



# Impact of land use and land cover changes on landscape structure in the dry lands of Southern Africa: a case of the Zambezi Region, Namibia

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**Abstract** The study evaluated patterns of land use and land cover (LULC) change in the Zambezi Region, Namibia between 1984 and 2010 using geospatial tools. Spatio-temporal dynamics of LULC changes were quantified using the post classification change detection method. The images were classified into five land use and land cover classes: forest land, shrub land, bare land, crop/grass land and other land. Landscape metrics were calculated using Fragstats to understand the landscape patterns and structural integrity of the landscape. The results showed that political transition (before and after independence) has resulted in dramatic decreases in patch density and increases in the interspersion and juxtaposition index values. The general pattern of LULC showed that the communal area compared to protected area became structurally diverse and ecologically more fragmented from 1984 to 2010. This study provides a foundation and baseline data demonstrating LULC alteration and landscape context suitable for monitoring future changes of protected and communal areas. Our

approach is a novel way to assess the drivers and patterns of LULC under different land tenure types for natural resources conservation and sustainable land management in the dry lands of Southern Africa.

**Keywords** Land use · Land cover · Metrics · Landsat · Protected area · Communal area

## Introduction

Land is the most important natural resource base for goods and services for all human activities such as food production, settlements, industry and recreation. However, it has been subjected to changes in terms of land use and land cover (LULC) influenced by socio-economic, policy development, climate and natural disasters (Olson et al. 2004). The most important drivers of LULC change include political structures, population, technology development and social relations among others (Lambin et al. 2003). In particular, population growth increases the demand for land resources such as residence and the extraction of forest resources to sustain livelihoods (Kalaba et al. 2010). In the Zambezi region of Namibia, people are highly dependent on land resources for their diverse livelihoods. After Independence in 1991, the government enacted and formulated legislations and policies which were aimed at improving rural livelihoods and sustainable management of land resources. These

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include the Communal Land Reform Act of 2002, Forest Act of 2001, Forest policy of 2001, Agricultural policy of 1995 and the Nature Conservation Amendment Act of 1996 which regulates the establishment of conservancies. Some of these policies and legislations encouraged the management of land resources and opened up economic opportunities that operate in tandem with the overall changes in LULC.

In particular, sustainable development is impacted by the changes in LULC (Lambin et al. 2000). The drivers of such change vary in magnitude, space and time (Drummond and Loveland 2010). From the forestry perspective, changes in LULC do not necessarily imply land clearing, but also include the recovery of abandoned fields and vegetation after forest fire. These dynamics need to be considered during the formulation of effective environmental policies relating to LULC to ensure sound decision and effective policy measures. The quantification of the landscape structure and composition is important because landscapes provide functions in which numerous goods and services can be obtained (Jaeger et al. 2007; Willemsen et al. 2008). In this case, our use of landscape metrics provides a systematic and objective quantification of these LULC characteristics (Kearns et al. 2005; Sarris et al. 2005; Narumalani et al. 2004; Wulder et al. 2004).

Our study attempted to show that observed changes in LULC relate to landscape structure and configuration. By analysing landscape dynamics at different temporal and spatial scales over time, the effects on the environment and human livelihoods and vice-versa can be studied, including their driving factors. In addition, the use of landscape metrics in landscape monitoring has previously been investigated in a number of studies (Herzog and Lausch 2001; Herold et al. 2005; Lambin et al. 2005) and have been grouped into three categories: (1) landscape composition metrics; (2) spatial configuration metrics; and (3) fractal metrics. However, these metrics have not yet been optimized for LULC change research and management options in the woodlands of Southern Africa which provide multiple functions to communities. While these metrics provide a general assessment of LULC change, fractal metrics, in particular, may better capture fragmentation of the landscape that has

become a major concern for decision makers in Namibia.

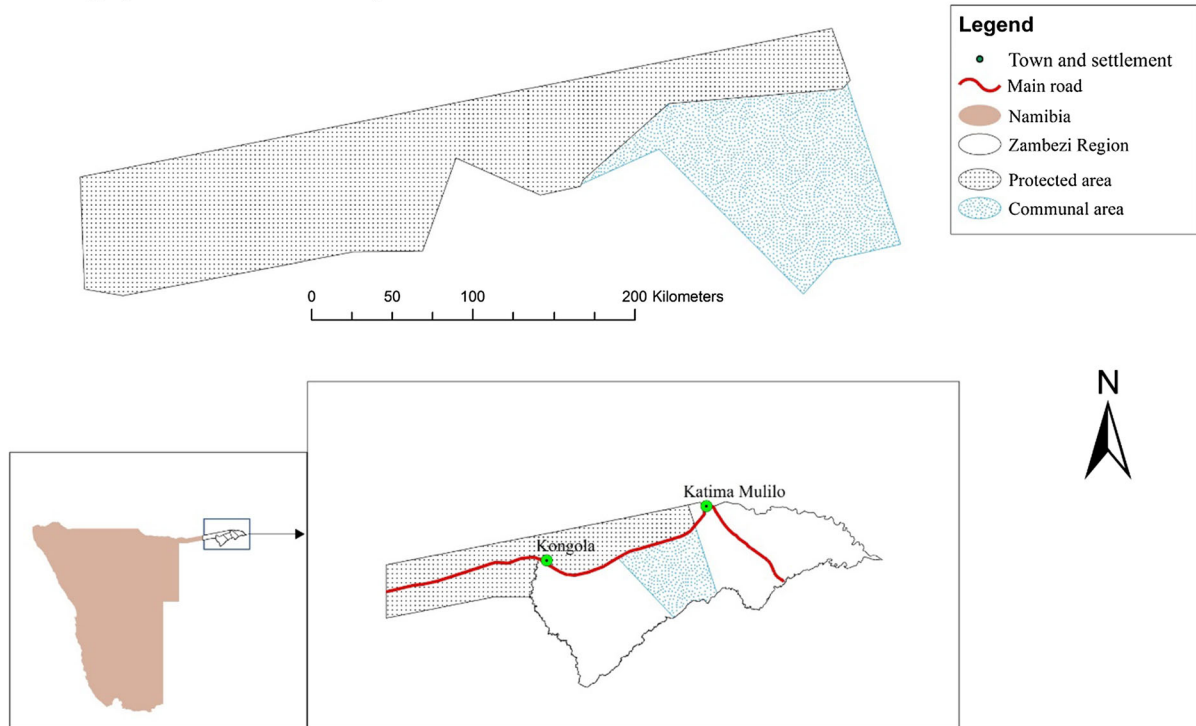
Our systematic form of landscape analysis also enables the monitoring of LULC change since the method is repeatable. The Zambezi region in north-eastern Namibia is an area of importance in terms of flora and fauna largely because of its rainfall patterns, woodlands and species-rich riverine habitats, flood plains and grasslands (Bethune et al. 2007). It also plays an important role in the Kaza Transfrontier Conservation Area (TFCA) which is the world's largest TFCA, spanning approximately 520 000 km<sup>2</sup> in southern Africa. In recent decades, however, the increasing pressure on land resources has significant impacts on the environment, particularly in communal areas. Unfortunately, there is lack of information about the dynamic change of LULC in dry woodlands of northern Namibia. Therefore, quantifying landscape in this biodiversity hotspot using several landscape metrics facilitates additional provides less subjective understanding of the structure, composition and drivers of change in both the protected and communal areas. In addition, improved landscape information is vital for planning and modeling future scenarios, which will ensure sustainable development. The objective of this study was to use the landscape ecological approach to quantify and examine the spatio-temporal changes in the Zambezi region's landscape composition and configuration between 1984 and 2010 and to link the changes to the drivers of change in the protected and communal area of the Zambezi. It is our hope that this research will contribute by providing essential landscape information for land resources conservation, land use planning and sustainable land management in the dry lands of Southern Africa with similar socio-economic, environmental and political conditions.

## Methodology

### Site description

We studied the Zambezi region, which is located in the northeast of Namibia and covers an area of 616,600 ha (Fig. 1). The study area was stratified into protected and communal areas. This is because these two land tenure types are under different management systems.

### Geographic location of the study area



**Fig. 1** Location of study area (Kamwi et al. 2017)

The vegetation as classified by Giess (1998) is a woodland savanna which is predominantly comprised of *Baikiaea plurijuga*, *Guibourtia coleosperma*, *Pterocarpus angolensis*, *Burkea africana* and *Dialium engleranum*. Mosaics of closed perennial grass cover with patches of shrubs are also found. The landscape is topographically homogenous, with an altitude of about 950 m above sea level, and a semi-tropical climate with alternating dry and wet seasons. Mean annual precipitation ranges from 650 mm in the western parts of the region to 900 mm in the east, mostly falling between October and March with a marked dry season between May and September. The annual gross evaporation ranges from 1680 to 1820 mm/year (Mendelsohn et al. 2009).

The population of the Zambezi region is estimated at approximately 90,000, of which 51% are female. The region has a population density of 6.1 inhabitants per square kilometer, which is more than double the average density (2.6) for Namibia. A total of 21 283 households were counted in the region, of which 56% have male household heads. The average household size is estimated to be 4.2 persons, which is slightly

lower than the national average of 4.4 persons (National Statistics Agency 2011). The population is largely rural (69%) and the majority of households have no electricity and use firewood for cooking. According to the national ‘Poverty Dynamics Report’ (National Statistics Agency 2012), the Zambezi is amongst the three poorest regions in the country. Throughout rural Namibia, communities engage in a diversity of productive livelihood activities dominated by crop farming and livestock keeping. In addition, communities in the Zambezi use forest resources to complement these livelihoods strategies.

#### Satellite data processing

Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data covering the years 1984, 1991, 2000 and 2010 were prepared using standard image processing procedures. These data were mosaicked and the study area was extracted using a subset technique. Images were chosen to cover periods of significant political change in Namibia, specifically the time before independence in 1990, the

time around independence, and times prior to the instatement of community-based forest management and around 10 years of community-based management. In addition, the periods used correspond closely with the periods that the landscape was influenced by a number of government policies. Images with the input spatial resolution of 30 m were downloaded from the University of Maryland's Global Land Cover Facility (GLCF) (<http://glcapp.umiacs.umd.edu>) and United States Geological Survey (USGS) Earth Resources Observation Systems (EROS) Data Center (EDC) (<http://glovis.usgs.gov>). This is in line with Lü et al. (2013) who indicated that the scale of remote sensing data in landscape spatial analysis should be no more than 30 m. The base of this data set was late rainy season and early dry season when the trees are in full leaf. Using the ERDAS Imagine version 2010, the images were atmospherically corrected to account for the variations in the solar illumination, scattering and absorption effects. These attributes are important during image processing because they could result in differences between radiance values which may not be related to the actual reflectance of the LULC (Song et al. 2001).

#### Land use and land cover classification

Based on prior knowledge of the study area, we adapted the classification scheme developed by Mendelsohn et al. (2009) to derive the LULC classes. We used the post classification comparison approach to quantify the dynamics of LULC in each class. Descriptions of the LULC classes considered are presented in Table 1. The approach was chosen because it offers the “from-and-to” perspective of each changed pixel (Fichera et al. 2012; Coppin et al. 2004). The supervised maximum likelihood classification algorithm was applied using the ERDAS

Imagine 2010 software. Of note is that the obtained LULC area change results should not be seen as absolute figures but rather as pointers of developments in LULC change because the climatic circumstantial parameters which are important for physiognomy of the vegetation vary a lot between the different registration years, hence reducing the accuracy of the classification of the LULC. A  $3 \times 3$  majority filter was applied on the LULC images to reduce salt and pepper effects. The detailed description of the development of the land cover classification and change maps in of the study area can be found in Kamwi et al. (2017).

The accuracy assessment of the classification of the 2010 images was evaluated using ninety-eight congruous training samples with known LULC. Confusion matrices and associated Kappa statistics of the agreement of each class were generated.

#### Landscape level metrics selection

It is important to note that landscapes are highly dynamic entities, hence one of the key challenges is the analysis and the quantification of temporal variations in landscape pattern metrics (Cushman and McGarigal 2008). In this study, we used landscape metrics to compare landscape configurations of the Zambezi region at different time periods to understand the spatial-temporal patterns and structure of LULC. Selection of metrics was based on the suitable reflection of the landscape characteristics of interest and to avoid redundancies among the metrics. Taking these factors into consideration, five landscape level metrics namely (1) patch density; (2) largest patch index; (3) contagion index (4) interspersion and juxtaposition index; and (5) effective mesh size were selected to quantify and examine the spatio-temporal changes in the landscape composition and configuration. We

**Table 1** Description of LULC classes

Class category	General description
Forest land	Areas with closed and open canopy forests and wooded landscapes with trees higher than 3 m
Shrub land	Areas with combined cover of shrubs, bushes and occasional trees
Crop/grass land	Areas which are predominantly under agriculture or grass land in nature
Bare land	Areas which are predominantly bare in nature
Other land	Areas not classified as forest, shrub land, crop/grass land or bare land

were more interested in landscape level pattern metrics that quantifying spatial configuration because they represent the magnitude of fragmentation taking place in the landscape of the Zambezi. A detailed description of these metrics and equations can be found in Leitão et al. (2006); Fichera et al. (2012); McGarigal et al. (2002).

Calculation of metrics

A stand-alone Fragstats software version 4.1 was used in the study. Change maps for the periods 1984–1991; 1991–2000 and 2000–2010 were developed. Among existing landscape metrics, we selected five to represent the spatial pattern of the study area and these metrics were interpreted more broadly as landscape heterogeneity indices because they measure the overall landscape structure. Furthermore, these metrics were evaluated quantitatively by plotting the metric values to reflect the scaling-up effect on the analysis of landscape patterns in the Zambezi region. The landscape metrics used in the study include:

- (i) Patch density (*PD*) which explains the heterogeneity and fragmentation process of the landscape and adds all the patches of the corresponding patch type per unit area (number per 100 ha) (Leitão et al. 2006).

$$PD = \frac{n_i}{A} (10,000)(100) \tag{1}$$

where  $n_i$  = number of patches in the landscape of patch type (class)  $I$ ;  $A$  = total landscape area ( $m^2$ ).

- (ii) Largest Patch Index (*LPI*) which gives the area of the largest patch in each class (in ha) and shows the percentage of class accounted for by largest patch (Fichera et al. 2012).

$$LPI = \frac{MAX(a_{ij})}{A} (100) \tag{2}$$

where  $a_{ij}$  = area ( $m^2$ ) of patch  $ij$ ;  $A$  = total landscape area ( $m^2$ ).

- (iii) Contagion Index (*CI*) which measures the degree to which the patch types are distributed and measures the landscape configuration in %. This metric is 0 when the patches are completely disaggregated and

100 when they are completely aggregated (Leitão et al. 2006).

$$CI = 1 + \frac{\sum_{i=1}^m \sum_{k=1}^m [Pi * (G_{ik} / \sum_{k=1}^m G_{ik})] * (\ln Pi (G_{ik} / \sum_{k=1}^m G_{ik}))}{2 \ln m} \tag{3}$$

where  $Pi$  = proportion of the landscape occupied by a specific class;  $g_{ik}$  = number of adjacencies (joins) between picture elements of each class;  $m$  = number of classes in the landscape.

- (iv) Interspersion and Juxtaposition Index (*IJI*) is 0 when the corresponding class is adjacent to only one other class type; and 100 when the corresponding class is equally adjacent to all other class types.

$$IJI = \left[ \left( \frac{e_{ik}}{\sum_{k=1}^m e_{ik}} \right) \ln \left( \frac{e_{ik}}{\sum_{k=1}^m e_{ik}} \right) \right] \div \ln(m - 1)(100) \tag{4}$$

where  $e_{ik}$  = the total length (in m) of edge in landscape between classes; and  $m$  = number of classes present in the landscape.

- (v) Effective Mesh Size (*meff*) gives the size of the patches when the landscape is subdivided into various patch values of the splitting index. It also gives a relative measure of patch structure in the landscape.

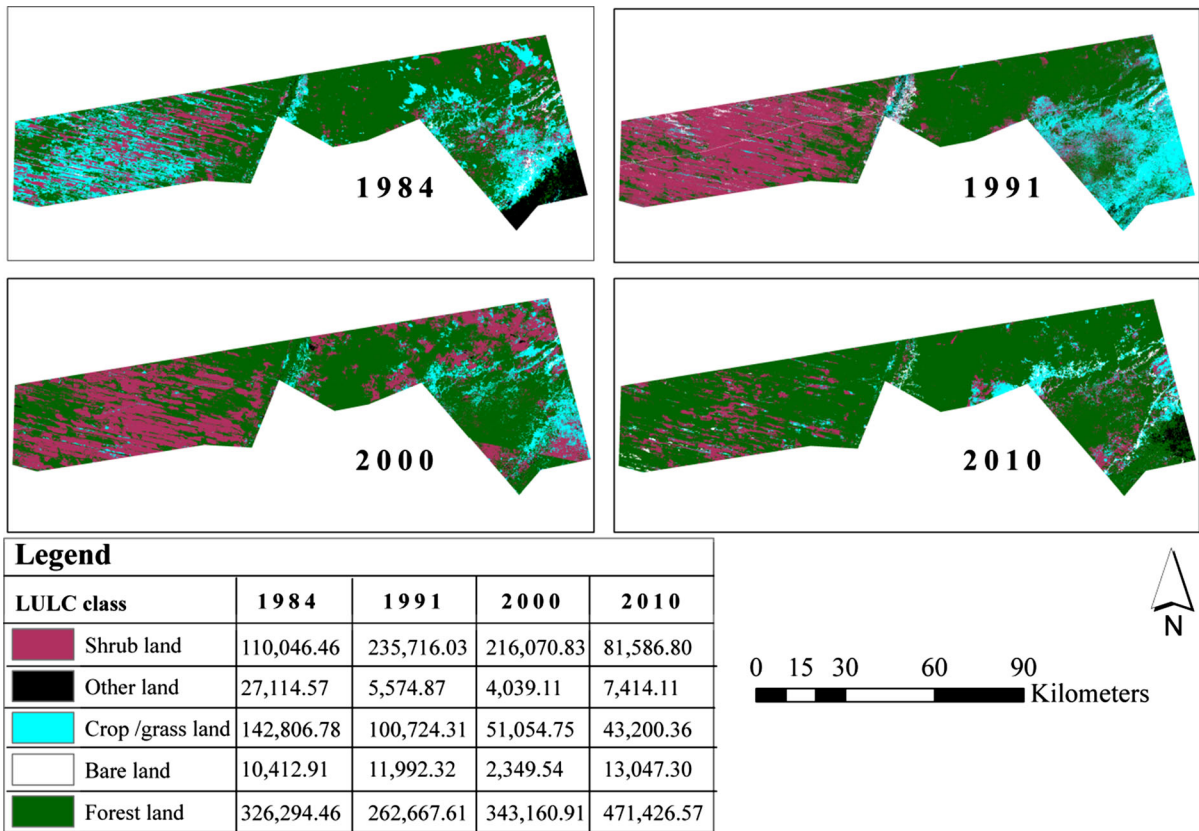
$$m_{eff} = \frac{\sum_{i=1}^m \sum_{j=1}^n a_{ij}^2}{A} \left( \frac{1}{10000} \right) \tag{5}$$

where  $a_{ij}$  = area ( $m^2$ ) of patch  $ij$ ;  $A$  = total landscape area ( $m^2$ ).

Results

Land-use and land-cover classification

The image processing results showed major changes within the LULC classes (Fig. 2). Forests were the dominant form of land-cover followed by shrub land. A closer inspection of the classified maps revealed that although forests occur mainly in all the epochs in the northern part of the study



**Fig. 2** Land use and land cover in the study area in ha for 1984, 1991, 2000 and 2010 (Kamwi et al. 2017)

area, most parts of the region were gradually covered between 2000 and 2010. Forest land occurred primarily in the middle part of the study area in 1984 and 1991. Forest land was also found in the eastern / south-eastern portion of the region in 2000, however. Forest land occupied nearly the entire region in 2010, while shrub land was mainly located in the western part of the study area.

Area statistics of the Land Use and Land Cover classes

Table 2 shows that there are prominent changes under different LULC classes from 1984 to 2010. The first stage between 1984 and 1991 (before independence) represented high deforestation and gradual increase in shrub land in both the protected and communal areas. The second stage between 1991 and 2000; 2000 and 2010 represented lower deforestation in both the

**Table 2** Changes in area of different LULC classes from 1984 to 2010

LULC class	Protected area				Communal area			
	1984	1991	2000	2010	1984	1991	2000	2010
Forest land	238,828	189,240	228,605	344,025	83,516	69,845	109,313	121,227
Shrub land	84,468	204,040	171,399	53,327	24,085	29,342	41,935	27,030
Bare land	3542	9219	491	4248	6657	2611	1791	8448
Other land	1245	1958	2011	212	23584	3365	1909	6643
Crop/grass land	90,682	14,308	16,260	16,955	50,155	82,833	33,048	24,649

protected and communal areas. However, shrub land decreased during the second stage between 1991 and 2010 (after independence) in the protected area. This trend was followed also in the communal area except in 2000 when there was an increase in shrub land. Overall, there was a gradual expansion of the area under forest land after 1991.

In terms of the classification accuracy, any error in classification directly flows into the landscape metrics. In order to ensure that the errors in classification are minimized, we collected 98 training sites and used them to classify the images. An overall classification accuracy of 81.6% was reached and is sufficient to meet the monitoring accuracy demands of LULC in the Zambezi region (Table 3). The Kappa coefficient which accounts for the randomness of the accuracy test was also fairly high (79%).

Landscape metrics

Patch density (PD)

The Patch Density indicates the number of patches per 100 hectares (McGarigal et al. 2002). Overall, the communal area had more patches compared to the protected area. PD in the communal area increased between the periods 1984–1991 and 1991–2000 (Fig. 3). In comparison, the PD in protected area dropped from 37.2 during 1984–1991 to 34.6 during 1991–2000 and 32.5 per 100 ha during 2000–2010.

Largest patch index (LPI)

As explained earlier, the LPI gives the area of the largest patch in each class (in ha) and shows the

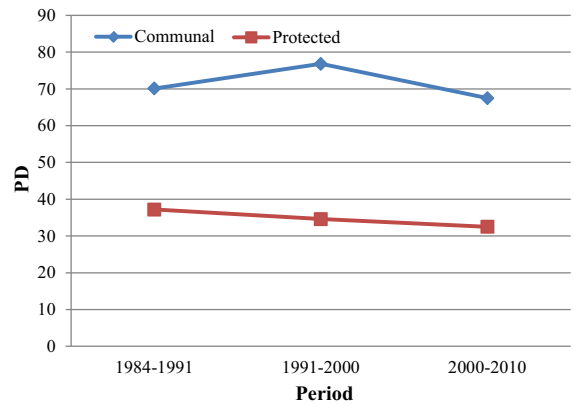


Fig. 3 Patch density (patches per 100 ha) for protected and communal area

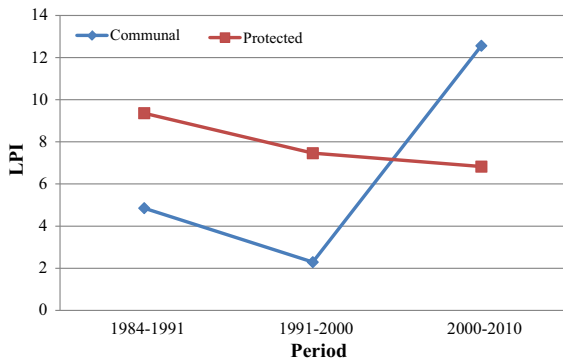
percentage of class accounted for by the largest patch (Fichera et al. 2012). That is, LPI represents the influence of large patches in the landscape. The patch analysis in the communal area showed a decrease during the 1984–1991 and 1991–2000 time periods (4.9–2.3%) (Fig. 4). However, a massive increase in LPI was observed during the 1991–2000 and 2000–2010 periods from 2.3 to 12.6%. In the protected area, a decrease in LPI was observed in all time periods.

Contagion index (CI)

The contagion index (CI) measures the degree to which the LULC classes are distributed in the landscape. This metric further illustrates the relationships among the patch shapes between the LULC classes. As indicated earlier, this metric approaches 0 when the patches are completely disaggregated and

Table 3 Accuracy assessment of the LULC classes

Class name	Reference totals	Producers accuracy	Users accuracy	Kappa statistics
Shrub land	20	0.820	0.849	0.860
Other land	7	0.857	0.888	0.950
Crop land	21	0.850	0.880	0.910
Bare land	18	0.833	0.859	0.900
Forest land	32	0.844	0.871	0.890
Total	98	–	–	–
Overall classification accuracy	81.6	–	–	–
Overall Kappa statistics	0.79	–	–	–

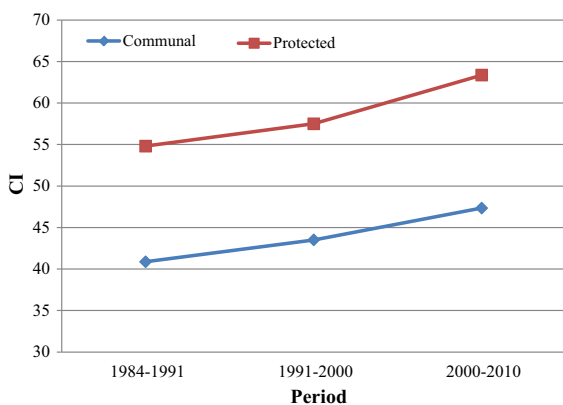


**Fig. 4** Largest patch index (in %) for protected and communal area

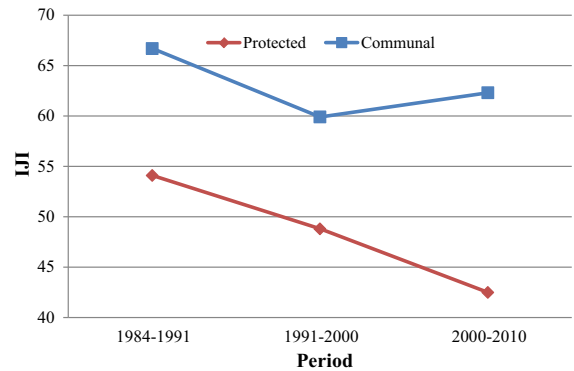
100 when they are completely aggregated (Leitão et al. 2006). The course of the lines in Fig. 6 is very analogous, reflecting a continuous increase in CI in both the protected and communal areas. In particular, CI increased throughout the study period in the protected area from 54.8% during 1984–1991 to 57.5% during 1991–2000 and 63.4% during 2000–2010 (Fig. 5). Similarly, CI increased from 40.9% during 1984–1991 to 43.5% and 47.4% during 1991–2000 and 2000–2010 in the communal area.

*Interspersion and juxtaposition index (IJI)*

The communal area shows higher IJI values in all time periods under consideration compared to the protected area. Particularly noteworthy was that for both communal and protected areas, the decrease in IJI between the periods 1984–1991 and 1991–2000 indicates a less uniform configuration of the landscape (Fig. 6). Thus,



**Fig. 5** Contagion index (in %) for protected and communal area

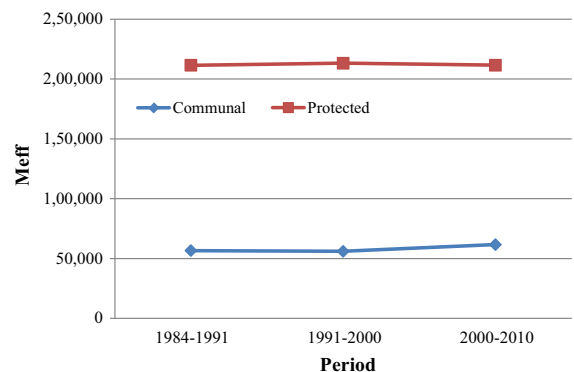


**Fig. 6** Interspersion and juxtaposition index (in %) for protected and communal area

the patches were not regularly distributed in the study areas. However, for the communal area, IJI increased from 1991–2000 to 2000–2010 indicating a more uniform spatial distribution of the LULC types.

*Effective mesh size (meff)*

The effective mesh size was used to evaluate structural diversity and degree of fragmentation as an indicator of biodiversity in the Zambezi. Changes of the meff in the protected area compared to the communal area during the periods of investigation were calculated (Fig. 7). In the protected area, the meff shows an increase of 0.8% between the period 1984–1991 and the period 1991–2000; and a decrease of 0.8% between the periods 1991–2000 and 2000–2010. In the communal area, this metric decreased by 1% between the periods 1984–1991 and 1991–2000; and



**Fig. 7** Effective mesh size (in ha) for protected and communal area



increased by 10% between the periods 1991–2000 and 2000–2010.

## Discussion

### LULC changes and landscape structure

The use of landscape metrics is constrained by the deficiency of a proper theoretical understanding of metric performance in response to variation in landscape configurations (Hargis et al. 1998). Most of the landscape metrics are correlated amongst themselves and most of them are consequential from these principal measures. Nonetheless, our results provide crucial information on the composition and structure of the landscape in the Zambezi region. This information is required for decision making aimed at ensuring sustainable landscape management. We used Landsat images with a spatial resolution of 30 m indicating that changes less than 900 m<sup>2</sup> may not be detected by the classifier. In addition, the slope and aspect may affect the natural spectral variability of classes during LULC classification. The results of the analysis of LULC change in the Zambezi showed that important changes took place during 1984 and 2010. It was clear, though not unexpected due to policy reforms, that the dynamics of LULC change revealed that forested landscape has become less fragmented during 1991–2010, thus avoiding the fragmentation of natural areas into smaller and more isolated elements in the protected area. This is in contrast to the communal area in which an increase in fragmentation as shown by the PD during 1991–2000 although it reduced during 2000–2010. The major driving force of these LULC changes were attributed to the socio-economic factors, technological and policy changes which have triggered competition for space in the study area including wildlife management and agriculture. Furthermore, the continued expansion of villages resulting from increasing population in the communal area may have rapidly led to the high landscape fragmentation during 1991–2000 (Kamwi et al. 2015). These suggest the need for combined efforts in land use planning centered on natural, economic, social and other factors in the Zambezi region. From a broad conservation viewpoint, coherent and sustainable use of land in time and space should not be compromised for short-term gains. Our

results are congruent with the outcomes and confirm that LULC management strategies which may improve livelihoods of communities in the rural areas are crucial. This is congruent with Meire et al. (2012) who reported an increase in woody vegetation complemented by a growing human population, as shown by the growth in both size and number of villages in Africa. A plausible explanation is that the government developed different strategies and efforts for natural resource management in Namibia such as the Community Forestry Programme, the Promulgation of Forest Act, 2001 (Act No. 12 of 2001) and the Promulgation of the Forest Amendment Act, 2005 (Act No. 13 of 2005) in which permits are required for the use of forestry resources from the Forestry Department or Local Authorities (Government Gazette of the Republic of Namibia 2001, 2005). Most notable, there is an apparent decline in the crop/grass land. The decline in crop/grass land observed in the study area may be attributed to classification errors which may occur during the merging of classes into composite LULC classes, as was encountered by Meire et al. (2012) who reported an apparent loss in cultivated land (– 11%) in northern Ethiopia. However, this decline could also be attributed to changes in the socio-economic status of rural communities that took place after independence. First, improved access to education has enabled many household members to enter into formal employment, thereby making it possible to support unemployed members of their household through remittances. Second, after the country's independence, the increase in basic income social grants to pensioners and vulnerable members of society has provided a regular source of income. These factors could have led to a larger number of households depending on cash income in lieu of farming activities. This is in contrast with other studies that have observed increases in agricultural land over time (e.g. Meneses et al. 2017; Alemu et al. 2015). Third, the promotion of community forests and conservancies through the Nature Conservation Amendment Act of 1996 and the Forest Act, 2001; and the subsequent absorption of these policies by communities could mean that more land is allocated for conservation, resulting in increased forest land.

Landscape metrics provided a basis for comparisons between protected and communal areas to better explain the spatio-temporal dynamics of LULC as an index of land degradation by accounting for

biophysical and socio-economic elements of LULC which vary due to economic and social factors. As expected, the PD increased in the communal area during the 1984–1991 and 1991–2000 periods, signifying a strong fragmentation of the landscape and hence the high density of patches. This was also confirmed by the meff metric in which 1% decrease was found. Of note is that a remarkable decrease in meff indicates lower connectivity and viability of habitats. The apparent increase in PD in the communal area is thus rather attributable to increased human interferences in response to increased local economic opportunities, strong economic interest from outside and social reforms after independence in 1991. This indicates additional fragmentation during these periods, thus, giving rise to isolated landscape patches which may affect ecological processes through the loss of connectivity. For rural communities in the study area, the fragmentation of the landscape is important because it reduces the supply of ecosystem services as it is an indicator of degradation of the resources upon which they are dependent. In comparison, the PD in protected area reduced during 1991–2000 and 2000–2010. This decrease in PD should not be seen as a reduction in human interference in the landscape but could rather imply that the fragmented areas in the early periods have merged together to form a big patch due to the enforcement of the Forest Act (Act No. 12 of 2001). However, a massive increase in LPI was observed in the communal area during the 1991–2000 and 2000–2010 periods. This is due to enhanced fire reduction efforts by the forest department and the establishment of community forests in the study area. This finding implies that the largest patch (shrub land) was dominant as it represents a greater percentage of total area during the 2000–2010 period. In the protected area, LPI decreased throughout the study periods indicating less landscape fragmentation and there was no dominant LULC class due to law enforcement efforts by the Government. The size of the largest patches in the landscapes may affect various ecological phenomena in the landscape (Forman 1995).

A continuous increase in CI in both the protected and communal areas was observed. By implication, this means that contiguous patches of the landscape were found on the landscape in both the protected and communal area. These trends found in this study are reasonable because the protected area is dominated by

forests that form principally one large cluster, thus giving a high index value for contagion. However, the low values of CI in the communal area compared to the protected area indicate dissected landscapes compared to protected area due to human development and influence. This is attributed to population growth in the communal areas since no farming activities are permitted in the protected area. Furthermore, it is accepted in the Zambezi that inheritance may be the primary cause of dissected lands; where the inheritance laws applied by communities may facilitate or demand the subdivision of the land among the heirs or descendants. The IJI decrease in the protected area indicates that the adjacencies of patches were more regularly spread in the landscape and is evidenced by the decrease in PD. The most likely reason is that Government increased forest protection activities such as law enforcement and fire management after independence (1991–2000 and 2000–2010 periods).

## Conclusions

The main goal of this paper was to quantify and examine the spatio-temporal changes in the Zambezi region's landscape composition and configuration between 1984 and 2010 and to link the changes to the drivers of change under the different land tenure types. The spatial complexity of the landscape was assessed using Fragstats at landscape level which revealed some interesting results of the landscape elements. By studying two areas with contrasting land tenure contexts, we were able to explore whether landscape structure differed based on tenure system. The results from our analysis showed that (1) the period before independence represented the high deforestation and gradual increase in shrub land in both the protected and communal areas (2) the second stage after independence represented lower deforestation in both the protected and communal areas (3) patch densities indeed increased exponentially in the communal area increased during 1984–1991 and 1991–2000 (Fig. 4). In comparison, the PD in protected area reduced throughout the study period (4) LPI in the communal area showed a decrease during the 1984–1991 and 1991–2000, but a massive increase in LPI was observed during the 1991–2000 and 2000–2010 periods. In the protected area, a decrease in LPI was observed across all time periods (5) there

has been a continuous increase in CI in both the protected and communal areas (6) the communal area showed higher IJI values in all time periods compared to the protected area. The local use of the forests must be understood in relation to the great importance Zambezi villagers attach to their land resources as a sustainable source of various products. The following resources have been cited to be extracted from the land: firewood, building material, grasses for thatching, medicinal plants, timber and fruits (Kamwi et al. 2015). In the communal area, the present situation is rapidly changing. There are growing economic interests from outsiders which tends to marginalize the influence that local communities have on their own land resources.

The time-based variation of LULC change and landscape metric values revealed when the major political transitions and changes took place. The estimate of LULC classes, particularly the forest cover assessed in this study, would enable foresters to develop good conservation strategies in order to conserve the forest land. This is also an example offering scientific evidence that active land tenure can influence LULC. The method may be used as a monitoring tool to provide information to guide decision making and the formulation of policies. Policies may be developed to enable the creation of connectivity among habitat types to ensure supply of ecosystem services to both the community and wildlife. However, the spatial resolution of the image may influence the metric results. The landsat images in the present study may not be sufficient to detect patches in an area less than 900 m<sup>2</sup>. However, it is important to make a trade-off in terms of the information needs and the cost of acquiring high resolution satellite imagery for assessing LULC change which can detect areas below the 900 m<sup>2</sup> threshold.

### Compliance with ethical standards

**Human participants and or animal rights** This study does not contain any studies with human participants or animals performed by any of the authors.

### References

- Alemu, B., Garedew, E., Eshetu, Z., & Kassa, H. (2015). Land use and land cover changes and associated driving forces in north western lowlands of Ethiopia. *International Research Journal of Agricultural Science and Soil Science*, 5(1), 28–44.
- Bethune, S., & Ruppel, O. C. (2007). *Review of policy and legislative support to the sustainable use of wetlands in the Zambezi Basin*. Windhoek: University of Namibia.
- Central Bureau of Statistics. (2001). *2001 population and housing census—National report*. Windhoek, Namibia: Central Bureau of Statistics.
- Coppin, P., Jonckheere, I., Nackaerts, K., & Muys, B. (2004). A review: Digital change detection methods in ecosystem monitoring: A review. *International Journal of Remote Sensing*, 25(9), 1565–1596.
- Cushman, S. A., & McGarigal, K. (2008). Landscape metrics, scales of resolution. In K. von Gadow & T. Pukkala (Eds.), *Designing green landscapes* (pp. 33–51). Berlin: Springer.
- Drummond, M. A., & Loveland, T. R. (2010). Land-use pressure and a transition to forest-cover loss in the Eastern United States. *BioScience*, 60(4), 286–298.
- Fichera, C. R., Modica, G., & Pollino, M. (2012). Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics. *European Journal of Remote Sensing*, 45(1), 1–18.
- Forman, R. T. T. (1995). *Land mosaics: The ecology of landscapes and regions*. Cambridge: Cambridge University Press.
- Giess, W. (1998). A preliminary vegetation map of Namibia (3rd revised edition). *Dinteria*, 4(3), 1–112.
- Government Gazette of the Republic of Namibia. (2001). *Proclamation of Forest Act, 2001 (Act No. 12 of 2001)*. Windhoek, Namibia.
- Government Gazette of the Republic of Namibia. (2005). *Proclamation of Forest Act, 2005 (Act No. 13 of 2005)*. Windhoek, Namibia.
- Hargis, C. D., Bissonette, J. A., & David, J. L. (1998). The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology*, 13(1998), 167–186.
- Herold, M., Couclelis, H., & Clarke, K. (2005). The role of spatial metrics in the analysis and modeling of urban land use change. *Computers, Environment and Urban Systems*, 29(4), 369–399.
- Herzog, F., & Lausch, A. (2001). Supplementing landuse statistics with landscape metrics: Some methodological considerations. *Environmental Monitoring and Assessment*, 72(6), 37–50.
- Jaeger, J. A. G., Schwarz von Raumer, H. G., Esswein, H., Müller, M., & Schmidt, L. M. (2007). Time series of landscape fragmentation caused by transportation infrastructure and urban development: A case study from Baden Württemberg, Germany. *Ecology and Society*, 12(1), 22.
- Kalaba, F. K., Chirwa, P. W., Syampungani, S., & Ajayi, O. C. (2010). Contribution of agroforestry to biodiversity and livelihoods improvement in rural communities of Southern African regions. In Teja Tschardtke, Christoph Leuschner, Edzo Veldkamp, Heiko Faust, Edi Guhardja, & Arifuddin Bidin (Eds.), *Tropical rainforests and agroforests under global change* (pp. 461–476). Berlin: Springer.
- Kamwi, J. M., Chirwa, P. W. C., Manda, S. O. M., Graz, F. P., & Kätsch, C. (2015). Livelihoods, land use and land cover change in the Zambezi Region, Namibia. *Population and Environment*, 37(3), 207–230.

- Kamwi, J. M., Kätsch, C., Graz, F. P., Chirwa, P. W. C., & Manda, S. O. M. (2017). Trends in land use and land cover change in the protected and communal areas of the Zambezi Region, Namibia. *Environmental Monitoring and Assessment*, 189(5), 242.
- Kearns, F. R., Kelly, N. M., Cater, J. L., & Resh, L. (2005). A method for the use of landscape metrics in freshwater research and management. *Landscape Ecology*, 20(1), 113–125.
- Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, 28, 205–241.
- Lambin, E., Geist, H., & Rindfuss, R. R. (2005). *Land-use and land-cover change: Developing and implementing an agenda for local processes with global impacts, IHDP update* (pp. 1–3).
- Lambin, E. F., Rounsevell, M. D. A., & Geist, H. J. (2000). Are agricultural land-use models able to predict changes in land-use intensity? *Agriculture, Ecosystems & Environment*, 82(1–3), 321–331.
- Leitão, B. A., Miller, J., Ahern, J., & McGarigal, K. (2006). *Measuring landscapes: A Planner's handbook*. Washington: DC (Island Press).
- Lü, Y., Feng, X., Chen, L., & Fu, B. (2013). Scaling effects of landscape metrics: A comparison of two methods. *Physical Geography*, 34(1), 40–49.
- McGarigal, K., Cushman, S. A., Neel, M. C., & Ene, E. (2002). *Fragstats: Spatial pattern analysis program for categorical maps*. Computer software program produced by the authors at the University of Massachusetts, Amherst.
- Meire, E., Frankl, A., De Wulf, A., Haile, M., Deckers, J., & Nyssen, J. (2012). *Land use and cover dynamics in Africa since the nineteenth century: Warped terrestrial photographs of North Ethiopia*. Regional Environmental Change: DOI. <https://doi.org/10.1007/s10113-012-0347-9>.
- Mendelsohn, J., Jarvis, A., & Robertson, T. (2009). *Atlas of Namibia: A portrait of the Land and its people*. Windhoek, Namibia: Ministry of Environment and Tourism.
- Meneses, B. M., Reis, E., Pereira, S., Vale, M. J., & Reis, R. (2017). Understanding driving forces and implications associated with the land use and land cover changes in Portugal. *Sustainability*, 9(3), 351.
- Namibia Statistics Agency. (2011). *Zambezi Census regional profile*. Windhoek, Namibia: Namibia Statistics Agency.
- Namibia Statistics Agency. (2012). *Poverty dynamics in Namibia: A comparative study using the 1993/94, 2003/04 and the 2009/10 NHIES surveys*. Windhoek, Namibia: Namibia Statistics Agency.
- Narumalani, S., Mishra, D. R., & Rothewell, R. G. (2004). Change detection and landscape metrics for inferring anthropogenic processes in the greater EFMO area. *Remote Sensing of Environment*, 91(3–4), 478–489.
- Olson, J. M., Misana, S., Campbell, D. J., Mbonile, M., & Mugisha, S. (2004). *Land use change impacts and dynamics (LUCID) Project working paper 47*. Kenya: International Livestock Research Institute.
- Sarris, A., Maniadakis, M., Lazaridou, O., Kalogrias, V., Bariotakis, M., & Pirintzos, S. A. (2005). Studying land use patterns in Crete Island, Greece, through a time sequence of landsat images and mapping vegetation patterns. In *2005 WSEAS international conference on environment, ecosystems and development, Venice, Italy, November 2–4, 2005* (pp. 112–119).
- Song, C., Woodcock, C. E., Seto, K., Lenney, M. P., & Macomber, S. (2001). Classification and change detection using Landsat TM data: When and how to correct atmospheric effects. *Remote Sensing of the Environment*, 75(2), 230–244.
- Willemen, L., Verburg, P. H., Hein, L., & Van Mensvoor, M. E. F. (2008). Spatial characterization of landscape functions. *Landscape and Urban Planning*, 88(1), 34–43.
- Wulder, M. A., Hall, R. J., Coops, N. C., & Franklin, S. E. (2004). High spatial resolution remotely sensed data for ecosystem characterization. *BioScience*, 54(6), 511–521.

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