MISCELLANEA GEOGRAPHICA – REGIONAL STUDIES ON DEVELOPMENT
Vol. 18 • No. 2 • 2014 • pp. 10-14 • ISSN: 2084-6118 • DOI: 10.2478/mgrsd-2014-0003

Variability in spectral characteristics of trampled high-mountain grasslands

Abstract
The goal of the paper is a presentation of field remote sensing methods for the analysis of the trampled plants of a highly protected mountain meadow ecosystem (M&B UNESCO Reserve and one of the most important Polish National Parks). The research area covers a core part of the Western Tatras – the Gąsienicowa Valley and Kasprowy Wierch summit, which are among the most visited destinations of the Polish Tatras. The research method is based on field hyperspectral measurements, using the ASD FieldSpec 3 spectrometer, on the dominant plant species of alpine swards. Sampling sites were located on trampled areas (next to trails) and reference plots, with the same species, but located more than 10 m from the trail (where the probability of trampling was very low, but the same composition of analysed plants). In each case, homogenous plots with a domination of one plant species were investigated. Based on the hyperspectral measurements, spectral characteristics as well as vegetation indices were analysed with the ANOVA statistical test. This indicated a varied resistance to trampling of the studied plant species. The analysis of vegetation indices enabled the selection of those groups which are the most useful for research into mountain vegetation condition: the broadband greenness group; the narrowband greenness group, measuring chlorophyll content and cell structure; and the canopy water content group. The results of the analyses show that vegetation of the High Tatras is characterised by optimal ranges of remote sensing indices. Only plants located nearest to the trails were in a worse condition (chlorophyll and water content was lower for the reference targets). These differences are statistically significant, but the measured values indicate a good condition of vegetation along trampled trails, within the range of optimum plant characteristics.

Keywords
Trampling • Tatra National Park • vegetation • hyperspectral measurements • ASD FieldSpec 3 • mountain grasslands

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Received: 3 September 2013
Accepted: 21 December 2013

Introduction

The Tatra National Park is one of Poland's highly protected areas. It is also recognized as part of the World Network of Biosphere Reserves from UNESCO's Man and the Biosphere Programme and European Natura 2000. This Park is one of the most visited Polish national parks (each year the number of tourists exceeds 3 millions). In some areas of the park the tourist traffic is very intensive, for example in the tested area of Kasprowy Wierch, where cable cars transport about 180 people per hour. The mentioned area is also visited by walking tourists, for whom Kasprowy Wierch is a centre of summer and winter activities. Such a large number of people causes devastation of the environment, which can be recognized and analysed by remote sensing techniques. Trampling of vegetation in the immediate vicinity of hiking trails causes stress (Grabherr 1982; Whinam et al. 2003), which may lead to adverse disturbance to the function and structure of a plant's organism (Kopcewicz et al. 2005). This stressor impact (trampling by tourists) can be measured using remote sensing methods in the form of spectral reflectance curves and remote sensing vegetation indices. The purpose of the study was to investigate the condition of alpine grassland vegetation and to compare differences between trampled and untrampled vegetation based on spectral characteristics of vegetation and remote sensing indices.

Previous research on trampling

Research into meadow conditions has so far been conducted in the Slovak part of the Tatra Mountains, focussing on plant phenology and the impact of treading. The study also takes into account seasonality. Studies have shown that trampling has the greatest impact at the beginning of the growing season rather than later in the season. It turns out that plant cells that are destroyed in the early stages of development cannot be rebuilt and die (Somsák et al. 1979; Piscová et al. 2011). The deterioration of alpine grasslands after opening cable car services has also been observed in the Austrian Alps, where researchers analysed the status and structure of plant biomass in individual transects

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Figure 1. Typical grassland species: Nardus stricta and Oreochloa disticha

that have undergone different tourist traffic. It was observed that even weak alpine vegetation trampling destroys the species composition, which leads to changes in the density and volume of soil and a decrease in plant regeneration capacity (Grabherr 1982). Changes in species composition, biomass and vegetation structure were also observed during monitoring carried out in the high mountain grasslands of the Central Alps (Klug et al. 2002). Impact studies carried out so far on the subject of treading emphasize the fact that each species has a different regenerative capacity (Whinam et al. 2003). The Park's activities are aimed at maintaining a balance between the development of the tourism infrastructure and curtailing the adverse effects of the pressure tourism inflicts on the environment of the Tatra Mountains (http://tpn.pl/poznaj). Channeling traffic in the area of Kasprowy Wierch allowed the regeneration of high-altitude grasslands (Guzik 2001).

Methods

Measurements were conducted using the hyperspectral ASD spectrometer FieldSpec 3 in transects located along the trails located at the Kasprowy Wierch summit. The studies were carried out in 2011 and 2012 years. Plant communities were determined based on real state and the actual vegetation map (Kozłowska 2006). Reference sample sites were selected at a distance greater than 10 m from trails.

Oreochloa disticha and *Nardus stricta* (Figure 1) were chosen as typical species of grasslands which cover significant parts of this research area.

The homogeneous sample plots were analysed by performing measurements of the spectral characteristics of these plant species in the spectral range of 350-2500 nm. The spectral characteristics of the selected species were measured both on the trail (trampled vegetation) as well as on the reference vegetation. The spectra allowed a comparison of spectral properties and the derivation of remote sensing vegetation indices. For the analysis the following group of indices were used:

1. Indices of an overall vegetation condition: *Normalized Difference Vegetation Index* (NDVI, Rouse et al. 1973), *Simple Ratio Index* (SR, Rouse et al. 1973), *Enhanced Vegetation Index* (EVI, Huete et al. 1997), *Atmospherically Resistant Vegetation Index* (ARVI, Kaufman 1992),
2. Chlorophyll content indices: *Red Edge Normalized Difference Vegetation Index* ($NDVI_{705}$, Gitelson et al. 1994), *Modified Red Edge Simple Ratio Index* (mSR_{705}, Datt 1999), *Modified Red Edge Normalized Difference Vegetation Index* ($mNDVI_{705}$, Datt 1999), *Vogelmann Red Edge Index 1*, *2*, *3* (VOG1, VOG2, VOG3, Vogelmann et al. 1993),
3. Carotenoid content indices: *Carotenoid Reflectance Index 1*, *2* (CRI1, CRT2, Gitelson et al. 2002), *Anthocyanin Reflectance Index 1*, *2* (ARI1, ARI2, Gitelson et al. 2001),
4. Nitrogen content index: *Normalized Difference Nitrogen Index* (NDNI, Fourty et al. 1996),
5. Indices of amount of light used for photosynthesis processes: *Photochemical Reflectance Index* (PRI, Gamon et al. 1992), *Structure Insensitive Pigment Index* (SIPI, Peñuelas et al. 1995),
6. Indices of carbon content in plants: *Normalized Difference Lignin Index* (NDLI, Fourty et al. 1996), *Cellulose Absorption Index* (CAI, Nagler et al. 2003), *Plant Senescence Reflectance Index* (PSRI, Merzlyak et al. 1999),
7. Indices of leaf water content: *Water Band Index* (WBI, Peñuelas et al. 1998), *Normalized Difference Water Index* (NDWI, Gao 1995, Gao 1996), *Moisture Stress Index* (MSI, Rock et al. 1985), *Normalized Difference Infrared Index* (NDII, Hardisky et al. 1983).

The acquired spectral characteristics and the remote sensing of vegetation indices were analysed by the variance ANOVA test at a significance level of 0.05.

Results

The studies showed a diverse resistance to trampling for different species (Figure 2, Figure 3). Remote sensing indicators reached different values depending on the distance from the trail. These differences are statistically significant, but the measured values are all within the range of optimum characteristics of plants in good condition. This method was used for field data from August 2011 and 2012. Multitemporal analyses showed that the condition of plants changes, depending mostly on the water content of the leaves, which is visible in figure 2 and figure 3 in the range wavelength 1400 nm to 2500 nm. The spectral characteristics of trampled and reference plants show significant differences in ranges of chlorophyll and water content (Figure 3, chlorophyll content in the range 500-700 nm, water content 1500-2500 nm). Such elements are key for plant physiology; they have a direct impact on growing properties and can be registered by remote sensing methods.

The analysis confirmed that vegetation in the Western Tatras is in a good condition. The more resistant species is *Nardus stricta* and the more fragile is *Oreochloa disticha*, which showed significant changes between trampled and reference plants. The significant changes are marked grey in the figures, illustrating the relevant wavelength range in which the details are important changes (Figure 2, Figure 3).

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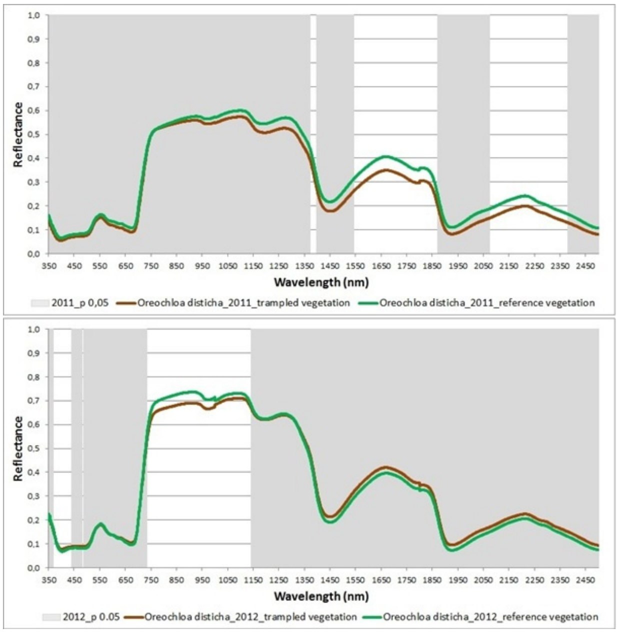

Figure 2. Spectral reflectance curve for species sensitive to trampling (Oreochloa disticha) in 2011 and 2012 at the statistical significance level of 0.05

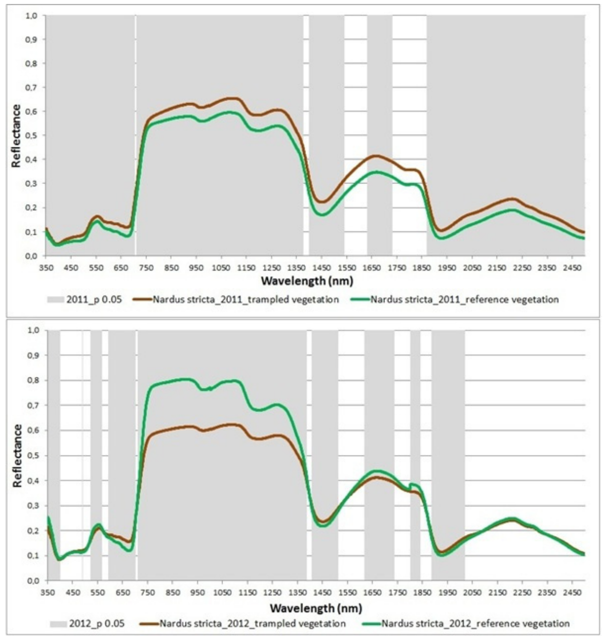

Figure 3. Spectral reflectance curve for species resistant to trampling (Nardus stricta) in 2011 and 2012 at the statistical significance level of 0.05

Table 1. Values of selected indices of trampling-sensitive (Oreochloa disticha) and resistant (Nardus stricta) species

Species	Year of research	Broadband Greenness		Narrowband Greenness		Canopy Water Content	
		NDVI	ARVI	NDVI 705	mSR 705	NDWI	NDII
Nardus stricta (reference polygons)	2011	0.74	0.66	0.46	3.34	0.03	0.24
	2012	0.71	0.67	0.45	3.76	0.07	0.29
Nardus stricta (trampled polygons)	2011	0.66	0.56	0.39	2.91	0.01	0.18
	2012	0.57	0.48	0.34	2.75	0.03	0.19
Oreochloa disticha (reference polygons)	2011	0.65	0.57	0.36	2.93	0.00	0.15
	2012	0.75	0.70	0.46	3.55	0.07	0.29
Oreochloa disticha (trampled polygons)	2011	0.68	0.61	0.40	3.11	0.02	0.21
	2012	0.71	0.66	0.44	3.48	0.04	0.23

The spectral reflectance curves for plants sensitive to trampling (Figure 2) are similar in both periods. Only in the cellular structures characterized by a spectral range from 700 to 1350 nm were differences observed in 2012 (Figure 3, where the green line is higher than the brown line for 2012). However, the spectral characteristics of plants resistant to well-trodden *Nardus stricta* (Figure 3) in both periods are significantly different. As for *Oreochloa disticha*, the reflectance value describing the structure of the cell is much higher. In figure 2 in both charts the green line for the reference vegetation is higher than the brown line for the trampled vegetation; what is more, the values in this range are statistically significant to the level 0.05 (Figure 2).

In 2012, conditions were very good for the development of vegetation, while 2011 was rainy and cold[1]. Total rainfall during the summer of 2011 was higher by about 200 mm than rainfall for 2012 in the same period. However, the average temperature in 2011 was lower by about 2 degrees than in 2012. Spectral characteristics made it possible to derive remote sensing vegetation indices. The values of the selected group of indicators for the reference and beaten plants in both years are similar, but a significant difference can be observed in the values of the indicators in comparing a reference plant with a trodden plant sample. In 2012, the ratio of NDVI for the *Nardus stricta* reference

[1]http://www.imgw.pl/klimat/

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plants reaches 0.71 while for trampled plants the ratio for this period is 0.57 (Table 1). The table shows only two examples of vegetation indices for the three groups of indicators whose values were relevant to the statistical significance level of 0.05.

Statistical analysis of the data revealed the feature range of the electromagnetic spectrum relevant to studies of vegetation damage. These spectrum ranges are marked in gray on the graph. The most significant differences were observed in three groups of indices: cell structure, leaf area and chlorophyll content (Broadband and Narrowband Greenness), and water content (Canopy Water Content; Kycko 2012; Kycko et al. 2012).

Conclusions

The research carried out over two years showed that the trampled vegetation (nearest to the trail) is characterized by lower parameters than the reference vegetation located more than 10 meters from the trail. However, these parameters are not indicators of a poor state of vegetation. Comparing the two year study of the same area, we see the significant impact of weather conditions, particularly rainfall and sunlight, on the vegetation. Multiannual vegetation analysis in solid research training grounds allows us to monitor the status of alpine grasslands. Remote sensing is a proper tool for long-term monitoring.

Acknowledgements

The authors would like to thank the Tatra National Park, the Institute of Geography and Spatial Organisation of the Polish Academy of Sciences and the Anna Pasek Foundation, which funded a scholarship for Marlena Kycko in 2012/2013.

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