Estimating Biodiversity in Remote Areas, Using Existing Vegetation Data: The Ngamiland Region

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Abstract

In data-poor regions, especially when they are large and remote, the measurement of biodiversity presents considerable challenges. This paper explores a way of estimating regional patterns of biodiversity through a combination of land-cover field mapping, remote sensing and interpretative GIS techniques. The results show spatial variations of potential biodiversity in the remote Ngamiland region of Botswana, with areas of higher variability of land-cover classes indicative of higher degrees of biodiversity. The methodology is potentially replicable in other data-poor regions in developing countries.

Introduction

Diversity is considered important in terms of the overall environmental stability of ecosystems. More complex systems are often more resilient, and have a greater potential to adapt to change in environmental parameters (Odum 1971). Biological diversity is often expressed hierarchically, in terms of species diversity at a particular site or within a given community, between communities or habitats, or as total species diversity in a region (Whittaker 1972 and Ricotta 2005). These indices can be related through additive or multiplicative partitioning of the smaller scale measures, as contributors to the larger scale measure (Ricotta 2005 and Crist 2003).

The issue of biodiversity at different geographic scales presents various challenges as aspects of species or ecosystem diversity can be considered at various spatial scales as landscape or regional variety at, for example the eco-subregion or ecoregion level (Sorokine, Bittner & Renschler 2004). Ecosystem diversity, a concept that encompasses the variety of habitats occurring within a region or the mosaic of patches found within a landscape, is harder to measure than species or genetic diversity because the 'boundaries' of communities (associations of species) and ecosystems are potentially elusive (World Resources Institute, World Conservation Union and United Nations Environment Programme 1992). Whittaker, Willis and Field (2001) suggest therefore to use the terms local, landscape and macro-scale as a more intuitive framework for addressing issues of geographic scale. Even then, the measurement of diversity and its intrinsic meaning continue to present challenges to the scientific community, particularly with respect to the interpretation of the various measures (Giles and Trani 1999). Nevertheless, politicians and scientists alike now agree that a priority list of global centres for preservation of biological diversity is required (Wood, Stedman-Edwards and Mang 2000). Hence, the need for biodiversity maps and other data.

The measurement of species diversity over large regions in third world countries with relatively poor ground data presents a major challenge (Williams 1996). Beta-diversity, also referred to as between-habitat diversity and spatial species turnover or differentiation (Koleff, Gaston and Lennon 2003, Whittaker 1972), describes the increase in diversity or species numbers when sub-areas are combined. Its measurement typically requires multiple closely spaced transects with detailed species information covering the entire region, making this a prohibitively data intensive procedure for large regions. Although higher taxon richness (using genera or families) has been suggested as a

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surrogate for species richness that is suitable for use in more cost-effective practical surveys (Vane-Wright, Humphries and Williams 1991), fieldwork demands over large regions is still prohibitive (Williams and Gaston 2002).

Landscape diversity has been suggested as a useful indicator for species richness at the landscape scale (Dauber et al 2003). Landscape diversity can be measured, for example in the manner suggested by the Corina Land use programme of the European Union. This can be done by recording the number of different landscapes in 3x3 km squares through satellite image interpretation supported by field-mapping (Willems et al 2000). This approach allows the identification of possible areas of high biodiversity, which can then be further investigated through more detailed surveys. The assumption is that a greater variety of landscape classes per unit area implies a greater diversity level of flora and, hence, related fauna and thus biodiversity. The Corina landscape classification system is to a large extent related to existing land-cover conditions (Willems et al 2000), a characteristic that makes it possible to utilise land-cover or vegetation-association classifications performed in other regions for a similar purpose, ie estimating regional landscape diversity and by implication regional biodiversity. Key elements of landscape pattern measures with diversity implications were identified by Giles and Trani (1999) who list six important factors for describing landscape patterns in a mapped area. The six factors comprise the (overall) size of the area, the total number of landscape classes (or units) in the area, the proportion of the dominant class, the number of polygons (or patches), the polygon size variance and the elevation range. Giles and Trani suggest that these variables and their map statistics encompass most of the observed phenomena associated with things perceived as land pattern. As Giles and Trani explain further, the average size of polygons allows an estimate to be made of the interior area for birds or other creatures for which behaviour relative to edge zones can be estimated. Conversely, edge length may be approximated from average area and thus correlative edge inhabiting biota estimated.

Giles and Trani (1999) argue that many of the land-pattern relevant spatial statistics calculated in the literature are actually interrelated. The larger the variance, the more likely it will be that many resources are available to biota, because, for example, the larger the variance, the longer the edge length. This suggests that many measures of landscape pattern are actually derivatives of a few common, well known measurements. They argue that edge by itself rarely has much meaning in ecology unless used with a contiguity matrix which is expressive of the relative importance of every linear join or union of two habitats to each species of managerial importance. Edge length can be used as a gross index of interspersion, but interspersion is probably equally efficiently estimated by mean-to-variance ratio in polygon size.

This study aims to make an assessment of land-cover diversity (and by implication biodiversity) of the remote Ngamiland region in central southern Africa by applying the pattern analysis methods (with the omission of elevation which is not a major variable factor in the region) suggested by Giles and Trani (1999) to a previously formulated digital habitat map, originally derived through satellite image interpretation (as explained below). Also, this work aims to produce from the same satellite-image derived data a land-cover diversity map of the study area through the application of the spatial, GIS-based approach pioneered by the EU Corina project (Willems et al 2000), thereby demonstrating the possibility of assessing aspects of biodiversity in data-poor regions on the basis of available land-cover information.

The results from the study are expected to contribute to improved management of biodiversity in the region in the context of the Okavango Delta Management Plan (Republic of Botswana 2008).

The Study Area

This study area covers the portion of Botswana's Ngamiland region covered by Landsat ETM satellite image scenes 174-073, 174-074, 175-073 and 175-074, measuring 107 910 square kilometres in extent. This largely coincides with the North West District Council administrative region, which covers 111,650 square kilometres (Figure 1) and is sparsely populated with, on average, about 1 person per square kilometre. Nonetheless, specific concentrations of people occur in and around the larger settlements of Maun (49,800 inhabitants), Gumare (7,400) and Shakawe (7,800) (CSO 2002). Ngamiland has attained world recognised status as a major tourist destination on account of its pristine natural flora and wildlife environment. This is largely related to the presence of the Okavango Delta, a unique alluvial fan that forms marshes (flooded areas) in an otherwise near-desert environment, thus combining dryland and wetland wilderness areas. The highly variable pattern of flooding in the delta depends on a number of parameters including previous flood conditions and rainfall patterns in the catchment area (McCarthy and Ellery 1998; McCarthy *et al* 2000). This determines the variable extent of the wetland units in the Delta (Ellery and Tacheba 200), while the riparian and most dryland units are relatively static (Ringrose *et al* 2007).

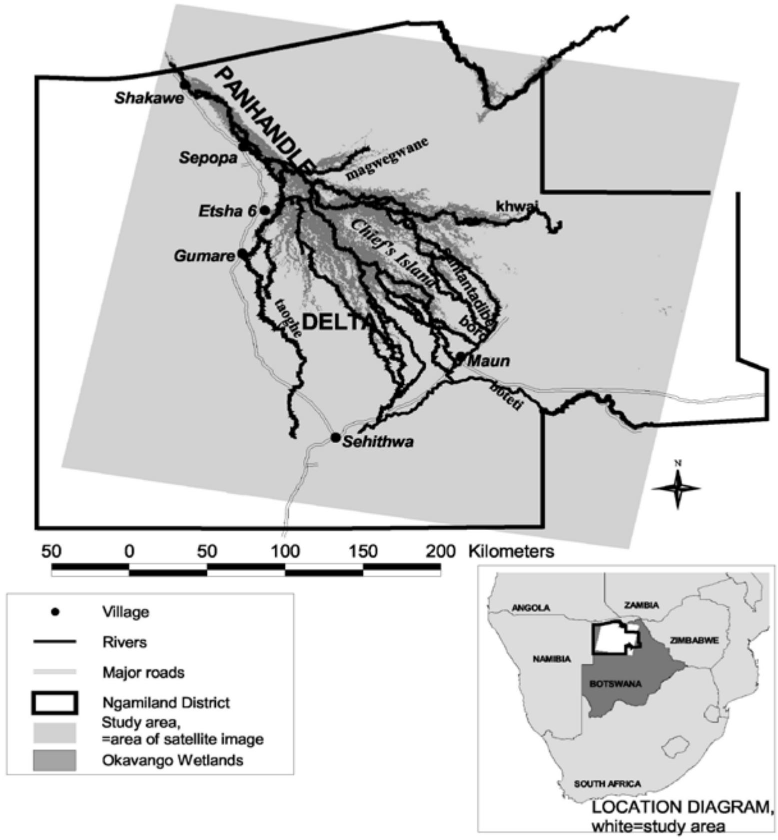
The Okavango Delta region is known to exhibit a high diversity of lifeforms. Until recently, most of the known variety was related to the 164 species of mammals, 540 bird species, 71 species of fish, 38 species of amphibians, over 162 arachnid (spiders, scorpion, ticks and mites) species and as many as 157 species of reptiles (Eldredge 2000, Alonso and Nordin 2003) with more limited information on flora and specifically on aquatic flora and fauna (Alonso and Nordin 2003). Nevertheless, recent studies have shown the region to be a host to over 1250 flora species and there are 80 common tree species (Ellery and Tacheba 2003). Pioneering research on plant identification and flora mapping was carried out by Smith (1977), while work on ecological zoning was produced by SMEC (1989) and Ringrose, Matheson and Boyle (1988) and more recently by McCarthy, Gumbricht and McCarthy (2005).

Some of the remaining aquatic knowledge gaps have recently been filled by a number of Conservation International initiated 'Aquarap' studies as well as research carried out under the auspices of the Okavango Research Institute (ORI) in Maun. Specific measurements of floral diversity have been attempted by Ellery and Tacheba (2003). In addition, a digital elephant-habitat map was constructed for the region in the context of a project by Conservation International and ORI on the basis of fieldwork combined with remote sensing (Jellema et al 2002). Given the data used in the formulation of this map (see below), it can be considered to represent a map of woody-vegetation and land-cover and as such provides a source for the measurement of some aspects of floral variation and thus bio-diversity at a regional scale. Although the map is not suited to the measurement of species diversity per se, it is useful for the measurement of land-cover variation over the region as a proxy for species diversity.

The Ngamiland Elephant-habitat Base-map: Fieldwork and Remote Sensing

The elephant-habitat map of the Ngamiland study area was constructed on the basis of field observations and satellite image interpretation followed by detailed classification procedures. Landsat-7-ETM images of April 2000 (end of wet season) covering the study area were geo-referenced and mosaiced. Due to observed extreme spectral variations within the mosaic, which comprised complex wetland and dryland areas, it was decided to sub-divide the mosaic into seven, spectrally more homogenous sub-areas, as described in Jellema and others (2002). These were independently classified on the basis of a supervised classification of the satellite imagery using Erdas-Imagine software. Table 1 portrays the habitat classes and the area occupied by each class.

Figure 1. Study Region (note that the study area corresponds to satellite imagery and not exactly to the Ngamiland district).



For the supervised classification, 'ground truthing' data were provided through extensive regional fieldwork. This was utilised in an iterative process to improve the classification. Field data consisted of woody-vegetation and land-cover information gathered along three 90 meter long transects at 134 sample sites and data for one 100 meter long transect at an additional 300 sample sites. At each site all woody species were recorded plus canopy diameter. In addition 3 quadrats per transect provided data for Alive Herbaceous Cover (AHC), Dead Herbaceous Cover (DHC), litter and bare soil percentages. Also, heights were recorded for trees and shrubs and notes added on structure, clearing size, and damage among other (for more details see Ringrose 2003).

The resulting classification is hierarchical in nature and uses international nomenclature (Grunblatt et al 1989). The classification breaks downs to: primary life form + secondary life form + canopy modifier + height modifier + dominant species description. This is reflected in the class names listed in Table 1 below, although several adaptations were made to accommodate specific conditions in the Okavango Delta. Hence a class may be referred to as low (<6 m), open (<50%), shrubbed woodland (>20%) in which the descriptors apply to the primary lifeform only (Table 1). An important aspect was the recording of dominant species which applied to the primary lifeform. Given that both vegetative and land-cover criteria were employed for the classification, the elephant-habitat map classes can be regarded as land-cover classes and as such used in a manner similar to the use of landscape-units in the EU Corina project (Willems *et al* 2000).

Table 1: Land-cover Classes: Ngamiland and Delta Regions (Jellema et al 2002).

LAND-COVER CLASS	Ngmiland (km2)	Delta km2
Low Open Grassed Shrubland on Dune Valley with Burkea and Baikiaea	1926.7011	38.2077
Low Open Grassed Shrubland on Dune Valley with Mopane and Combretum	1256.7933	113.3199
Low Open Grassed/Treed Shrubland on Dune Valley with Terminalia and Baffia	1638.1323	7.2927
Low Open Shrubland on Dune Crest with mixed species	3262.4739	197.9559
Dense Treed Shrubland on Dune Side with Burkea Baikiaea	5092.7679	152.0883
Low Open Grassed Shrubland on Dune Valley with Terminalia and Baffia	3807.7893	319.5243
Low Open Grassed Shrubland in Palaeo Delta with Accacia	2181.7548	190.3599
Low Open Shrubbed Grasland with Sage Bush	7951.7115	839.4309
Open Treed Shrubland on Dune Side with Burkea and Baikiaea	2011.2111	44.7966
Low Open Grassed Shrubland on Dune Valley with Terminalia and Baffia	462.9348	32.9229
Low Open Grassed Shrublandin Palaeo Delta with Acacia	7421.8023	2036.477
Densely vegetated palaeo-riparian ridges	306.6993	116.9208
Low Open Grassed Shrubland in Palaeo Delta with Combretum	4758.3081	739.3185
Low Dense Thickets on Former Lake Ridges with Acacia	43.3332	25.4421
Low Open Shrubbed/Treed Grassland with Acacia and Terminalia	1267.7373	1.8009
Low Open Bare Woodland in Meso Delta Channels with Tall Mopane	2560.2282	1432.895
Tall Open Shrubbed Woodlands in Meso Delta with Tall Mopane	3655.7838	783.9504
Low Open Shrubbed Woodland in Meso Delta with Mopane	4404.0897	383.1129
Low Bare Shrubland in Meso Delta with Shrub Mopane	2744.2737	376.2567
Low Open Bare Grasland with Sage Bush	188.1252	31.5657
Cloud and Shadow	1821.7269	1.305
Open Mixed Mopane in Meso Delta Channels with Mopane	6540.8103	1582.265
Low Open Grassland with Baikiaea Trees and mixed Shrubs	3565.6236	0
Low Open Grassland with Burkea Trees and mixed Shrubs	2473.1793	0
Low Open Grassland with Baikiaea/Mopane Trees and mixed Shrubs	2296.3428	5.8932
Low Open Grassed/Treed Shrubland with Terminalia and Acacia	1753.4349	32.598
Low Open Shrubbed Grasland with mixed Shrubs	4911.9066	2.6082
Low Open Shrubbed Woodland of Terminalia Tree islands	446.949	18.8433
Low Open Treed Shrubland with Accacia	3468.4119	408.3255
Tall Open Treed Grassland with Acacia	6476.1066	446.7537
Low Open/Dense Shrubbed Grassland on Former Floodplain	513.4338	512.5887
Grassland on Dry Floodplain and Island Interiors	2093.823	1758.416
Tall Open Shrubbed Woodland Dry Riparian zones and Adjacent Acacia thicket	601.0479	523.2888
Open Shrubbed Woodlands on Islands	1046.5785	1046.538
Low Open Shrubbed Grasland with Acacia	804.3894	801.7038
Low Open Grassed/Treed Shrubland with Terminalia and Acacia	533.448	532.3284
Low Open Shrubbed Woodland on Former Floodplain with Acacia	1738.2447	1736.148
Low Open Shrubbed Grassland on Former Floodplain	96.6726	96.6411
Low Open Grasslands on Former Floodplain with Burned Peat	620.1837	619.8516
Low Open Combretum Woodlands of Former Riparian Zone	415.8405	413.4879
Tall Dense Grassland on Inundated Higher Floodplain	851.6376	552.258
Dense Grassland on Inundated Lower Floodplain	829.4247	829.4211
Tall Open Shrubbed Woodland Island Riparian Zone and Adjacent Acacia thicke	876.8043	876.7431
Tall channel fringing emergents and mats of Reeds and Sedges	1009.2933	818.8614
Channels and Recently Inundated Floodplains	2366.7012	2366.462
Seasonal Swamp and Floodplain edges with Reeds, Sedges and Grasses	2044.5813	2044.523
Permanent - Backswamp areas with Reeds and Sedges	770.6214	770.6061
TOTAL	107909.87	26662.1

Previous Biodiversity Measurement in Ngamiland

The Ngamiland region and the Okavango Delta have been described as biologically diverse (Eldredge 2000) and are known to host 1256 flora species. Specific measurement of floral diversity was attempted by Ellery and Tacheba (2003). Their study lists data on species richness and diversity (using Shannon's diversity index) for five small study areas in the Okavango Delta as measures of alpha or within community diversity. Highest values were recorded for island woodlands where the species richness mean was 15.8 and the Shannon index 2.0, while the lowest values were found in the upper Panhandle (Figure 1) with values of 7.5 and 1.1 for the same measures. The overall density of species was determined at between 0.029 and 0.039 taxa per sq km, a figure considered equivalent to grasslands and succulent Karoo biomes in South Africa (Ellery and Tacheba 2003). Generally, Ellery and Tacheba (2003) observed an increase in mean species richness and in the Shannon diversity index from the upper Panhandle to the lower mid-Delta reaches in Moremi. This is consistent with the overall increasing trend in landscape variability between the more permanently flooded areas (the Panhandle and adjacent permanent swamp) and the more seasonally inundated areas downstream.

Beta-diversity or between-habitat diversity was also assessed by Ellery and Tacheba (2003) in terms of what they describe as landscape level heterogeneity at their sample locations. This was achieved by recording the number of different communities sampled and by calculating the Simpson diversity index that assesses the evenness of representation of plant communities. Using these measures, the highest diversity was encountered in the Panhandle, declining gradually to the lower permanent and seasonal swamps.

So far, no attempts have been made in the Ngamiland study area to measure or estimate broad-scale patterns of variation in species richness, in terms of gamma or regional diversity. Nor have there been attempts to measure regional landscape or land-cover diversity. While the available Ngamiland digital elephant-habitat (land-cover) data is not suitable for measuring beta diversity because complete plant species data were not collected and transects with detailed species data (grasses, trees and shrubs) as typically used for beta-diversity measurement could thus not be constructed over an adequate portion of the study area, comprehensive data were, nevertheless, collected concerning woody vegetation (tree and shrub) at the sample locations as well as aspects of vegetation structure and land-cover.

This work employs this data to estimate land-cover diversity at the landscape level, identified elsewhere as relevant at an approximate scale of 10 square miles (Sorokine et al 2004), with the intention to employ this as a proxy measure for biodiversity over the Ngamiland region. The spatial approach as suggested by the Corina Land use programme of the European Union (Willems et al 2000), ie by recording the number of different landscape units by 3x3 km squares is applied to the Ngamiland region to produce a land-cover diversity map and to compute related diversity statistics. In particular, five of the six key elements of landscape pattern measures, as identified by Giles and Trani (1999) are applied to describe Ngamiland's diversity in statistical terms, by considering the size of the area, the number of classes, the proportion of the dominant class, the number of polygons and the polygon size variance. The 'elevation range' variable is omitted because elevation is not a major variable factor in the region and has no real bearing on land-cover diversity, particularly as the gradients in the study area are extremely low.

Land-cover Variety Ngamiland: Statistical Picture

Statistical analysis was performed on the digital land-cover (elephant-habitat) map of the study region. The original grid map was for this purpose converted to a polygon map, using the gridpoly routine in ArcInfo-Grid. Standard GIS routines were applied to calculate the size of the study area(s) in square kilometres and the number of land-cover classes for the study areas. Available ArcInfo routines also allowed the counting of the total number of polygons and the calculation of average (mean) polygon size with accompanying variance (standard deviation) value. Calculation of the area covered by each land-cover class allowed the determination of the proportion of area occupied by the dominant class.

The statistical values of the measures that were suggested by Giles and Trani (1999) are given in Table 2 below. Results are given for the total Ngamiland study area, but also separately for the Okavango Delta region to highlight differences between the mainly wetland Delta and the mainly dryland (rest of) Ngamiland. The Delta (or Okavango Wetlands) is here defined as the Panhandle and the Delta-fan as delimited by channels active during historic times. It can be noted (Table 2) that the average polygon size is significantly smaller in the Delta area when compared to the overall Ngamiland study area, suggesting greater spatial variability.

Table 2: Land-cover diversity statistics, Ngamiland and Okavango Delta

Diversity Statistic	Ngamiland Study Area	Okavango Delta
Area in square km	107,910	26,662
Number of land-cover classes	46	44
Proportion of Dominant Class (% of total area)	7.4	8.9
Number of polygons (land-cover patches)	1,374,236	520,079
Average polygon (patch) size (m2)	78,524	51,265
Polygon size Variance	6,638,546	2,599,788
Mean to Variance ratio	0.012	0.019
Fragmentation Index (patches/km2)	12.7	19.5

(Note: dominant class Ngamiland=Low open shrubbed grassland with sage bush; dominant class Okavango Delta=Channels and recently inundated floodplains.)

From Table 2 it is evident that the study region covers a large extent, thereby limiting the possibility of comprehensive ground-based studies. Ngamiland is 2.5 times larger than The Netherlands, while the Delta is larger in area than Luxembourg in Europe. Generally, the larger the area, the greater will be the probability of the presence of resources for plant or animal species. Area size thus presents an indication about the potential number of home ranges that can fit in a region (Primack 1993). The study region is large by any standard and, as a result of past and present flood regimes, offers the space for a variety of ecosystems as well as home ranges for many different species of flora and fauna. The land-cover classification discussed above identified 46 distinct classes with differing combinations of dominant and other woody species and other land-cover characteristics. In general, the more classes exist, the more resources are likely to be available for example for different bird species (Giles and Trani 1999). So, the number of different classes alone may help explain why some regions have more species of plants or birds and other animal life than others.

Having considered area size and number of classes, we next observe from Table 2 that the proportion of the Okavango Delta occupied by the dominant class (ie Channels and recently inundated floodplains) is a fairly low 8.9 per cent. In the larger Ngamiland region, the dominant class (Low open shrubbed grassland with sage bush) occupies also a low proportion of the total area, 7.4 per cent. If this dominant proportion is small, the other classes are likely to be abundant and small (Giles and Trani 1999). If large, there are likely to be few other classes or many very small ones. In the Ngamiland region there are many land-cover classes, while the dominant class occupies a relatively small proportion of the total area, which is a condition conducive to diversity.

Next, the number of mappable units (polygons) in the study area is of relevance as it relates to fragmentation and size of average contiguous land-cover patches. The number of polygons per unit area is known as Monmonier's (1982) fragmentation index. In the delta portion of our study area there are 19.5 polygons per square kilometre, while this is 12.7 polygons for the total Ngamiland study region. The inverse of the fragmentation index is the average size of the polygons, which is probably a more intuitive measure of class coherence (Table 2). In the delta study area, the average polygon (class fragment) is a fairly small 51,266 square metres (about 5 hectares) which is significantly lower than 78,524 square metres (almost 8 hectares) for the Ngamiland region as a whole. Since these fragmentation levels relate mostly to natural conditions (and not to human disturbance, except in specific areas along the delta margin), they can be regarded as indicative of high relative land-cover variety and thus, potentially, bio-diversity.

Even more significant to potential bio-variety is the variability (or variance) in polygon (ie land-cover fragment) size because a range of larger and smaller polygons is likely to result in greater species diversity than polygon size uniformity. To increase the comparative value of the variance, the mean-to-variance ratio can be employed (Shaw and Wheeler 1985). The mean-to-variance ratio in our study area is low (Table 2). Statistically, when the mean-to-variance ratio in polygon size equals 1.0, polygons are considered to be randomly distributed. When the variance is large and the mean-to-variance ratio small, as in our case, the polygons tend to be clustered (Giles and Trani 1999). Since clustering is typical in most natural systems it can be regarded as indicative of natural and by implication high diversity conditions. Thus, all statistics presented in Table 2 point toward potentially high land-cover diversity levels for our study area, with the highest diversity potential concentrated in the Okavango Delta wetland and somewhat lower values for the rest of the Ngamiland study area.

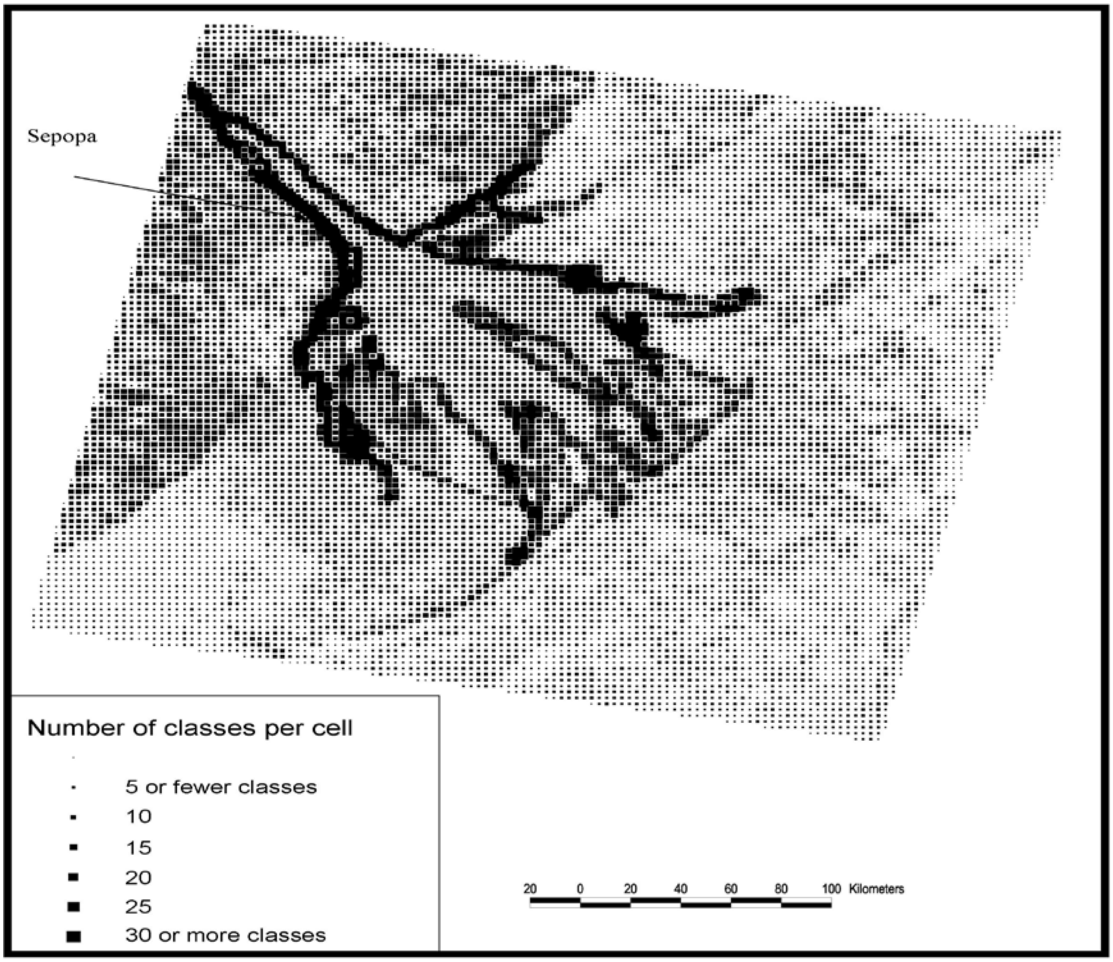
Ngamiland-Okavango Diversity Map: Spatial Pattern

Using the procedure developed for the European Corina landcover project (Willems et al 2000) as an example, the next step in this work was to construct a spatial expression (map) of land-cover diversity in our study region on the basis of the existing digital land-cover map. For this purpose, the Ngamiland map was subjected to appropriate GIS analysis routines, using ArcInfo-Grid software. The analysis was performed on the original digital land-cover (elephant habitat) map that consisted of a 30x30m grid of land-cover types.

Firstly, an aggregation procedure was performed to transform the original grid data with a resolution of 30 meters to a coarser grid of 3x3 km as suggested by the Corina project (Willems et al 2000). Next, employing the 'Variety' procedure in ArcInfo-Grid, which uses multiple input grids to determine the variety of the values (ie the number of unique values) on a cell-by-cell basis within the analysis window. For each new cell the number of different land-cover types as found in the original 30x30 m cells (10,000 for each larger cell of 3x3 km) was recorded, registering a value between 1 (indicating a homogeneous (large) cell with only one land-cover type) and a maximum of 31 (i.e. a very heterogeneous cell with 31 different land-cover types).

Figure 2 shows the resulting spatial distribution of cells with varying degrees of land-cover variety. The high variety zones along the edges of the Okavango Panhandle and Delta stand out and contrast with the lower degree of variety within the interior delta and the dry-lands further from the delta. Also noteworthy is the higher diversity in the north-western study region, which corresponds to an area of old alluvially washed dune fields supporting a mixture of Baikiaea-Burkea woodland on sandy dunes with grassland savanna in the interdunes, under slightly higher rainfall than the mopane-acacia dominated areas to the south-east.

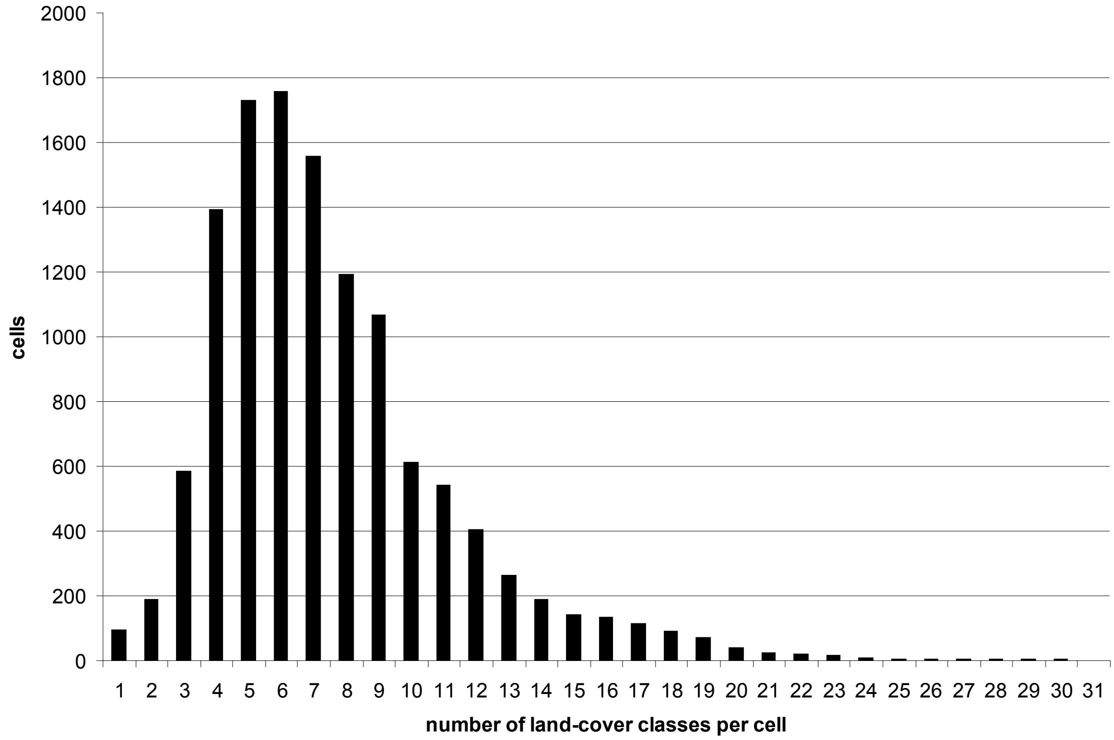
Figure 2: Land-cover class diversity by 3x3 km blocks



The skewed distribution of values over the spectrum (from 1 to 31) is shown in Figure 3. The clustering of cells in the 3-11 range is obvious as are the low frequencies of cells with 20 or more land-cover classes. A definite peaking of frequencies occurs at values 5 and 6. Thus, the majority of 3x3 km cells contain 5 or 6 different land-cover classes. The Corina project uses a specially adapted median value for interregional variety comparison. In the EU these median values vary between a low of 2.4 in Austria to a high of 4.4 in Luxembourg. The average for the EU is 3.6 (Willems *et al*. 2000).

The (ordinary) median value for our study region is about 7. This is a relatively high value indicative of a high degree of variety of land-cover types per unit area. Comparison with the European Union is not necessarily meaningful as conditions in the European landscape are very different from those in the Ngamiland-Okavango region and a different classification was used in the two regions. Nevertheless, a median value of 7, ie 50 % of the 3x3 km squares in the study region contain more than 7 different land-cover classes, may be considered high.

Figure 3: Frequencies of land-cover classes per 3x3 km cell



Discussion

The land-cover diversity map (Figure 2) presents the spatial overview of land-cover diversity (and by implication biodiversity) for the Ngamiland region. While the detailed explanation of the patterns is somewhat beyond the scope of this work, some observations can be made. Please note that the map is made up of dots proportional to the number of landscape classes per cell, resulting in dark grey shades where high diversity exists and light grey shades for less diverse areas.

As the outline of the Okavango Delta shows clearly in the map through darker (higher variability) cells, it is clear that the high variability portions of the study area are located along the dryland/wetland interface (Figure 2). Less variability is found in the permanently flooded areas in the delta interior and in dryland areas at some distance from the delta. It is along the edges of the delta where flooding alternates with non-flooded conditions from season to season that high variability is concentrated. In some instances, such as along the Panhandle, such areas are also the preferred locations for human settlement and related activities such as cultivation and livestock husbandry. This results in a mixture of natural and human-altered landscapes, typically a fragmented pattern of fields interspersed with pockets of remaining natural vegetation as in the vicinity of the village of Sepopa. This is illustrated in the Google-Earth image shown in Figure 4 below. High diversity in these areas may thus be the outcome of human alteration of natural landscapes that has resulted in fragmented remaining portions of natural vegetation cover and man-made land-cover types such as villages and fields.

Figure 4: High landscape diversity north of Sepopa (see Figure 1 and Figure 2 for location) shown on 2008 Google Earth satellite imagery. Note the rectangular fields and surrounding dry-lands on the left and the complex wetland areas with riparian forest and sandy floodplains on the right.

In other locations, however, diversity appears to be virtually completely natural and not influenced by human landscape alteration. This is particularly so along the eastern margins of the delta, where there are very few people. In these areas, the regime of flooding and drying over the seasons and variations over the years may have resulted in a natural level of patchiness or fragmentation due to a concentration of both dryland and wetland vegetation types in the narrow wetland-dryland margin. The importance of surface water availability for biodiversity is emphasized by the relatively low diversity in dryland areas, even when these occur as (large) islands in the delta interior, such as at Chief's Island (Figure 1). Of particular interest are the cells with exceptionally high land-cover diversity (over 15 classes per cell). These are mostly located along the perimeter of the Wet Delta, along the Panhandle, the major (former) flow channels of the Taoghe, Boro, Santandandibe and Khwai systems and the eastern Magwegwane system (Figure 1). These tend to be areas that receive flow water at intermittent periods. In some cases, again, they are areas with a high incidence of human-altered landscapes existing side by side with natural landscapes.

Conclusion

In large remote regions, such as Ngamiland, it may be impractical to conduct detailed fieldwork at a sufficient number of sites to allow the construction of a regional overview of floral (and other) biodiversity at landscape or macro-scale levels (Whittaker *et al* 2001). This work demonstrates that a spatial biodiversity overview can be constructed from existing digital land-cover information compiled through remote sensing supported by fieldwork at selected sites.

For this work, a classified land-cover grid map of the study region was converted to a polygon map and subjected to statistical analysis, resulting in measures regarded as relevant to the measurement of variety and variability (Table 2; Giles and Trani 1999). All statistical measures calculated during this procedure point toward a relatively high level of land-cover diversity in the study area, particularly in the Okavango Delta section; somewhat less in the remaining portion of the Ngamiland study area.

The original gridded land-cover map was then subjected to an aggregation procedure, followed by a 'Variety' procedure. This permitted the construction of a diversity map that shows the spatial pattern of land-cover diversity over the region. The median number of classes per enlarged grid cell of 3 x 3 kilometres, a summary statistic used to describe the overall status of regional biodiversity, was found to be 7, a value that can be regarded as high. The map allows the identification of locations with above average or high (potential) biodiversity, ie in our study region the wetland-dryland interface along Panhandle and Delta wetlands, and as such can provide guidelines toward the protection of regional biodiversity.

The fairly simple methodology employed in the construction and statistical analysis of the Ngamiland land-cover diversity map is potentially replicable in other data-poor regions in developing countries.

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