APPLICATION OF NATIONAL FOREST INVENTORY FOR REMOTE SENSING CLASSIFICATION OF GROUND LICHEN IN NOTHERN SWEDEN

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ABSTRACT:

Lichen is a major forage resource for reindeer and may constitute up to 80% of a reindeer's winter diet. The reindeer grazing area in Sweden covers almost half of the country, with reindeer using mountainous areas in the summer and forested areas in the winter. Knowledge about the spatial distribution of ground lichens is important for both practical and sustainable decision-making purposes. Since the early 1980s, remote sensing research of lichen cover in northern environments has focused on reindeer grazing issues. The objective of the present study was to use lichen information from the Swedish Forest Inventory (NFI) for classification of satellite data into ground lichen classes. The classification procedure was focused on using of NFI plots as training sets for supervised classification of the ground lichen cover in purpose to classify areas with different lichen coverage. The present research has shown the advantage of use forest inventory plot data by assessment of three methods: mahalanobis distance (MD) classification, maximum likelihood (ML) classification and spectral mixture analysis (SMA). The results of this study demonstrate high classification accuracy of SPOT imagery in distinction between lichen-abundant and lichen-poor areas by mahalanobis distance classifier (overall accuracy 84.3%, kappa=0.68). The highest classification accuracy for Landsat scene was achieved by maximum likelihood classification (overall accuracy 76.8%, kappa=0.53). The continuation research on more detailed fragmentation of lichen cover into fractions is proposed.

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1. INTRODUCTION

Lichen is an important nutrient source in boreal environments, like North America, Scandinavia and Russia. In Sweden the reindeer husbandry area covers almost half of the country, with reindeer using mountainous areas in the summer period and forest areas in winter. Lichen is a major forage resource for reindeer and may constitute up to 80% of a reindeer's winter diet. Thus, the importance of knowledge about spatial distribution of ground lichen is extremely high. In Sweden, over almost half of the country (230 000 km^2) is used as grazing lands by the Sámi. The fact that these same areas with Sámi grazing rights also have rights tied to forestry activities, makes resource management especially complicated and knowledge dependent. Consultations between representatives from the herding districts and the forestry sector are regularly held to address questions of forest use. However, these consultations are not as effective as they could be, in part because both parties lack information about the lichen resource [Sandström, 2004].

In this study, the objective was to use lichen information from the Swedish NFI in purpose of ground lichen classification different satellite data sources and different supervised classification methods. Most previous studies have performed image classification using a single method or sensor [Nordberg and Allard, 2002; Colpaert et al, 2003; Rees et al, 2003; Sandström et al, 2003; Tømmervik et al, 2003; Johanson et al, 2003]. However, only few attempts have been focused on evaluation of the most appropriate method for mapping lichen in forest areas, i.e. [Theau et al., 2005]. Particularly in boreal forest environment when classification of ground lichen is rather complicated by its co-occurrence with variably closed canopies.

The two most commonly available and suitable sensors with an appropriate scene size to map lichen cover of large areas in Sweden are the SPOT and Landsat sensors. With regards to investigating these sensors, we aim to study whether the higher spatial resolution of SPOT imagery provides an advantage, as well as whether the larger swath width of a Landsat

scene (and consequently a larger NFI training data set) provides higher classification accuracy.

Training data for the supervised classification are taken from the Swedish National Forest Inventory (NFI), which have not been previously tested for use in lichen classification. Three different supervised classification methods were checked in our study: mahalanobis distance, maximum likelihood and spectral mixture analysis. Classification accuracy is assessed using an independent validation dataset in which detailed field measurements of lichen cover and height were taken.

The study area is located in the northern part of Sweden in the Västerbotten County and is used as winter grazing lands by five local reindeer herding communities. The study area lies entirely within the boreal forest belt and consists of managed pine, spruce and mixed forests. The two main reasons for selection of this study area was representativeness of vegetation types and availability of satellite imagery and NFI plots.
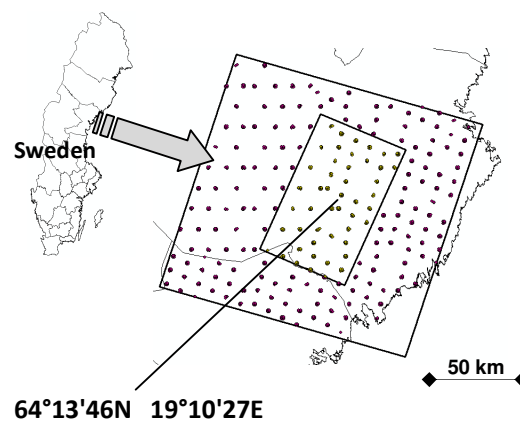

Figure 1. The NFI plots within the study area with outlines of Landsat (bigger rectangle) and SPOT (smaller rectangle) imagery in the County of Västerbotten in Northern Sweden.

The study area is covered by extent of two merged SPOT 5 images (7,200 km^2) from July 4, 2005 and the Landsat 7 ETM+ scene (32,600 km^2) from August 11, 2002 (see Fig. 1).

Most previous studies have performed image classification using a single method or sensor, and only few attempts have focused on evaluating the most appropriate method or comparison of sensors for classification of lichen cover in the boreal forest (i.e. Theau et al, 2005). Thus, the main objective of our study was to use lichen information from the NFI in sake of ground lichen cover classification from different satellite data sources and by different supervised classification methods.

2. STUDY DATA

2.1 NFI data

The forest inventory plot data are taken from the Swedish NFI that is an annual national field sample of landuse, forest, ground and vegetation variables. It is a nationwide stratified systematic sample consisting of square clusters with eight (or twelve for temporary plots) circular sample plots with 10 meters radius (7m for temporary plots). Approximately 30 % of all plots are permanent and they are re-measured after 5-10 years. An annual inventory consists of approximately 10 000 plots. The remaining plots are temporary, which means that they are only measured once. Both temporary and permanent plots which were inventoried during last decade (1996-2005) were selected for our study. In our study area, the permanent clusters have sides measuring 1200 m, while the temporary squares have sides measuring either 1500 or 1800m. The coordinates for all NFI plots since 1996 have been recorded in field using GPS. Variables include the percent forest cover within plot, tree species percentage, height, age, mean diameter, site index, wood volume per tree species, field layer vegetation, soil moisture, age of clear-felling, and lichen coverage, among others. In the NFI, lichen cover is represented as a percentage of the total plot area (~314 m^2), and during field inventory

each NFI plot is assigned to one of several classes according to a visual assessment of the lichen cover (see Table 1). The relevant types are called "lichen-poor", "lichen-moderate" and "lichen-abundant". Lichen-poor type represents low lichen cover with less than 25% lichen in the plot area; lichen-moderate type represents intermediate lichen coverage (25-50%); and lichen-abundant type represents high lichen cover (more than 50%).

Lichen cover	Lichen class	SPOT (943 plots)	Landsat (3670 plots)
< 25%	Lichen-poor	808 (85.7%)	3275 (89.2%)
25% - 50%	Lichen-moderate	72 (7.6%)	232 (6.3%)
> 50%	Lichen-abundant	63 (6.7%)	163 (4.4%)

Table 1. Distribution of NFI plots within different image extents.

2.2 Satellite data

Satellite data from SPOT-5 and Landsat 7 ETM+ were used to classify ground lichen cover in our research. The SPOT-5 imagery has a scene size of 60 x 60 km, a pixel size of 10 meters, and four wavelength bands: Green (1), Red (2), near infrared (NIR) (3) and mid-infrared (MIR) (4). Two adjacent SPOT-5 image scenes (054-217-J0 and 054-217-J8) with look angle 15.85°, acquired on July 4, 2005) were illumination corrected using the c-correction (Teillet et al., 1982) and then mosaiced to cover the study area in the Vilhelmina Norra herding district (7,200 km^2). Geometrically precision corrected Landsat data (re-sampled to 25 x 25 m pixels) cover a swath width of 185 km in 7 wavelength bands: the visible bands 1 - 3, band 4 (NIR), bands 5 and 7 (MIR) and thermal band 6 (at 60 m resolution). Band 6 was excluded from the analysis. The Landsat image (32,600 km^2, path 194, row 15 from August 11, 2002) has been haze-corrected by

calculating a haze-index based on the satellite image's digital values over forest and relating it to NFI plots with known forest properties (Hagner and Olsson., 2005; Hagner and Reese 2007). Haze correction, particularly of the blue band which is normally affected by atmospheric scatter, was important for classification of the Landsat data. An illumination correction was also performed with the c-correction (Teillet et al., 1982).

2.3 Field data

Field inventories have been carried out to measure the fraction of lichen coverage and lichen thallus height on sample plots. The field validation plots were allocated through a stratified random sample over the study area. The stratification was based on an unsupervised classification of the SPOT data into three strata: forest land with low probability of lichen, forest land with medium probability of lichen and forest land with high probability of lichen; equal numbers of plots were randomly allocated to each stratum. The definition of "forest land" in Sweden is all land which has the potential to produce at least 1 m^3/ha of forest, and therefore excludes water bodies, wetland, and urban areas. In addition, the field sampling area was restricted to a distance of 300 meters from the roads for the sake of survey logistics. Field validation plots have been designed in form of a square 50 meters in length. In every field square, four parallel cross-section profiles (10 m apart) of 26 systematic measurements (every two meters) of presence or absence lichen or moss, lichen species, and lichen thallus height were made, in order to characterize lichen cover within the square. Measurement of lichen thallus height may be useful in any potential future validation of lichen biomass, as lichen thallus height has a relationship with biomass [Moen and Holt, 2007]. Over three summer seasons (2006-2008) a total of 229 validation plots were field inventoried to estimate these lichen characteristics.

3. IMAGE CLASSIFICATION

The main challenge of the present study was to observe a suitability of the NFI lichen types for remote sensing classification of ground lichen cover in boreal forest environment. The amount of available NFI plots provided a statistically sound source of information regarding the three discrete lichen classes (lichen-poor, lichen-moderate and lichen-abundant). Due to the potential heterogeneity of "lichen-moderate" training sets (because of the mixed spectral response of lower lichen coverage together with moss), two different class divisions of the training data were tried: 1) plots of lichen-abundant and lichen-poor type only, leaving out lichen rich training plots, which will be referred to here as the Dataset 1; and 2) plots of combined lichen types (lichen-moderate + lichen-abundant type) and lichen poor type, referred to here as the Dataset 2 (see Table 2). In similar way in order to validate the classification results for the different lichen classes, two validation datasets were created. For validation of Dataset 1 classification results, lichen-moderate field plots (25%-50% of lichen coverage) were assigned to the same group as lichen-poor type (Validation 1) and for validation of Dataset 2 classification results, field lichen-moderate plots were assigned to the same group as lichen-abundant field plots (see Table 2). Thus, the "lichen abundant" class is most lichen containing class in the Dataset 1 and "Lichen moderate + Lichen abundant" class is most lichen containing class in the Dataset 2.

Dataset1 :	Lichen-poor	Lichen-abundant
Dataset 2:	Lichen-poor	Lichen-moderate + Lichen-abundant

Validation 1:	Lichen-poor + Lichen-moderate	Lichen-abundant
Validation 2:	Lichen-poor	Lichen-moderate + Lichen-abundant

Table 2. Organization of training sets and validation sets of lichen classification

After haze- and illumination correction, the satellite data has been masked to include only forested areas, using a 1:100 000 scale land

cover map produced by the National Land Survey. Training image data were extracted from the extent of the two-scene SPOT mosaic and the entire Landsat scene. Since the Landsat scene covers a larger area than SPOT it contains a greater number of NFI training plots. Thus the selected classification methods were carried out for merged SPOT scene and the Landsat scene. On the basis of our previous experience and the literature review, we decided to test three methods of supervised classification: mahalanobis distance (MD), maximum likelihood (ML) and spectral mixture analysis (SMA), using ITT ENVI 4.5 software package.

In our study parametric methods of classification assume equal probability of occurrence and the frequency of class occurrence is not taken into consideration. Thus the results of more-frequently occurring classes might be underclassified and less frequently occurring classes might be overclassified [Hagner and Reese, 2007]. To overcome this issue in this study, as a part of post-classification procedure for the parametric methods (MD and ML) and spectral mixture analysis (SMA), the proportions of result classes were calibrated to match the NFI proportionality of lichen cover fractions (see Table 1). Thus lichen-abundant class in Dataset 1 was set to 7% for classification of SPOT when lichen-poor class was set to 93% of the classified area. In case of Dataset 2 the part of combined class (lichen-moderate + lichen-abundant) was set to 15% for SPOT when lichen-poor class was respectively set to 85%. Since the Landsat extent has different proportions between lichen classes, the part of lichen-abundant class in Dataset 1 was set to 4% (lichen-poor 96%) and the part of combined lichen class (lichen-moderate + lichen-abundant) in Dataset 2 was set to 11% (lichen-poor 89%).

The accuracy for the classified images was assessed on the level of field surveyed plot. For this purpose the dominating (majority) class of the classified pixels within a field plot quadrant was compared with the class according to the field measurements. Thus the majority class was defined as a class that contains more than 50%

of pixels within the area covered by the field plot.

All classification results were evaluated using a confusion matrix based on the field survey. Among the basic classification assessment characteristics of overall accuracy (number of correctly classified field plots divided by total number of field plots) and kappa coefficients (indicates the agreement among classes where a value of 1 indicates a perfectly effective classification with no contribution from chance agreement), statistical estimators of producer and user accuracies, were reported for every method and sensor (see Tables 3-5). In Tables 3-5 the upper number of overall accuracy and kappa coefficient (above the diagonal line), refers to the classes in Dataset 1 and the lower number is for the classes in Dataset 2. For producer and user accuracies, the upper number refers to the most lichen containing class in the dataset and the lower number to the lowest lichen class in the dataset.

	Overall Acc, %	Kappa	Producer Acc, %		User Acc, %	
			Dataset 1	Dataset 2	Dataset 1	Dataset 2
SPOT	84.3 / 79.6	0.68 / 0.60	72.6 / 91.2	87.6 / 76.5	81.5 / 86.2	66.6 / 92.0
Landsat	75.4 / 67.3	0.51 / 0.34	82.2 / 71.7	46.6 / 78.2	53.2 / 86.7	50.1 / 73.4

Table 3. Accuracy assessment for MD classification.

	Overall Acc, %	Kappa	Producer Acc, %		User Acc, %	
			Dataset 1	Dataset 2	Dataset 1	Dataset 2
SPOT	80.6 / 74.9	0.61 / 0.49	82.2 / 78.9	79.6 / 71.6	67.3 / 89.3	60.5 / 87.2
Landsat	76.8 / 74.8	0.53 / 0.49	56.9 / 94.5	73.6 / 82.0	67.0 / 79.8	65.2 / 81.1

Table 4. Accuracy assessment for ML classification

	Overall Acc, %	Kappa	Producer Acc, %		User Acc, %	
			Dataset 1	Dataset 2	Dataset 1	Dataset 2
SPOT	72.9 / 70.5	0.46 / 0.41	25.0 / 97.6	25.0 / 97.6	68.9 / 80.2	84.6 / 71.1
Landsat	67.7 / 72.9	0.35 / 0.46	25.0 / 97.6	43.0 / 96.1	58.4 / 69.5	85.4 / 76.1

Table 5. Accuracy assessment for SMA.

4. DISCUSSION

Our work presents the attempt to assess different classification methods and different image sources for the task considering the preexisting lichen data from the Swedish NFI. The challenge of our study was to distinguish the ground lichen cover when there is an overstory of a canopy in the way. In such a case, the NFI plots provide not the spectral response of pure lichen endmember but a natural mixed response which characterizes the presence of some lichen cover together with other phenomena (i.e. various canopy closures or shades). We assume that presence of lichen has affected on spectral response of the forest in remotely sensed imagery and similar lichen coverage has caused to similar spectral response from the pixels of the same NFI class. Thus the task of lichen cover classification is actually about the assigning of every pixel in the imagery with NFI lichen classes when the accuracy of lichen classification depends a lot on the correctness of NFI lichen classes. Only in case of trustful NFI lichen information it is possible to distinguish between different lichen covers by supervised classification methods. The classification results of the present research have showed better accuracy characteristics for training Dataset 1 which based on most distinguishable lichen classes: lichen poor and lichen abundant. For most of tested classification methods (except SMA) the Dataset 1 has showed better result than Dataset 2. Hence the addition of most ambiguously defined NFI lichen class (lichen-moderate) has caused considerable decreasing of classification accuracy.

Although the study was based on ambiguous definition of lichen classes in the Swedish NFI, the best found method by this study (mahalanobis distance classification) has succeeded to achieve considerable parameters of classification accuracy. The ambiguity of the NFI lichen classes when distribution of spectral characteristics within the class is not normal could make a mahalanobis distance (which uses as the decision rule of the maximum likelihood classification) to be non representative for the probability of a given pixel value being a member of a particular class. Since the selection

of pure and representative endmembers is a critical process in SMA, the fail of this method in the present study, may be also explained by ambiguity of used lichen classes.

5. CONCLUSION

The results of our study provide best accuracy characteristics in case of mahalanobis distance classification over SPOT-based imagery, when most confident lichen classes are lichen poor and lichen-abundant. The ambiguity of used lichen classes seemed to be a main reason for classification confusion by maximum-likelihood and SMA methods. The definition of more detailed lichen classes may improve a performance of these methods. The usage of Landsat imagery was also showed as possible way of lichen classification for larger areas under constrains of accuracy characteristics. The Swedish NFI was found as appropriate source of lichen training data for task of classification of ground lichen cover. The results of the study provide a basis for continuation research of more detailed classification of lichen cover, based on incorporation of NFI forest parameters into the process of definition of lichen sub-classes.

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