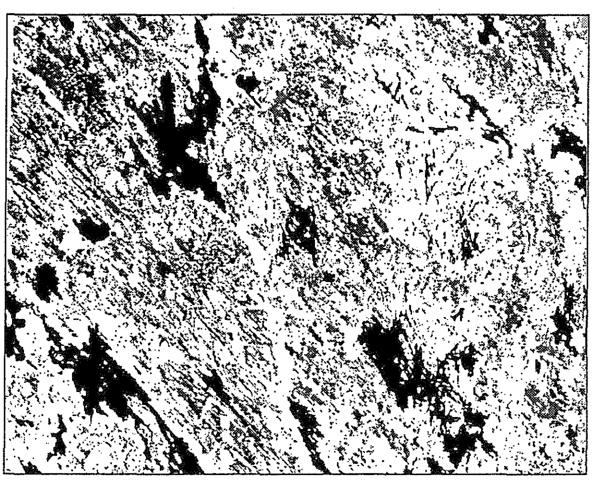

Fig. 4. Mask of peatlands from the 1 : 100 000 topographical map. Waters from the Landsat data.

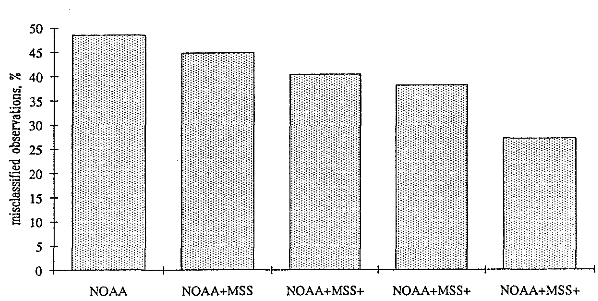

Fig. 5. Proportion of incorrectly classified test plots in classifications using different image variable sets. Classification mineral soil land/peatland.

Table 1. Test result of the classification to peatland subgroups. External test data. Image variables TM43, TM3, TM5, TM23, and MSS32.

		classified into			
		spruce dominated peatlands	pine dominated peatlands	open bogs	total
from	spruce dominated peatlands	**126** 77.30	27 16.56	10 6.13	163 100.00
	pine dominated peatlands	65 33.68	**106** **54.92**	22 11.40	193 100.00
	open bogs	1 11.11	1 11.11	7 **77.78**	9 100.00
	total	192 52.60	134 36.71	39 10.68	365 100.00
error		0.2270	0.4508	0.2222	**0.3000**
priors		0.33	0.33	0.33	

Peat type

The type of peat reflects the amount of nutrients in the peat. *Carex* species dominated peatlands usually indicate high nutrient levels, while *Sphagnum* peat dominated sites are poor of nutrients. The image variables that were significant in 1 percent significance level to separate the peat type were the ratio near infrared/red of MSS (MSS32), TM4, the second principal component of TM (TMPC2), and GammaK. The majority of variation in TMPC2 was explained by the near infrared channel of Landsat TM (TM4). Peatlands with *Carex*-peat had higher intensities in near infrared than peatlands with *Sphagnum*-peat. The percentage of correctly classified pixels in discriminant analysis was 67.4 percent. According to clustering analysis peatlands could not be separated on ground of peat type.

CONCLUSIONS

From the point of view of carbon storage estimation the most important task is to separate open bogs and pine dominated peatlands from mineral soil lands since they have the highest storage of carbon. On spruce dominated peatlands the peat layer is usually thinner and much bigger part of the carbon is in trees.

Peatlands could not be separated from mineral soil lands very reliably using spectral data only. However, the open bogs and poorest pine dominated peatlands, i.e. the peatland types with a high carbon storage, could be separated moderately. The unditched pine dominated peatlands were also separated better from the mineral soil lands than the ditched peatlands. The middle infrared wavelength range seemed to be very important. Note that the thermal data were not proven useful.

The separation performance was much better when the aerogeophysical data were used. Especially the gamma radiation (GammaK) measurements were useful, because of the absorption of gamma radiation caused by the water.

To conclude, Landsat TM data only can be used in peatland discrimination on areas with mostly virgin or unditched peatlands. The best way for using the Landsat data may be correcting and completing an actual mask of peatlands from topographical maps. Airborne gamma radiation measurements, if available, should be used. The resolution of NOAA AVHRR is too a coarse for peatland separation in most cases. Also the digital terrain model is not very useful because peatlands often occur on areas where also mineral soil lands are relatively even. The terrain model, if used, should be more detailed than the model available in this study.

It was noteworthy that the definition of the peatland in the topographical map and in forest inventory is different. Seventy (70) percent of the plots classified as spruce dominated peatlands in the national forest inventory were in the mineral soil land category in the topographical map. It would have been easier to separate the peatlands if the definition of peatlands of the topographical maps were used.

The subgroups of peatlands were separated best using spectral data only. This indicates that subgroups of peatlands differ from each other mostly on basis of vegetation, not on ground of moisture in the peat layer. Open bogs and spruce dominated peatlands were separated well. The richer pine dominated peatlands were mixed with spruce dominated peatlands and the poorer pine dominated peatlands were mixed with open bogs. The intensities of the red light as well as the intensities of the middle infrared was clearly higher from open bogs than from wooded peatlands. The peatlands with *Carex* peat had a higher reflectance in the near infrared than the peatlands with *Sphagnum* peat.

The difference may be partly caused by the tree species proportions and partly by *Carex* and *Sphagnum* species and other undergrowth vegetation. In peatlands with *Carex*-peat the majority of undergrowth vegetation consists of sedges (*Carex*) and herbs, that have a high reflectance in the near infrared.

The ground truth data, although carefully measured, had some drawbacks. The area represented by the sample plots was very small when compared to the areas of the pixels in the image data. The map coordinates of the plots were not very accurate. No information about the location of the plots in respect to the closest boundary of a canopy type was available. This uncertainty most likely lead to too pessimistic results in the image analysis. Some of the weaknesses of the national forest inventory data have been corrected in the new inventory.

In the future work the suitability of radar images in discrimination of peatlands and mineral soil lands should be studied.

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