WORKING PAPER

# Remote sensing of bush encroachment on commercial cattle farms in semi-arid rangelands in Namibia

by
Matthias Schröter, Oliver Jakoby, Roland Olbrich,
Marcus Eichhorn and Stefan Baumgärtner

University of Lüneburg
Working Paper Series in Economics

**No. 131**

June 2009

www.leuphana.de/vwl/papers

ISSN 1860 - 5508

# Remote sensing of bush encroachment on commercial cattle farms in semi-arid rangelands in Namibia

Matthias Schröter[a*], Oliver Jakoby[b], Roland Olbrich[a], Marcus Eichhorn[b] and Stefan Baumgärtner[a]

a Sustainability Economics Group, Department of Sustainability Sciences, Leuphana University of Lüneburg, Germany
b Department of Ecological Modelling, UFZ – Helmholtz-Centre for Environmental Research, Leipzig, Germany

## 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

---

* Corresponding author. E-Mail: matthias.schroeter@uni-lueneburg.de

# 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 ($\rho_{pixel}$) 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.

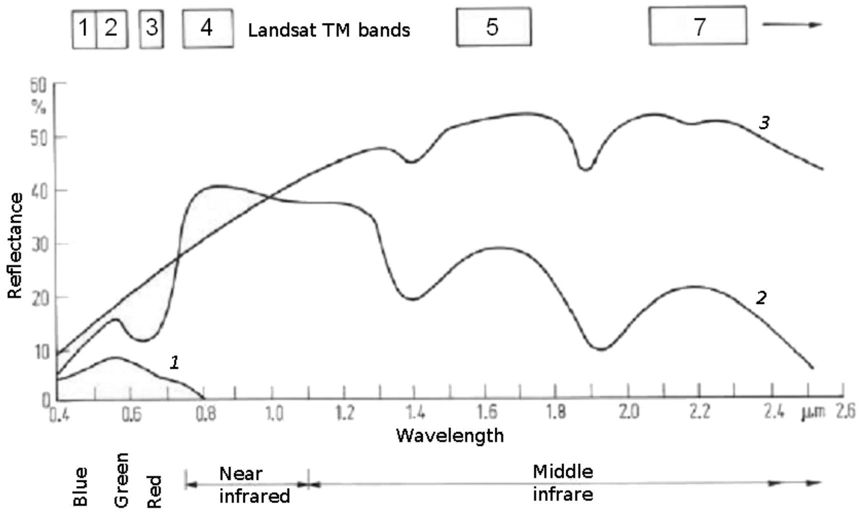


Figure. 1: Spectral reflectance characteristics of common surface materials in the visible and near-to-mid infrared wavelength spectrum for water (1), vegetation (2) and soil (3). The boxes above the diagram indicate the ranges of the spectrum covered by one channel/band of the sensor. Only Landsat TM 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).

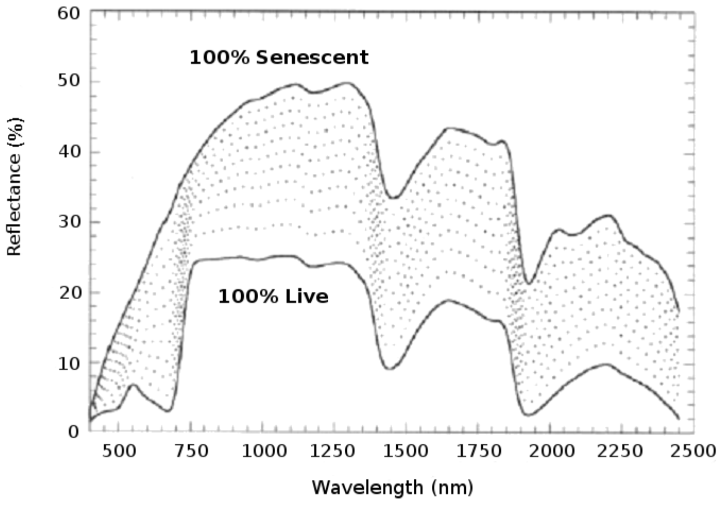


Figure. 2: Reflectance behavior of senescent and photosynthetically active vegetation in the wavelength spectrum 440-2500 nm. Depending on the stage of senescence, the pattern of a specific vegetation cover may be located anywhere between the 100% live and 100% senescent signature patterns. Source: Asner (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-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):

$$\mathrm{NDVI} = \frac{near\ infrared\ [band4] - red[band3]}{near\ infrared\ [band4] + red[band3]}$$

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:

$$\text{SAVI} = \frac{near\ infrared\ [band4] - red[band3]}{near\ infrared\ [band4] + red[band3] + L} \cdot (1+L) \qquad \text{with } 0 \leq L \leq 1,$$

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):

$$\text{SR} = \frac{near\ infrared[band4]}{red[band3]}$$

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 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* (Blackthorn 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.

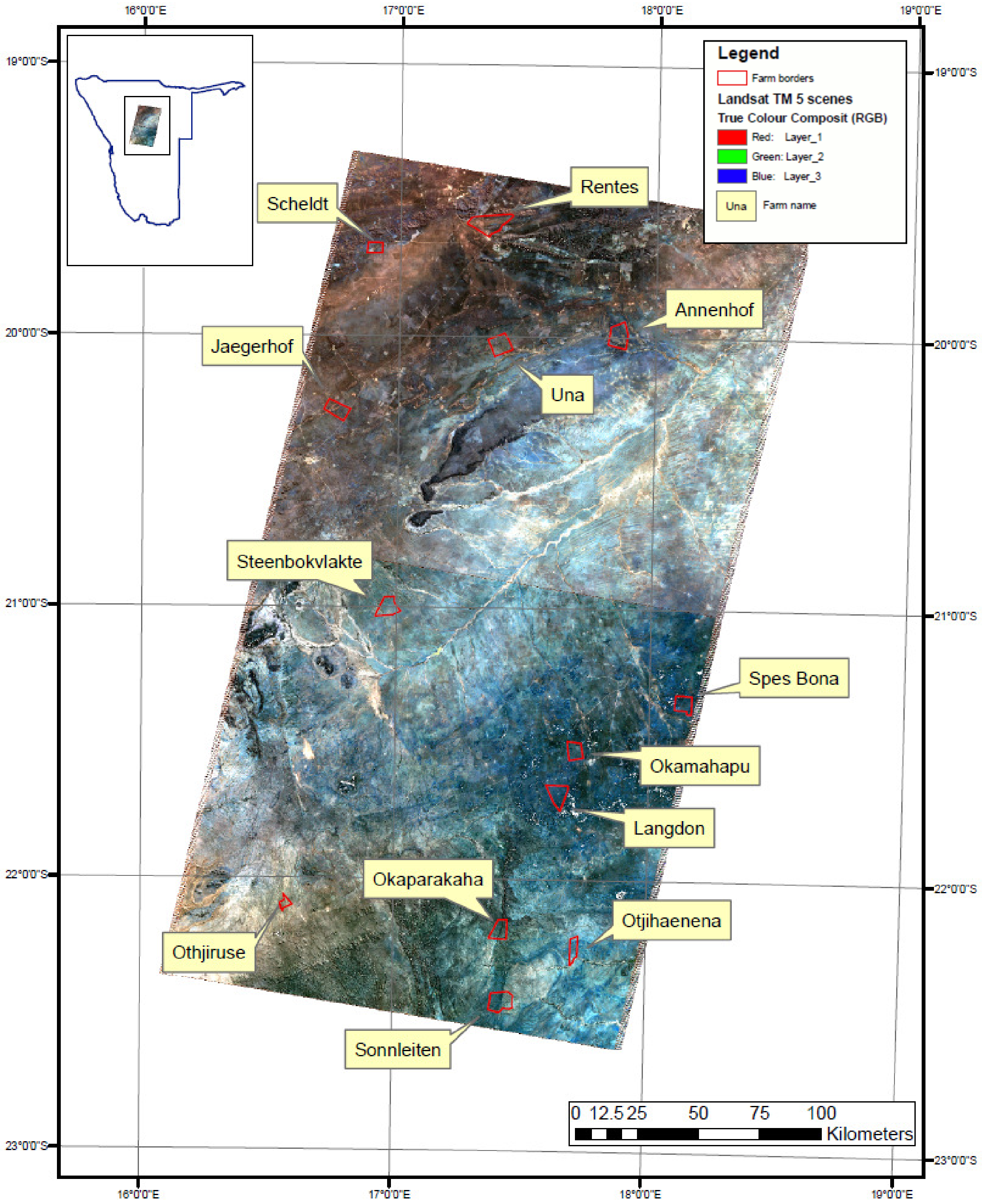


Figure. 3: Study area and selected cattle farms in Central Namibia as pictured by Landsat TM 5 satellite images (path 178, rows 174 & 75). Acquisition date was the 23rd of May 2005.

## 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

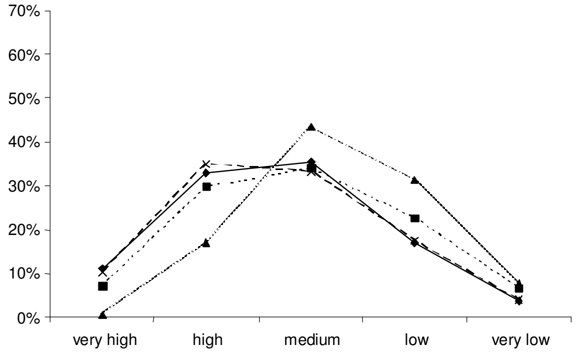
Results of the unsupervised classification are displayed in table 1. The fraction of each land cover class is calculated, and percentages of the total farm area are likewise given. The degree of detected bush cover differs between farms (Fig. 4).

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.

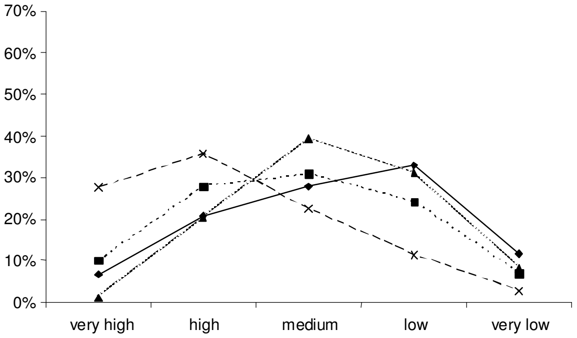
Table 1: Bush cover classes per farm for multispectral image (MS) and the indices Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR) and Green Vegetation Index (GVI). Areas per class is given in hectares, numbers in brackets denote percentages. Deviations in total farm area per index were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

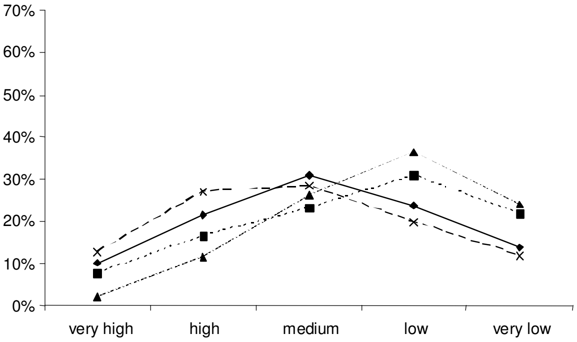
Farm Jaegerhof



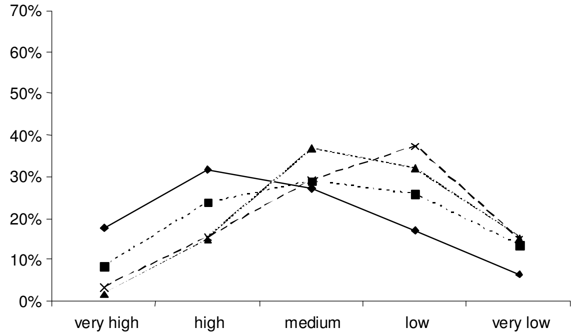
Farm Una



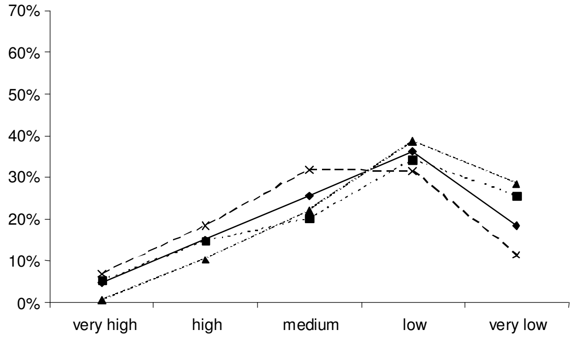
Farm Annenhof



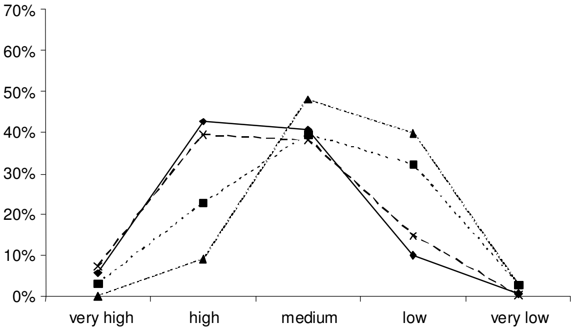
Farm Rentes



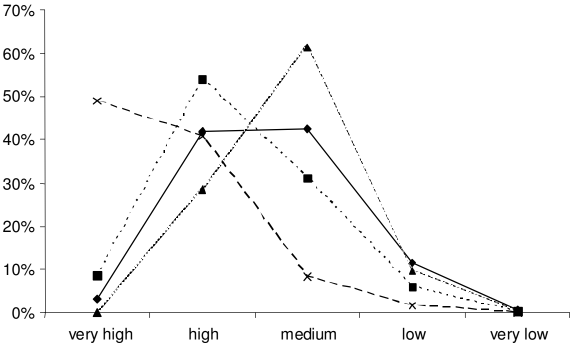
Farm Scheldt



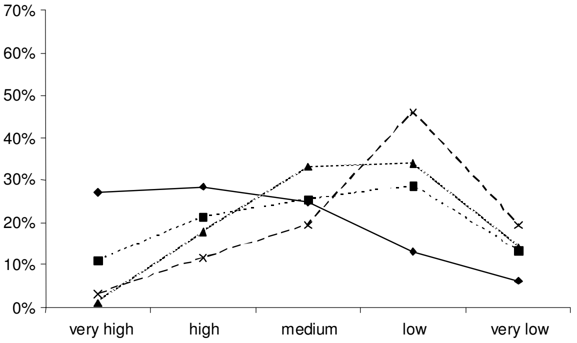
Farm Langdon



Farm Okamahapu



Farm Okaparakaha



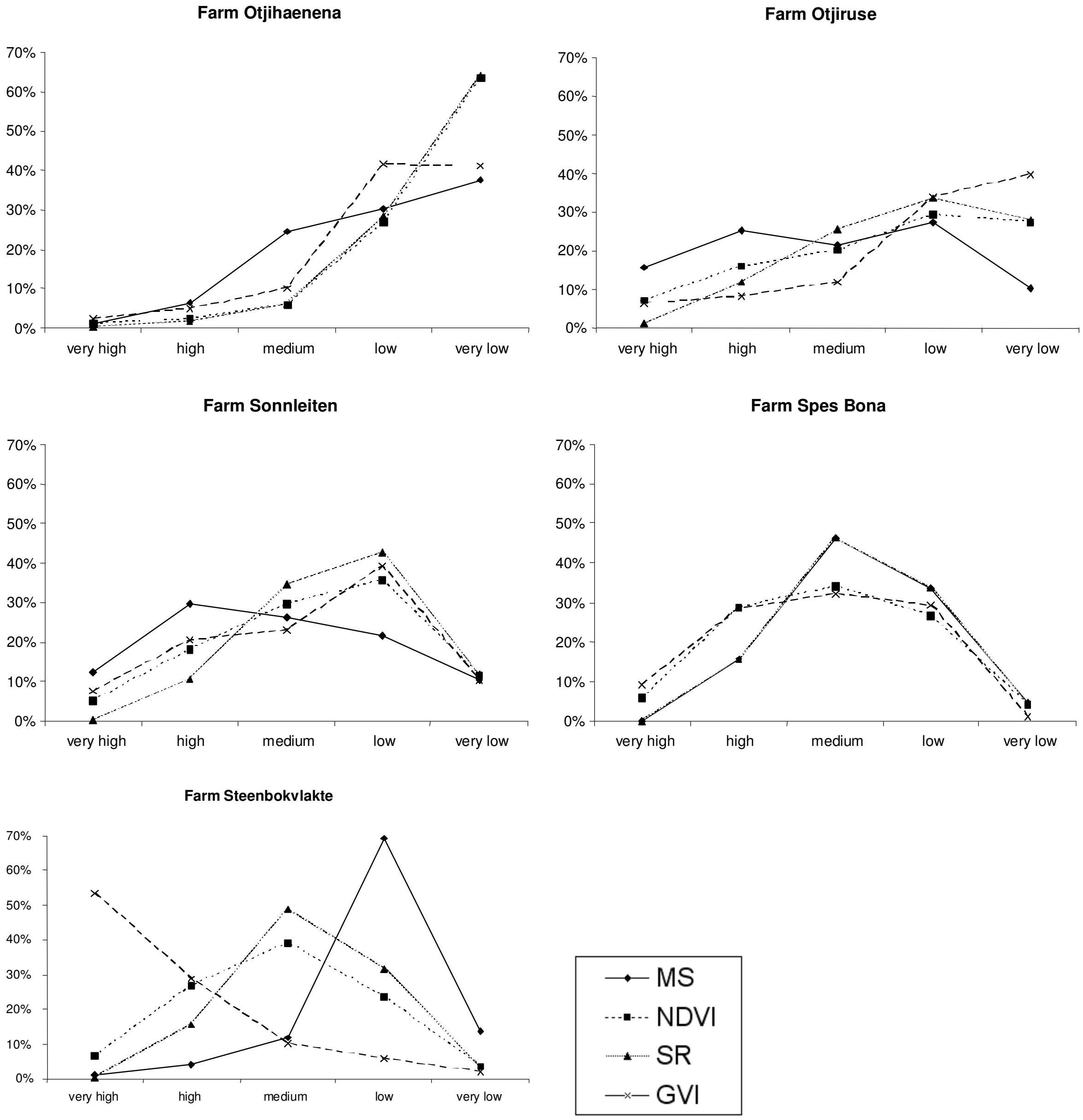


Fig. 4: Percentage of bush cover classes for each farm. Graphs show the classification results for the multispectral image (MS) and the three indices Normalized Difference Vegetation Index (NDVI), Simple Ratio (SR) and Green Vegetation Index (GVI).

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).

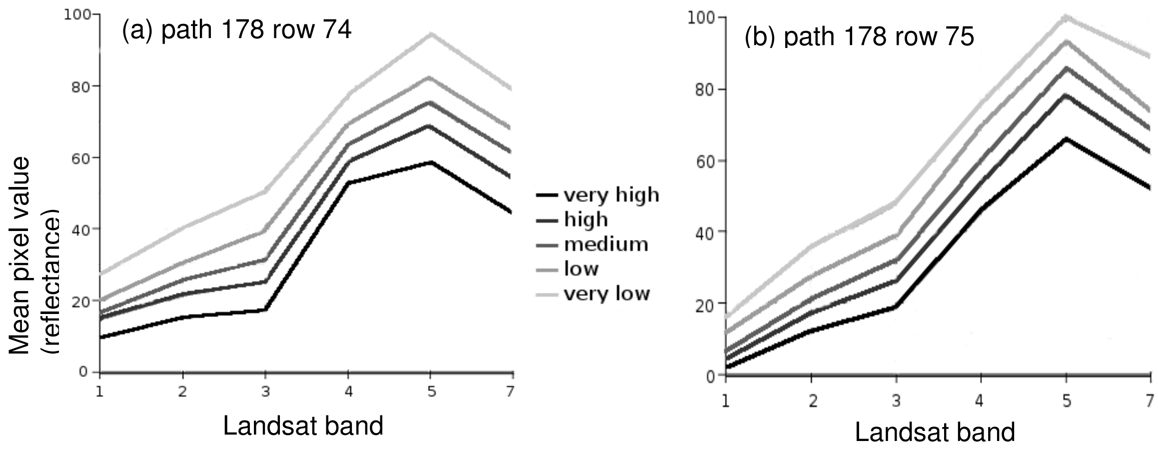


Figure 5: Spectral signatures of the classes on satellite image path 178 row 74 (a) and path 178 row 75 (b).

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 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.

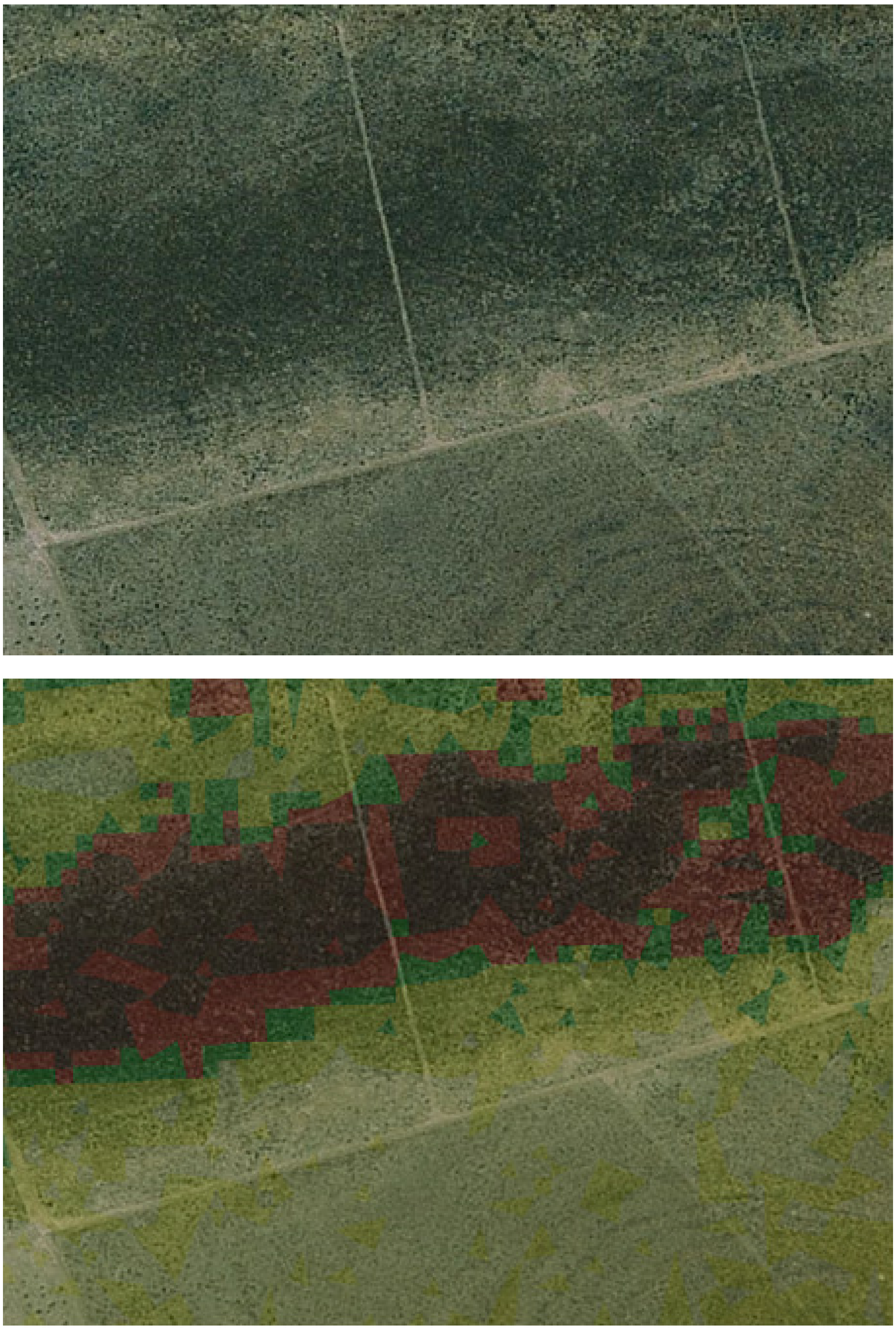


Figure 6: Upper picture: Cutout of Spot satellite image of the farm Rentes. Lower picture: Classification result of the GVI performed on the Landsat Image (dark red="very high", red="high", green="medium", yellow="low", light yellow="very low" bush cover).

*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

This study is part of the research project “Sustainable use of ecosystem services under uncertainty. Ecological-economic modelling and evaluation of economic policy options” (grant No. 01UN0607), funded by the German Federal Ministry of Education and Research. We thank the Helmholtz Centre for Environmental Research – UFZ, Leipzig for the opportunity to carry out this study. Special thanks go to René Höfer for his support during the project. We would also like to thank the Ministry of Agriculture, Water and Forestry of the Republic of Namibia for providing geospatial information on Namibia.

## References

Albertz, J. (2007), *Einführung in die Fernerkundung: Grundlagen der Interpretation von Luft- und Satellitenbildern*, 3rd ed., Wiss. Buchgesell., Darmstadt.

Asner, G. P. (2004), Biophysical Remote Sensing Signatures of Arid and Semiarid Ecosystems, in: Ustin, S.L. (ed.), *Remote Sensing for Natural Resource Management and Environmental Monitoring* (Manual of Remote Sensing), 3rd ed., vol. 4, pp. 53-109.

Crist, E.P. and R.C. Cicone (1984), Application of the Tasseled Cap Concept to Simulated Thematic Mapper Data, in: *Photogrammetric Engineering and Remote Sensing* 50(3), pp. 343-352.

Crist, E.P. and R.J. Kauth (1986), The Tasseled Cap De-Mystified, in: *Photogrammetric Engineering and Remote Sensing* 52(1), pp. 81-86.

Curtis, B. and C. Mannheimer (2005), *Tree Atlas of Namibia*, National Botanical Research Institute, Windhoek.

de Klerk, J. N. (2004), *Bush encroachment in Namibia: Report on Phase 1 of the Bush Encroachment Research*, Monitoring and Management Project, Ministry of Environment and Tourism, Windhoek.

de Lange, N. (2006), *Geoinformatik in Theorie und Praxis*, 2nd ed., Springer, Berlin et al.

du Plessis, W.P. (1999), Linear regression relationships between NDVI, vegetation and rainfall in Etosha National Park, Namibia, in: *Journal of Arid Environments* 42(4), pp. 235-260.

Elvidge, C.D. and R.J.P. Lyon (1985), Influence of Rock-Soil Spectral Variation on the Assessment of Green Biomass, in: *Remote Sensing of Environment* 17(3), pp. 265-279.

Espach, C. (2006), Rangeland productivity modelling: developing and customizing methodologies for land cover mapping in Namibia, in: *AGRICOLA* 2006, pp. 20-27.

Espach, C., L.G. Lubbe and N. Ganzin (2006), Determining grazing capacity in Namibia: approaches and methodologies, in: *AGRICOLA* 2006, pp. 28-39.

Hildebrandt, G. (1996), *Fernerkundung und Luftbildmessung: für Forstwirtschaft, Vegetationskartierung und Landschaftsökologie*, Wichmann, Heidelberg.

Hill, J. (2000), Semiarid Land Assessment: Monitoring Dry Ecosystems with Remote Sensing, in: Meyer, R. A. (ed.), *Encyclopedia of analytical chemistry: applications, theory and instrumentation*, Wiley, Chichester, pp. 8769-8794.

Huete, A.R. and R.D. Jackson (1987), Suitability of Spectral Indices for Evaluating Vegetation Chracteristics on Arid Rangelands, in: *Remote Sensing of Environment* 23(2), pp. 213-232.

Huete, A.R. (1988), A Soil-Adjusted Vegetation Index (SAVI), in: *Remote Sensing of Environment* 25(3), pp. 295-309.

Janssen, L.L.F. and B.G.H. Gorte (2001), Digital image classification, in: Janssen, L.L.F. & G.C. Huurneman (eds.), *Principles of Remote Sensing: An introductory textbook*, pp. 151-166.

Kauth R. J. and G. S. Thomas (1976), The Tasseled Cap -- A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by LANDSAT, in: *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data*, June, 29 – July, 1 1976, West Lafayette, New York, pp. 4B-41-4B-51.

Leica Geosystems (2008), *ERDAS Field Guide, Vol. 2.*, available: http://gi.leica-geosystems.com/documents/pdf/FieldGuide_Vol2_March2008.pdf, retrieved: October, 27, 2008.

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

McDaniel, K.C. and R.H. Haas (1982), Assessing Mesquite-Grass Vegetation Condition from Landsat, in: *Photogrammetric Engineering and Remote Sensing* 48(3), pp. 441-450.

Mendelssohn, J., A. Jarvis, C. Roberts and T. Robertson (2002), *Atlas of Namibia*, David Philip, Cape Town.

Olbrich, R., M. Quaas and S. Baumgärtner (2009), Sustainable use of ecosystems under uncertainty – a survey of commercial cattle farms in semi-arid rangelands, *Manuscript.*

Richards, J.A. and X. Jia (1999), *Remote Sensing Digital Image Analysis: An Introduction*, 3rd ed., Springer, Berlin et al.

Sweet, J. (1998), *Livestock – Coping with drought: Namibia – A case study*, http://www.odi.org.uk/networks/pdn/drought/sweet.pdf, retrieved: October, 29, 2008.

Tainton, N. (1999), *Veld Management in South Africa*, University of Natal Press, Pietermaritzburg.

Tucker, C. J. (1979), Red and Photographic Infrared Linear Combinations for Monitoring Vegetation, in: *Remote Sensing of Environment* 8(2), pp. 127-150.

van Leeuwen, W.J.D. and A. R. Huete (1996), Effects of Standing Litter on the Biophysical Interpretation of Plant Canopies with Spectral Indices, in: *Remote Sensing of Environment* 55(2), pp. 123-138.

Wagenseil, H. and C. Samimi (2006), Assessing spatio-temporal variations in plant phenology using Fourier analysis in NDVI time series: results from a dry savannah environment in Namibia, in: *International Journal of Remote Sensing* 27(16), pp. 3455-3471.

Wagenseil, H. (2008), *Savannen im Satellitenbild: Ein Ansatz zur Modellierung von Gehölzdichte und Verbuschung in Namibia*, Ph. D. thesis, University of Erlangen-Nürnberg.

Weier, J. and D. Herring (n.d.), Measuring vegetation (NDVI & EVI), in: *Earth Observatory Library*, available: http://earthobservatory.nasa.gov/Library/MeasuringVegetation/, retrieved: October, 27, 2008.

Xiao, J. and A. Moody (2005), A comparison of methods for estimating fractional green vegetation cover within a desert-to-upland transition zone in central New Mexico, USA, in: *Remote Sensing of Environment* 98(2-3), pp.237-250.

# Working Paper Series in Economics

(recent issues)

---

No.130: *Nils Braakmann:* Other-regarding preferences, spousal disability and happiness: Evidence for German Couples, May 2009.

No.129: *Alexander Vogel and Joachim Wagner:* Exports and Profitability – First Evidence for German Services Enterprises, May 2009

No.128: *Sebastian Troch:* Drittelbeteiligung im Aufsichtsrat – Gesetzliche Regelung versus Unternehmenspraxis. Ausmaß und Bestimmungsgründe der Umgehung des Drittelbeteiligungsgesetzes in Industrieunternehmen, Mai 2009

No.127: *Alexander Vogel:* The German Business Services Statistics Panel 2003 to 2007, May 2009
[forthcoming in: Schmollers Jahrbuch 129 (2009)]

No.126: *Nils Braakmann:* The role of firm-level and regional human capital fort he social returns to education – Evidence from German social security data, April 2009

No.125: *Elke Bertke und Markus Groth:* Angebot und Nachfrage nach Umweltleistungen in einem marktanalogen Agrarumweltprogramm – Ergebnisse einer Pilotstudie, April 2009

No.124: *Nils Braakmann and Alexander Vogel:* The impact of the 2004 EU-enlargement on enterprise performance and exports of service enterprises in the German eastern border region, April 2009

No.123: *Alexander Eickelpasch and Alexander Vogel:* Determinants of Export Behaviour of German Business Services Companies, March 2009

No.122: *Maik Heinemann:* Stability under Learning of Equilibria in Financial Markets with Supply Information, March 2009

No.121: *Thomas Wein*: Auf der Speisekarte der DPAG: Rechtliche oder ökonomische Marktzutrittsschranken? März 2009

No.120: *Nils Braakmann und Joachim Wagner:* Product Diversification and Stability of Employment and Sales: First Evidence from German Manufacturing Firms, February 2009

No.119: *Markus Groth:* The transferability and performance of payment-by-results biodiversity conservation procurement auctions: empirical evidence from northernmost Germany, February 2009

No.118: *Anja Klaubert:* Being religious – A Question of Incentives? February 2009

No.117: *Sourafel Girma, Holger Görg and Joachim Wagner:* Subsidies and Exports in Germany. First Evidence from Enterprise Panel Data, January 2009

No.116: *Alexander Vogel und Joachim Wagner:* Import, Export und Produktivität in niedersächsischen Unternehmen des Verarbeitenden Gewerbes, Januar 2009

No.115: *Nils Braakmann and Joachim Wagner:* Product Differentiation and Profitability in German Manufacturing Firms, January 2009

No.114: *Franziska Boneberg:* Die Drittelmitbestimmungslücke im Dienstleistungssektor: Ausmaß und Bestimmungsgründe, Januar 2009

No.113: *Institut für Volkswirtschaftslehre:* Forschungsbericht 2008, Januar 2009

No.112: *Nils Braakmann:* The role of psychological traits and the gender gap in full-time employment and wages: Evidence from Germany. January 2009

No.111: *Alexander Vogel:* Exporter Performance in the German Business Services Sector: First Evidence from the Services Statistics Panel. January 2009
[revised version forthcoming in: The Service Industries Journal]

No.110: *Joachim Wagner:* Wer wird subventioniert? Subventionen in deutschen Industrieunternehmen 1999 – 2006. Januar 2009

No.109: *Martin F. Quaas, Stefan Baumgärtner, Sandra Derissen, and Sebastian Strunz:* Institutions and preferences determine resilience of ecological-economic systems. December 2008

No.108: *Maik Heinemann:* Messung und Darstellung von Ungleichheit. November 2008

No.107: *Claus Schnabel & Joachim Wagner:* Union Membership and Age: The inverted U-shape hypothesis under test. November 2008

No.106: *Alexander Vogel & Joachim Wagner:* Higher Productivity in Importing German Manufacturing Firms: Self-selection, Learning from Importing, or Both? November 2008
[revised version forthcoming in: Review of World Economics]

No.105: *Markus Groth:* Kosteneffizienter und effektiver Biodiversitätsschutz durch Ausschreibungen und eine ergebnisorientierte Honorierung: Das Modellprojekt „Blühendes Steinburg“. November 2008

No.104: *Alexander Vogel & Joachim Wagner:* Export, Import und Produktivität wissensintensiver KMUs in Deutschland. Oktober 2008

No.103: *Christiane Clemens & Maik Heinemann:* On Entrepreneurial Risk – Taking and the Macroeconomic Effects Of Financial Constraints, October 2008

No.102: *Helmut Fryges & Joachim Wagner*: Exports and Profitability – First Evidence for German Manufacturing Firms. October 2008

No.101: *Heike Wetzel*: Productivity Growth in European Railways: Technological Progress, Efficiency Change and Scale Effects. October 2008

No.100: *Henry Sabrowsk*i: Inflation Expectation Formation of German Consumers: Rational or Adaptive? October 2008

No.99: *Joachim Wagner*: Produktdifferenzierung in deutschen Industrieunternehmen 1995 – 2004: Ausmaß und Bestimmungsgründe, Oktober 2008

No.98: *Jan Kranich:* Agglomeration, vertical specialization, and the strength of industrial linkages, September 2008

No.97: *Joachim Wagner:* Exports and firm characteristics - First evidence from Fractional Probit Panel Estimates, August 2008

No.96: *Nils Braakmann:* The smoking wage penalty in the United Kingdom: Regression and matching evidence from the British Household Panel Survey, August 2008

No.95: *Joachim Wagner:* Exportaktivitäten und Rendite in niedersächsischen Industrieunternehmen, August 2008
[publiziert in: Statistische Monatshefte Niedersachsen 62 (2008), 10,552-560]

No.94: *Joachim Wagner:* Wirken sich Exportaktivitäten positiv auf die Rendite von deutschen Industrieunternehmen aus?, August 2008
[publiziert in: Wirtschaftsdienst, 88 (2008) 10, 690-696]

No.93: *Claus Schnabel & Joachim Wagner:* The aging of the unions in West Germany, 1980-2006, August 2008
[forthcoming in: Jahrbücher für Nationalökonomie und Statistik]

No.92: *Alexander Vogel and Stefan Dittrich:* The German turnover tax statistics panels, August 2008
[published in: Schmollers Jahrbuch 128 (2008), 4, 661-670]

No.91: *Nils Braakmann:* Crime does pay (at least when it's violent!) – On the compensating wage differentials of high regional crime levels, July 2008

No.90: *Nils Braakmann:* Fields of training, plant characteristics and the gender wage gap in entry wages among skilled workers – Evidence from German administrative data, July 2008

No.89: *Alexander Vogel:* Exports productivity in the German business services sector: First evidence from the Turnover Tax Statistics panel, July 2008

No.88: *Joachim Wagner:* Improvements and future challenges for the research infrastructure in the field *Firm Level Data*, June 2008

No.87: *Markus Groth:* A review of the German mandatory deposit for one-way drinks packaging and drinks packaging taxes in Europe, June 2008

No.86: *Heike Wetzel:* European railway deregulation. The influence of regulatory ans environmental conditions on efficiency, May 2008

No.85: *Nils Braakmann:* Non scholae, sed vitae discimus! - The importance of fields of study for the gender wage gap among German university graduates during market entry and the first years of their careers, May 2008

No.84: *Markus Groth:* Private ex-ante transaction costs for repeated biodiversity conservation auctions: A case study, May 2008

No.83: *Jan Kranich:* R&D and the agglomeration of industries, April 2008

No.82: *Alexander Vogel:* Zur Exporttätigkeit unternehmensnaher Dienstleister in Niedersachsen - Erste Ergebnisse zu Export und Produktivität auf Basis des Umsatzsteuerstatistikpanels, April 2008

No.81: *Joachim Wagner:* Exporte und Firmenerfolg: Welche Firmen profitieren wie vom internationalen Handel?, März 2008

No.80: *Stefan Baumgärtner:* Managing increasing environmental risks through agro-biodiversity and agri-environmental policies, March 2008

No.79: *Thomas Huth:* Die Quantitätstheorie des Geldes – Eine keynesianische Reformulierung, März 2008

No.78: *Markus Groth:* An empirical examination of repeated auctions for biodiversity conservation contracts, March 2008

No.77: *Nils Braakmann:* Intra-firm wage inequality and firm performance – First evidence from German linked employer-employee-data, February 2008

No.76: *Markus Groth*: Perspektiven der Nutzung von Methanhydraten als Energieträger – Eine Bestandsaufnahme, Februar 2008

(see www.leuphana.de/vwl/papers for a complete list)

Leuphana Universität Lüneburg
Institut für Volkswirtschaftslehre
Postfach 2440
D-21314 Lüneburg
Tel.: ++49 4131 677 2321
email: brodt@leuphana.de
www.leuphana.de/vwl/papers