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WORKING PAPER

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Abstract:

Bush encroachment is one of the most extensive changes in land cover in Namibia and an urgent problem for cattle farming, rapidly reducing the productivity of the rangeland. Despite the severity of these consequences, a complete and accurate assessment of bush encroached areas is still missing at large. This study aims at assessing bush encroachment on commercial cattle farms in central Namibia by employing remote sensing methods to distinguish between areas covered by bush and open rangeland. Herein we use different classification techniques and vegetation indices to characterize the nature of vegetation cover. Our analysis shows that results are sensitive to specific classifications of indices. As an accuracy assessment could not be run on these results we could not analyze which classification approximates real bush encroachment best. Hence, this study highlights the need for further analysis. Ground truth data, in the form of field mappings, high resolution aerial photographs or local expert knowledge are needed to gain further insights and produce reliable results.

Keywords: remote sensing, semi-arid rangelands, cattle farming, bush encroachment

JEL-Classification: Q57, Q15, Q24

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1 Introduction

Changes in land cover in semi-arid rangelands of Namibia have been the subject of research for many years. Bush encroachment is seen to be one of the most extensive changes in land cover and is perceived as an urgent problem for cattle farming (Sweet 1998, Mendelsohn et al. 2002, de Klerk 2004). Encroachment is caused by a combination of factors including overgrazing, suppression of bushfires and changing climate conditions , leading to a reduction of grazing capacity due to a lower amount of pasture and a reduced penetrability of the rangeland (Mendelsohn et al 2002, Espach et al. 2006). The central and northern parts of the country are especially affected by increasing density of bushes (Mendelsohn et al. 2002).

The economic well-being of more than two thirds of the population of Namibia depends directly or indirectly on agriculture and 65 percent of the national agricultural output is produced on commercial rangeland (Sweet 1998, Mendelsohn et al. 2002, Espach et al. 2006). Therefore, the condition of the ecosystem has an immediate effect on the economic subsystem and bush encroachment severely restricts profitability of cattle farming (Sweet 1998). However, despite the severity of consequences arising from bush encroachment (de Klerk 2004), a complete and accurate mapping of bush encroached areas in Namibia is still missing (Wagenseil 2008).

One way to assess bush encroachment is the in-field assessment of bush densities on the farm land. However, this approach is time consuming and expansive due to the large number of work force necessary to pursue this approach. An alternative approach is remote sensing of vegetation cover. This approach has been applied successfully for mapping of bush encroachment (Wagenseil 2008).

This study aims at assessing bush encroachment on commercial cattle farms in central Namibia. We approach this problem by applying Geographic Information Systems (GIS) and remote sensing to distinguish between areas covered by bush and open rangeland. We link this to on-site assessments of bush encroachments collected in a survey of commercial cattle farms (Olbrich et al. 2009).

This paper proceeds as follows: Section 2 reviews the use of remote sensing of vegetation and introduces the vegetation indices used in this study. Section 3 presents the study sites, data sources and index classifications. Results are given in Section 4 and are discussed in Section 5. Finally, Section 6 concludes.

2 Background

2.1 Remote sensing of vegetation cover

Remote sensing can be defined as "the science of collecting information about objects without coming into physical contact with them" (Hill 2000). This definition applies to recording of electromagnetic radiation by aircraft or satellite-born sensors (Richards & Jia 1999, de Lange 2006, Albertz 2007). Distinguishing between different objects on the images relies on difference in their spectral reflectance behavior (Albertz 2007). Sensors record electromagnetic radiation being reflected by objects on the earth's surface, e.g. plants, buildings, water bodies, or in the atmosphere, e.g. clouds. These objects show characteristic patterns of reflectance across the wavelength spectrum allowing for determination of specific types of objects (de Lange 2006). These patterns, referred to as spectral signatures or "spectral fingerprints" (de Lange 2006), differ among specific types of objects, e.g. vegetation, water and soil, but also between similar objects, e.g. different kinds of vegetation and soils (de Lange 2006).

The spectral signature of a pixel of a satellite image (ρ_{pixel}) is a function of various factors (Asner 2004):

$$\rho_{pixel} = f(\text{geometry, tissue optics, canopy structure, landscape structure, soil optics})$$

where 'geometry' refers to the sun and sensor zenith and azimuth angles, 'tissue optics' describes the different reflectance and transmittance characteristics of living (photosynthetic) and senescing (non-photosynthetic) vegetation due to chemical characteristics and structure, 'canopy structure' characterizes the distribution and abundance of biomass tissue, 'landscape structure' refers to shadowing of trees and 'soil optics' describe physical and chemical differences of soil types (Asner 2004).

Fig. 1 shows such a spectral signature for common surface types. The vegetation curve exhibits a steep increase in reflectance from the red to the near infrared wavelength spectrum. This "red edge" (Hildebrandt 1996, de Lange 2006) is distinctive for living, photosynthetically active vegetation and can therefore be used in the detection of this vegetation type.
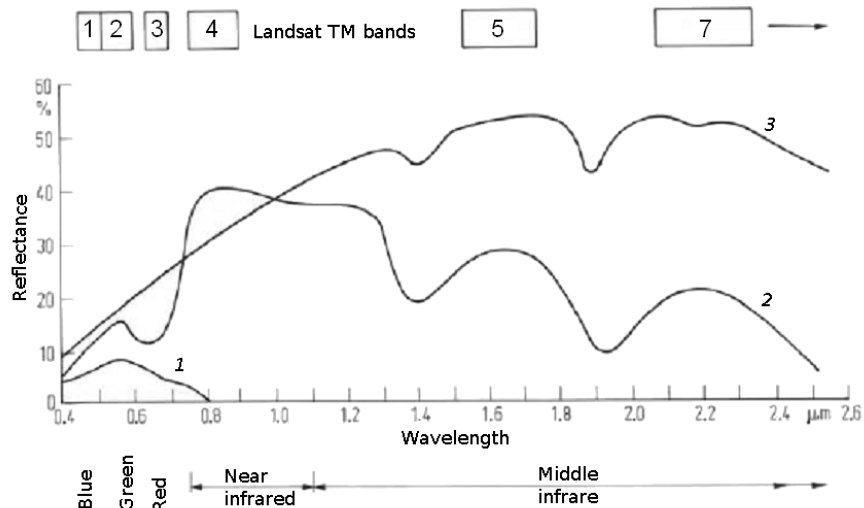
Figure. 1: Spectral reflectance characteristics of common surface materials in the visible and near-to-mid infrared wavelength spectrum for water (1), vegetation (2) and soil (3). The boxes above the diagram indicate the ranges of the spectrum covered by one channel/band of the sensor. Only Landsat TM data was used in this study. Source: Richards & Jia (1999).

Fig. 2 depicts the development of the spectral signature of senescing vegetation. The senescent vegetation also exhibits an increase from the red to the infrared spectrum the magnitude of which depends on the stage of senescence. Due to this, care has to be taken when interpreting vegetation indices that incorporate the difference between the infrared and red reflectance values (van Leeuwen & Huete 1996).
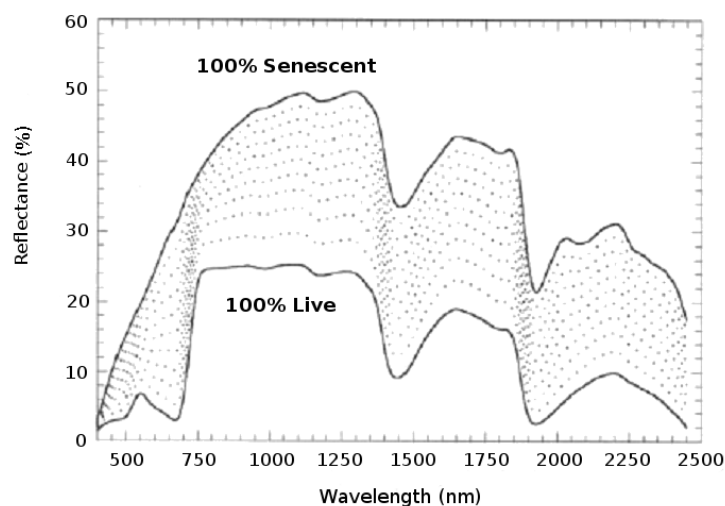
Figure. 2: Reflectance behavior of senescent and photosynthetically active vegetation in the wavelength spectrum 440-2500 nm. Depending on the stage of senescence, the pattern of a specific vegetation cover may be located anywhere between the 100% live and 100% senescent signature patterns. Source: Asner (2004).

The use of Landsat TM 5 images with a resolution of 28.5x28.5m per pixel in this study implies that one pixel might represent different kinds of objects, e.g. leave-

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bearing shrubs, senescent grass and bare soil. Such a coarse resolution necessarily leads to spectral mixture that might end in falsified classification results that are due to spectral variability within the area represented by one pixel (Asner 2004).

2.2 Vegetation indices

Parameters allowing for discrimination between areas being covered with living, photosynthetic biomass and bare or litter-covered areas are called vegetation indices (Hildebrandt 1996). Several distinct indices have been developed that make use of the difference between the red and the infrared reflectance values (for overviews see Tucker 1979, Hildebrandt 1996, de Lange 2006). We employed four vegetation indices in this study and briefly describe them in the following.

a) Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is seen to be the index most commonly used (Asner 2004). It is calculated as the normalized difference between the Landsat band 4 (near infrared) and band 3 (red) reflectance values (Hildebrandt 1996):

$$\text{NDVI} = \frac{near\ infrared\ [band\,4] - red[band\,3]}{near\ infrared\ [band\,4] + red[band\,3]}$$

The NDVI ranges from -1 to +1, where values at 0.1 and below correspond to barren soil, values from about 0.2 to 0.3 represent grass and shrubland, and high values (0.6-0.8) can be found in tropical rain forests (Weier & Herring n.d.). The higher the NDVI the higher the amount of photosynthetically active vegetation (de Lange 2006). The NDVI has been found to correlate with chlorophyll and water contents of canopies in semi-arid regions (du Plessis 1999, Asner 2004, Xiao & Moody 2005). Land cover change, however, turned out to be difficult to measure by using the NDVI, as it can not be determined whether changes in the NDVI are due to different climatic conditions (e.g. drought) or a real change in land cover (Asner 2004). The use of the NDVI to determine shrublands with low vegetation cover has also shown to be limited because of the distorting influence of litter and soil reflectance (Asner 2004, de Lange 2004, Xiao & Moody 2005, Wagenseil & Samimi 2006). Nevertheless, the NDVI has also been applied successfully in semi-arid regions (e.g. Wagenseil 2008).

b) Soil-Adjusted Vegetation Index

The Soil-Adjusted Vegetation Index (SAVI) is an extension of the NDVI, aimed at minimizing soil brightness influences (Huete 1988). Soil surface might reflect near infrared radiation being scattered from a vegetation canopy, therefore leading to an overestimation of vegetation on dark soil substrates (Huete 1988) and to an underestimation on bright backgrounds (Elvidge & Lyon 1985). The SAVI is calculated as follows:

$$\text{SAVI} = \frac{near\ infrared\ [band\,4] - red[band\,3]}{near\ infrared\ [band\,4] + red[band\,3] + L} \cdot (1{+}L) \qquad \text{with } 0 \leq L \leq 1,$$

where L is a correction factor which is usually set at L=0.5 for regions with medium vegetation cover. Higher L values might be applied to regions with lower vegetation cover and vice versa (Huete 1988).

c) Simple Ratio Index

Another widely-used ratio-based vegetation index is the Simple Ratio (SR), which is calculated by the division of the infrared by the red reflectance value (Hildebrandt 1996, Hill 2000):

$$\text{SR} = \frac{near\ infrared[band\,4]}{red[band\,3]}$$

The SR has been shown to correlate strongly with vegetation cover in a mixed shrubland/grassland area (McDaniel & Hass 1982). Huete & Jackson (1987) discovered that the SR overestimates vegetation on dark soil in arid grasslands, but was more reliable in discriminating green vegetation from mixtures of green and yellow grass than the Tasseled Cap Greenness discussed below.

d) Tasseled Cap Greenness/Green Vegetation Index

The Tasseled Cap Index, also referred to as Green Vegetation Index (GVI), transforms multispectral images into a new feature spaces (Kauth & Thomas 1976; Christ & Cicone 1984; Christ & Kauth 1986). For Landsat 5 TM these feature spaces

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refer to brightness, greenness, wetness and haze. The greenness is characterized as the "plane of vegetation" which allows for discrimination of photosynthetic biomass (Liang 2004). The GVI was used successfully in Namibia to classify different land cover types (Espach 2006). Huete & Jackson (1987) studied the GVI in arid grasslands and found that darker soils produced lower GVI values and that low vegetation cover, reddish soils and yellow litter result in higher GVI values.

2.3 Vegetation in Namibia

Photosynthetically active vegetation can be measured by different vegetation indices. A distinction between bushes and trees on the one hand and grasses on the other can be made at certain times of the year with the help of vegetation indices. Precipitation in central Namibia is concentrated on the summer months, i.e. most of the rain falls between October and March (Mendelsohn et al. 2002). After the rainy season, grasses senesce quickly, while bushes keep their leaves longer (dependent on the species). At the time when the satellite images we used in this study were taken in May 2005, the main bush species are expected to still be green, while the grass is already senescing and thus brown. Consequently, grass no longer reflects highly in the infrared spectrum.

This assumption is supported by available bush encroachment data together with phenological information. According to a large-scale mapping of bush encroached areas the two dominant bush species in the study area are *Acacia mellifera* (Black-thorn Acacia), with up to 8,000 individuals per hectare, and *Dichrostachys cinerea* (Kalahari Christmas Tree, Sickle Bush), with up to 10,000 individuals per hectare (Mendelsohn et al. 2002, de Klerk 2004). Both *Acacia mellifera* and *Dichrostachys cinerea* bear leaves mainly in the period between December and May, and partly in November, June and July. Most of the shrubs are bare the remainder of the year (Curtis & Mannheimer 2005). Tainton (1999) shows that both subclimax grasses, as well as ephemerals and annuals concentrate their main growth activity in the period December to March and show almost no production in May. On the other hand, climax grasses have a growth period from November until April and are to some degree still active in May which might contradict our assumption.

If the assumption holds true, values of vegetation indices will indicate low photosynthetic activity for areas that are not covered by leave-bearing bushes. On the other hand, areas covered by leave-bearing bushes should have a higher value

of the different vegetation indices. In northern Namibia, Wagenseil (2008) observed such a pattern. He discovered that in areas with low bush cover the NDVI declined quickly after the end of the rainy season, whereas areas with a higher bush cover showed a delayed decline.

2.4 Unsupervised classification

By far the biggest obstacle in this study was the lack of detailed ground truth data that could be used for a supervised classification and an accuracy assessment of the classification results. As suitable ground truth data for bush coverage was missing, the approach chosen was an unsupervised classification which groups the picture into classes of similar spectral attributes by use of clustering algorithms (Richards & Jia 1999, Janssen & Gorte 2001, Albertz 2007). ERDAS IMAGINE uses the Iterative Self-Organizing Data Analysis Technique (ISODATA). This technique uses the minimum spectral distance to assign a cluster to a pixel (Leica Geosystems 2008). In an unsupervised classification it is the analyst's task to determine the number of classes, to interpret the results and to attach meanings to the different classes.

3   Material and methods

3.1   Study area and base data

We analyzed 13 cattle farms in the study area in central Namibia. The northernmost farms lies at about 19°33'S, the southernmost at 22°30'S, the westernmost at 16°33'E and the easternmost at 18°9'E. These farms were selected from those targeted in a survey of commercial cattle farms conducted in July/August 2008 (Olbrich et al. 2009) as they were pictured by two Landsat TM 5 satellite images (Fig. 3).

The study area is characterized by three landscape types: the Karstveld in the North, the Central-Western Plains in the West and the Kalahari Sandveld in the East (Mendelsohn et al. 2002). The median annual rainfall in the study area ranges from 250 mm in the South around Windhoek to 650 mm in northern central region between Tsumeb and Grootfontein and is thus considered semi-arid (Mendelsohn et al. 2002). Rainfall is very variable and the coefficient of variation of average annual rainfall is at 30-50% in the study region (ibid.). Most of the rain falls between November and April, reaching a peak in January and February (ibid.). On a large

scale, the dominant vegetation structure can be characterized as woodland in the North, dense shrubland in the West and shrubland-woodland in the East (ibid.).

The analysis focused on cattle farms in central Namibia that were visible on two Landsat Thematic Mapper (TM 5) scenes (path 178, row 74 and 75). Each image covered an area of about 180x180 km and had a resolution of 28.5x28.5 m per pixel. Both images were taken on May 23rd in 2005 when shrub trees were still leave-bearing. In this study area, 13 cattle farms were randomly selected for further empirical investigations. Five farms are situated on the northern scene (path 178, row 74) and eight farms on the southern scene (path 178, row 75). We used a geospatial farm data base (ArcMap shape file) of the Ministry of Agriculture, Water and Forestry of Namibia, as per February 2008, to localize the different farms (Fig. 3).

For five farms (Jaegerhof, Una, Annenhof, Otjihaenena and Steenbokvlakte) data from the survey was used for further analysis in this study, specifically information on farm area and an assessment of farmers pertaining to the percentage of bushed areas of their farm land.
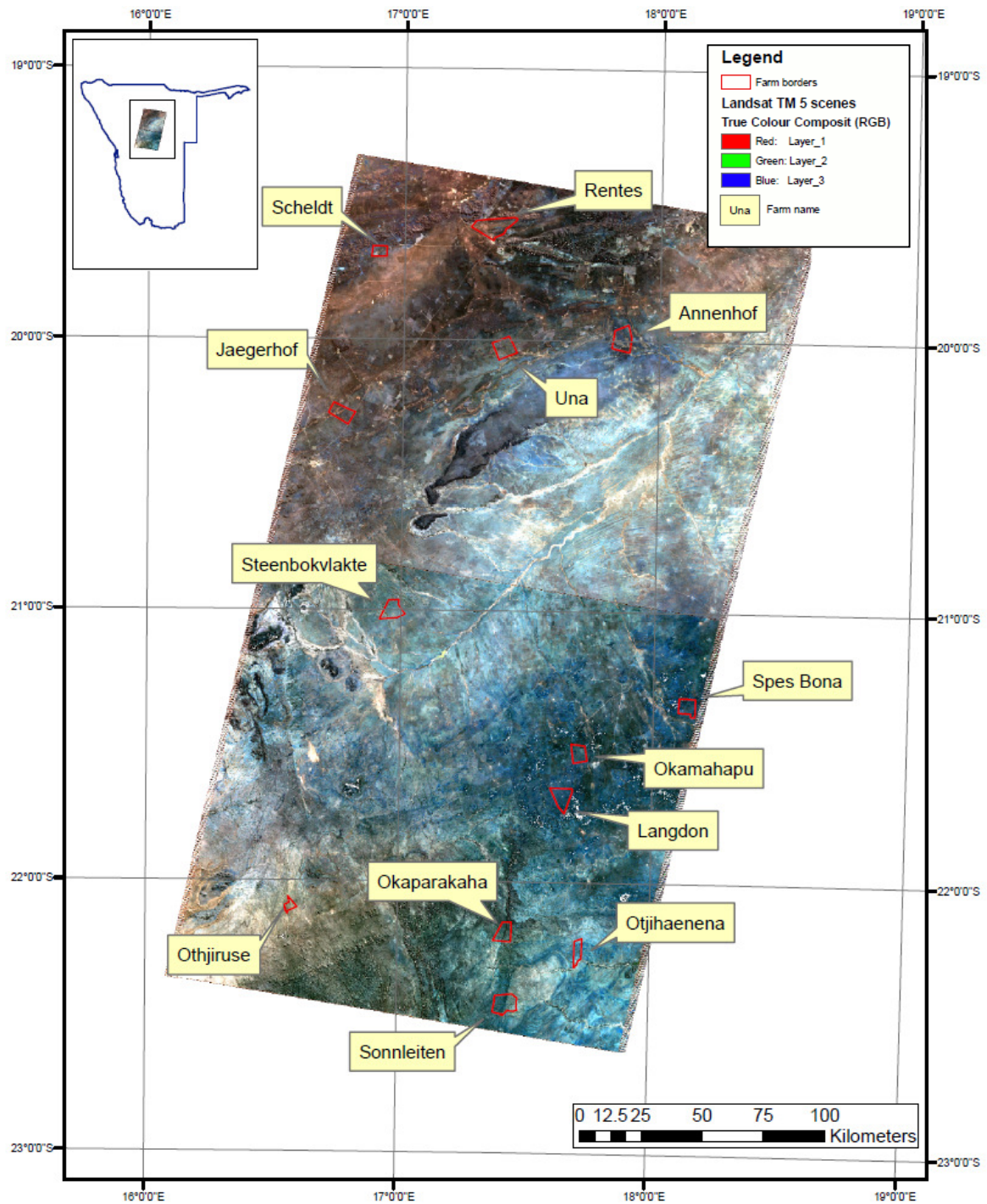
Figure. 3: Study area and selected cattle farms in Central Namibia as pictured by Landsat TM 5 satellite images (path 178, rows 174 & 75). Acquisition date was the 23rd of May 2005.

3.2   Data preprocessing

By using ERDAS IMAGINE 9.2 (Leica Geosystems), the raw images were projected to the projected geographic system, UTM WGS 1984 South (zone 33). The images were geometrically corrected by adjusting them to Landsat 7 scenes taken in 2000 and Landsat 5 scenes taken in 1990 of the same area. As atmospheric scattering

could be detected in the spectral signatures (cf. Richards & Jia 1999), atmospheric correction was carried out using the ATCOR tool of ERDAS IMAGINE 9.2. Bare soil areas were used as a reference spectrum, as they were easily detectable (e.g. sandy roads and crossings, debushed areas).

3.3 Unsupervised classification

An unsupervised classification with three classes was carried out for the five farms on the northern scene (path 178, row 74) following the maximum likelihood classification algorithm. These were attached the attributes "low", "medium" and "high" bush cover. Due to the lack of ground truth data representing different degrees of bush coverage, the accuracy of the different classification results could not be assessed. A visual comparison of the results with high resolution satellite images from about the same date (2002-2005 Spot satellite scenes used in the GIS software Google Earth) indicated that a more differentiated classification with more classes is useful for this study. A higher number of classes can be used to merge certain classes later on that are thematically similar. Therefore, the unsupervised classification was carried out with five classes following the maximum likelihood classification algorithm. These classes were attributed "very high", "high", "medium", "low" and "very low" bush cover.

A subset of the relevant farms was created for each picture. This procedure ensured that only relevant farmland would be classified in the unsupervised classification whereas clouds, shadows, water bodies, salt pans, settlement areas could be excluded as these did not appear in relevant extents on the farms. Farm buildings, due to the relatively small area they cover, appeared to influence the spectrum of a maximum of one to four pixels (i.e. 100-500 sq.m) per farm and could therefore be neglected.

The unsupervised classification was carried out on three indices and the multispectral image of each satellite scene in order to compare the results and the effects of different vegetation indices:

- the multispectral image (MS, bands 1-5, 7)
- the NDVI
- the SR
- the GVI

The SAVI was calculated for two farms and led to results that where only marginally different from the NDVI (0 - 0.6% deviation per class in the five-class-clustering). Therefore the SAVI was not calculated for all farms.
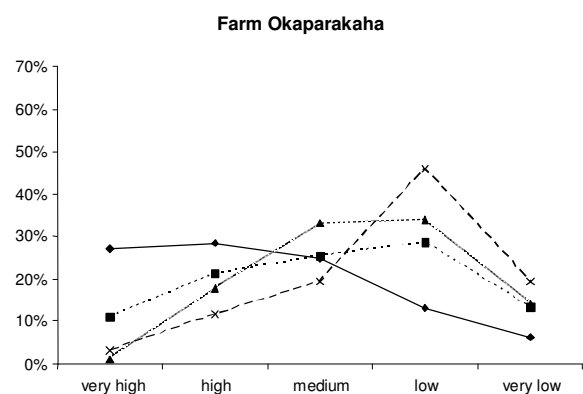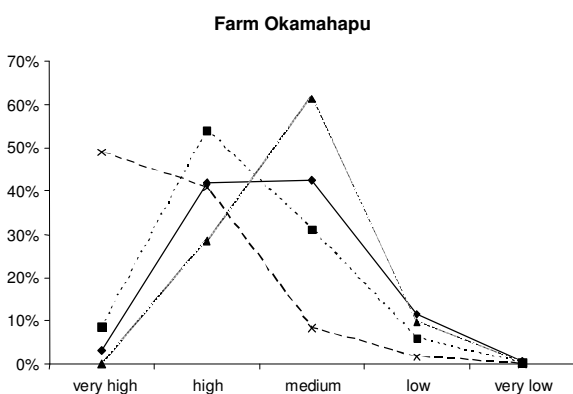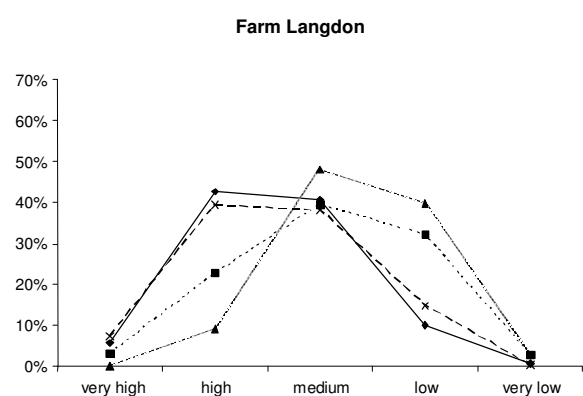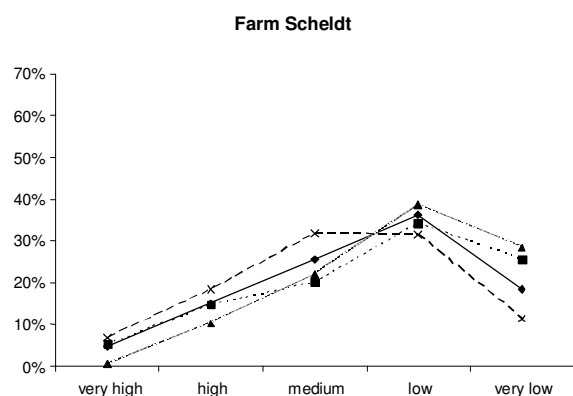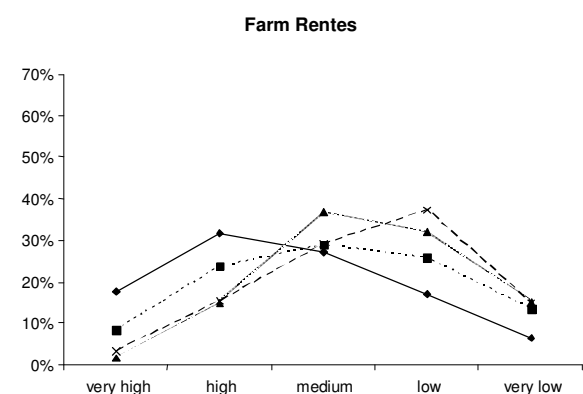
4 Results

Results of the unsupervised classification are displayed in table 1. The fraction of each land cover class is calculated, and percentages of the total farm area are likewise given. The degree of detected bush cover differs between farms (Fig. 4). Classification of the multispectral image and the three vegetation indices leads to ambiguous results. For some farms the classification leads to similar fractions of each class (e.g. Jaegerhof, Annenhof, Scheldt, Otjihaenena, Spes Bona), whereas the results for others differs highly (e.g. Okamahapu, Okaparakaha, Steenbokvlakte). Map 1 in the appendix shows the classification results for a farm with rather similar results for each index (farm Scheldt), and map 2 depicts a farm with ambiguous results (farm Steenbokvlakte). Deviations in two indices are apparent for some of the farms. On Steenbokvlakte, the GVI classification leads to remarkably higher results in the classes, "very high" and "high". Similarly, the GVI produces high values for very high bush cover on the farms Una and Okamahapu. The SR classification yields the lowest values for the "very high" bush cover class for all farms, and only in three cases do other classifications yield higher percentages in the "high" bush cover class. This index tends to yield classes in the medium to low classes.

Table 1: Bush cover classes per farm for multispectral image (MS) and the indices Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR) and Green Vegetation Index (GVI). Areas per class is given in hectares, numbers in brackets denote percentages. Deviations in total farm area per index were due to pixel failures in the index calculations.

Farm name	Classification input	Bush cover					Total farm area
		Very high	High	Medium	Low	Very low	
Jaegerhof	MS	559.9 [11.09]	1656.4 [32.80]	1792.6 [35.49]	858.9 [17.01]	182.8 [3.62]	5050.6
	NDVI	363.6 [7.20]	1500.6 [29.71]	1710.8 [33.87]	1136.3 [22.50]	339.1 [6.71]	5050.6
	SR	32.9 [0.65]	860.1 [17.03]	2193.4 [43.43]	1573.7 [31.16]	390.1 [7.72]	5050.2
	GVI	519.0 [10.28]	1767.1 [34.99]	1674 [33.14]	884.7 [17.52]	205.8 [4.08]	5050.6
Una	MS	379.0 [6.62]	1188.3 [20.74]	1594.6 [27.84]	1889.8 [32.99]	676.7 [11.81]	5728.4
	NDVI	579.0 [10.11]	1591.4 [27.78]	1779.3 [31.06]	1381.8 [24.12]	397.0 [6.93]	5728.4
	SR	62.1 [1.08]	1172.7 [20.47]	2247.7 [39.24]	1783.1 [31.13]	462.9 [8.08]	5728.4
	GVI	1574.0 [27.47]	2043.6 [35.68]	1282.1 [22.38]	666.5 [11.64]	162.6[2.84]	5728.4
Annenhof	MS	668.6 [10.17]	1411.1 [21.46]	2031.8 [30.90]	1558.0 [23.70]	905.5 [13.77]	6575.0
	NDVI	501.7 [7.63]	1090.9 [16.59]	1523.6 [23.17]	2032.7 [30.91]	1426.1 [21.69]	6575.0
	SR	141.3 [2.15]	757.4 [11.52]	1718.9 [26.15]	2387.6 [36.32]	1568.4 [23.86]	6573.5
	GVI	830.2 [12.63]	1778.4 [27.05]	1874.8 [28.51]	1303.5 [19.83]	788.1 [11.99]	6575.0
Rentes	MS	1715.0 [17.69]	3065.4 [31.62]	2622.0 [27.05]	1669.2 [17.22]	622.9 [6.43]	9694.0
	NDVI	801.1 [8.27]	2318.4 [23.92]	2782.0 [28.71]	2487.5 [25.67]	1302.5 [13.44]	9691.6
	SR	155.7 [1.61]	1427.2 [14.75]	3556.7 [36.77]	3077.6 [31.82]	1456.2 [15.05]	9673.4
	GVI	333.2 [3.44]	1483.3 [15.30]	2828.2 [29.16]	3603.7 [37.16]	1449.2 [14.94]	9697.6
Scheldt	MS	123.5 [4.77]	390.1 [15.09]	660.2 [25.53]	936.1 [36.20]	476.1 [18.41]	2586.0
	NDVI	138.7 [5.36]	383.1 [14.81]	516.0 [19.95]	884.6 [34.21]	663.7 [25.66]	2586.0
	SR	17.6 [0.68]	264.1 [10.21]	567.4 [21.94]	1002.6 [38.77]	734.4 [28.40]	2586.1
	GVI	183.6 [7.10]	475.8 [18.40]	819.1 [31.67]	815.1 [31.52]	292.5 [11.31]	2586.0
Langdon	MS	310.1 [5.81]	2282.6 [42.80]	2173.4 [40.75]	529.7 [9.93]	37.4 [0.70]	5333.2
	NDVI	159.9 [3.00]	1212.7 [22.74]	2107.4 [39.51]	1708.8 [32.04]	144.4 [2.71]	5333.2
	SR	1.5 [0.03]	486.8 [9.13]	2564.6 [48.09]	2126.6 [39.87]	153.8 [2.88]	5333.2
	GVI	395.4 [7.41]	2107.2 [39.51]	2040.3 [38.26]	782.1 [14.67]	8.1 [0.15]	5333.2
Okamahapu	MS	129.2 [3.29]	1645.6 [41.89]	1670.8 [42.53]	458.2 [11.66]	24.9 [0.63]	3928.7
	NDVI	338.4 [8.61]	2123.5 [54.05]	1224.3 [31.16]	232.1 [5.91]	10.5 [0.27]	3928.7
	SR	3.5 [0.09]	1124.6 [28.63]	2411.4 [61.38]	378.4 [9.63]	10.7 [0.27]	3928.7
	GVI	1924.0 [48.96]	1604.9 [40.85]	329.6 [8.39]	65.9 [1.68]	4.7 [0.12]	3928.7
Okaparakaha	MS	1193.0 [27.10]	1256.0 [28.54]	1094.5 [24.87]	576.0 [13.09]	281.5 [6.40]	4400.6
	NDVI	499.1 [11.35]	932.3 [21.20]	1117.3 [25.40]	1257.4 [28.59]	592.6 [13.47]	4398.7
	SR	51.1 [1.17]	782.7 [17.89]	1447.5 [33.08]	1488.7 [34.03]	605.3 [13.83]	4375.3
	GVI	147.8 [3.36]	518.5 [11.78]	859.4 [19.53]	2019.5 [45.89]	855.4 [19.44]	4400.6
Otjihaenena	MS	31.3 [1.08]	184.7 [6.40]	709.3 [24.59]	873.9 [30.30]	1085.3 [37.62]	2884.5
	NDVI	31.8 [1.10]	69.7 [2.42]	173.3 [6.01]	776.2 [26.91]	1833.6 [63.57]	2884.5
	SR	5.7 [0.20]	44.9 [1.56]	171.3 [5.94]	816.0 [28.31]	1844.8 [64.00]	2882.7
	GVI	70.4 [2.44]	143.4 [4.97]	287.1 [9.95]	1199.0 [41.57]	1184.6 [41.07]	2884.5
Otjiruse	MS	242.1 [15.74]	391.2 [25.43]	330.8 [21.50]	418.5 [27.20]	155.8 [10.13]	1538.4
	NDVI	109.2 [7.10]	244.2 [15.88]	310.3 [20.17]	453.2 [29.46]	421.5 [27.40]	1538.4
	SR	17.9 [1.16]	182.6 [11.88]	392.5 [25.54]	516.7 [33.62]	427.3 [27.80]	1536.9
	GVI	96.7 [6.28]	129.0 [8.38]	181.9 [11.82]	520.5 [33.83]	610.4 [39.68]	1538.4
Sonnleiten	MS	825.7 [12.37]	1979.3 [29.65]	1748.0 [26.19]	1443.0 [21.62]	678.5 [10.16]	6674.6
	NDVI	334.7 [5.01]	1203.6 [18.03]	1984.7 [29.74]	2384.4 [35.72]	767.2 [11.49]	6674.4
	SR	26.2 [0.39]	705.4 [10.57]	2312.1 [34.65]	2841.1 [42.58]	787.2 [11.80]	6672.1
	GVI	501.8 [7.52]	1362.5 [20.41]	1524.7 [22.84]	2608.8 [39.09]	676.8 [10.14]	6674.5
Spes Bona	MS	508.9 [9.27]	2421.2 [28.50]	976.0 [31.93]	275.2 [29.34]	145.2 [0.96]	4326.4
	NDVI	252.2 [5.83]	1245.4 [28.79]	1483.1 [34.28]	1155.1 [26.70]	190.6 [4.40]	4326.4
	SR	2.0 [0.05]	675.6 [15.62]	2000.0 [46.2]	1451.9 [33.6]	196.2 [4.54]	4325.7
	GVI	401.1 [9.3]	1233.0 [28.50]	1381.5 [31.93]	1269.5 [29.34]	41.3 [0.96]	4326.4
Steenbokvlakte	MS	50.0 [0.99]	208.4 [4.12]	601.0 [11.88]	3505.8 [69.33]	691.8 [13.68]	5056.9
	NDVI	339.8 [6.72]	1362.6 [26.94]	1978.6 [39.13]	1199.2 [23.71]	176.8 [3.50]	5056.9
	SR	8.5 [0.17]	797.5 [15.77]	2471.6 [48.88]	1596.2 [31.57]	183.0 [3.62]	5056.8
	GVI	2706.0 [53.50]	1451.7 [28.71]	507.1 [10.03]	296.6 [5.86]	95.9 [1.90]	5056.9

Farm Jaegerhof

Farm Una

Farm Annenhof

Farm Rentes

Farm Scheldt

Farm Langdon

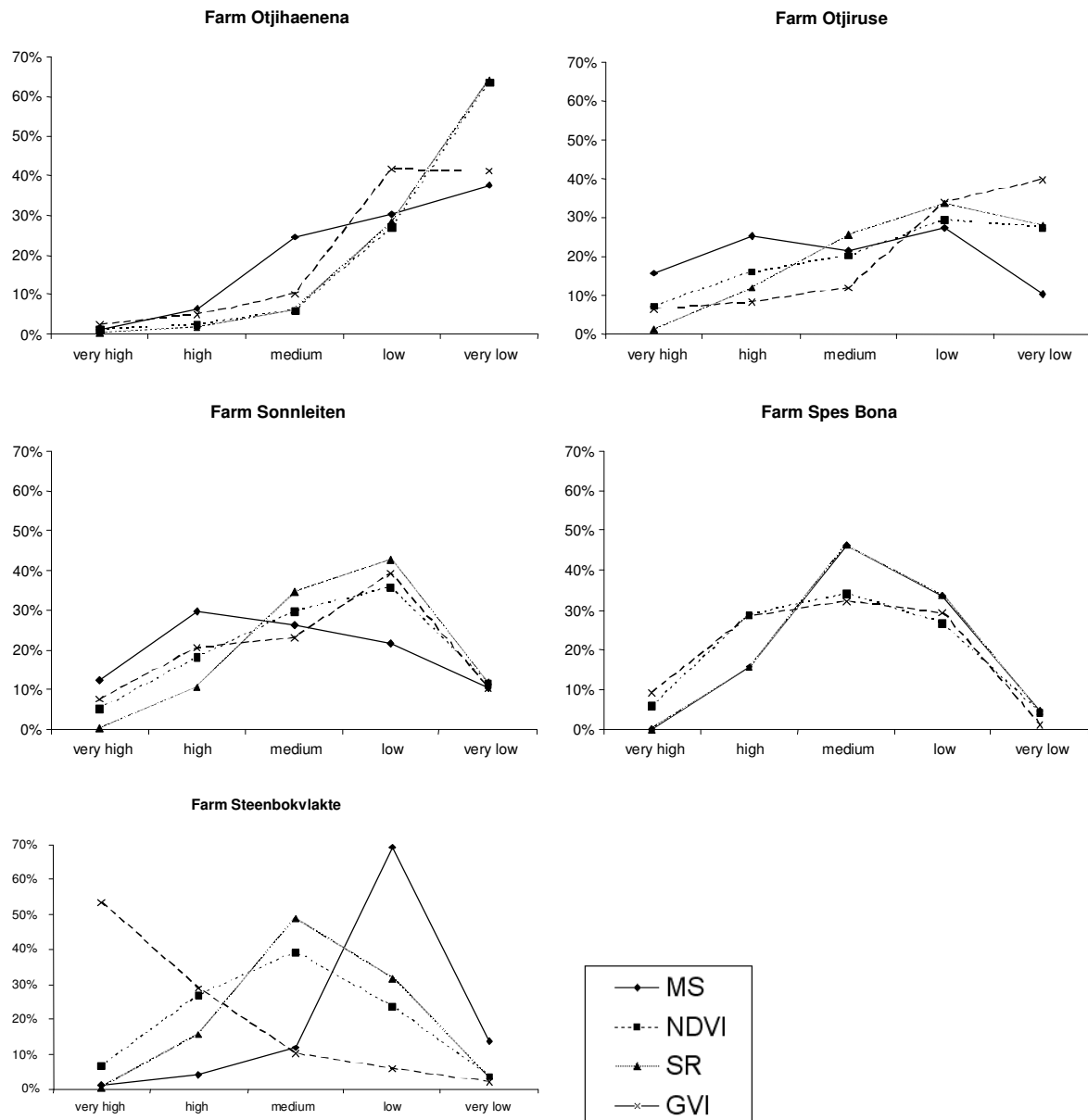**Farm Okamahapu**

Farm Okaparakaha

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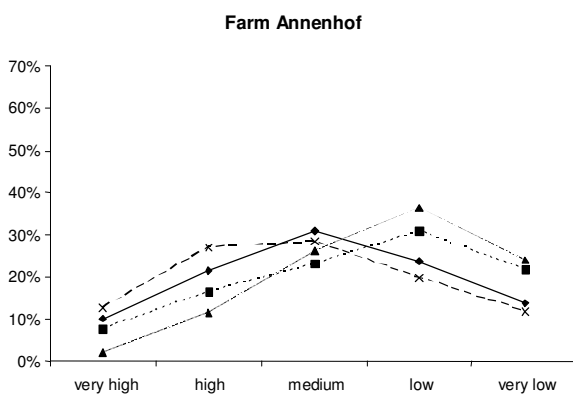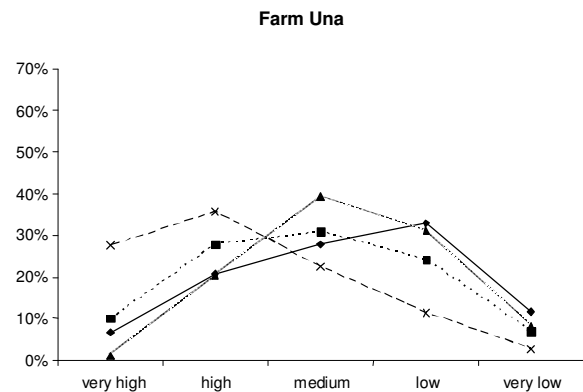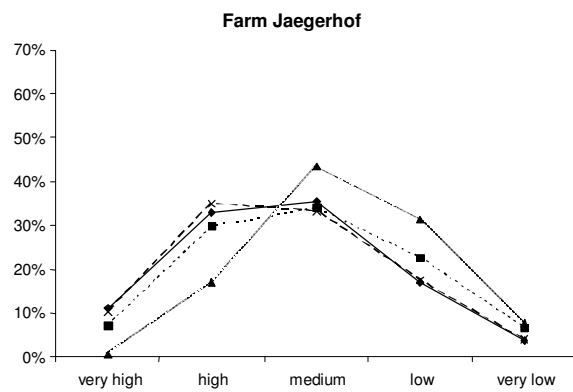
Fig. 4: Percentage of bush cover classes for each farm. Graphs show the classification results for the multispectral image (MS) and the three indices Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR) and Green Vegetation Index (GVI).

We compared expert knowledge from empirical data on farms (Olbrich et al. 2009) with the results of our classification (Tab. 2). In the study of Olbrich et al., farmers were asked what percentage of their rangeland was covered by bushes. For five farms (Jaegerhof, Una, Annenhof, Otjihaenena and Steenbokvlakte) we could compare the farmers' estimations with our results. We assumed that from the point of view of a farmer bush cover on the farm is represented by the whole area of the two classes, "very high" and "high". Medium and low bush cover classes were excluded as it can be assumed that farmers asked about the bush cover only consider densely

bushed areas as affected by bush encroachment. In spite of this being only a rough estimation, it can still be discussed here as it is not clear which kind of farm land farmers classify as "covered by bushes". Is this only the area with high encroachment or is it an assessment of the area covered by bushes on the whole farm land?

Table 2:   Comparison of estimated bush cover with classified bush cover (sum of percentage of farm land of the classes "very high" and "high" bush cover), green = within range ± 5 percentage points, orange = out of range.

farm name	bush cover estimation by farmer	MS	NDVI	SR	GVI
Jaegerhof	41-60%	43,88%	36,91%	17,68%	45,26%
Una	21-40%	27,36%	37,89%	21,55%	63,14%
Annenhof	61-80%	31,63%	24,22%	13,67%	39,67%
Otjihaenena	61-80%	7,49%	3,53%	1,76%	7,41%
Steenbokvlakte	21-40%	5,11%	33,66%	15,94%	82,21%

5 Discussion

Unsupervised classification of different vegetation indices and the multispectral image lead to ambiguous results with the indices corresponding on some farms and differing on others. Subsequent to a classification, an accuracy assessment would necessarily need to be carried out in order to verify the results. However, due to insufficient data this assessment could not be performed, a problem that is present in many similar studies (Richards & Jia 1999).

5.1 Accuracy assessment

a) Comparison of spectral signatures
One way to assess the results of a classification is to compare it to spectral signature patterns of known surface structures. For the MS image classification the spectral signatures could be calculated for each class (Fig. 5).
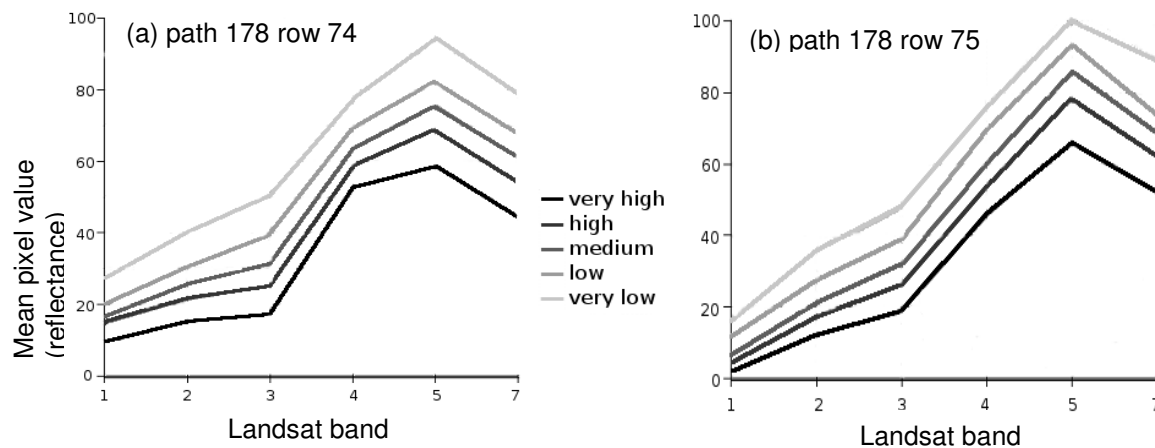
Figure 5: Spectral signatures of the classes on satellite image path 178 row 74 (a)
and path 178 row 75 (b).

As expected from knowledge based on reflectance behavior of vegetation, senescing
vegetation and soil, the spectral signatures show that a lower bush cover leads to a
higher mean reflectance value (cf. Fig. 1 & 2). The spectral signature for very high
bush cover approaches the signature of photosynthetically active vegetation,
especially on the northern satellite scene (path 178, row 74), although the typical
decrease of the curve in the 3rd band cannot be observed. This might be due to the
spectral mixing effect of both soil and senescent vegetation. Both have higher
reflectance values in this wavelength. Another remarkable difference is the
continuing increase of the reflectance values from the 4th to the 5th band, which could
also be explained by the influence of soil and senescent vegetation (cf. Fig. 1 & 2).
The transition of the signatures from very high to very low bush cover equals the
pattern that can be observed in Fig. 2. We conclude that the classification of the
multispectral image provides a fairly good segmentation of land surface types into
areas with photosynthetically active vegetation and senescent vegetation or bare soil
respectively.

b) Field mappings

Obtaining and using relevant ground truth data was subject to ample considerations
during this study. As ground truth data was not collected during the project we had to
rely on data previously collected in other studies. Unfortunately, the only source of
such data, the *Bush Encroachment Research, Monitoring and Management Project*
(de Klerk 2004) of the Ministry of Environment and Tourism of Namibia, was not

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suitable for our purpose. First, the study determined bush encroachment by measuring the number of species per hectare. Using this data as a measure of bush cover is problematic as every species has different phenological traits resulting in different extents of cover (Wagenseil 2008). Second, the geospatial information of this study was imprecise. For example, the exact location of the study sites could not be determined satisfyingly as some data points were directly located on roads whereas the respective study sites were located next to the roads. Third, important additional information on the study, such as size of the study sites and the date of the field work was missing. Thus, it was not possible to ground truth data with available field data.

c) Comparison with high resolution satellite images
High resolution Spot (Système Probatoire d'Observation de la Terre) satellite images are available through the GIS software Google Earth on which single trees and shrubs were distinguishable. Two main problems occurred when using these images as a ground truth reference. First, the acquisition dates of the scenes covering the study area differed from the date the analyzed images were taken. Spot data available in Google Earth was taken approximately in the years 2002–2005, but many scenes lacked the acquisition date and could only be used as an approximate representation of the study area. Furthermore, the images were taken in different points during the year. This results in pictures of both green savanna where single trees and shrubs can be detected, and brown landscapes with senescing vegetation making it difficult to distinguish woody vegetation from grasses. Second, although the Spot images allowed for a distinction of single trees, it is not clear up to which size bushes are recognizable. Therefore, real bush cover can hardly be detected with the help of these images.

Nevertheless, due to lack of other resources, the Spot images were compared to the results in order to perform a rough qualitative assessment. It turned out that this is a good way to visualize the results, but that an objective accuracy assessment is hard to perform. However, Fig. 6 shows a cutout of the farm Rentes with a half-transparent layer of the GVI classification results. The GVI turned out to be able to distinguish properly between densely encroached areas (dark red and red refer to classes "very high" and "high" bush cover) on the one hand and open rangeland (light yellow and yellow refer to "very low" and "low" bush cover) on the other.
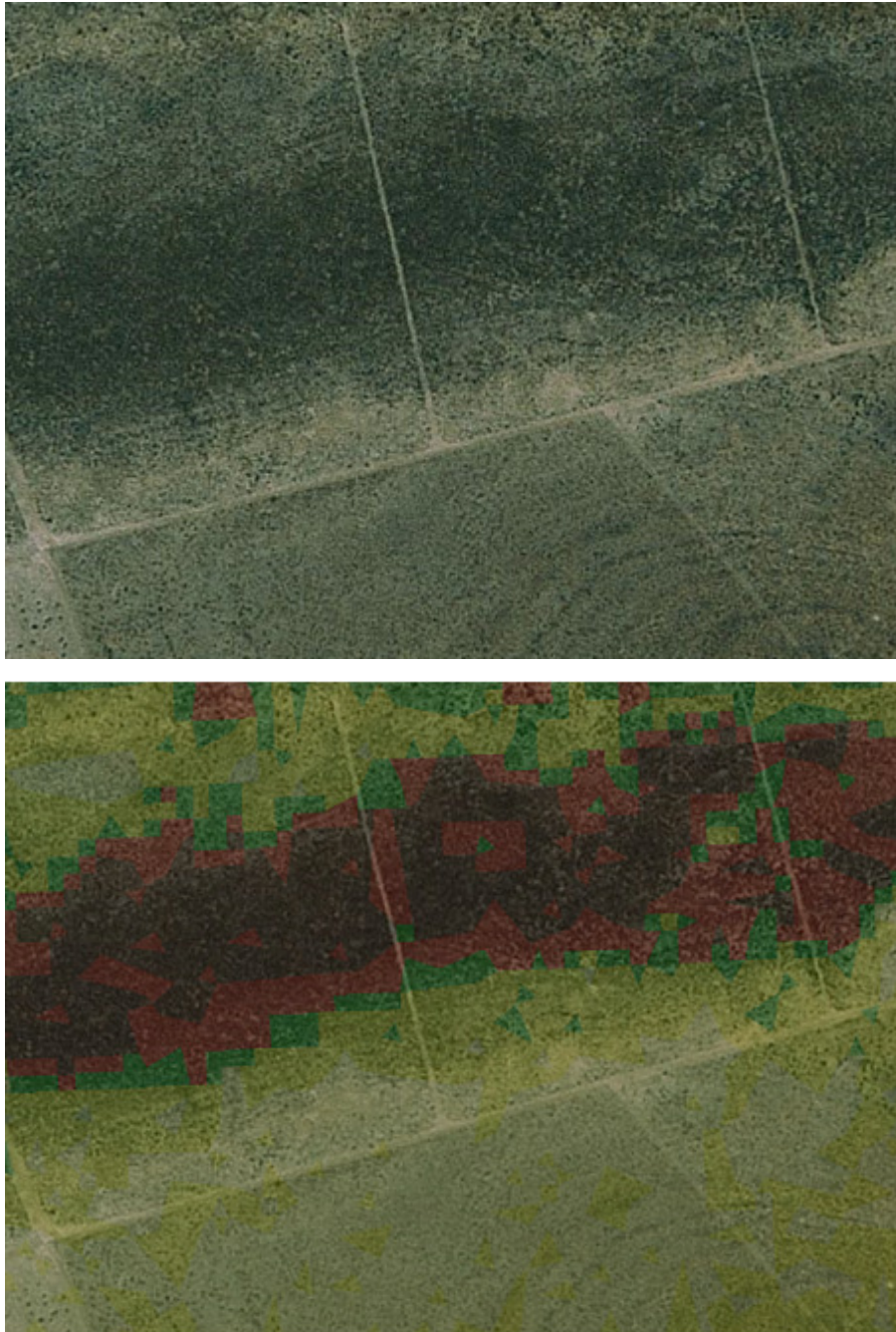
Figure 6: Upper picture: Cutout of Spot satellite image of the farm Rentes. Lower picture: Classification result of the GVI performed on the Landsat Image (dark red="very high", red="high", green="medium", yellow="low", light yellow="very low" bush cover).

d) Comparison with empirical farm data

We compared the farmers' knowledge about bush encroachment on their farms with our results. The MS image classification leads to results lying within the range given by the farmers for Jaegerhof and Una. The NDVI is within the range on Una and Steenbokvlakte, and a bit out of the range for Jaegerhof. Only on the farm Una, does the SR index lie within the range and the GVI yields a good estimation only for

Jaegerhof. Approximation of bush cover was ambiguous when deviating from the farmers' assessment with some indices lower than the farmers' assessment. The exception was the GVI, which leads to relatively high results of high bush cover for Una and Steenbokvlakte. The question remains open if there are any climax grasses that are detected as "green stuff" (Kauth & Thomas 1976) by the GVI but not by the other indices.

Given this approximation of real bush cover, none of the classifications leads to reliable results for Annenhof and Otjihaenena. Both farmers estimated high bush cover on their farms, despite that all of the classifications indicated rather low bush encroachment, especially on Otjihaenena. This might be due to three reasons. First, extensive change in land cover (large scale debushing, fire, spread of a disease) might have occurred between the date the satellite images were taken (May 2005) and the date the interviews were carried out (August 2008). Second, vegetation cover on these farms might not be in line with our assumption. Bushes on these farms might loose their leaves early or their spectral behavior might be different (e.g. lower reflectance values in the 4th band). Third, farmers might have a differing subjective estimation of how total bush cover on their farm is measured.

5.2 Restrictions

Without ground truth data it seems to be impossible to explain the differences between the different classification results properly. However, some deviations between the different indices can be explained.

The multispectral image classification turned out to place areas with shadows into the highest bush cover class. The farms Rentes and Okaparakaha are situated on hilly areas which led to casting of shadows on slopes. Both farms have a higher percentage of the "very high" bush cover class in the MS classification than in the classification of the other indices. This can be explained by shadows occurring in these areas. The MS classification might therefore have to be restrained to areas without shadows.

As mentioned above, the method chosen is restricted to the assumptions that bushes bear leaves at the time the satellite images were taken. For Otjihaenena, a relatively low percentage of rangeland was classified as densely bushed rangeland, even though the farmer estimated a high portion of bush encroached areas. On this farm,

bushes might have lost their leaves early. This might be due to species traits or local environmental conditions, like soil type. For Annenhof, the farmer estimated a high bush cover as well. A comparison with high resolution satellite imagery indicated that areas which were apparently densely covered by bushes were classified into "low" and "medium" bush cover classes. This indicates that a species might be abundant there that had lost leaves early in 2005, resulting in spectral mixtures that are more alike senescent vegetation and bare soil. However, bushes might still be abundant. Wagenseil (2008) points out that precipitation variability restricts remote sensing analyses in semi-arid landscapes, an effect that complicates the interpretation and is found regularly in these areas.

Another restriction of the chosen method might be the classification run on the subset of farms instead of taking the whole satellite scene as a data base. Classifications of subsets yields more differentiated results but might also exclude spectral information that is important to cover the whole range of bush cover in a certain region. However, as the farms on each scene were chosen randomly and not by a certain bush cover type, we expect a representative variety of bush cover in each region.

6 Conclusion

Our analysis of bush encroachment using remote sensing and a variety of indices showed that different classifications of vegetation indices lead to ambiguous results. As an accuracy assessment could not be run on these results, we cannot analyze which classification approximates real bush encroachment best. Hence, this study highlights the need for further research. On some farms the results of the different classifications equal each other, whereas on some farms classifications of certain indices pointed to local specifics of farmland that cannot be determined by remote sensing alone. This might be due to different types of land cover on farmland in Central Namibia which lead to different results in bush cover classes in the unsupervised classification. Ground truth data, in the form of field mappings, high resolution aerial photographs or local expert knowledge is needed to gain reliable results in these cases. With the help of this data we could determine in which cases an unsupervised classification would lead to reliable results and which index would yield the most accurate results.

Acknowledgements

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