SEASONAL VARIABILITY IN SPECTRAL REFLECTANCE OF COASTAL DUNE VEGETATION

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ABSTRACT

The coastal dunes belong to the most important ecosystems in the Netherlands, but they have also suffered from prolonged desiccation, changes in land use, diminished coastal dynamics, and acidification. Environmental management is applied to counteract the deterioration of threatened dune vegetation and to maintain biodiversity. An efficient and reliable monitoring system is necessary to investigate autonomous vegetation development and to evaluate the effects of nature conservation and restoration measures such as cattle grazing. Monitoring of the vegetation is supported by the classification of remote sensing images. As the spectral characteristics of vegetation change during the growing season, the discrimination between vegetation types may vary too. In order to determine an appropriate period for collecting hyperspectral imagery of coastal sand dunes, a GER field spectrometer was used to collect reflectance data of several dune grassland types in the Amsterdam Water Supply Dunes in different periods from May to July 2001. The data were transformed into the spectral configuration of a hyperspectral GER EPS-A scanner, which was used to make a hyperspectral image of this area (1). The reflectance spectra were analysed for statistically significant differences between vegetation types. The results illustrate that the spectral characteristics of dry dune vegetation do change during the growing season. It is concluded that the best discrimination is achieved by the end of May and that a field spectrometer can help to determine a convenient period for hyperspectral imagery.

Keywords: field spectrometry, coastal dune vegetation, spectral discrimination, hyperspectral imagery

INTRODUCTION

The coastal dunes in the Netherlands form an extended area of joined nature reserves of high ecological value. They play an important role in the coastal defence of the western part of the Netherlands and they have been used for a long time for the production of drinking water and for recreation. The coastal dunes are important as natural ecosystem, offering habitats for a substantial part of the Dutch flora and fauna. However, during the past decades they have been suffering from eutrophication, acidification (2) and desiccation (3), causing a loss in biodiversity.

According to the EU Habitat Directive large parts of the dunes are covered with characteristic habitats of the Atlantic, North Sea and Baltic coasts, like shrub vegetation with *Hippophae rhamnoides* and *Salix repens* and humid dune slacks. All kinds of species-rich dune grasslands, belonging to the so-called ‘Fixed coastal dunes with herbaceous vegetation (grey dunes)’ are considered to be ‘priority habitats’, which implies that as natural habitats in danger of disappearance they deserve special attention (4). Dune grasslands have deteriorated on a large scale as a result of atmospheric pollution, which causes soil acidification and nutrient enrichment, followed by grass en-

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croachment (2; Figure 1). As the preservation, protection, and improvement of the quality of the natural environment, and the creation of a coherent European ecological network are essential objectives of general interest, it is necessary to take measures in order to conserve the grey dunes. Nature managers like the Amsterdam Water Supply have the responsibility for the preservation of threatened natural habitats, and therefore dune management is applied such as cattle grazing and mowing. Monitoring the vegetation development is necessary in order to evaluate autonomous vegetation succession and the effects of nature conservation measures on the preservation and restoration of important habitat types like dune grasslands.

Figure 1: During the past decades species-rich dune grasslands (left) have suffered from extensive grass encroachment (right).

Remote sensing is used for measurements required for the study of landscape and vegetation development (5,6). Aerial photography has long been applied in the Dutch coastal dunes for long-term vegetation survey to support dune management by means of conventional mapping with manual photo interpretation (7) and semi-automatic classification (8,9). However, both methods have their limitations. Manual photo-interpretation introduces problems with respect to the geometric and thematic accuracy, which is a particular disadvantage when used for vegetation monitoring (10). The consistency of the delineation and classification of objects is limited, especially in a gradient-rich landscape (9). In image classification of false colour photos a limited number of only three channels with wide bandwidths in the range of the visible and near infrared region of the spectrum (400 – 900 nm) can be used. In recent years, new imaging sensors have been developed, yielding much higher quality information about vegetation (6), like the HYMAP (11,12) and the EPS-A scanner (1). These hyperspectral sensors make use of the spectral characteristics of vegetation in a large number of narrow spectral bands in the visible, short-wave infrared, near-infrared, and mid-infrared regions (400 – 2500 nm).

The spectral characteristics of vegetation depend on many factors causing absorption, transmission, and reflection of incoming solar radiation (6). In the visible region of the spectrum (400 – 700 nm) most of the radiation is used for photosynthesis and is absorbed by foliar pigments, like different types of chlorophyll, carotene and xanthophyll. In the near-infrared (700 – 1300 nm) and mid-infrared region (1300 – 2500 nm) the reflectance is generally higher and is determined by differences in internal leaf structure of plants, water absorption, and absorption features of other biochemical contents, like lignin and cellulose (13,6). Spectral characteristics depend on species. Differences in the spectral signature of plant communities or vegetation types are determined by differences in the floristic composition and for example the dominance of plant species (14). Furthermore, the amount of bare soil and dead organic material also influences the spectral signature (9). Phenologic changes in plant species (15) and in the vegetation (16) during the growing season do affect the spectral properties of vegetation types. Recent applications of false colour aerial photography in two coastal dune areas in the Netherlands made clear that a recording date late in the season led to poor classification results due to overlap in spectral properties of the vegetation

(17). Hence, the success of discrimination of vegetation types may vary during the growing season.

In co-operation with the International Institute for Geo-information Science and Earth Observation, the Survey Department of the Ministry of Transport, Public Works and Water Management, and the Amsterdam Water Supply investigated the potential for hyperspectral imagery (1). As part of this study the spectral reflectance of the vegetation was studied in the Amsterdam Water Supply Dunes. This coastal dune area of 3400 hectares is situated along the Dutch coast near Haarlem. It is an important nature reserve, which is used for the production of drinking water. The area is characterised by a landscape gradient with younger, calcareous soils close to the seashore to older decalcified soils in the inner dunes. The Amsterdam Water Supply Dunes are very rich in both large-scale and small-scale gradients, which has led to a large variety of dune grasslands (‘grey dunes’). Recently, the area has been proposed as an EU Habitat Directive area.

An appropriate vegetation mapping system for coastal dune management should enable the spectral discrimination and thus, the monitoring of important habitat types including dune grasslands and the roughs into which they change due to unfavourable processes like extensive grass encroachment. With such a monitoring tool, the success of counteracting these processes by applying management tools can be evaluated. The objective of this study was to determine an appropriate period for collecting hyperspectral imagery, using the GER Environmental Probe System (EPS-A), a hyperspectral scanner of the Ministry of Transport, Public Works and Water Management. Therefore field spectra were measured in two different periods early in the growing season. The EPS-A scanner was applied in order to develop a reliable and efficient tool for vegetation mapping in coastal sand dunes (1).

METHODS

Spectral reflectance was measured in 100 field plots, which were selected by an experienced ecologist in 10 herbaceous vegetation types and were marked in the field (10 plots per type). The vegetation types were assigned according to a local vegetation typology, based on differences in vegetation structure and species composition (18). The field plots cover an area of 5 meters by 5 meters and are situated in herbaceous vegetation in the prevailing dry coastal sand dunes (19) and the xeroseries of vegetation succession (20; see Table 1).

Table 1: Herbaceous vegetation types of the xeroseries of dry coastal sand dunes (20). Plant communities marked with an asterisk (*) belong to the priority habitats according to the EU Habitat Directive (21).

Code	Vegetation	Plant community*
veg1	Open moss vegetation on decalcified sand	Violo-Corynephoretum koelerietosum*
veg2	Dense moss vegetation on decalcified sand	Violo-Corynephoretum typicum*
veg3	Short dune grassland on decalcified sand	Festuco-Galietum veri*
veg4	Tall dune grassland on decalcified sand	Festuco-Galietum veri*
veg5	Rough with *Calamagrostis epigejos* on decalcified sand	Frame community of *Calamagrostis epigejos*-[Koelerio-Corynephoretea]
veg6	Open moss vegetation on calcareous sand	Phleo-Tortuletum cladonietosum*
veg7	Short dune grassland on calcareous sand	Taraxaco-Galietum veri*
veg8	Tall dune grassland on calcareous sand	Taraxaco-Galietum veri*
veg9	Rough with *Ammophila arenaria* on calcareous sand	Frame community of *Ammophila arenaria-Carex arenaria*-[Koelerio-Corynephoretea]
veg10	Rough with *Elymus* spec. on calcareous sand	Derivate community of *Elymus* spec-[Koelerio-Corynephoretea]

Geomorphologic wind activity, (rabbit) grazing and grass encroachment play an important role. The vegetation types cover the extremes of a gradient from decalcified to calcareous soils and they represent several syntaxa belonging to the grey dunes in the Netherlands (21).

Spectral reflectance data of the vegetation were measured under excellent, sunny and cloudless weather conditions, between 11h00 and 16h00. Using a field spectrometer, variables in the field which influence radiance should be taken into account. As the sun's irradiance varies with the time of the day and atmospheric conditions, a white calibration panel was frequently used. So the effects of differences in solar illumination could be eliminated (5). The spectral reflectance of the vegetation was calculated as fraction of the approximately 100% reflectance of the white calibration panel.

The spectra are also influenced by variation in the vegetation, so the field spectra were collected in homogeneous vegetation. Reflectance was measured about 1 m above the vegetation canopy and at nadir, in order to obtain an appropriate measure of the vegetation. However, a certain degree of heterogeneity in natural vegetation cannot be excluded because of differences in species distribution. The effect of bi-directional reflectance was taken into account by using a field of view of 23° - 25°, so that the bi-directional reflectance distribution is averaged within the field of view range of 0° - 25°. Besides, several spectrometer measurements were collected randomly within all plots. Research in three different land cover types from bare sand to scrub has made clear that 10 measurements within each plot and 10 plots per vegetation type are adequate values for a reliable sample size (22). Finally, approximately 2000 measurements were made. Each plot is characterised by one spectral fingerprint, which is the average of 10 internal measurements, in order to reduce noise in signal and in bi-directional reflectance.

Two types of field spectrometers were applied. In the beginning an ASD Fieldspec FR was used, but due to technical failure it was replaced by a GER 2600 field spectrometer. The comparison of the spectral reflectance of one vegetation type collected with both spectrometers revealed that the differences are accepTable. However, the bandwidth differs between both spectrometers, and the Fieldspec data were transformed into the GER 2600 output to obtain full spectra for all plots. As the application of remote sensing imagery late in the growing season led to severe problems with regard to the discrimination of different grassland types (17), spectral signatures were obtained in two periods early in the growing season, at the end of May and the end of June 2001. Some measurements failed, so finally in each period the spectra of 93 vegetation plots were available for analysis. To determine which of the periods is best for applying a hyperspectral scanner, the field spectrometer data were interpolated into the central wavelength of the 30 spectral bands of the EPS-A scanner (Table 2). Band 30 was excluded because of noise appearing in the GER 2600 spectrometer.

Table 2: Spectral bands of the EPS-A scanner selected for vegetation research (22).

Spectral band	Central wavelength (nm)	Spectral band	Central wavelength (nm)	Spectral band	Central wavelength (nm)
1	371.2	11	554.3	21	762.8
2	378.5	12	563.7	22	772.8
3	385	13	666.8	23	854.8
4	392	14	676.2	24	865.4
5	402	15	685.6	25	876
6	432.8	16	694.9	26	886.5
7	442.1	17	704.8	27	929.2
8	451.2	18	714.5	28	995.3
9	460.6	19	734	29	1691.4
10	545	20	753.3	30	2173.6

To compare the spectral signatures of the various vegetation types, a Mann-Whitney U-test (23) and a Redundancy Analysis, using Canoco for Windows (24), were applied.

The reflectance of the ten herbaceous vegetation types was statistically tested to investigate whether there is a significant difference between every pair of vegetation types per spectral band. The Mann-Whitney U-test is an appropriate test as it is a non-parametric test, which does not assume a normal distribution of the sample sets (14). The null hypothesis was tested, stating that there is no significant difference ($p < 0.01$) between the median reflectance of a pair of vegetation types at a certain spectral band. If the null hypothesis is rejected, the alternative hypothesis is true, which means that the variance within the two types is smaller than the variance between them. For every pair of vegetation types and each spectral band the null hypothesis was tested. First of all, the number of statistically significant differences between vegetation types was counted per spectral band, which gives an impression of the discrimination that can be achieved at any spectral band in the two periods. Besides, it illustrates the relative importance of the various spectral bands for discrimination of the selected herbaceous vegetation types. Next, the discrimination between every pair of vegetation types was studied in detail, by presenting the number of significantly different bands per combination of vegetation types in a matrix. So it becomes clear which vegetation types may cause problems in the classification of a hyperspectral EPS-A image.

Finally a multivariate analysis, the Redundancy Analysis (RDA; 24), was applied in order to determine the percentage of variance of the data that can be explained by all vegetation types together in a multidimensional feature space, which is built up by all EPS-A spectral bands. RDA is also known as Reduced Rank Regression, a constrained form of Principal Components Analysis, and reveals the most important differences between the vegetation types. The result of this analysis is a lower dimensional space in which the relations between a set of dependent (in our case wave bands) and a set of independent variables (here the vegetation types) are displayed. The RDA was both executed with the raw reflectance data and after data transformation. In order to avoid bias and noise caused by deviations in the measurements stemming from deviations from the protocol (orientation of the spectrometer with respect to the sun and the vegetation) the data were normalised. The raw reflectance values for each band were divided by the sum of the values of all bands per plot. In fact RDA aims at the best prediction of the measured species variables, the field spectra, on the base of the explaining environmental variables, the vegetation types.

Theoretically only a few vegetation types may be able to explain a substantial part of the variance. These types can differ very much in spectral characteristics from the other vegetation types, while some of the remaining types may hardly show any difference from other types. The statistical significance of the RDA relationship between the field spectra and the whole set of vegetation types is evaluated by using RDA with ‘Manual Forward Selection’ of each variable (vegetation type) in a Monte Carlo permutation test ($p < 0.05$; 24). Hence, it can be analysed which types play a statistically significant role in the explanation of the variance of data and which types cannot be discriminated significantly due to an overlap in spectral characteristics.

RESULTS

The overall capacity to discriminate between vegetation types in both periods is illustrated by the sum of pairs of vegetation types, for which there exists a significant discrimination at each spectral band (Figure 2). This graph shows the relative importance of the spectral bands. The better discrimination is achieved in May (upper line) for all spectral bands. In this period, bands between 370 and 690 nm especially support the overall discrimination, while in June (lower line) mainly the spectral region between 370 and 460 nm contributes to the discrimination of several vegetation types. In both periods a distinction can also be made at a spectral band from 730 to 930 nm. In the red edge region at about 700 nm the discrimination is worse, as was also found for salt marsh vegetation (14).

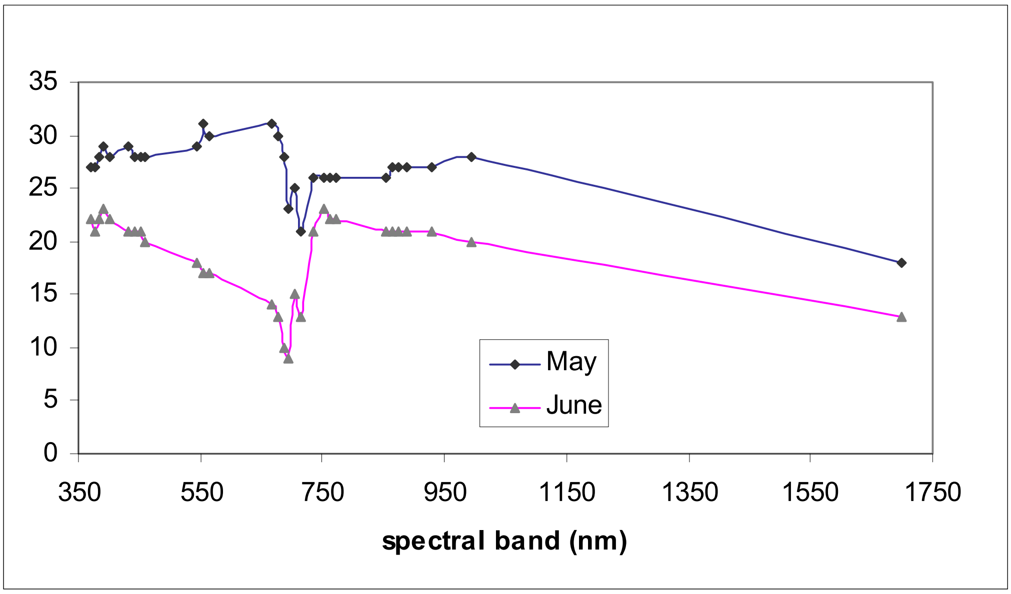

Figure 2: Number of significantly different pairs of vegetation types in May and June 2001 (Mann-Whitney U-test, p<0.01; max. number = 45). See Table 2 for explanation of spectral bands.

The results from the Mann-Whitney U-test (p<0.01) have been listed in a matrix in Table 3 (May) and Table 4 (June) in order to evaluate the significance of the differences between the two periods with regard to the discrimination of vegetation types. For each pair of vegetation types the sum of spectral bands has been calculated, for which the types differ significantly from each other. The higher the number in the matrix, the more spectral bands there are for which the types can be discriminated significantly, to a maximum of 29 bands.

At the end of May most vegetation types can be discriminated from each other for a high number of bands. At the end of June this number is much smaller for some combinations. In the first period there are three pairs, for which there is no discrimination possible at any spectral band and one pair for which discrimination can be achieved for only one band. In the second period these numbers are eight and four, respectively.

In June a considerably better discrimination is achieved between open moss vegetation on decalcified sand (veg1) and both roughs on calcareous sand (veg9, veg10) and between short (veg3) and tall dune grassland on decalcified soil (veg4). In both periods a significant difference is found neither between open moss vegetation on decalcified soil (veg1) and open moss vegetation on calcareous soil (veg6) nor between short dune grassland on decalcified soil (veg3) and short dune grassland on calcareous soil (veg7).

In May no discrimination can be made between rough with *Ammophila arenaria* (veg9) and tall dune grassland on calcareous soil (veg8). Besides, there is only one band, for which rough with *Calamagrostis epigejos* (veg5) and rough with *Ammophila arenaria* (veg9) can be discriminated. In June there is little or no difference between all three types of roughs (veg5, veg9, veg10). Furthermore, short dune grassland on calcareous soil (veg7) can hardly or not be discriminated from tall dune grassland on calcareous soil (veg8) and all types of rough (veg5, veg9, veg10). The difference in discrimination between the two periods is illustrated with an example in Figure 3 for short dune grassland on calcareous sand (veg7) and rough with *Elymus* spec. (veg10). In the first period a significant discrimination is achieved at all spectral bands, except the bands from 545 to 694.9 nm, and the band at 1,691.4 nm. In the second period the discrimination is not significant at any spectral bands. Thus, the discrimination between a priority habitat type, belonging to the ‘grey dunes’, and an undesirable substitution type, favoured by grass encroachment, fails in June.

Table 3: Matrix with the number of significantly different spectral bands (Mann-Whitney U-test; p<0.01; $n_{max.}$=29) for all possible pairs of 10 vegetation types of dry coastal sand dunes in May 2001; for a description of the vegetation types see Table 1. Pairs with no significant differences are marked in dark grey, pairs with only one significantly different spectral band in light grey.

	veg1	Veg2	veg3	veg4	veg5	veg6	Veg7	veg8	veg9	veg10
veg1	-1	15	20	17	10	0	20	11	10	3
veg2		-1	16	12	29	29	18	29	28	26
veg3			-1	4	18	26	0	15	16	17
veg4				-1	29	19	24	29	28	18
veg5					-1	16	18	16	1	29
veg6						-1	27	25	17	18
veg7							-1	15	15	21
veg8								-1	0	13
veg9									-1	17
veg10										-1

Table 4: Matrix with the number of significantly different spectral bands (Mann-Whitney U-test; p<0.01; $n_{max.}$=29) for all possible pairs of 10 vegetation types of dry coastal sand dunes in June 2001; for a description of the vegetation types see Table 1. Pairs with no significant differences are marked in dark grey, pairs with only one significantly different spectral band in light grey.

	veg1	Veg2	veg3	veg4	veg5	veg6	Veg7	veg8	veg9	veg10
veg1	-1	18	16	18	11	0	9	12	22	20
veg2		-1	18	9	16	17	12	14	15	16
veg3			-1	22	11	24	0	15	16	13
veg4				-1	16	16	12	21	15	15
veg5					-1	21	0	0	1	0
veg6						-1	19	22	20	20
veg7							-1	0	1	0
veg8								-1	1	0
veg9									-1	1
veg10										-1

The results from the Redundancy Analysis of the raw field spectra reveal that there is a striking difference in the percentage of variance accounted for the vegetation in both periods (see Table 5). In May the variance explained by all variables (vegetation types) comes to 70%. This value is the sum of all canonical eigenvalues (24). In this period seven of the ten types contribute significantly to the explanation of the variance (Monte Carlo permutation test; $p < 0.05$). In June the variance is 51% and only four types play a significant role. The differences between both periods are illustrated in Figure 4. The ordination diagram at the upper left shows some overlap between different vegetation types. Rough with *Calamagrostis epigejos* (veg5), tall dune grassland on calcareous sand (veg8), and rough with *Ammophila arenaria* (veg9) do not support the explanation of the variance. The diagram at the upper right illustrates that there is much more overlap between the vegetation types, with the exception of all types of moss vegetation (veg1, veg2, veg6) and tall dune grassland on decalcified sand (veg4).

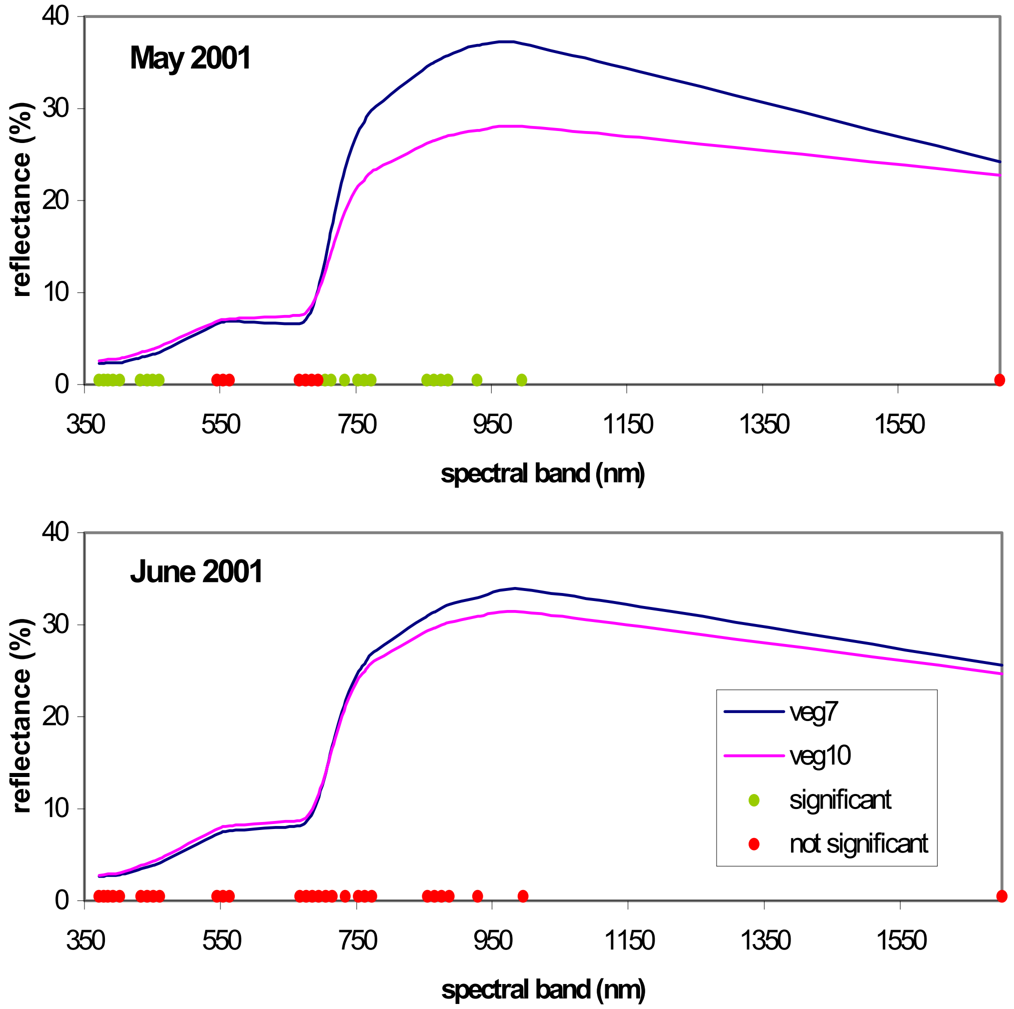

Figure 3: Spectral discrimination between short dune grassland on calcareous sand (veg7) and rough with Elymus spec. (veg10) in May and June 2001. Spectral reflectance has been interpolated from 29 reflectance values and is plotted against spectral bands (nm). Bands with a significant difference are marked in grey and with no significant difference in black (Mann-Whitney U-test; p < 0.01).

Table 5: Variance explained by all vegetation types and contribution of different vegetation types in the explanation of the variance of the raw field spectra in May 2001 (RDA with Manual Forward Selection, Monte Carlo's permutation test; p<0.05).

Period	% explained variance	Significant vegetation types	Non-significant vegetation types
May	70	veg1-2-3-4-6-7-10	veg5-8-9
June	51	veg1-2-4-6	veg3-5-7-8-9-10

Table 6: Variance explained by all vegetation types and contribution of different vegetation types in the explanation of the variance of the transformed (normalised) field spectra in June 2001 (RDA with Manual Forward Selection, Monte Carlo's permutation test; p<0.05).

Period	% explained variance	Significant vegetation types	Non-significant vegetation types
May	82	veg1-2-3-4-6-7-8-9	veg5-10
June	75	veg1-2-3-4-6-9	veg5-7-8-10

Normalisation of the data leads to a higher percentage of explained variance and a higher number of vegetation types, which contribute significantly to the explanation of the variance (see Table 6). Nevertheless, there still remains a slight difference between the two periods. At the end of May the variance explained by all vegetation types is 82%, whilst at the end of June it is 75%. By executing RDA with 'Manual Forward Selection' the statistical significance of each selected variable (i.e. vegetation type) has been tested by a Monte Carlo permutation test. Only six of the ten types contribute significantly to the explanation of the variance in June. In both periods two types of rough (veg5 and veg10) cannot be discriminated from all remaining types, while in June short and tall dune grassland on calcareous soil (veg7, veg8) have also been omitted from the predictive model. The ordination diagrams of the transformed data illustrate the minor differences between the two periods in comparison with the raw spectral data (Figure 4).

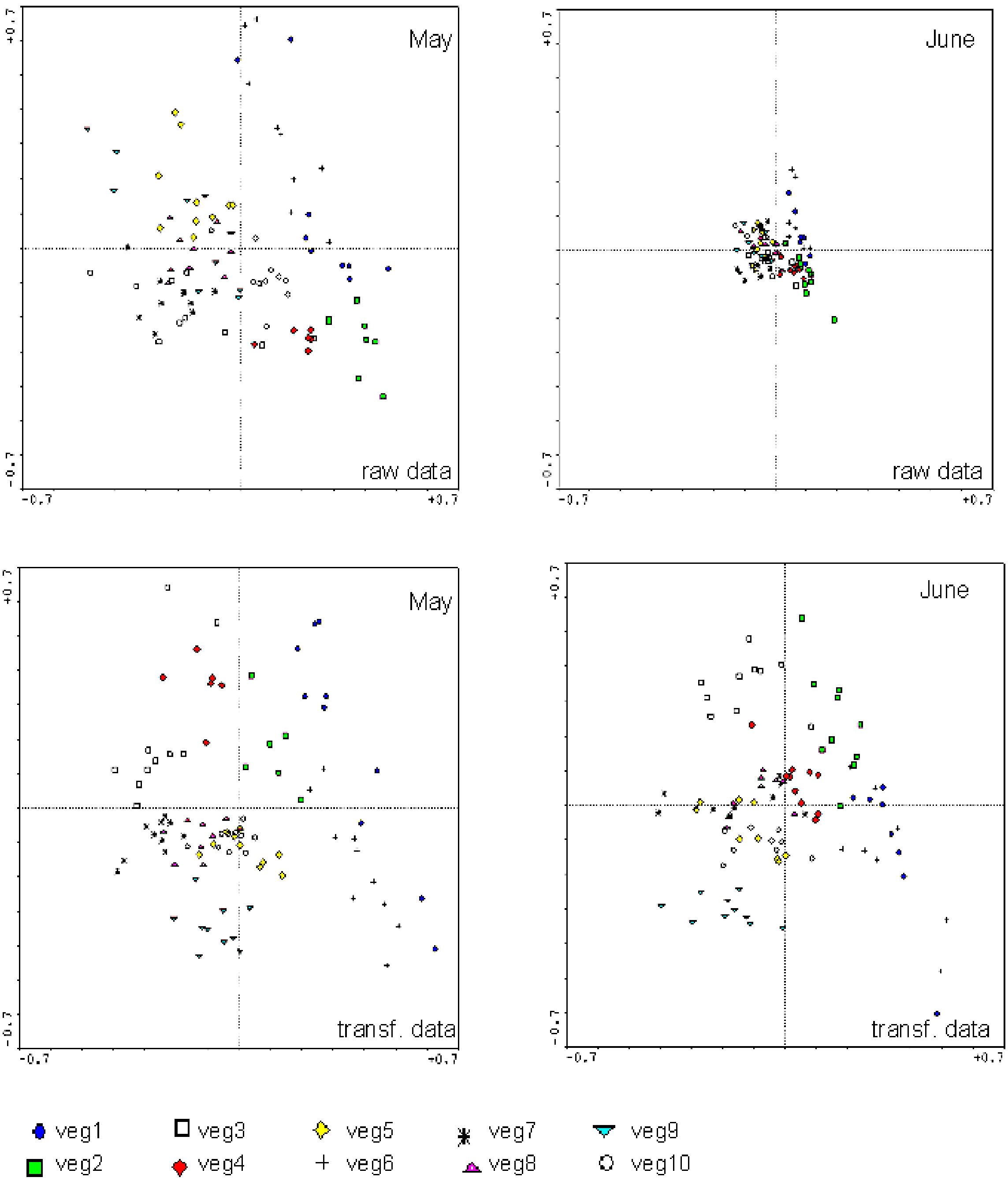

Figure 4: Ordination diagrams, with axes RDA-1 and RDA-2, of raw (upper part) and transformed data (lower part) for May (left) and June 2001 (right).

DISCUSSION AND CONCLUSIONS

According to the EU Habitat Directive coastal dune managers have the task to monitor the vegetation succession and the effects of nature conservation measures aiming at the preservation and restoration of priority habitat types, such as 'grey dunes'. Vegetation mapping with remote sensing images plays an important role in spatio-temporal monitoring of the vegetation succession (5,6). With respect to the spectral discrimination of important vegetation types in coastal sand dunes, this study made clear that not all types can be distinguished in May and June. In both periods there are some difficulties within open moss vegetation, some dune grassland types, and roughs. Open moss vegetation and dune grassland both belong to the 'grey dunes'.

In the second period the spectral overlap between dune grassland types and all types of rough becomes a problem. Changing proportions between living biomass, dead organic material, and bare sand seem to play an important role in the success of the discrimination of these vegetation types. During the growing season, the amount of living biomass diminishes quickly in dune grasslands due to summer drought and the prevailing therophytes and tiny grasses with a shallow root-system die, as a result of which dead organic material increases. Hence, the spectral properties of dune grasslands and roughs, which contain a large amount of litter, resemble each other at the end of June (see Figure 3). Although at a much larger scale, the influence of drought also played a role in vegetation mapping in South Africa, where spectral discrimination failed in dry season imagery (25). The discrimination of these vegetation types is essential in order to be able to monitor relevant processes in vegetation succession, like grass encroachment. Another application of remote sensing for vegetation mapping in coastal dunes earlier revealed that a recording date late in the growing season leads to very poor classification results with respect to the discrimination of dune grasslands and roughs (17).

Although the Mann-Whitney U-test and Canoco's Redundancy Analysis give comparable results, they also reveal differences. Some vegetation types cannot be discriminated from each other in the pair wise U-test, for example open moss vegetation on calcareous and decalcified soil. The multivariate RDA offers better opportunities for the discrimination of these types. Data transformation can lead to better results, but there still remain differences between the two periods. Both analyses elucidate which types may cause problems in the ultimate goal of this project, the classification of the EPS-A image. The Mann-Whitney U-test provides very detailed information about the discrimination between all vegetation types at every spectral band. Nevertheless, the RDA quickly provides insight into the main differences, which are illustrated by the RDA ordination diagrams (see Figure 4). To gain insight into the success of classification of all individual plots, a canonical variate analysis can be applied (14). However, the field spectra were measured and analysed in order to support the decision about the optimal flying period for the collection of hyperspectral imagery. To answer the question of whether coastal dune managers are able to monitor vegetation succession, the accuracy of the EPS-A image classification should of course be considered (1).

This study revealed that with respect to the prevailing open dry coastal sand dunes and the priority habitat type 'grey dunes' of the Atlantic, North Sea and Baltic coasts, a better discrimination is achieved at the end of May in comparison with the end of June. The incorporation of expert knowledge about environmental conditions might offer a solution for remaining problems in the spectral confusion within different types of dune grasslands and roughs and support the classification of a hyperspectral image (1,11,12). For example, short dune grassland on decalcified and calcareous sand can be separated using a decalcification map of the area. For a successful application of hyperspectral imagery, i.e. the EPS-A scanner, a flying period should be selected early in the growing season, at the end of May.

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