SPECTRAL REFLECTANCE PROPERTIES OF *SPHAGNUM* MOSS SPECIES IN FINNISH MIRES

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ABSTRACT:

The mosses growing in northern peatlands are indicators of moisture and nutrient state of the substrate. The genus *Sphagnum*, which in Finland consists of about 40 different species, is especially sensitive to hydrological changes and forms the main component in peat accumulation. The water status of peatlands has a remarkable role in greenhouse gas fluxes and has been a target of great interest during recent years.

The high resolution scanners with broad spectral range produce data which are utilized in mapping large areas of peatland. The genus *Sphagnum* forms the dominant vegetation cover in peatlands having an effect to remote sensing signals. In this study the behaviour of the reflectance of different *Sphagnum* species in diverse substrates in Finnish mires was studied. The mires receive water and chemical elements from atmosphere, from surroundings by surface water flow or from groundwater flow. Ore formations and other contamination sources nearby may be a source of water enriched in potentially harmful elements and compounds.

1. INTRODUCTION

Earlier studies have shown that the reflectances of *Sphagnum* species have their own spectral properties differing from those of vascular plants and also of other mosses (Vogelmann & Moss, 1993; Bubier et al., 1997). Because the species of *Sphagnum* have enormous water holding capacities, the interest has been focused on the study of the influence of water status on *Sphagnum* reflectance properties (Bryant & Bair, 2003; Harris et al., 2005, 2006; Harris 2007). The system of hyaline cells in stems, branches and leaves of *Sphagnum* species enable them to absorb and store large quantities of water, and nearly all species are also able to survive short dry periods (Daniels & Eddy, 1985). Changes in near-surface and surface wetness and the position of the mean water table have been reported to have remarkable effects on the reflectances of *Sphagnum* species (Harris et al., 2005, 2006).

In addition to hydrology another major factor influencing the distribution of *Sphagnum* species is the chemistry of the substrate. The water source of peatlands is usually reflected in their chemistry (Laine & Vasander, 1996). Ombrothophic peatlands receive water and chemical elements only from atmospheric deposition and are characterized by nutrient-poor waters. Minetrophic peatlands are typically discharge areas receiving water from the local groundwater or surrounding catchments. According to nutrient status minetrophic mires are usually divided further into oligotrophic-, mesotrophic- and eutrophic mires the last one representing the most nutrient-rich miretype (Laine & Vasander, 1996).

Methods to estimate plant water concentration and water stress are widely used. The chemical composition of water can be favourable for the plant but can also cause stress. In order to widen the understanding of the components effecting to the reflectances of *Sphagnum* moss a large amount of different *Sphagnum* species growing in substrates which differ both in hydrology and chemistry were studied.

2. METHOD

The reflectances of *Sphagnum* species were measured in their natural habitat in three different geographical locations in Finland, representing various kinds of mire types, underlying bedrock and chemical environments. The reflectance spectra were measured by FieldSpec Pro FR Spectroradiometer with a 350 – 2500 nm spectral range. The contact probe sensor was placed on the *Sphagnum* canopy so that the measurement area was 35 mm in diameter. The artificial light source inside the contact probe was tungsten halogen lamp. After measurement moss samples from the same places were collected for analysing water content and chemistry in laboratory. Water content was measured gravimetrically weighing the sample as fresh and after drying at 40 ^{0}C. From the dried and milled samples 35 different chemical elements were analyzed by a combination of ICP-AES and ICP-MS. The reflectance of dried samples was measured again by FieldSpec Pro FR Spectroradiometer. The reflectances between samples from different substrates and between different species were analyzed. Many spectral indices were calculated and correlations between them and water content and chemical elements were calculated

3. RESULTS

3.1 Main spectral and chemical features of *Sphagnum* species

Reflectance measurements in the field included 18 different *Sphagnum* species (Table 1). From 56 samples 48 most representative samples were chosen for further studies. According to moisture condition the species are usually divided into hummock (water level deeper than 20 cm), intermediate (5-20 cm) and flark-level species (less than 5 cm) (Laine & Vasander, 1996). The amount and structure of hyaline cells, which act as water-conducting systems, varies between *Sphagnum* species. The hummock-forming species have typically larger hyaline cells than those growing in wetter habitats (Daniels & Eddy, 1985).

The differences in reflectance of the *Sphagnum* species are mainly controlled by colour, cell structure, morphology, water content and chemistry. Majority of *Sphagnum* species are green but pigmentation can appear also as yellow, brown, orange or red (Daniels & Eddy, 1985). Differences in pigmentation are seen in VIS(400-700 nm) wavelength area (Fig. 1). In addition of colour, the size, arrangement and apices of branch leaves form the overall appearance of *Sphagnum* species giving them characteristic features in NIR (700-1400 nm). Low reflectances in SWIR(1400-2500 nm) is related to high water content.

Species	Nutrient level	Moisture condition
(S. = sphagnum)		
S. fuscum	ombro-oligotrophic	hummock
S. rubellum	ombro-oligotrophic	hummock-intermediate
S. magellanicum	ombro-oligotrophic	hummock-intermediate
S. russowii	ombro-oligotrophic	hummock
S. compactum	ombro-oligotrophic	intermediate
S. balticum	ombro-oligotrophic	intermediate-flark
S. tenellum	ombro-oligotrophic	intermediate
S. lindbergii	ombro-oligotrophic	intermediate-flark
S. angustifolium	ombro-oligo-mesotrophic	hummock-intermediate
S. jensenii	oligo-mesotrophic	flark
S. fallax	oligo-mesotrophic	intermediate-flark
S. papillosum	oligo-mesotrophic	intermediate
S. riparium	oligo-mesotrophic	flark
S. fimbriatum	mesotrophic-(eutrophic)	intermediate
S. girgensohnii	mesotrophic-(eutrophic)	hummock-intermediate
S. obtusum	mesotrophic-(eutrophic)	intermediate-flark
S. squarrosum	mesotrophic-(eutrophic)	intermediate
S. warnstorfii	mesotrophic-eutrophic	intermediate

Table 1. Measured *Sphagnum* species in the study area.

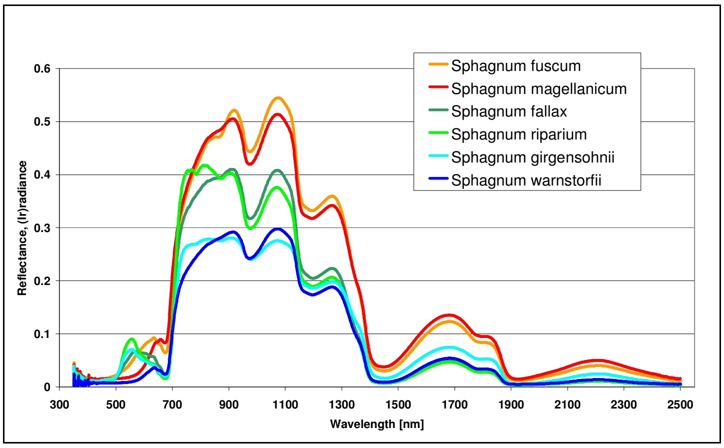

Fig. 1. Typical reflectance spectra of *Sphagnum* species.

The main feature of in situ reflectances of *Sphagnum* species was the decrease in overall reflectance level when the thropic level increases (Fig. 1). This is mainly due to the masking effect of increasing surface and near-surface water content and the variation in canopy morphology. The reflectances of ombro-oligotrophic hummock species form the most compact group, the shape and level of the spectra being quite similar irrespective of measurement area. Typically the capitula of ombro-oligotrophic species are small and compact. Variation in other groups was greater due to the greater variation in leaf water and surface water content. Also the morphology varies more in other groups, *Sphagnum riparium* and *Sphagnum girgensohnii* have typically loose capitula and long branch leaves. Some species, like indifferent *Sphagnum angustifolium*, have fairly wide tolerance with the wetness condition of the substrate in which they are growing (Fig. 2).

The nutrient status of *Sphagnum* species is characterized by the availability of chemical elements like potassium (K), magnesium (Mg) and phosphorus (P). K, Mg and P content is increasing as trophic level increases (Fig. 3).

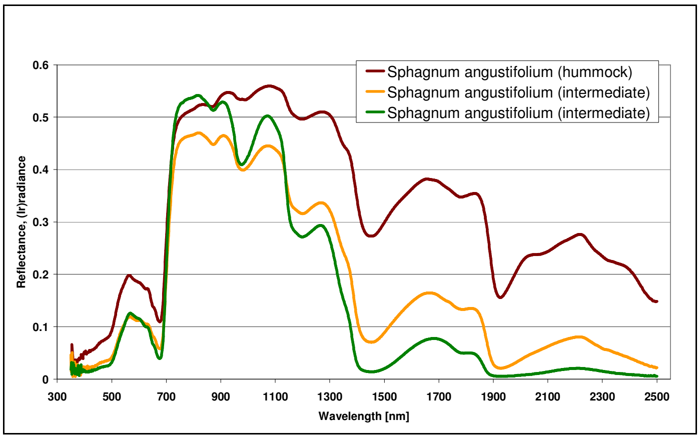

Fig. 2. Reflectance spectra of *S angustifolium* in different moisture level

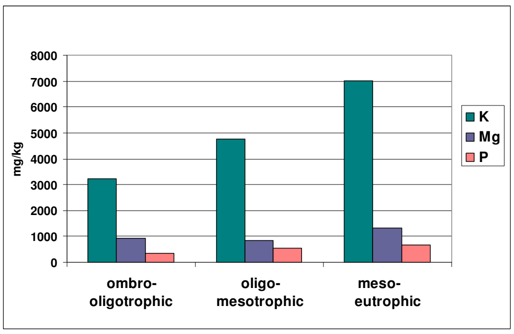

Fig. 3. Content of K,Mg and P in different trophic level.

Chemical stress which has long been a known phenomena of green vegetation and causes also changes to reflectance (Horler et al., 1983; Singhroy et al., 1991). Changes have been observed in whole VIS area but especially at chlorophyll absorption maximum near 680 nm and in red edge area (680-750 nm). In this work measurements were also carried in the area where the impact of old sulphide mine is evident. In figure 4 there are two measured spectra of *Sphagnum balticum* having elevated content of harmful elements. The measured water content of the samples is nearly the same. Typical features due to the increase of water content are overall decrease of reflectance, deeper water absorption peaks (960 nm, 1200 nm) and strong decrease in SWIR reflectance. Metal stress is increasing reflectance in VIS blue and red and decreasing reflectance in VIS green and NIR wavelength area. In SWIR reflectance there is no change when the metal content is increasing.

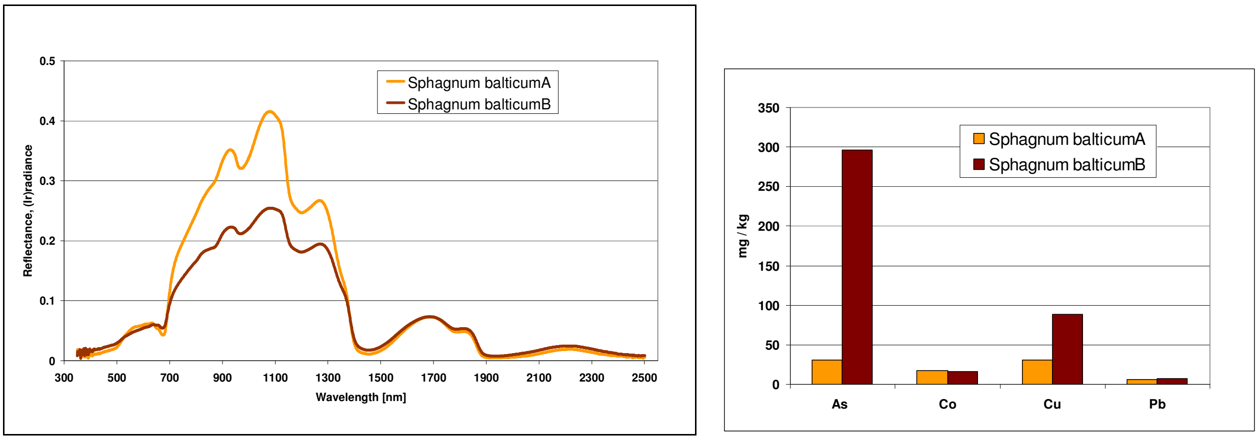

Fig 4. Reflectance spectra of *Sphagnum balticum* suffering from stress. Arsenic, copper, lead, and nickel concentrations of samples.

3.2 Biophysical Indices

Biophysical indices have been used to detect physiological stress of plants caused by water or contamination by potentially harmful elements. In this work 4 water indices and 7 other biophysical indices were correlated with measured water content and analyzed chemical elements.

The Moisture Stress Index (MSI) represented by Vogelman and Rock (1986) and used for *Sphagnum* moss by earlier researches (Bryant & Bair, 2003; Harris et al., 2005, 2006) is a ratio between band in SWIR (1550 - 1750 nm) and reference band in NIR (760 – 800 nm). In this study MSI = $\max R_{1660\text{-}1700}/R_{820}$ has significant correlation with measured water content ($r = -0.67$, $p = 0.0$). Correlations did not change much when calculating separately for hummock-intermediate ($r = -0.69$, $p = 0.0$) and intermediate-flark ($r = -0.66$, $p = 0.0$) species. Many Water Band Indices, for example represented by Penuela et al. (1993, 1997), were tested and they gave fairly good correlations. In our case even better correlation give Water Band Index calculated as a ratio between the highest reflectance peak near 1075 nm and deepest absorption peak near 1200 nm (Fig 5). The formula used was WBI = $\max R_{1065\text{-}1095}/\min(R_{1100\text{-}1300})$.

Table 2: Significant correlations between indeces MSI and WBI and measured water content.
Significant level p varies from 0.0 to 0.1 for all correlations.

	All dataset	Hummock-intermediate	Intermediate-flark
MSI	r = - 0.67	r = - 0.69	r = - 0.66
WBI	r = 0.69	r = 0.78	r = 0.81

The availability of nutrients in addition of water forms the basis for trophic status of *Sphagnum* species and futher for mire type they are growing. Many indices characterizing the health status of green vegetation have been formed. The basis of them lie in most cases in the variation of pigment concentration or changes in red edge area.

Vogelman and Moss (1993) reported that green *Sphagnum* species have steeper red edge (680-750 nm) than nongreen species. Bubier et al. (1997) found that REIP (red edge inflection point) values of *Sphagnum* species are smaller than those of vascular plants, varying between 682 – 704 nm. REIP values calculated for *Sphagnum* species in this study were of the same order being 692-715 nm. REIP values have been used also as indirect indications of water stress of *Sphagnum* moss (Harris et. al., 2005, 2006).

Following indices used in many earlier research (among others Ustin et al., 2006) indicating plant stress: PS1 = $R_{440}/\min(R_{665\text{-}685})$, PS2 = $\min(R_{665\text{-}685})/ R_{740}$ were formed. Changes in the red edge area are characterized by the indices PS3 = R_{750} / R_{700} (simple slope ratio) and GRAD = $R_{775\text{-}700} / R_{775+700}$. Metal stress seems to straighten the spectra in VIS (see in Fig 4) and therefore a Vegetation Health Index VHI = $\max R_{550\text{-}660} / \min(R_{665\text{-}685})$ was formed (Fig 6). Indices related to photosynthetic efficience: vegetation index NDVI and Structure-Independent Pigment Index SIPI (Penuelas et al., 1995; Harris 2007) are also correlated with water content and chemistry.

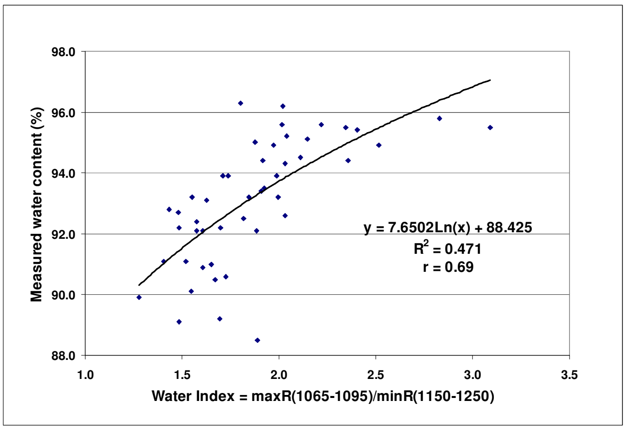

Fig 5. Logarithmic correlation between measured water content and calculated WBI of *Sphagnum* species.

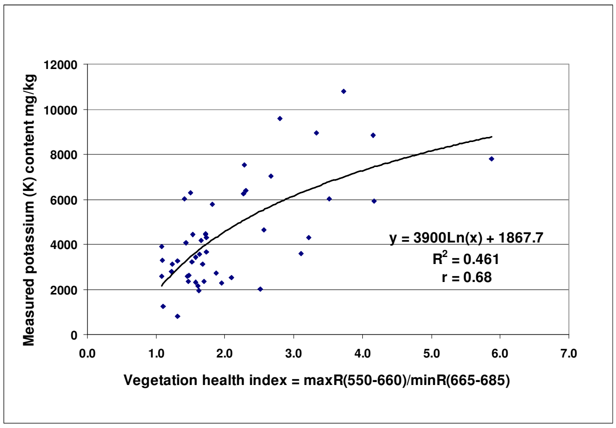

Fig 6. Logarithmic correlation between potassium content and calculated Vegetation Health Index (VHI).

The correlations of the nutrients K, Mg and P were calculated first for the dataset excluding the samples from the mining area. In this dataset potassium and phosphorus seem to have significant correlations with the indices indicating the changes in the red edge area (PS3, GRAD) and the changes in pigment content (PS1, VHI) (Table 3).

Table 3: Significant correlations between some spectral indices and potassium and phosphorus content. Significant level p varies from 0.0 to 0.1 for all correlations.

	K	P
PS3	0.61	0.65
GRAD	0.53	0.60
PS1	0.53	0.52
VHI	0.53	0.58

The situation is more complicated if the samples are enriched in potentially harmful elements and compounds causing stress for plants. When including the samples from the mining area it seems that the Plant Stress Index PS2 = min($R_{665\text{-}685}$)/ R_{740} has best correlations with arsenic, copper, lead and nickel content. Also NDVI and SIPI have significant correlations with these elements.

Ombro-oligotrophic species which are mainly hummock-intermediate species having smaller water content contained more As, Co, Cu and Ni. In this group the indices PS2, NDVI and SIPI have slightly better correlations with As, Co, Cu and Ni than in the whole dataset.

In the group of oligo-mesotrophic species no significant correlations with As, Co, Cu and Ni contents and spectral indices are found. Potassium instead has elevated significant correlations with slope ratio PS3 (r = 0.76), GRAD (r =0.74), VHI (r = 0.80), NDVI (r = 0.76) and SIPI (r = -0.68). Phosphorus has significant correlation with VHI (r = 0.65).

The number of samples in meso-eutrophic group is too small to form significant correlations.

4. CONCLUSIONS

The *Sphagnum* species growing in northern peatlands are dominant reflectors especially in pristine treeless mires (Middleton et al. 2009). The reflectances of *Sphagnum* species have their own spectral properties differing from those of vascular plants and also other mosses. Each mire type has typical *Sphagnum* species, therefore it is important to know the reflectance properties of each species. Also it is useful to recognize the elements which might have effect to the reflectance .

The results of the present study confirm that *Sphagnum* species have characteristic spectral properties which are strongly controlled by colour, cell structure, morphology, water content and chemistry. Water stress decreases the reflectance through whole spectra but especially in water absorption bands and in SWIR. Moisture Stress Index MSI has significant correlations with measured water content. The correlation is nearly the same even when calculated separately from hummock-intermediate and intermediate-flark species. Water Band Index WBI = max$R_{1065\text{-}1095}$/min($R_{1100\text{-}1300}$) proved to have better correlations, for all dataset (r = 0.69), for hummock-intermediate (r = 0.78) and for intermediate-flark species (r = 0.81) .

The nutrients potassium (K) and phosphorus (P) exhibit good correlations with the indices calculated from the red edge area. The pigment ratios calculated in VIS seems to correlate with potassium and phosphorus also significantly, especially as the trophic level increases.

The situation is more complicated if the samples are enriched in potentially harmful elements and compounds which may cause stress for plants. The increasing content of these elements may change also the content of nutrients, especially the amount of potassium. It seems, however, that the Plant Stress Index PS2 = min($R_{665-685}$)/ R_{740} has the best correlations in this case with arsenic, copper, lead and nickel content. Also NDVI and SIPI show significant correlations with these elements.

The results of this study are preliminary and need more measurements and research to confirm the ways the elevated concentrations of potentially harmful elements and compounds in different moisture conditions change the reflectance of *Sphagnum* species.

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