USE OF SPECTRAL MIXTURE ANALYSIS FOR CHARACTERISATION OF FUNCTION AND STRUCTURE OF HEATHLAND HABITAT TYPES

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ABSTRACT:

Habitat monitoring of designated areas under the EU Habitats Directive requires every 6 years spatially explicit information on area, range, structure and function for the protected (Annex I) habitat types. Hyperspectral remote sensing could be an important technique to assist in the evaluation of the habitat conservation status by providing continuous maps of habitat quality indicators (e.g., structure types, age distribution, invasive species, management activities). This paper assesses the use of hyperspectral imagery to study the structure and function of a heathland ecosystem in the Veluwe nature reserve in the Netherlands. Spectral mixture analysis (SMA) was applied on AHS-160 (Airborne Hyperspectral Scanner) imagery to investigate their appropriateness to characterize the spatial coverage and configuration of relevant heathland habitat types (wet and dry heathlands and inland sand dunes). For the *Calluna vulgaris* dominated dry heath there was a specific emphasis on the characterization of different development stages of the heather (pioneer, developing, climax and degenerating). In addition, fraction maps for the endmembers grass and coniferous forest (e.g., Pinus spp.) were made to assess the process of grass and forest encroachment in the heathland which are considered as unfavourable developments. Results indicate that SMA is suitable for mapping the main components of the heathland ecosystem. However, additional research is required to assess the influence of sensor type and phenology of the vegetation. The results of this study show that hyperspectral remote sensing can complement the traditional vegetation field surveys. Remote sensing derived continuous habitat maps and their associated quality indicators can help to optimize sampling schemes and focus effort on rare and often inaccurately mapped habitat types. Moreover, the remote sensing derived information does not only provide useful information for the habitat reporting obligations but also provides useful (site specific) information for the nature reserve managers. In this way costly fieldwork effort can be employed in a more efficient way.

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1. INTRODUCTION

With the designation of over 25,000 Natura 2000 sites within Europe, the European Commission is aiming to create an ecological network of protected areas covering valuable natural habitats and species of particular importance for the conservation of biological diversity within the EU. Member states are obliged to report every six years about the conservation status of the habitats for the designated Natura 2000 sites. Within this context, conservation status is defined in terms of (Bijlsma *et al.*, 2008):

- the evolution of the range and the area covered by the defined habitat types;
- the overall quality of the habitat type as expressed by its structure and ecological functioning (species composition, amount and distribution of different plant life forms, conservation status of the typical species, ...).

However, collecting these data by field-driven survey alone will often not be feasible and has serious financial consequences. Therefore, remote sensing based methods could be important alternative data acquisition techniques for accurate habitat reporting which can complement field-based methods.

Opportunities for space-based remote sensing in habitat and biodiversity monitoring at the regional level have recently been described in two review papers by Duro *et al.* (2007) and Gillespie *et al.* (2008). However, monitoring of habitat quality at the local level (e.g., structure and function) is still a challenging application because this requires methods which can deal with complex transitional zones present within natural vegetation. Instead of looking at vegetation as a group of classified patches with sharp boundaries, one could also treat compositional variation as a continuous field. In a recent study, Schmidtlein *et al.* (2007) combined ordination measures derived from floristic field data with spectral data from HyMap to derive continuous maps which represent abrupt transitions between habitats as well as within heterogeneity and gradual transitions. Another approach for continuous field mapping is the use of spectral mixture analysis (SMA). Here, vegetation is seen as a mixture of class fractions where reflectance in a pixel is a mixture of end member spectra for the vegetation classes present in the pixel. Because the same endmembers can be used to analyze a time sequence, SMA has the capability to estimate changes in abundance (Rosso *et al.*, 2005). The potential to estimate the spatial distribution and abundance of species or species types has great value in monitoring aspects related to habitat structure and function (e.g., grass encroachment), because changes can be detected and quantified.

This study assesses the use of imaging spectroscopy to evaluate the structure and function of a heath land ecosystem in the Netherlands. Spectral mixture analysis (SMA) was applied on hyperspectral AHS-160 imagery to investigate their appropriateness to characterize the spatial coverage and configuration of relevant heath land habitat types. SMA is examined as a possible technique that takes advantage of the high-dimensional spectral information content of imaging spectroscopy data to discriminate habitat types in complex ecosystems at the sub-pixel level and in a spatial continuous manner. In the discussion we will especially focus on the opportunities for remote sensing to complement the traditional vegetation field surveys.

2. MATERIALS AND METHODS

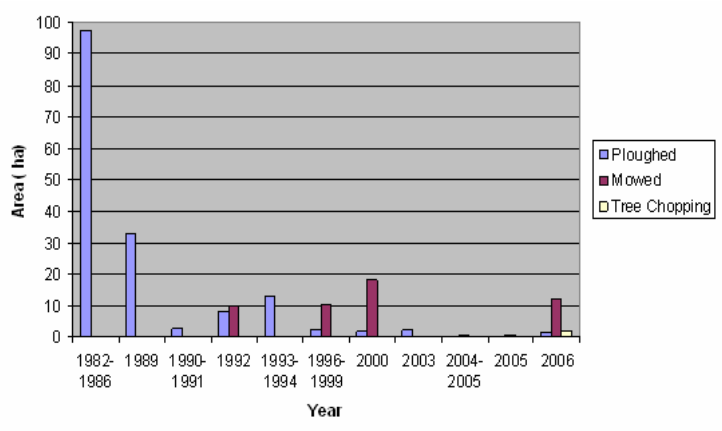
2.1 Study site

This research was conducted at the Eder and Ginkelse heath land Nature Reserve (5º 45’ E, 52º 03’ N), which is part of the Natura 2000 site the Veluwe located in the centre of the Netherlands. The Veluwe is situated at relatively higher located dry sandy soils and is one of the largest Natura 2000 sites in the Netherlands (91.200 ha). The area includes some highly valued habitats, e.g., inland sand dunes, dry and wet heath land, and dry deciduous forest. In addition, it provides habitat for several national and EU listed threatened and endangered species. The Eder and Ginkelse heath land (400 ha) is known for its large area covered by dry heath land vegetation dominated by Calluna. The Ginkelse heath land is the area located to the south of the main road N224 going from Ede to Arnhem, and the Eder heath land is located to the North of this road (Figure 1).

The heath land vegetation has developed during the Middle Ages as part of agricultural use. For many centuries, the organic layer was removed from the surface by sod-cutting. That organic layer was transported to farm stables where it was mixed with the animal manure and subsequently re-used on arable land. Due to overexploitation and mismanagement, the sandy soils lost fertility and extensive heath land and inland dune systems developed. This practice continued until the 19th century, in addition the area was used intensively for grazing. Starting already at the beginning of the 20th century, the study area was used as a military terrain and intensively used for exercises. As a result ecological processes are under pressure and this causes continuous change of the landscape. Currently, the area is managed and owned by the Dutch Ministry of Defence.

Figure 1. Aerial photograph for study area Eder and Ginkelse heath land nature reserve including the location of the two AHS flight lines (line 1: red; line 2: blue) and the vegetation sampling plots.

Especially as a result of increased atmospheric nitrogen deposition, the quality of the heath land declined rapidly during the 1980s as indicated by increasing grass and tree encroachment. Several management practices were carried out to reduce the influence of these process: sod-cutting, ploughing, grazing etc. Based on an analysis of a time-series of aerial photographs, the management over the period 1982-2006 was reconstructed (Figure 2). Initially ploughing was applied on a large scale which still can be detected in the patch-like structure of the heath land in especially the Ginkelse heath land (Figure 1). In the beginning of the 1990s less intensive practices like mowing and sod cutting were applied more frequently, however clearly with a lower surface coverage.



ıre 2. Heath land management practices for Eder and Ginkelse heath land area over the od 1982-2006 derived from a time series of al photographs.

Heathland: Calluna-dominated	Hdc
of predominantly young age	Hdcy
of predominantly adult age	Hdca
of predominantly old age (open)	Hdco
mixed age classes	Hdcm
Heathland: Molinia-dominiated	Hgmd
Grassland permanent with semi-natural vegetation	Gpn
Forest coniferous	Fc
Forest deciduous	Fd
Sand bare	Sb
Sand fixated dune with grass	Sfg

Table 1: Heath land habitat types present in study area

The heath land vegetation in the study area (Table 1) consist mainly of *Calluna vulgaris* dominated dry heath land (Hdc). Due to succession within this habitat type different *Calluna* age classes can be distinguished: pioneer (Hdcy), climax (Hdca) and degenerating (Hdco). A heath land structure with a mixed composition of age classes (Hdcm) is considered as highly valuable. According to habitat assessment requirements for function and structure (Bijlsma *et al.*, 2008), grass encroachment with *Molinia* (Hgmd) is considered a negative process while a scattered distribution (< 10%) of shrubs and trees (Fc and Fd) is considered as favourable. Finally, bare sand areas (Sb) and sand fixated dunes (Sfg) are important indicators for the occurrence of wind erosion processes which is considered an important process for the development of this landscape.

2.2 Image data acquisition and processing

Two flightlines with the AHS-160 (Airborne Hyperspectral Scanner) sensor were acquired over the Eder and Ginkelse heath land reserve on October 7, 2007, around 11:15 (UTC). Images were acquired by INTA from Spain using a CASA 212-200 airplane. For this study , 63 bands of the AHS-160 sensor were used divided over the visible and near-infrared (20 bands from 430-1030 nm with 30 nm resolution), short-wave infrared region 1 (1 band from 1550-1750 nm with 200 nm resolution) and short-wave infrared region 2 (42 bands from 1995-2540 nm with 13 nm resolution). Processing of the images from DN values to radiance and surface reflectance was carried out by the processing and archiving facility of VITO (Biesemans *et al.*, 2006). The PARGE and ATCOR model were used for geometrical and atmospheric correction of the data, respectively. The spatial resolution of the final images was 2.4 m. A flightline mosaic was created for the study area. The bands in the 1995-2540 nm region showed a relatively higher noise component compared to the other bands of the sensor. In addition, illumination differences were observed along the edge of the flight lines which could not be attributed to objects in the field.

2.3 Ground reference data

Ground reference data to train and validate SMA were collected in the period after image acquisition between October 2007 and April 2008. Sampling locations were selected as regular grid over the study area with a sampling distance of approximately 250 m. Geographic coordinates for every location were collected with a Garmin handheld global position system unit. For every location a description of the habitat types was made according to the methodology established in the BioHab project (Bunce *et al.*, 2008). For an area of 3 by 3 m we noted the lifeforms present and noted the percent coverage of dominant species for every lifeform. Based on this information a classification into habitat type was made (Table 1). A total of 104 plots were recorded in the study area and for every plot overhead and oblique field photos were taken.

2.4 Endmember selection and spectral mixture analysis

The endmembers were selected manually by extracting spectra from the AHS-160 image based on vegetation distribution information derived from the field observations. Candidate pixels were selected from locations were the habitat types appeared pure and had a relative homogeneous species composition. For all habitat types presented in Table 1, endmembers were selected as input for SMA. A minimum noise fraction (MNF) transformation was performed on the mosaiced AHS-160 image. MNF bands occurring after an 80% variance threshold were discarded from further analysis (band 15-63). In addition, bands that contained dramatic brightness differences between flightlines in the mosaic were also removed (band 4 and 6). SMA was performed on the preprocessed MNF mosaic with 7 endmember spectra as input. The heathland habitat types were treated as one endmember. SMA was implemented using ENVI and a high weight (10,000) was assigned to the unit sum constrained factor.
To assess the accuracy of SMA two methods were used. First, the fit of the SMA model was assessed based on the spatial continuous map for the root mean square error (RMSE). Higher values of RMSE indicate regions that could contain lacking endmembers. Secondly, the dataset with field observed species and habitat abundances was compared to SMA modelled abundances for these locations.

3. RESULTS AND DISCUSSION

3.1 Endmember selection

At the main level (not including Hdc age classes) the identified habitat types for the study area (Table 1) show distinct canopy spectral characteristics (Figure 3). Grass related habitat types (Hgmd and Gpn) show relatively high reflectance in visible and SWIR compared to Hdc and the two forest classes (Fc and Fd). The latter have relatively low reflectance's in the SWIR and high absorbance in the red band. Sand fixated with dune grass (Sfgm) shows relatively higher reflectance values in the red band and the SWIR compared to the other habitat types. Bare sand has high reflectance over the complete measurement range. The different age classes of the Calluna dominated heath land show relatively small differences in reflectance (Figure 3). Also the pattern is not consistent, e.g., we don't observe an increasing NIR reflectance for older classes. An important reason for the small differences between the different Calluna age classes could be attributed to the late acquisition date of the AHS-160 image at the end of the growing season in October. At this moment, the heath land has already flowered (beginning September) and is quickly losing its photosynthetically active vegetative parts. In addition, the identified *Calluna* habitat type with mixed age classes (Hdcm) which from a conservation point of view is an important class will be difficult to distinguish as it is already a spectral mixture by definition. This point shows that it will not always be possible to implement ecological relevant definitions using a remote sensing based method. As a result, the different *Calluna* age classes were treated as one endmember in SMA.

3.2 Fraction images for habitat types

SMA generated seven fraction images and an RMS error image. Figure 4 shows the fraction maps for the main habitat types in the southern part of the study area, the Ginkelse heath land. SMA was reasonably successful in modeling the *Calluna* and *Molinia* coverage (R^2 of 0.4 and 0.39, respectively, Figure 5). Values for RMS error were relatively low with some higher values along boundaries between sandy roads and vegetation. This could be caused by the effect of shadow, an endmember which was not included in our model. The *Calluna* coverage (Hdc) is clearly abundant over the complete area (Figure 4), however differences between plots resulting from former management practices can be observed. The spatial distribution of grass encroachment can be observed from the Hgm fractional image and suggests both natural processes due to wetness gradients and management related occurrence. Two intensively grazed areas with short grasses can be identified from the Gpn fraction image. Sand dunes fixated with grass (Sfg) are present throughout the area and are an indicator of management intensity but also of dynamic processes like heath land succession. All fraction images show to a certain extent the effect of mosaicing of the images with abrupt fraction changes along the boundaries of the two flight lines. This is mainly the result of across track illumination differences for both flight lines which results for example in relatively high Hdc fractions in the Western flight line compared to the Eastern flight line. This effect also partly explains the overestimation of some of the image based *Calluna* fractions compared to the actual field coverage (Figure 5). Because we didn’t completely constrain the SMA model, only unit sum was constrained, fractions smaller than 0 and larger than 1 were calculated (Figure 5). Although care was taken to select most representative endmembers for the present habitat types, there still is within class spectral variation which has not been accounted for in this analysis. A possible alternative approach, would be the use of Multiple Endmember SMA (MESMA) which evaluates a list of candidate endmembers and selects the best fit for each pixel, thus avoiding overfitting due to too many endmembers (Rosso *et al.*, 2005).

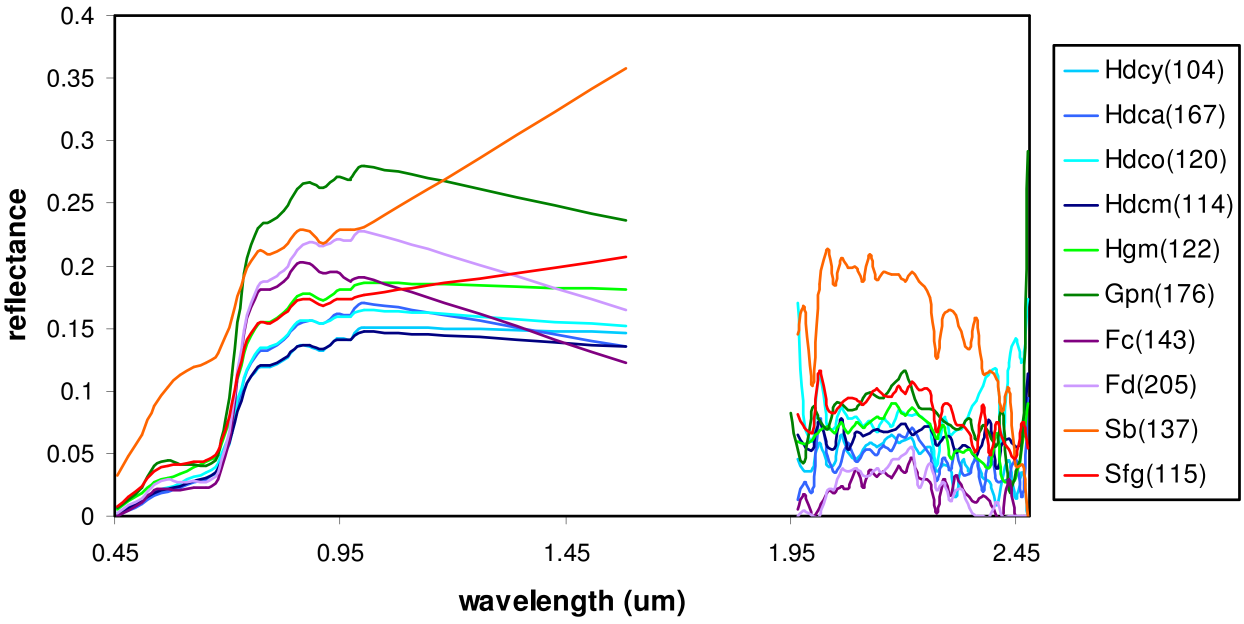


Figure 3. AHS-160 based endmember spectra derived for the heath land habitat types present in the study area.

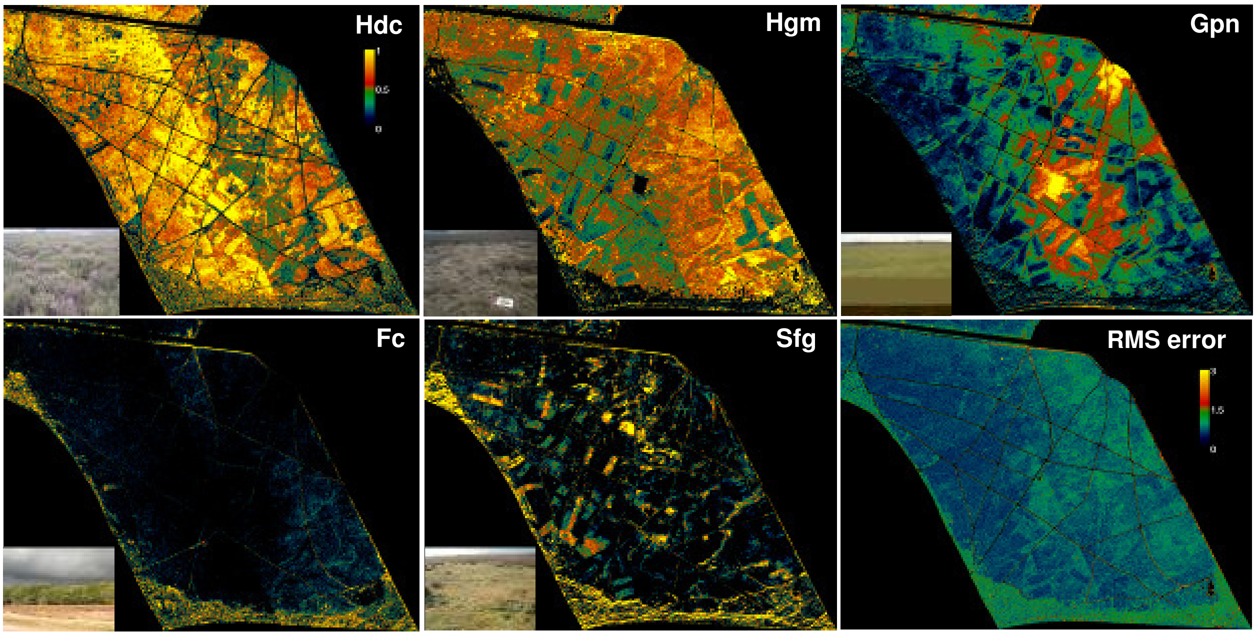


Figure 4. Fraction images for the main habitat types of the Ginkelse heath land (Table 1) derived from the AHS-160 image.

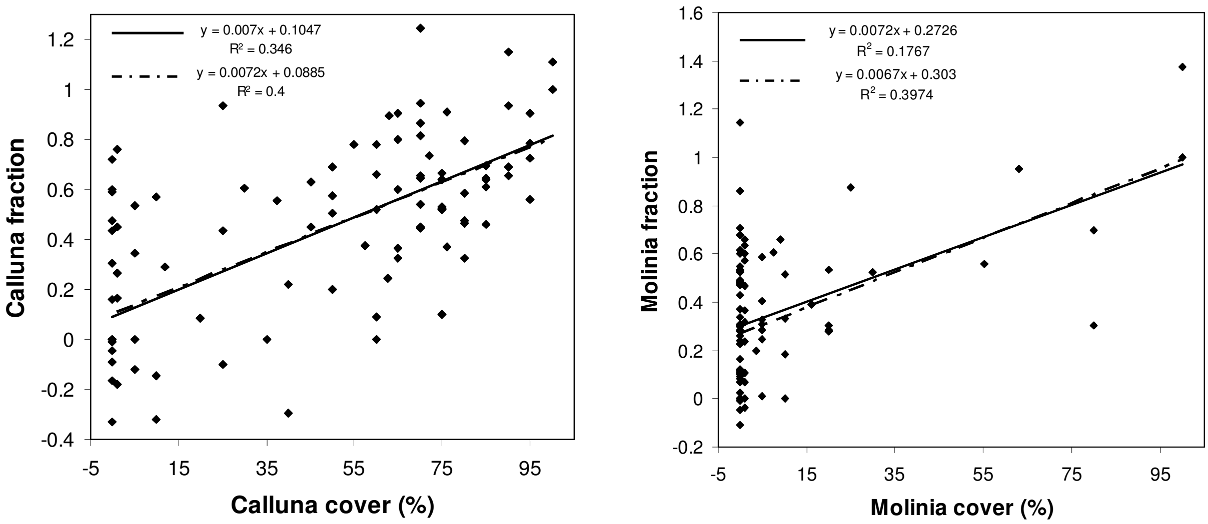


Figure 5. Comparison of results from predicted fractions using SMA and fractions observed in field plots (n = 104) for *Calluna* associated with Hdc (left) and *Molinia* associated with Hdgm (right). The solid line is the regression line when considering all field points. The dashed line includes only points with nonzero percent cover in the regression.

3.3 Assessment of habitat function and structure

The ecological functioning of heath land ecosystems in the Netherlands is seriously hampered by the process of grass and tree encroachment. Management practices like grazing and tree removal can reduce the encroachment process, however, reserve managers require information on the spatial distribution of grass and tree densities. Next to the SMA fraction maps (Figure 4), fraction composites (Figure 6) can provide reserve managers with area estimates and the location of unfavourable processes. Remote sensing derived continuous habitat maps and their associated quality indicators can help to optimize sampling schemes and focus effort on rare and often inaccurately mapped habitat types. In this way costly fieldwork effort can be employed in a more efficient way.

Based on the SMA results of this study, it was not possible to distinguish different *Calluna* heath land age classes (Table 1) which are an important indicator for the structural quality of the heath land habitat. Further analysis is required to investigate if alternative remote sensing based analysis methods would be appropriate. For example, Andrew and Ustin (2008) present the use of aggregated classification and regression tree models (CART) combining the results of mixture analysis based methods and spectral physiological indexes. The latter is relevant in the case of heath land age classes as photosynthesising biomass can differ substantially during the heath land succession cycle. Alternatively, techniques like directional remote sensing using the CHRIS/PROBA sensor could be successful to identify structural differences of the canopy structure between heath land age classes (Chan *et al.*, 2008). CHRIS/PROBA images for the study area are available and will be studied further.

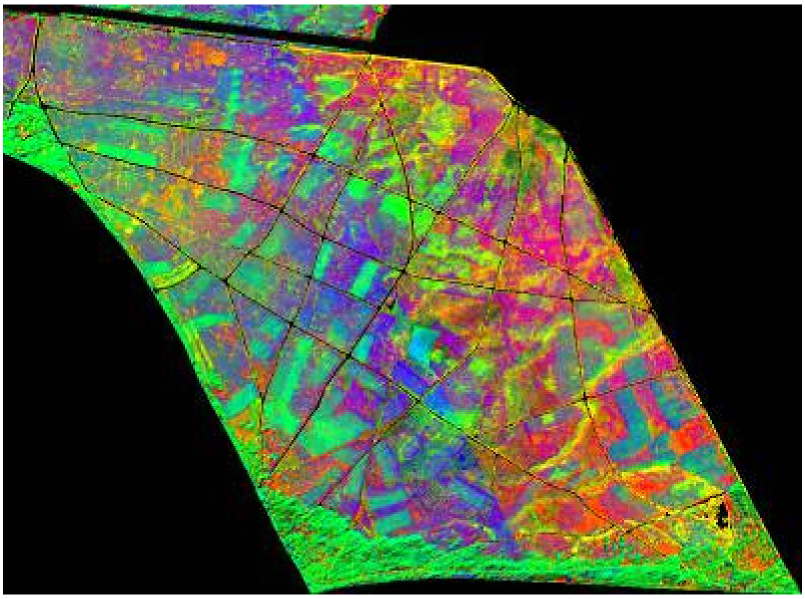


Figure 6. Fraction composite (right) for Hgmd (red), Sfg (green) and Hdc (blue) shows influence of management activities (top) on distribution of habitat function within the study area.

4. CONCLUSIONS

The results of this study show that spectral mixture analysis is a suitable technique for mapping heath land habitat types. The resulting fraction maps can be used to assess the quality of the habitat types related to structure and function. In addition, the resulting continuous maps can complement the traditional vegetation field surveys by optimizing sampling schemes and focus effort on rare and often inaccurately mapped habitat types. However, sensor type, quality of processing (e.g., mosaicing) and timing of acquisition (e.g., phenology of vegetation) have an important effect on the accuracy of the results. Further research activities will focus on the application of alternative SMA techniques (e.g., MESMA), transferability of SMA endmembers to other areas and automated derivation of indicators for habitat structure and function.

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