From Land Cover to Landscape Structure: Change and Fragmentation Analysis in Korup National Park, Cameroon

Ndoh Mbue Innocent (Corresponding author)
Faculty of Industrial Engineering, University of Douala
P.O Box 2701, Douala, Cameroon
Tel: 237-7754-0384 E-mail: dndoh2009@gmail.com

Bitondo Dieudonne
Faculty of Industrial Engineering, University of Douala
P.O Box 2701, Douala, Cameroon
Tel: 237-7741-4928 E-mail: bitondodieudonne@yahoo.fr

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Abstract

Can the designation of protected area status in a human inhabited ecosystem limit anthropogenic activities within the boundaries of the protected area? To attempt an answer to this question, we used the Central zone of Korup National Park, Cameroon as an example. Comparing two satellite imageries (1986 and 2000), it was possible to assess land cover transformations, and with the FRAGSTATS software it was possible to quantify the changes of landscape characteristics in the area fourteen years after the creation of the park in 1986. The results revealed an increase in exposed surfaces (15.61%), which came at the expense of forest-land-cover (-12.69%) and water bodies (-2.92%). Meanwhile, landscape metrics demonstrated significant changes including, an increase in the number and size of patch, diversity and fragmentation. Overall, structural metrics for landscape indicated that anthropogenic activities still continue within the boundaries of the park. The results confirm the effectiveness of the combined method of remote sensing and metrics.

Keywords: Korup National Park, FRAGSTATS, Landscape metrics, Patch, Diversity, Fragmentation

1. Introduction

Sustainable development of natural resources has become a key issue for survival of planet earth. In recent times, the conservation of biodiversity has been given the highest priority through global diversity convention. This has led to the creation of protected areas, which are today recognized as the most important core units for *insitu* conservation. Protected areas are also indicators for success in achieving the Millennium Development Goal 7 (ensuring environmental sustainability), Target 9 (integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources) and Indicator 26 (land area protected to maintain biological diversity).

Unfortunately, the unwanton deforestation/degradation and poor management of such ecological systems threaten their own existence. Increasing evidence indicates that anthropogenic influences lead to dramatic changes in landscape pattern and thus changes in ecosystem functions (Herold *et al*., 2003). Examples include the rapid reduction of biodiversity, the shortage of water resources and the heavy deterioration of air quality (Wilson *et al*., 2003).

The loss in biodiversity especially resulting from habitat destruction is of concern due to its widespread implications for environmental security and/or ecosystem functioning (Myers *et al.,* 2000; Loreau *et al*., 2002), human well-being for all (Diaz *et al*., 2006), ethical reasons (Ghilarov, 2000), as well as sustainable development and poverty reduction. Such insecurity situation might in the long run further insecure the people, especially the poor smallholder farmers, who cannot integrate traditional markets, but need alternatives for income generation.

While tropical forest loss is recognized as a regional as well as a global problem, little is known on a local scale about the extent, dynamics and the complex relationships between environmental, economic, social and natural resource policy factors that induce changes in land use patterns. This is particularly important in the forest regions of Cameroon where forest fragmentation has been a common phenomenon in the past few decades and most of the surviving forests consist of systems of small patches of natural forests, which are increasingly coming under large scale deforestation without measures to combat its consequences.

In this context, the importance of monitoring ecosystem heterogeneity attending the composition, structure and functioning is well recognized in both management and conservation (Noss, 1990; Christensen *et al*., 1996). Monitoring provides early warning information on land cover, landscape and other biophysical parameters. Although Protected area Managers have used remote sensing data products to monitor active fires (Justice *et al*., 2003; Csiszar *et al*., 2005), there is considerable potential to expand land managers' operational use of other satellite observational data sets to monitor natural resources (Turner *et al*., 2003; Gross *et al*., 2006). Monitoring landscape dynamics in parks and protected areas is important because changes within and adjacent these systems can alter water quality and flow regimes, increase the likelihood of invasive plant and animal range expansions, reduce contiguous forest, and influence ambient sounds and clear night skies, among other impacts (Mitchell *et al*., 2006; Theobald, 2001). Monitoring land-cover changes will guide decision-making for resource management of these protected lands. Monitoring and evaluating protected areas is complex and difficult because it requires considering historical, geographical and social contexts within which the protected area exists which is hardly the case in most developing countries. Yet, without such efforts, maintaining environmental diversity and counteracting the rate at which landscape change is occurring will be an elusive goal. The relatively uncommon use of such information in routine, operational monitoring by land managers speaks to the very real difficulties in designing and implementing a program that provides useful information at management-relevant scales and at affordable cost. Effective monitoring of our ecological systems requires an understanding of the variability in time and space of these resources and the role of human cultures and institutions in bringing those variations.

Recently, advances in remote sensing (RS) and geographic information system(GIS) technologies and methodologies, and in the integration of analytical results and evaluation schemes in a long-term monitoring protocol, have created new and exciting opportunities for applying remote sensing data to meet monitoring needs (Fancy *et al*., 2009). Repeated satellite images and/or aerial photographs are useful for both visual assessment of natural resources dynamics occurring at a particular time and space as well as quantitative evaluation of land use/land cover changes over time (Tekle and Hedlund, 2000). Remote sensing also provides information on processes and phenomena that act over larger areas. For example, it has been used to track the impacts of macro-scale events and processes on protected areas, specifically climate variability in Alaska (Reed *et al.,* 2009), insect defoliation in Utah (Dennison *et al*., 2009), drought and its impact on net primary productivity in Yellowstone National Park (Crabtree *et al*., 2009), forest fires in Mexico (Ressl *et al.,* 2009), and urbanization across the coterminous United States (Svancara *et al*., 2009). Analysis and presentation of such data, on the other hand, can be greatly facilitated through the use of GIS technology (ESCAP, 1997). Hence, a combined use of RS/GIS technology, therefore, can be invaluable to address a wide variety of resource management problems including land use and landscape changes.

Quantifying landscape structure constitutes one of the basis for studies of landscape function (Note 1) and change (McGarigal and Marks, 1994). The quantification of landscape fragmentation to assess landscape structure has become more common in studies that use remote sensing (Herzog and Lausch, 2001, Nagendra *et al.,* 2006). Remote sensing provides a robust tool for deciphering the patterns on a landscape and connecting ecological patterns to temporal and spatial processes that drive landscape change (Narumalani *et al*., 2004, Southworth *et al*., 2006). In conjunction with landscape metrics, the use of remote sensing will provide a useful and informative interpretation of landscape configuration and change. Landscape metrics is one of the imperative methods for understanding the structure, function and dynamics of landscapes and has a pivotal role to play in finding those solutions and navigating sustainable land use.

This study is part of a broader research designed to assess the role of protected areas in conserving the ecological status/integrity of forests in the Central zone of Korup National Park (CKNP), Cameroon. The central question is, "does the designation of protected area status for Korup National Park limit pressure from anthropogenic activities within the park boundaries?" The aim is to assess land cover and landscape change patterns in the central zone of Korup National Park, Cameroon.

Specifically, the research aims to:

(i) provide a perspective for land cover types and land cover changes that have taken place in the central zone of the Korup National Park, 14 years after its creation in 1986, and use categorical data from , and

(ii) quantify the spatial structure of the region's landscape during the period under study, with special focus on forest fragmentation.

The approach consists of two main steps: (1) Land cover analysis to understand changes in forest cover since the creation of the park in 1986; and (2) a landscape analysis to understand the change in landscape using landscape metrics. The approach to land cover and/or landscape analysis increases ecosystem knowledge, and provides land managers with a more informed basis for making management decisions and to provide a comprehensive ecosystem management plan.

2. Methods

2.1 Study Area

The Korup National Park (KNP) is located in Ndian Division, southwestern Cameroon, between latitudes 4° 54′ and 5° 28′ north; and longitudes 8° 42′ and 9° 16′ east, in the southwestern corner of the Southwest Region of Cameroon at the Cameroon-Nigerian border and is contiguous with the Oban National Park-Nigeria. The total surface area is 1,260 km^2. It is part of the Guineo-Congolian forest, with a rainfall ranging from 1500 to more than 10,000 mm per year (Zimmermann, 2000). This ecoregion is considered an important center of plant diversity because of its probable isolation during the Pleistocene (Davis *et al*., 1994). We conducted this study in the central zone of the Korup National Park (Figure 1), which makes up 41% of the park and is bounded by three villages (Erat, EkonI, and Ekundo-kundo/resettlement site).

Ekundo-kundo was formally in the heart of the Korup forest, but resettled by the Korup project through voluntary resettlement.

2.2 Site Selection Criteria

Our broad criteria for study area selection were that the chosen area be:Representative of the Korup National Park ,At risk of degradation or loss of functional value and Very little or no research had been carried out there because of its enclaved nature.

2.3 Data Sources

Landsat Thematic Mapper satellite from 1986 and Enhanced Thematic Mapper Scanner satellite Plus for 2000 were the main datasets used for the study (Table 1).

Both images, orthorectified and projected to a Universal Transverse Mercator (UTM) coordinate system (Datum WGS 1984, zone 32 north), were freely downloaded from Landsat.org. The root mean-square error (RMSE) between the images was around 0.3 pixel which is acceptable according to Lunetta and Elvidge (1998) who reported that the accepted RMSE between any two dates should not be more than 0.5 pixel. Obtaining images at near anniversary dates is considered important for change detection studies (Jensen, 2007). However, due to our limited financial means, we could not obtain latest images for this region. The year 1986 shows the state of ecological system at the creation of the Park. The year 2000 is chosen as an intermediate point to distinguish the immediate effects of post park creation and resettlement. Landsat satellite images were used, because they were freely available. The ground-truth information required for the classification and accuracy assessment of images was collected from a field survey from February to June, 2009. In addition, a self-designed format was used to collect forest level information on forest types, floristic diversity, condition and history of land use provided by the local people and direct observation in the field.

2.4 Data Analysis

2.4.1 Image Preparation for Classification

The image processing software ERDAS IMAGINE 9.2 (Leica Geosystems, 2008) was used for pre-and post-processing of the remote sensing imageries for land cover analysis. As the satellite images were orthorectified, the following image processing steps were performed: mosaiking- a process of joining georeferenced images together to form a larger image or a set of images. The input images must contain all map and projection information.

In the mosaiking process, the image patches, 187/056 were each joined to 187/057 to form the required composite multispectral images. Being a montane/cloud mountain area, shadows were more like deep water bodies. Cloudy pixels generally have high brightness values and low greenness values. If not reduced (or un-flagged), they will most likely be mapped as non-forest, regardless of the actual surface conditions. Cloud shadow over forest may also be mapped as disturbance, as the spectral signature of forest under shadow can be quite different from that of sunlit forest. Hence, to improve on the image quality, the following steps were employed: the image scenes were subjected to haze removal using ERDAS Imagine's Tasselled Cap transformation, reducing the haze-related atmospheric noise in each of the dates processed; the de-hazed images were then processed using principal components analysis (PCA) to complete noise removal and reduce data redundancy. PCA was run separately on the visible and near infrared bands, and the first three principal components from the separate analysis were retained for further processing. The higher order components captured random as well as systematic noise in the data, such as striping, and were dropped from further analysis; using the de-hazed red and infrared bands, NDVI images were produced for each date for subsequent analysis; and texture analysis was performed on the 3-band principal components image. The resulting three texture bands were stacked with the three PCA bands to produce a 6-band image. Next, the NDVI image produced from the originally de-hazed red and infrared bands was added to the PCA and texture bands to generate a final 7-band image for signature development and classification. The mosaiked images were then subsetted (a process of extracting the required area after the mosaiking of the images) with the aid of with the aid of ground truth data; and supervised classification followed.

2.4.2 Image Preparation for FRAGSTATS and Patch Analyst

Based on ERDAS images, satellite images were pre-processed, displayed, and analyzed. For FRAGSTATS input raster, 0's (background data) was removed. To remove the 0's, we re-coded them as a negative (-) integer background so that FRAGSTAS will ignore them. To change 0's in an image, the recode function in ERDAS Imagine Model Maker was used (with 0 being changed to -10), making sure the output data type is set to signed-8 bit. Finally, a class property file was prepared as specified in FRAGSTATS User Guidelines (Note 2).

2.4.3 Image Classification

Supervised classification based on the maximum likelihood classificaion method as a parametric rule was used for the classification of both images. The basis of the maximum likelihood classifier is the probability density function, which depends on the Mahalanobis distance between each pixel and the centroid of the belonging class. A total of 135 sample points including vegetation sampling points, household locations, farmlands, river paths, bare surfaces, open canopies, etc were collected during our survey. These were used as training sets. With these, various spectral signatures for each class were developed and evaluated using seperability analysis to estimate the expected error in the classification for various feature combinations (Landgrebe, 2003). Using a separability cell array, different spectral signatures in each class were merged together (Jensen, 2004). For producing land cover maps for 1986 and 2000 and to investigate changes that occurred between these periods, the three land cover classes were considered in image classification (Table 2).

Among all the land cover classes, water bodies are the most complex class. In fact, it includes other combinations of land cover, which are not included in the rest of the two classes. During the dry season, marshes and riverbeds in the study area are mostly shallow and have spectral values similar to those of degraded/open forest (exposed surfaces). This condition made it impossible to distinguish them from earth roads, new construction sites and other built-up areas. This justifies combining settlements, rocks, barren lands and built-up areas with exposed surfaces in this study, which may not be acceptable at any other time of the year.

2.4.4 Post Classification

The principal advantage of post-classification comparison is that the images are separately classified, thereby minimizing the problem of radiometric calibration between dates (Song *et al*., 2001) and reducing the amount of data pre-processing. Two stages were used in post-classification: Change detection of land cover categories, and Change in landscape using landscape metrics.

2.4.4.1 Change Detection in Land Cover Categories

Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times (Jensen, 2007). Different methods of change detection exist including image differencing and image rationing (Singh, 1989). The compound-interest-rate formula (Puyravaud, 2003) was employed here due to its explicit biological. This is:

$$P = \frac{100}{t_2 - t_1} In\left(\frac{A_2}{A_1}\right)$$

Where,

P is percentage of vegetation loss per year, and

A_1 and A_2 are the amount of vegetation cover at time t_1 and t_2, respectively.

2.4.4.2 Change in Landscape Using Landscape Metrics

Landscape metrics were calculated using FRAGSTATS version 3.3 algorithms (McGarigal *et al*, 2002). Fragstats was used because it provides a detailed suite of spatial statistics and descriptive metrics of pattern at the patch, class, and landscape levels (Nagendra *et al*., 2003). While FRAGSTATS provides a large number of spatial metrics, a specific subset of them was specifically selected for this study (Table 3).

The spatial pattern measurements in the table represent diverse aspects of pattern such as responses to average patch size, patch size distribution and patch shape complexity. The basis of these metrics calculations is a thematic map representing a landscape comprising of spatial patches categorized in different patch classes (Herold *et al*., 2003). The 8-neighbor rule for delineating patches was chosen for all landscape metrics.

3. Results

3.1 Changes in Land Cover

Major changes took place in the ecological system fourteen years after the creation of the park in 1986 (Figure 2).

Great changes occurred around the settlement sites of Erat, EkonI and Ekundo-kundo (resettlement site). (2000 image, Figure 2).

Overall, exposed surfaces increased (6774.79ha) while Forest Cover and Water bodies decreased by 5610.80 ha and 1275.85ha respectively. This modification of land cover over time suggests that the creation of the park caused little relative stability in landscape characteristics in a quite short period of time. A change trajectory (Figure 3 a&b) shows that forest (12.69%) and water bodies (2.92%) were lost to exposed surfaces, resulting to a net gain of 15.1% in exposed surfaces.

The observed trends of decreasing forest and water cover in the nature reserve could be explained by: Natural factors such as evapotranspiration, siltation, climate change, etc; and anthropogenic factors: the increase in human population over time comes along with increase in human settlements and smallholder subsistence farming (Figure 4).

Accuracy assessment results indicated that land cover changes have been accurately identified and extracted using the PCA-NDVI-Texture analysis based method during the period, confirmed by the reasonable and approving overall accuracy (87.47%) and Kappa statistic (0.89). The overall accuracy clearly exceeds the minimum standard of 85% stipulated by the United States Geological Survey (USGS) classification scheme (Anderson *et al*., 1976). Furthermore, comparison from table 3 shows that the PCA-based method even outperformed the post-classification according to the accuracy assessment and confirms its effectiveness for land use change detection.

3.2 Changes in Landscape Structure

A useful indicator of natural habitat fragmentation is the patchiness of the landscape, especially in forest areas. These and other useful landscape characteristics were modified barely 14 years after the creation of the Park in 1986, and this process varied according to land cover types (Table 4).

Up to 2000 forest-clearing activities in support of shifting agriculture left significant fragmented pattern in what were contiguous forest areas especially around the village areas of Erat and EkonI. Classes with the highest total areas at park creation (in 1986) were forest cover (39930.13 ha) and water bodies (2747.74 ha); and in the transition period (2000), forest cover (34319.33 ha) and exposed surfaces (7604.02 ha).

The PD value of all land cover increased over time with forest cover recording the least while exposed surfaces recorded the most increase. This suggests significant modification of the ecological system following the creation of the park in 1986 had generated more heterogeneous land covers in the landscape. The small increase in PD values for forest cover and water bodies might be simply caused by the reduction of their total coverage, resulting in smaller but more homogenous land covers. Unlike forest cover and water bodies, exposed surfaces became more heterogeneous after the creation. While PD increased MPS decreased over time.

3.2.1 Fragmentation

Under the disturbance of natural and human forces, the landscape will be changed from simple to complex. This process is called landscape fragmentation. The minimum fractal index is positively related to the patch number ($r = 0.867$, $p<0.05$). The fragmentation indices are however low since the number of land use types are not highly diversified. However, it is expected that landscape will become complex in future if the population continues to grow and market for food crops continue to increase.

Furthermore, over the time period 1986–2000, the edge density (ED) and Landscape Shape Index (LSI) increased acutely and reached their peak values in 2000 (Figure 5).

This can be explained by the increase in human population, local infrastructure (houses) and expansion in smallholder farming over the years. Together, these have resulted to larger but more complicated patches.

Furthermore, the clumpiness of land cover classes ranged from 0.3 to 0.85 in 1986 and from 0.4 to 0.7 in 2000; Cohesions varied from 60 to 100% in 1986 and from 87 to 100% in 2000, while the Interspersion and Juxtaposition Index varied from 10 to 82% over the entire period (Table 5).

3.2.2 Diversity

Shannon's diversity (SHDI) and evenness (SHEI) indices both showed a positive change over the period (Figure 6).

SHDI increased from 0.33 in 1986 to 0.61 in 2000, while SHEI increased from 0.299 in 1986 to 0.5502 in 2000. Hence, the landscape was dominated by heterogeneous land use types in 2000, while in 1986, by a more homogenous distribution of land use types. This suggests that the area, as at the year 2000, was more fragmented than it was before the creation of the park in 1986.

4. Discussions

4.1 Land-cover Change Modeling

The findings clearly show human activities as the key driver of land cover change and land degradation in the study area. Strong evidence of environmental change is suggested by the increasing trend at which natural land cover classes are transiting into degraded lands. The impact of certain anthropogenic activities on CKNP has been an issue before park creation in 1986. Although the government has attempted to remove illegal squatters and regulate the use of the land, these attempts have often failed. Poorly implemented management plans and limited incorporation of the local communities in management have led to a national park that exists on paper, but in reality appears less than effective.

When this progressive increase in degraded lands (though not very significant today) is added to losses recorded by delicate ecosystems such as ponds, mangrove and forest, the need for urgent steps to halt this negative trend becomes imperative. The human vulnerability and implications of these negative changes on livelihoods of communities require proper and serious attention. Recent researches on semiarid environments have shown that land degradation resulting from such changes may lead to changes in the distribution of different types of vegetation cover, even when the total biomass is not necessarily changed (Tanser & Palmer, 1999). In many instances land degradation results in increased runoff and soil redistribution within the area through erosion and sedimentation processes (Payton *et al*., 1992; Yanda, 1995). This leads to spatial heterogeneity in soil / land properties that in turn influences agricultural productivity and the livelihoods of communities concerned. Though no studies on soil erosion in the area have been carried out, it can be explained that soil erosion dates a long way back in time, even to the late Pleistocene, when wetter climates prevailed.

However, despite the fact that the region's cropland has increased steadily since 1986 (as reflected in area of exposed surfaces and forest cover), total area cultivated is insignificant and do not correspond with the population growth, which increased significantly between 1986 and 2000s. This indicates that the agricultural land use system of the area has somehow managed to adapt itself to the prevalent land degradation, thereby being able to sustain the livelihood of the increasing population. The plausible explanation of how the population has managed to sustain their livelihoods on the generally small infertile cultivated fields is possibly as a result of the rich non timber forest products and fauna of the forest. It should be recalled that hunting is one of the main activities in the area (even if it has now reduced because of the restrictions following the creation of the park). Also, non timber forest products such as *Irvingia gabonensis*, *Gnetum africanum* are very high food and income generating resources in the area, contributing over 70% of total household income (Innocent and Ge, 2009).

Countries of biodiversity regions of the world including Cameroon have over the past two decades attempted to set aside protected areas and conserve biodiversity and ecological integrity (environmental processes) within these areas in order to meet up with international regimes demands. The effectiveness of such efforts is questionable and needs to be addressed. Conservation that is driven externally, for example, protected areas that are set as a result of an agreement with an international conservation organization (e.g., the area under study), frequently are not adequately monitored and therefore are not being managed adaptively. The lack of monitoring of the effects of management schemes on the landscape leads to inefficient conservation that is unsustainable.

The results also demonstrate the difficulties in distinguishing features. Certain thematic classes generated confusion and resultant misclassification, indicating that further research is warranted in identifying improved methods for separating these classes. Errors between similar land-cover types, in respect of water bodies, vegetation cover and cloud cover/bodies accounted for nearly all errors. For example, errors between cloud forest and water/moisture were common, as were errors between shallow water paths cover with riparian vegetation and deep water bodies. As Wrbka *et al.* (2004) and Peterseil *et al.* (2004) noted that the coarse spatial resolution of Landsat TM5 images of 30 m × 30 m may cause problems when depicting fine-grained vegetation landscapes. It is realized that it could be insignificant to select smaller spatial reference units than this because of relative monotonous vegetation cover in the Korup region. Despite these problems, satellite images remain the one major data source for vegetation dynamics on a regional scale. The encountered constraints can be considered as a more technical problem. Methodological enhancement is needed to solve the shortcomings of data. With comprehensive application of high-resolution remote sensing data in the future, it is impossible for assessment of environmental indicators. Besides the use of high resolution satellite images, a larger number of sample plots for the field survey may help to solve this problem (Peterseil *et al.,* 2004).

4.2 Fragmentation Analysis

The general change in landscape metrics over time suggests that despite the creation of the Park, human activities have not yet been restricted in the area. A closer look at the land use map reveals the reason for this dramatic change in the patch. The expansion in settlements in the constitutive villages (resettlement site at Ekundo-kundo; Erat and EkonI) and natural factors, probably related to climate change could have resulted in a more fragmented distribution of both classes.

The increase in PD over time has been found to impact the number of subpopulations in a spatially-dispersed population, or metapopulation, for species exclusively associated with that habitat type. The number of subpopulations could influence the dynamics and persistence of the metapopulation (Gilpin and Hanski 1991). The number or density of patches also can alter the stability of species interactions and opportunities for coexistence in both predator-prey and competitive systems (Kareiva 1990). The increases suggest that despite the creation of the Park, human activities have not yet been restricted in the area. Alternatively, management might not be doing enough to implement government policies on conservation, and most probably, insufficient or absent of funds for management. The possibility of corruption cannot be completely ruled out because this phenomenon has become the order of the day at all levels of government. Only the unfortunate hunters are caught and detained. Some members of the forces of law and order prefer to seize bush meat for their household consumption than apply the law. This explains why some secret police staff in Mundemba could be seen with hunted bush meat.

4.3 Limitations and Future Research

While the current procedures produce useful information, there are several avenues of research that will be applied to further develop the techniques presented here. One such avenue is the derivation of better land cover information. Techniques that will incorporate information aside from multispectral imagery such as Artificial Neural Networks and Knowledge Based Expert Systems could improve on the results. Additional information will include a measure of texture proposed by Haralick (1986) and based on brightness value spatial-dependency gray-level co-ocurrence to produce texture measures. Additional information will also include image segmentation features outlined by Tilton (2000) that will be used to divide the image into spectrally similar regions or objects that can be included in the knowledge based classifier and neural networks. The benefits of improved classification images for identifying patterns of forest fragmentation are two-fold:

First, having improved information would provide a more accurate picture of fragmentation and where it is occurring; and

Second, more detailed informational classes would allow for better analysis as to the cause of fragmentation.

The use of remotely sensed data and observations collected in the field could allow an analysis of the spatial and temporal landscape patterns in KNP that facilitates the identification of linkages between biophysical and social processes. Robbins (2001), demonstrates how biophysical patterns, such as those identified in this paper, must then be connected to historical and social data to provide the linkage between human decisions and actions, and landscape changes. This is of particular importance when studying protected areas because although land cover change within protected areas is often associated with human use, the complex drivers of change are poorly understood (Robbins *et al*., 2007).

Furthermore, although the use of landscape fragmentation indices is useful for identifying and comparing patterns of change in many landscapes, there are limitations to using such indices to assess change in CKNP. Currently used indices of landscape fragmentation were developed for use in North America and Europe where areas can be mapped into homogeneous and distinct units (Pearson, 2002). However as seen in other developing countries (Southworth *et al*., 2002), these indices may not necessarily be useful for landscape analyses that are dependent on classifications of highly heterogeneous areas. The existence of gaps in the dataset caused by clouds in the satellite imagery leads to an already fragmented image, which when compounded by classification error could result in an ineffective fragmentation analyses of the landscape.

The preliminary results of the investigation concerning temporal changes show that changes in landscape structures can be traced and interpreted by means of landscape metrics. However, some critical remarks concerning data availability and data quality have to be mentioned. The mapped changes are influenced by the methodological approach and caused by the primary data source. Some doubts remain regarding the plausibility of some of the land use change between 1986 and 2000, which might have an effect on the structural metrics and their interpretation.

We have acquired landscape structure information that could be valuable in the management of KNP. The types of datasets, statistical approaches, mapping techniques, and spatial analyses implemented in this study could provide appropriate information for both the assessment and planning of landscape patterns. While our quantification of landscape structural changes was supported by GIS software, more indices relevant to landscape structural change analysis are needed to assess more complex landscape structural changes.

Again, monitoring changes require a high quality standard of input data (temporal consistency) in order to avoid any data related distortion of the results. In this case, the need for higher resolution satellite imageries at least in tropical cloud forest areas cannot be over emphasized.

5. Conclusion

This study quantified the altered conditions of CKNP landscape during the period from 1986–2000, changes that were mainly due to conversion to other landscape types. The study integrated remote sensing and spatial metrics to analyze the spatio-temporal dynamics and evolution of landuse change. Forested areas have become more fragmented and are currently characterized by a proliferation of mixed forest patches. This process has brought about conspicuous land use changes and smallholder farming at an unprecedented scale and rate, and consequently given rise to substantial impacts on the landscape pattern. This study also revealed a spatial pattern of vegetation, as well as a temporal trend of vegetation pattern. The study reveals that, although the magnitude and spatial patterns of land cover change may be artefact of the particular theoretical framework, there is potential in understanding the inadvertent consequences of human activities on the land which have feedback loops on human well-being.

Our case study provides further evidence of how human inhabited protected areas show a constant transformation of their ecological systems. This analysis illustrates how natural vegetation cover tends to diminish in a very subtle and slow fashion due to smallholder agriculture and natural phenomena. Although current rates of clearing may not be seen as alarming for the central KNP itself, the current activities in the reserve are alarming. The cry for more farmland, the current administrative/management constraints, the inaccessibility of the area, increasing population and hunting suggests that, everything being equal, the future the of ecological system is at stake. Even now, the Cross River gorilla populations are thought to be largely cutoff from one another and critically endangered.

The management of KNP, particularly in terms of rehabilitation and preservation, will benefit from information on spatio-temporal changes in landscape structure. The implementation of policies that will strictly limit vegetation clearing in KNP could be adequately supported by the findings of this study. While more forest vegetation clearing occurred in the study zone, the proportional difference was not large enough to produce a strong correlation. Further studies over a longer period are necessary to develop a better understanding of the relationships between changes in landscape structure, human impacts, and other factors. However, the increasing proportion of forest vegetation cleared within CKNP raises serious questions with regard to both the landscape health and the longer term potential for land degradation by smallholder farming.

Park and protected area managers confront a daunting range of decisions, many of which could be informed by data from satellite remote sensing. Especially in sub-Sahara Africa and Cameroon in particular, there is considerable potential to expand land managers' operational use of other satellite observational data sets to monitor natural resources. The relatively uncommon use of such information in routine, operational monitoring by land managers speaks to the very real difficulties in designing and implementing a program that provides useful information at management-relevant scales and at affordable cost.

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Notes

Note 1:

Structure = the spatial relationships among the distinctive ecosystems or “elements”

Function = the interactions among the spatial elements

Change = the alteration in the structure and function of the ecological mosaic over time

Note 2:

http://www.umass.edu/landeco/research/fragstats/documents/User%20guidelines/User%20guidelines%20content.htm

Table 1. Characteristics of Sensors used

Path/Row	Imagery date	Sensor	Pixel size (m)	Bands used
187/56/57	2000-12-10	LandsatETM+	Bands 1–5 &,7:30x 30 m Band 6:60 x 60 m Band 8:15x15 m	1–5 & 7
197/56/57	1986-12-12	LandsatTM	Bands 1–5 &,7:30 9 30 m Band 6:120x 120m	1–5&7

Table 2. Descriptions for land cover types in the study area

Code	Land use/cover category	Class description
1	Forest cover	All vegetation types, including wetland forest types, forest plantations
2	Exposed Surfaces	Every other feature other than forest cover and water bodies (e.g., Bare rocks, settlements, farmlands, etc.)
3	Water bodies	Open water, swamps, ponds, etc

Table 3. Spatial metrics measured for CKNP (adopted from McGarigal *et al*. (2002))

No.	Metrics	Denotation	Description	Unit
1	Number of patches	NP	Total number of patches in the landscape	n/a
2	Patch density	PD	The number of patches of per 100 ha	Number/100ha
3	Edge density	ED	The sum of the lengths of all edge segments in the landscape, divided by the total landscape area, multiplied by 1000	Meters per hectare
4	Mean patch size	MPS	The area occupied by a particular patch type divided by the number of patches of that type	Hectares
5	Shannon's diversity index	SHDI	Equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion	n/a
6	Shannon's evenness index	SHEI	A measurement of patch diversity, which is determined by the distribution of different types of patch in landscape	n/a
7	Interspersion and Juxtaposition Index	IJI	IJI equals minus the sum of the length (m) of each unique edge type divided by the total landscape edge (m), multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types times the number of patch types minus 1 divided by 2; multiplied by 100 (to convert to a percentage).	Percent
8	Clumpiness	CLUMPY	Frequency of different pairs of patch types (including like adjacencies between the same patch types) that appear side-by-side on the landscape.	n/a
9	Cohesion	COHESION	The physical connectedness of the corresponding patch type.	n/a

Table 4. Variation in area, NP and PD for the different cover types over time

	Area (ha)	NP	PD (number/ha)
Forest Cover			
1986	39930.13	91	0.209
2000	34319.33	1662	3.83
Exposed Surfaces			
1986	829.23	2625	**6.034**
2000	7604.02	46206	**106.47**
Water Bodies			
1986	2747.59	588	1.352
2000	1471.74	4994	11.51

Table 5. Variation in IJI, CLUMPY and COHESION for the different cover types over time

	IJI	CLUMPY	COHESION
Forest Cover			
1986	82.09	0.709	99.991
2000	33.504	0.4619	99.99
Exposed Surfaces			
1986	6.068	0.355	63.80
2000	10.064	0.4352	87.38
Water Bodies			
1986	8.88	0.842	94.60
2000	40.27	0.6854	96.84

IJI = Interspersion and Juxtaposition Index; CLUMPY=Clumpiness; COHESION=Patch Cohesion Index

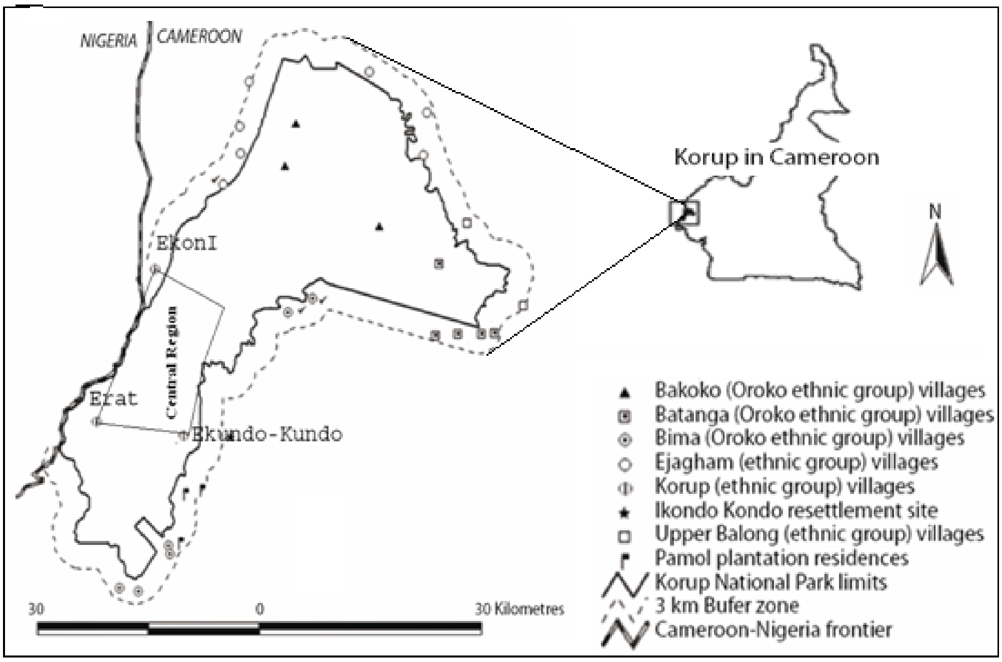


Figure 1. Location of Study area

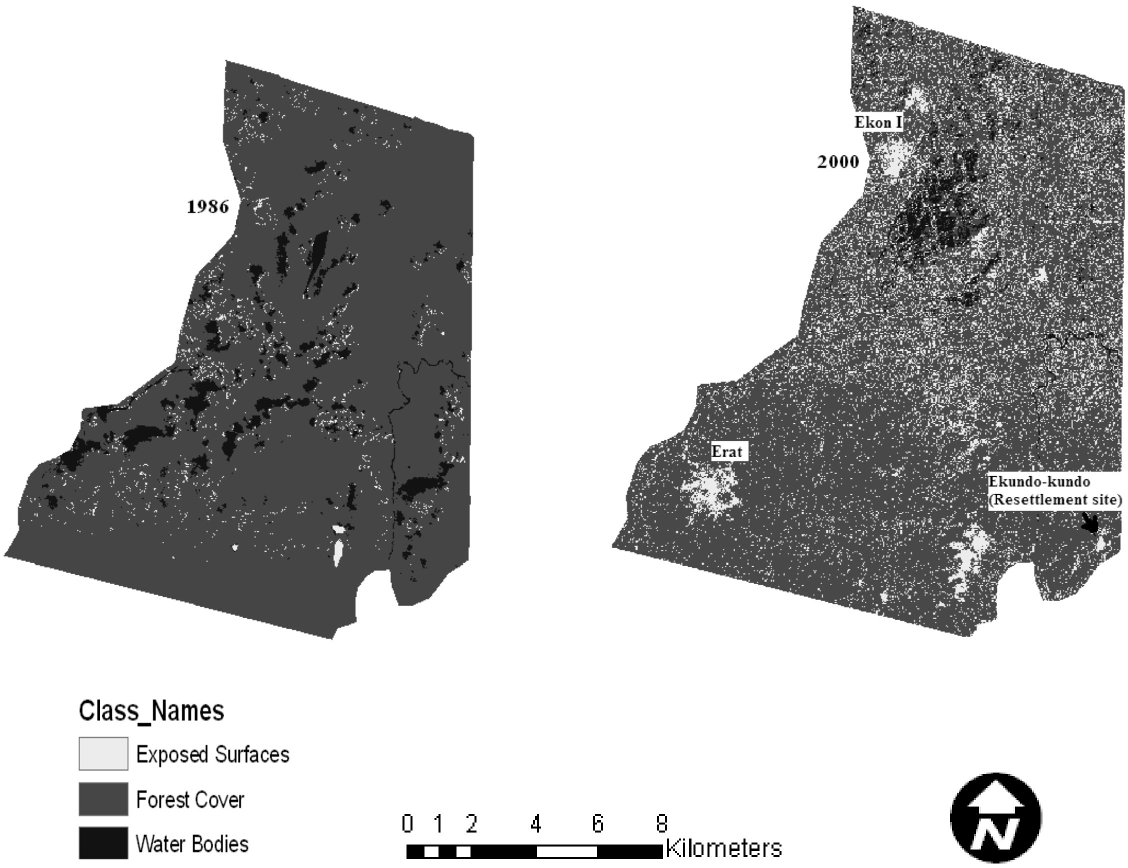


Figure 2. Land cover maps (1986 and 2000) for CKNP

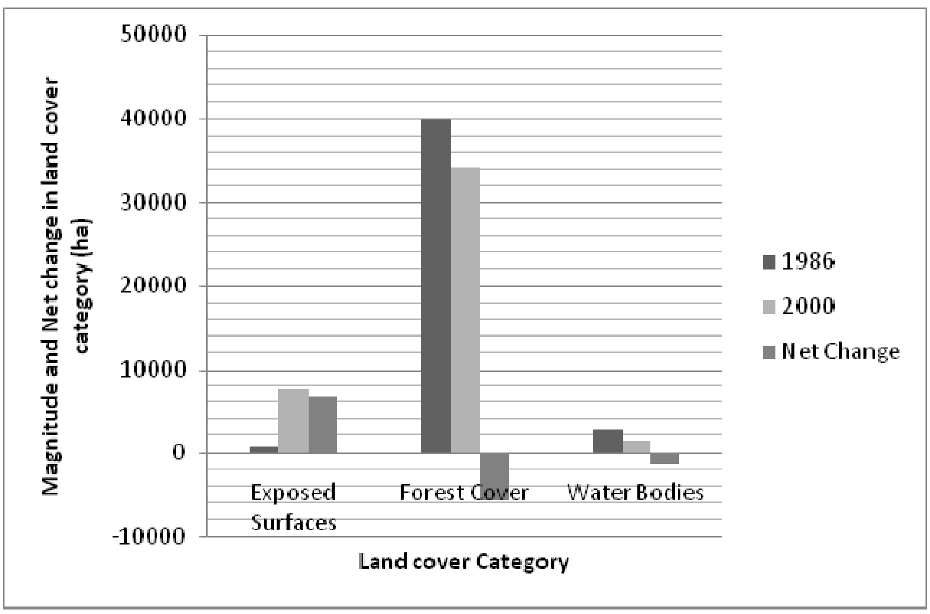
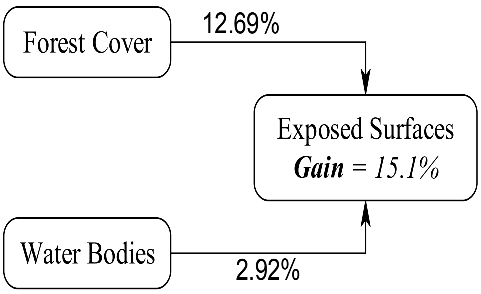


Figure 3. Dynamics of land use pattern: 1986-2000



(a) Change trajectory

(b) shrinkage of the main river draining the park

Figure 4. (a) Change Trajectory (land cover): 1986-2000 (b) shrinkage of Main River draining the park

(a) Fire clearing

(b) Machet clearing

Figure 5. Ecologically unfriendly modifications of the ecological system

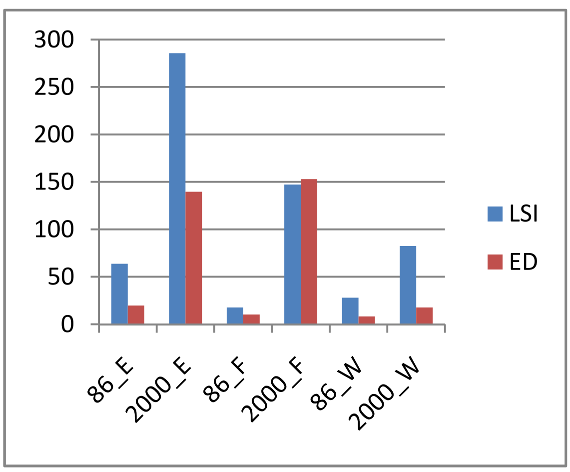


Figure 6. Variation of PD and MPS: 1986-2000

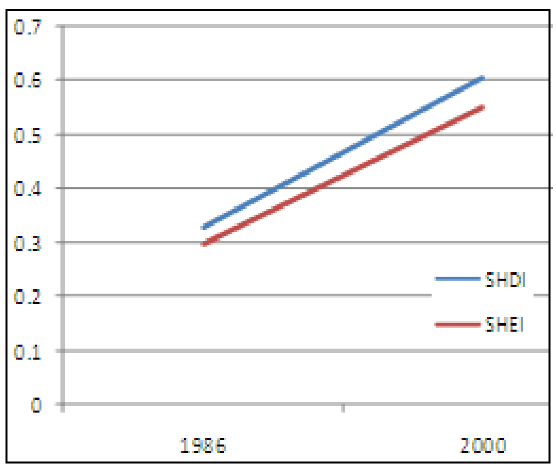


Figure 7. Trends in diversity indices: 1986-2000