RANGELAND PRODUCTIVITY MODELLING: DEVELOPING AND CUSTOMISING METHODOLOGIES FOR LAND COVER MAPPING IN NAMIBIA

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ABSTRACT

There is an increasing need to precisely describe and classify land cover and land use in Namibia in order to develop sustainable land use systems that are best suited for each agro-ecological zone. Land resources need to be better matched to land use requirements to increase production, protect the environment, and maintain biodiversity. Land cover mapping formed an integrated part of a pilot project designed to develop methodologies for the quantification of land production potential in Namibia as inputs for land use planning, land valuation, the land taxation programme, and improved environmental and land management in Namibia. Baseline information on biophysical factors (land cover, vegetation, terrain, soil, climate) and socio-economic factors (land use, farming systems, access to supplies and markets), which influence land productivity in Namibia, were collected and analysed. The land cover component focused on defining and confirming suitable land cover mapping methodologies, the feasibility of these methodologies, and a practical achievable mapping accuracy. A land cover classification system was designed for the whole country, as was a legend for the pilot area. A land cover map was produced for the pilot area, based on field sample data and supervised classification of multi-seasonal Landsat images. Verification was done through point-based field sample data, an area-based assessment using recent digital orthophotos, and a comparison with the MODIS continuous field vegetation dataset. The suitability and limitations of Landsat satellite imagery were investigated for the delivery of desired levels of information in an arid environment. Secondary products of this project are information on the time and costs involved in such an exercise, data requirements, and human capacity and infrastructural needs, to be employed in planning the upscaling of the project to national level at a scale relevant for planning.

INTRODUCTION

At national and regional level, one of the main requirements of an agricultural policy is knowledge of land cover and agricultural cash crop production. There is an increasing need to be able to precisely describe and classify land cover and land use in order to define sustainable land use systems that are best suited to the place concerned. Land resources need to be better matched to their uses to increase production, while at the same time attempting to protect the environment and biodiversity. It is essential, therefore, to have detailed and in-depth knowledge of the potentials and limitations of present uses. This type of information is required in many aspects of land use planning and policy development, as a prerequisite for monitoring, modelling and environmental change, and as a basis for land use statistics at all levels.

One of the most important elements for describing and studying the environment is land cover, as it is the main resource in controlling primary productivity for terrestrial ecosystems. It is also an important parameter for environmental databases due to the fact that land cover changes quickly over time and that it is the easiest indicator of human intervention on the environment. The patterns that one sees are the products of many years of natural and human influences (Lillesand and Kiefer, 1994). With its geographic features, land cover can serve as a reference base for other environmental applications such as soil and vegetation. Land cover mapping is only about mapping the present cover of a specific area and has no reflection on or reference to the ecology or habitat of a certain area. The latter can be derived by integrating the land cover units with geographical zones (Kalahari), landscape types (escarpment, flood plains), or terrain types (beach, dune, sand areas).

Land cover can be defined as "the observed (bio) physical features on the earth's surface" (Di Gregorio and Jansen, 1997), and can include vegetation and man-made features, as well as bare rock, soil, and inland water systems.

Land use is based on function – the purpose for which the land is being used. A given land use may take place on one or more than one piece of land, and several land uses may occur on the same piece of land. The definition of *land use* in this way provides a basis for precise and quantitative economic and environmental impact analyses, and permits precise distinctions between land uses, if required.

Land use can be "characterized arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (ibid.).

Land cover and land use are the key inputs into determining land productivity. The concept of *land productivity* can be better understood if one takes into account the three main land potential categories for land productivity as defined by Westman (1985):

- The land suitability or the immediate potential of the current state of land

- The capability/productivity of the land or the full potential for an area after development, and
- The feasibility factor or the likely potential of a given area, considering socio-economic and political constraints on development.

MATERIALS AND METHODOLOGY

Pilot area selection

The study area for all the components of the pilot project is between Windhoek and Gobabis. This area consists of a one- by two-degree square (S22°–23° and E17°–19°) and is about 200 km x 100 km in size. It was considered most suitable for the pilot phase, because of the following:

- The area contains a wide range of vegetation types and landscape habitats.
- It is located within easy reach of Windhoek in terms of travelling distance and time.
- It is located within associated soil, vegetation, infrastructural, biomass and socio-economic pilot areas, and
- Various land tenure and land use systems exist in the area.

After discussions with the consultant for the land cover component of the pilot project, Mark Thompson, it was decided that mapping per satellite image scene would be done to reduce the costly and time-consuming task of accurately edge-matching the sets of digital data. Therefore, only a one-degree block (S22°–23° and E18°–19°) was chosen as it is contained within a single Landsat acquisition date, thus excluding overlap problems due to different dates.

Reference year

The total seasonal biomass production estimation (BPE) for the period 1985/6 to 2003/4 was used to select a 'normal' rainfall year. One disadvantage of the total BPE is that it does not differentiate between grazable (palatable grass, forbs, some bush) and non-grazable (unpalatable grass, some bush, trees) vegetation, but is still a good indication of what the vegetation cover is at national scale. These images were calculated from NOAA (National Oceanic and Atmospheric Administration)/AVHRR (Advanced Very High Resolution Radiometer) (1 km resolution) and SPOT (Systeme Pour l'Observation de la Terre)/VEGETATION (980 m resolution) satellite images, with the aid of Satellite Monitoring of Arid Rangelands software, which is based on the Monteith (1972) model.

Two seasons have been identified as being close to 'normal': 1991/2 and 2001/2. The 2001/2 season was chosen as a reference year as it is more recent.

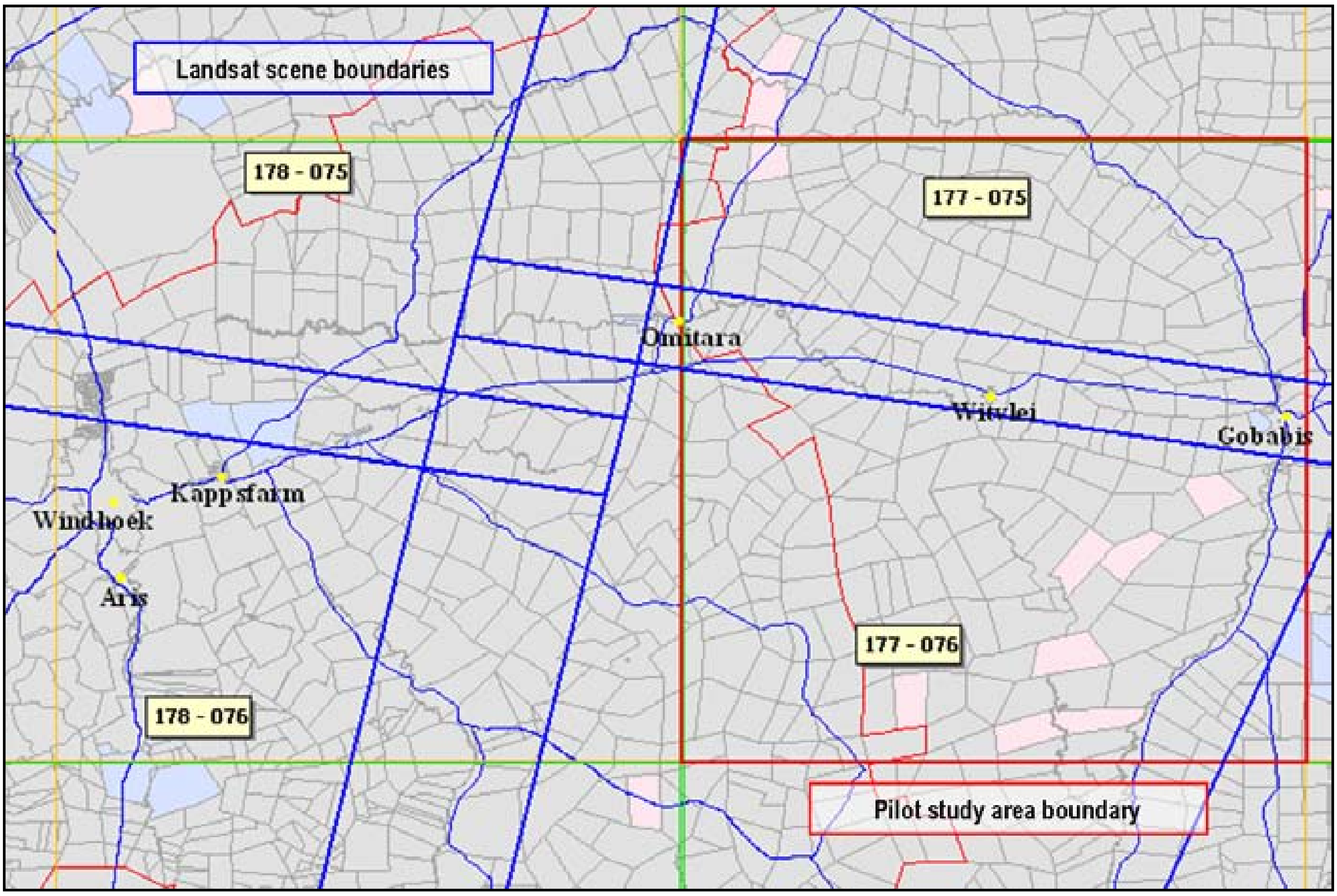

Figure 1. Pilot study area (eastern part of Namibia) indicated in red. Overlaps of Landsat scene boundaries are indicated in blue. The path/row imagery p177r075 and p177r076 were used, as they have the same acquisition date.

Classification scheme

After much refinement and review by the relevant stakeholders, a classification scheme was developed for the whole country, as was a legend for the pilot area. This scheme is based on the principles used in the FAO/AFRICOVER/LCCS to ensure international standards and protocols. It is based on the principle that there is only a single land cover for any point on the earth's surface, which in turn may be associated with multiple land uses (Di Gregorio and Jansen, 1997). For each of the class combinations, as indicated in Table 1, a definition was developed. An illustrated field guide containing the definitions and a supporting digital reference photo was developed during the pilot phase, and this will be used during the national land cover mapping project.

Field survey datasheet

The fieldwork took place from 4 to 13 January 2005. For this a field survey datasheet was designed, based on the one used successfully in the 1994 and 2000 National Land Cover projects in South Africa. The design utilised all public road networks to establish a series of sample sites along a predetermined transect layout. The systematic road transect sample dataset was supplemented by additional ad-hoc roadside edge samples of extra points of interest. During the various feedback meetings, suggestions and recommendations as to which landscape attributes to include during the field data collection were tabled. The basic proviso was that such attributes are visually determined from a roadside edge position in a standardised

Table 1. Modified threshold parameters for defining vegetation land cover classes, which are comparable with the FAO Forestry Act of 2005, the Namibian Vegetation Classification, and the FAO-LCCS specifications and requirements

Land cover type (vegetation)	Minimum threshold parameters	Modifiers (for each vegetation group)
Forest (dominated by single-stemmed trees)	Canopy cover > 70% Height > 5 m	Canopy cover thresholds (all types): 0–10% Very sparse 10–40% Sparse 40–70% Open 70–100% Closed Note: Forests, by definition, are closed, with > 70% canopy cover Note: 0–10% modifier not applicable to classes dominated by trees and shrubs.
Woodland (dominated by single-stemmed trees)	Canopy cover > 10% + < 70% Height > 5 m	
Shrubland (tree/multi-stemmed shrub mix)	Canopy cover > 10% Height > 0.5 m	
Herbaceous: Grassland	Tree/shrub cover < 10% Vegetation cover > 1%	
Herbaceous: Forbs	Tree/shrub and grass cover < 10% Vegetation cover > 1%	
Herbaceous: Lichen fields	Lichen-dominated Vegetation cover > 1%	
		Canopy height for shrubland < 2 m – Low > 2 m – Tall

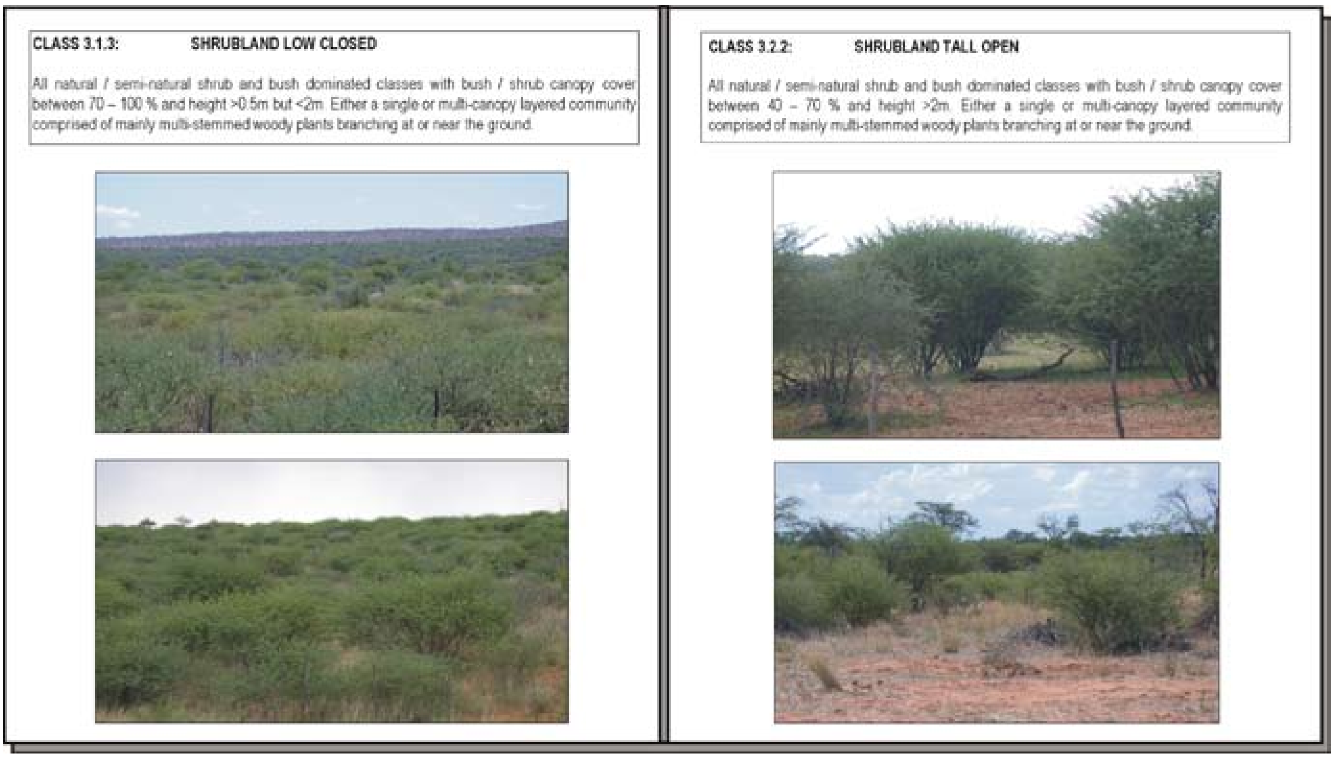

Figure 2. Example of the illustrated field guide that was developed during the pilot phase, indicating the class definition and, accordingly, a representative photo of that class.

and repeatable manner, without requiring physical access to the viewed site, or physical removal of any object.

Satellite geo-correction

As with single-date imagery, the objective is to define periods which will maximise the variation between important (but not necessarily spatially dominant) cover types, whilst minimising any possible error-inducing effects, such as enhancing cloud and shadow coverage, or rainfall-induced local abnormalities in vegetation conditions (Thompson *et al.,* 2001). The term *multi-temporal*, by definition, implies at least more than one image acquisition date, and often – in terms of global or continental land cover/vegetation mapping – refers to an entire sequence of images throughout several seasons (Townshend and Justice, 1988). When an image (raster map) is created, either by a satellite, airborne scanner or an office scanner, the image is stored in row and column geometry in raster format. There is no relationship between the rows/columns and real-world coordinates, geographic coordinates, or any other reference map projection). In a process called *geo-referencing*, the relation between row and column numbers and real-world coordinates is established.

Eighteen multi-seasonal Landsat images, ranging between 1 January 2001 and 31 December 2002, were obtained for free from the Satellite Application Centre in South Africa. In line with current worldwide land cover mapping applications, the precision ortho-rectified 2000 Stock scenes available from EarthSAT were used to geo-correct the Landsat images. These stock scenes represent a global dataset of sub-pixel level, ortho-rectified, single-date Landsat images, which are easier and more accurate to use as geographical references for image projection and registration. From these 18 satellite images, 10 scenes were chosen (Table 2). These scenes are representative of the dry and wet periods of 2001/2, during which the optimum land cover could be observed. Fifty ground control points, which were easily identifiable on both the stock scenes and raw imagery, were chosen for the geo-correction process.

Table 2. Acquired satellite imagery for the wet and dry periods during 2001 and 2002, with their respective Root Mean-Square Error (RMSE) where the reference point in terms of X and Y coordinates is less than one pixel out

Sensor	Date	Path/Row	RMSE error	Path/Row	RMSE error
Landsat 7 ETM+	2001–11–21	177–075	0.9682	177–076	0.8599
Landsat 7 ETM+	2001–12–23	177–075	0.9734	177–076	0.6944
Landsat 7 ETM+	2002–01–08	177–075	0.7591	177-076	0.6747
Landsat 7 ETM+	2002–04–30	177–075	0.5534	177–076	0.4176
Landsat 7 ETM+	2002–08–20	177–075	0.3450	177–076	0.5007

Vegetation indices

Various mathematical combinations of satellite bands have been found to be sensitive indicators of the presence and condition of green vegetation, and are thus referred to as *vegetation indices*. The Normalized Difference Vegetation Index (NDVI) and Tasselled Cap are two types of indices that were used during the analysis stage of the satellite images. The reason for the use of these (spectral) vegetation indices, rather than original spectral image data, is to standardise the input imagery prior to analysis and mapping, as well as minimise the influence of background 'noise' in arid, low-vegetation covers.

NDVi's were calculated for all the five selected images, as the discrimination between three land cover types (vegetation, water, and bare soil) is greatly enhanced. Green yields high values; in contrast, water yields negative values; whereas bare soil gives indices near zero. The NDVI also compensates for changes in illumination condition, surface slopes, and aspect.

The Tasselled Cap transformation was also applied to the five selected images. This transformation offers a way to optimise data viewing for vegetation studies. Research has produced three data structure axes that define the vegetation information content (Crist and Kauth, 1986):

- Brightness: A weighted sum of all bands, defined in the direction of the principal variation in soil reflectance.
- Greenness: Orthogonal to brightness, a contrast between the near-infrared and visible bands. Strongly related to the amount of green vegetation in the scene.
- Wetness: Relates to canopy and soil moisture (Lillesand and Kiefer, 1987).

The Global Positioning System (GPS) field points which represent the vegetation cover classes were selected and buffered by 75 m, as this is representative of the pixel/ground area of approximately 5 x 5 pixels/2.25 ha. This is comparable with the theoretical Landsat Thematic Mapper/Enhanced Thematic Mapper (TM/ETM) minimum mapping unit, and fits within the 250 x 250 (homogenous) field sample unit size used as independent validation references during the final classification verification. These points were then split 50:50, based on every alternate site to be used as an independent validation reference set during the final classification, and to ensure no bias of any geographically defined vegetation variations existed.

Class separability

Signature separability is a statistical measure of distance between two spectral signatures. Separability can be calculated for any combination of bands used in the classification, enabling one to rule out any bands that are not useful in the results of the classification. A *separability listing* is a report of the computed divergence for every class pair and one band combination. The listing contains every divergence value for the bands studied for every possible pair of signatures. The separability listing also contains the average divergence and the minimum divergence for the band set. These numbers can be compared with other separability listings (for other band combinations) to determine which set of bands is the most useful for classification (ERDAS Imagine field guide 2003).

For the satellite classification of the pilot area, the Transformed Divergence distance measurement was used. The 'bands' that were selected are represented by the respective satellite imagery for the period 2001/2. An important factor to take into account is that the satellite imagery should be in the correct date sequence to select the best separability bands. For the classes identified, this method determines the best combination of satellite imagery with which to perform the classification. Separability reports were generated for two-, three-, four- and five-band combinations, as one cannot perform a separability analysis for one band alone.

Masking

After the first iterative supervised classification of the three-date composite, it was realised that clouds were present in the satellite imagery of 2001-01-08. Thus, a cloud mask and model was created to filter out the cloud areas from the final classified dataset. Supervised classification was run on the clouds and their shadows by making use of the signatures of the original classified image. A model was then designed to embed the classified cloud image onto the original classified image. For the final clean-up of the cloud edges in both the non-parallelepiped and parallelepiped image, a 3 x 3 majority filter was used to eliminate all zero values.

Supervised classification

Classifying data that have been spectrally merged or enhanced can produce very specific and meaningful results. However, it is recommended that only the original, remotely sensed data be classified to reduce the influence of these enhancements.

After the reliable signatures have been created and evaluated, one can classify the data. Each pixel within the image is analysed independently. The measurement vector for each pixel is compared with each signature, according to a decision rule, or algorithm. Pixels that pass the criteria established by the decision rule can then be assigned to the class for that specific signature. The decision rule depends largely on the user; one can classify the data both parametrically with statistical representation, and non-parametrically as objects in feature space. A parameter can be any variable that determines the outcome of a function of operation, which can be the mean and standard deviation of data. The deviations are sufficient to describe a normal curve.

The Maximum Likelihood algorithm was chosen as the parametric decision rule on which to run this classification. One advantage is that it is the most accurate of all the classifiers (if the input samples have a normal distribution), because it takes the most variables into consideration by making use of the covariance matrix. The training samples were used to estimate the parameters of the distributions. The boundaries between the different partitions in the feature space were placed where the decision changes from one class to another. These partitions are called *decision boundaries*. A disadvantage of this decision rule is that it tends to over-classify signatures with relatively large values in the covariance matrix.

RESULTS AND DISCUSSION

During the two-week fieldwork period, 787 km of public access roads were travelled in the pilot area, in which 261 sample points were collected every 3 km on the left-hand side of the road to insure consistency. The sites were homogenous in terms of land cover for a minimum area of 250 x 250 m. GPS readings were taken for a point at the roadside edge and a re-projected point in the centre of the sample site; which were approximately 100–150 m from the road. A representative photo was also taken for the re-projected site.

A spreadsheet was generated from the GPS field points (latitude and longitude) to indicate all the necessary information for mapping land cover. The median and standard deviation statistical measures of all these points in both the NDVI and Tasselled Cap images were calculated. The median was chosen as it is the midpoint of the values, whereas the mean is the arithmetic average of the values. Only the greenness and wetness values from the Tasselled Cap images were used, as those are the main indicators of vegetation.

After various calculations and graphs, it was decided that the Tasselled Cap greenness median values would be used as prime indices for spectral vegetation class delineation. The Tasselled Cap greenness showed greater range in seasonal variation than the NDVI and Tasselled Cap wetness. The results confirm that there is a good intra-class separation amongst the sparse, open and closed conditions, but some inter-class confusion remains, i.e. Low Shrub, Tall Shrub, and Woodland. A parameter rule has been generated to determine distinct separability between the different signature classes.

Separability reports were generated for two-, three-, four- and five-band combinations. Each of these signature separability listings/reports was studied, and it was determined that a combination of three bands gave the best separability between the class signatures. These bands were represented by satellite imagery of :

- 2001-11-21
- 2002-01-08, and
- 2002-04-30.

A table (Table 3) was generated indicating the signature separability for the best three bands as well as the classes where there was either a good or a poor separation.

Extension officers indicated that during previous classifications, areas of naturally low shrub/grass cover on Kalahari sands were miscoded as *Degraded* (low vegetation cover) areas. A practical method was developed which involved summing the Tasselled Cap values for all five optimal image dates previously identified at the beginning of the project as being optimal in recognising seasonal change in cover. This was done to quantify, numerically and spatially, all areas within the miscoded degraded class that had a low vegetation cover as opposed to a seasonally low vegetation cover. Therefore, all seasonally/temporarily low vegetation cover areas were reclassified as *Low shrub – sparse*, and the permanently low vegetation cover areas remained classified as *Degraded*.

Accuracy assessment is a general term for comparing the classification with geographical data that are assumed to be true, in order to determine the accuracy of the classification process. Usually, the assumed-true data are derived from ground-truth data. Land cover classification accuracies were verified and compared for several land cover datasets, which were derived from applying different mapping procedures (i.e. 25-, 50- and 75-m training site buffer zones). Applying a 75-m buffering of the initial signature extraction appears to give better overall classification accuracy (±70%, within an upper 60% kappa range), compared with 50-m and/or 25-m buffering, when evaluated in terms of an aerial derived reference set. This might be a result of the field GPS reference coordinates being visually estimated from the roadside edge rather than exactly determined. This might also be a result of the GPS field reference points buffered by 75-m to classify the different land cover classes based on their spectral signatures, as opposed to using single defined pixels for the classification. The 75-m buffering is to ensure that the dominant cover at the locality is representative within a 250 x 250 m homogenous area of the specific cover

Table 3. Signature separability of the best three bands, indicating the separability condition amongst the different classes

Land Cover Classes	Tall shrub – closed	Tall shrub – open	Low shrub – closed	Low shrub – open	Woodland – sparse	Grassland – closed	Grassland – open	Woodland – open	Low shrub – sparse	Tall shrub – sparse	Bare	Forest	Riverine
Tall shrub – closed	Good	Poor	Good	Moderate	Poor	Good	Excellent	Poor	Good	Good	Excellent	Excellent	Excellent
Tall shrub – open		Good	Good	Moderate	Poor	Good	Excellent	Poor	Good	Good	Excellent	Excellent	Excellent
Low shrub – closed			Good	Poor	Poor	Good	Excellent	Good	Good	Good	Excellent	Excellent	Excellent
Low shrub – open				Good	Poor	Good	Excellent	Good	Good	Good	Excellent	Excellent	Excellent
Woodland – sparse					Good	Good	Excellent	Poor	Good	Good	Excellent	Excellent	Excellent
Grassland – closed						Good	Excellent	Good	Good	Good	Excellent	Excellent	Excellent
Grassland – open							Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Woodland – open								Good	Good	Moderate	Excellent	Excellent	Excellent
Low shrub – sparse									Good	Good	Good	Excellent	Excellent
Tall shrub – sparse										Good	Excellent	Excellent	Excellent
Bare											Good	Excellent	Good
Forest												Good	Excellent
Riverine													Good

Separability condition	Range
Poor	< 500
Moderate	> 500 < 1 000
Good	> 1 000 < 1 990
Excellent	> 1 990 > 2 000

type. This results in the spectral signatures being derived from an area-based process for the final classification process, wherein the total area used per class type is equal to approximately 0.5 ha per class-specific sample site.

Classification accuracies, as determined from the aerial survey (i.e. gyrocopter) reference data, show significantly higher mapping accuracies (±70%) than those calculated from the roadside transect survey data (±30%) for the *same* land cover classification. This is not unexpected, given the problem of accurately identifying vegetation canopy characteristics from an oblique, roadside edge position, as opposed to the vertical viewing perspective provided by the gyrocopter. Since the majority of cover types in the pilot land cover mapping area were natural/semi-natural vegetation classes, which are defined primarily in terms of canopy cover characteristics, this aerial perspective is likely to allow more accurate identification and interpretation of true field conditions. For this reason the higher mapping accuracies, as derived from the aerial survey data, are assumed to be more representative of the true mapping accuracies achieved in the pilot study area.

The aerial survey reference data captured as part of the pilot study were limited to only 17 points (in comparison with the ±130 field survey reference points), which is acknowledged to be limited in terms of overall statistical reporting. Having said that, the kappa index derived for aerial survey assessment results is consistently > 0.60, which is a fair indication of overall data repeatability and confidence. However, it is recommended that, in terms of standard operating procedures for a national (Namibian) land cover mapping programme, more aerial survey points per image scene are recorded (minimum of 30, maximum 100). This can be implemented using a stratified approach since only those land cover units dominated by vegetation gradients need to be assessed in this manner. Other non-vegetated homogenous areas, such as deserts, can be validated using the alternative roadside edge method.

These ±70% *base* accuracy values represent calculated accuracies for all land cover classes as per the initial land cover legend structure. It can be expected that even higher mapping accuracies will result from sub-class amalgamation into broader class types/definitions, should this be required in terms of future GIS (Geographic Information Systems) modelling applications.

RECOMMENDATION

Vegetation is one of the key information sources on land productivity. The current information the Ministry has is only in the form of the Seasonal Biomass Production Estimation, which is determined each year at the end of the growing season. As mentioned above, this method has the limitation that it estimates the total biomass, which includes trees, bush, grass, forbs, etc. Land cover information can break down this 'total' vegetation into cover classes, i.e. grass, shrub and tree. Through the predetermined cover percentages one can add a quantitative value to a specific cover type in an area, and, thus, also differentiate between grazable and non-grazable areas.

Land cover information can be a useful tool to employ when developing methodologies for various applications within the agricultural sector. It can be used to improve methodologies for the estimation of seasonal biomass production. The present scope of this method is reduced by the fact that it estimates *total* biomass, and does not differentiate between grazable (grass, forbs, some bush) and non-grazable (bush, trees, unpalatable grass) vegetation.

The biomass produced is not necessarily accessible to animals in terms of height and density, and is not necessarily liked or well digested by animals. In addition, trees and shrubs are less productive than the herbaceous layer. Moreover, the biomass production estimations are often over-estimated, as if the cover was entirely herbaceous. There is a need to correct the values of biomass production to get to a reasonably accurate estimation of the utilisable vegetative cover that is available to animals.

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