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MIRE SITE TYPE MAPPING OF BOREAL PEATLANDS WITH HYPERSPECTRAL AIRBORNE HYMAP IN NORTHERN FINLAND

Hilkka Arkimaa[1], Maarit Middleton[2], Eija Hyvönen[2], Viljo Kuosmanen[1], Jukka Laitinen[1] and Raimo Sutinen[2]

1. Geological Survey of Finland, P.O.Box 96, 02151 Espoo, Finland; hilkka.arkimaa@gtk.fi
2. Geological Survey of Finland, P.O.Box 77, 96101 Rovaniemi, Finland

ABSTRACT

Peatlands are important ecosystems in the cool and humid boreal climatic zone covering over one third of the landscape in northern Finland. Classification of mire site types, based on soil nutrient and water regimes driven plant communities, provides primary information for peatland inventories and ecological studies. In this study, the treeless pristine mire site types were classified from high resolution (5 m) airborne hyperspectral (126 bands, 450–2450 nm) data. The geo- and atmospherically corrected HyMap™ imagery was processed with hyperspectral mapping methods and Geological Survey of Finland (GTK) peatland inventory data was used for ground referencing. The preliminary results of signature separability and mixture tuned matched filtering analyses resulted in a 61.3% overall classification accuracy (kappa 0.526) of the four most common treeless pristine mire site types. *Carex* (sedge) fens (mire site types: 'tall-sedge fen', 'flark fen') were easily distinguished from *Sphagnum* bogs ('*Shagnum fuscum* bog', 'low-sedge bog'). The abundance of sedge, herbaceous and broad-leaved species along with the wet surface conditions in the *Carex* fens produced both a prominent green peak and red well, and lower NIR and SWIR reflectance values as compared to those of *Sphagnum* bogs. High heterogeneity of peatland surface conditions, even within a single mire site type, is one of the contributors to the classification uncertainty. Future research will involve a detailed vegetation inventory and surface moisture measurements directed at revealing the true effectiveness of hyperspectral remote sensing in peatland surface mapping.

INTRODUCTION

Peatlands are ecosystems where wetland specific plant species decompose and gradually accumulate as peat. Peat deposits with decomposed plant material greater than 0.3 m in thickness cover 33.2% of the land area in northern Finland (1). The abundance of peatlands is attributed to cool and humid boreal climate where annual precipitation exceeds evaporation by about 50 mm. Peatlands are of considerable economic importance nationwide. Approximately half of the peatlands in northern Finland are drained for forestry and agriculture, or used for peat production and other purposes. The rest of the peatlands are still in a pristine state. Peat is utilized for energy production, horticultural and environmental use, and in the chemical industry. Peatlands are also store a significant amount of green house gases (carbon dioxide, methane and nitrous oxide) release of which into the atmosphere is somewhat controlled by their hydrological state.

Peatlands are generally classified into three primary groups in accordance with the floristic site type classification by Cajander (3): spruce (*Picea abies* L. Karst), pine (*Pinus sylvestris* L.) and treeless peatlands. On the basis of the nutrient regimes of the peat forming species, treeless peatlands are divided into nutrient-rich *Carex* (sedge) fens (subtypes: 'eutrophic', 'herb-rich' and 'tall-sedge'), and nutrient-poor *Sphagnum* bogs ('low-sedge' and '*Shagnum fuscum*' subtypes; see examples in Fig. 1). The surface vegetation associations finally determine the mire site types which were the focus of this study. Depending on the drainage conditions, the peatlands are also classified into pristine, ditched or transformed peatlands. The drained peatlands are often covered with downy birch (*Betula pubescens*) saplings and other deciduous or conifer species. Since forest inventory ground data was not available for this study, the focus was on treeless pristine peatlands.

Figure 1: Carex fen and Sphagnum bog (photography by Jari Väätäinen).

In Finland, systematic mapping of peatlands is carried out by the GTK. Prior to the design of the survey lines and field sampling, airborne gamma radiation measurements are used to estimate the thickness of the peat deposits (4). A relatively simple vegetation structure of peatlands with low surface roughness would offer great potential for surface mapping of peatlands with optical methods. Peatlands are heterogeneous with high variations in plant communities and surface moisture content. Hyperspectral high resolution (<5 m) remote sensing could therefore serve as an effective tool in compilation of detailed maps of peatland surface properties.

The northern Finland study area (Fig. 2) belongs to the southern aapa mire zone. Morphologically, aapa mires have a shallow peat layer (0.3-2.5 m, GTK peat inventory data) and the center of the peatland does not rise above the level of the surrounding mineral ground (5). One third of the peatlands in the northern Finland study area are approximated to be treeless (2). The most common mire site types, according to the GTK peat inventory data are *Carex* dominated 'flark fen', 'tall-sedge fen' and 'herb-rich sedge fen', and *Sphagnum* dominated '*S. fuscum* bog' and 'low-sedge bog'.

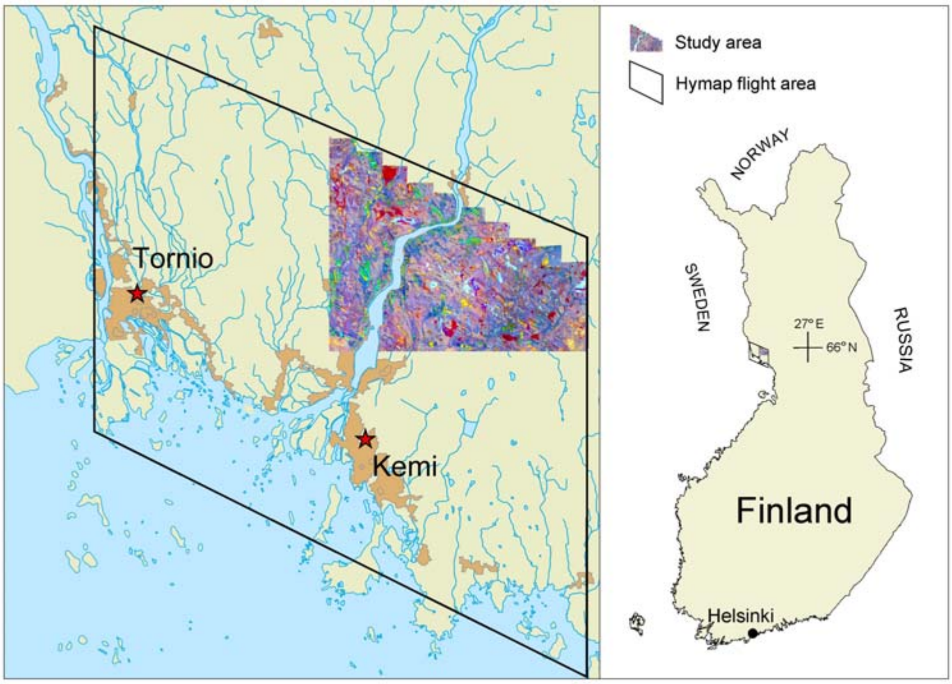

Figure 2: HyMap flight area and northern Finland study area.

In this study, an attempt was made to gain insight and understanding into the spectral characteristics of the most common treeless pristine mire site types in northern Finland. Special attention was given to distinguishing the *Carex* fens and *Sphagnum* bogs. The airborne HyMap™ (Integrated Spectronics Inc., Sydney, Australia) hyperspectral data was further classified using hyperspectral mapping methods. The hyperspectral methodology would offer an additional rapid tool for mire surface mapping as part of the process of peatland inventory programs and ecological studies of boreal peatlands.

METHODS

HyMap data

On July 29th, 2000, between 10.50 am and 3.40 pm local time, the HyMap™ sensor was flown across a 1200 km^2 flight area (see Fig.2). Airborne imaging at a flight altitude of 2 km, ground speed of 278 km/h and 60 degree field of view resulted in data with 5 m spatial resolution along and across a track with 2 km swath width. HyVista Corporation Pty. Ltd. (Sydney, Australia) operated the HyMap™ sensor which measured on board radiation from the ground in 126 contiguous bands at 12-to-16-nm intervals across a wavelength range from 450 to 2450 nm (see 6).

Geometric correction and geocoding were performed with the PARGE software (PARametric GEocoding, University of Zürich, Switzerland; 7; 8) and atmospheric correction with ATCOR (Atmospheric/Topographic CORrection for Airborne Imagery, DLR, Germany; 9). Spectra of five pseudo invariant features were measured with hand held spectroradiometers during the flight campaign. A white and a black plastic reflectance panel were spread, and three homogenous flat surfaces, 15 m by 15 m in size, were prepared within the flight area.

Bands with low signal-to-noise ratio were removed and the remaining 118 bands in wavelength regions 449-1337 nm, 1448-1793 nm, 1970-2454 nm were input for further image processing. An average 200 km^2 study area was delineated for the analysis since the GTK peat inventory data (10) was only available for the northernmost corner of the HyMap flight area (see Fig. 2).

Ground data

Peat inventory in the field is done systematically along survey lines. The peat deposits are drilled every 100 meters along the lines with 200–400m spacing between lines. The quality of the peat obtained from the drill cores is analysed visually and sampled for chemical and physical analyses. The mire site type is reported along with many other variables (2). Sampling points with less than 0.3 m of peat were removed which resulted in 491 observation points to aid in processing the HyMap imagery.

Hyperspectral image processing

The hyperspectral mapping tools implemented in ENVI® 3.6 image processing software (Research Systems Inc., Boulder, CO, U.S.A.; 11) were used to process the imagery. A mask was created by thresholding the band centered at 784 nm to exclude open water from the analysis. Minimum Noise Fraction (MNF) transformation was applied to reduce the data dimensionality. Eleven MNF components, having large eigenvalues and being visually coherent, were chosen for further processing.

Based on GTK peat inventory data, 12 different training areas (600-1000 pixels in each) were delineated to represent five different treeless pristine mire site types. Several areas with varying depths of peat were chosen to represent the most common types. Validation sites were also delineated simultaneously. The separability of the signatures was evaluated in the MNF feature space with the n-dimensional visualizer and by calculating the Jeffries-Matusita signature separability statistics. Signatures were merged or eliminated if they were not separable. Mean reflectance spectra calculated from the remaining signatures were put into a spectral library. The spectral differences between the mire site types were interpreted from the signature mean spectra, and compared to a mean spectrum collected from a downy birch (*B. pubescens*) stand. The remaining spectra representing the mire site types were entered into a mixture tuned matched filtering

(MTMF) algorithm. The class specific matched filter score images (MF-score) were thresholded to produce a classification map (Fig. 4). Threshold limits were set where the training site was completely covered by the class. The results were thereafter median filtered. Results of an accuracy assessment are presented in an error matrix (Tab. 1).

RESULTS AND DISCUSSION

Signature separability analysis produced six different signatures (Jeffries-Matusita separability values > 1.999). They represented the most common mire site types in the study area. The remaining *Carex* fen signatures were 'tall-sedge fen', 'flark fen' and 'herb-rich sedge fen'. *Sphagnum* bog signatures were two '*Shagnum fuscum* bog' signatures, and a signature representing 'low-sedge bog'.

The most pronounced spectral differences between peatlands and a downy birch stand, as an example of 'green' vegetation, were in the near infrared region (NIR, 700-1300 nm, see Fig. 3). Peatlands had low reflectance values in NIR as compared to that of the birch stand. Differences in the strongest water absorption bands at the short wave infrared region (SWIR, 1300-2500 nm) were not pronounced (except for '*Shagnum fuscum* bog -dry' signature). The green vegetation was characterized by relatively high green (500-600 nm) in comparison with low red (600-700 nm) reflectance. The shape of the VIS (400-700 nm) spectrum obtained from peatlands was flatter except that for 'herb-rich sedge fen' which often had, among the dominant *Carex* species, a significant amount of broad- leaved species in the upper canopy.

The signature separability analysis demonstrated that *Carex* fens and *Sphagnum* bogs were spectrally distinguishable. Since *Sphagnum* species often appeared to be brownish, yellowish or reddish in colour their VIS reflectance was higher and the shape of reflectance spectra also flatter than those of *Carex* fens which had a prominent green peak and red well (see Fig. 3). *Carex* fens appeared green to the naked eye especially during the HyMap flight mission in late July. *Carex* fens also had lower NIR reflectance than *Sphagnum* bogs. Since the NIR reflectance of plants is related to cell structure and cell wall/intercellular air space characteristics, without any microscopic or biochemical analysis it can only be stated that the differences between the types exist. *Sphagnum* bogs tend to be dryer on the surface than *Carex* fens since their SWIR reflectance was higher overall. Ridges are often composed of *Sphagnum* and can be very dry at the surface in July. In the case of *Carex* fens, the ground water table is often close to the surface, hence open water can be present.

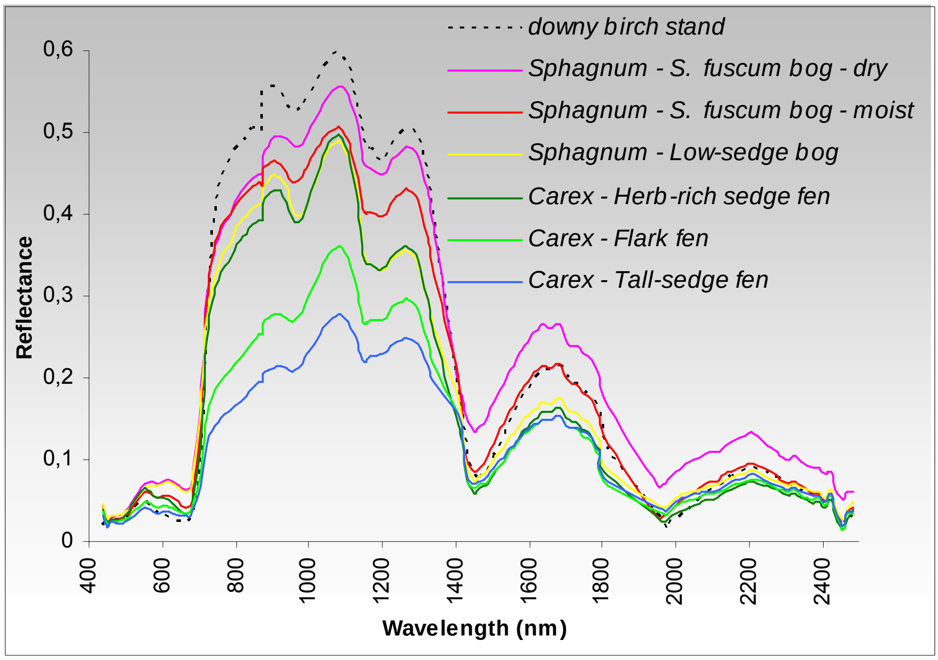

Figure 3: Mean spectra of signatures representing Carex fen and Sphagnum bog mire site types and a birch stand.

The mire site types of *Carex* fens had differences in their reflectance spectra (see Fig. 3). The 'herb-rich sedge fen' had a more pronounced green peak and red well and higher reflectance in NIR than those of the 'flark fen' and the 'tall-sedge fen'. The number of herbaceous and broad-leaved species is usually higher in 'herb-rich sedge fens' which may explain the difference. The reflectance of 'herb-rich sedge fen' is quite similar to 'low-sedge bog' (a *Sphagnum* bog) in NIR and SWIR and, as such, created confusion in the MTMF classification. The 'herb-rich sedge fen' class was removed from the final classification due to low measures of accuracy.

Sphagnum and bogs overall were previously reported to have had low reflectance values in the 1000-1200 nm and 1300-2400 nm regions (12, 13). However, *Sphagnum* is highly tolerant of water content fluctuations since surface water regimes in peatlands may undergo significant seasonal changes. In this study, two '*Sphagnum fuscum* bog' sites were chosen since their spectral properties in VIS and SWIR were significantly different (see Fig. 3). The '*Sphagnum fuscum* bog - dry' had higher VIS and SWIR reflectance values than '*Sphagnum fuscum* bog - moist' indicating the moisture and species difference. In general, *Sphagnum* also has a flat VIS reflectance spectrum compared to that of "green" vegetation. In nature it often appears brownish. The *Sphagnum* bog mire site types may also include dwarf shrubs, herbaceous and other *Sphagnum* species. For example, the moist *S. fuscum* bogs often have patches of sedge which may in fact explain the difference of VIS spectra between the moist and dry *S. fuscum* bogs (see Fig. 3). A similar phenomenon was also experienced on a site where a 'low-sedge bog' (*Sphagnum* bog) was partly classified as a *Carex* fen. The reflectance spectra of *Sphagnum* is also species dependent (12).

An overall accuracy of 61.3% (kappa 0.526) was achieved when a classification image with the five mire site type classes was produced (Fig. 4, Tab. 1). There is hardly any confusion between the *Carex* fens and *Sphagnum* bogs but classification errors mostly occurred when dealing with the mire site types within them. Within the *Sphagnum* bogss good user's (66.4-99.8%) and producer's (60.4-99.7%) accuracies were obtained. More confusion existed between the *Carex* fens (47.1-56.6% user's accuracies, 23.5-46.4 % producer's accuracies). They also overlapped with agricultural fields (see Tab. 1, a high number of pixels in 'Unclassified' class) which was most likely as a result of the spectral similarities between pasture/cereal species and sedge.

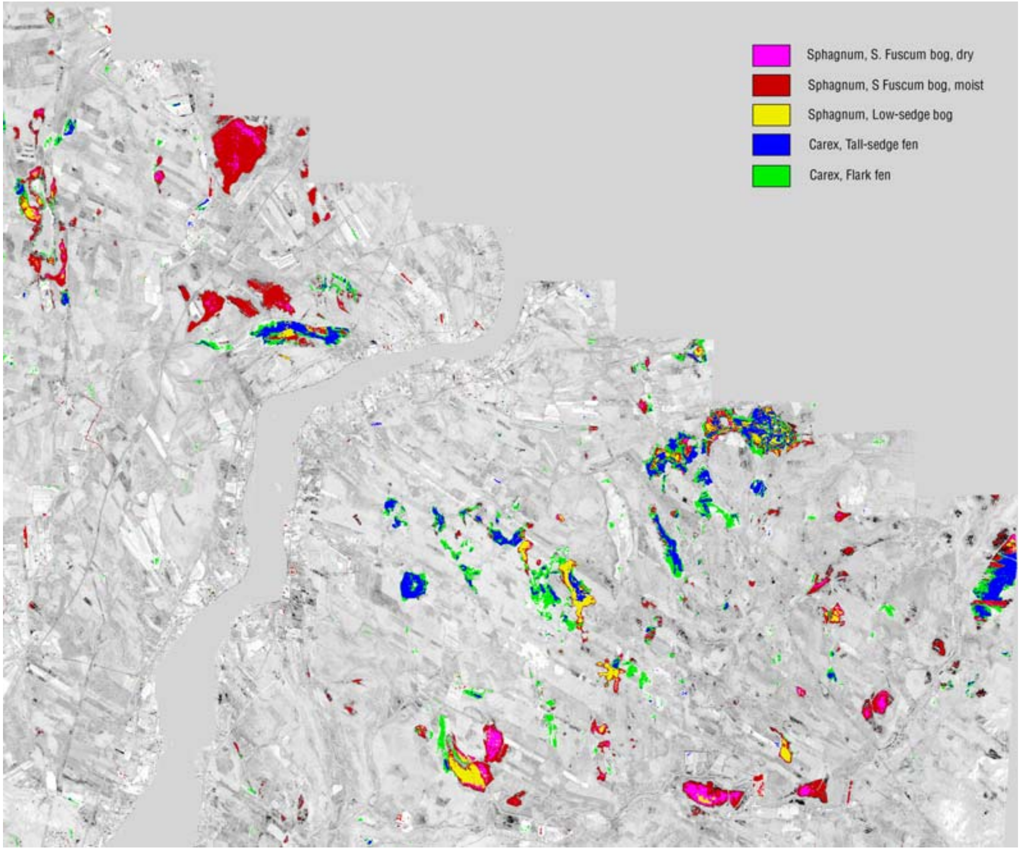

Figure 4: Classification result of MTMF for Sphagnum bogs and Carex fens. Width of the area is 19 km.

Previous attempts to classify boreal mire site types using remote sensing techniques are rare. Digitized aerial photographs were classified into 16 peatland vegetation types in southern Finland with 66.5 accuracy (14). A more generalized classification of prairie wetland habitats in Canada from multitemporal Ikonos-2 images resulted in an overall classification accuracy of 84% (15). Ecological classification of boreal peatlands from hyperspectral CASI data resulted in approximately 60% overall accuracies in Canada too (16). In this study, an overall accury of 63.1% was obtained for the four treeless pristine mire site types. Acceptable but low accuracy measures seem to be a common factor between this study and other studies that have been reported.

Table 1. Error matrix of MTMF classification. Values are in number of pixels.

Ground control	Low-sedge bog	*S.fuscum* bog - moist	*S.fuscum* bog - dry	Tall-sedge fen	Flark fen	User's accuracy (%)
Classification						
Unclassified	8	0	1	180	271	
Low-sedge bog	453	1	0	0	0	99.8
S. fuscum bog - moist	54	496	2	0	0	89.9
S. fuscum bog - dry	211	231	873	0	0	66.4
Tall-sedge fen	3	0	0	167	125	56.6
Flark fen	21	0	0	365	343	47.1
Producer's accuracy (%)	60.4	68.1	99.7	23.5	46.4	Overall 61.3 %

CONCLUSIONS

Promising results were obtained in classification of boreal mire site types from HyMap imagery with hyperspectral mapping methods. As compared to ‘green’ vegetation, peatlands often have a weak green peak and red well along with low NIR reflectance. The *Carex* fens and *Sphagnum* bogs were easily distinguished from one another. The *Carex* fens were characterized by lower VIS, NIR and SWIR reflectance values than *Sphagnum* bogs, since sedge, herbaceous and broad-leaved species are common and the ground water table is close to the surface in *Carex* fens. The *Carex* fens being nutrient-rich and *Sphagnum* bogs nutrient-poor this division already provides valuable information regarding the surface conditions in peatlands. The four most common mire site types were classified with reasonably good success (overall accuracy of 61.3%). The classification uncertainty was caused by the heterogeneity of plant communities and surface moisture conditions within mire site types. A HyMap pixel (5m x 5m) can contain a range of plant species, therefore delineation of ‘pure’ signatures was difficult. The mire site type classification systems may also not be detailed enough to be used as reference data in classifying high spectral and spatial resolution remote sensing data. The true success of the method will be evaluated in the future when both species inventory data and measurements of the mire surface moisture at the time of the flight will be available.

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