Conference Volume	5th Symposium for Research in Protected Areas 10 to 12 June 2013, Mittersill	pages 631 - 638

Biomass-mapping of alpine grassland with APEX imaging spectrometry data

Maja Rapp[1,2], Anna Schweiger[2], Ruedi Haller[2]

[1]UNIGIS MSc, Universität Salzburg
[2]Schweizerischer Nationalpark

Abstract

Today remote sensing is a standard technique for mapping land cover in high spatial resolution over large areas. Not only land cover but also the quality and quantity of vegetation can be classified by the analysis of hyperspectral data. In the Swiss National Park (SNP) we use data from the Airborne Prism Experiment (APEX) imaging spectrometer to expand the possibilities of vegetation analysis in alpine territories. The high spectral and spatial resolution of APEX data allows the correlation of the measured reflection with ground truth data. We generated an optimized simple ratio index (SRI) with selected bands to model the biomass content of the alpine grassland of one particular valley in the SNP, the Val Trupchun. The correlation between biomass *insitu* measurements and SRIs was non-linear, most likely due to sensor saturation. The model underestimated high biomass values above 600 g/m². The accuracy of 57% was good considering the challenging terrain. The biomass prediction map showed plausible values for the grassland with high concentrations around former alps. High biomass sources were linked to former anthropogenic land use, dominant vegetation structure and to preferred ungulate habitat today. The high-resolution map is now a useful basis for future research in the SNP to investigate forage amount and analyse ungulate habitat pattern in Val Trupchun. This a welcoming issue for ungulate research, which is an important research area of the SNP.

Keywords

imaging spectrometry, hyperspectral data, biomass modeling, vegetation indices

Introduction

Imaging spectrometry or imaging spectroscopy is a remote sensing technique recording the earth's surface by a hyperspectral sensor. With increased number of spectral bands and increased spatial resolution the technique allows today not only the mapping of land cover types but also the mapping of vegetation quality and quantity.

An imaging spectroscometer samples contiguously in the optical part of the electromagnetic spectrum using dozens to hundreds of narrow spectral bands. For each image pixel, the sensor acquires the reflectance of the earth's surface from the ultraviolet through the visible to the near- and mid-infrared (i.e. 250 - 2500 nm) part of the electromagnetic spectrum at a high spatial resolution.

In Fig. 1 a schematic of the function of an imaging spectrometer is illustrated.

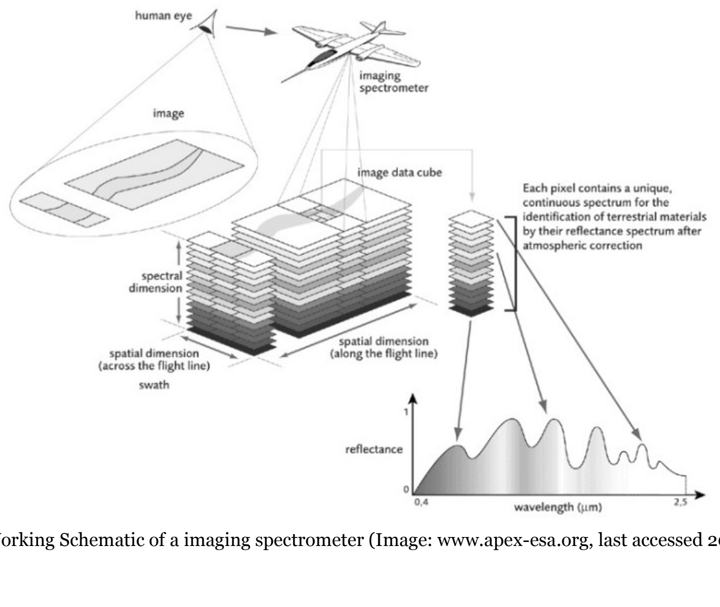

Figure 1: Working Schematic of a imaging spectrometer (Image: www.apex-esa.org, last accessed 20.03.2013)

Analysing the vegetation using remotely sensed data requires knowledge of the biochemical, structural and functional vegetation characteristics and its optical properties. Water, pigments, nutrients and carbon are each expressed in the reflected optical spectrum from 400 nm to 2500 nm, with often overlapping, but spectrally distinct, reflectance behaviours. The absorption characteristics of these compounds determine the optical properties, which as a result are then visible in e.g. the reflectance spectra. With these known signatures it is possible to combine reflectance measurements at different wavelengths to enhance specific vegetation characteristics. Vegetation indices (VIs) have been widely adopted for studying vegetation cover, chlorophyll content or quantifying other vegetation properties. As different materials have characteristic spectra with maxima or minima at particular wavelengths, there is often no need for complex physical models to determine key biophysical parameters. VIs based on empirical or semi-empirical models are new variables generated by mathematical combination of two or more of the original spectral bands chosen in such a way that the new indices are related to the biophysical parameters of interest. A variety of VIs have been published so far. A well-known and simply applicable VI is the Simple Ratio Index (SRI, BIRTH & MCVEY 1968; ROUSE et al. 1974; TUCKER 1979). This index is typically used for modelling the healthy green vegetation or quantifying the photosynthetic capacity of plant canopies. With the advent of imaging spectroscopy and the availability of the large amount of narrow spectral bands, VIs can be individually designed for a specific vegetation property and a specific territory. By correlating the results of the VIs with on site field data, the optimal VI is chosen to model the desired vegetation property. The advantage of the index implementing two to many bands is to minimize the sensitivity to irradiance, illumination and to other factors such as variation in atmospheric transmission. The disadvantage of empirical models and VIs is that the structural property of the vegetation can't be modelled. Especially for dense canopies (high biomass) the VI have its limitations due to saturation.

Studies using hyperspectral data to estimate biomass by relating field data to vegetation indices have been carried out in several studies. (MUTANGA & SKIDMORE 2004; RAHMAN & GAMON 2004; MIRIK et al. 2005; TARR et al. 2005; BEERI et al. 2007; CHO et al. 2007; PSOMAS 2009). These studies show the complexity of the spectral response of mixed grasslands, especially in the presence of a high fraction of non-photosynthetic active vegetation (NPV) and exposed soil (BEERI et al. 2007; HE et al. 2006; BOSCHETTI et al. 2007), grazing impact (NUMATA et al. 2007), canopy architecture complexity due to mixed species composition and phenology (CHO et al. 2007), and sensor saturation occurring at high biomass concentration (MUTANGA & SKIDOMRE 2004).

The Swiss National Park (SNP) was mapped by APEX (Airborne Prism Experiment) for the first time in June 2010. Land cover mapping and monitoring of landscape dynamics are essential for the management of protected areas. Since ungulate research plays an important role in the SNP, the application possibilities of the APEX data are of great interest. Until now, vegetation mapping has been based on the interpretation of single plots and visual observations, which enables only limited interpolations over large areas. Since 1917, the vegetation has been monitored on more than 150 permanent plots (BRAUN-BLANQUET et al. 1931). In 1968 an analogue vegetation map of part of the SNP was produced in cartography work by Trepp/Campell at a scale of 1:10'000 (TREPP & CAMPBELL 1968). In 1992, Zoller published a vegetation map of the entire SNP (ZOLLER 1992). It was based on observation plots and field trips, and mapped at a 1:50'000 scale. An interpretation of colour infra-red aerial images was conducted over the whole territory of the SNP as part of the project Alpine Habitat Diversity in 2006 (HABITALP 2006). The HABITALP project has been the first study with a standardized method to classify vegetation types area-wide from aerial images. With APEX not only a classification of habitat types is possible, but also pixel-based modelling of vegetation composition at a scale of 2 x 2 meters.

Despite the 100 years of protection, traces from the former land use can still be found on subalpine and alpine grassland. Cattle and sheep grazed the territory of the SNP for several centuries until 1914 (PAROLINI 1995). As a result, tall-herb communities dependent on nutrient enrichment from the excreta of cattle or sheep can still be found on several former pastures in the SNP (BRAUN-BLANQUET 1931; BRAUN-BLANQUET et al. 1954; ACHERMANN et al. 2000).
The aim of this MSc thesis is to generate a biomass map of the grassland of one particular valley of the SNP (Val Trupchun) with APEX imaging spectrometry data from June 2010. A semi-empirical method is implemented in the modelling process. The produced biomass map is analysed for accuracy and plausibility relating to the former land use of the Val Trupchun.

Methodology

Study site

The study site is located in the upper Engadin valley in south-eastern Switzerland (46°40'N, 10°15'E), within the territory of the Municipality of S-chanf. The Val Trupchun is dominated by grassland communities distributed over a large gradient of altitude and phenological stages (fig. 1). Large numbers of red deer (*Cervus elaphus, L.*), ibex (*Capra ibex, L.*) and chamois (*Rupicapra rupicapra, L.*) are inhabiting the valley which makes it an interesting area for ungulate research.

The APEX instrument

In June 2010 the SNP has been mapped by the APEX pushbroom imaging spectrometer for the first time. The Airborne Prism Experiment (APEX) is an airborne imaging spectrometer developed under the scientific lead of a Swiss-Belgian collaboration between the Remote Sensing Laboratories (RSL, University of Zurich (CH)) and the Flemish Institute for Technological Research VITO (B) on behalf of the European Space Agency (ESA) PRODEX programme. APEX is collecting 301 bands covering wavelengths from 380 - 2500 nm with a spatial resolution of 2x2 meters (fig. 2). The APEX data sets were geometrically and atmospherically corrected by the RSL using standard approaches (PARGE, Atcor4,) (Schläpfer & Richter 2002). The APEX flight was carried out on 24 of June under cloud free conditions. The specific study site Val Trupchun was covered by four image strips, each with an extend of about 2x6 km and a ground resolution of 2 m. The flight lines are SW to NE oriented, cross-wise to the valley and the mountain ridge (see Fig. 2).

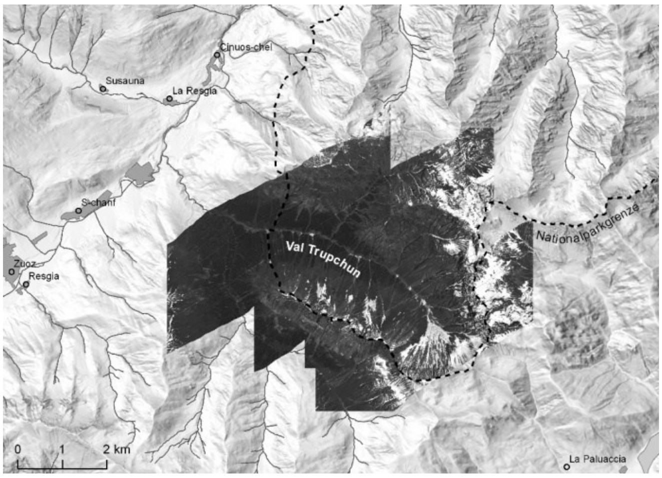

Figure 2: Overview of the research area Val Trupchun in the SNP which was mapped by 4 flight strips.

Field data collection

Fieldwork was carried out to collect ground-truth data of the grassland. Twenty-five plots had previously been defined, which were distributed over the valley and at various altitudinal gradients in order to account for differences in species composition, productivity, phenological stages and soil type. On the day of the flight we clipped 1m² of vegetation in 25 homogenous plots and measured the wet and the dry weight.

Data analysis

The collected biomass samples were randomly divided into two groups, one used for the calibration and one for the validation of the model. Simple ratio vegetation indices (SRI) are developed from the hyperspectral data with all possible combination of bands and regressed against the calibration data set. The result is illustrated in a 2D-correlation plot. For our biomass model we chose the best SRI within the range of visible (RED) and near-infrared (NIR) region (700 - 1300 nm). Within this range high reflection on healthy biomass occurs and no water absorption interferes the signal. We computed a regression model to predict and map the biomass content and used the validation data set to test the accuracy of the model.

Results

Simple ratio indices (SRI) were calculated with all possible combinations of bands and correlated against the calibration data set. Spearman's rank correlation coefficients (R) were plotted on a 2D-contour plot to identify the best wavelength combination, shown in Fig. 3.

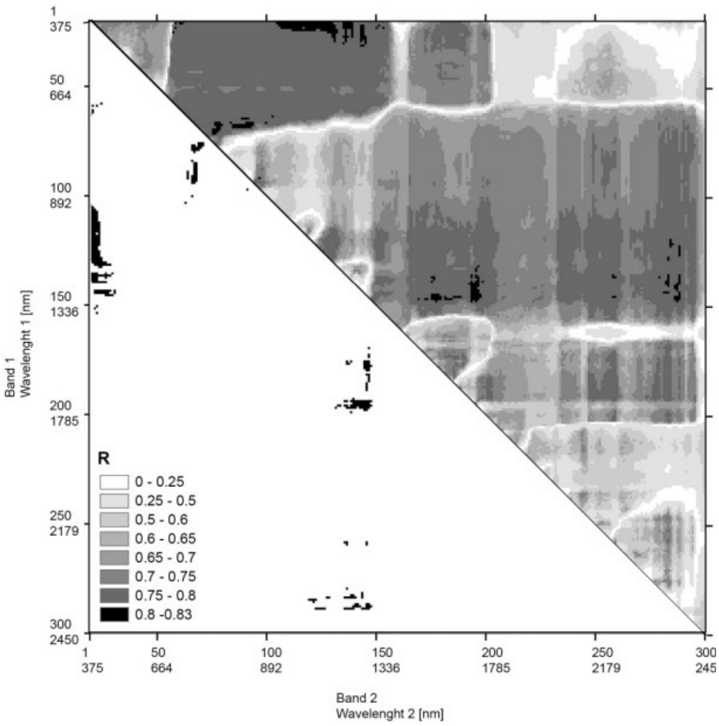

Figure 3: 2D-correlation plot showing the correlation between measured wet weight biomass and Simple Ratio Indices (SRI) from all combination of bands. The matrix is symmetrical. Below the diagonal, band combination are marked in red where R> 0.8.

For our final biomass model the best SRI within the range of visible (RED) and near-infrared (NIR) (700 - 1300 nm) region was chosen. Within this range high reflection on healthy biomass occurred and no water absorption interfered with the signal.

The SRI of band 92 (842 nm) and band 68 (727 nm) achieved the best R (0.823) overall. This combination was chosen for the final biomass model. An exponential regression model was computed again between SRI and wet weight biomass of the calibration data set resulting in an R^2 of 0.77 (see Fig. 4).

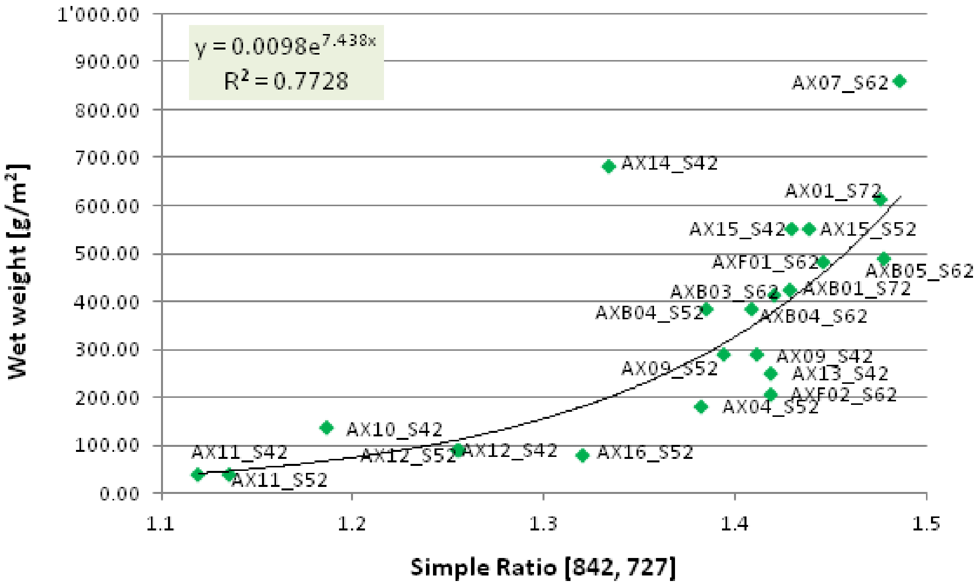

Figure 4: Regression between SRI derived from APEX reflectance spectra from band at 842 nm and 727 nm and the wet weight biomass calibration sample data.

The validation of the model was carried out by calculating the predicted biomass using the model equation for the validation sample plots and comparing them to the true wet weight values. The R^2 and RMSE were 0.57 and 238 g/m^2 respectively (see Fig. 5). The outliers were again AX14, AX06 and AX07. The calibration model under-estimated biomass values above 600 g/m^2.

Fig. 6 shows the resulting biomass prediction map.

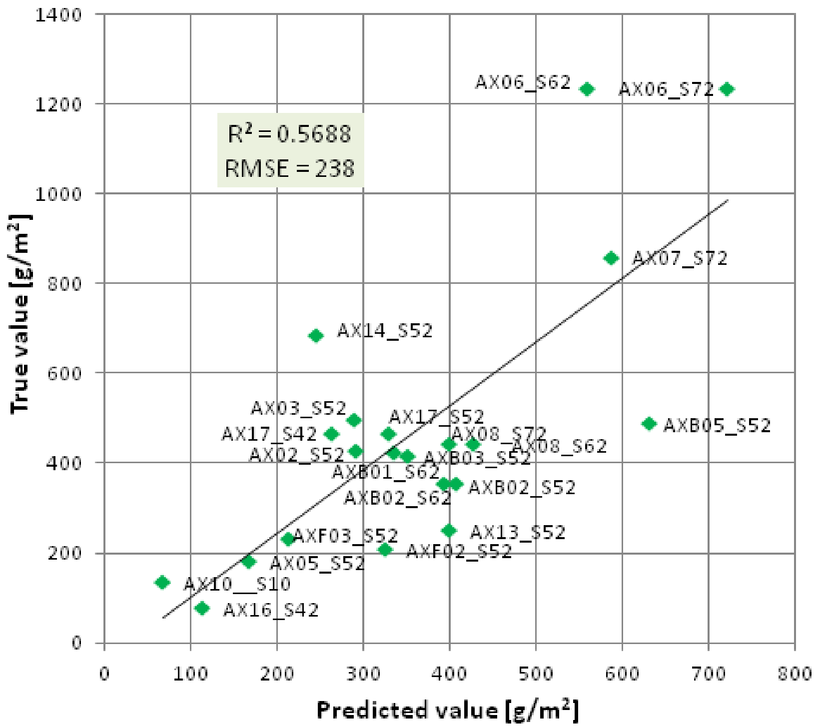

Figure 5: Regression between the predicted biomass value calculated from the SRI model calibration and the true biomass value of the validation sample plots

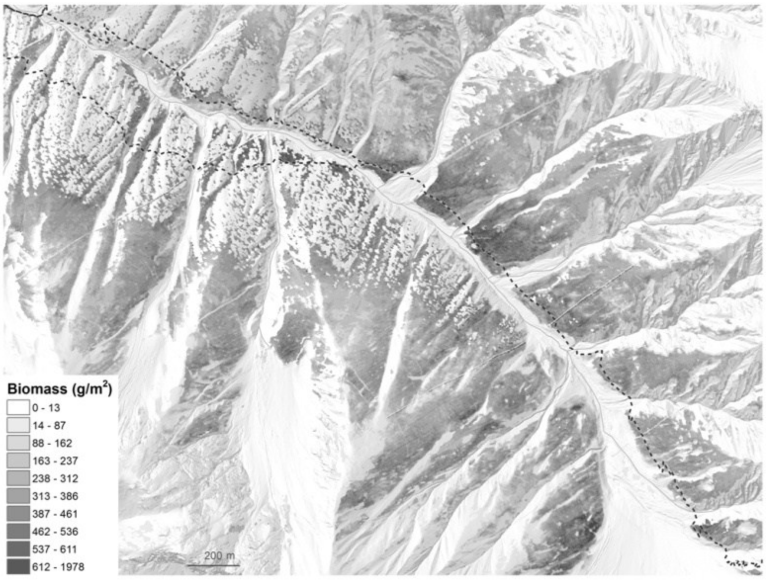

Figure 6: Biomass map of the grassland of Val Trupchun

Estimated biomass values were generally in a reasonable range. On the map, it can be seen that biomass decreases with increasing altitude at the slopes. Three locations with high biomass are noticeable. The highest biomass sources are located around the former Alp Trupchun, Alp Putcher and on the bottom south slope. Fig. 7 shows a close-up of the map around Alp Trupchun. To analyse the biomass source, the HABITALP dataset is overlaid. This map includes herb/grass functional types or dominant species if one vegetation unit stands out. It can be seen that high biomass correlates with the occurrence of monkshood. This means that excessive nutrients are available in this area which stem from former anthropogenic activities on the alp (cattle or sheep excreta). It can be concluded that high biomass concentration occurs where former anthropogenic activities took place (cattle or sheep excreta).

Figure 7: Close up of the area around former Alp Trupchun

Discussion

The model is non-linear and underestimates high biomass values (above 600 g/m^2). Such bias can be caused by random noise or fundamentally non-linear relationship in the true physical relationship (GELADI et al. 1999). Another reason is saturation of NIR reflectance in dense vegetation, which can affects SR indices.

The 57% accuracy of the SRI model (842/747) validation means that 57% of the biomass variance can be explained. This is a comparatively good validation for such a complex terrain conducted with completely independent plots. The uncertainties are mainly due to sensitivity to external factors, which overlap the measured signal and influence the model, such as atmospheric effects (cloud, haze and other scatterers), topographic effects (shading), illumination effects (sun angle and viewing geometry), soil effects (soil fraction), structural effects (scattering due to objects/leaf architecture) or random noise.

The biomass prediction map showed plausible values for the grassland with high concentrations around the former Alp Trupchun, Alp Purcher and on the south slope at the end of the valley.

Conclusion

Imaging spectroscopy techniques permit not only the classification of vegetation, but also the quantitative mapping of different vegetation variables due to their high spectral and spatial resolution. This study demonstrates the utility of vegetation indices involving APEX bands for estimating biomass in alpine grasslands.

The SRI model was suitable for the generation of the biomass prediction maps implementing biophysical parameters. We found that the correlation between biomass *insitu* measurements and SRIs was non-linear, most likely due to sensor saturation. The model underestimated high biomass values above 600 g/m^2. The model accuracy of 57% was good considering the challenging terrain.

The biomass prediction map showed plausible values for the grassland with high concentrations around the former Alp Trupchun, Alp Purcher and on the south slope at the end of the valley. We found that high biomass sources were linked to former anthropogenic land use, dominant vegetation structure and to preferred ungulate habitat today.

The high-resolution map is now a useful basis for future research in the SNP to investigate forage amount and analyse ungulate habitat pattern in Val Trupchun.

Outlook

The generated biomass prediction map can be used for future research in Val Trupchun. This work was carried out within the scope of a PhD thesis at the Swiss National Park analysing ungulate habitat patterns relating to biophysical and biochemical parameters. The APEX campaigns have been continued during the years 2011 and 2012.

The produced model is applicable only for the study area, since semi-empirical. These predictive models are site- and sensor-specific and unsuitable for application to other areas or to different seasons. With this model we tried to predict another area of the SNP, the grassland of Il Fuorn, which is located ca. 15 km north-east, and didn't find suitable agreement with *insitu* measurements. This finding highlights the importance of local models, based on local measurements for small scales in complex terrain.

The main proposal for a model improvement based on this work is to increase the number of sample plots in the study area. With more samples covering the full range of biomass concentrations, we suppose that the model accuracy and stability will improve. However, the improvement proposal would require a lot more effort in the field which is a limiting factor.

References

ACHERMANN, G., SCHÜTZ, M., KRÜSI, B. O. 2000. Tall-herb communities in the Swiss National Park: Long-term development of the vegetation. Nationalpark-Forschung in der Schweiz, Band 89.

BEERI, O., PHILLIPS, R., HENDRICKSON, J., FRANK, A. B., KRONBERG, S. 2007. Estimating forage quantity and quality using aerial hyperspectral imagery for northern mixed-grass prairie. Remote Sensing of Environment, 110, pp. 216-225

BIRTH, G. S., MCVEY, G. R. 1968. Measuring the colour of growing turf with a reflectance spectrophotometer. Agronomy Journal 60, pp. 640-643.

BOSCHETTI, M., BOCCHI, S., BRIVIO, P. A. 2007. Assessment of pasture production in the Italian Alps using spectrometric and remote sensing information. Agriculture, Ecosystems Environment, 118(1-4), pp. 267-272.

BRAUN-BLANQUET, J., BRUNIES, S., CAMPELL, K., FREY, E., JENNY, H., MEYLAN, CLI. & H. PALLMANN 1931. Vegetationsentwicklung im Schweiz. Nationalpark. Ergebnisse der Untersuchung von Dauerbeobachtungsflächen, 1. Dokumente zur Untersuchung des Schweizer Nationalparks. Jahresberichte der Nationalforschenden Gesellschaft Graubündens, 69, pp. 3-82.

BRAUN-BLANQUET, J., PALLMANN, H., BACH, R. 1954. Planzensoziologische und bodenkundliche Untersuchungen im Schweizerischen Nationalpark und seinen Nachbargebieten. II Vegetation und Böden der Wald- und Zwergstrauch-gesellschaften (Vaccinio-Piceetalia). Ergebnisse der wissenschaftlichen Untersuchungen des schweizerischen Nationalparks. Band 4, Kapitel 28.

CHO, M. A., SKIDMORE, A., CORSI, F., VAN WIEREN, S. E., SOBHAN, I. 2007. Estimation of green grass/herb biomass from airborne hyperspectral imagery using spectral indices and partial least squares regression. International Journal of Applied Earth Observation and Geoinformation 9, pp. 414-424

GELADI, P., HADJIISKI, L., HOPKE, P. 1999. Multiple regression for environmental data: nonlinearities and prediction bias. Chemometrics Intell. Lab. Syst. 47 (2), pp 165-173.

HABITALP, Alpine Habitat Diversity. Information available at: http://www.habitalp.org/ (last accessed: 30/03/13)

HE, Y., GUO, X.L., WILMSHURST, J. 2006. Studying mixed grassland ecosystems I: suitable hyperspectral vegetation indices. Canadian Journal of Remote Sensing 32, pp. 98-107.

MIRIK, M., NORLAND, J. E., CRABTREE, R. L., BIONDINI, M. E. 2005. Hyperspectral one-meter-resolution remote sensing in Yellowstone National Park, Wyoming: II. Biomass. Rangeland Ecology and Management 58, pp. 459-465.

MUTANGA, O., SKIDMORE, A. K. 2004. Narrow band vegetation indices overcome the saturation problem in biomass estimation. International Journal of Remote Sensing, Vol. 25, pp. 3999-4014.

MUTANGA, O., SKIDMORE, A. K., PRINS, H. H. T. 2004. Predicting in situ pasture quality in the Kruger National Park, South Africa, using continuum-removed absorption features. Remote Sensing of Environment, 89, pp. 393-408.

NUMATA, I., ROBERTS, D. A., CHADWICK, O. A., SCHIMEL, J., SAMPAIO, F. R., LEONIDAS, F. C., SOARES, J. V. 2007. Characterization of pasture biophysical properties and the impact of grazing intensity using remotely sensed data. Remote Sensing of Environment, 109, pp. 314-327.

PAROLINI, J. D. 1995. Zur Geschichte der Waldnutzung im Gebiet des Schweizerischen Nationalparks. PhD Thesis ETH Zurich, Nr. 1187.

PSOMAS, A. 2009. Hyperspectral remote sensing for ecological analyses of grasslands ecosystems. Spectral separability and derivation of NPP related biophysical and biochemical parameters. Dissertation, University of Zurich.

RAHMAN A. F., GAMON J. A. 2004. Detecting biophysical properties of a semi-arid grassland and distinguishing burned from unburned areas with hyperspectral reflectance. Journal of Arid Environments 58(4), pp. 597-610.

ROUSE, J. W., HAAS, R. H., SCHELL, J. A., DEERING, D. W., HARLAN, J C. 1974. Monitoring the vernal advancement and retrogradation (greenwave effect) of natural vegetation. NASA/GSFC Final report, Greenbelt, MD, USA.

SCHLÄPFER, D., RICHTER, R. 2002. Geo-atmospheric processing of airborne imaging spectrometry data. Part 1: parametric orthorectification. International Journal of Remote Sensing, Vol. 23, pp. 2609-2630.

TARR, A. B., MOORE, K. J., DIXON, P. M. 2005. Spectral reflectance as a covariate for estimating pasture productivity and composition. Crop Science, 45(3), pp. 996-1003.

TREPP, W., CAMPELL, E. 1968. Vegetationskarte des Schweizerischen Nationalpark. Nationalparkforschung in der Schweiz, Band 11, Heft 58

TUCKER, C. J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 8, pp 127-150.

ZOLLER, H. 1992. Vegetationskarte des Schweizerischen Nationalparks und seiner Umgebung. Nationalpark-Forschung in der Schweiz, Band 85.

Contact

Maja Rapp
maja.rapp@nationalpark.ch

UNIGIS MSc, Universität Salzburg
Schweizerischer Nationalpark
Schloss Planta Wildenberg
7530 Zernez
Switzerland