

# Modelling Herbivore grazing resources using hyperspectral remote sensing and GIS

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## SUMMARY

*We report on studies that successfully map the distribution of plant species as well as parameters indicative of the quality of forage for herbivores. We show that rangeland and wetland species and types may be discriminated and mapped using GIS and hyperspectral remote sensing. Using artificial medium, as well as field experiments, insect herbivore growth is positively related to nitrogen content, while significantly higher abundance of large herbivores occurs on nutrient enriched sites in southern Africa. Plant nitrogen concentration is shown to be significantly related to a shift in the red edge as well as key wavelength absorption points. Finally the reflectance of other leaf biochemicals associated with forage quality (P, K, Mg, Ca) are also discriminated and mapped..*

**KEYWORDS:** Ecology, Analysis, Imagery, Hyper spectral

## INTRODUCTION

Research in ecology has revealed that, both the quantity (biomass) and quality (the foliar concentration of nitrogen, phosphorous, calcium, magnesium, potassium and sodium) of grass are important factors influencing the feeding patterns and distribution of wildlife and livestock in savanna rangelands (Drent & Prins, 1987; McNaughton, 1990; McNaughton & Banyikwa, 1995; Prins, 1989; Prins, 1996). Therefore, mapping the quantity and quality of tropical grasses is critical for understanding wildlife distribution patterns.

However, the causative parameter for herbivore species richness and abundance is difficult to ascertain – high correlations can be obtained between herbivore species richness and abundance and many biophysical parameters (e.g. soil nutrients, climatic factors such as rainfall and temperature, net primary production, solar insolation, etc) as well as vegetation quality and quantity. This complicates the identification of causative factors.

Why is it important whether we can map the distribution of vegetation species? A herbivore may eat a small variety of plant species (eg. giant panda) or be a generalist (eg. goat). In addition, plant species may be attractive at different times of the year to a particular herbivore. Thus knowledge of plant species distribution is basic to understanding an individual animal's choices, as well as habitat suitability for herbivore species. The quantity and quality of biomass available for consumption by a herbivore is obviously linked to species. Quality and quantity parameters change over time (seasonally or inter-annually). Thus, quantity and quality are also interesting parameters to map in addition to species, as these parameters provide insights about the density and diversity of herbivores.

## MAPPING PLANT SPECIES

Hyperspectral imagery (HYMAP) was flown in the summer of 2000 over the Island of Schiermonnikoog, The Netherlands. The imagery was radiometrically calibrated using the empirical line technique, and geometrically corrected to ground control points using differential GPS. Laser altimetry data were made available by Rijkswaterstaat, and were processed to yield slope and terrain position information. Additional information (viz. ecological expert knowledge and vegetation spectra) was collected during a combined fieldwork campaign, where the required floristic data and

field spectrometer (using a GER 3100) data were collected. The vegetation classification, and the spectra of the vegetation types, were used as input for the classification of vegetation types from the airborne hyperspectral imagery (HYMAP). Two new GIS algorithms were written (in IDL): A terrain position classification algorithm suited for salt marsh environments and a Bayesian expert system. The Bayesian expert system was modified in order to use a spectral angle mapper (SAM) classification of the hyperspectral imagery as well as terrain information (i.e., slope, terrain position and elevation). The last part of the project encompassed the comparison of a new expert system approach with a traditional vegetation map produced using air photo interpretation generated using the Braun-Blanquet method. The accuracy of the maps were assessed, as well as an efficiency analysis of the alternative techniques, permitting recommendations for improvement of the mapping and monitoring procedure in terms of efficiency, objectivity and repeatability. Details of the methods can be found in the project report (Skidmore, Schmidt et al. 2001).

It was proven that each of the 16 salt-marsh vegetation types had a characteristic spectral signature (Schmidt and Skidmore 2002; Schmidt and Skidmore 2003) (Figure 1). In addition, a better understanding has been gained about those parts of the electromagnetic spectrum that offer the greatest information content for discriminating between and identifying vegetation types. We also show that continuum removal (which is widely applied in geological hyperspectral applications) has mixed results when applied to vegetation spectra.

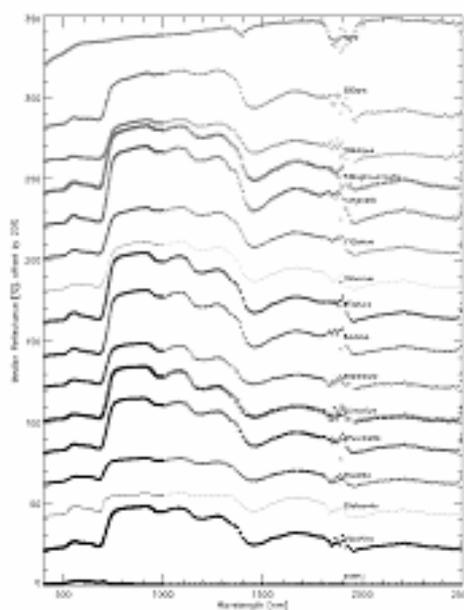


Figure 1: Vegetation spectra superimposed on grey scale showing the number of significant differences between mean reflectance at each band. High grey scale frequency translates to a wavelength with excellent discriminatory power between species.

From this study we conclude that there is a lot of information in reflectance spectra collected in the field, but extracting the information relevant for vegetation studies is a difficult task. The timing of the field sampling and the acquisition of the remotely sensed data is important, since the properties of vegetation change in a relatively short time. It is shown that the reflectance of some vegetation types

are statistically different, and with high quality calibration it is anticipated that vegetation species may be identified from spectral libraries.

Mapping vegetation using conventional methods is time consuming and expensive. An expert system used five input maps considered important in influencing the distribution of vegetation. The first was a spectral angle mapper (SAM) supervised classification of hyperspectral (HYMAP) image. The other map layers were derived from a digital elevation model and represented elevation, slope gradient, aspect, and topographic position. From knowledge of vegetation distributions, the relationships between the vegetation units and the five data layers were quantified and used as rules in a rule-based expert system. The thematic layers accessed from the GIS provided data for the expert system to infer the most likely vegetation unit occurring at any given grid cell. The vegetation map output by the expert system compared favorably with a conventional landscape guided map generated using aerial photograph interpretation.

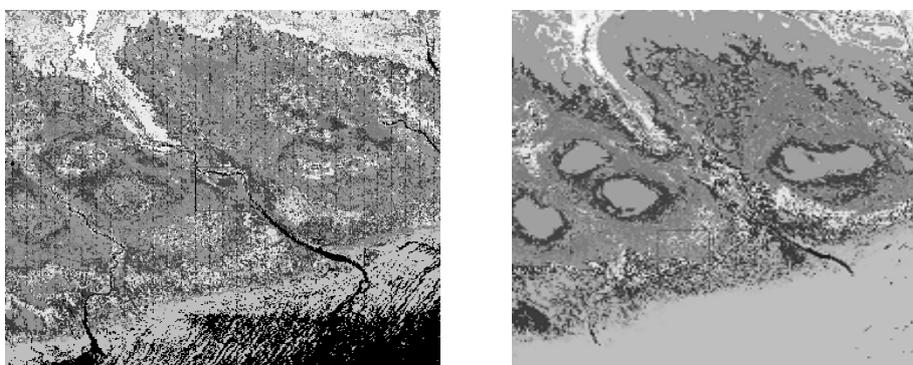


Figure 2a: Spectral angle mapper (SAM) classification of the HyMap image – map accuracy 40%  
Figure 2b: combined SAM, terrain and expert knowledge – map accuracy 62%

### **FOLIAR QUANTITY ASSESSEMENT**

Net primary production (NPP) is the net amount of carbon captured by land plants through photosynthesis each year. In a series of modeling experiments, (Hazeltnine 1996) proved theoretically that NPP is roughly proportional to APAR on a seasonal and annual basis, thereby validating the empirical observations of (Monteith 1972; Monteith 1977). FPAR (the fraction of photosynthetically active radiation that is intercepted by green vegetation) is a fundamental variable for the prediction of NPP and hence biomass production. It is possible to estimate FPAR using NDVI (Sellers, Los et al. 1994; Sellers, Los et al. 1996) and to estimate biome-averaged global FPAR values against observed monthly maximum FPAR, with an  $r^2$  of 0.76 (Hazeltnine 1996).

However, a problem limiting the application of remote sensing to map the quantity of tropical grasses is that NDVI saturates at higher canopy density - the saturation level is usually reached at about  $0.3 \text{ g cm}^{-2}$  (Mutanga and Skidmore 2003). In other words, the widely used vegetation indices (such as NDVI) asymptotically approach a saturation level after a certain biomass density or LAI (Tucker 1977; Sellers 1985; Clevers 1994), thus yielding poor estimates of biomass during the productivity peak of seasons. Results from (Said, Skidmore et al. in press) used regional data from Africa to demonstrate that the NDVI response is linear in areas of intermediate rainfall but shows little variation at high and low rainfall (Figure 3). This empirical result confirms why poor results have been obtained with NDVI over arid and forest regions, though in grasslands and savannas NDVI can yield reasonable estimates of LAI or biomass.

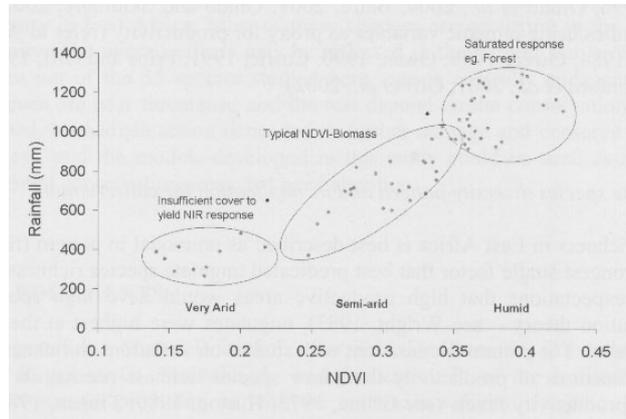


Figure 3: Relationship between rainfall and NDVI; a poor correlation in the very arid and humid regions of East Africa (Said et al. in press).

For a grassland in the Kruger National Park, (Mutanga and Skidmore 2003) tested the utility of the widely used vegetation indices for estimating biomass (in particular NDVIs involving all possible two band combinations between 350 nm and 2500 nm were tested). Results of this analysis are presented in form of  $R^2$  for each  $\lambda_1$  (350 nm to 2500 nm) and  $\lambda_2$  (350 nm to 2500 nm) pair, in Figure 4.

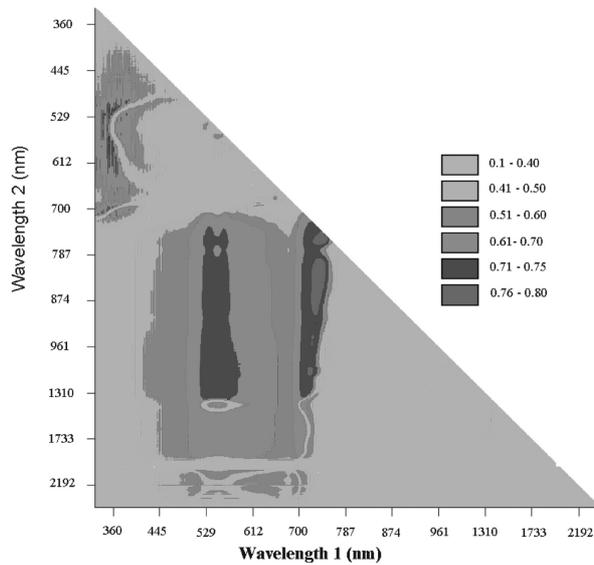


Figure 4. Map showing the correlation coefficients ( $R^2$ ) between biomass and narrow band NDVI values calculated from all possible combinations spread across  $\lambda_1$  (350 nm to 2500 nm) and  $\lambda_2$  (350 nm to 2500 nm)

Figure 4 (Mutanga and Skidmore 2003) show that biomass information is not only contained in the red absorption trough and near infrared wavelengths. Most narrow bands selected by the indices (Normalised Difference Vegetation Index, Transformed Vegetation Index, Simple Ratio) that yielded the highest correlation with biomass are located in the red edge slope. The red edge position also yielded a higher coefficient of determination with biomass as compared to the standard NDVI (Mutanga and Skidmore 2003). In summary, the key finding was that, at higher canopy density, grass biomass may be more accurately estimated by vegetation indices based on narrow wavelengths located in the red edge slope than the standard NDVI involving bands located in the near infrared and the red absorption trough.

## **FOLIAR QUALITY ASSESSMENT**

There is generally a strong positive correlation between leaf nitrogen concentration and photosynthesis (as long as other factors such as water availability or light are not limiting) (Field and Mooney 1986). Of the nitrogen found in a leaf, a large fraction (over 50%) is contained in the carbon-fixing enzyme ribulose biphosphate carboxylase. It is therefore not surprising that there is a strong positive correlation between photosynthetic capacity and leaf nitrogen content.

The enhancing effect of increased nitrogen supply on dry matter production as well as protein (including vitamin B compounds) is well established in the agricultural literature (Marschner 1995). Using artificial medium, as well as field experiments, insect herbivore growth is positively related to nitrogen content (Lincoln et al. 1982), while significantly higher abundance of large herbivores occurs on nutrient enriched sites in southern Africa (East 1984; Owen-Smith and Danckwerts 1997). Foliar nitrogen concentration has been shown as an important environmental factor (Coe 1983). The relationships between leaf chlorophyll concentration, leaf nitrogen concentration and nitrate concentration in petiole sap are strong, and linear (Vos and Bom 1993).

Turning to a resource that large herbivores more typically consume (i.e. native grass in South Africa Kruger Park), obtaining adequate protein from vegetation is a critical parameter determining success of an animal. For example, Dublin (1995) demonstrated that the elephant shifts from a grass diet during the wet season to a woody species diet during the dry season, as the latter maintains a higher percentage of crude protein (13-17%). In contrast, the crude protein of long grasses declines from about 11% to 3% over the course of the dry season. (Mutanga and Skidmore 2003) measured the reflectance of a native grass species *Cenchrus ciliaris* grown under three nitrogen levels. They demonstrated that higher canopy nitrogen concentration in African native grass is significantly correlated with a shift of the red edge to longer wavelengths.

Recently (Mutanga and Skidmore 2004) demonstrated that grass foliar chemistry may be successfully mapped. In this case, nitrogen was predicted from hyperspectral imagery (HyMap) flown over a test area in the Kruger National Park. They further showed that a fenced area (Roan Camp), which had been treated with a burnt and an unburnt area, had a noticeable difference in foliar nitrogen concentration. The burnt area had a significantly higher foliar nitrogen content.

## **CONCLUSION**

It is demonstrated that techniques are being designed to map both resource quantity and quality. These techniques will in the future allow change in resource quantity and quality to be estimated, thereby facilitating improved estimates of total resource availability from season to season. These environmental features are known to determine the behaviour and survival of herbivore populations, as well as species richness. Such results may be combined using spatial-temporal models in a GIS to better understand the resources available to large herbivores, the response of large mammals to these resources, and to assist in the management of herbivores.

## BIBLIOGRAPHY

- Abers, J. D. and C. A. Federer, 1992. A generalized linked parameter model of photosynthesis, evapotranspiration and net primary production in temperate and boreal forest ecosystems. *Oecologia*, 92, pp. 463-474.
- Bernays, E. A. et al., 1989. Herbivores and plant tannins. *Advances in Ecological Research*, 19, pp. 263-302.
- Coe, M. J. (1983). Nitrogen as an ecological factor. J. A. Lee, J. McNeill and I. H. rorison. Oxford, Blackwell.
- Clevers, J. P. G. W. (1994). Imaging spectroscopy in agriculture - plant vitality and yield indicators. Imaging spectrometry - a tool for environmental observations. J. Hill and J. Megier. Dordrecht, Kluwer
- Curran, P. J. et al., 2001. Estimating the foliar biochemical concentration of leaves with reflectance spectrometry. Testing the Kokaly and Clark methodologies. *Remote Sensing of Environment*, 76, pp. 349-359.
- Curran, P. J., 1992. Reflectance spectroscopy of fresh whole leaves for the estimation of chemical concentration. *Remote Sensing of Environment*, 39, pp. 153-166.
- Drent, R.H., & Prins, H.H.T. (1987). The herbivore as prisoner of its food supply. In: J.v. Andel, J. Bakker & R.W. Snaydon (Editors), *Disturbance in grasslands; species and population responses*. Dr. W. Junk Publishing Company, Dordrecht, pp. 133 - 149.
- East, R. (1984). "Rainfall, nutrient status and biomass of large African savannah mammals." *African Journal of Ecology* 22: 245-270.
- Field, C. and H. A. Mooney (1986). The photosynthesis-nitrogen relationship in wild plants. On the economy of plant form and functions. T. J. Givnish. Cambridge, Cambridge University Press.
- Gong, P. et al., 2002. Analysis of in situ hyperspectral data for nutrient estimation of giant sequoia. *International Journal of Remote Sensing*, 23(9), pp. 1827-1850.
- Greene, S. W. (1935). "Relation between winter grass fires and cattle grazing in teh longleaf pine belt." *Journal of Forestry* 33: 338-341.
- Hazeltine, A. (1996). Modelling the vegetation of the Earth. Department of Ecology. Lund, Sweden, Lund University.
- Lincoln, D. E., T. S. Newton, et al. (1982). "Coevolution of the checkerspot butterfly *Euphydras Chalcedona* and its larval food plant *Diplacus Aurantiacus*: larvae response to protein and leaf resin." *Oecologia* 52: 216-223.
- Marschner, H. (1995). Mineral nutrition of higher plants 2nd ed. London, Academic Press.
- McNaughton, S.J. (1990). Mineral nutrition and seasonal movements of African migratory ungulates. *Nature*, 345, 613 - 615.
- McNaughton, S.J., & Banyikwa, F.F. (1995). Plant communities and herbivory. In: A.R.E. Sinclair & P. Arcese (Editors), *Serengeti II - dynamics, management, and conservation of an ecosystem*. Chicago Pree, Chicago, pp. 49 - 70.
- Monteith, J. L. (1972). "Solar radiation and productivity in tropical ecosystems." *Applied Ecology* 9: 747-766.
- Monteith, J. L. (1977). "Climate and efficiency of crop production in Britain." *Philosophical Transactions of the Royal Society of London B* 281: 277-297.
- Mooney, H. A. (1986). Photosynthesis. Plant ecology. M. J. Crawley. Blackwell, Oxford.
- Owen-Smith, N. and J. E. Danckwerts (1997). Herbivory. Vegetation of southern Africa. R. M. Cowling, D. M. Richardson and S. M. Pierce. Cambridge, Cambridge University Press.
- Mutanga, O. Skidmore, A.K., 2004. Integrating imaging spectroscopy and neural networks to map grass quality in Kruger National Park, South Africa. *Remote Sensing of Environment*, 90:104-115.
- Mutanga, O. and A. K. Skidmore (2004). "Narrow band vegetation indices overcome the saturation problem in biomass estimation." *International Journal of Remote Sensing* in press.

- Mutanga, O., Skidmore, A.K., van Wieren S, 2003. Discriminating tropical grass (*Cenchrus ciliaris*) canopies grown under different nitrogen treatments using spectroradiometry. *ISPRS Journal of Photogrammetry and Remote Sensing* 57:263-272.
- Prins, H.H.T. (1989). A balanced diet as a goal of grazing: the food of the Manyara buffalo. *African Journal of Ecology*, 27, 241 - 259.
- Prins, H.H.T. (1996). Ecology and behaviour of the African buffalo : social inequality and decision making. Wildlife Ecology and Behaviour Series. Chapman Hall, London, 293 pp.
- Said, M. Y., A. K. Skidmore, et al. (2004). "Declining population of wild ungulates in the Masai Mara ecosystem: a sign of resource competition." *Journal of Animal Ecology* in press.
- Schmidt, K. S. and A. K. Skidmore (2002). "Spectral discrimination of vegetation types in a coastal wetland." *Remote sensing of Environment* 85: 92-108.
- Schmidt, K. S. and A. K. Skidmore (2003). "Derivative analysis of saltmarsh vegetation reflectance spectra." *International Journal of Remote Sensing* in press.
- Sellers, P., S. O. Los, et al. (1994). "A global 1 by 1 degree NDVI data set for climate studies. Part 2: The generation of global fields of terrestrial biophysical parameters from the NDVI." *International Journal of Remote Sensing* 15(17): 3519-3545.
- Sellers, P., S. O. Los, et al. (1996). "A revised land surface parameterization (SiB2) for atmospheric GCMs. Part 2: The generation of global fields of terrestrial biophysical parameters from the NDVI." *Journal of Climate*.
- Skidmore, A. K., K. S. Schmidt, et al. (2001). Hyperspectral imagery for coastal wetland vegetation mapping. PO Box 5023, 2600 GA, Delft, BCRS - Beleids Commissie Remote Sensing.
- Tucker, C. J. (1977). "Asymptotic nature of grass canopy spectral reflectance." *Applied Optics* 16(5): 1511-1516
- Vos, J. and M. Bom (1993). "Hand-held chlorophyll meter: a promising tool to assess the nitrogen status of potato foliage." *Potato Research* 36: 301-308.