Education & Training

Case Studies – Hyperspectral Remote Sensing of Vegetation

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Outline

- **Introduction**
- **Spectral Characteristics of Vegetation**
- **Case Studies from Literature (Methods)**
- **Case Studies from my PhD**
  - Mapping vegetation types
  - Biomass extrapolation
  - Bush encroaching species
  - Linking Traits and Spectra
  - Biodiversity

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About me

- **2005: Diploma in Botany, Soil Science and Genetics:**

  Title: *„Vegetation modelling at the southern Slopes of the High Atlas, Morocco – Application of Habitat Models in drylands"*

- **2005 – 2010 Ph.D. in Vegetation Ecology and Remote Sensing**

  Title:"*Modelling patterns of vascular plant diversity in central Namibian savannah ecosystems using hyperspectral remote sensing*

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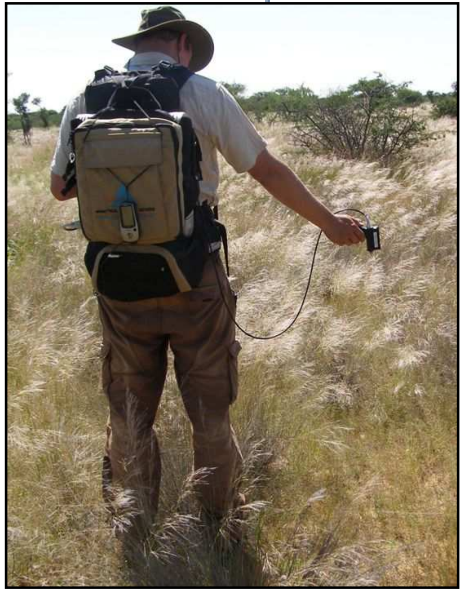
Scales of remote sensing in my PhD

ASD-FieldSpec



Spatial res.: 0.5 m
Temp.res: 1 days
Channels: 2000
Platform: Person
System: Hyper
Costs: High

HyMap

Spatial res.: 5m/3m
Temp.res: on demand
Channels: 128
Platform: Airplane
System: Hyper
Costs: High

CHRIS-Proba

Spatial res.: 32m/17m
Temp.res: on demand
Channels: 32 / 64
Platform: Satellite
System: Hyper.
Costs: Free (Science)

Company

- **June 2010: Founded**
- **EcoSystems** **Analysis|Training|Projects**

Research Interests

Research Interests

- Vegetation ecology
- Applied & theoretical biodiversity
- [Hyperspectral] Remote Sensing
- Dryland ecology
- High mountain ecology
- Spatial Pattern (Point Pattern)
- Statistics

Geographic Focus

- N-Africa (Morocco)
- SW-Africa
  - Namibia
  - South Africa
  - Angola

Spectral Characteristics of Plants

- Leaf Structure
- Leaf Pigments
- Leaf Water Content
- Dry Matter Content

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Light Effects

- 3 groups of effects of light on plants:
  - **Thermal effects** (~70% of absorbed radiation is converted into heat)
  - **Photomorphogenic effects** (i.e. regulation of plant growth in form, size, cell structure, epidermis thickness etc., ~2% of absorbed radiation)
  - **Photosynthetic effects**: photosynthetically active radiation (PAR, ~28% of absorbed radiation),
    $6\ CO_2 + 6\ H_2O \xrightarrow{PAR} C_6H_{12}O_6 + 6\ O_2$
    - depends on species, leaf thickness, leaf structure, chlorophyll & carotenois content, dry matter content, leaf surface (waxes, leaf hairs…)

Spectral Characteristics

Energy balance relationship:

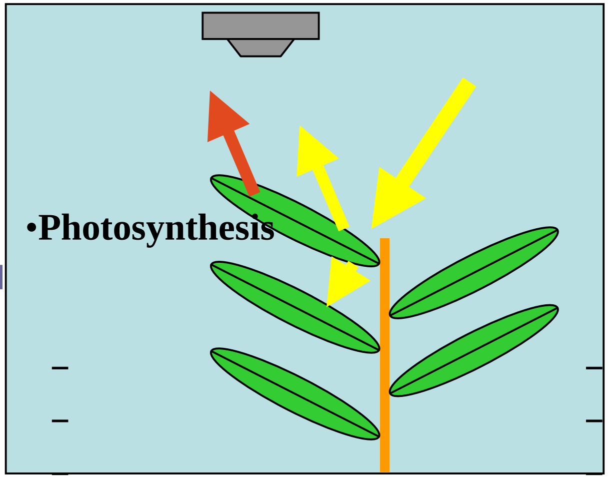
- $E_{\text{emitted by sun}} = E_{\text{reflected}} + E_{\text{transmitted}} + E_{\text{absorbed}}$

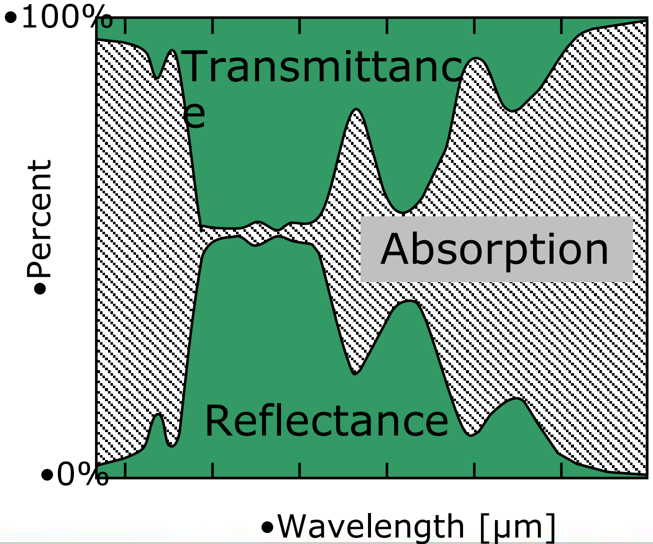
  E... Incident Energy [W]

- $1 = E_r / E_i + E_t / E_i + E_a / E_i$
- $1 = R + T + A$

  ...Reflection-coefficient + Transmission-coefficient + Absorption-coefficient

⇒ **Material property, independent of incoming radiant energy!**



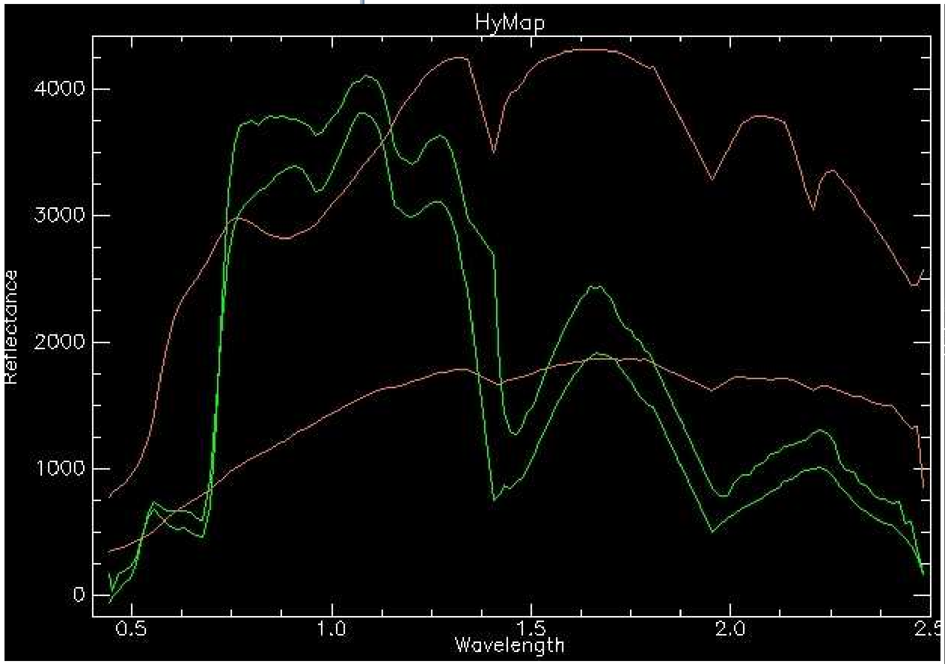


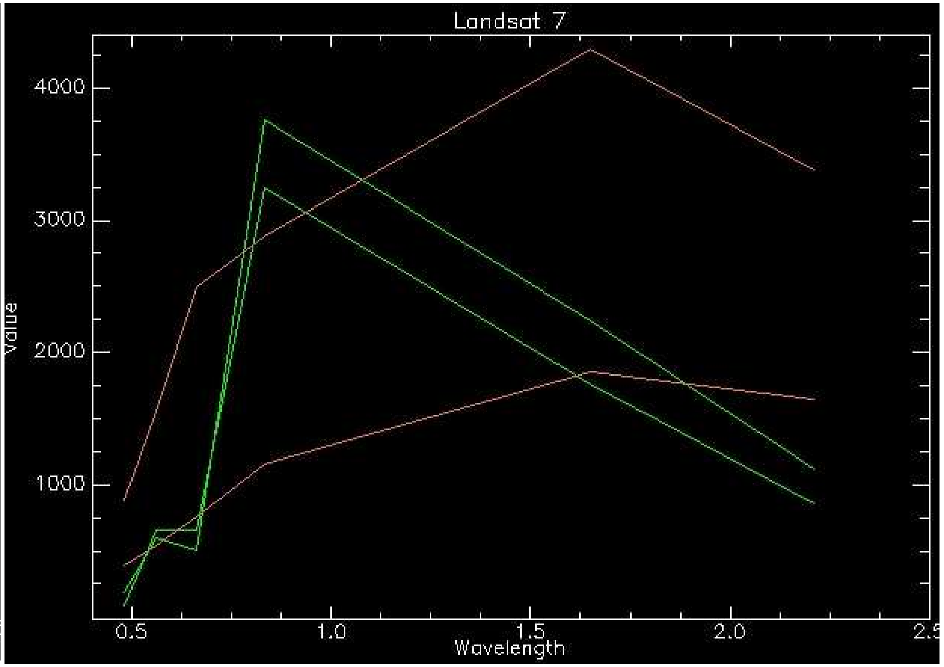
•Source: M.Bachmann (DLR)

Typical Spectra

Hymap Resolution

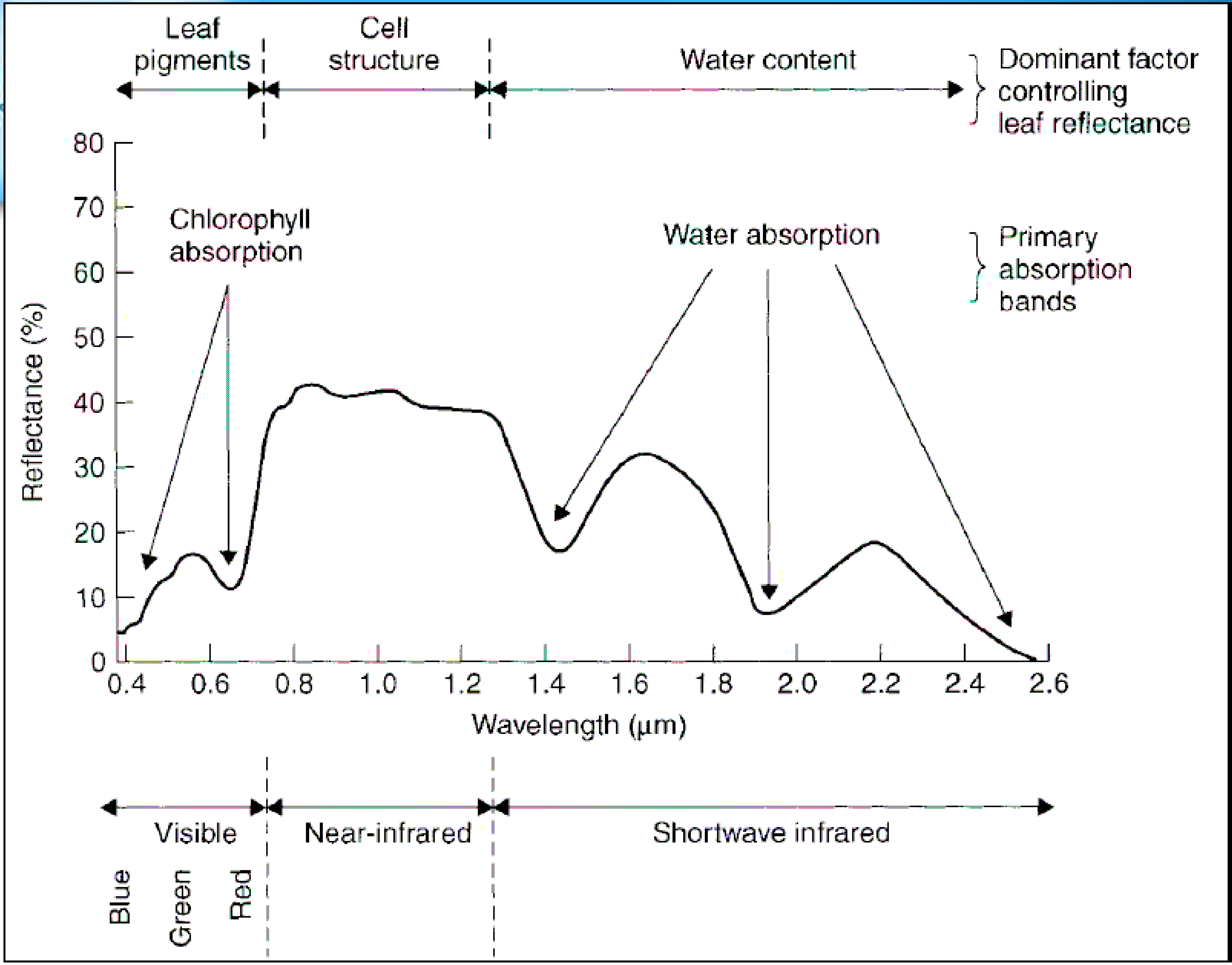
Landsat Resolution





- **Green: Vegetation**
- **Brown: Soil**

- Source: M.Bachmann (DLR)



Liang, S. (2004). *Quantitative Remote Sensing of Land Surfaces*. Hoboken, New Jersey: Wiley

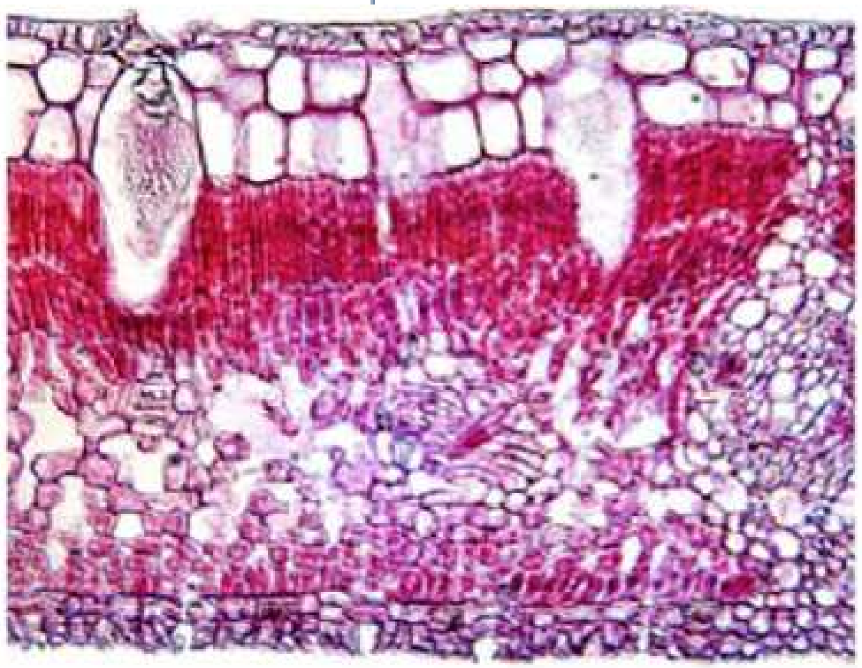
Absorption features of plants – some examples:

- 0.28 μm intense Lignin feature, thus extending through the VIS
- Chlorophyll a: 0.420 / 0.490 / 0.660 μm
- Chlorophyll b: 0.435 / 0.643 μm
- α-Carotene: 0.420, 0.440 0.470 μm
- β-Carotene: 0.425 0.450 0.480 μm
- Xanthophyll 0.425, 0.450, 0.475 μm
- 0.91 μm protein
- 0.93 μm oil
- 0.97 μm WATER, starch
- 0.99 μm starch
- 1.02 μm protein, n
- 1.04 μm oil
- 1.73 μm wax
- 1.98 μm protein, NITROGEN
- 2.00 μm starch
- 2.06 μm NITROGEN, protein
- 2.08 μm sugar, starch
- 2.10 μm STARCH, cellulose, holocellulose
- 2.13 μm protein, n, tannin
- 2.18 μm protein, NITROGEN
- 2.24 μm protein, n
- 2.25 μm starch
- 2.26 μm lignin
- 2.27 μm cellulose, sugar, starch, lignin
- 2.28 μm starch, cellulose, holocellulose
- 2.30 μm protein, n
- 2.31 μm OIL
- 2.34 μm cellulose, holocellulose
- 2.35 μm cellulose, protein, n
- 2.38 μm LIGNIN

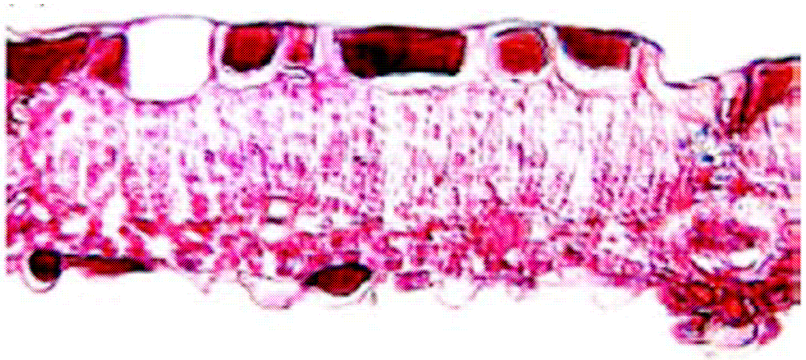
- Chlorophyll: electron transition
- > 0.9 mainly caused by C-H, O-H, N-H stretches & overtones

- Source: M.Bachmann (DLR)

Example leaves: Trees and Lianas

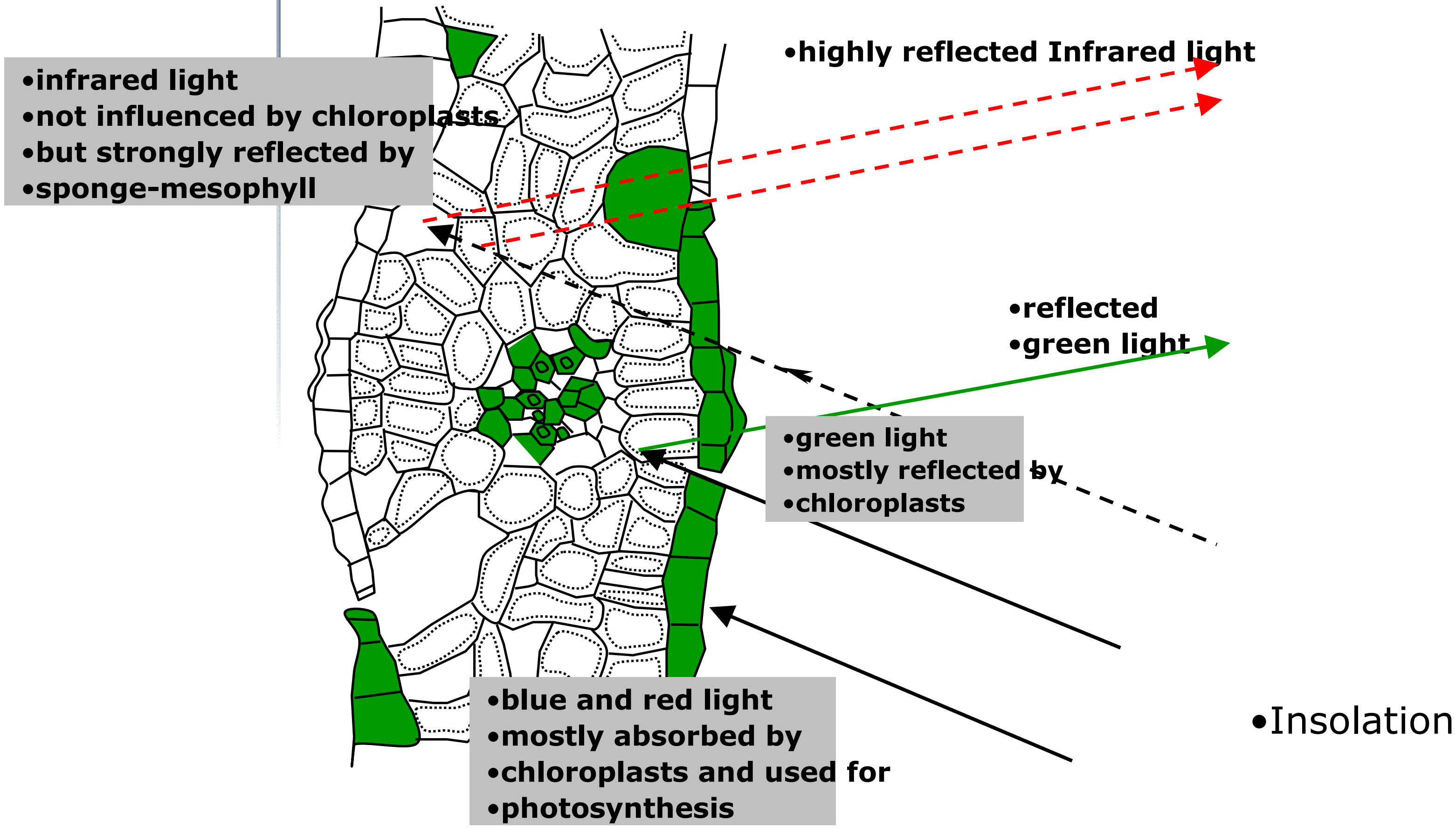


Ficus insipida



Passiflora vitifolia

Leaf cell structure



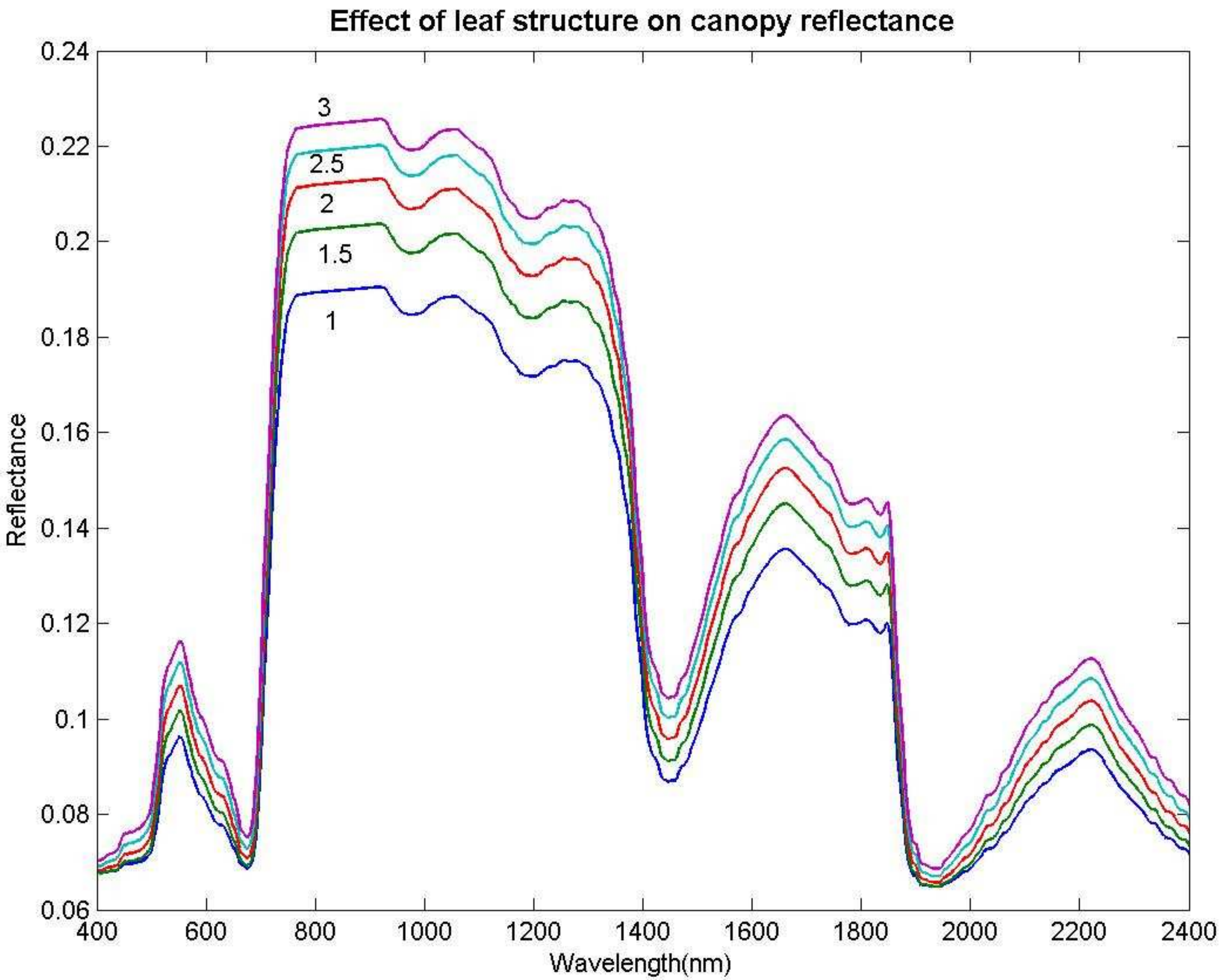
•Source: M.Bachmann (DLR)

•Colwell 1963

Effects of leaf structure

Parameters:

- Leaf Mass
- Leaf Thickness
- Leaf Area
- …



- Source: M.Bachmann (DLR)

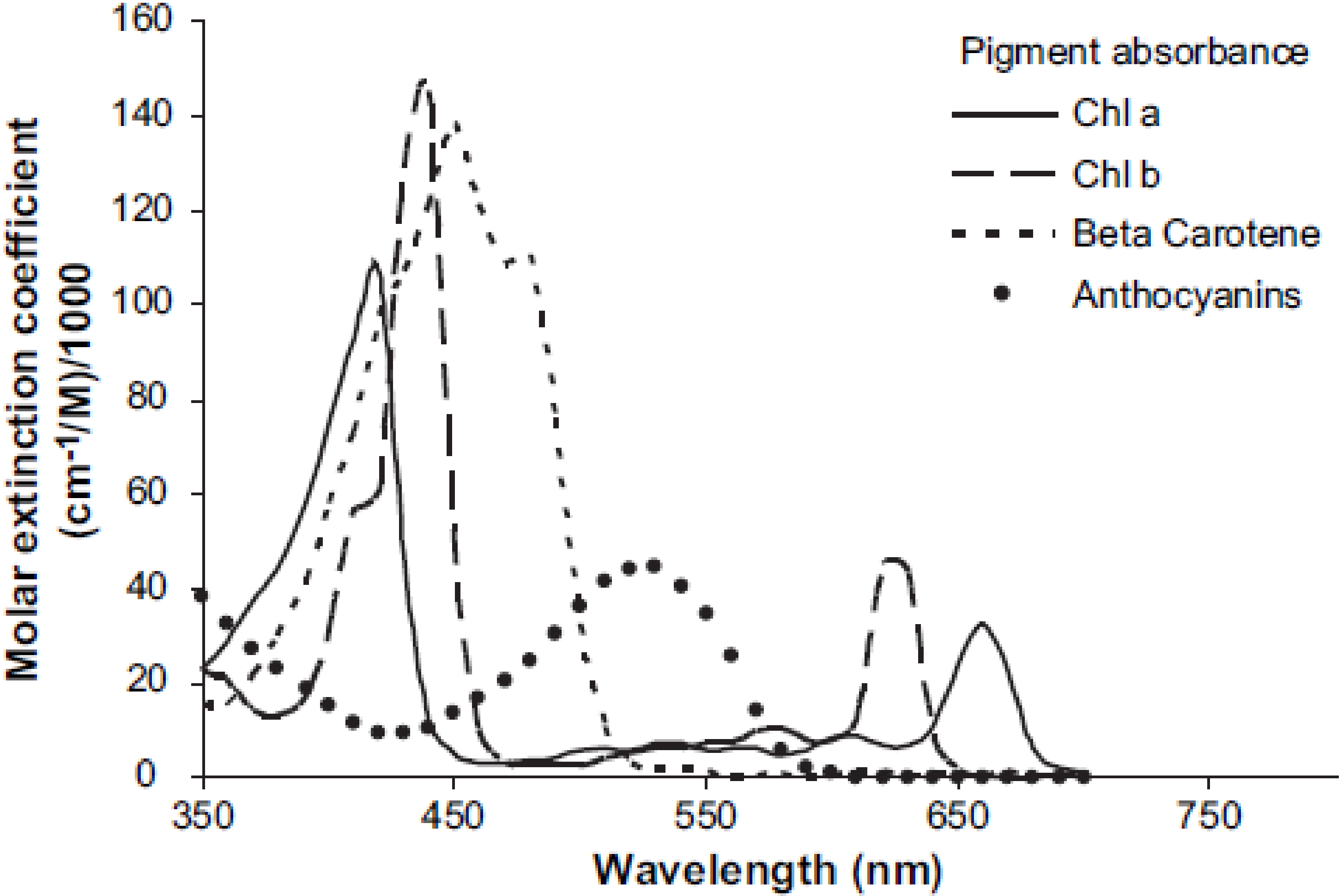
Three major plant pigments

Chlorophyll a + b:
Photosynthesis
→Primary Production
→Health

Anthocyanins:
Photoprotection

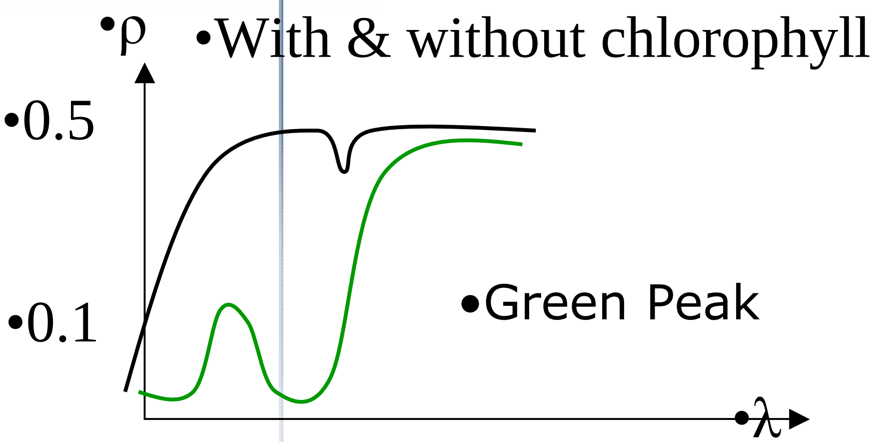
Carotenoids:
Light Use Efficency
(amount of carbon fixed per unit radiation intercepted)

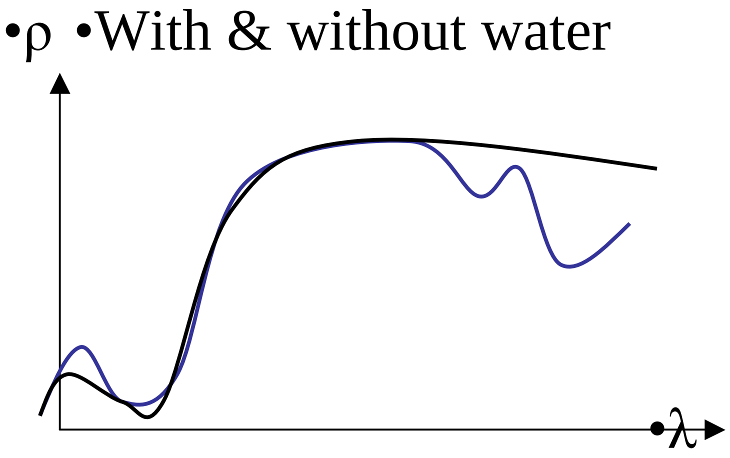
Absorption spectra of plant pigments

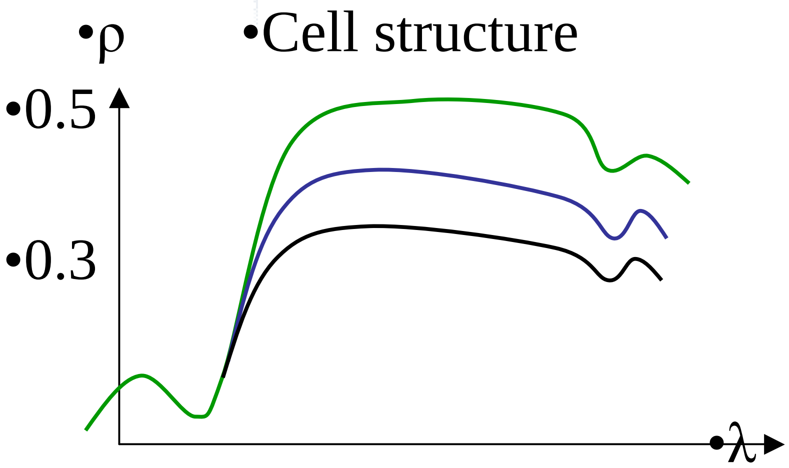


Blackburn, G.A. (2007). Hyperspectral remote sensing of plant pigments. *Journal of Experimental Botany, 58*, 855-867

Chlorophyll / Water / Cells



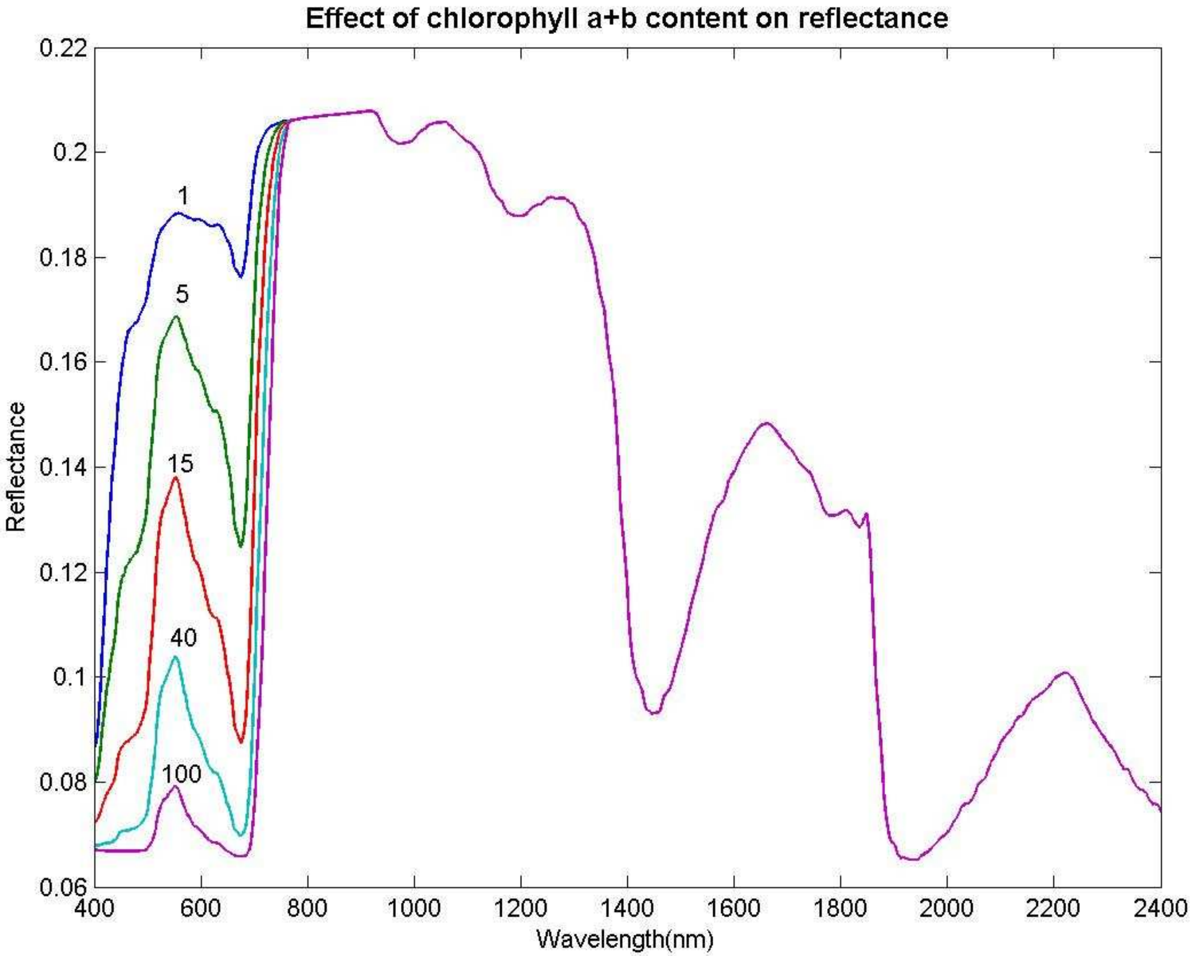




- Cell spacings filled with
- Air (drying plant)
- Water (healthy plant)
- Oil

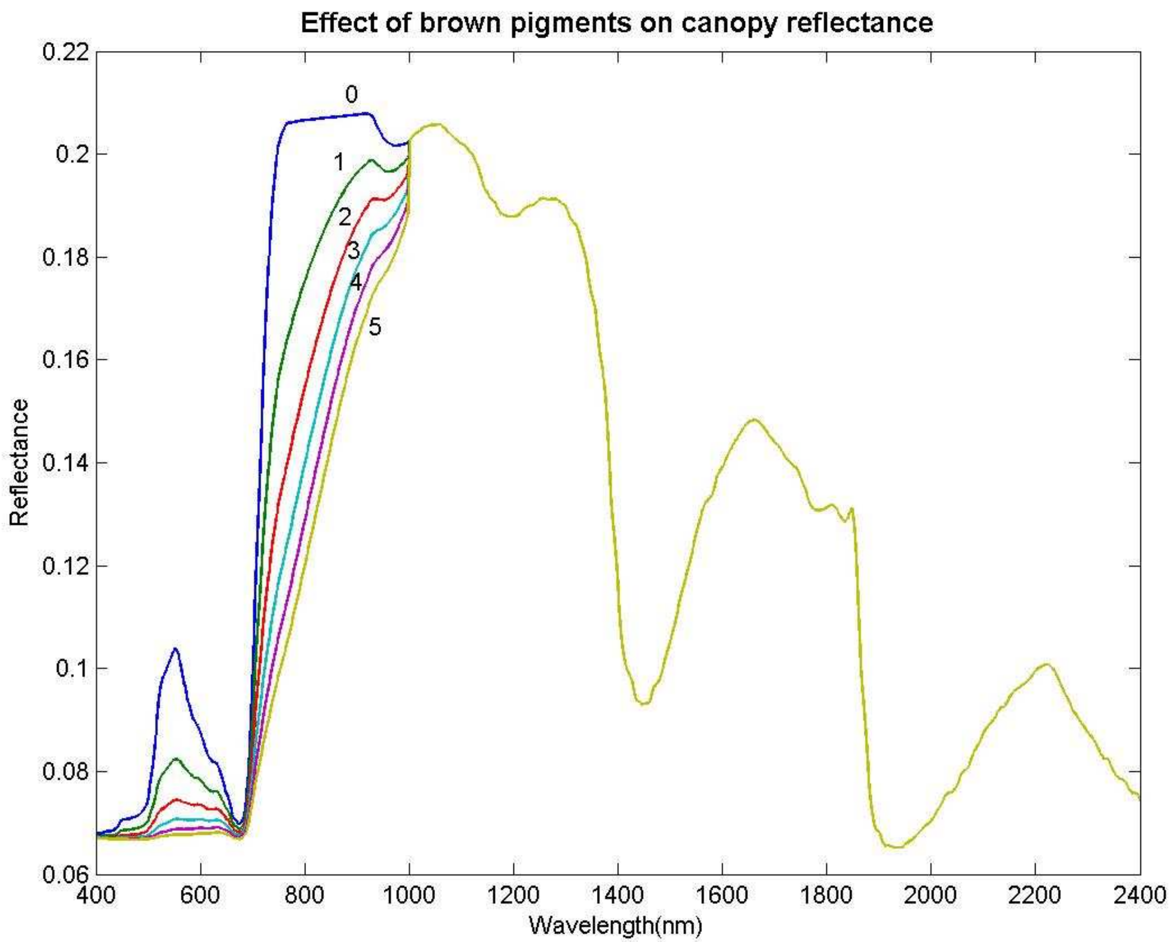
•Source: M.Bachmann (DLR)

Chlorophyll

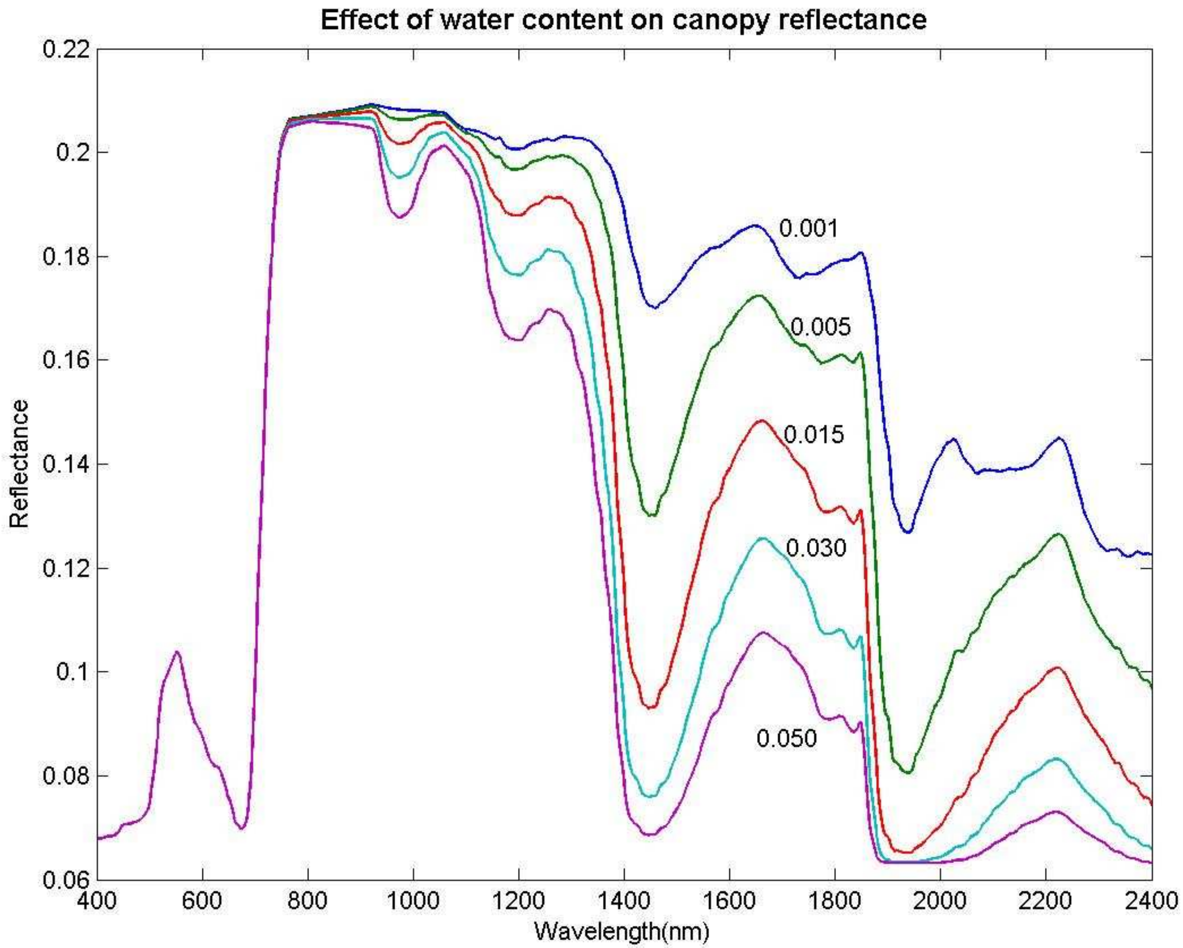


•Source: M.Bachmann (DLR)

Brown Pigments (Tannins)

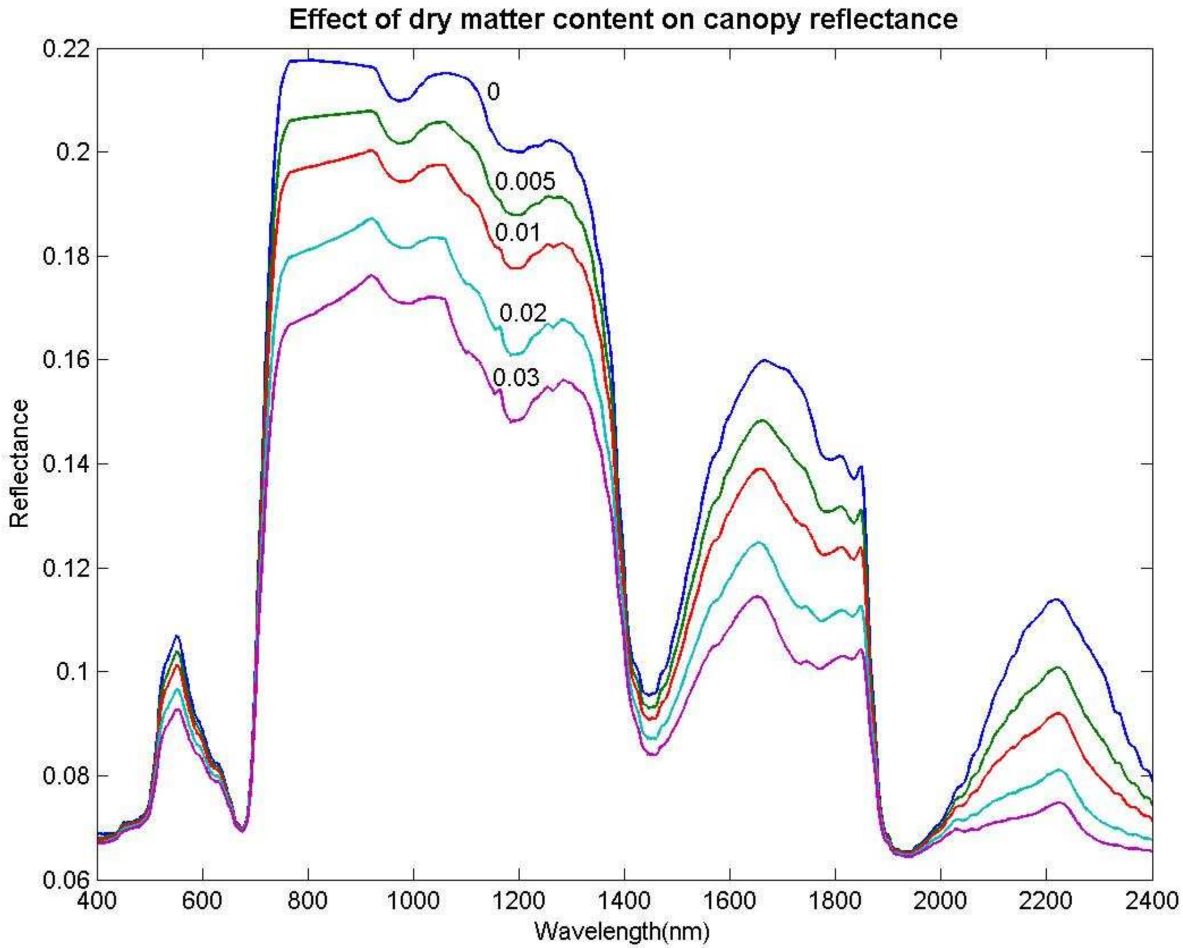


Water content



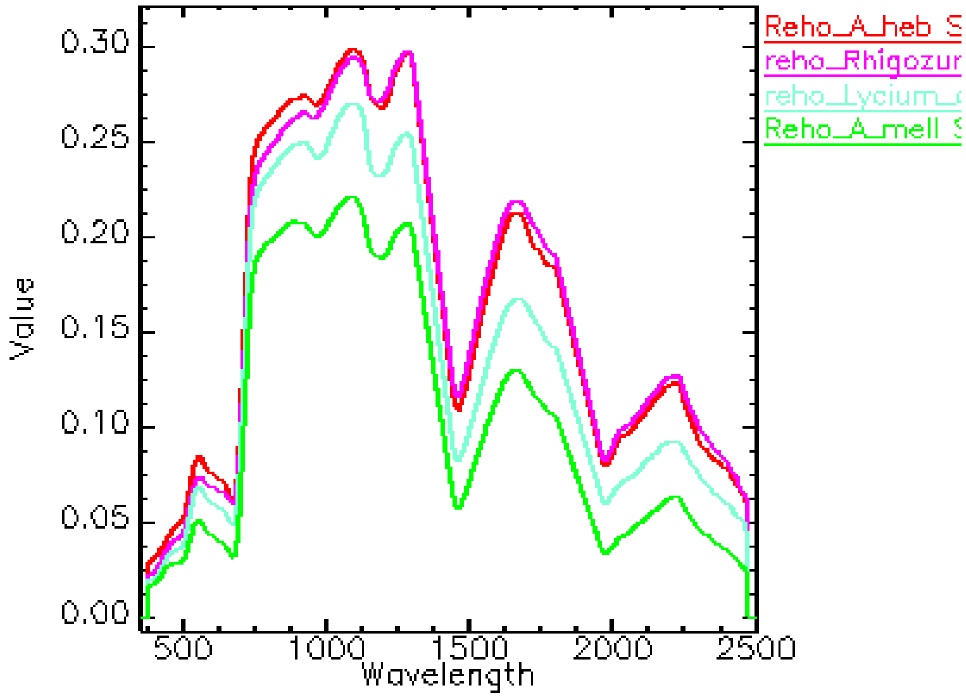
•Source: M.Bachmann (DLR)

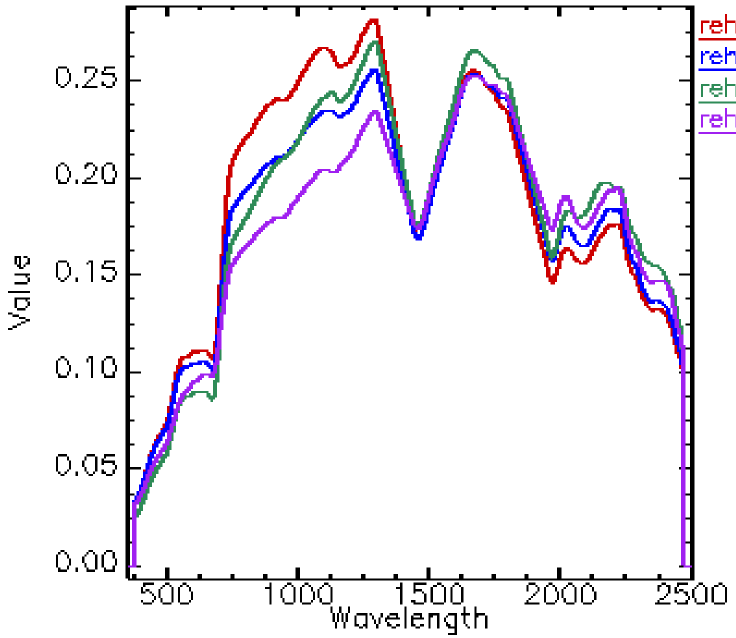
Dry matter content



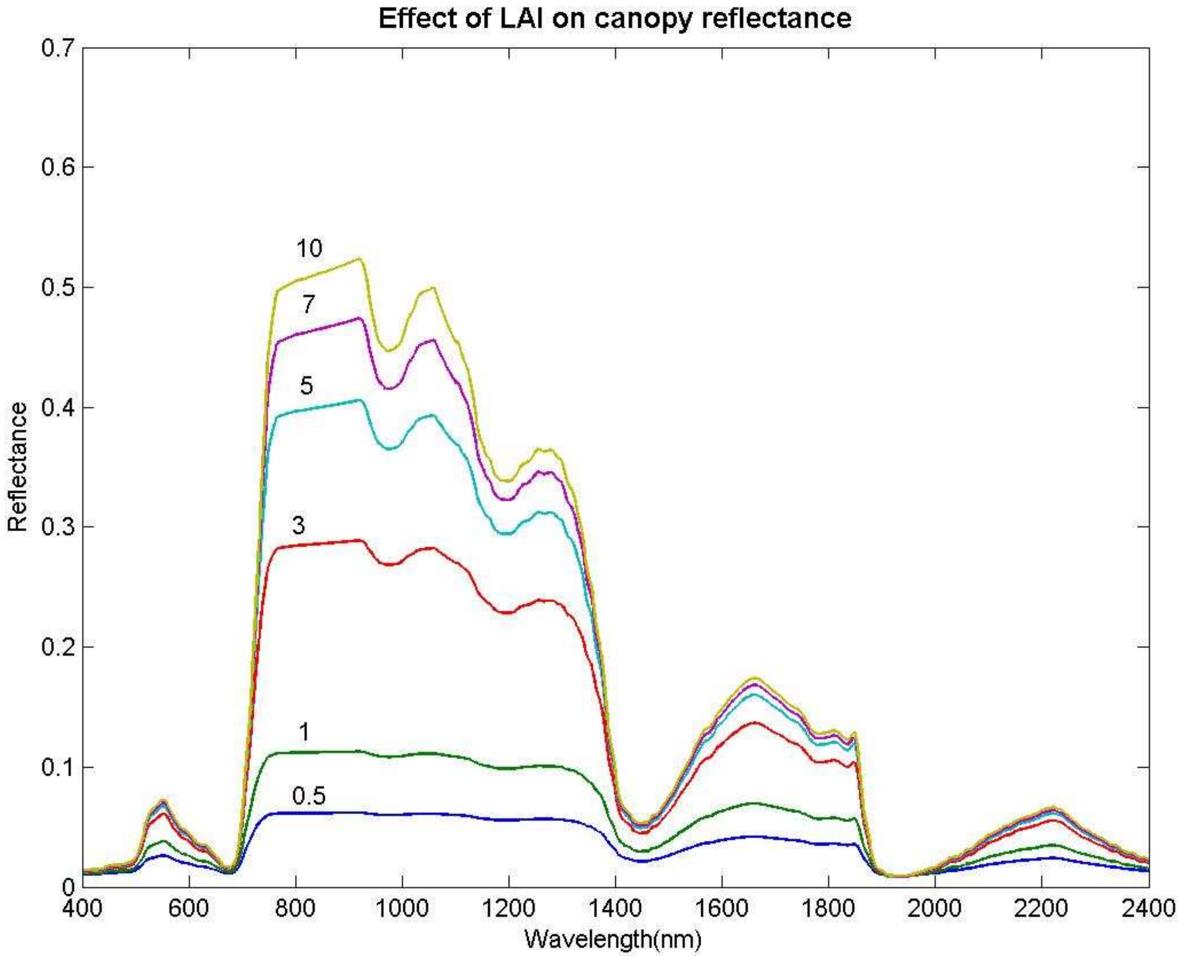
•Source: M.Bachmann (DLR)

Dry Matter: Cellulose and Lignin





Leaf Area Index



•Source: M.Bachmann (DLR)

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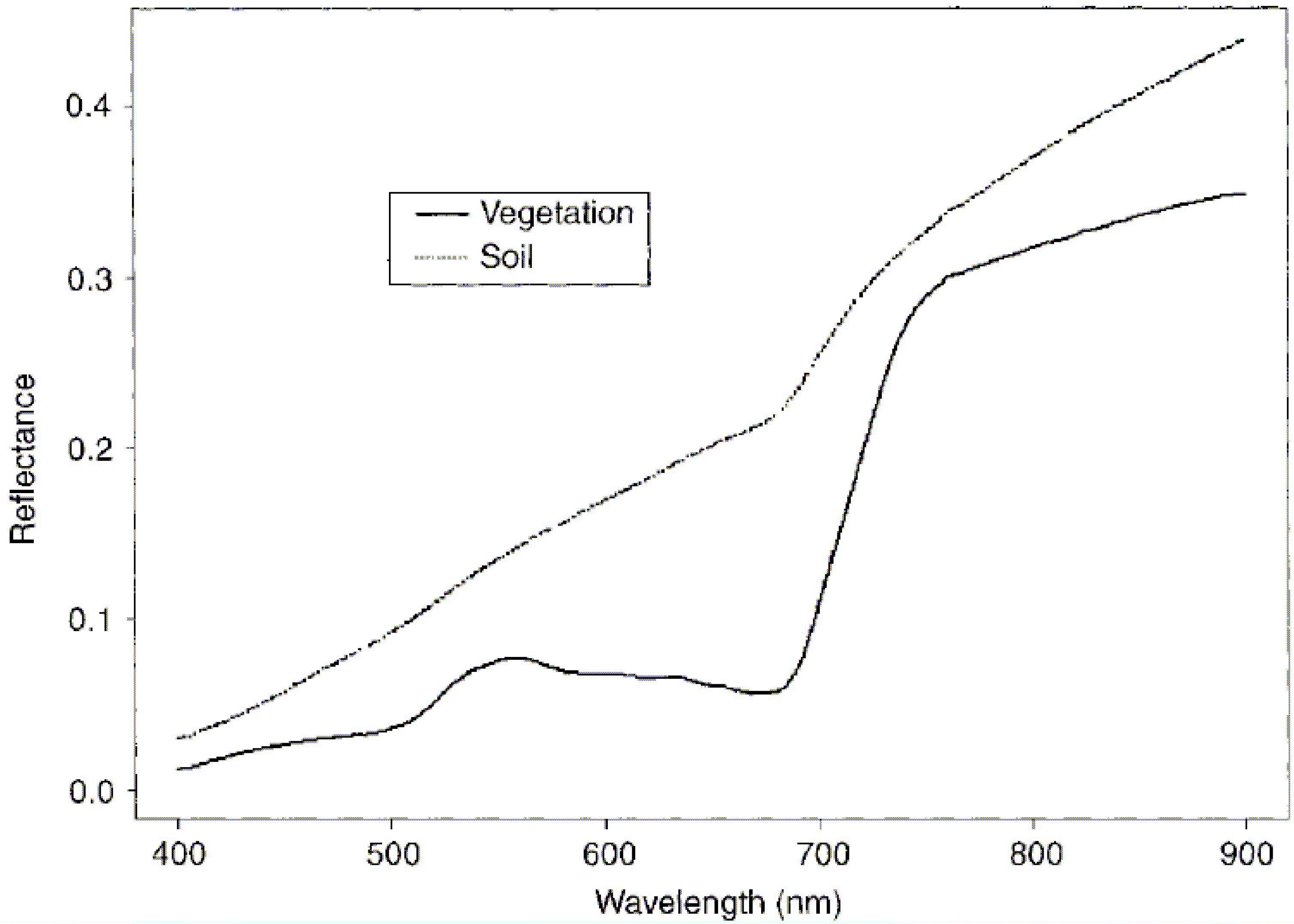
Senescense

- Chlorophyll less stable than carotenes & xanthophylls ➔ yellow color
- Fructose, glucose, starch, protein are either withdrawn by the plant or consumed by microbiotic activity
- Most stable: tannins ➔ brown color

- Plant water decreases, no masking of features above ~1.1 μm
  ➔ biochemical features are now visible

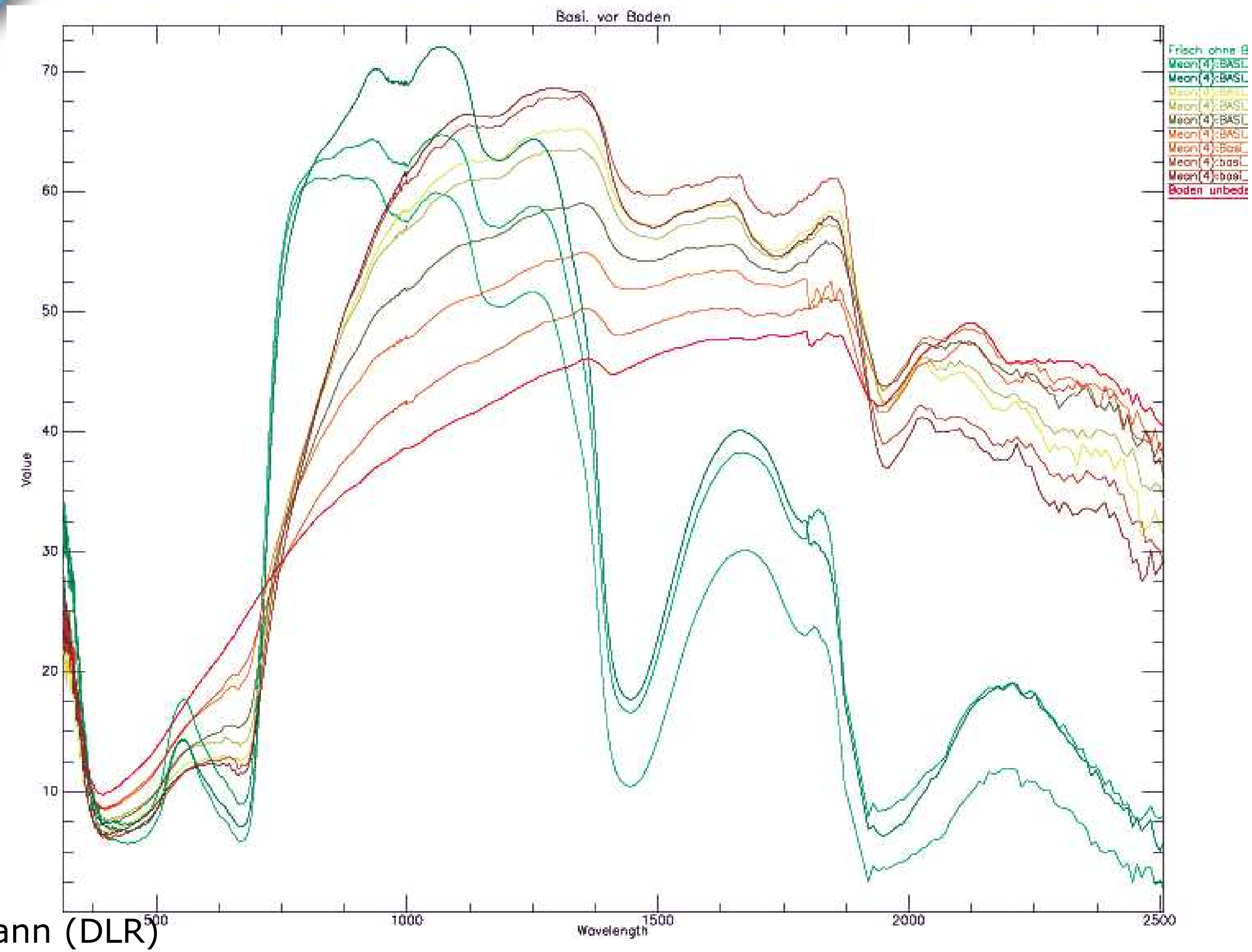
- Holocellulose and Lignin(10-35% of dry weigth): stable, main components of plant litter
- Also: cellulose (main component, but mostly mixed with lignin, cellulose or xylan), waxes, terpenes, polysaccharide

Vegetation vs. Soil



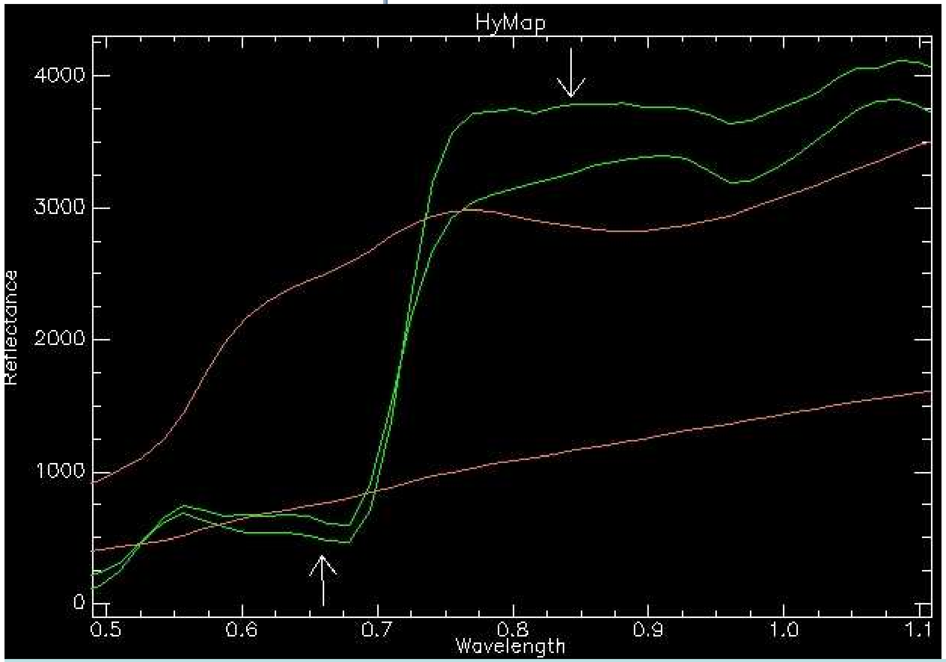
Comparison: Leaf development vs. Soil

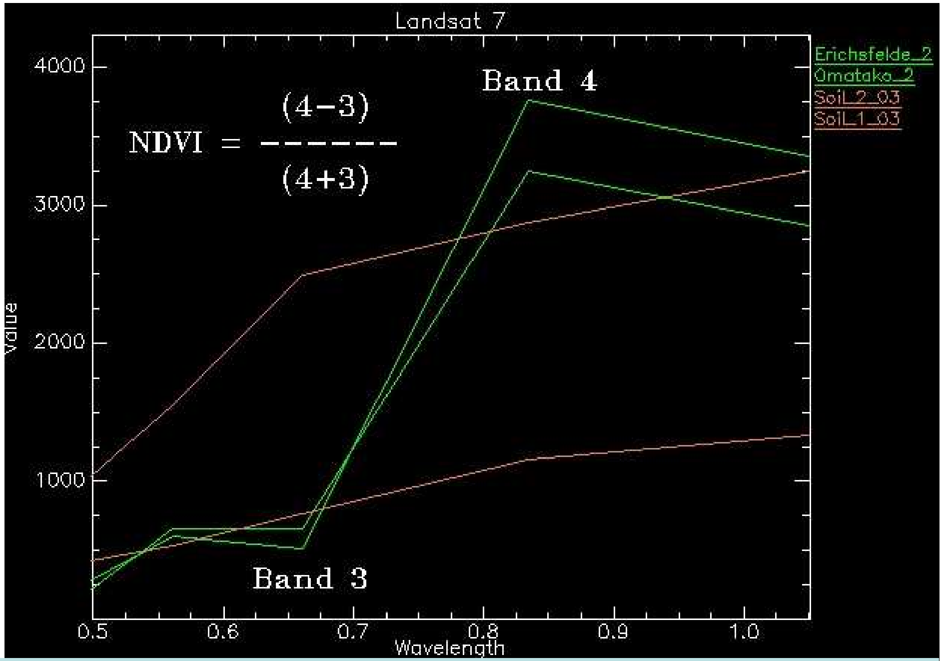
- Senescence of leaves + soil background



- Source: M.Bachmann (DLR)

Vegetation Indices





Normalized Difference Vegetation Index (NDVI) = (NIR – Red) / (NIR + Red)

Scaling (theoretic) from -1 till +1

Typical values:

Forest & dense vegetation	~0.8	Grassland	~0.6
Soil	~0.1 – 0.2	Urban areas	~0 – 0.2

•Source: M.Bachmann (DLR)

Pigment Indices	
NDVI, SR	"greenness" (~LAI, biomass)
mNDVI	Chlorophyll concentration
PRI	Xanthophyll cycle, LUE
SRPI	Carotenoid content
NPQI	Chlorophyll degradation
PI3, PI4	Chlorophyll fluorescence
Water Indices	
WBI, NDWI	Foliar water content
Foliar Chemistry Indices	
NDNI	Foliar nitrogen content
NDLI	Foliar lignin content
CAI	Cellulose

- … and around hundreds of other possible indices.

Spectral Indices

Structural

- Closed Canopy Cover
- Veg.Structure

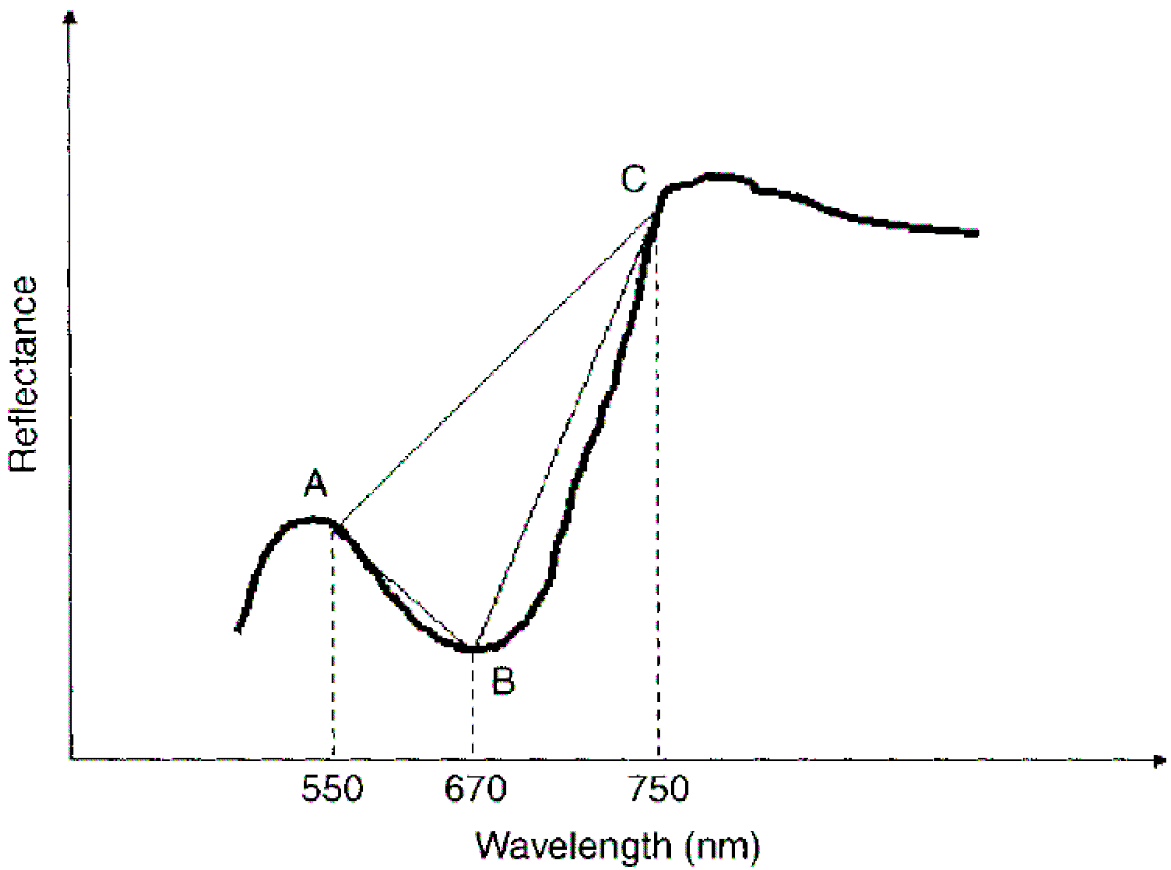
STATE - Variables

- fAPAR
- Albedo

- **Soil Indices !!**
  - Carbonate
  - Iron oxide
  - Clay content
  - Brightness
  - Colour

‚True' hyperspectral indices

Triangular Vegetation Index (TVI) Broge and Leblanc (2000)



Spectral Continuum Measures

Chlorophyll absorption continuum index (CACI)

$$\mathrm{CACI} = \sum_{\lambda_i}^{\lambda_n} \left(R_1 + i \frac{dR}{d\lambda} \Delta\lambda_i - R_i \right) \Delta\lambda_i$$

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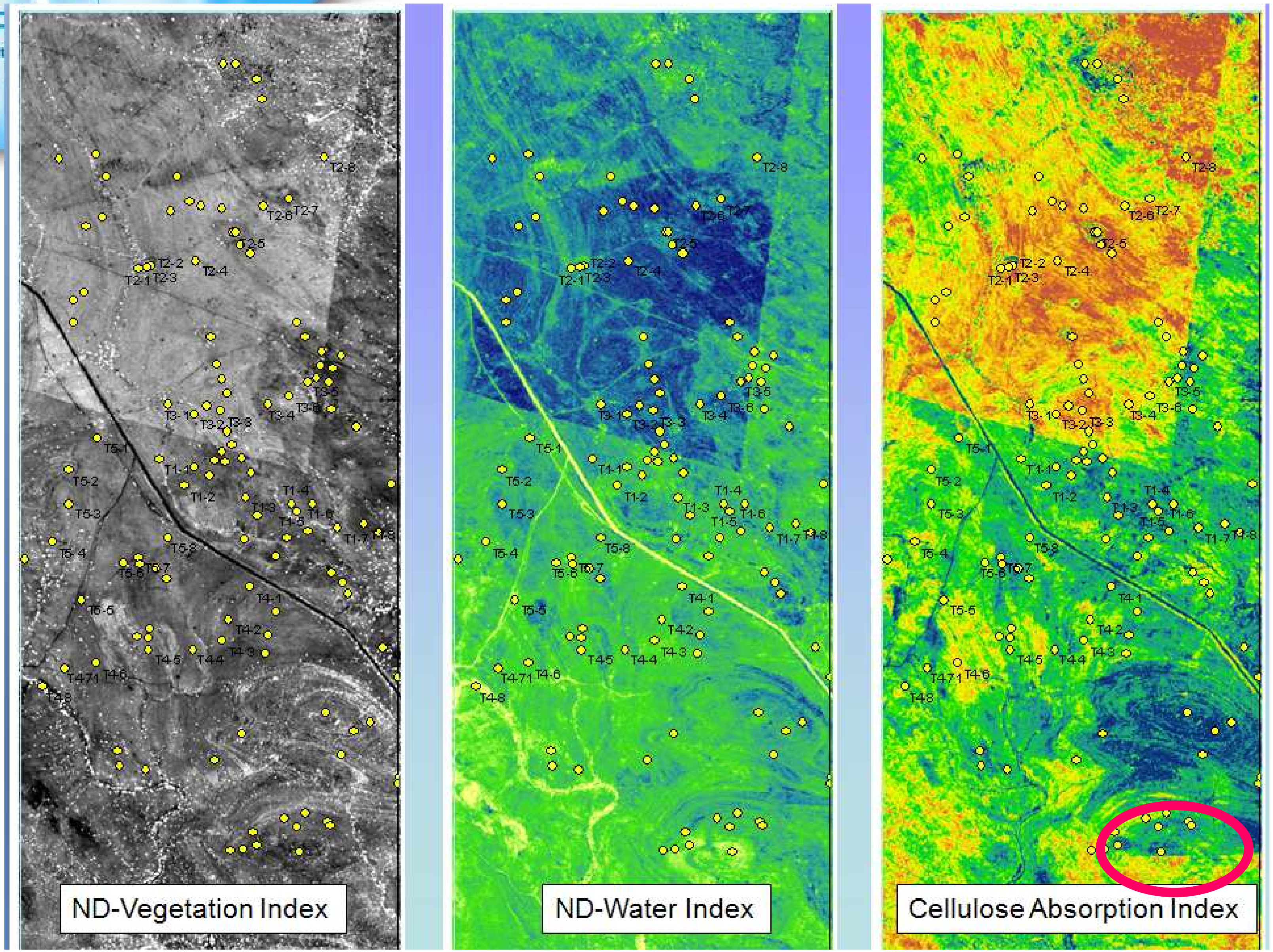
Research



Case Study I: Crop growth

METHOD: Red-Edge analysis

Patel, N.K., Patnaik, C., Dutta, S., Shekh, A.M., & Dave, A.J. (2001). Study of crop growth parameters using Airborne Imaging Spectrometer data. *International Journal of Remote Sensing, 22*, 2401 - 2411

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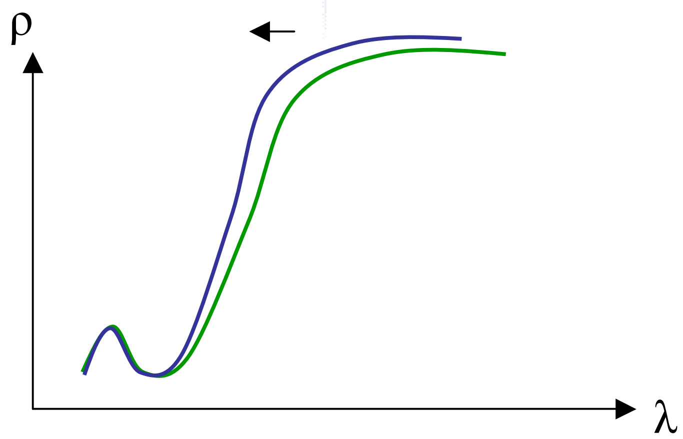
Background

- Wheat plots at different growth Stages
- Biomass, LAI, Chlorophyll content
- Can growth parameter of wheat be detected by hyperspectral RS?
- Groundtruth using FieldSpectrometer
- Sensor: AIS (Spat.Resolution: 15m)

Red Edge Inflection Point (REIP)

- **Red Edge:**
  > Chlorophyll => shift to longer wavelength
  < Chlorophyll (Stress) => Blueshift
- **But: > LAI => also shift to longer wavelength (saturation at LAI ~4)**
- **„Sharpness" of Edge**



•Source: M.Bachmann (DLR)

RedEdge – Parameterization:

REIP = f (LAI, chlorophyll, leaf inclination angle)
➔ independent from soil reflectance, only minor impact of solar zenith angle

- Inflexion Point (Wendepunkt)
- Ratios:
  $R_i = (670 + 780) / 2$
  REIP = 700 + 40 * ((Ri - 700) / (740 - 700))

How to estimate REIP ?

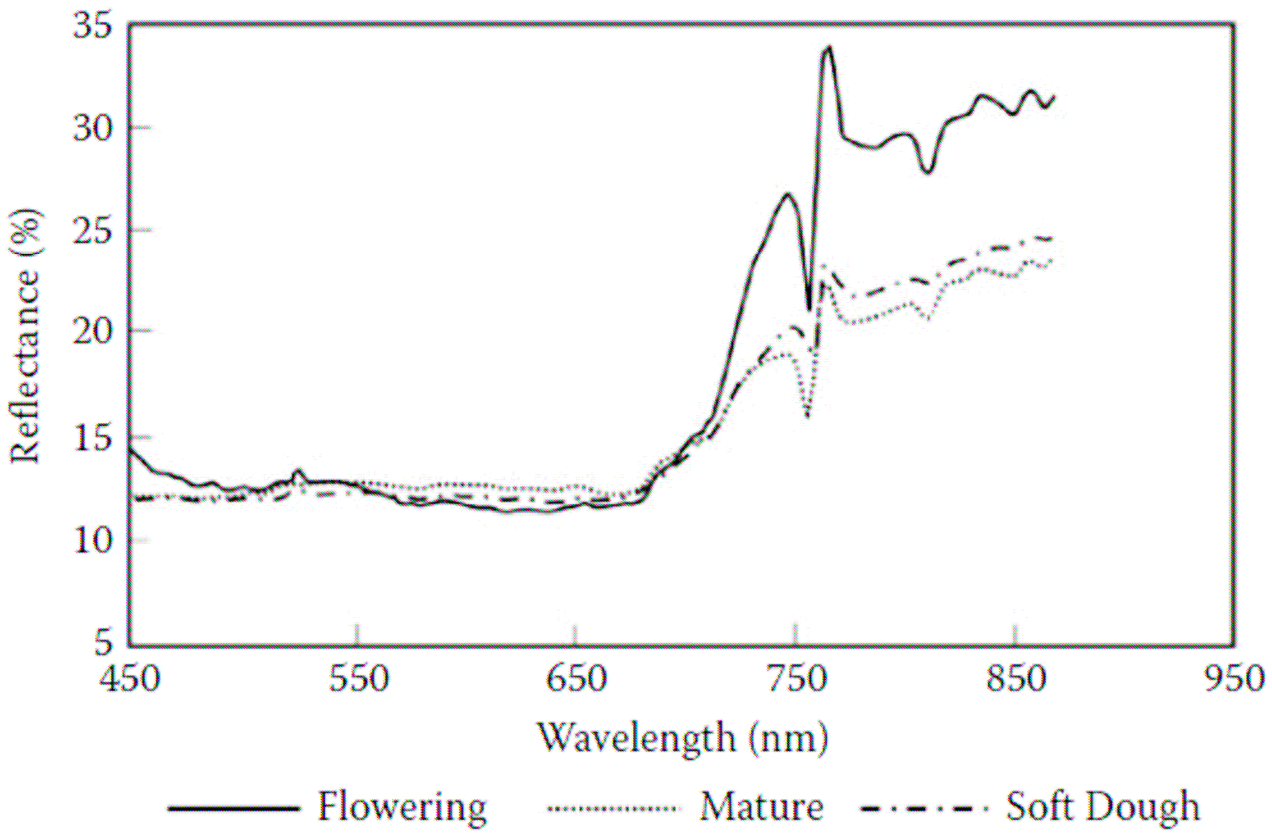
- Polynomial Function Model
- Interpolation Techniques
- Derivative Techniques
- (Inverted) Gaussian Model

In practice:
Set R0=670 and fit nonlinear regression to identify parameters

$$R(\lambda) = R_s - (R_s - R_0)e^{(\lambda - \lambda_0)^2/2\sigma^2}$$

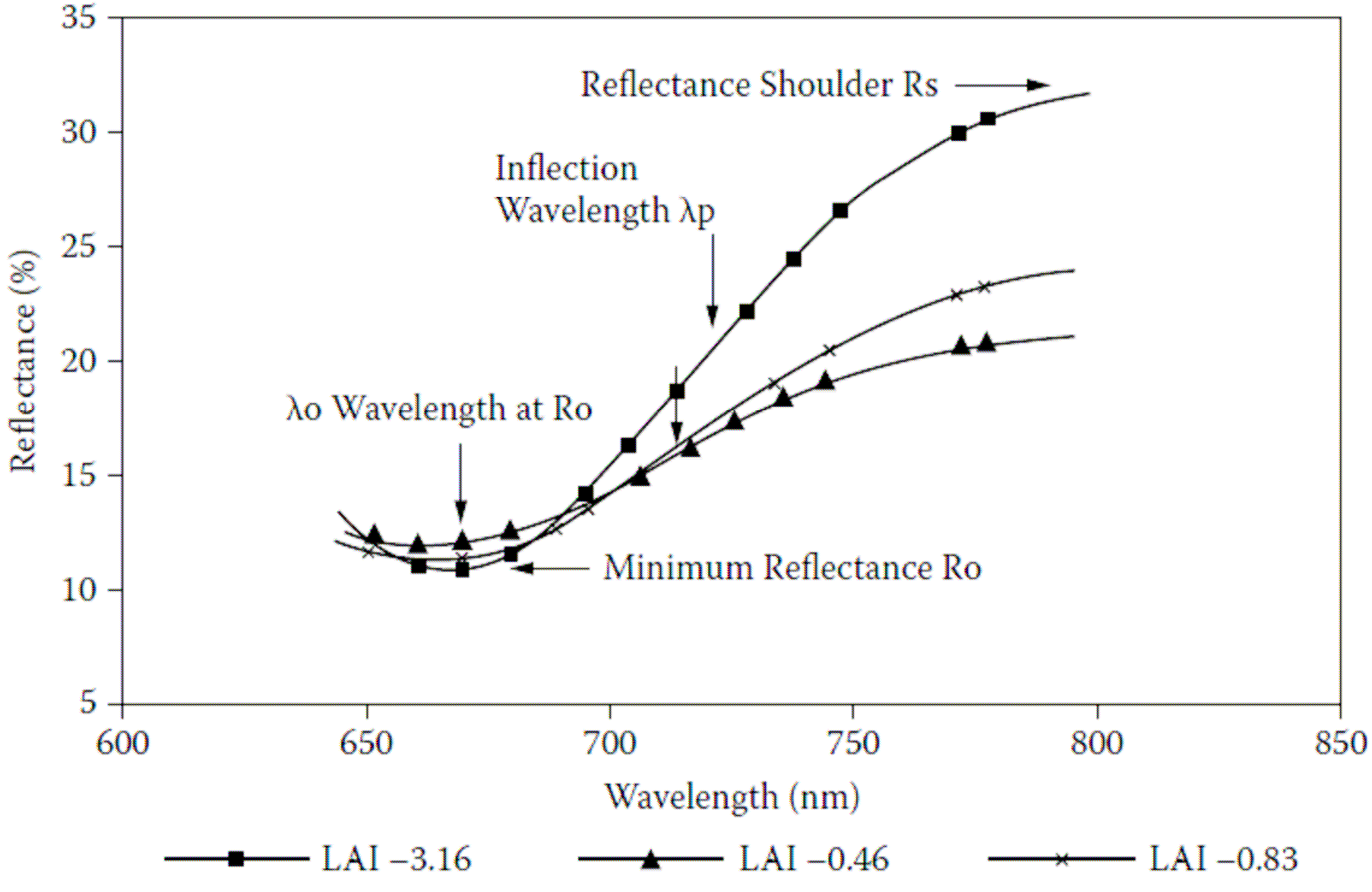
- Rs = Shoulder Reflectance of NIR-Plateau (780nm)
- R0 = Minimum Reflectance of Chlorophyll Trough (670nm)
- Lambda-0 = wavelength of R0
- Sigma = Gaussian Shape Parameter

Red Edge Example



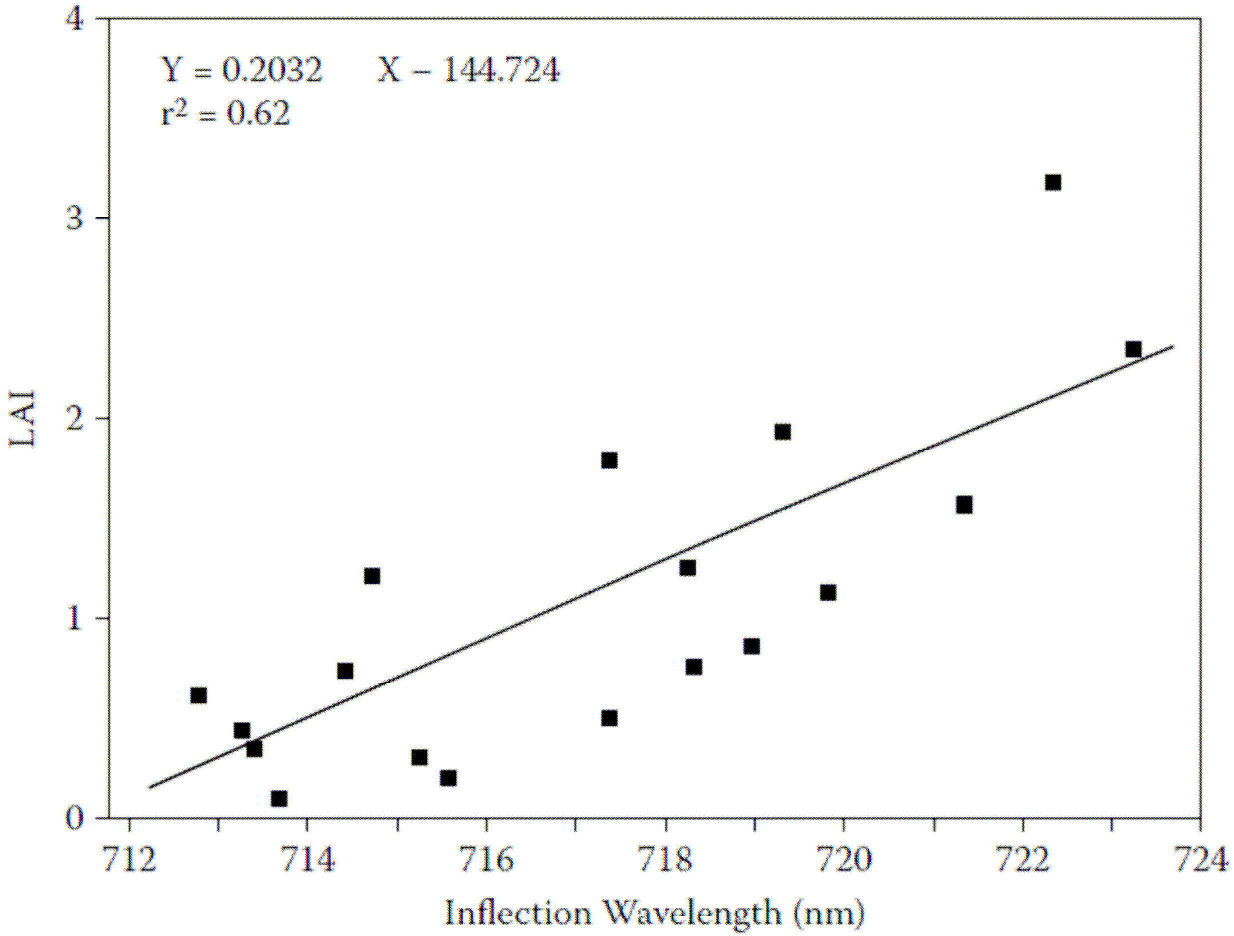
Spectral reflectance of wheat at different growth stages. (Patel et al., 2001.)

Shifting red edge



;ure 7.5 Inverted Gaussian fit of wheat spectra. (Patel et al., 2001.)

Relationship LAI vs Inflection point



5 Relationship between inflection wavelength of wheat spectra and LAI.

Case Study II: weed mapping

Environmental Management (2008) 41:853–862
DOI 10.1007/s00267-008-9092-8

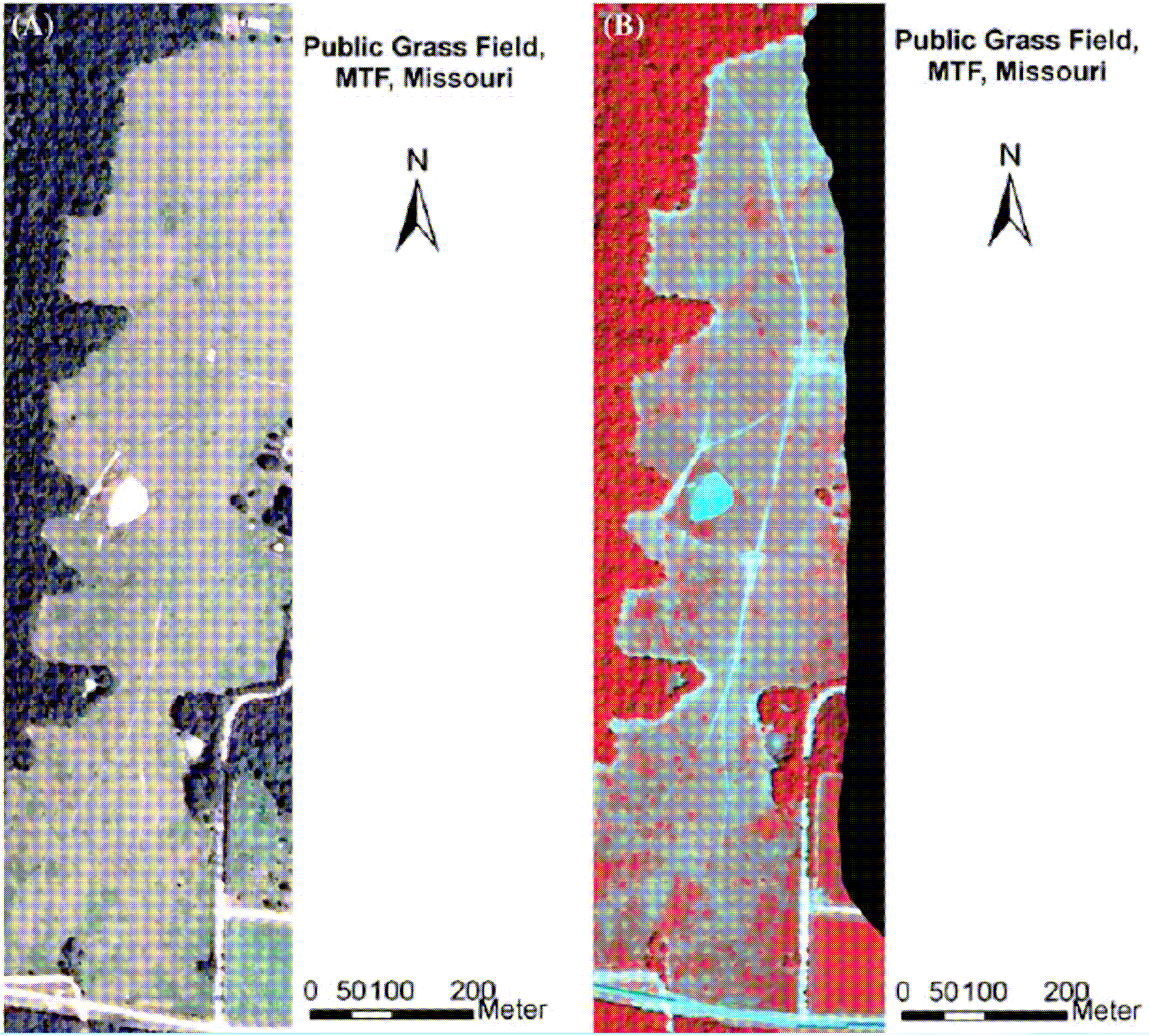
Detecting Invasive Sericea Lespedeza (*Lespedeza cuneata*) in Mid-Missouri Pastureland Using Hyperspectral Imagery

Cuizhen Wang · Bo Zhou · Harlan L. Palm

- **METHOD: Derivative Analysis**

Study Area

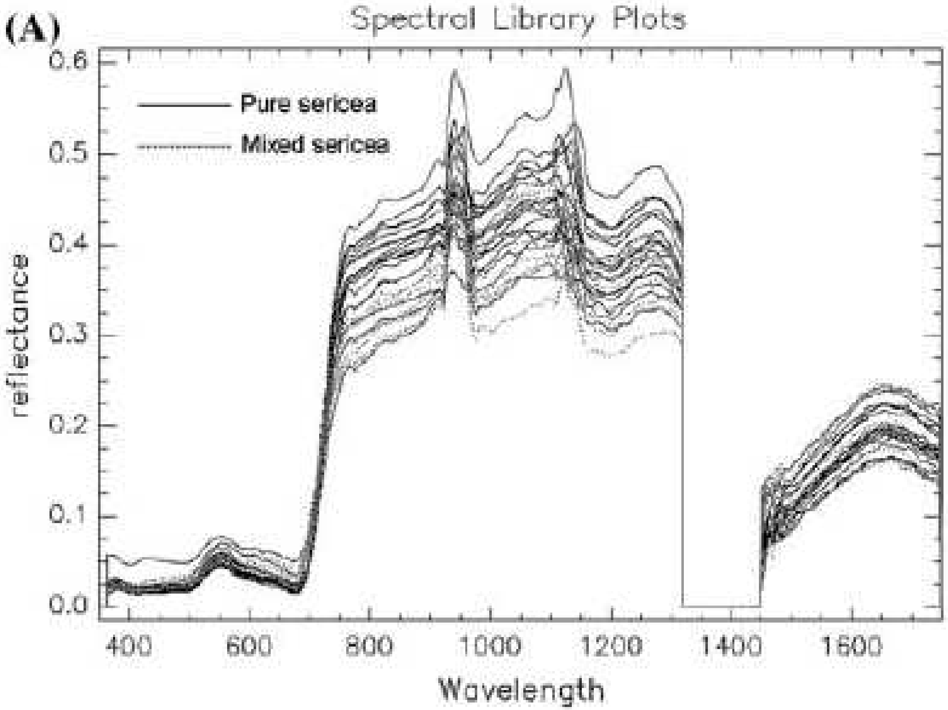
Fig. 2 The true-color NAIP aerial photo (A) and the hyperspectral AISA image (B) in false-color display (800 nm, 676 nm, 657 nm as R, G, B) in the study area

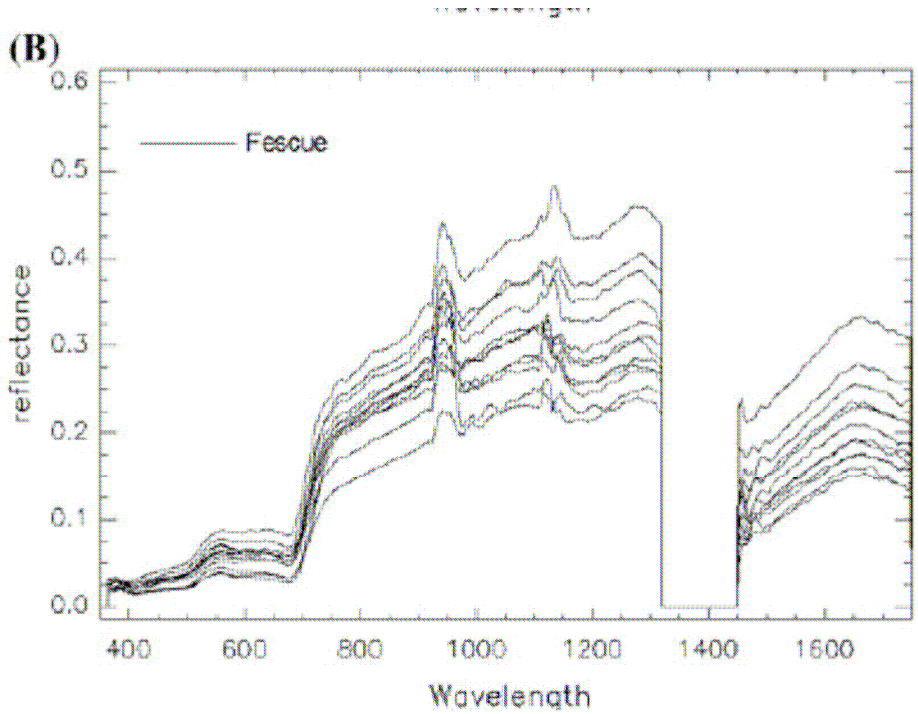


Field methods

ASD measurements of patches of pure and mixed Sericea as well as Fescue (*Festuca sp.*)
→ Spectral Library

Spectral Library





1st-order derivative

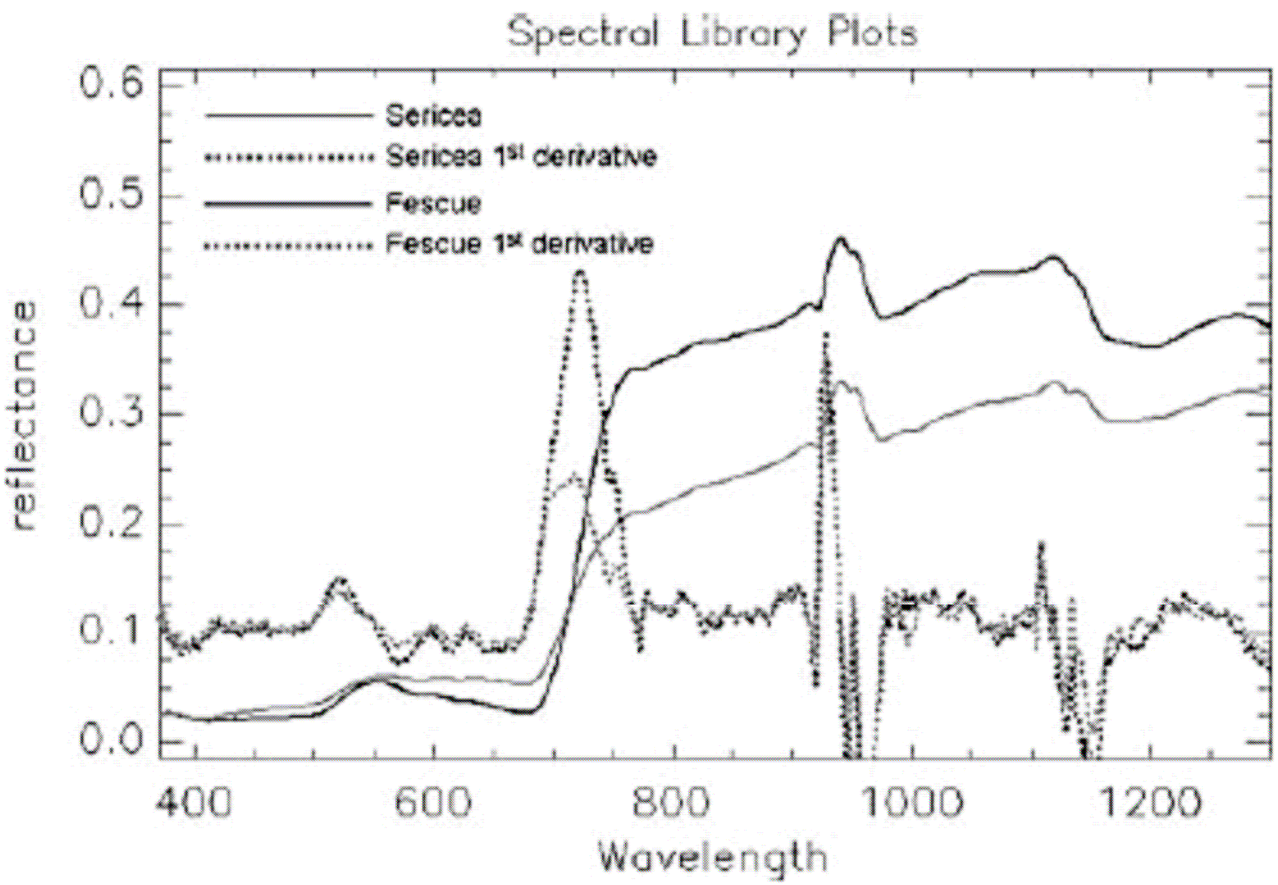


Fig. 5 Average in-situ reflectance and the 1st-order derivative curves of sericea and fescue. To match the scale of reflectance (0–1), derivatives were multiplied with a factor of 50 and offset by adding 0.1 to all values

Compare classes ! (Anova?)

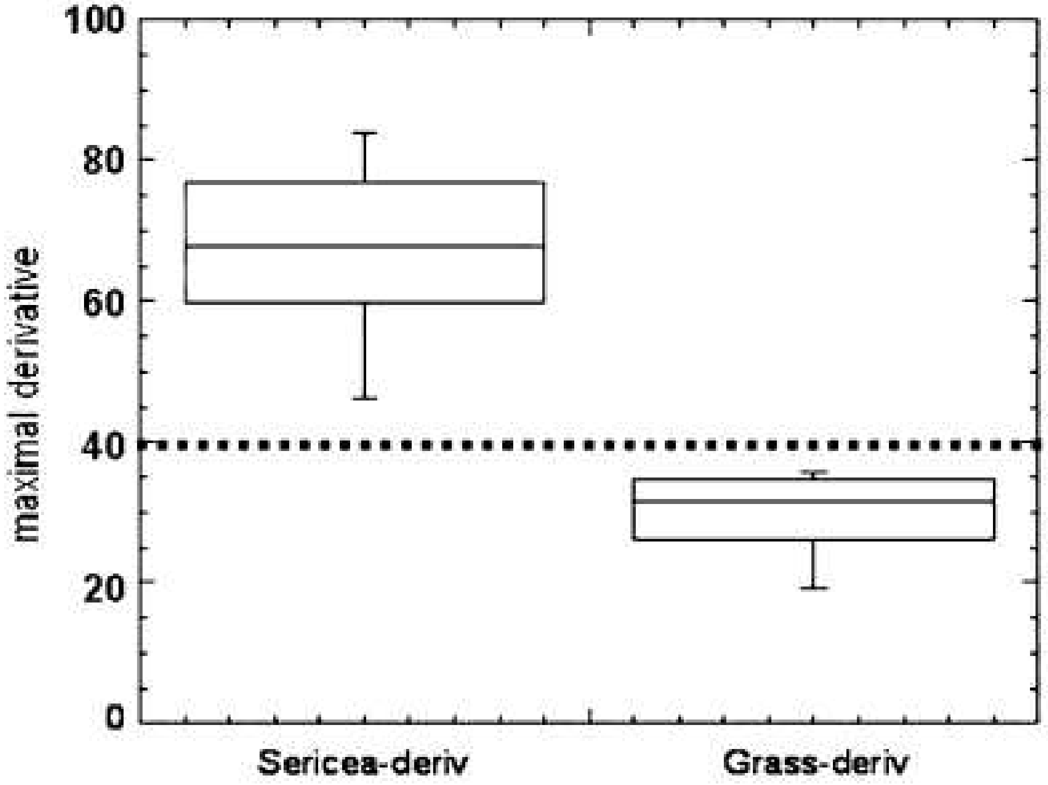
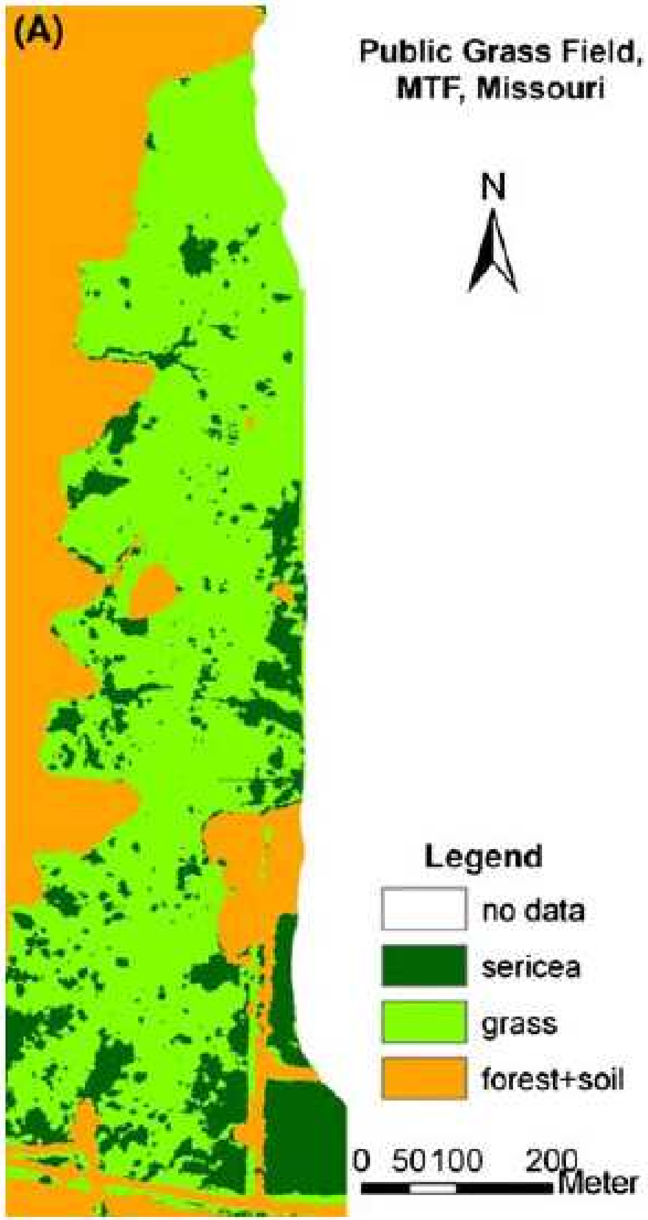


Fig. 6 The boxplots of maximal derivatives in the red-NIR region of spectra at the 27 sericea samples and 12 fescue samples. A normalization factor of 10,000 was applied to maximal derivative at each sample site

Binary Map of Sericea occurrence

Fig. 8 The binary sericea map (A) and sericea "volume" map (B) in the study area



Case Study III: Mapping Submerged Vegetation

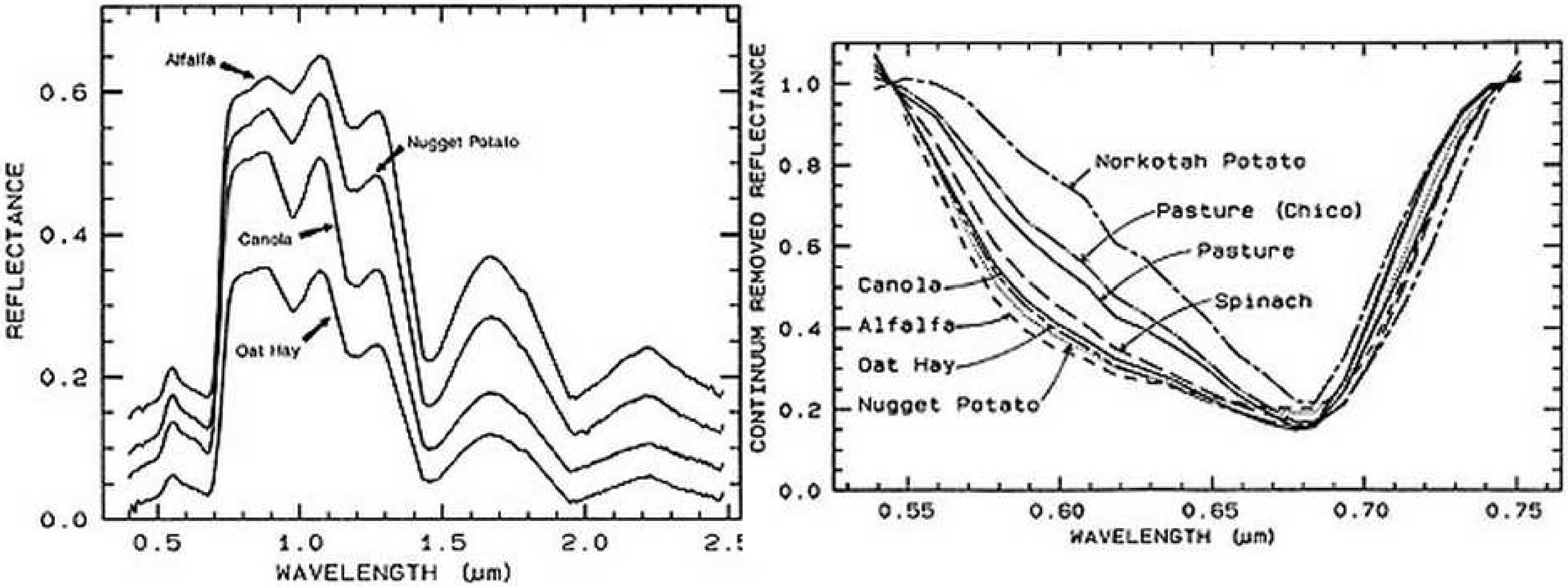
PRELIMINARY INVESTIGATION OF SUBMERGED AQUATIC VEGETATION MAPPING USING HYPERSPECTRAL REMOTE SENSING

DAVID J. WILLIAMS[1*], NANCY B. RYBICKI[2], ALFONSO V. LOMBANA[2]
TIM M. O'BRIEN[3] AND RICHARD B. GOMEZ[4]

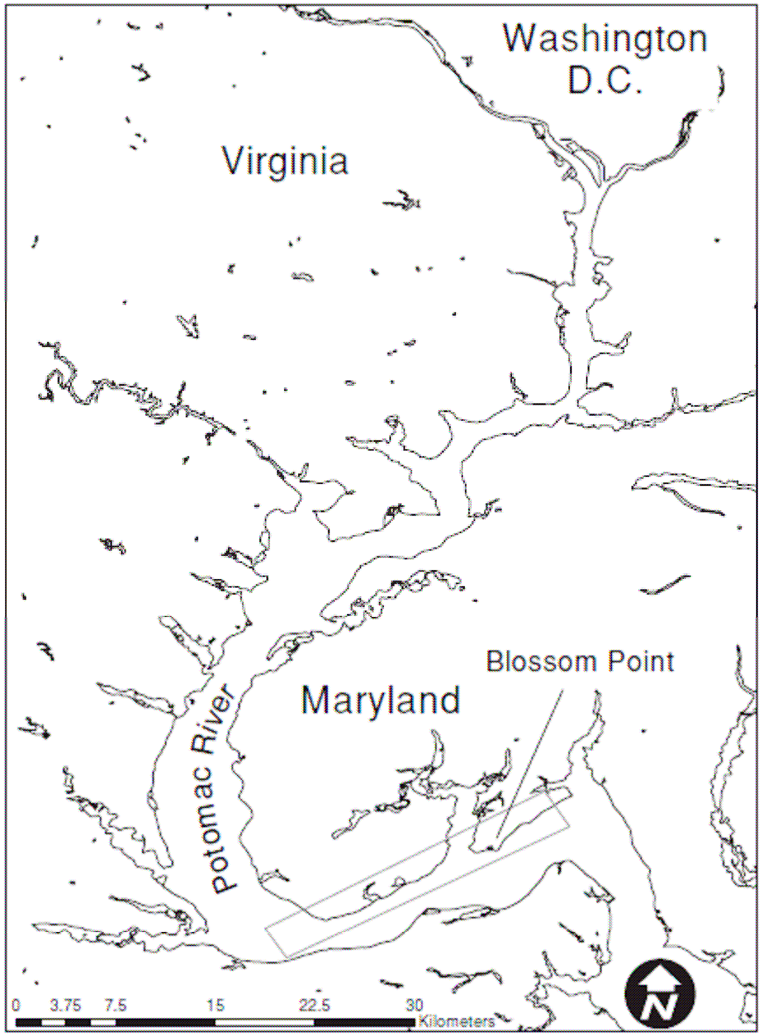
- Environmental Monitoring and Assessment 2003

Method: Continuum removal

Principle of continuum removal

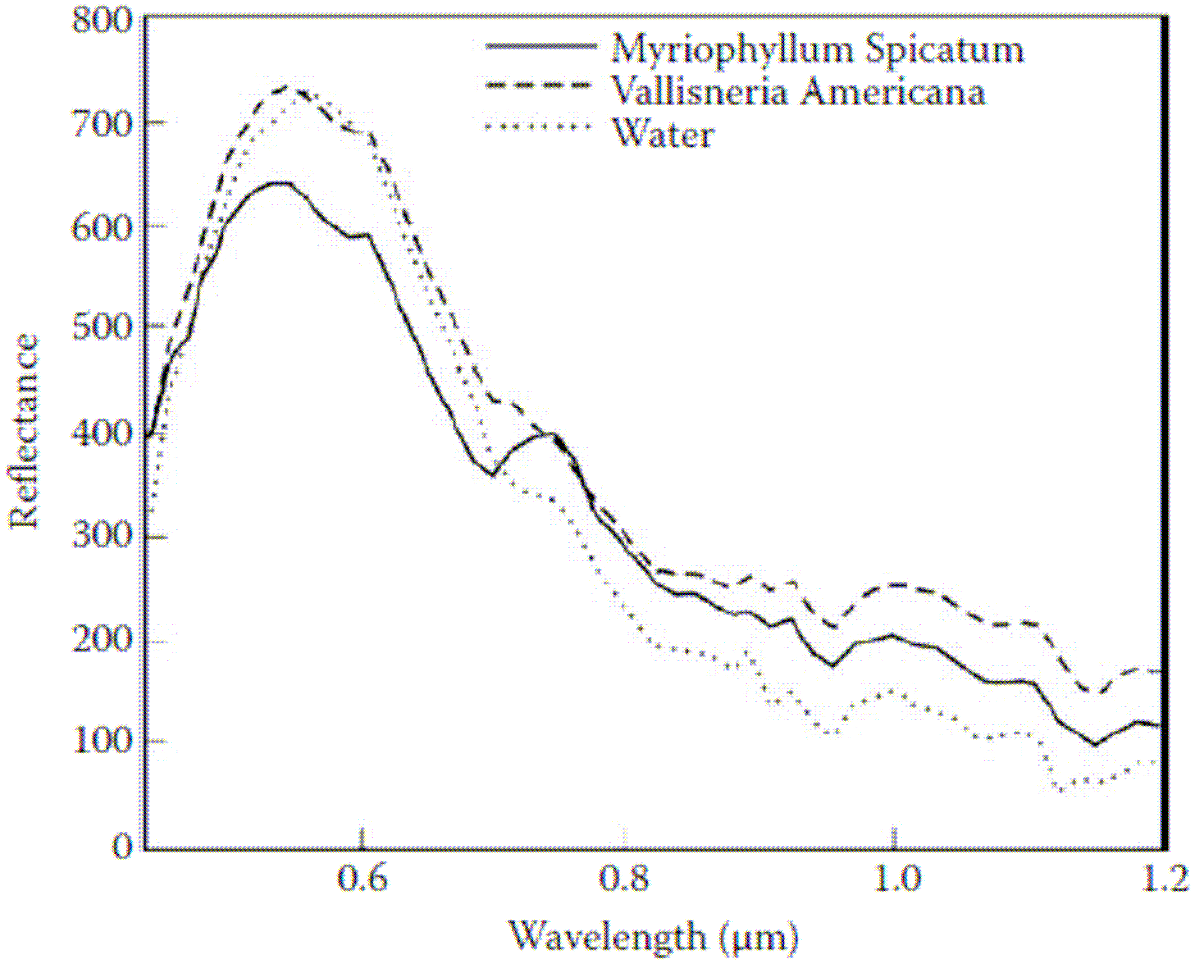


Study Area

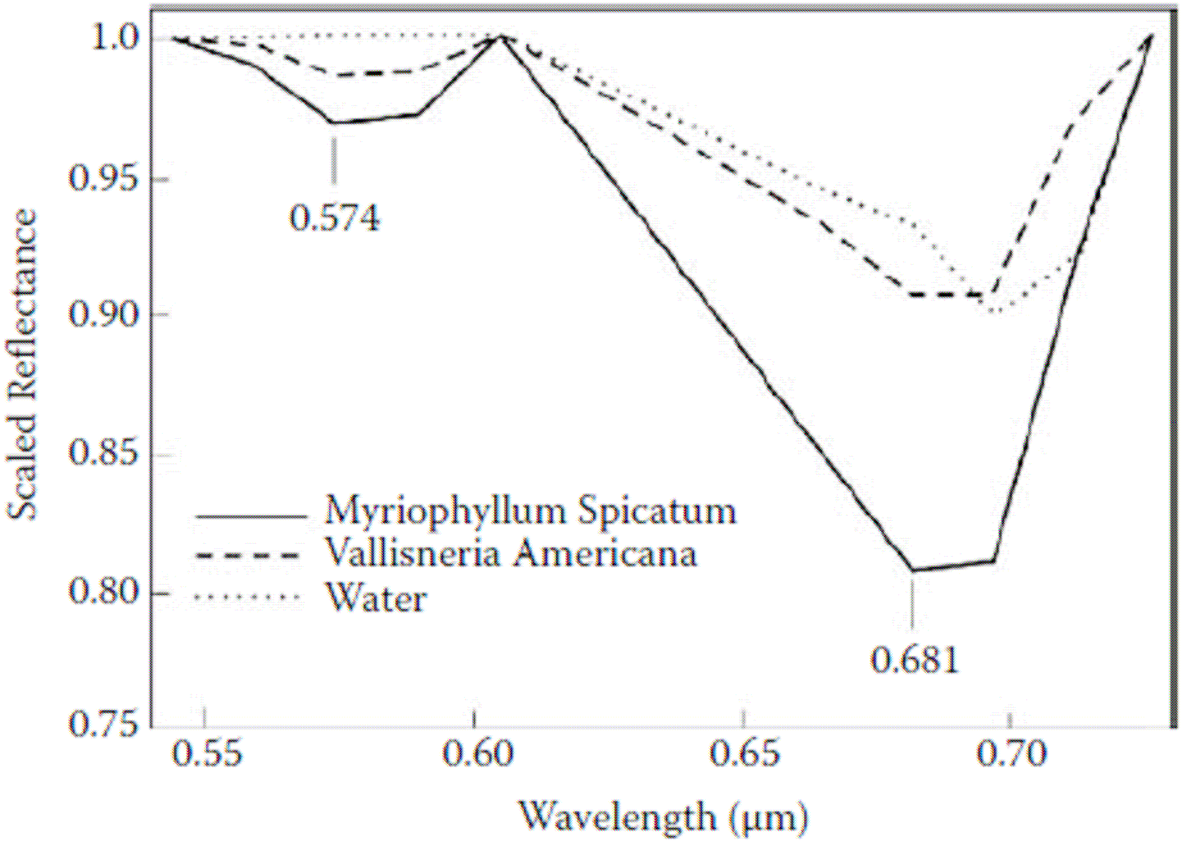

Washington D.C.
Virginia
Maryland
Potomac River
Blossom Point
0 3.75 7.5 15 22.5 30 Kilometers
N


PR
SAV beds
SAV beds
BP
Nanjemoy Creek
Potomac River

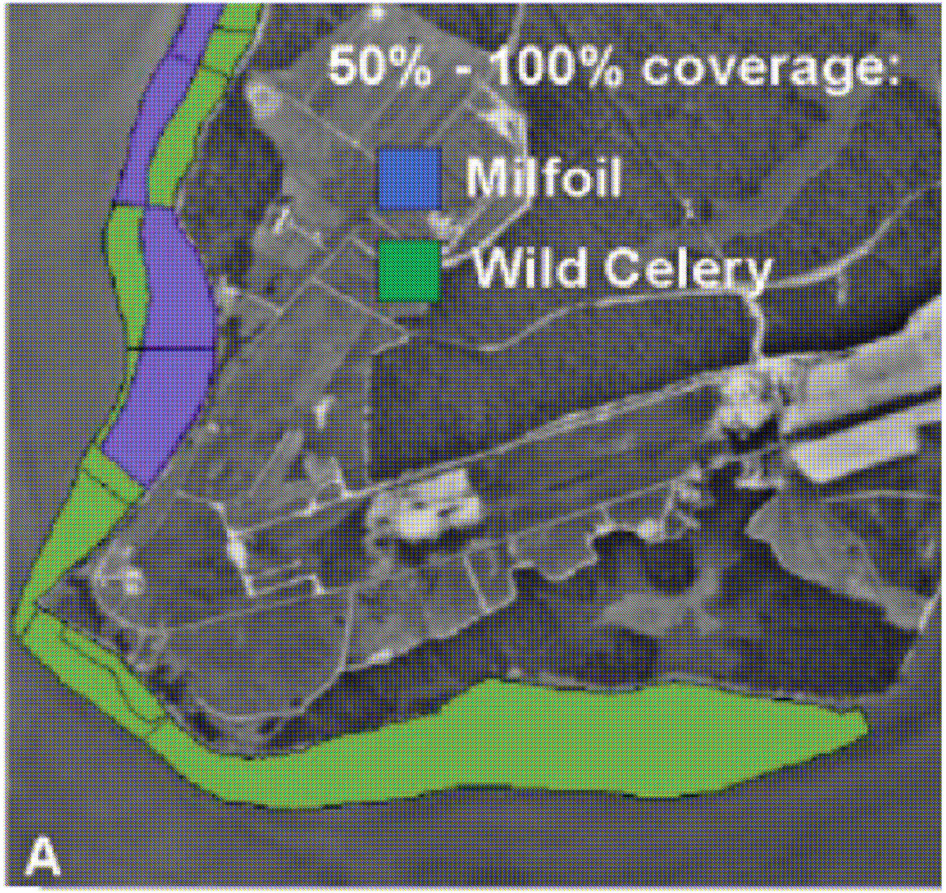
ASD - Field Spectra



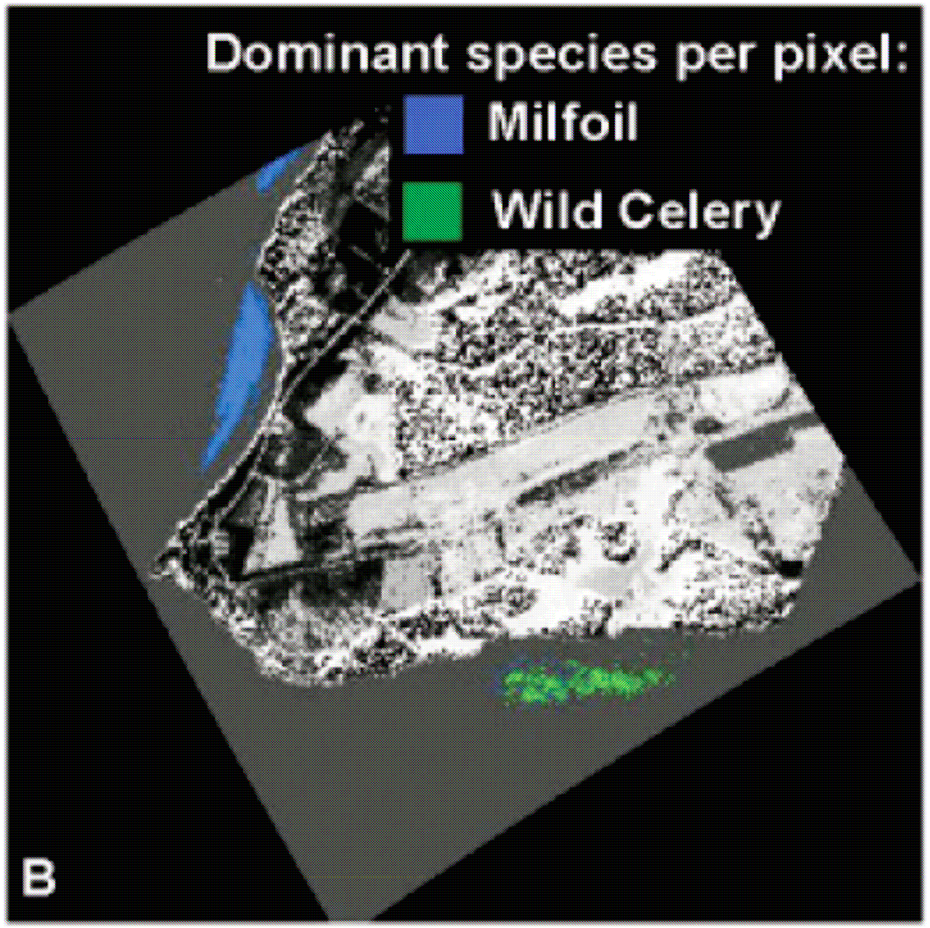
Continuum removed spectra



Final Map



•USGS August 2000

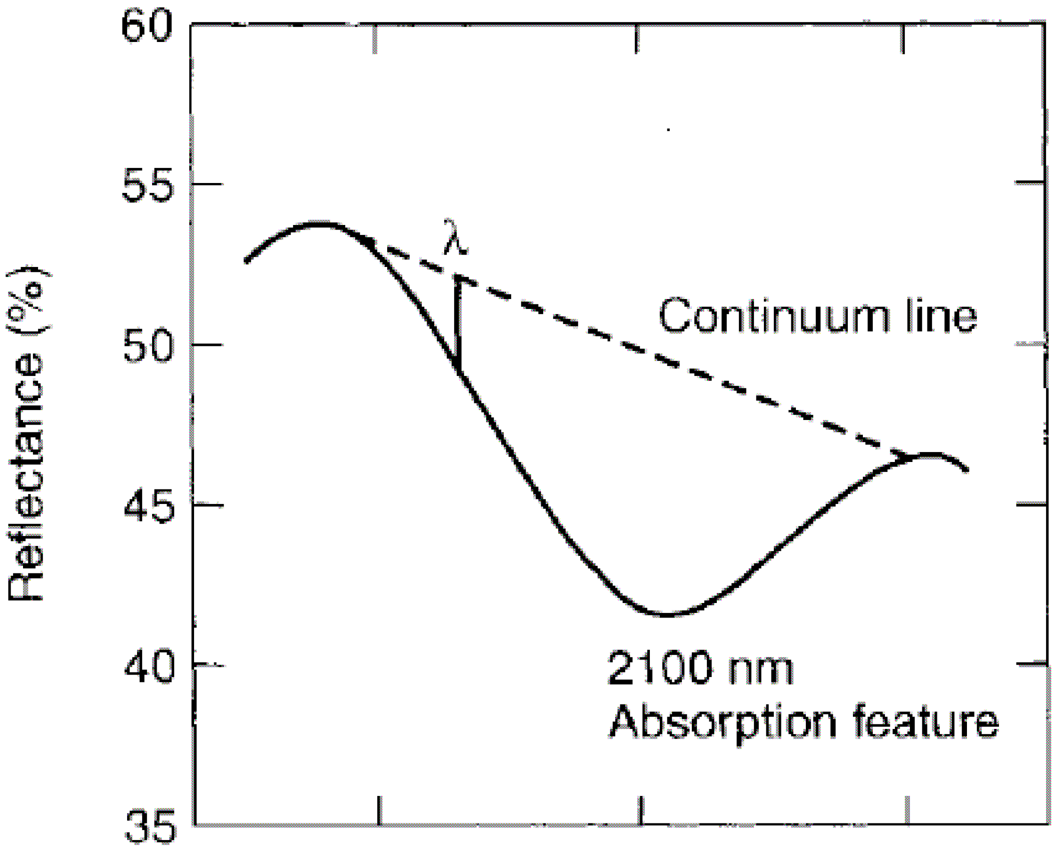


•HyMap October 2000

BNC: Kokaly and Clark (1999)

- band depth normalized to (band depth at) the center of the absorption feature (BNC)

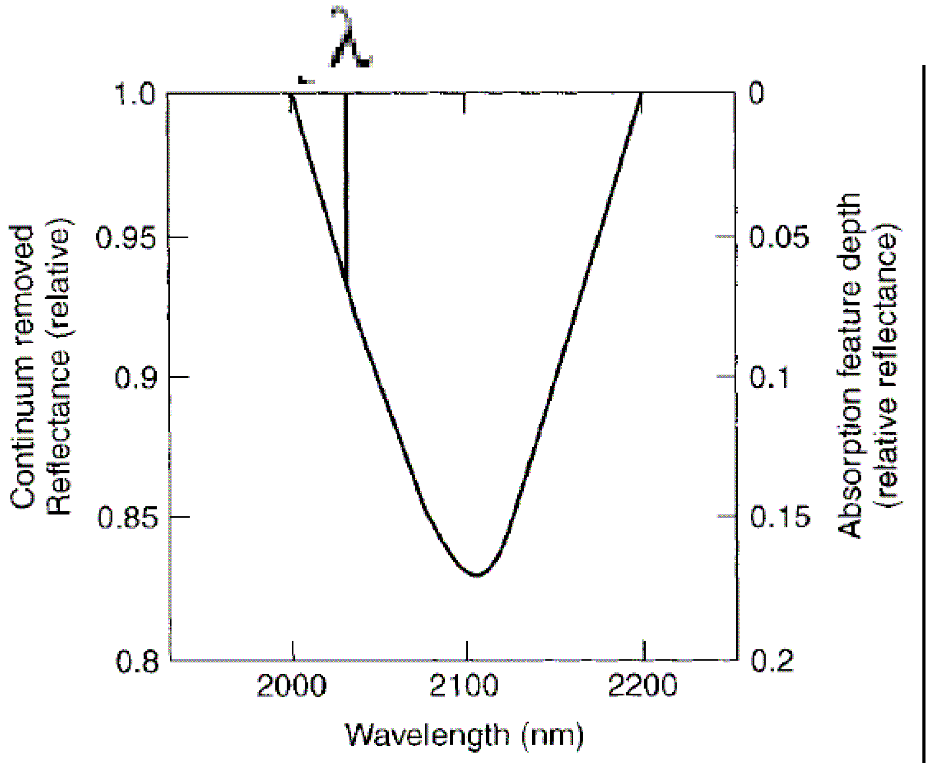
$$\mathrm{BNC} = \frac{1 - \dfrac{R}{R_i}}{1 - \dfrac{R_c}{R_{ic}}}$$



BNA: Kokaly and Clark (1999)

- BNA measures the depth of the waveband of interest from the continuum line, relative to the area ***(A)*** of the absorption feature

$$\mathrm{BNA} = \frac{1 - \frac{R}{R_i}}{A}$$



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Case Study IV:

Ecosystems (2003) 6: 368–383
DOI: 10.1007/s10021-003-0168-2

ECOSYSTEMS

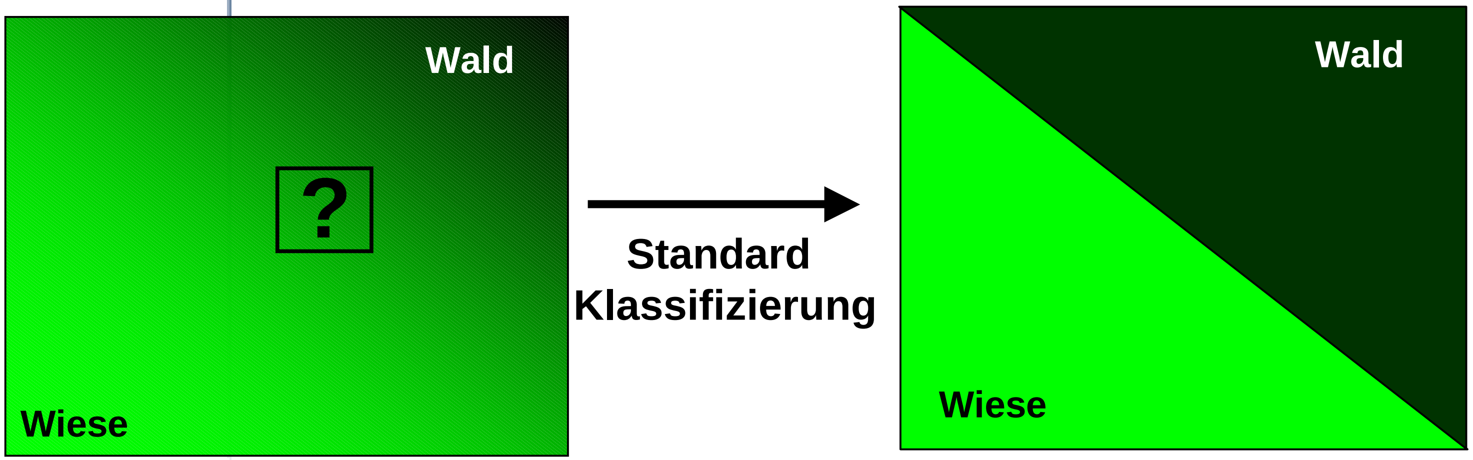
Changes in Vegetation Structure after Long-term Grazing in Pinyon-Juniper Ecosystems: Integrating Imaging Spectroscopy and Field Studies

A. Thomas Harris,[1] Gregory P. Asner,[1*] and Mark E. Miller[2]

[1]*Department of Global Ecology, Carnegie Institution of Washington, Stanford, University, Stanford, California 94305, USA;*
[2]*Northern Colorado Plateau Network, National Park Service, 2282 S. West Reserve Blvd., Moab, Utah 84532, USA*

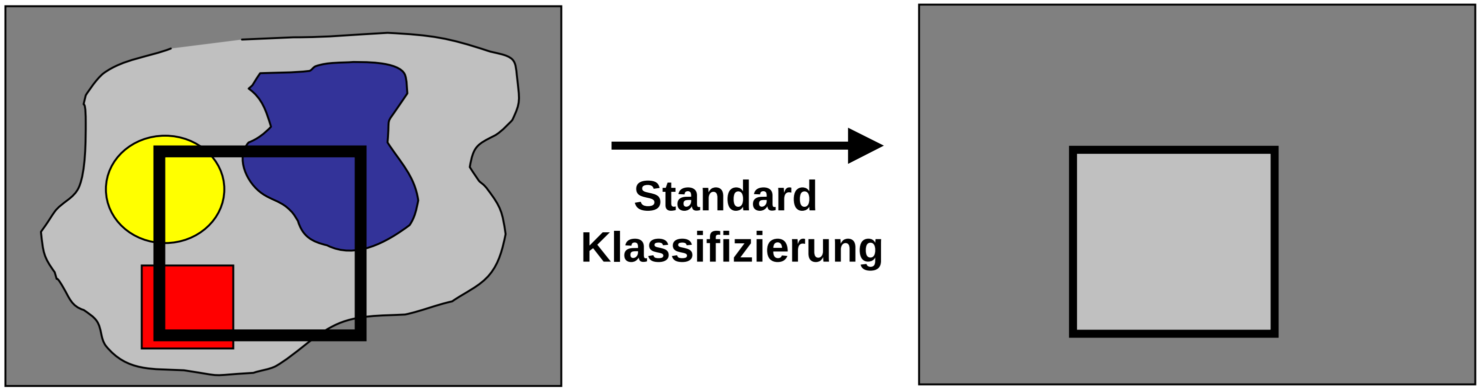
Mixed Pixel Problem

Transitions between classes

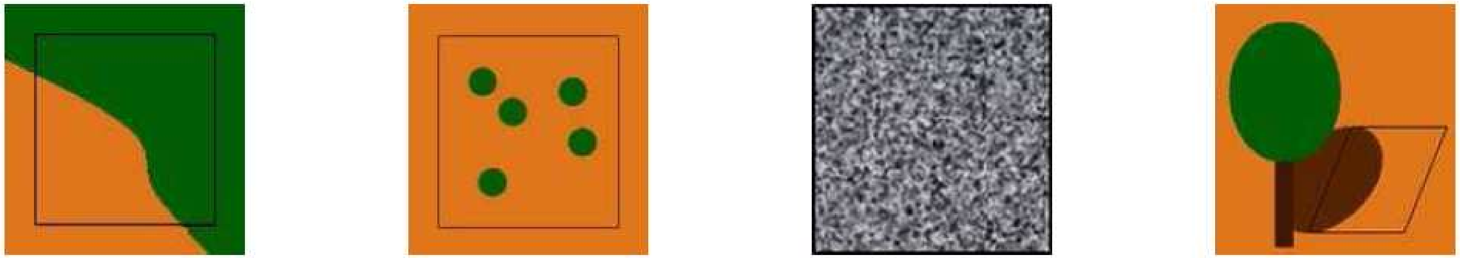


Source: Arko Lucieer
University of Tasmania

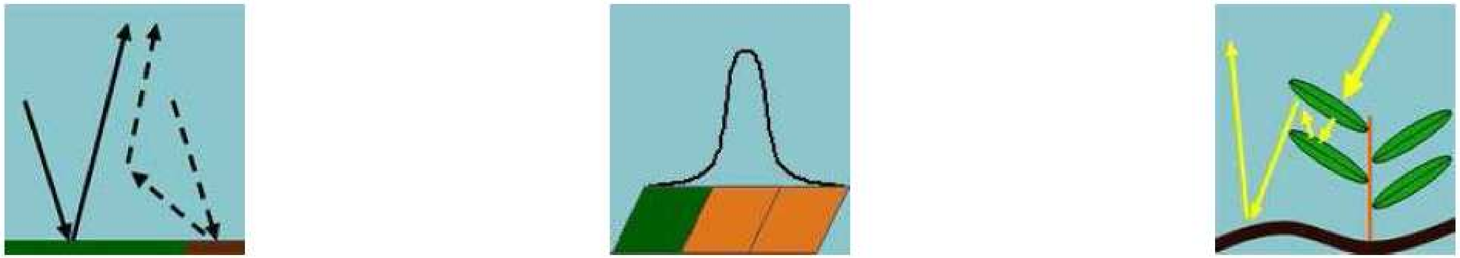
Mixed Pixelds



Causes for mixed pixels



(a) Objektgrenze (b) Diskrete Objekte (c) Materialmischung (d) Abschattung

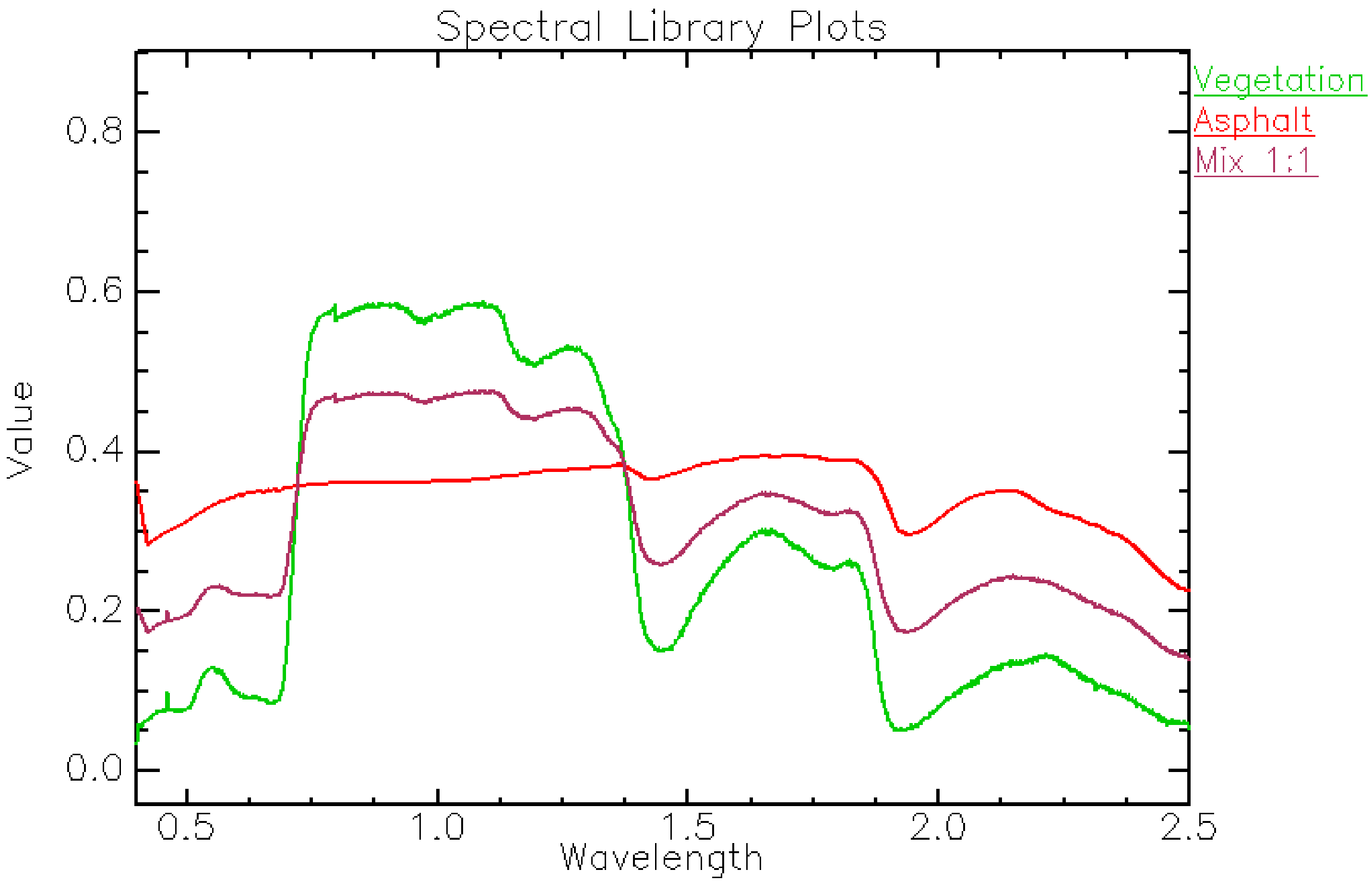


(e) Adjacency-Effekt (f) PSF-Effekt (g) Mehrfachreflexion

- Spectral unmixing
- Fuzzy logic Classification

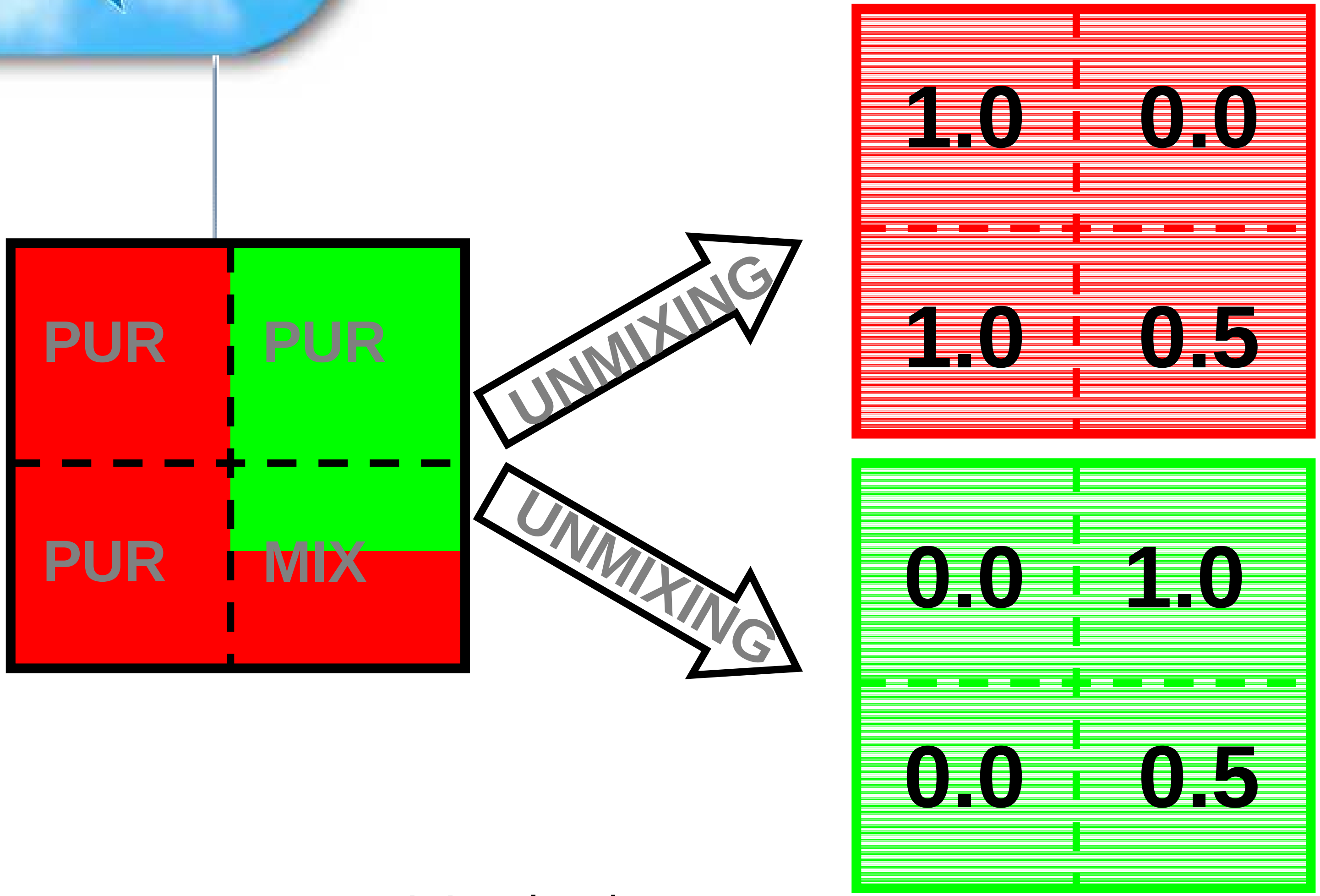
Example

- **Here; one mixed pixel contains two ENDMEMBER; vegetation and asphalt in 50:50**



•Source: Wouter Dorigo (TU Vienna)

Unmixing → Fractional Images



- Unmixing leads to fraction images

- Source: Wouter Dorigo (TU Vienna)

Study Area

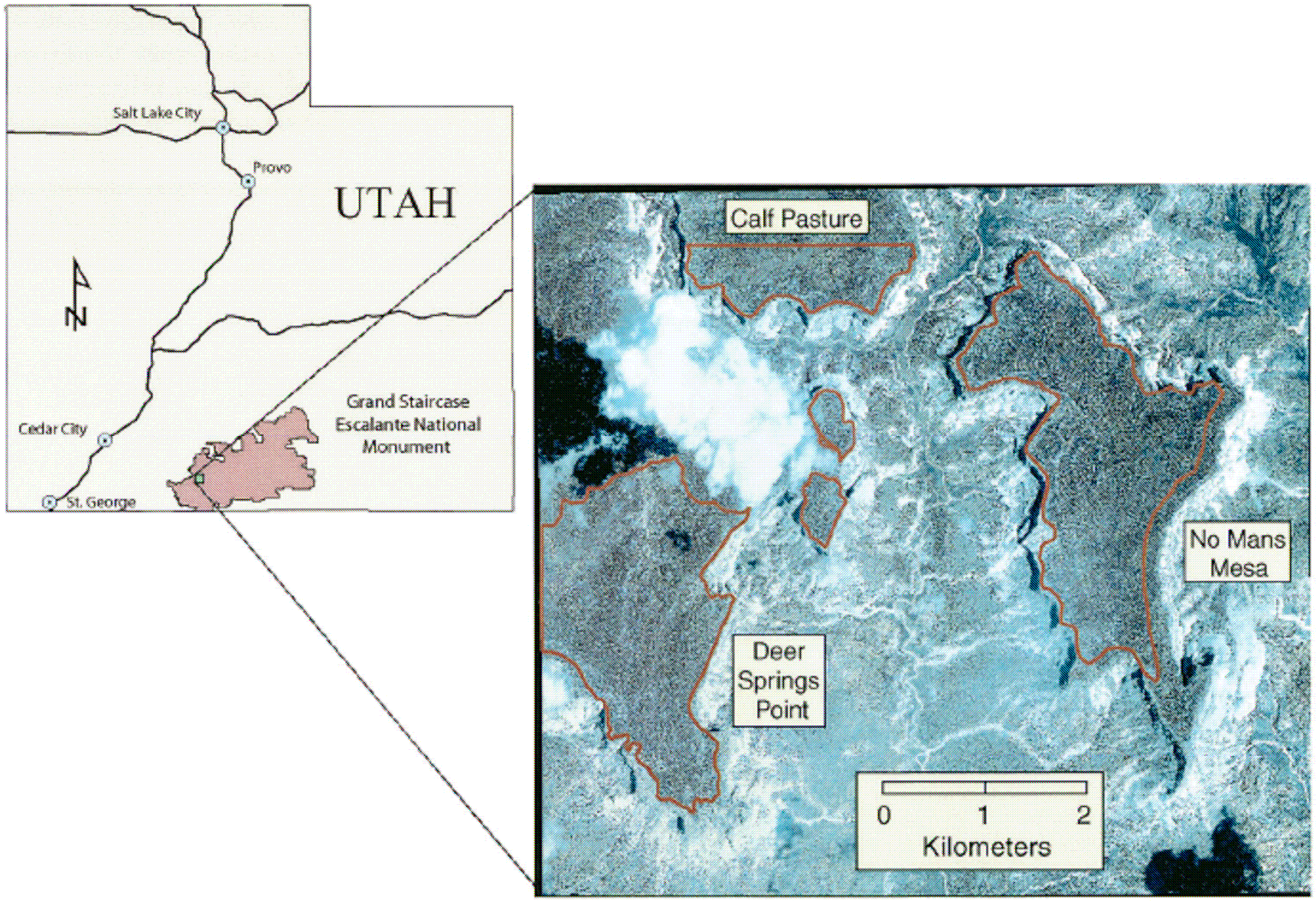


Figure 1. Location of the study area within Grand Staircase–Escalante National Monument, Utah, USA. The image of the study area is a color infrared aerial photo acquired at the time of the AVIRIS overflight. Study area mesas are outlined in red.

Field Measurements

Table 1. Field-measured Fractional Cover of Photosynthetic Vegetation (PV), Nonphotosynthetic Vegetation (NPV), and Bare Soil

Fractional Cover Component	Fractional Cover (%)		
	Ungrazed (No Man's Mesa)	Grazed (Deer Springs Point)	*P* Value
PV	21.0(0.01)[b]	28.3(0.08)[a]	< 0.001
NPV	50.0(0.01)[a]	50.4(0.11)[a]	0.545
Soil	26.1(0.02)[b]	20.6(0.14)[a]	0.041

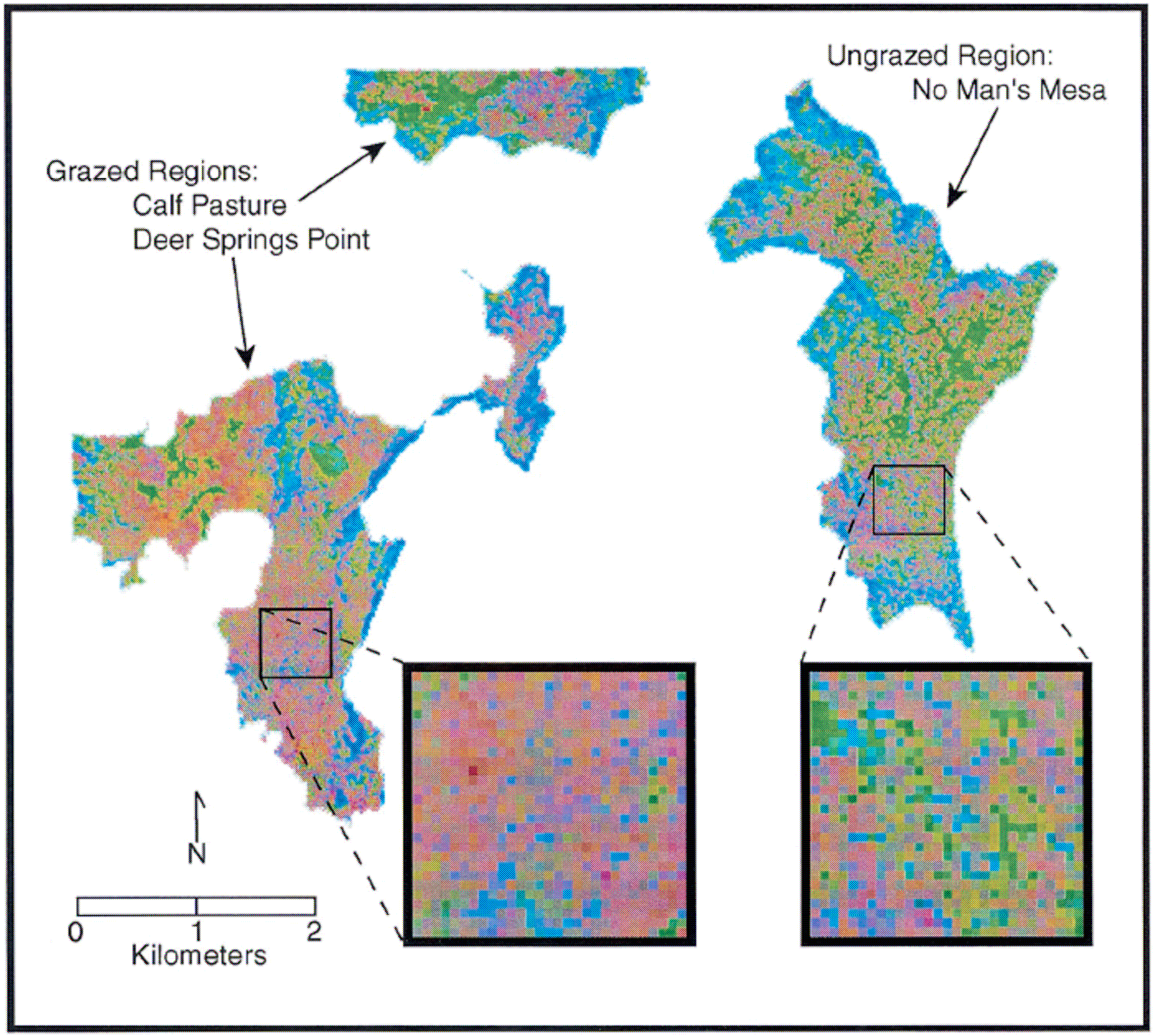
Reported values are means calculated by averaging all convolved values from three transects on each study area.
Values in parentheses are SE. Different lower-case letters between columns denote statistically significant difference (Student's t-test, $n = 50$).

Unmixing → Literature

- Schott, J.R. (2007). *Remote Sensing: The image chain appraoch*: Oxford University Press
- Liang, S. (2004). *Quantitative Remote Sensing of Land Surfaces*. Hoboken, New Jersey: Wiley

RGB

- R=PV
- G=NPV
- B=SOIL



Case Study V:

Journal of Vegetation Science 18: 131-140, 2007

131

Mapping the floristic continuum: Ordination space position estimated from imaging spectroscopy

Schmidtlein, S.[1,2*]; Zimmermann, P.[1]; Schüpferling, R.[1] & Weiß, C.[3]

*[1]Biogeographie, Universität Bayreuth, DE-95440 Bayreuth, Germany; [2]Current address: Geographisches Institut, Universität Bonn, DE-53115 Bonn, Germany; [3]Sektion Geographie, Universität München, DE-80333 München, Germany; E-mail c.weiss@iggf.geo.uni-muenchen.de; *Corresponding author; E-mail s.schmidtlein@uni-bonn.de*

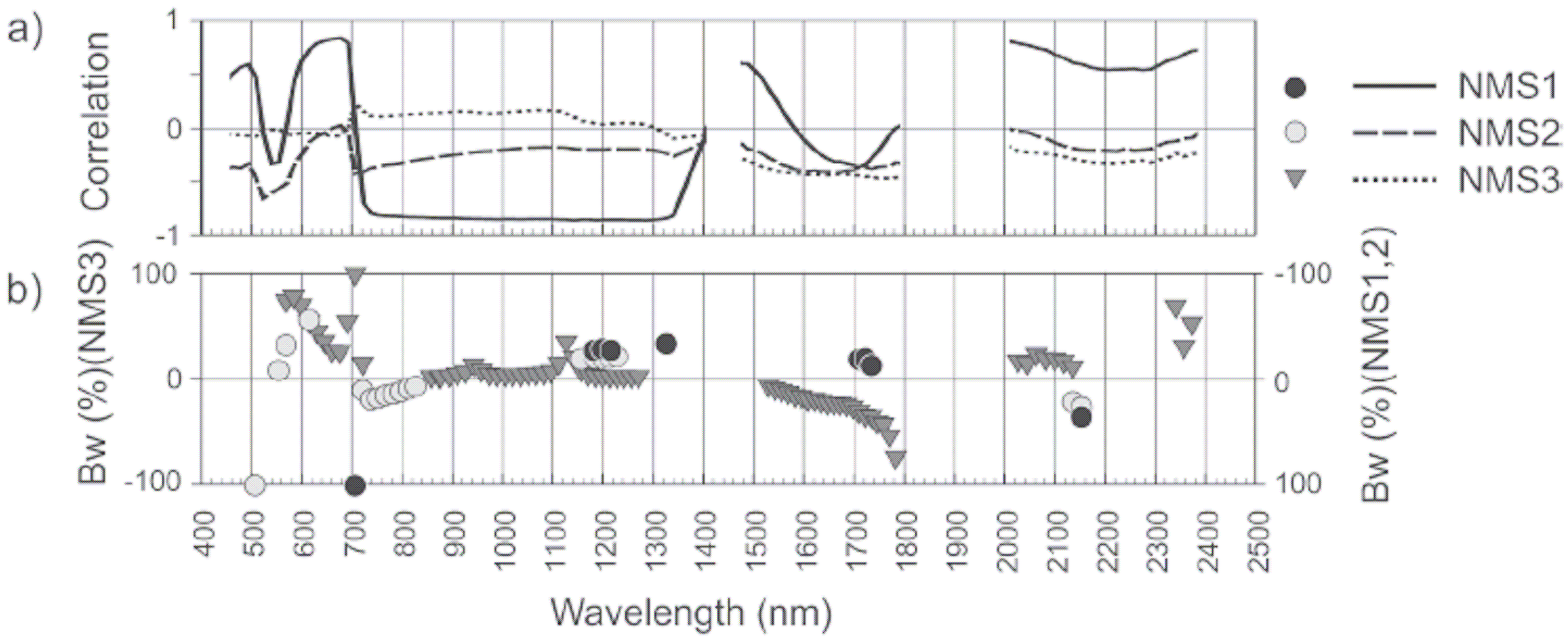
Methods: Partial Least Square Regression and NMDS-Ordination

Methodology

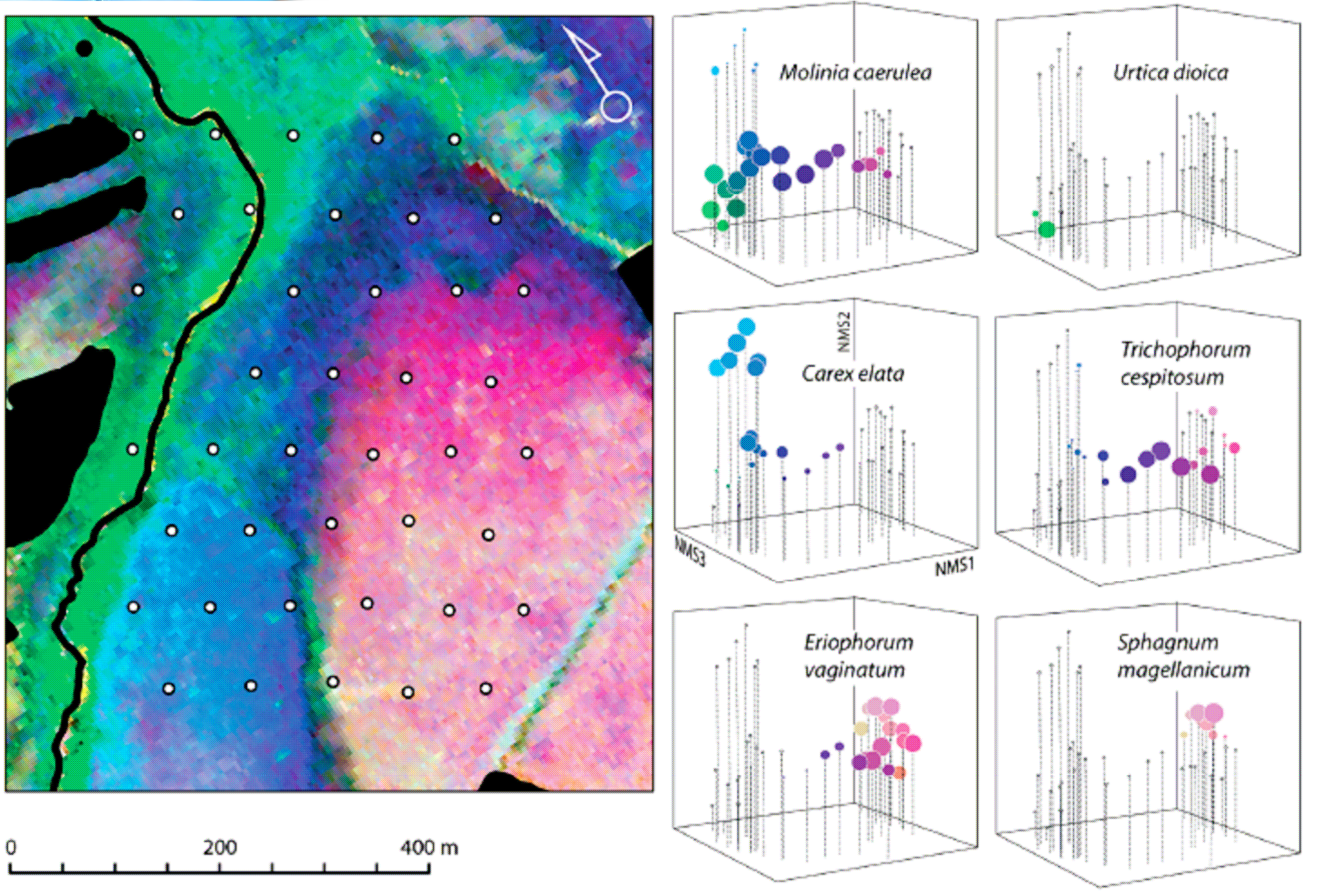
- **Field samples on plant composition and abundance in Vegetation Plots**
- **Ordination of vegetation gradients in vegetation data using NMDS**
- **PLS regression for each NMDS-Axis and HyMap 126 Bands**

	NMS1	NMS2	NMS3
Reflectance	$\log_{10}(1/R)$	$\log_{10}(1/R)$	R
Min	–0.84	–0.87	–0.74
Max	1.27	1.10	0.60
# PC	4	5	4
# Bands	9	20	71
1 PC ($RMSE_{val}$)	0.73	0.20	0.10
2 PC ($RMSE_{val}$)	0.19	0.17	0.08
3 PC ($RMSE_{val}$)	0.09	0.14	0.05
4 PC ($RMSE_{val}$)	0.05*	0.08	0.02*
5 PC ($RMSE_{val}$)	0.05	0.03*	0.02
6 PC ($RMSE_{val}$)	0.05	0.03	0.03
R^2_{cal}	0.94 ***	0.87 ***	0.82 ***
R^2_{val}	0.92 ***	0.82 ***	0.78 ***

PLSR Results



Gradient-based Vegetation Map



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Case study: Mapping

Remote Sensing of Environment 114 (2010) 1155–1166

Contents lists available at ScienceDirect

Remote Sensing of Environment

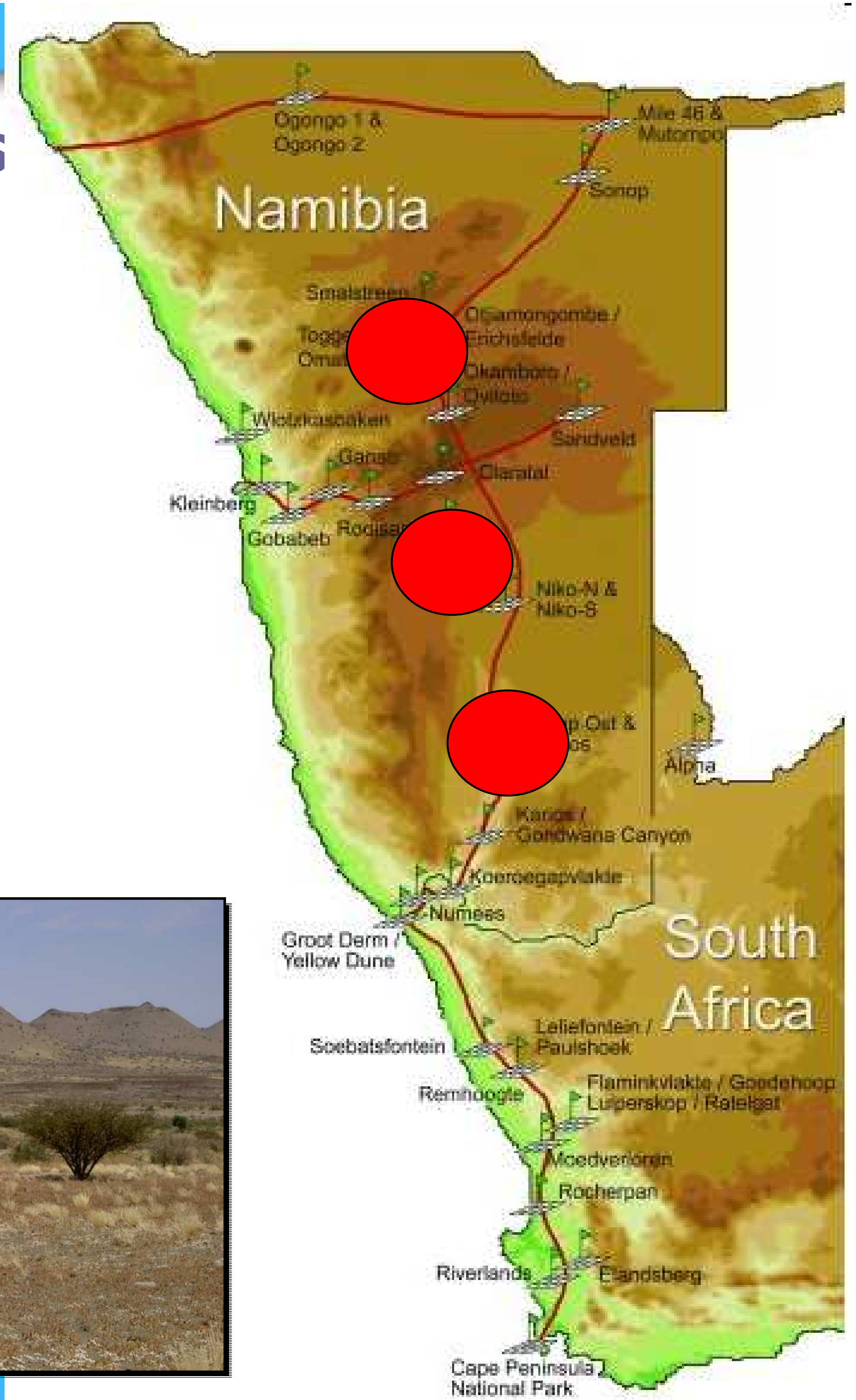
journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Combining vegetation indices, constrained ordination and fuzzy classification for mapping semi-natural vegetation units from hyperspectral imagery

Jens Oldeland [a,b,*], Wouter Dorigo [c], Lena Lieckfeld [a,b], Arko Lucieer [d], Norbert Jürgens [a]

[a] Biocentre Klein Flottbek and Botanical Garden, University of Hamburg, Ohnhorststr. 18, 22609, Hamburg, Germany
[b] German Aerospace Center, 82203 Oberpfaffenhofen, Germany
[c] Institute of Photogrammetry and Remote Sensing, University of Technology, Gusshausstrasse 27-29, 1040 Vienna, Austria
[d] School of Geography and Environmental Studies, University of Tasmania, Private Bag 76, Hobart 7001, Tasmania, Australia


Namibia
Ogongo 1 & Ogongo 2
Mile 46 & Mutompo
Sonop
Otjamongombe / Erichsfelde
Okamboro / Ovitoto
Sandveld
Wlotzkasbaken
Ganab
Claratal
Kleinberg
Gobabeb
Niko-N & Niko-S
Alpha
Karios / Gondwana Canyon
Koeroegapvlakte
Numees
Groot Derm / Yellow Dune
South Africa
Soebatsfontein
Leliefontein / Paulshoek
Remhoogte
Flaminkvlakte / Goedehoop
Luiperskop / Ratelgat
Moedverloren
Rocherpan
Riverlands
Elandsberg
Cape Peninsula National Park

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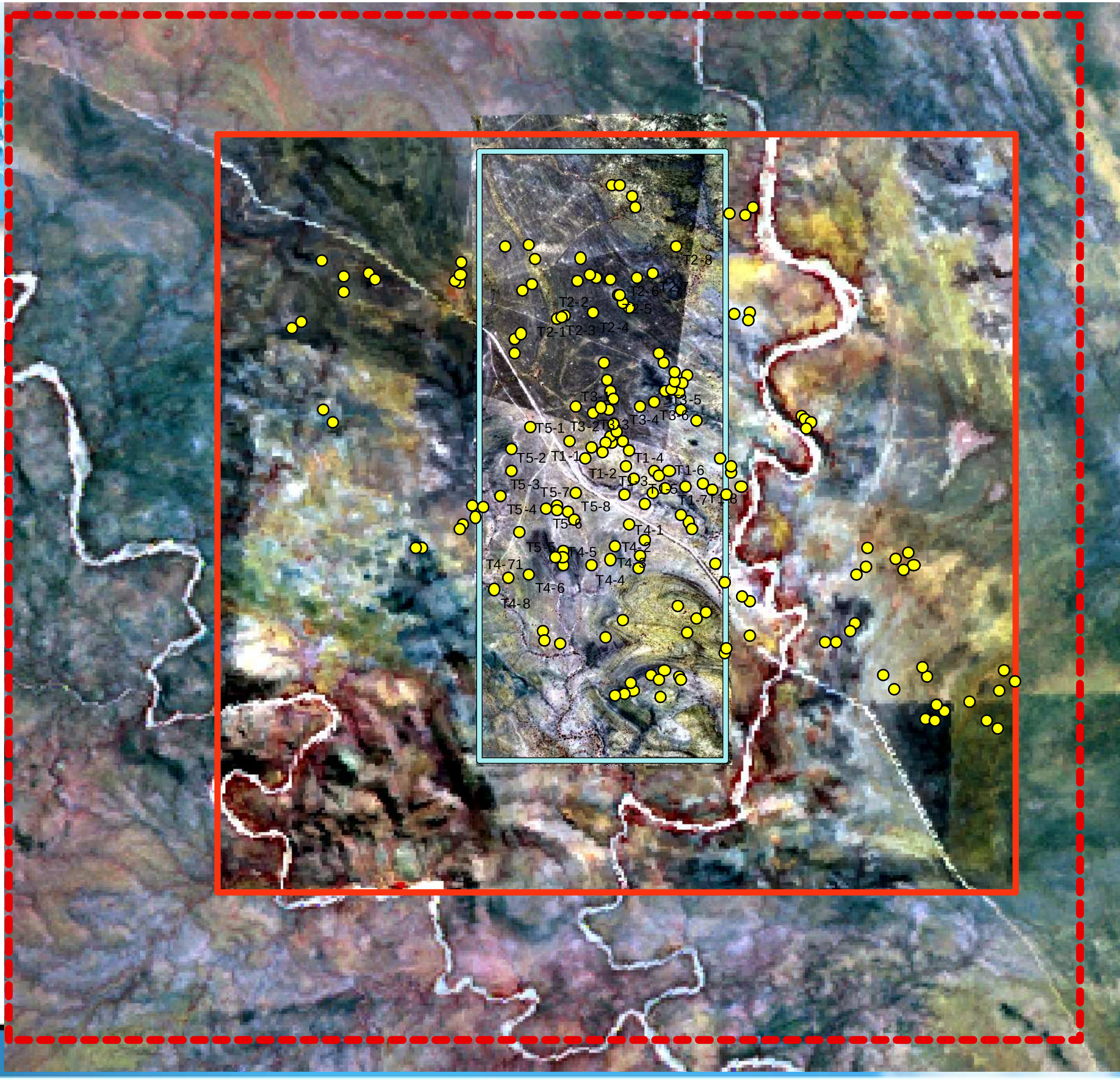

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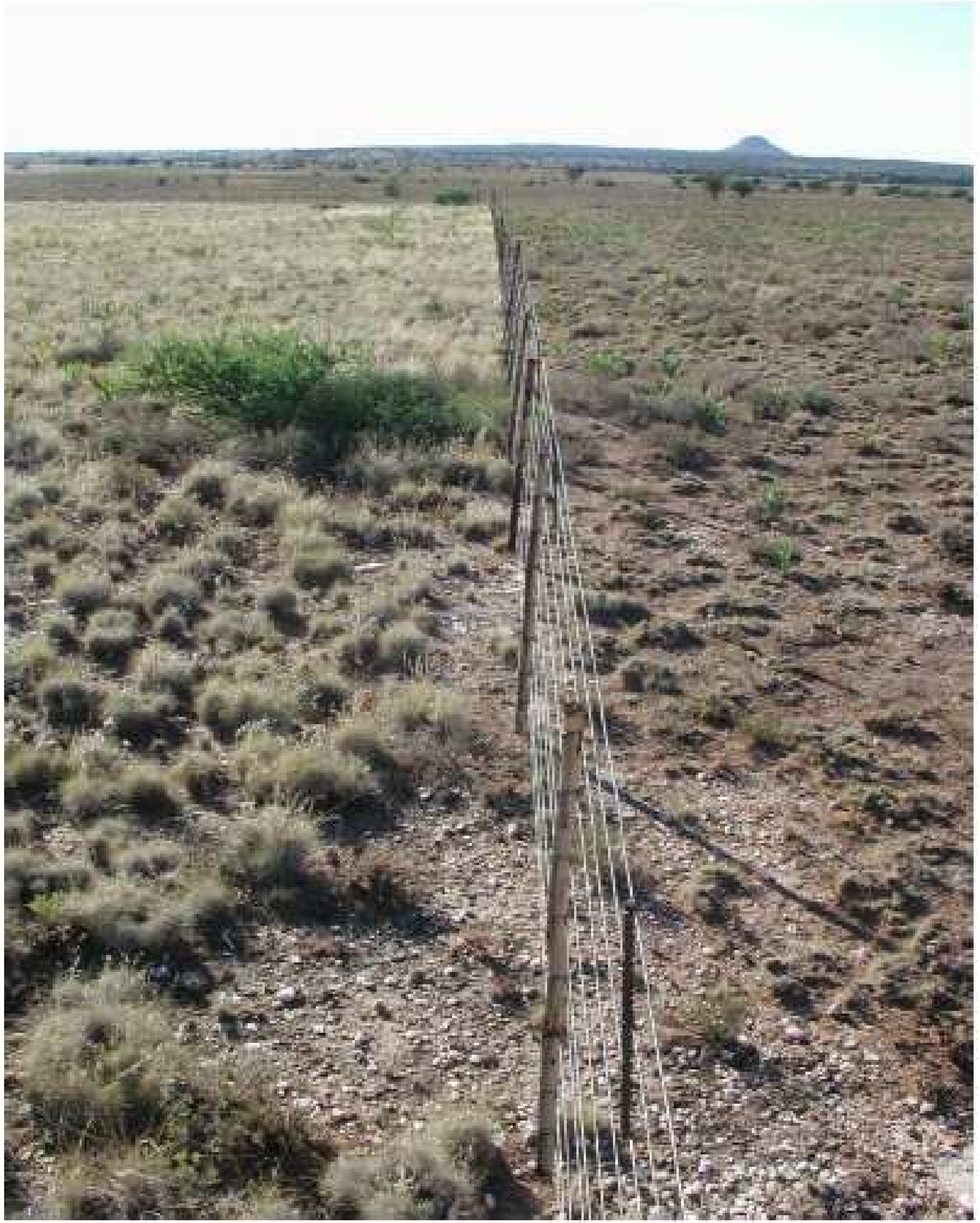

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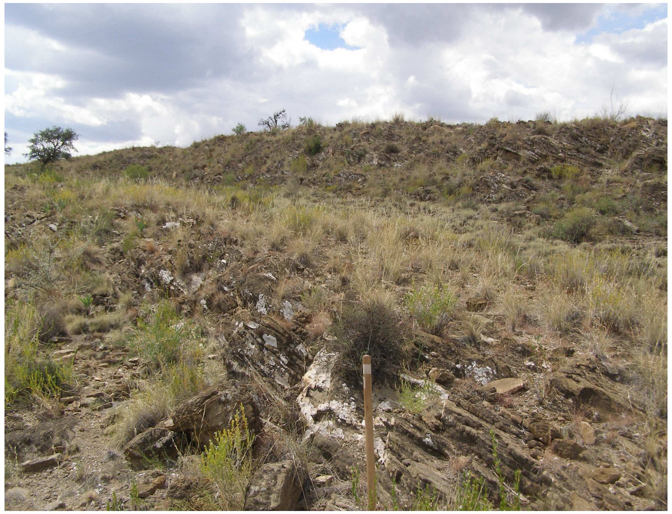
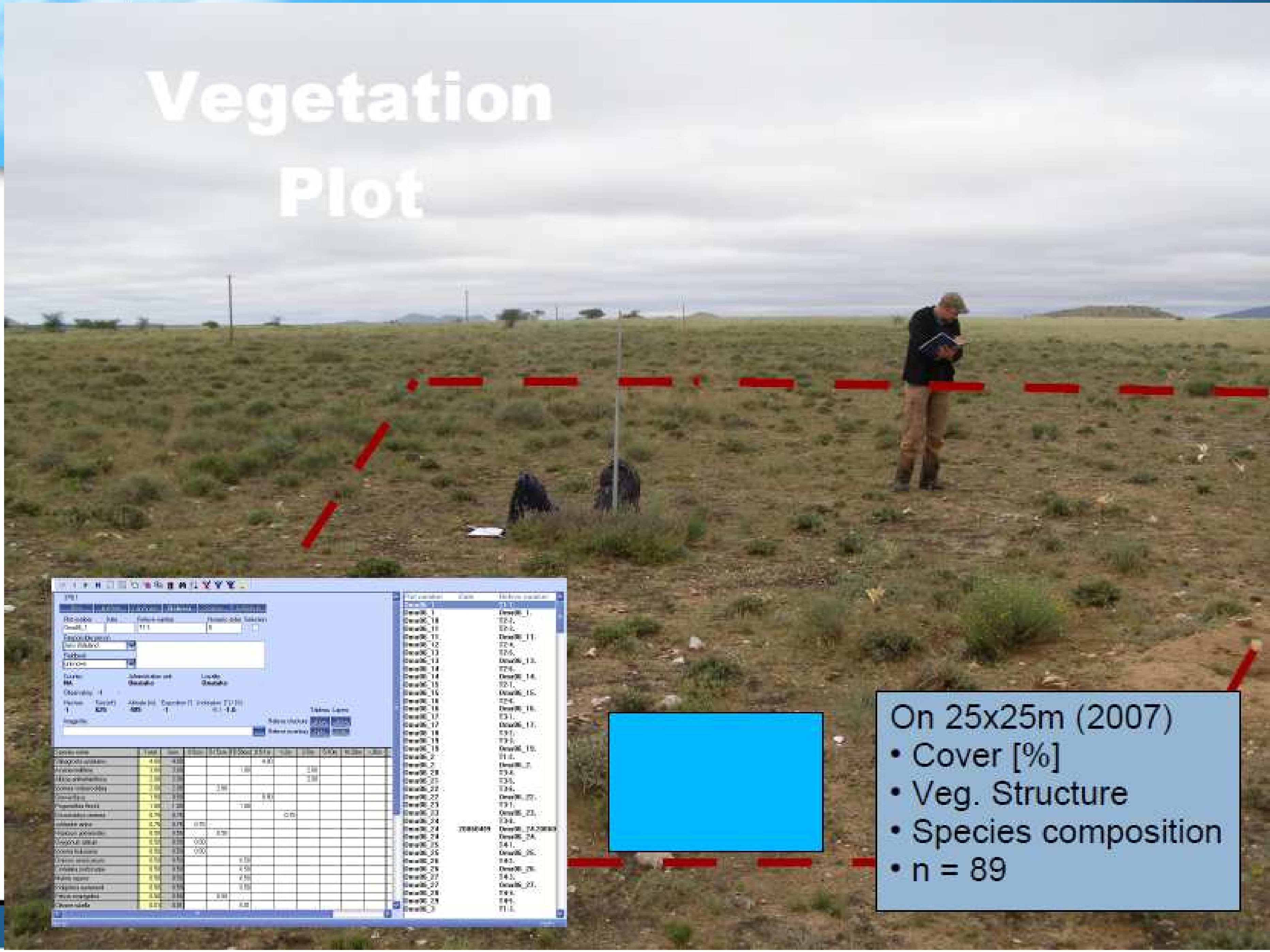
Vegetation

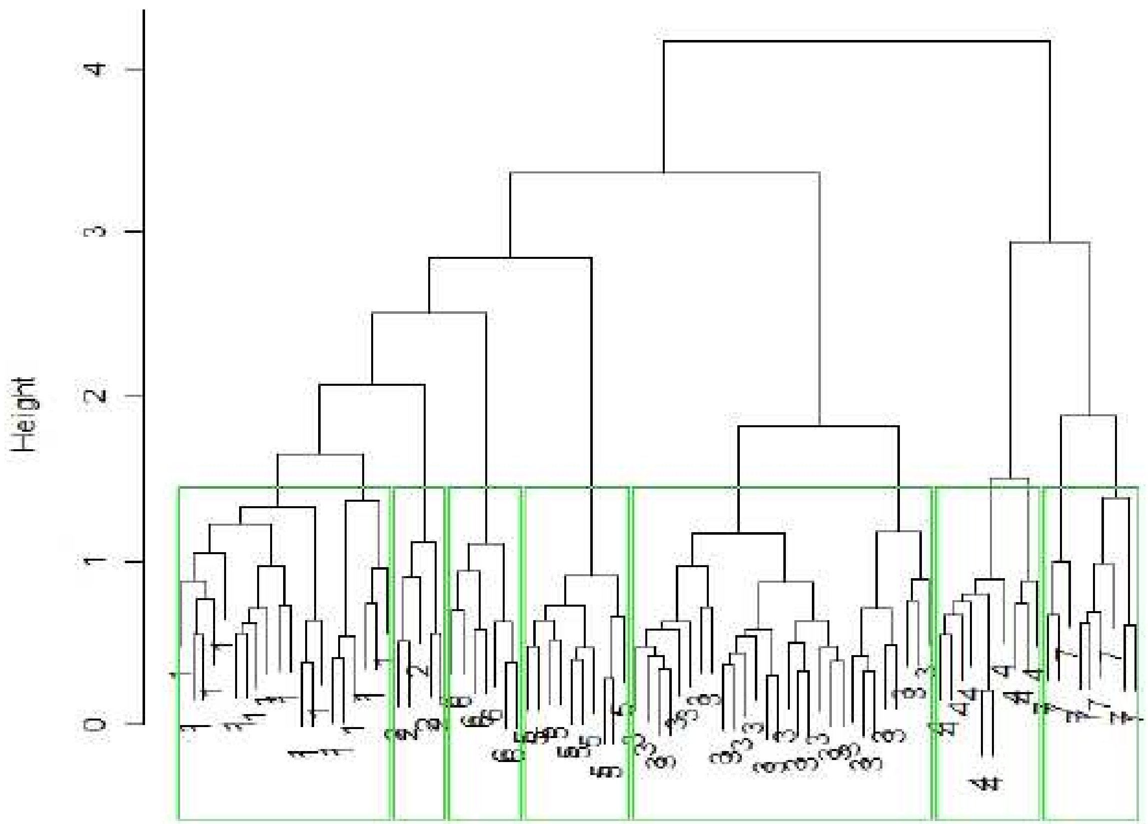


Vegetation Plot



On 25x25m (2007)
- Cover [%]
- Veg. Structure
- Species composition
- n = 89

Cluster Analysis: Hellinger Transformation / Euclidean Distance



spec.dis.hell
ANOSIM = 0.82; Aggl.Coeph. = 0.86 Coph.Corr. 0.75

Cluster Quality:

ANOSIM = 0.82
Aggl.Coeph. = 0.86
Coph.Corr. = 0.75
21.08.10

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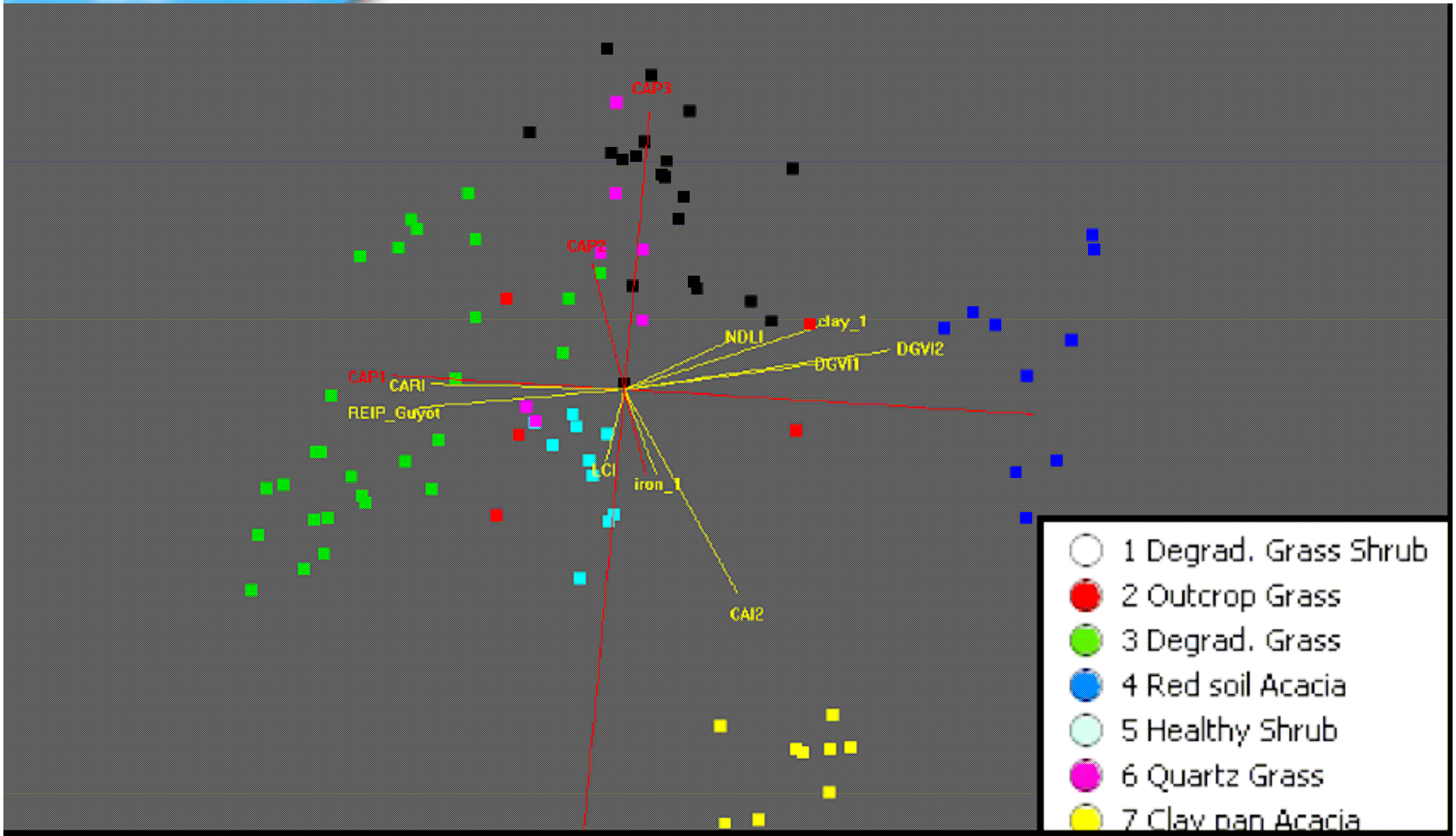
Table 2
Overview of vegetation units that were derived by cluster analysis. Characteristic species for each type are sorted after average abundance in the cluster. Number of plots (n) show cluster size.

Type	n	Characteristic species	Description of the vegetation unit
1	20	*Monechma genistifolium* *Pentzia calva* *Geigeria ornativa*	Open dwarf shrub with sparse cover, mainly *Monechma genistifolium* on calcareous rocky soils
2	5	*Stipagrostis ciliata* *Felicia clavipilosa*	Grass and shrub vegetation on outcrops and deeply incised rocky drainage lines
3	28	*Stipagrostis obtusa* *Monchema genistifolium* *Melolobium microphyllum*	Sparse grassland and open patches, mainly *Stipagrostis obtusa*, only few dwarf shrubs
4	10	*Acacia mellifera* *Albizia anthelminthica* *Stipagrostis uniplumis*	Woody acacia shrub on shallow red soils
5	10	*Leucosphaera bainsii* *Aizoon schellenbergii* *Enneapogon desvauxii*	Dwarf shrub savanna with many dwarf shrubs, and perennial grasses on dark biological soil crusts
6	7	*Fingerhuthia africana* *Aizoon giessii* *Melhania virescens*	Grassland with mainly *Fingerhuthia africana* and few dwarf shrubs on rocky siliceous soil.
7	9	*Panicum lanipes* *Eragrostis rotifer* *Rhigozum trichotomum* *Acacia hebeclada*	Shrub vegetation at the border of clay pans and shallow drainage lines with clay soils; grasses and herbs in center of pans

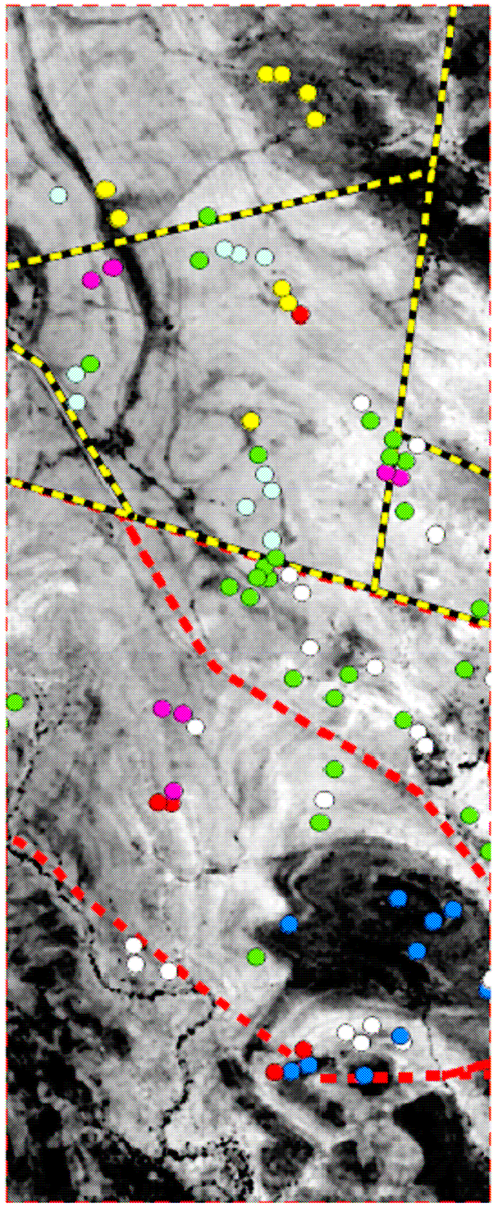
Spectral data

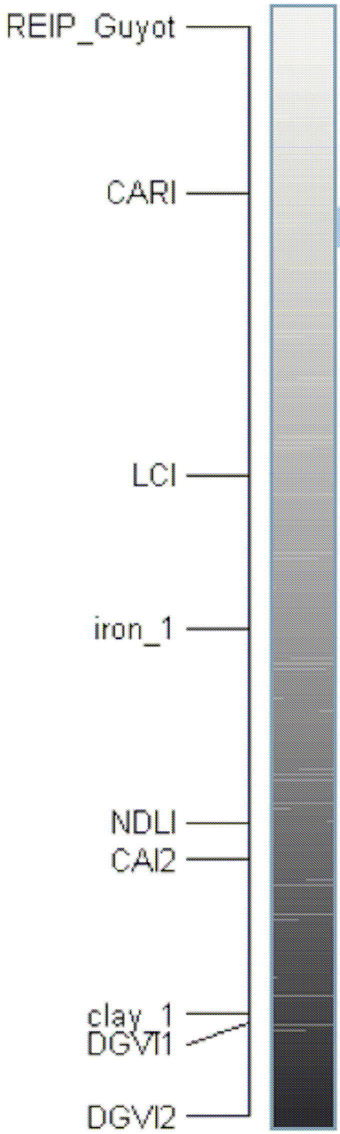
Table 1
Final set of spectral indices used in the analysis.

Nr.	Index	Full name	Feature	Reference
1	CARI	Chlorophyll absorption in Reflectance Index	Chlorophyll	Kim et al. (1994)
2	LCI	Leaf Chlorophyll Index	Chlorophyll	Datt et al. (2003)
3	DGVI1	First-order derivative green vegetation index	Greenness	Chen et al. (1998)
4	DGVI2	Second-order derivative green vegetation index	Greenness	Chen et al. (1998)
5	NDLI	Normalized Difference Lignin Index	Lignin	Serrano et al. (2002)
6	CAI	Cellulose Absorption Index	Litter	Daughtry (2001)
7	CLAY	Clay ratio	Soil	Dorigo et al. (2006)
8	IRON	Iron ratio	Soil	Dorigo et al. (2006)


CAP3
CAP2
CAP1
CARI
REIP_Guyot
NDLI
clay_1
DGVI2
DGVI1
LCI
iron_1
CAI2
1 Degrad. Grass Shrub
2 Outcrop Grass
3 Degrad. Grass
4 Red soil Acacia
5 Healthy Shrub
6 Quartz Grass
7 Clay pan Acacia

RDA 1





- 1 Degrad. Grass Shrub
- 2 Outcrop Grass
- 3 Degrad. Grass
- 4 Red soil Acacia
- 5 Healthy Shrub
- 6 Quartz Grass
- 7 Clay pan Acacia

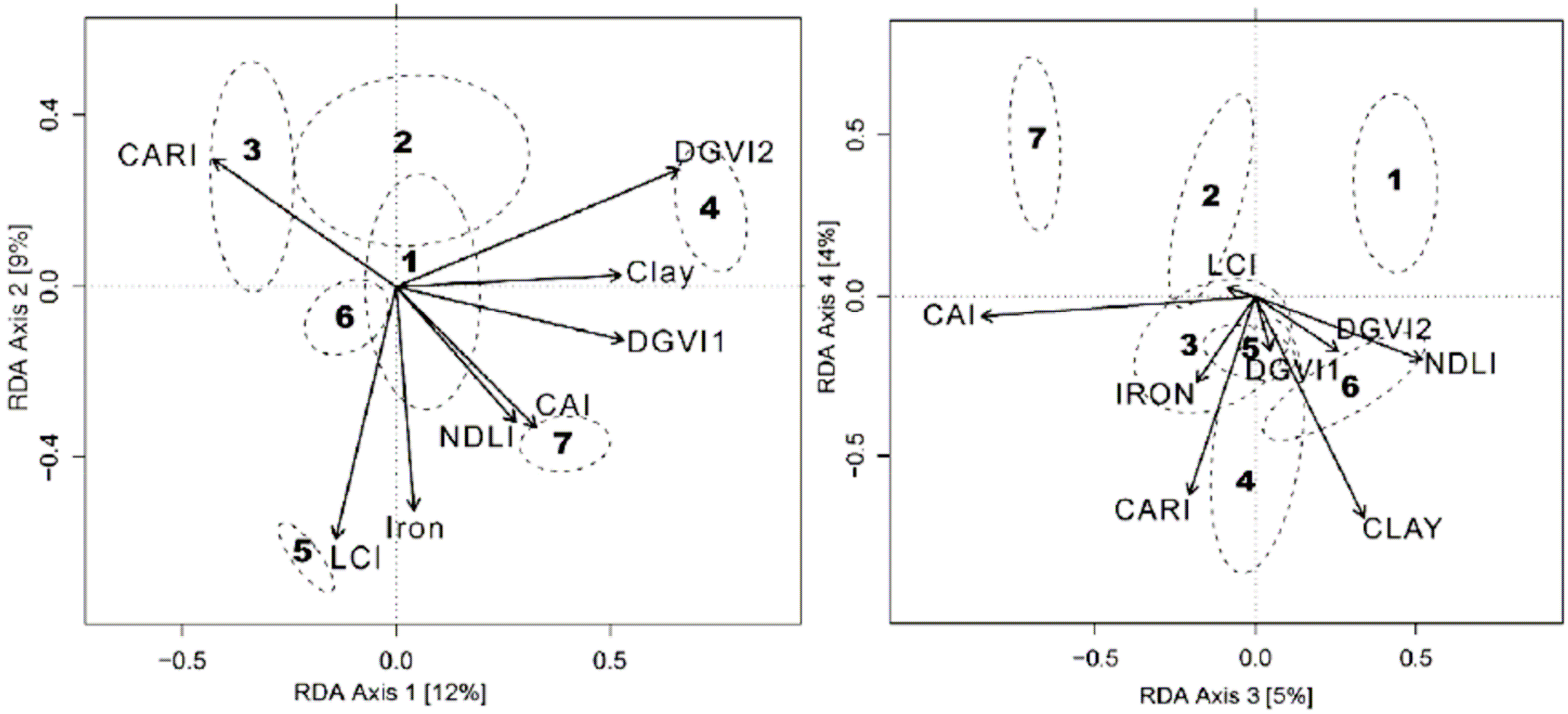

CARI
3
2
DGVI2
4
1
Clay
6
DGVI1
CAI
NDLI
7
Iron
5
LCI
0.4
0.0
-0.4
-0.5
0.0
0.5
RDA Axis 1 [12%]
RDA Axis 2 [9%]
7
2
1
LCI
CAI
3
5
DGVI2
NDLI
DGVI1
6
IRON
4
CARI
CLAY
0.5
0.0
-0.5
-0.5
0.0
0.5
RDA Axis 3 [5%]
RDA Axis 4 [4%]

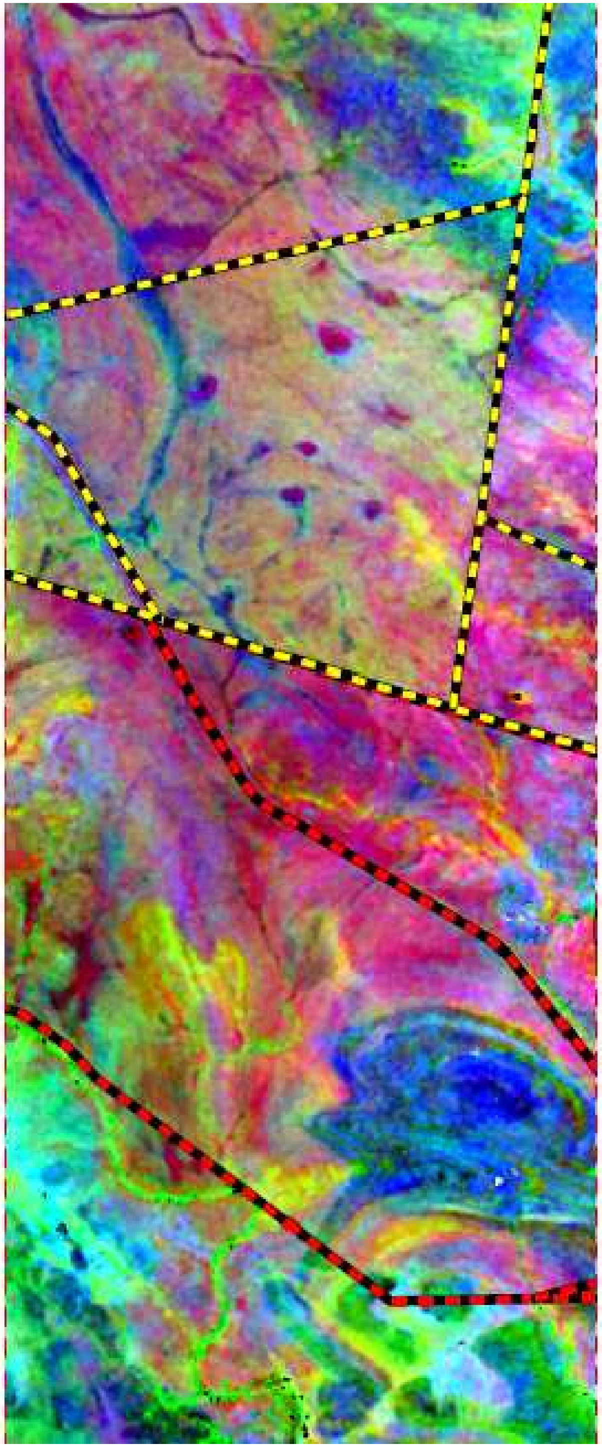
Table 3
Significance of relationships between spectral indices, vegetation units and ordination axes.

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6	RDA7	RDA8
Spectral indices								
CARI	*	*	***	***				*
LCI			***	*	***	**	**	
DGVI1			.	**	***			.
DGVI2	***	**			***		*	
NDLI	*	***	***		*		**	*
CAI	*	.	***		.		*	
CLAY			**	***				*
IRON		**	*			***		
R^2	0.6323	0.6305	0.6209	0.5326	0.4206	0.3217	0.2604	0.1779
F-value	17.41	17.28	16.58	11.54	7.35	4.802	3.564	2.192
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.05
Vegetation unit								
1	*		***	***			**	
2		**	***		***			
3	***	***	***	***		.	*	
4	***	*	***	***	**		*	
5	***	***	***	***	**	.		*
6	***		.	***		*	***	
7	***	***	***		*	**	**	
R^2	0.9027	0.6716	0.7651	0.6206	0.4873	0.2643	0.3226	0.1656
F-value	126.7	27.95	44.52	22.36	12.99	4.91	6.509	2.713
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.05

Signif. codes: < 0.001 ***; 0.01 = **; 0.05 = * 0.05; '.' = 0.1.

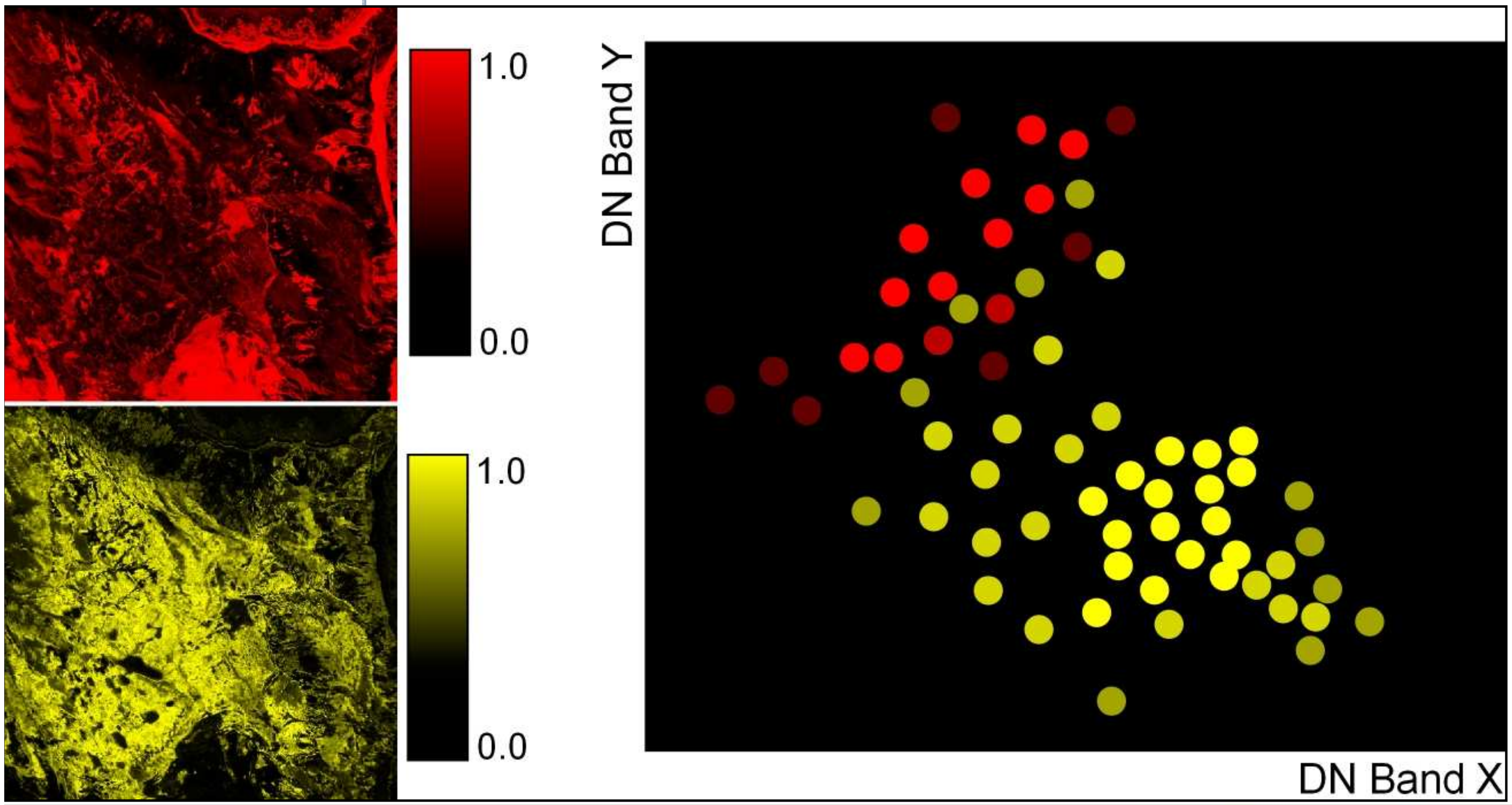
RGB Composite

R = RDA 5
G = RDA 3
B = RDA 1

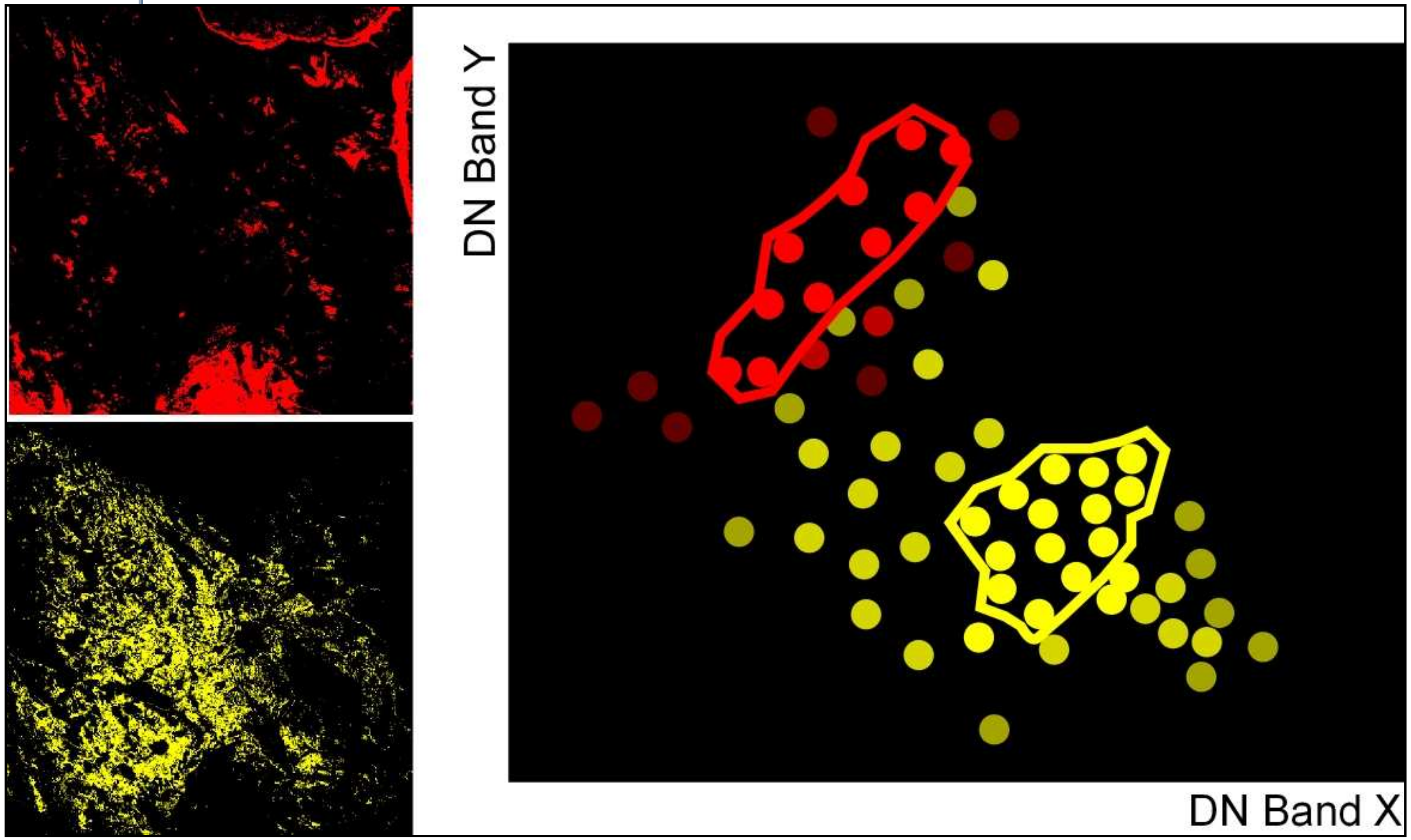


Supervised Fuzzy-C-Mean Classifyier

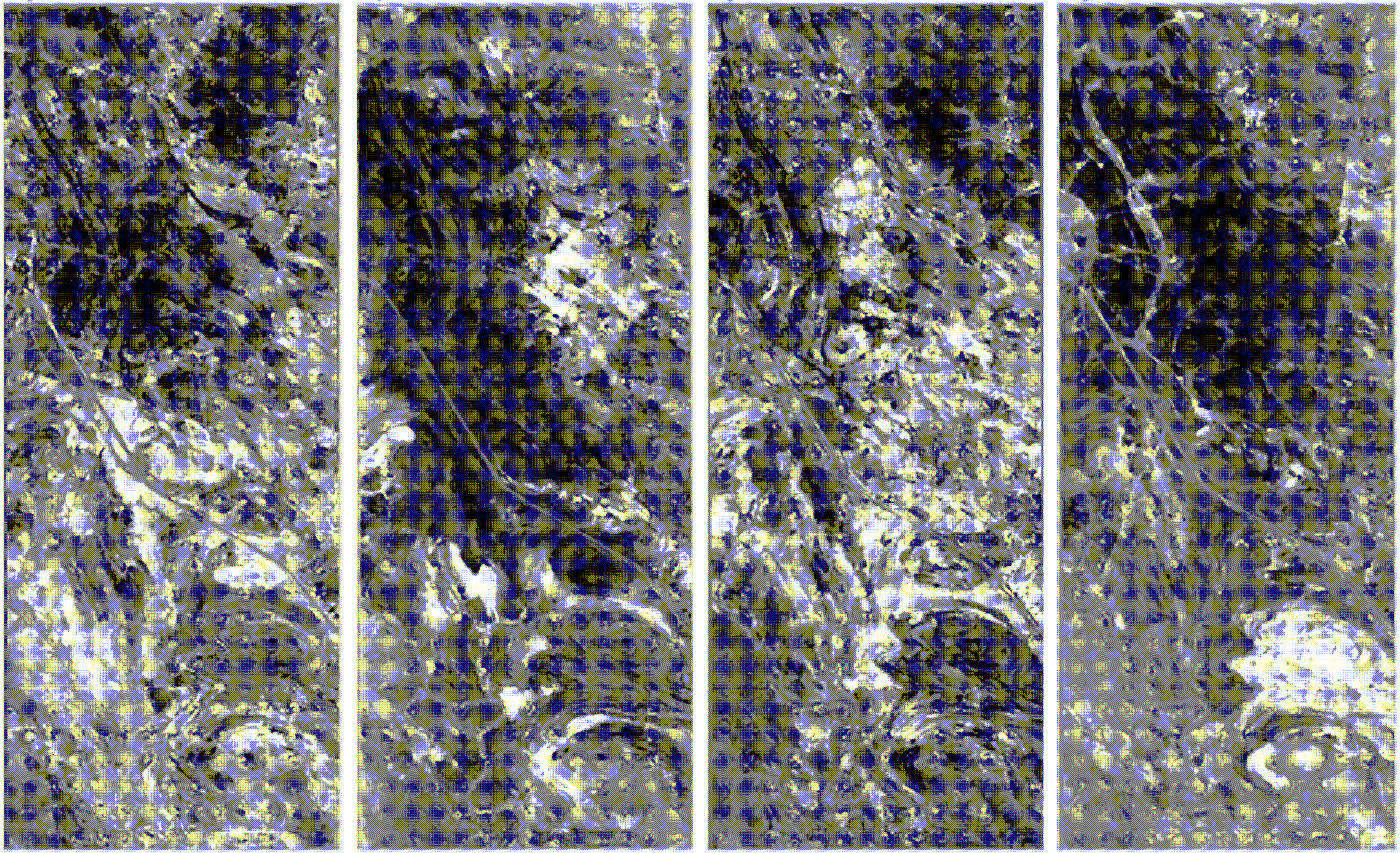
$$\mu_{ic} = \frac{[(d_{ic})^2]^{-1/(q-1)}}{\sum_{c=1}^{k}[(d_{ic})^2]^{-1/(q-1)}}$$

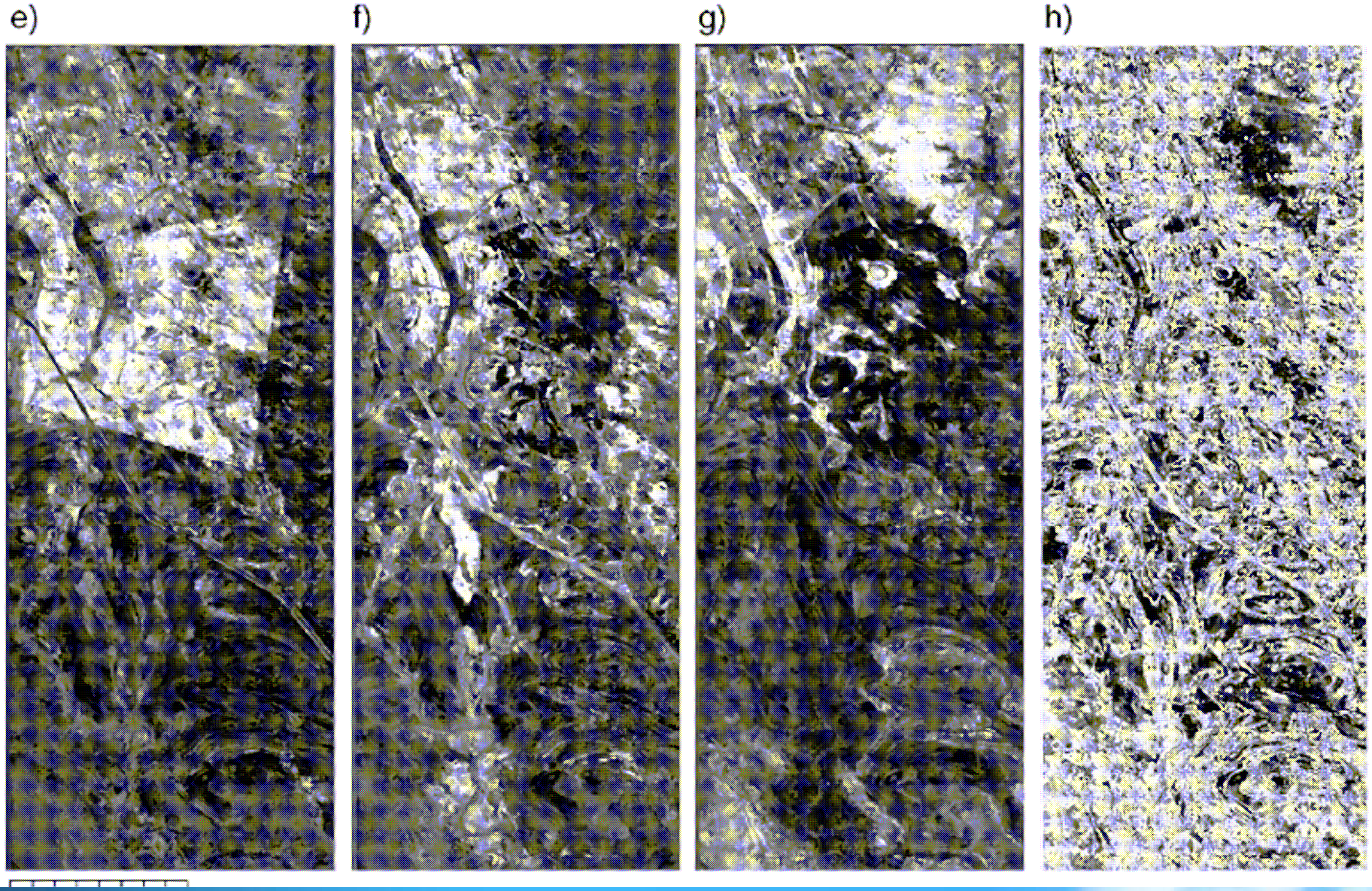


Source: Arko Lucieer
University of Tasmania


DN Band Y
DN Band X

a) b) c) d)




e)
f)
g)
h)

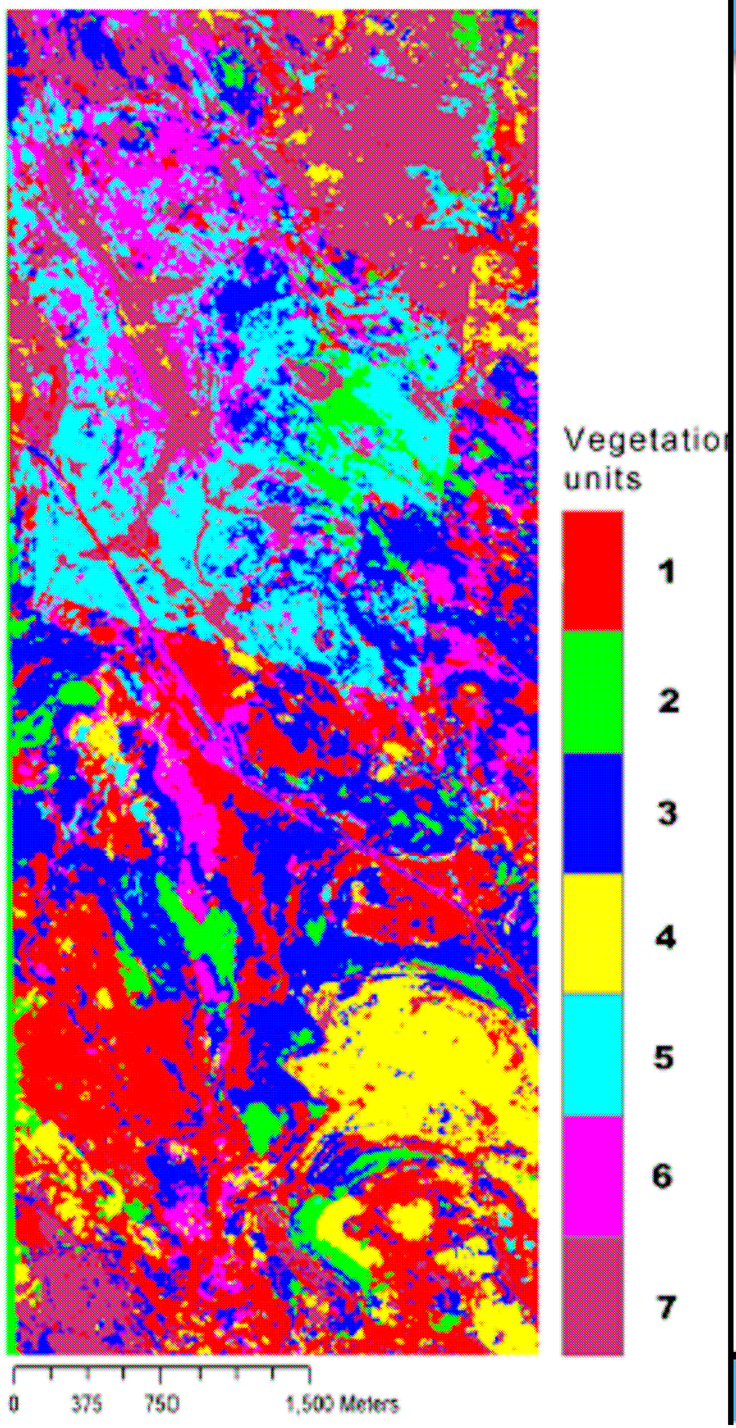


Table 5
Error matrix for eight axes solution using *k*-NN algorithm on internal validation dataset. Values represent percent of pixels classified into class.

Unit	Pixels	1	2	3	4	5	6	7	Total
Unclassified	0	0	0	0	0	0	0	0	0
1	116	93.1	0	0	0	0	0	0	15.1
2	31	0	100	0	0	0	0	0	4.34
3	195	1.72	0	97.44	0	0	0	0	26.85
4	110	0.86	0	0	100	0	0	0	15.52
5	84	4.31	0	2.05	0	100	0	0	13.01
6	71	0	0	0.51	0	0	100	0	10.07
7	108	0	0	0	0	0	0	100	15.1
Total	715	100	100	100	100	100	100	100	100

Overall accuracy = 98.18%; kappa = 0.98.

Table 6
Error matrix for eight axes solution using *k*-NN algorithm on independent validation dataset. Values represent percent of pixels classified into class. No vegetation plots from independent dataset did fit into classes four and six leaving them empty.

Unit	Pixels	1	2	3	4	5	6	7	Total
Unclassified	0	0	0	0	–	0	–	0	0
1	68	97.06	42.86	35.00	–	4.13	–	0	35.88
2	21	0	0	0	–	13.22	–	0	4.71
3	121	2.94	57.14	51.67	–	6.61	–	0	24.71
4	–	–	–	–	–	–	–	–	–
5	131	0	0	4.17	–	65.29	–	0	24.71
6	–	–	–	–	–	–	–	–	–
7	10	0	0	9.17	–	10.74	–	100	10
Total	351	100	100	100	–	100	–	100	100

Overall accuracy = 63.82%; kappa = 0.52.

Case Study: Traits and Spectra

Fourth-corner analysis of plant species traits and spectral indices derived from HyMap and CHRIS-Proba imagery

Journal:	*International Journal of Remote Sensing*
Manuscript ID:	Draft
Manuscript Type:	IJRS Research Paper
Date Submitted by the Author:	n/a
Complete List of Authors:	Oldeland, Jens; University of Hamburg, Department of Biology Wesuls, Dirk; University of Hamburg, Department of Biology Jürgens, Norbert; University of Hamburg, Department of Biology
Keywords:	HYPERSPECTRAL DATA, VEGETATION INDEX, ECOLOGY, SEMI-ARID LAND
Keywords (user defined):	Plant Functional Type, scale, RLQ

Spectral Indices

Table 1. Spectral indices used in this study. The spectral ranges of Visual to Near-Infrared (VNIR) comprise 400-1000µm while the Shortwave Infrared (SWIR) covers 1000-2.480µm.

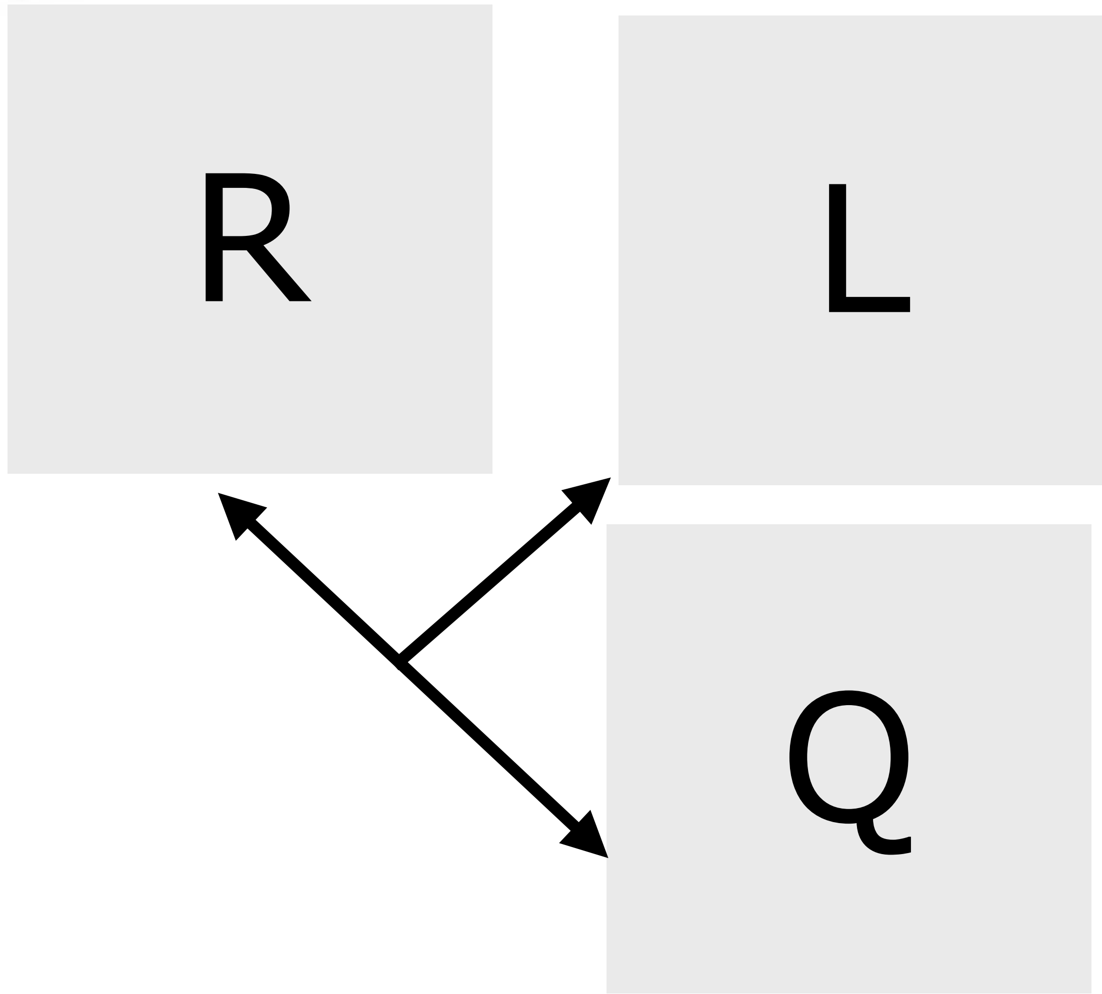
Nr.	Full name and Abbreviation	Spectral Range	Feature	Reference
1	Normalized Difference Vegetation Index (NDVI)	VNIR	Greenness	Rouse *et al.* (1973)
2	Triangular Vegetation Index (TVI)	VNIR	Greenness	Broge & Leblanc (2001)
3	Derivative Green Vegetation Index (DGVI)	VNIR	Greenness	Elvidge & Chen (1995)
4	Chlorophyll Absorption in Reflectance Index (CARI)	VNIR	Chlorophyll	Kim *et al.* (1994)
5	Photochemical Reaction index (PRI)	VNIR	Pigments	Gamon *et al.* (1997)
6	Cellulose Absorption Index (CAI)	SWIR	Cellulose	Nagler *et al.* (2003)
7	Normalized Difference Lignin Index (NDLI)	SWIR	Lignin	Serrano *et al.* (2002)
8	Normalized Difference Index (NDI)	SWIR	Soil/Litter	McNairn & Protz (1993)
9	Normalized Difference Nitrogen Index (NDNI)	SWIR	Nitrogen	Serrano *et al.* (2002)
10	Moisture Stress Index (MSI)	SWIR	Water	Hunt & Rock (1989)

Plant Traits

Table 2. Plant functional traits used in the Q-Table: attributes of categorical traits and units for quantitative traits including abbreviations and explanations.

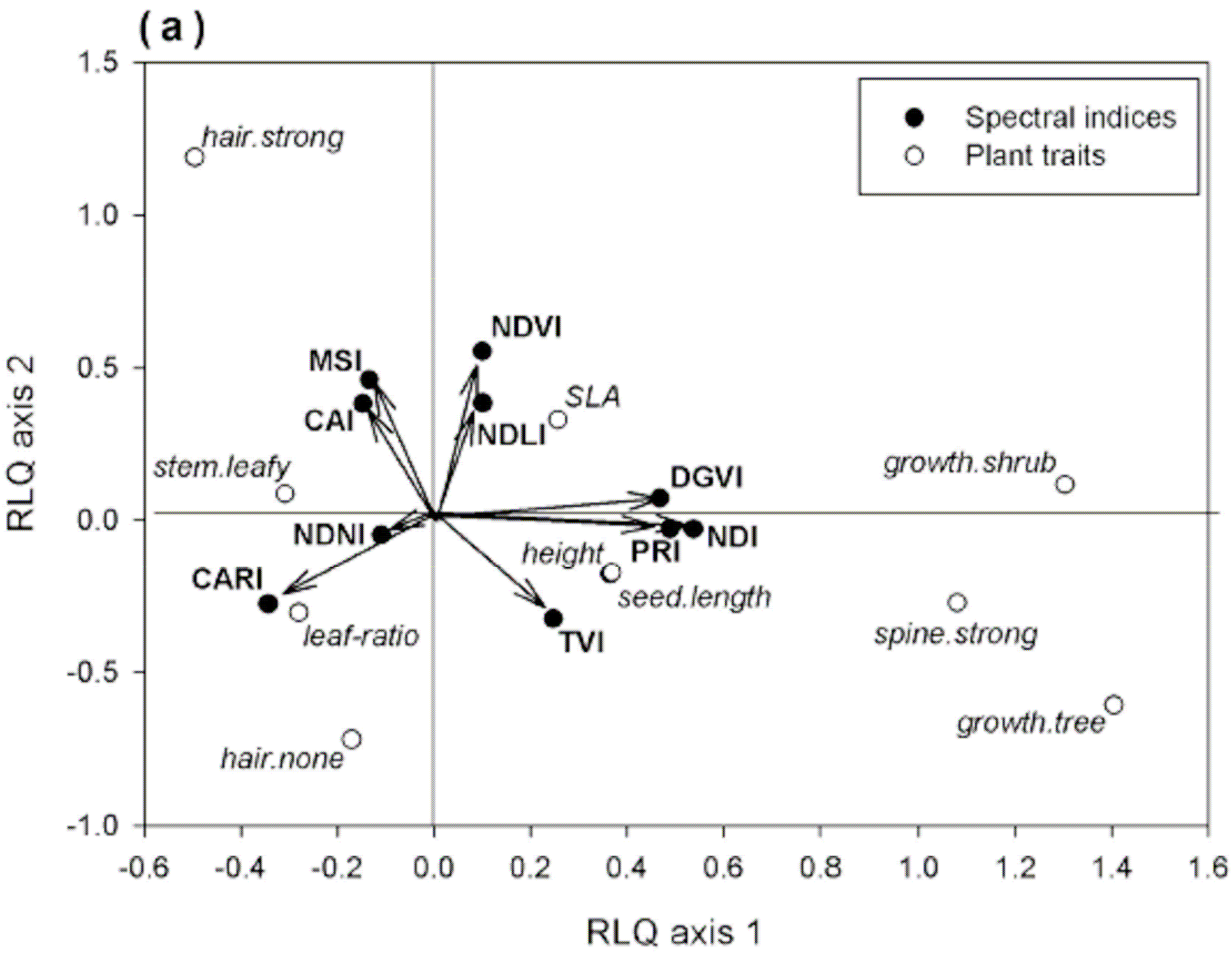
Traits	Abbreviation	Trait attributes of categorial traits, units of quantitative traits
Whole plant traits		
Growth form	gB, gD, gF, gS, gT	bulb, dwarf shrub, forb, shrub, tree,
Height		plant maximum height [cm]
Above Cover Density	ACD	percentage cover of the plant canopy [%]
Stem-leaf ratio	stL,stM,stS	leafy, moderately leafy, stemmy
Spinescence	sN, sS, sI, sD	none, sparse, intermediate, dense
Hairiness	hN, hS, hI, hD	none, sparse, intermediate, dense
Waxes	wY, wN	yes, no
Leaf traits		
Leaf consistency	lSoM, lHM, lScM, sSS	soft mesomorphic, hard mesomorphic, scleromorphic, subsucculent
Leaf ratio	leafratio	leaf length [mm] divided by leaf width [mm]
Leaf height		leaf height (thickness) [mm]
Leaf area		leaf area [mm²]
Specific Leaf Area	SLA	specific leaf area [mm²/mg], i.e., leaf area divided by dry weight of the leaf
Regenerative traits		
Seed length		length of seed [mm]

- Environment

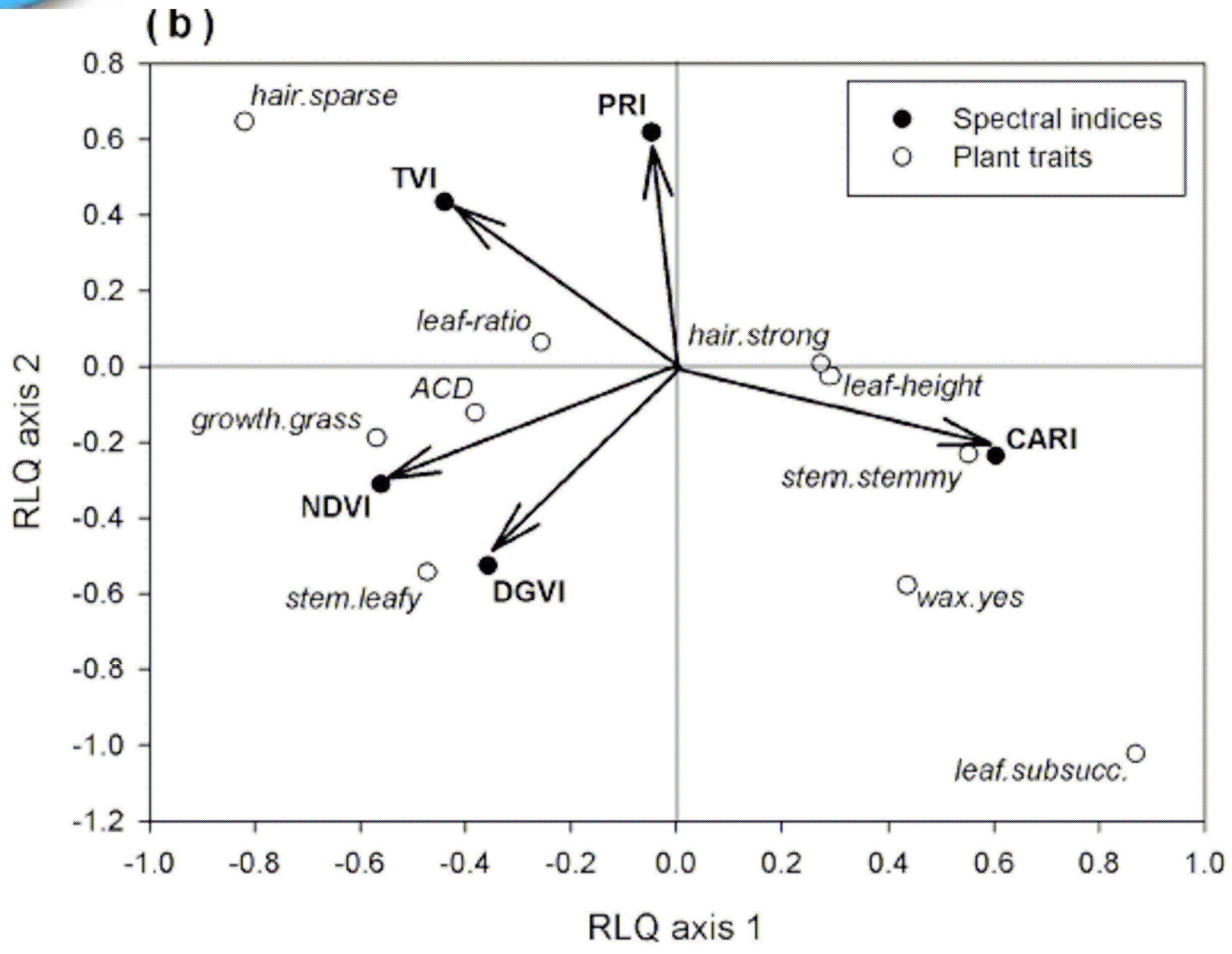


- Species
- Traits

HyMap-RLQ


(a)
Spectral indices
Plant traits
hair.strong
stem.leafy
MSI
CAI
NDVI
NDLI
SLA
DGVI
growth.shrub
NDNI
NDI
PRI
height
seed.length
CARI
leaf-ratio
TVI
spine.strong
growth.tree
hair.none
RLQ axis 2
RLQ axis 1
1.5
1.0
0.5
0.0
-0.5
-1.0
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

CHRIS-RLQ


(b)
Spectral indices
Plant traits
hair.sparse
PRI
TVI
leaf-ratio
hair.strong
leaf-height
ACD
growth.grass
CARI
stem.stemmy
NDVI
stem.leafy
DGVI
wax.yes
leaf.subsucc.
RLQ axis 2
RLQ axis 1
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0

EV-RLQ

Table 3. Summarizing statistics for RLQ. The first two components of the HyMap RLQ explain more than 90% of the variation and show high correlation ratio values with the species table (L-Table). The first two components of the CHRIS-RLQ explain only 84% of the variation and show low correlation ratio values with the species table (L-Table).

Sensor	RLQ	Eigenvalue	Covariance	Inertia	$corr_L$
HyMap	1	1.812	1.35	0.76	0.35
	2	0.425	0.65	0.93	0.29
Chris	1	0.068	0.26	0.67	0.10
	2	0.017	0.13	0.84	0.06

- Rand permutation test not significant for CHRIS ! P =0.22

Table 5. Direct correlation of traits and spectral indices based on fourth-corner-statistic. correlation statistics. Positive or negative signs indicate direction of correlation. Correlations are based on the D2-Metric (Dray and Legendre 2008).

	HyMap D2 p=0.05										CHRIS D2 p=0.05				
Spectral	VNIR					SWIR					VNIR				
Traits	NDVI	TVI	DGVI	CARI	PRI	CAI	NDLI	NDI	NDNI	MSI	NDVI	TVI	DGVI	CARI	PRI
gB															
gD															
gF															
gG															
gS				-	+										
gT			+		+			+							
hI									-						
hN	-						-			-					
hSp															
hSt		-								+					
lHM															
lScM															
lSoM															
lSS															
sI															
sN			-		-			-							
sSp															
sSS		+	+		+			+							
stL			- -		-	+		-							
stM						-									
stS														++	
wN														-	
wY														+	
ACD											++		+	-	
height		+	+ +		++			++							
leaf.area															
leaf.height														+	
leaf.ratio	-		- - -	+	-		- -	-	+ +					-	
seed.length		++	+ +	-	+++			++		-					
SLA	+		+	- -	+			+							

+/- p <= 0.5 ; ++/-- p < =0.01; +++/--- p < 0.001

Case Study: Biomass

Tropentag 2009

Monitoring and assessment of desertification

Spatial Extrapolation of Biomass Measurements in Savannah Ecosystems by Means of Remote Sensing

Jens Oldeland[1,2] & Lena Lieckfeld[1,2]

[1]Universität Hamburg, Biozentrum Klein Flottbek, Hamburg
[2]Deutsches Fernerkundungs-Datenzentrum (DFD) des DLR, Oberpfaffenhofen

Universität Hamburg
Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Background

- Plant biomass is the weight of „organic“ material in a defined area , usually in [Kg/ha]
- Plant biomass is an indicator of ecosystem condition
- Comparing different ecosystem states → Degradation?
- Methods for Spatial recognition and quantification of degradation processes needed !

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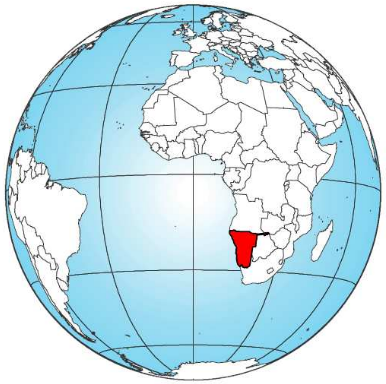
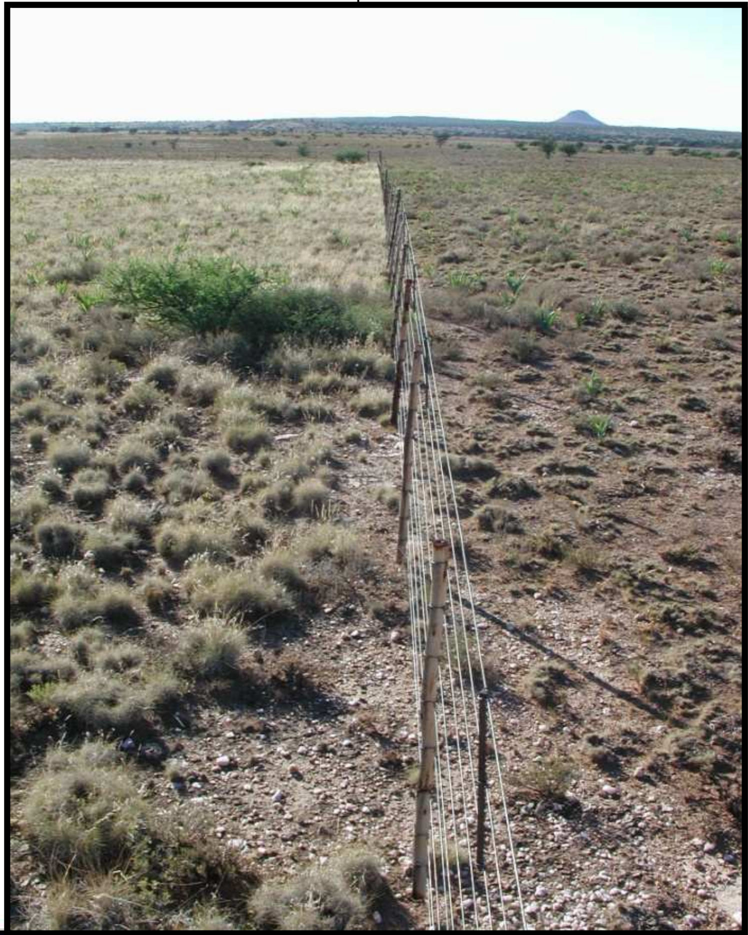
Motivation

- Sampling of biomass, usually destructive by „clipping“ small areas, e.g. $1m^2$
- Non-destructive methods needed for sampling
- Sampling has to be effecient (time & money)
- Spatial extrapolation of field measurements required

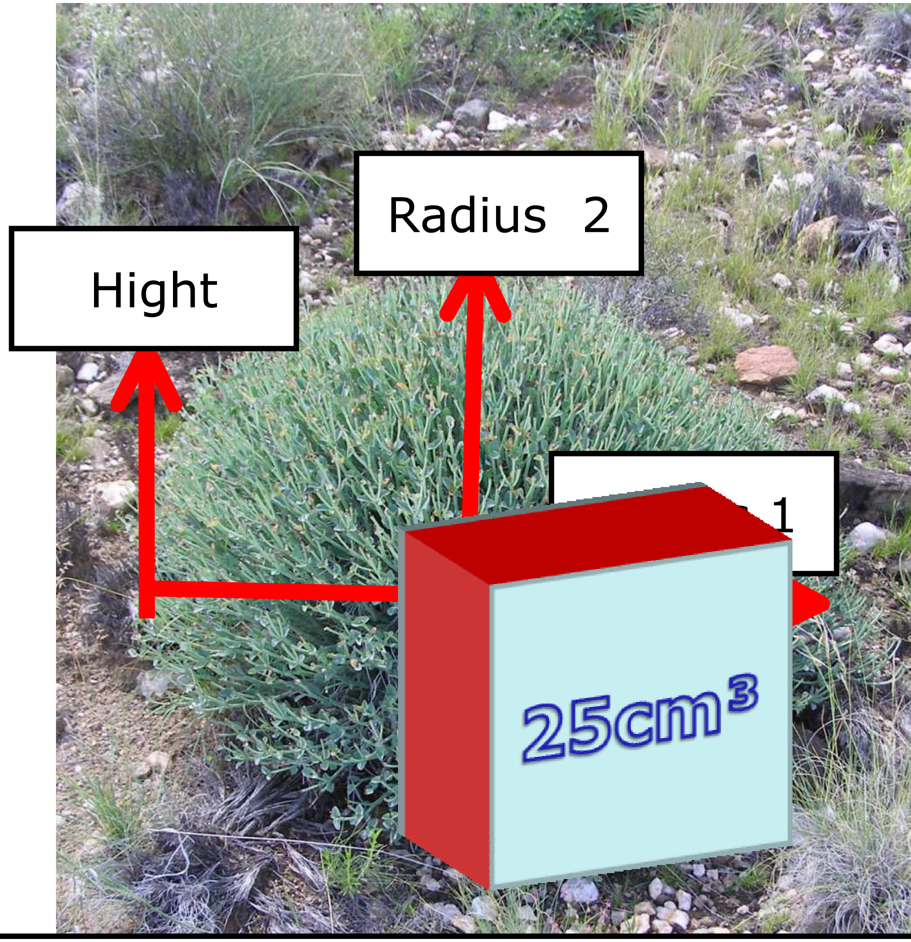
Apply a **cost-efficient non-destructive biomass sampling** in a Namibian rangeland **within one week** and use hyperspectral **remote sensing** products for **spatial extrapolation** of plant biomass.

Study Area



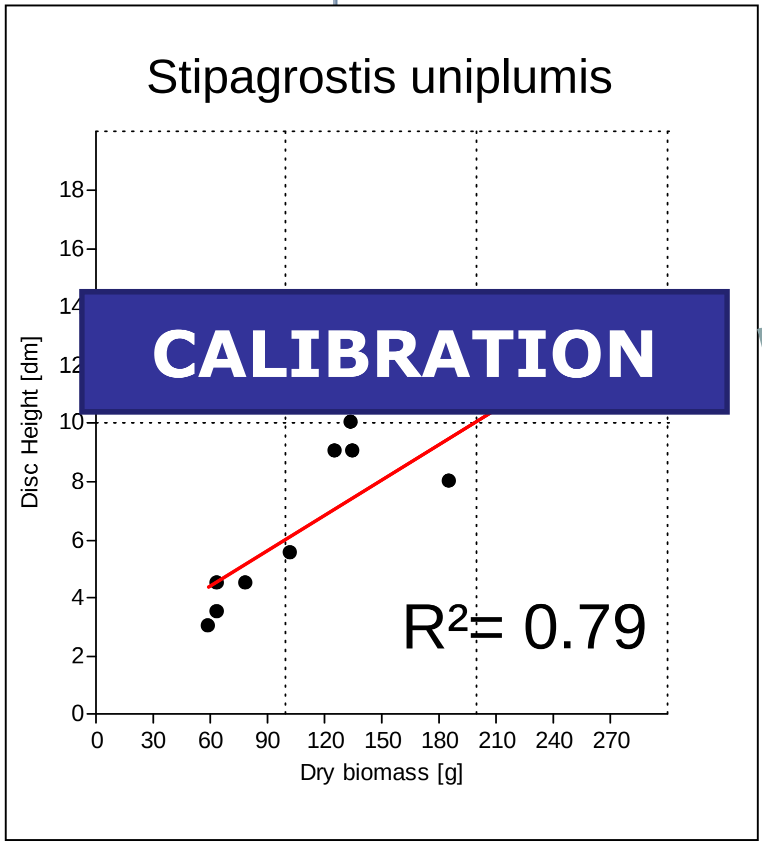


Plot based Biomass measurements



Jones, E. W. G. (2000). Non-destructive Sampling of Cretan Garigue Biomass as Ground Truth for Remote Sensing. Vegetation Mapping: From Patch to Planet. R. Alexander and A. C. Millington. Chichester, John Wiley

Biomass calculations



Field Measurements

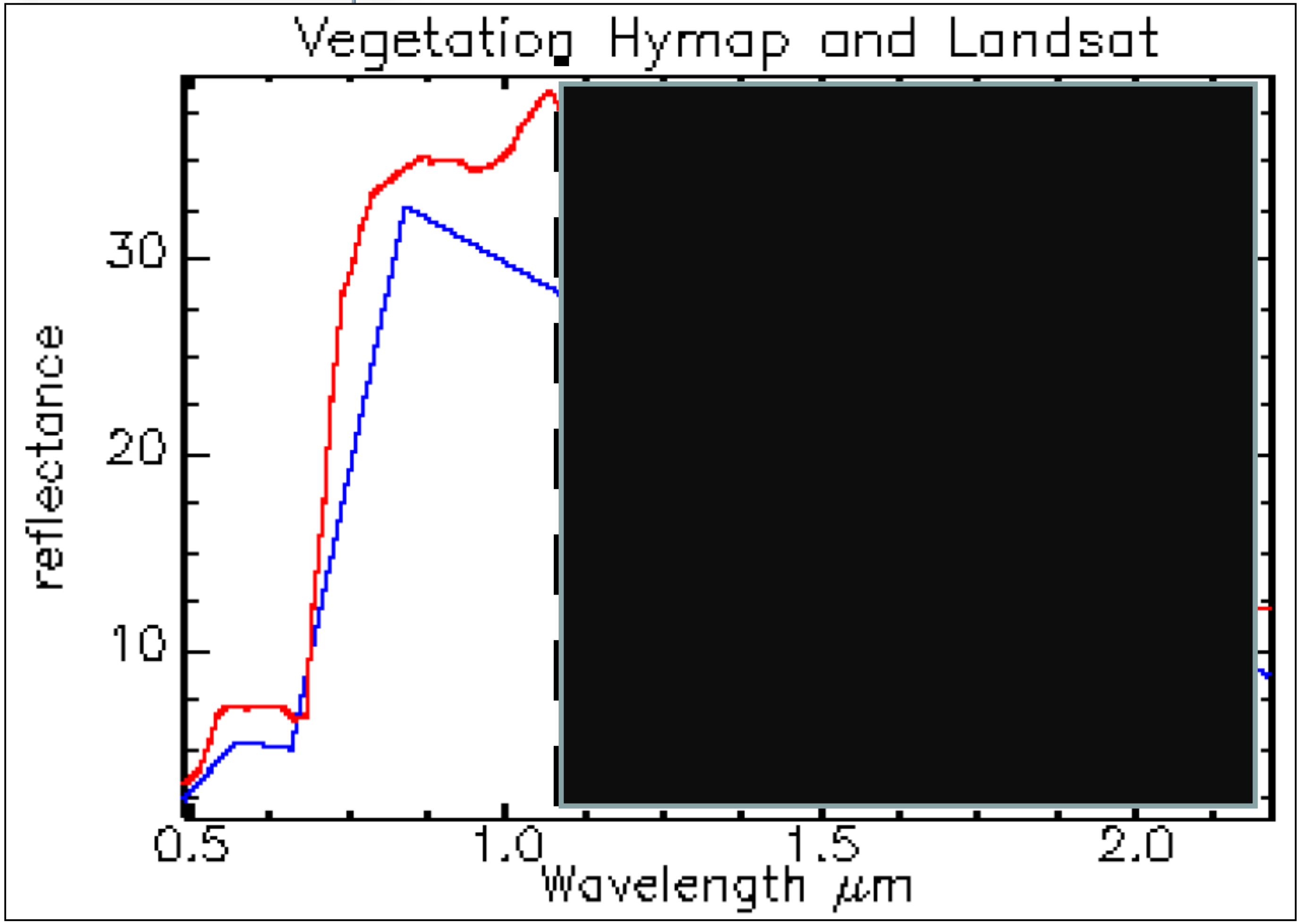
Mean Kg/ Species

∑(Cover [%] / Species)

∑(Species [Kg/625m²])

Total Biomass per Plot [Kg/625m²]

Hyperspectral Remote Sensing



Spatial res.: 32m/17m
Temp.res: on demand
Channels: 32 / 64
Platform: Satellite
System: Hyper.
Costs: Free (Science)

CHRIS-Proba: http://earth.esa.int/missions/thirdpartymission/p

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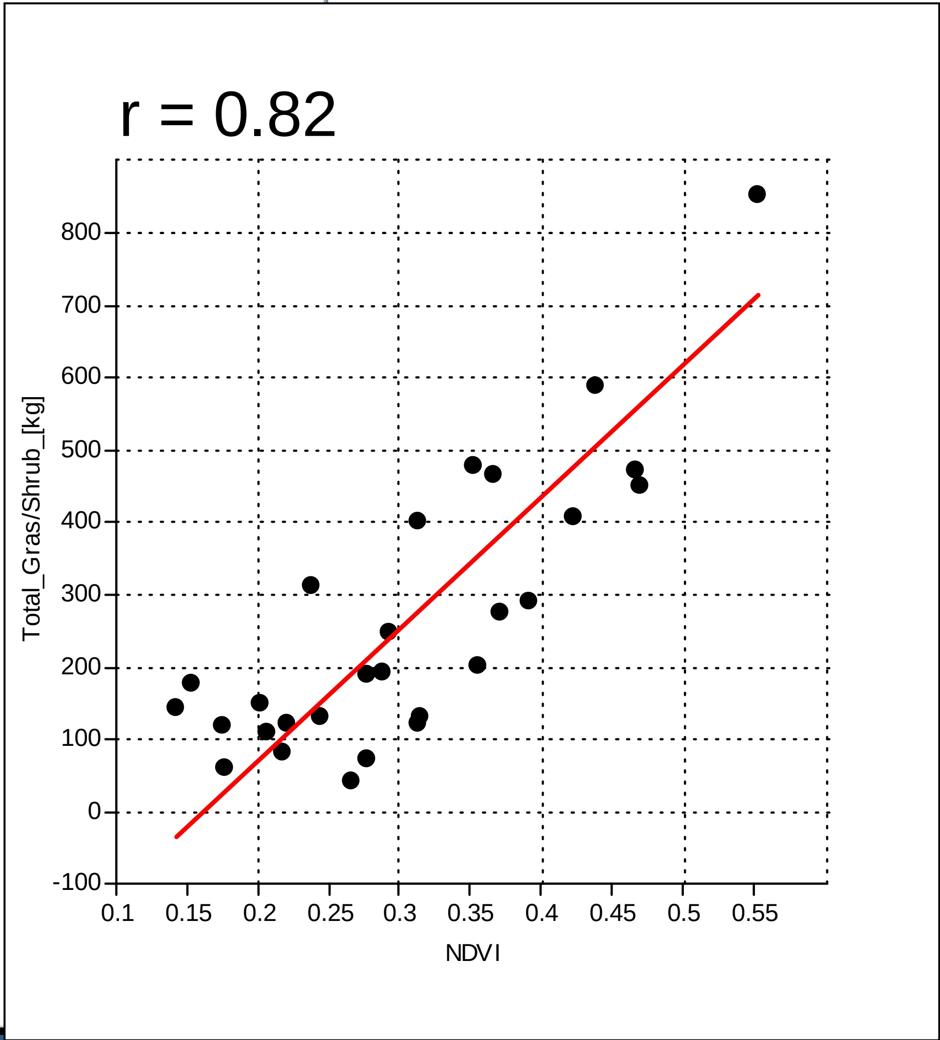
Spectral Indices

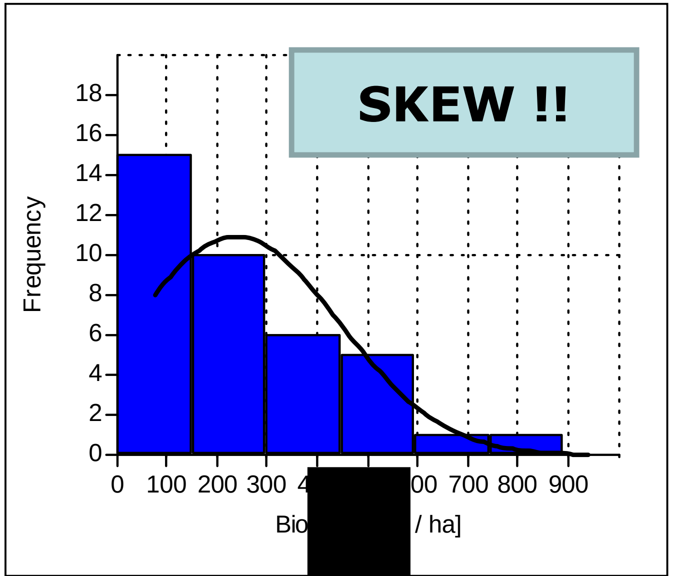
Index	*Information on…*	*Index class*
NDVI	**Greeness**	**VI-Broad**
EVI	**Greeness**	**VI-Broad**
Vogelmann 1	**Greeness**	**VI-Narrow**
ATSAVI	**Greeness**	**VI-Narrow**
PRI	**Carot/Chloro**	**Light Use Efficency**
RedGreenRatio	**Carot/Chloro**	**Light Use Efficency**
SR705	**Chlorophyll**	**Pigment Index**
MCARI2	**Carotenoid**	**Pigment Index**
AnthoRef 1	**Anthocyan**	**Pigment Index**
NDLI	**Lignin**	**Foliar Chemistry**
NDNI	**Nitrogen**	**Foliar Chemistry**
CAI	**Cellulose**	**Foliar Chemistry**
PSRI	**Plant Senescence**	**Foliar Chemistry**
NDWI_MIR	**Canopy Water +**	**Foliar Water**
MSI	**Canopy Water -**	**Foliar Water**
SWIR_Soil	**Curve in SWIR**	**Soil Index**
Brightness Index	**brightness**	**Soil Index**
Redness Index	**iron**	**Soil Index**
Saturation Index	**Soil saturaton**	**Soil Index**
NDI	**Discriminates Litter & Soil**	**Soil Index**

Model

N= 40

N= 30

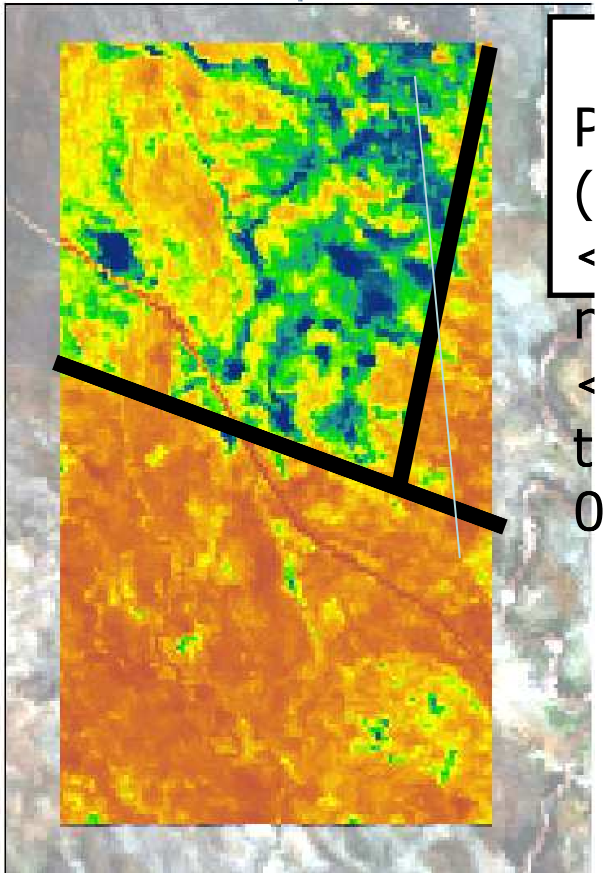


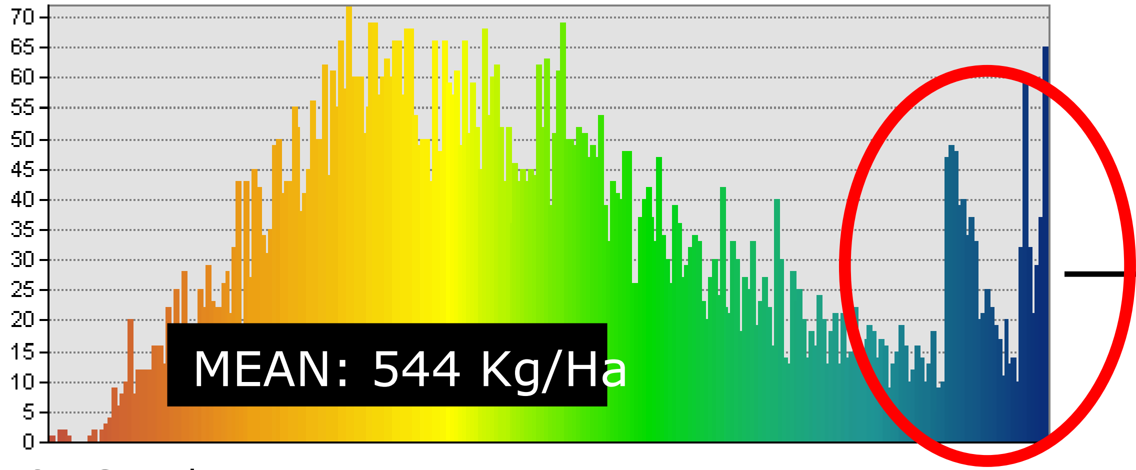


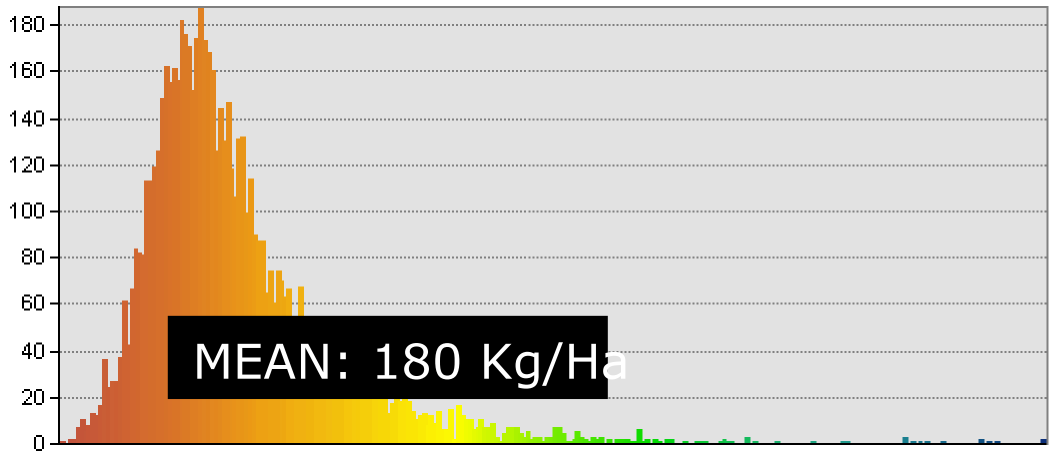
Generalized Linear Model GLM (poisson link)

Biomass map and quantification

GLM(Biomass~ MCARI2+TVI ,family=pois







R^2: 0.713, p = <0.001

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Conclusion

- Biomass maps were produced by combining field measurements and remote sensing products
- Rapid biomass sampling was applied to get quick results
- Sampling has to be adjusted to Remote Sensing
- Good regression calibration is needed, otherwise not all measured species can be considered
- However, one week is not enough! Sampling should be iterative and resampling when necessary
- Biomass maps based on simple field measurements can quantify ecosystem states and allow comparisons

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Case Study: Invasive Species

Remote Sens. **2010**, *2*, 1416-1438; doi:10.3390/rs2061416

OPEN ACCESS

Remote Sensing

ISSN 2072-4292

www.mdpi.com/journal/remotesensing

Article

Mapping Bush Encroaching Species by Seasonal Differences in Hyperspectral Imagery

Jens Oldeland [1,2,*], Wouter Dorigo [3], Dirk Wesuls [1] and Norbert Jürgens [1]

[1] Biocentre Klein Flottbek and Botanical Garden, University of Hamburg, Hamburg, Germany; E-Mails: dirk.wesuls@botanik.uni-hamburg.de (D.W.); norbert.juergens@botanik.uni-hamburg.de (N.J.)

[2] German Remote Sensing Data Center, German Aerospace Center, Oberpfaffenhofen, Germany

[3] Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Vienna, Austria; E-Mail: wd@ipf.tuwien.ac.at

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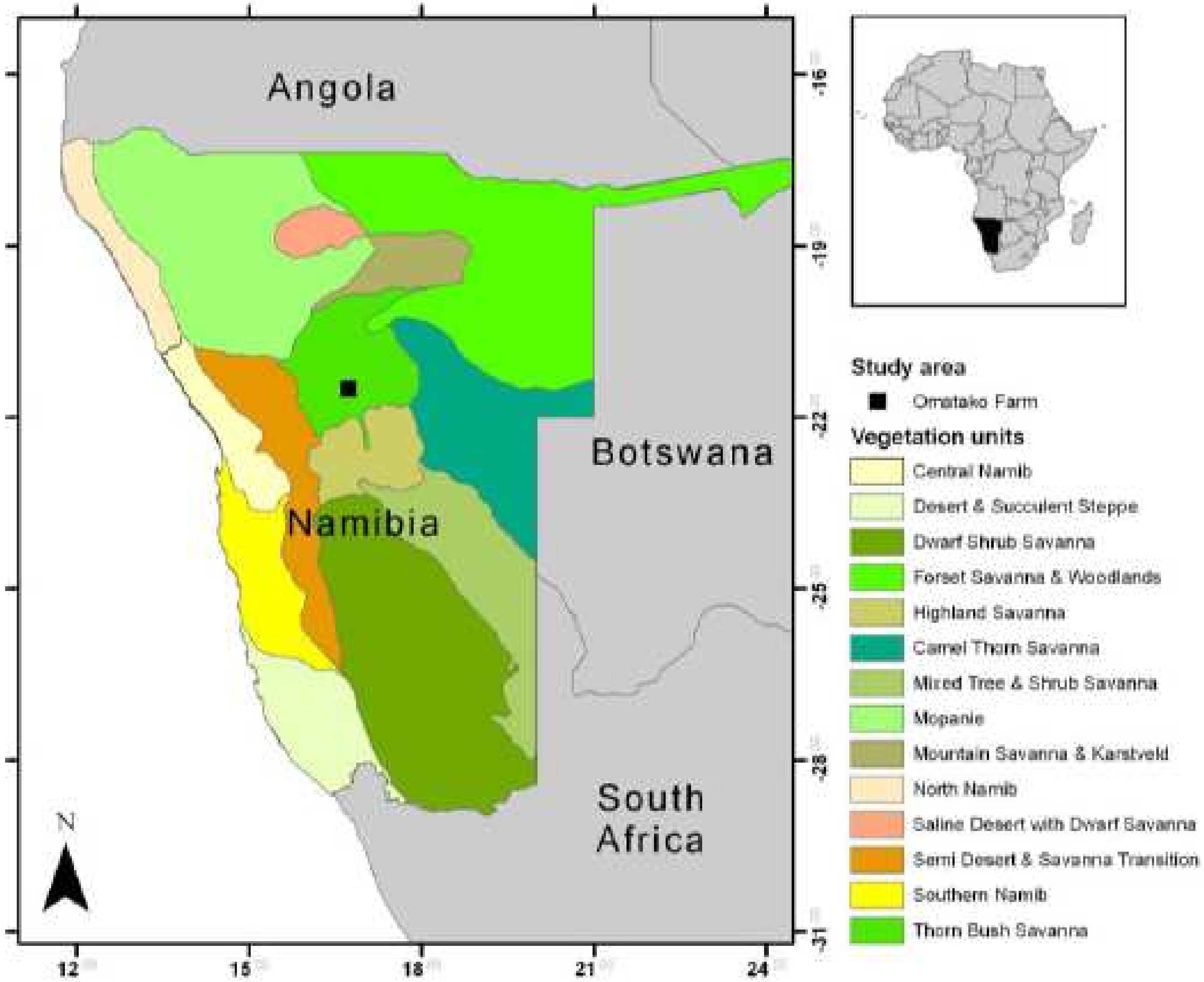
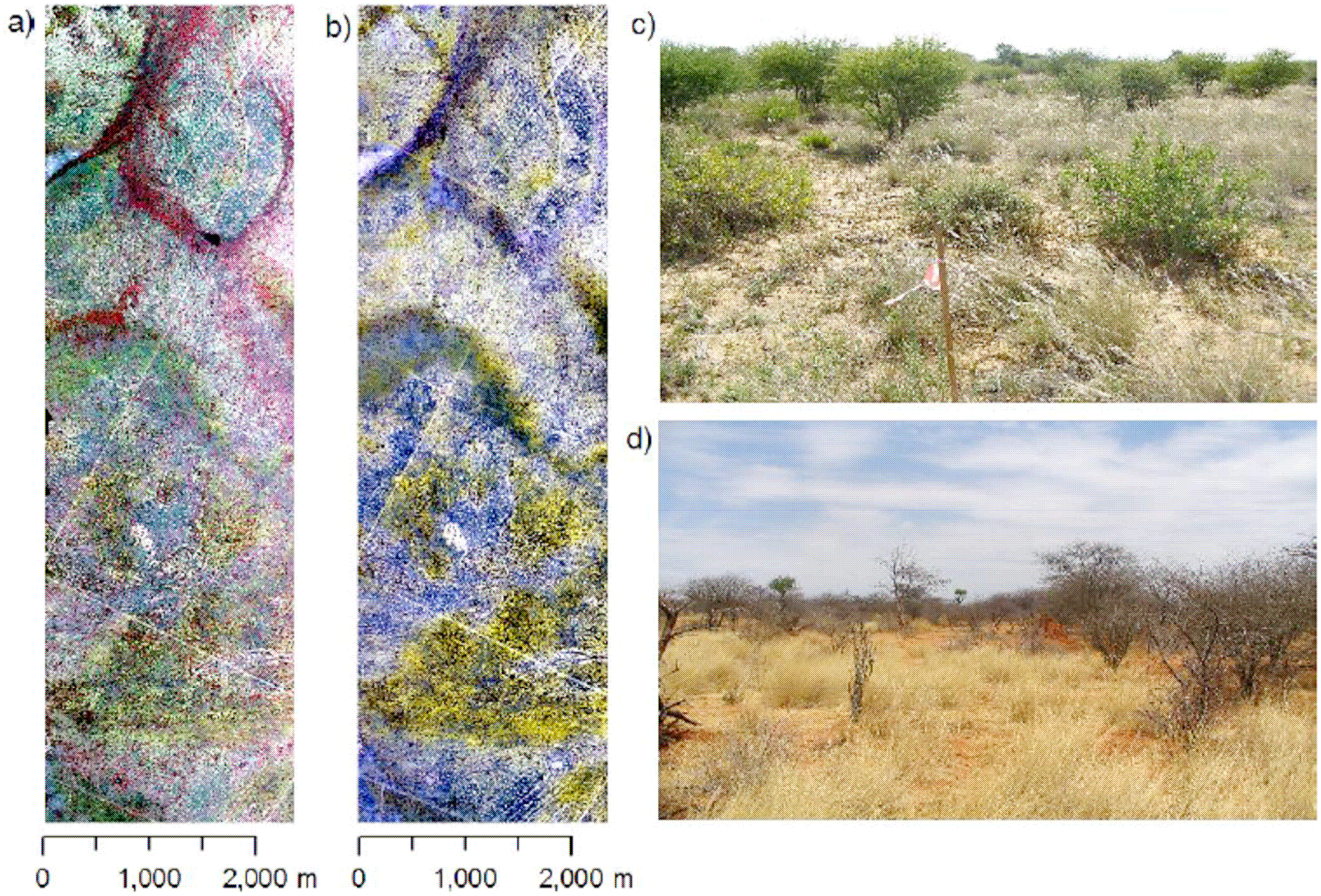


Thornbush Savannah

Seasonal difference



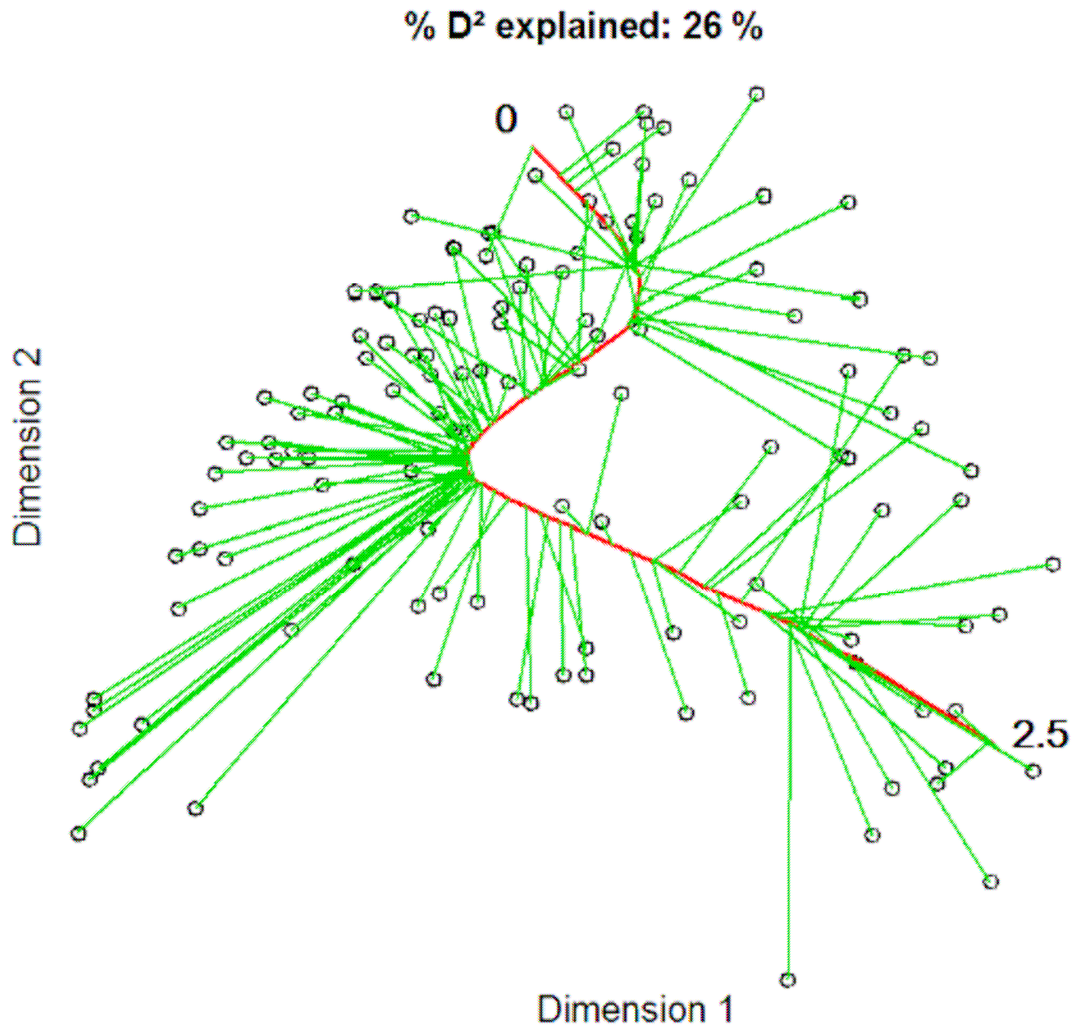
Selected Indices for Differencing

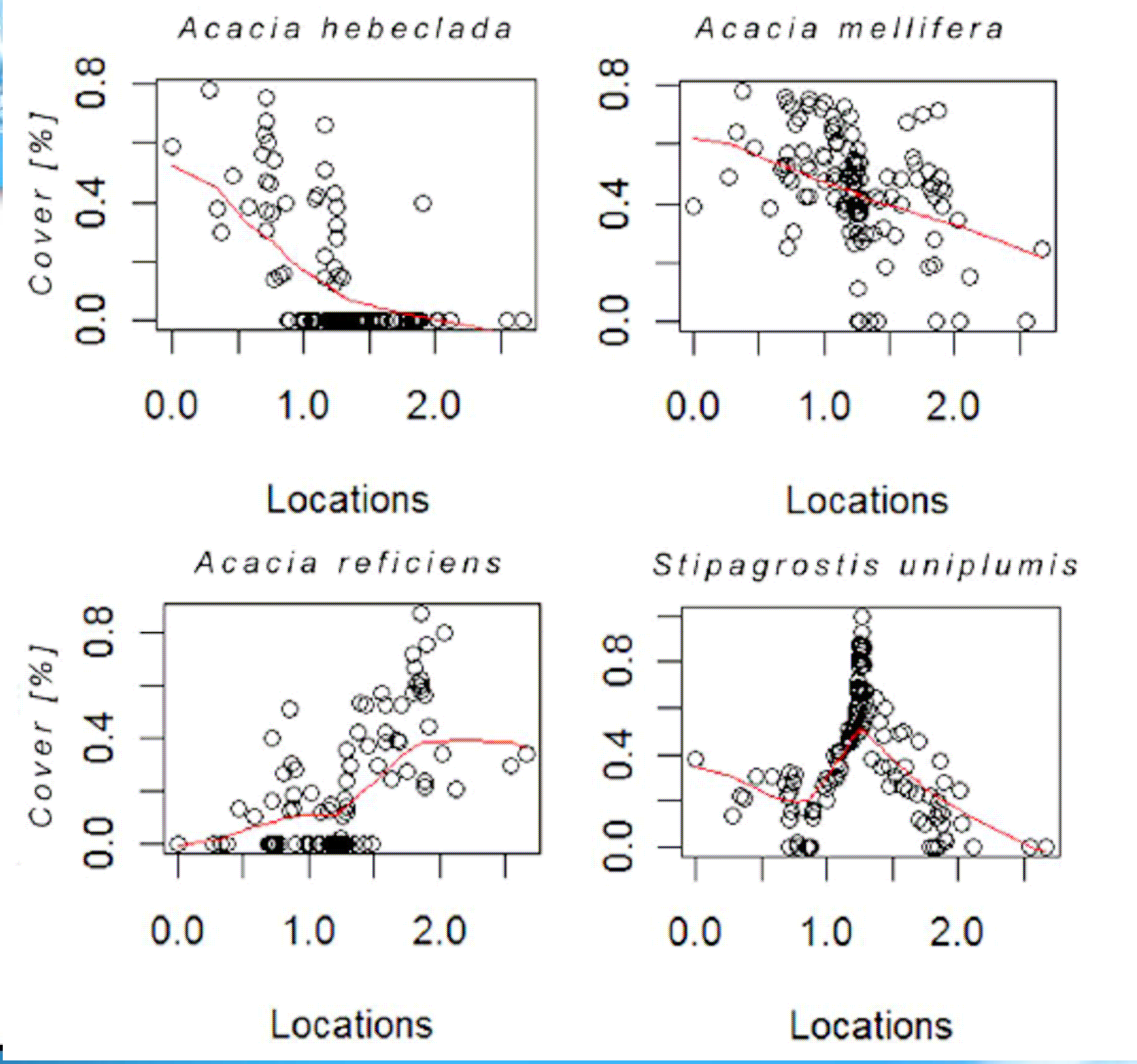
Table 1. Overview of the selected vegetation indices and their canopy related feature. For index formulas see Dorigo *et al*. [39].

Nr.	Index	Full name	Feature	Reference
1	CARI	Chlorophyll Absorption in Reflectance Index	Chlorophyll	[40]
2	DGVI	Derivative Green Vegetation Index (1st order)	Greenness	[41]
3	LWVI	Leaf Water Vegetation Index	Water	[42]
4	NDLI	Normalized Difference Lignin Index	Lignin	[43]
5	NDNI	Normalized Difference Nitrogen Index	Nitrogen	[43]
6	CAI	Cellulose Absorption Index	Cellulose	[44]

- [39] Dorigo, W.; Richter, R.; Baret, F.; Bamler, R.; Wagner, W. Enhanced automated canopy characterization from hyperspectral data by a novel two step radiative transfer model inversion approach. *Remote Sens*. **2009**, *1*, 1139-1170.

Constrained Principal Curve




Acacia hebeclada
Acacia mellifera
Acacia reficiens
Stipagrostis uniplumis
Cover [%]
0.0
0.4
0.8
0.0
1.0
2.0
Locations

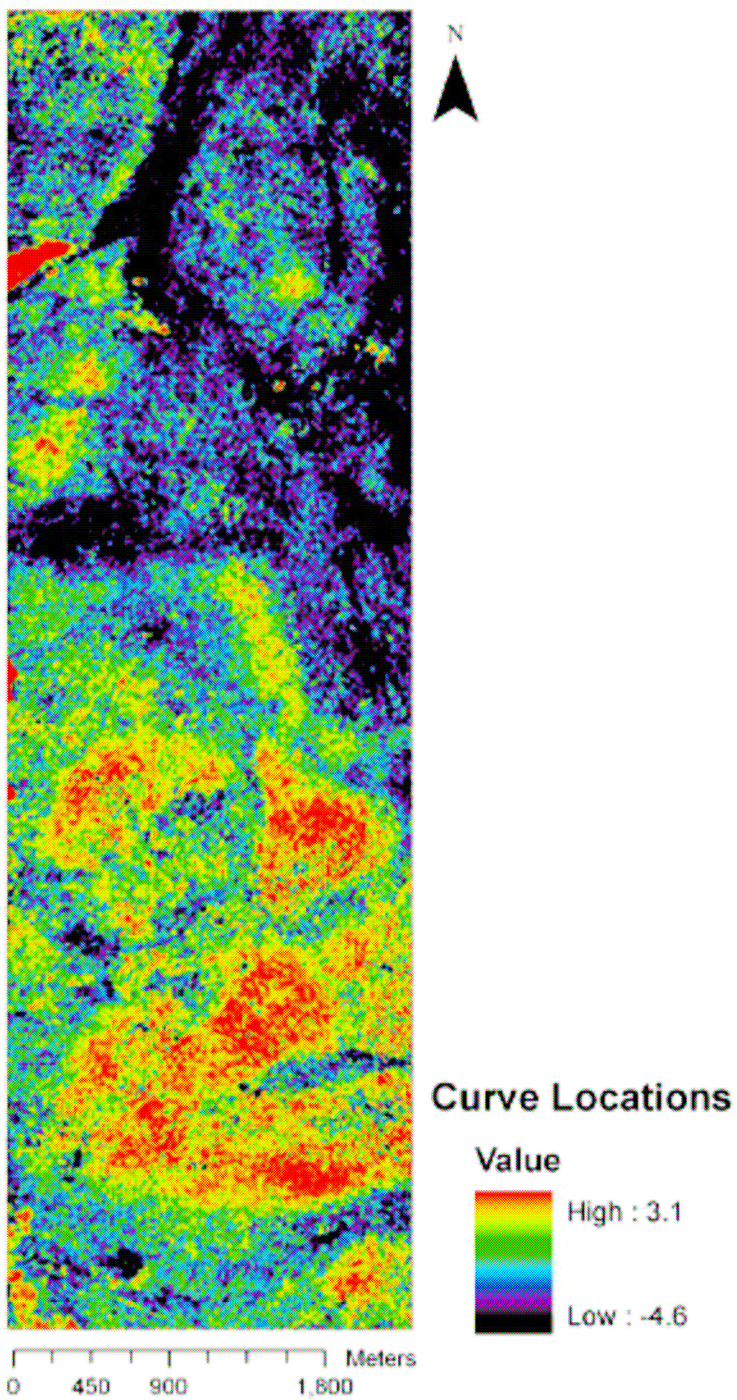
Info

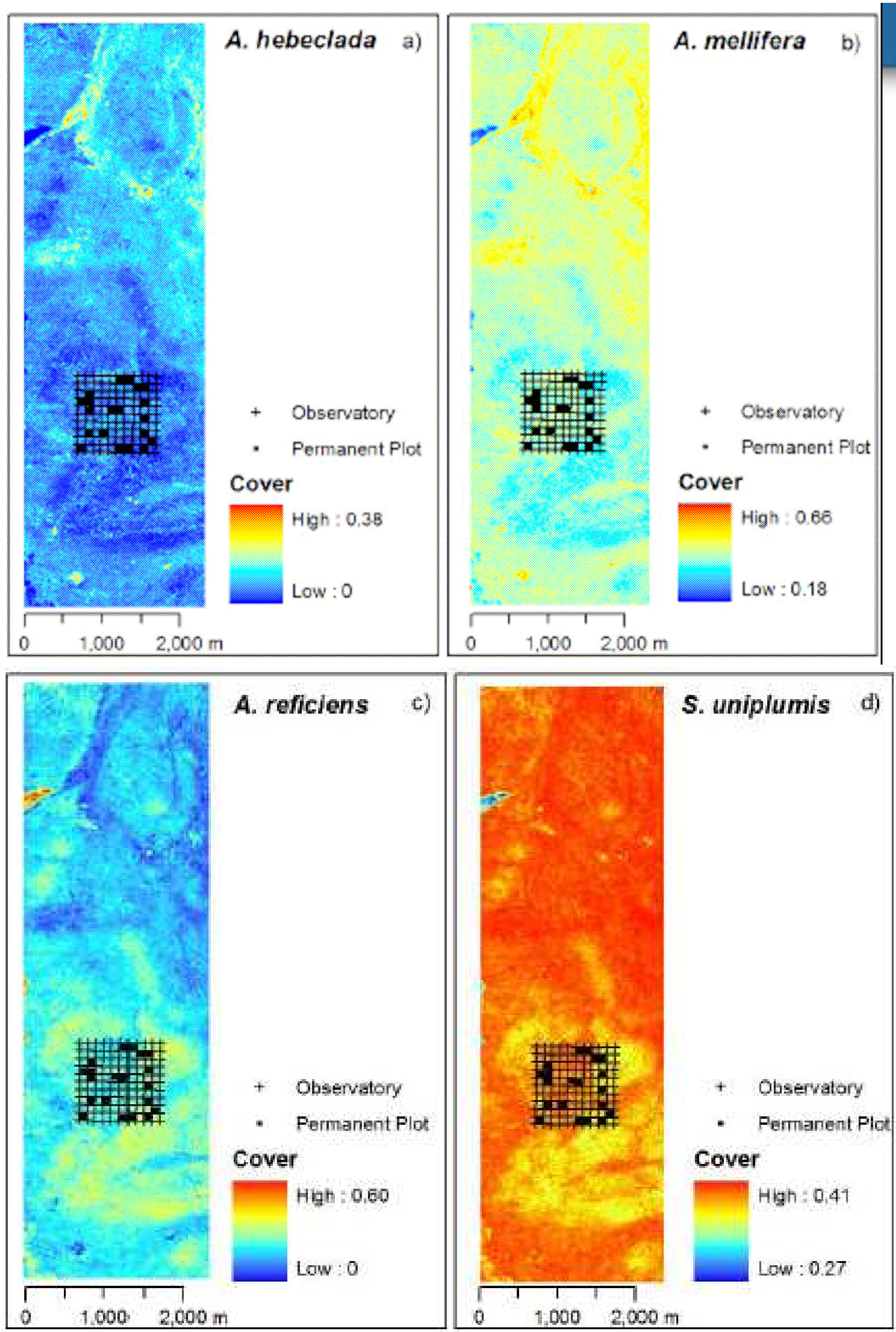
Regression coefficients

Table 2. Regression coefficients of the final partial linear model.

	slope	Std. Error	t value	p
intercept	2.6646	0.3826	6.9647	<0.001
Δ CARI	−3.7014	0.6685	−5.5365	<0.001
Δ LWVI	38.5399	9.4153	4.0933	<0.001
Δ CAI	10.3821	4.5146	2.2997	<0.05
Δ NDLI	−18.3285	13.1827	−1.3903	<0.1
Δ NDNI	−32.9389	5.589	−5.8935	<0.001
Δ DGVI	14.3914	3.4836	4.1312	<0.001

R^2: 0.53, p => 0.001


N
Curve Locations
Value
High : 3.1
Low : -4.6
Meters
0
450
900
1,800


A. hebeclada
a)
Observatory
Permanent Plot
Cover
High : 0.38
Low : 0
0
1,000
2,000 m
A. mellifera
b)
Observatory
Permanent Plot
Cover
High : 0.66
Low : 0.18
0
1,000
2,000 m
A. reficiens
c)
Observatory
Permanent Plot
Cover
High : 0.60
Low : 0
0
1,000
2,000 m
S. uniplumis
d)
Observatory
Permanent Plot
Cover
High : 0.41
Low : 0.27
0
1,000
2,000 m

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External validation

Table 3. External validation of the species cover maps for two plot sizes. The number of plots where a species occurs (n) is given per plot size. Parametric (Pearson) and non-parametric (Spearman) correlation values are shown. The p-value is based on a two-tailed probability test for correlating values. The column 'year' marks the year with the highest correlation values found.

Size	Species	n	Pearson's r	p	year	Spearmann's r	p	year
10 × 10	*A.hebeclada*	3	−0.11	0.642	2004	−0.27	0.248	2004
	A.mellifera	12	0.54	0.014	2005	0.21	0.375	2005
	A.reficiens	9	0.23	0.333	2005	0.46	0.043	2004
	S.uniplumis	20	0.37	0.105	2005	0.32	0.174	2005
20 × 50	*A.hebeclada*	6	0.13	0.592	2004	0.18	0.443	2004
	A.mellifera	19	0.45	0.047	2004	0.45	0.049	2004
	A.reficiens	17	0.32	0.165	2005	0.52	0.020	2005
	S.uniplumis	20	0.38	0.099	2004	0.26	0.262	2005

Case Study: Biodiversity

Ecological Indicators 10 (2010) 390–396

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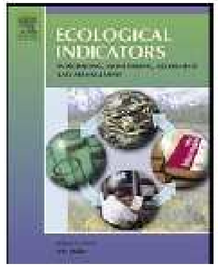
journal homepage: www.elsevier.com/locate/ecolind



Does using species abundance data improve estimates of species diversity from remotely sensed spectral heterogeneity?

Jens Oldeland [a,d,*], Dirk Wesuls [a], Duccio Rocchini [b,c], Michael Schmidt [d], Norbert Jürgens [a]

[a] University of Hamburg, Biocentre Klein Flottbek, Ohnhorststrasse 18, 22609 Hamburg, Germany
[b] Università di Siena, Dipartimento di Scienze Ambientali, via Mattioli 4, 53100, Siena, Italy
[c] TerraData environmetrics, Dipartimento di Scienze Ambientali, via Mattioli 4, 53100, Siena, Italy
[d] German Aerospace Center, 82203 Oberpfaffenhofen, Germany

COMMUNICATION www.rsc.org/jem | Journal of Environmental Monitoring

Spectral variation *versus* species β-diversity at different spatial scales: a test in African highland savannas

Duccio Rocchini,[*a] Kate S. He,[b] Jens Oldeland,[cd] Dirk Wesuls[c] and Markus Neteler[a]

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First published as an Advance Article on the web 16th February 2010
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Ecological Informatics xxx (2010) xxx–xxx

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Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Remotely sensed spectral heterogeneity as a proxy of species diversity: Recent advances and open challenges

Duccio Rocchini [a,*], Niko Balkenhol [b], Gregory A. Carter [c,d], Giles M. Foody [e], Thomas W. Gillespie [f], Kate S. He [g], Salit Kark [h], Noam Levin [i], Kelly Lucas [c], Miska Luoto [j], Harini Nagendra [k,l], Jens Oldeland [m,n], Carlo Ricotta [o], Jane Southworth [p], Markus Neteler [a]

Spectral Variation Hypothesis

(Palmer 2002)

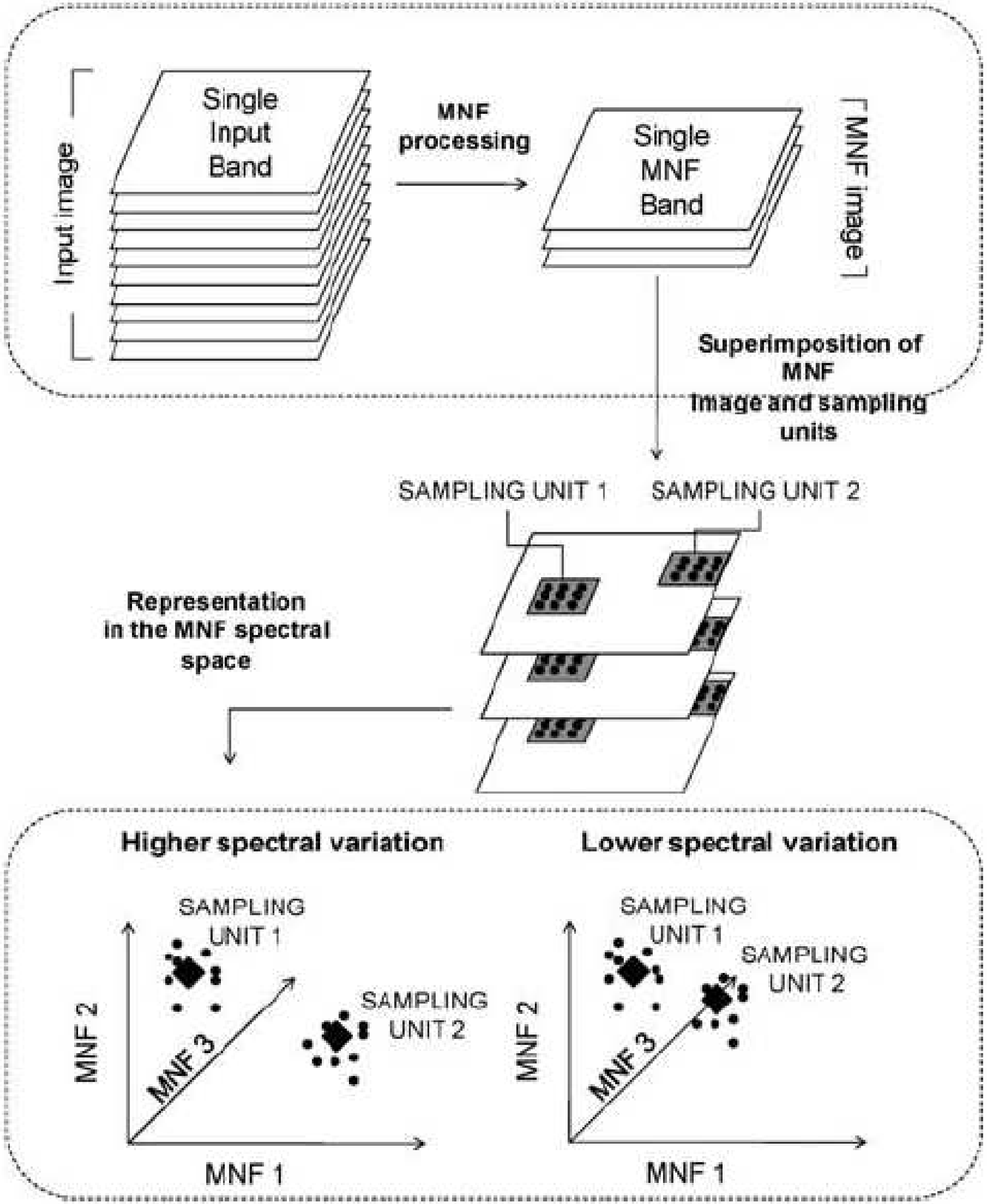
An indirect way to measure biodiversity

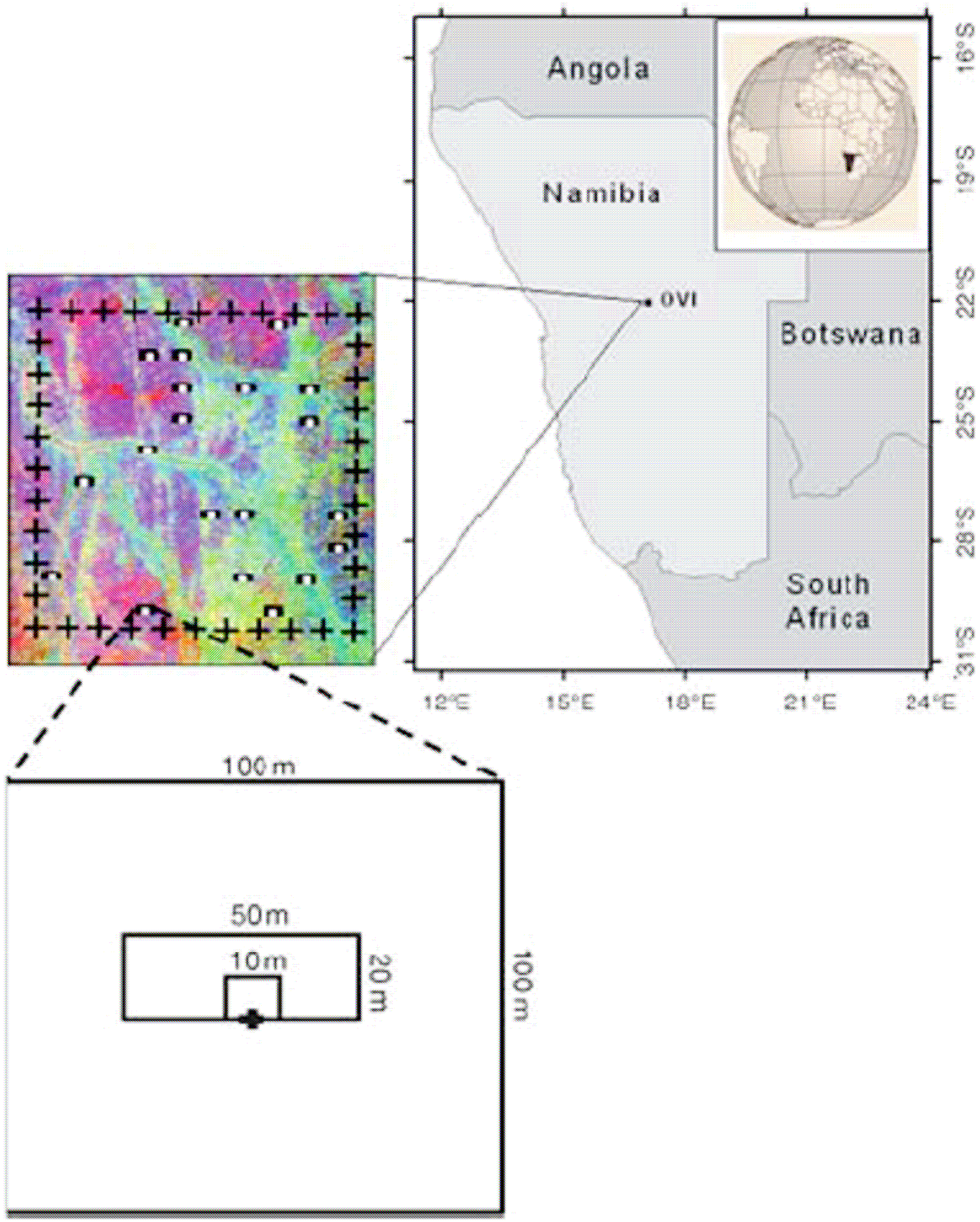
The theory of SVH states that spectral heterogeneity of a remotely sensed image is correlated with landscape structure and complexity which also reflects habitat heterogeneity (Dauber *et al.*, 2003; Ewers *et al.*, 2005). Habitat heterogeneity itself again is linked to niche complexity which is known to enhance species diversity (Tews *et al.* 2004)

→ correlations between biodiversity measures and spectral heterogeneity of a remotely sensed image

Until now, theory was tested only with regard to species richness (S). No other biodiverstiy measure was considered.

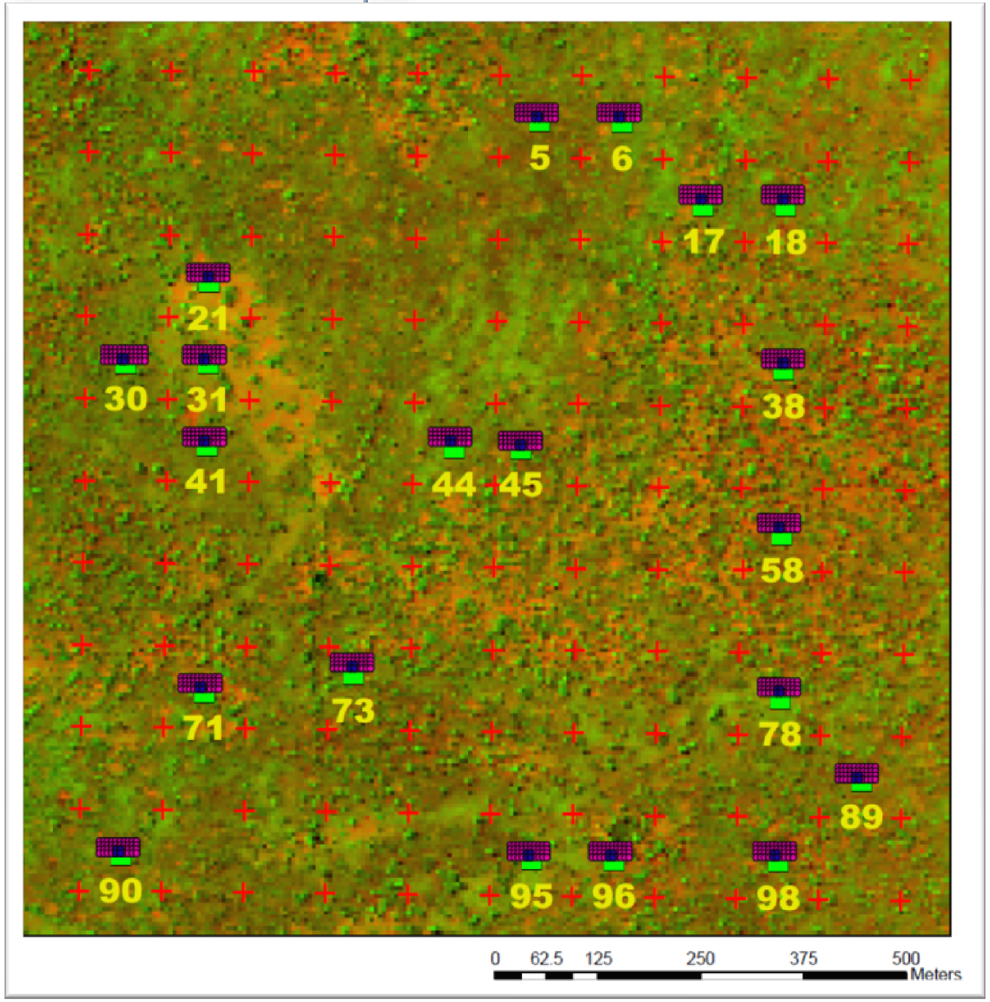
BUT especially evenness related measures of biodiversity should reflect habitat heterogeneity and therefore spectral heterogeneity much better


Input image
Single
Input
Band
MNF
processing
Single
MNF
Band
MNF image
Superimposition of
MNF
image and sampling
units
SAMPLING UNIT 1
SAMPLING UNIT 2
Representation
in the MNF spectral
space
Higher spectral variation
Lower spectral variation
SAMPLING
UNIT 1
SAMPLING
UNIT 2
MNF 1
MNF 2
MNF 3


Angola
Namibia
Botswana
South Africa
OVI
16°S
19°S
22°S
25°S
28°S
31°S
12°E
15°E
18°E
21°E
24°E
100 m
50m
10m
20 m
100 m

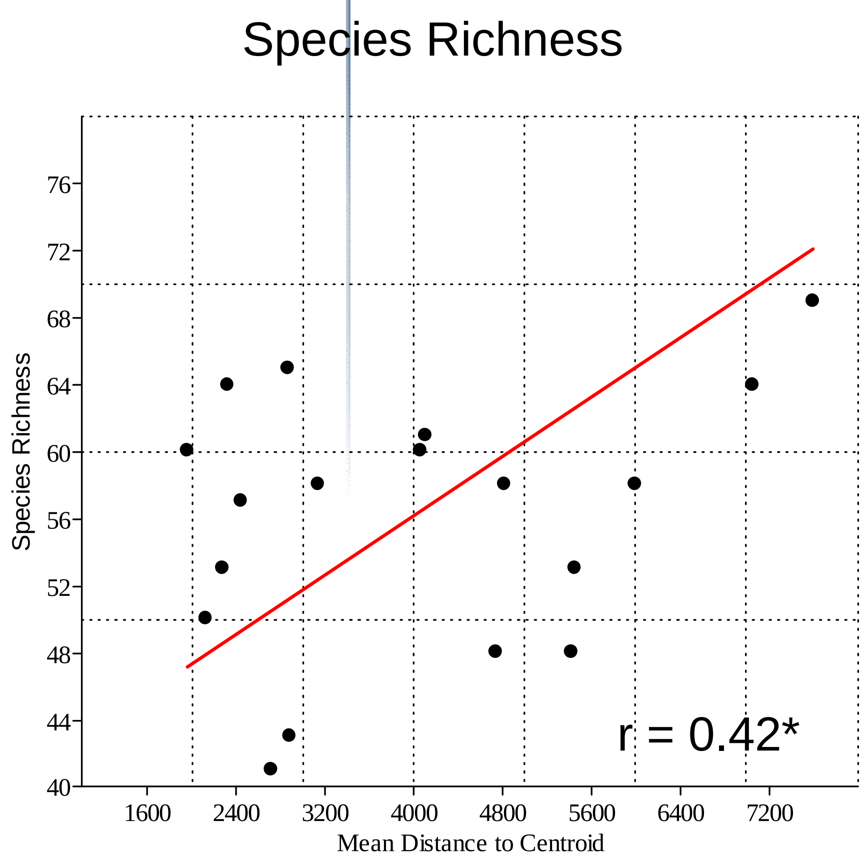
BIOTA - Biodiversity observatories:

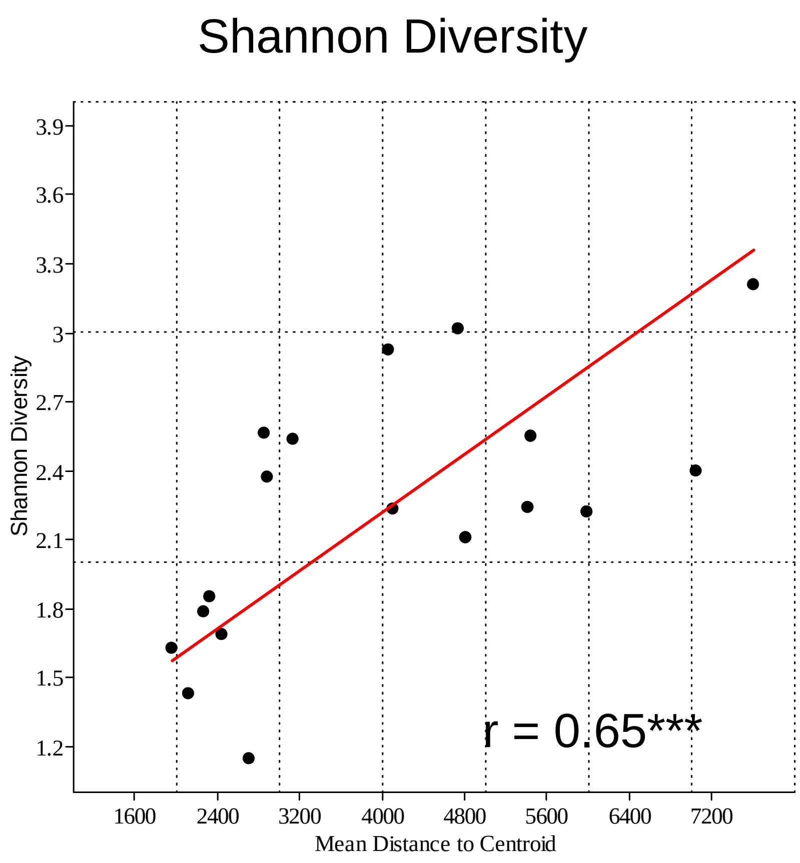
Plant diversity was sampled at scales of 10m x 10m and 20m x 50m in habitats with increasing structural complexity.



Biota-Obs.4 - HyMap PCA 1,2,3

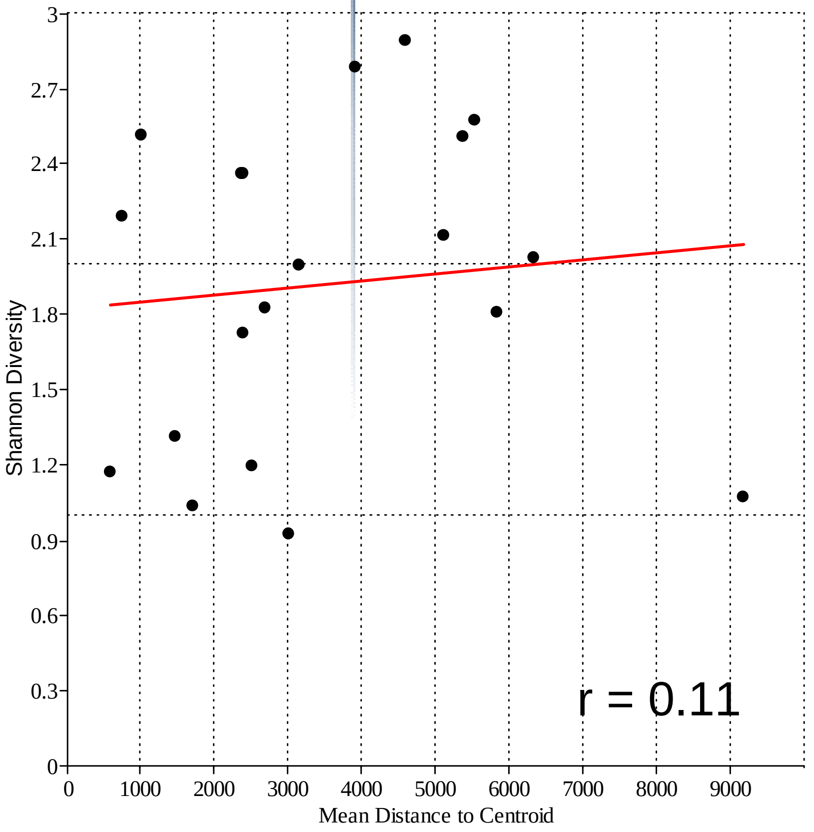
Choice of diversity measure matters!



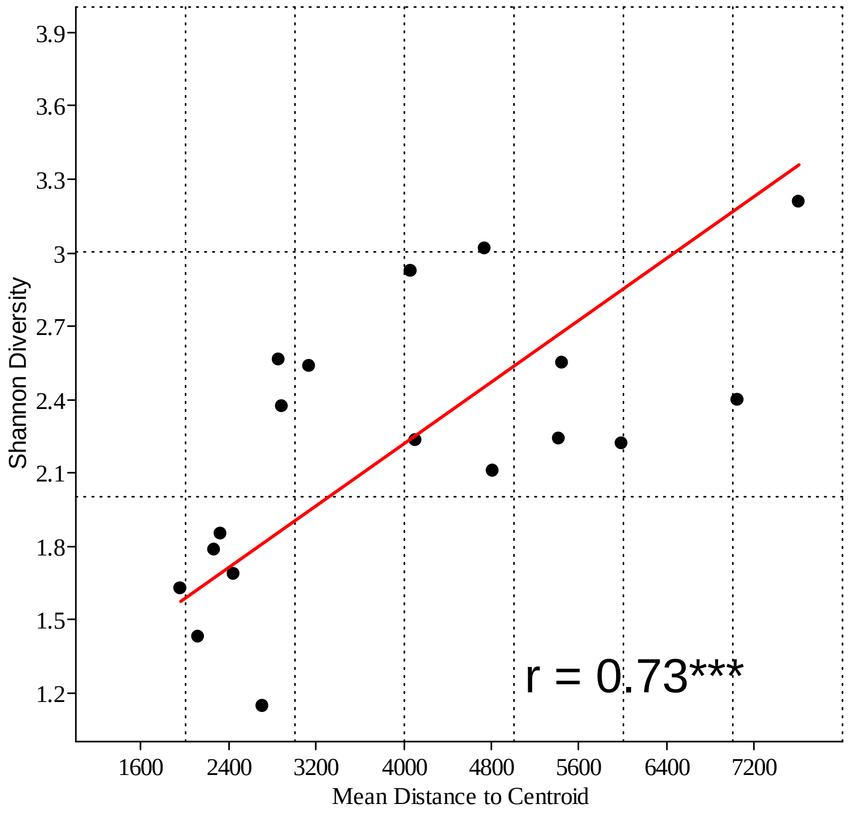


Scale of observation matters, too !

10m x 10m = $100 m^2$



20m x 50m = $1000 m^2$



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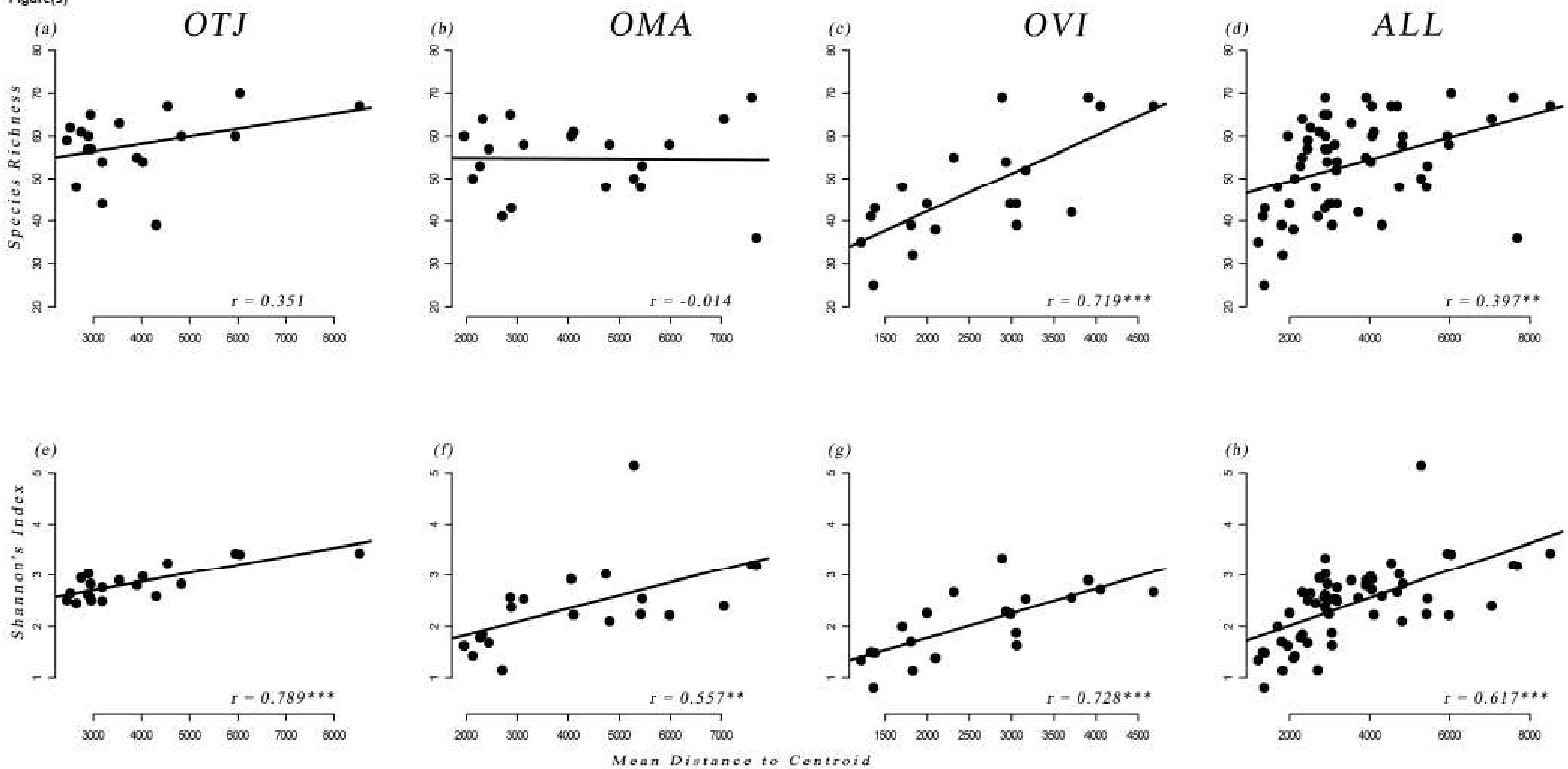
More Sites

Figure(s)



Removing the outlier would result in an improved correlation of 0.698 (p <0.001).

Table 1

Summary of regression results for diversity measures at different sites and scales.

Scale	Site	*n*	Species richness		Shannon Index	
			R^2	*p*-value	R^2	*p*-value
10 m × 10 m						
	OTJ	20	0.13	0.126	0.18	0.066
	OMA	20	0.01	0.635	0.01	0.676
	OVI	20	0.10	0.175	0.24	0.029
	ALL	60	0.03	0.182	0.05	0.097
20 m × 50 m						
	OTJ	20	0.12	0.130	0.62	<0.001
	OMA	20	0.00	0.952	0.31	0.011
	OVI	20	0.52	<0.001	0.53	<0.001
	ALL	60	0.16	0.002	0.38	<0.001

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