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Monitoring Spatiotemporal Changes in Land Use/Land Cover and its Impacts on Ecosystem Services in Southern Zambia

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Abstract

Ecosystems play a vital role in human well-being, yet the widespread loss of ecosystem services due to human activities, including agricultural expansion and deforestation, remains a significant concern. Despite the wealth of research highlighting the importance of ecosystem conservation in Zambia, a critical gap exists in understanding the interplay between the conservation of ecosystem services and the socio-economic needs of local communities. This study presents a comparative analysis of ecosystem services in two distinct landscapes within southern Zambia: the protected area of Kafue National Park (KNP) and the agricultural landscape of Kalomo district between 2000-2020. Employing a combination of quantitative and qualitative methods, we evaluate the impacts of land/use and land cover (LULC) changes on selected ecosystem services, with a particular focus on carbon storage and the habitat quality of the trumpeter hornbill. The results of the comparison indicate that: (1) the Kalomo district has suffered from extensive land conversion, with forest changing to cropland, while KNP was well protected from encroachment, with forest area increasing over time; (2) carbon stocks and the habitat quality of trumpeter hornbills continually decreased in the Kalomo district but improved in KNP; (3) Kalomo district has suffered rapid environmental degradation due to an imbalance between economic development and environmental conservation, while strict enforcement in KNP has preserved ecosystems. The findings underscore the importance of integrated and inclusive land-use planning and natural resource governance for maintaining and enhancing ecosystem services in Zambia. To progress towards landscape management that is both

sustainable and equitable, aligning with the objectives of the Global Biodiversity Framework, it is proposed that a comprehensive approach be adopted in the region. This approach should encompass a more thorough consideration of local livelihood requirements, as well as the wider political-economic and social factors at play.

Keywords: *Ecosystem services, InVEST model, LULC change, protected area, deforestation, Zambia, Convention on Biological Diversity, Global Biodiversity Framework*

Declarations

Ethical Approval

This study did not involve human or animal subjects. However, ethical principles were considered throughout the study, and all research procedures were conducted in compliance with ethical standards for scientific research.

Competing interests

We confirm that we have no conflicts of interest associated with this publication. We confirm that the manuscript has been read and approved for submission by all the named authors.

Authors' contributions

All authors have contributed significantly to the study, as detailed below:

Diling Liang: Conceptualization, study design, data collection, data analysis and interpretation, manuscript writing.

James Reed: Conceptualization, study design, data analysis and interpretation, visualization, review and editing.

Sima Fakheran: Conceptualization, data analysis and interpretation, review and editing.

Kaala Moombe: Conceptualization, data analysis and interpretation, review and editing.

Freddie Siangulube: Conceptualization, data analysis and interpretation, review and editing.

Terry Sunderland: Conceptualization, study design, data analysis and interpretation, visualization, review and editing.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article and its supplementary information files. Additionally, the datasets used in this study are available from the corresponding author upon reasonable request.

1. Introduction

Ecosystem services (ES) are the benefits humans directly or indirectly obtain from nature, categorized into four functional groups: provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment 2005, Lanzas et al 2019, Liu et al 2010, Neugarten et al 2018). Human survival and quality of human life ultimately depend on this range of ecosystem services (Summers et al 2018). For instance, the availability of food, fresh water, and shelter from ecosystems are the basic materials for human life. However, human activities have drastically altered landscapes and ecosystems (Berihun et al 2021), and approximately 60% of ES are being degraded due to anthropogenic drivers such as land-use and climate change (Millennium Ecosystem Assessment, 2005, Lanzas et al 2019).

Land-use change is the primary direct driver of ecosystem degradation, thereby critically affecting their ability to maintain the provision of goods and services to humanity (Li et al 2015, Rai et al 2018). Pressures resulting from increasing population, consumption, inequality, urbanization, and globalization have led to increased demand for land, food, water, and other natural resources. Such pressures have resulted in agricultural expansion, deforestation, land degradation, and biodiversity loss, impacting human well-being by significantly altering the provision of ecosystem services (Elmhagen et al 2015, Henderson and Loreau 2018, Reader et al 2022). Zambia's land-cover has undergone a series of complex changes during the past three decades, largely due to social, political, and economic influences (Phiri et al 2019), and these changes have negatively impacted the provision of many ES. The ES framework is a comprehensive approach employed for the management of ecosystems, with a notable impact on the process of decision-making (Evers et al. 2018). Consequently, there is an increasing prevalence of policymakers seeking environmental sustainability assessments in relation to development. However, the predominant focus of research on ecosystem services (ES) in Zambia is around the use of case studies that examine a solitary landscape to evaluate and delineate ES, commonly centred on provisioning services (Deuteronomy et al 2019, Van der Horst et al 2014, Lehner et al 2021).

In contrast to provisioning services, regulating services, cultural services, and supporting services are particularly underestimated in Zambia. Furthermore, few studies have taken into account the simultaneous consideration of conservation objectives and the social-economic demands of local communities. Notably, Zambia has just committed to the Kunming-Montreal Global Biodiversity Framework, which outlines a comprehensive set of measures designed to "enhance biodiversity and ecosystem functions and services, ecological integrity and connectivity," while also emphasizing the "recognition and respect the rights of indigenous peoples and local communities." This commitment exemplifies an increasing acknowledgement of the significance of supportive services in advancing sustainable development and safeguarding the welfare of indigenous populations.

In Zambia, a substantial portion of the land, approximately 40%, is designated as protected areas (PAs), comprising 20 national parks and 36 Game Management Areas (GMAs), all established with the primary aim of conserving biodiversity (Lindsey et al 2014, Hou-Jones et al 2019, Lecina-Diaz et al 2019). Zambian national parks are regarded as strict PAs where human settlement is strictly prohibited and agricultural activities are forbidden (Lindsey et al 2014). Conversely, to promote socio-economic development, agriculture has been extensively developed in Zambia. The country faces considerable deforestation rates, driven largely by agricultural expansion (Richardson et al 2021), resulting in an annual deforestation rate of 250,000 to 300,000 hectares per year (Phiri et al 2022). Consequently, it becomes imperative to comprehend the diverse impacts of various land management policies on LULC, ES, and local communities, and to propose integrated approaches to natural resource management at the landscape scale that effectively harmonize both conservation objectives and the needs of local communities in Zambia.

To understand the influence of land management policies on ES, this study conducted an assessment and comparative analysis of the long-term (2000-2020) land-use dynamics on regulating services (carbon storage) and supporting services (habitat quality), in Kafue National Park and Kalomo district in Zambia. Kafue National Park represents a stringent PA, while Kalomo district epitomizes a well-established agricultural region within the Zambian landscape. The objectives of this study encompass the following: (1) evaluation of LULC changes within both landscapes, each subject to distinct land management policies; (2) quantification and spatial mapping of carbon storage and habitat quality for the Trumpeter hornbill employing ecological models; (3) comparative analysis of the land management policies that propel land-use alterations in the two contrasting landscapes; (4) formulation of recommendations for divergent landscape management strategies. Through the pursuit of this research endeavour, our overarching objective is to enhance our comprehension of how to effectively harmonize the livelihood requirements of local communities with the imperative task of conserving ES.

2. Methodology

2.1 Study sites

The study areas are Kafue National Park and Kalomo District (Figure 1). Both landscapes are characterized by Miombo and Mopane woodlands. The Miombo woodlands of southern Africa are one of the most significant dry forests in Africa (Rduch 2016, Phiri et al 2019) and are significant sources of livelihood benefits and have critical functions in conserving biodiversity and mitigating climate change (Chanda 2007, Moombe et al 2020).

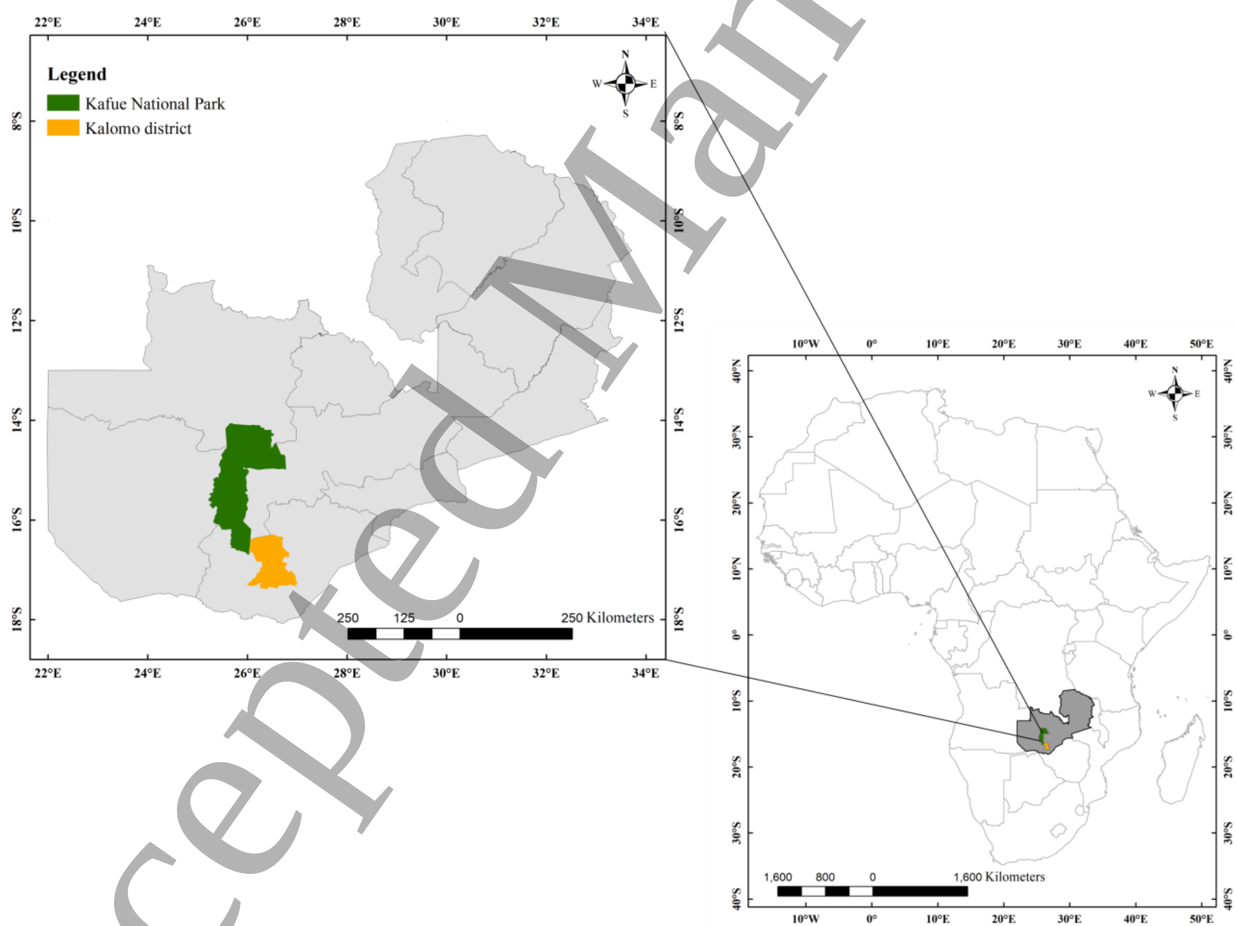

Figure 1. The locations of study areas in Zambia

The KNP is located in the central area of southwestern Zambia. It is the oldest and largest national park in Zambia, covering an area of 22,480 km^2 (Gula and Phiri 2020). Nine Game Management Areas (GMAs) border the KNP, and it is estimated that more than 174,796 people live in the proximity of the KNP (Namukonde and Kachali 2015). While KNP is a national asset that brings rewards at the national level and is important for the conservation of unique biodiversity, its stringent restrictions on access to natural resources have profound socio-economic repercussions on the surrounding communities (Vezina et al 2020). These communities heavily rely on natural resources for their livelihoods, yet they are largely excluded from the park to the extent that most people consider visiting the park to be illegal (Watson et al 2014, Namukonde and Kachali 2015, Milupi et al 2021).

Kalomo district is located in the Southern province, covering 8,075 km^2 (Moombe et al 2020). Kalomo is a typical agricultural landscape in Zambia. It is referred to as the "Farmers' Nest" because of the commercial, small to medium-scale livestock and crop (specifically maize) farming enterprises (Bush 2014, Moombe et al 2020). However, Kalomo district also ranks as one of the economically poorest in the country (Sialubanje et al 2017). Agriculture is predominantly rain-fed and the primary economic resource for local people, accounting for 34.4% of local household income (Moombe et al 2020). Maize is the primary staple crop in Kalomo and occupies 55% of the cultivated area. Indigenous and hybrid maize varieties account for 25% and 30% of the cultivated crops, respectively (Kalinda et al 2010). In addition to crop production activities, households keep livestock and cattle are the most important livestock species owned by local farmers for various purposes (Kalinda et al 2010). Moombe et al (2020) stated that in the Kalomo district as of 2020, the human population is 395,471 and the total number of livestock is 411,765.

2.2 Ecosystem Services Assessment

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model is a geospatial model to quantify and map ecosystem services (Keller et al 2015). It operates on a gridded map with an average annual time step, making it suitable for evaluating the effects of land-use change on various ES (Tallis et al 2014). The InVEST model includes different modules, and carbon storage and habitat quality modules are used to estimate the status and variation in carbon stock and habitat quality provided by the different LULC types (Maanan et al

2019, Nematollahi et al 2020). It is extensively utilized for quantifying ES due to its ability to customize input data and settings, as well as its requirement for limited data for researched ES (Grafius et al 2016, Daily et al 2009, Ochoa and Urbina-Cardona 2017).

2.2.1 Carbon storage

Carbon sequestration is one of the key supporting services (Sintayehu 2018). Preserving carbon stocks is an important objective of the United Nations Framework Convention on Climate Change (Soto-Navarro et al 2020). The practical assessment of carbon stock could guide how carbon targets can be incorporated into national policies and implemented in climate change mitigation and adaptation (Soto-Navarro et al 2020). The carbon storage module of InVEST can estimate the spatial distribution of carbon stock across the study areas based on the simple carbon cycle (Maanan et al 2019, Piyathilake et al 2022). The total carbon storage of the landscape is the sum of four different carbon pools assigned for each LULC type: (i) aboveground biomass, which includes all living plant materials; (ii) belowground biomass, which comprises the living roots systems; (iii) soil organic matter; and (iv) dead organic material (Sialubanje et al 2017, Dietz 2021, Duarte et al 2016, Piyathilake et al 2021).

2.2.2 Habitat quality

Birds serve as valuable tools for biodiversity monitoring in forest ecosystems due to their sensitivity to environmental changes and their ease of identification (Copper et al 2020). This unique combination of attributes makes monitoring programs not only feasible but also accessible to both scientists and the general public (Copper et al 2020, Wade et al 2013). In our study, we have chosen the Trumpeter hornbill (*Bycanistes buccinator*) as the focal species due to its distribution encompassing both the KNP and the Kalomo district (Figure 2). Unlike the Ground-Hornbill (*Bucorvus leadbeateri*), with limited habitat preference in KNP and listed as Vulnerable (Gula and Phiri 2020), the Trumpeter hornbill has been a Least Concern species on the IUCN Red List since 1984 (BirdLife International 2018). However, trumpeter hornbills are considered large, frugivorous birds, facilitating the functional connectivity of fragmented landscapes. This is attributed to their remarkable ability to disperse seeds over considerable distances and among suitable habitat patches (Mueller et al 2014, Lenz et al 2015). Such actions support gene flow, range expansion, and natural forest regeneration, all of which are crucial for biodiversity conservation (Mueller et al 2014, Lenz et al 2015).

The miombo woodlands in Zambia have a high diversity of plants, animals, and avifauna, while also serving vital ecological roles (Malunga et al 2021). However, the miombo woodlands are heavily fragmented due to anthropogenic interference, with only a few natural forest patches remaining. Safeguarding the trumpeter hornbill within Zambia's miombo woodlands is crucial to maintaining biodiversity and landscape connectivity amid escalating habitat fragmentation. Thus, it is important to monitor and evaluate the status of the trumpeter hornbill to ensure that it remains protected.

The habitat quality module of InVEST combined “information on LULC and the threats to biodiversity to produce habitat maps” (Tallis et al 2014). This module used habitat quality and rarity as proxies to represent the biodiversity of a landscape, and it also estimated the extent of habitat and vegetation type throughout the landscape, as well as their level of degradation (Tallis et al 2014). This module was based on the hypothesis that “areas with higher habitat quality supported higher richness of native species, and that decrease of habitat extent and quality led to a decline in species persistence” (Terrado et al 2016). This module was used to assess how the study areas provide suitable habitat for Trumpeter hornbills based on available data. The value of habitat quality is assigned to LULC types to show habitat suitability. The range of the value is between 0 to 1, where 1 indicates the highest habitat quality, while 0 means unsuitable habitat for certain species (Terrado et al 2016, Chu et al 2018). To visually display the habitat quality according to the output values of the habitat quality model, the equal interval breakpoint method in ArcGIS was applied to assign grades to three different habitat quality groups (Wang et al 2022b).

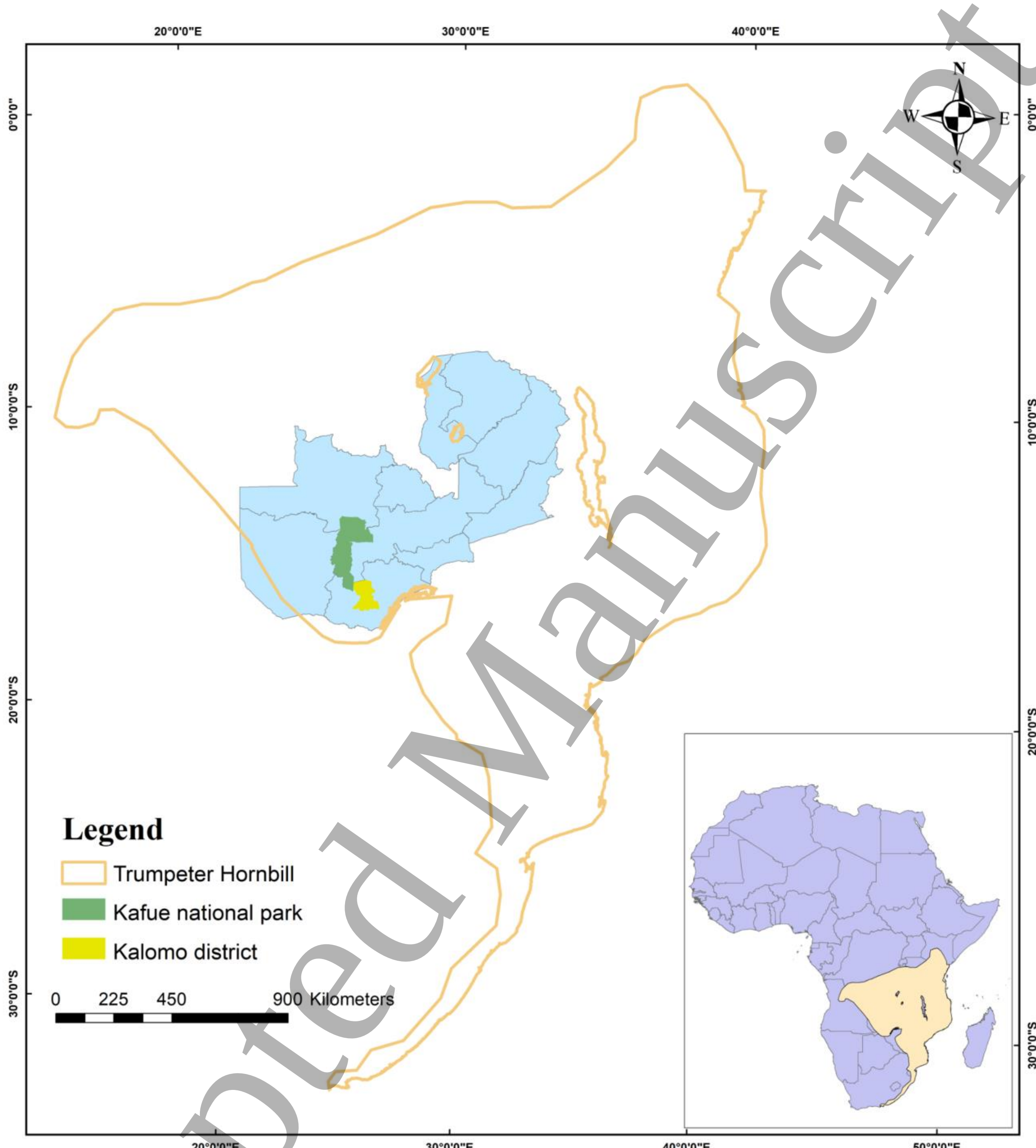

Figure 2. The distribution of trumpeter hornbill

2.3 Data Resources

The types of data used in this study mainly include land cover/land use data (used to assess land use change), satellite images (used to validate the accuracy of land-use classification), carbon stock parameters (used for carbon storage assessment), and other data. The specific data resources and their descriptions are shown in Table 1. All data is open-access.

Table 1. Data sources and descriptions

Data name	Data description	Data resource
Land use/Land cover	30m-resolution land-cover datasets in 2000 and 2010	https://rcmrd.africageoportal.com/
Land use/Land cover	30m-resolution land-cover maps in 2020	Supervised Classification in the Environment for Visualizing Images (ENVI)
Satellite images	Landsat-5 and Landsat-8 images	https://www.usgs.gov/
Carbon stock parameters	Carbon storage data for different land use/land cover types	Dietz (2021); Day et al (2014); Forest Reference Emission Level (2021); Gumbo et al (2018); IPCC 2006 report; Sialubanje et al (2017); Piyathilake et al (2022)
Habitat quality parameters of Trumpeter Hornbill	Threat factors; sensitivity of each land-use class; maximum distance	Expert knowledge
Road data	Main roads in Zambia	http://riskprofilesundrr.org/
Administrative boundary shapefile	Obtaining study area shapefile by cropping	https://data.grid3.org/
Trumpeter Hornbill	Trumpeter Hornbill's distribution map	https://datazone.birdlife.org/

In addition to using the above data, the land cover classification of the study *area re*ferred to the *Guidelines for National Greenhouse Gas Inventories (IPCC) in 2006.*

3. Results

3.1 Land use and land cover change

The results of the study areas are presented in Figures 3 and 4, and the area of land cover and land-cover change in the study areas are summarized in Table 2. In KNP, there was no significant land-use conversion observed from LULC maps. Between 2000 and 2020, the land-use cover was dominated by grassland, and it was mainly distributed in the middle and northern parts of the study area. The area of grassland decreased from 59% (13, 245 km^2) 2000 to 49% (10,832 km^2) in 2010, but subsequently increased to 53% (11,868 km^2) of the total area in 2020. The forest was the second dominant land-use type, and the area of the forest increased from 38% (8484 km^2) in 2000 to 45% (10,070 km^2) in 2020. The area of water bodies was relatively stable, and their area decreased from 1.8% (398 km^2) in 2000 to 1.5% (331 km^2) in 2020. Both water bodies and wetlands decreased from 2000 to 2020, losing 67 $km^2$and 66 km^2, respecively.

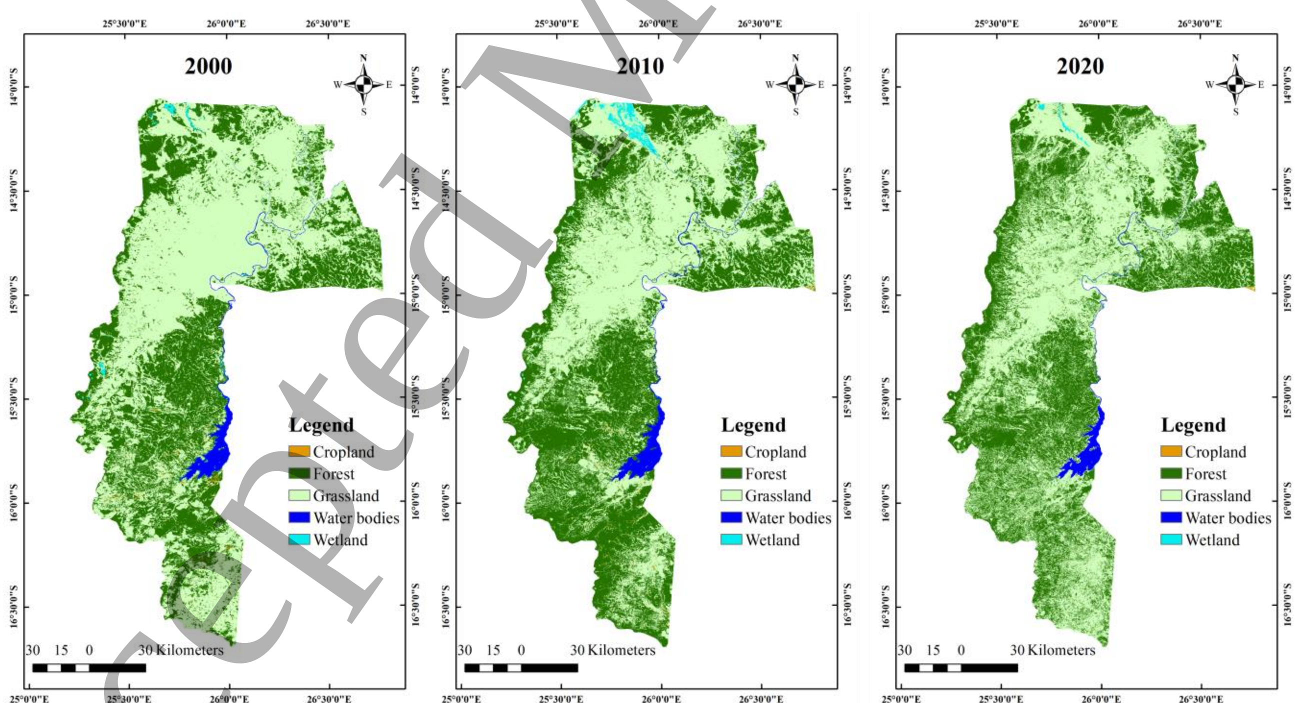

Figure 3. Spatial and temporal LULC in KNP in 2000, 2010 and 2020

Table 2. LULC changes in 2000, 2010, and 2020 for KNP and Kalomo

Areas	LULC Area (km^2)	2000	2010	2020	Changes(2000-2020)
KNP	Cropland	80.86 (0.36) *	76.03 (0.34)	4.56 (0.02)	-76.30 (-0.34)
	Forest	8484.50 (38.03)	10767.03 (48.26)	10070.34 (45.14)	1585.83(7.11)
	Grassland	13244.92 (59.37)	10832.22 (48.55)	11867.85 (53.20)	-1377.07 (-6.17)
	Water bodies	398.01 (1.78)	409.32 (1.83)	331.22 (1.48)	-66.79 (-0.30)
	Wetland	100.24 (0.45)	223.86 (1.00)	34.41 (0.15)	-65.83 (-0.29)
Kalomo District	Cropland	1263.38 (15.64)	4058.34 (50.26)	2158.15 (26.73)	894.76 (11.08)
	Forest	2115.29 (26.19)	1313.73 (16.27)	544.39 (6.74)	-1570.90 (-19.45)
	Grassland	4684.10 (58.01)	2685.28 (33.25)	5355.42 (66.33)	671.32 (8.32)
	Settlement	4.55 (0.06)	8.88 (0.11)	10.90 (0.14)	6.35 (0.08)
	Water bodies	7.96 (0.10)	0.00 (0)	5.53 (0.07)	-2.43 (-0.03)
	Wetland	0.00 (0)	9.12 (0.11)	0.00 (0)	0.00 (0)

Note: (0.36) *: Percentage of each LULC type (%), others as same. The total area of the KNP and Kalomo district is 22,308. 85 km^2 and 8,075.32 km^2, respectively.

In the Kalomo district, there was a significant land-use transition between 2000 and 2020. Generally, the pattern of land use transition was characterized by the change from forest to cropland from 2000 to 2020. The forest decreased from 26% (2115 km^2) in 2000 to 16% (1314 km^2) in 2010, and then continued to decline to 7% (544 km^2) in 2020. However, the cropland sharply increased from 15% (1263 km^2) in 2000 to 50% (4058 km^2) in 2010, and then decreased to 27% (2158 km^2) in 2020. The grassland was the dominant land-use type in 2000, accounting for 58% (4684 km^2). However, it decreased to 33% (2685 km^2) in 2010 but increased to 66% (5355 km^2) in 2020. The settlement steadily increased from 0.06% (5 km^2) in 2000 to 0.14% (11 km^2). The rest of the other land-use types, including water bodies and wetland, only occupied a small area, and the percentage of these LULC types is less than 0.1%.

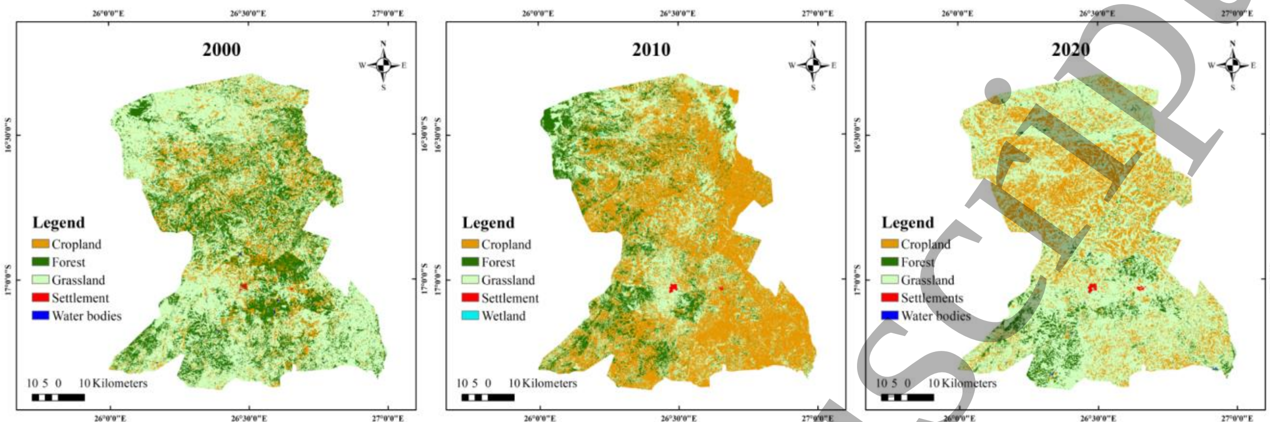

Figure 4. Spatial and temporal LULC in Kalomo in 2000, 2010 and 2020

3.2 Assessment of Ecosystem Services

3.2.1 Carbon storage

KNP. The spatial changes of carbon storage in KNP are spatially shown in Figure 5. The maps show that the range of carbon stock in each grid cell is from 0 to 12.56 t/C. During 2000-2020, the carbon storage of KNP slightly changed and exhibited overall growth. Total carbon storage values were 189, 209 and 204 million t/C in 2000, 2010, and 2020, respectively. The carbon value changed with the exchange of LULC classes. The corresponding average carbon densities were 8.24, 8.43 and 7.66 tons per grid cell in 2000, 2010, and 2020, respectively. The carbon storage was mainly distributed in the southern and eastern areas because forests occupied these areas and exhibited an increase in carbon storage from 2000 to 2010, then decreased from 2010 to 2020. However, less carbon storage appeared in the central-northern area because grassland has a lower ability to store carbon. Carbon stored in this area increased gradually from 2000 to 2020 because of decreasing grassland. There was no carbon storage in Itezhi-Tezhi Lake and Kafue River because the carbon stored in such water bodies is negligible.

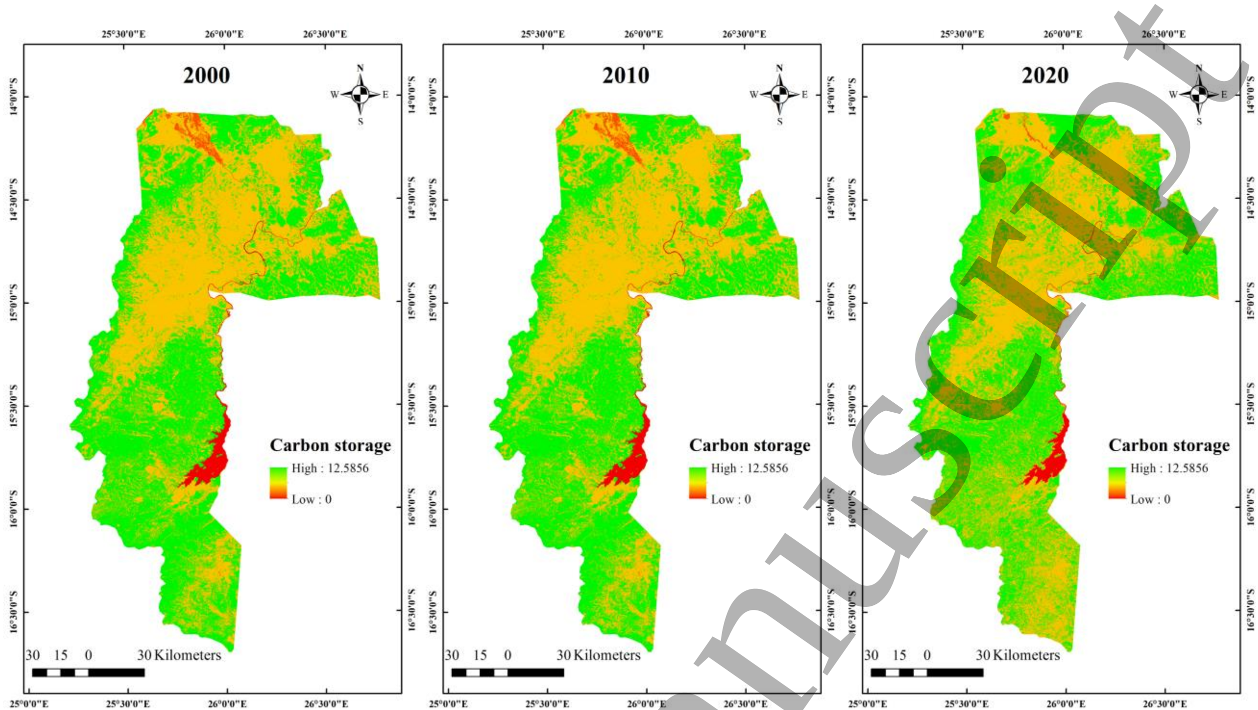

Figure 5. Spatial distribution of carbon storage in KNP

Kalomo. The change in carbon storage in Kalomo is spatially shown in Figure 6. The carbon storage of the Kalomo district continually decreased from 2000 to 2020. The average carbon densities were 5.8, 5.0, and 4.8 tons per grid cell in 2000, 2010, and 2020, respectively. The total carbon storage values were 52.04, 44.94, and 43.31 million t/C, respectively. Reduced carbon storage was caused by severe land conversion, whereby forest was converted into cropland. Over the past twenty years, there have been about 9 million tons of carbon loss due to agricultural expansion and associated forest loss. Regarding spatial distributions, carbon storage mainly decreased across the study area from 2000 to 2010, except for the northwestern areas because agriculture expanded from the center to the periphery. Then carbon continually decreased from 2010 to 2020, and limited carbon remained in the center and southwestern area in 2020 because the fallow areas had relatively low vegetation coverage.

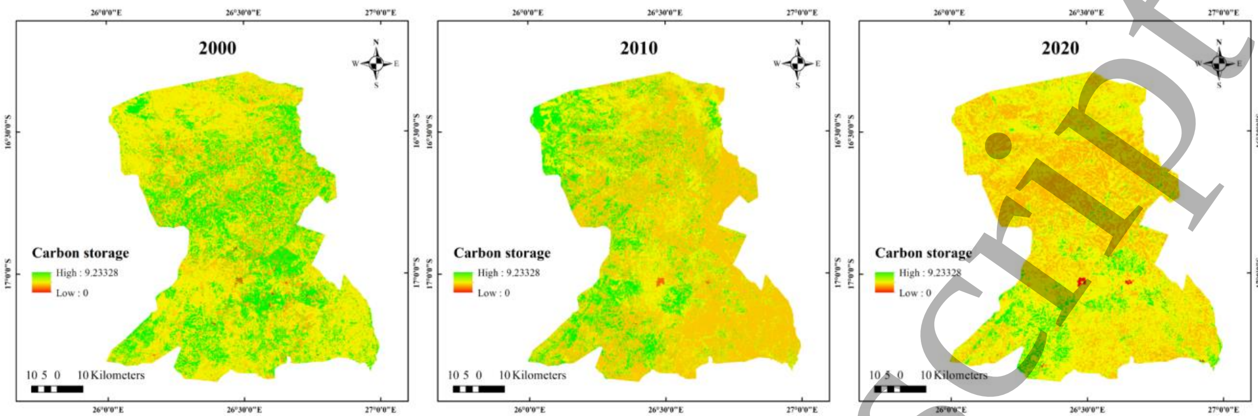

Figure 6. Spatial distribution of carbon storage in Kalomo district

3.2.2 Habitat quality

To visually represent the output values of the habitat quality model, the equal interval breakpoint method was applied (Wang et al 2022b). This method was used to assign grades to three habitat quality groups, which were designated as low, medium, and high, and these classes represent poor habitat quality, medium habitat quality, and high habitat quality, respectively (Table 3). Spatial distributions of habitat quality maps are shown in Figures 7 and 8, and the statistical analysis of the changes in habitat quality is presented in Table 4. The area in green shows high habitat quality, while the area in red shows poor habitat quality.

Table 3. Classification values of trumpeter hornbill's habitat quality in study areas

Habitat quality grade	Range of values	Description
Low	0 – 0.33	Poor habitat quality
Medium	0.33 – 0.67	Medium habitat quality
High	0.67 - 1	High habitat quality

KNP. Overall, habitat quality for trumpeter hornbill in KNP has improved from 2000 to 2020, with an increase of 1586 km^2 (7.11%) in high habitat quality, but a decrease of 209 km^2 (0.94%) and 1377 km^2 (6.17%) in poor and medium habitats, specifically (Table 4). The overall habitat grade increased from 0.59 in 2000 to 0.65 in 2010 but slightly decreased to 0.64 in 2020. From Figure 7, we can see that medium and high grades dominated the habitat quality of KNP because grasslands and forests occupied 97% of the whole area. The area with high habitat quality grade was mainly distributed in the south and northeastern regions, where there is greater coverage of forest. These areas increased from 8484 km² (38.03%) to 10767 km² (48.27%) in 2010, but slightly decreased to 10070 km² (45.14%). The areas with medium habitat quality were mainly distributed in the central region, decreasing from 13245 km² (59.37%) in 2000 to 10832 km² (48.56%) in 2010, but increasing to 11868 km² (53.20%) in 2020. The areas with poor habitat quality increased from 579 km² (2.59%) in 2000 to 709 km² (3.18%) in 2010, but decreased to 370.19 km² (1.66%) in 2020.

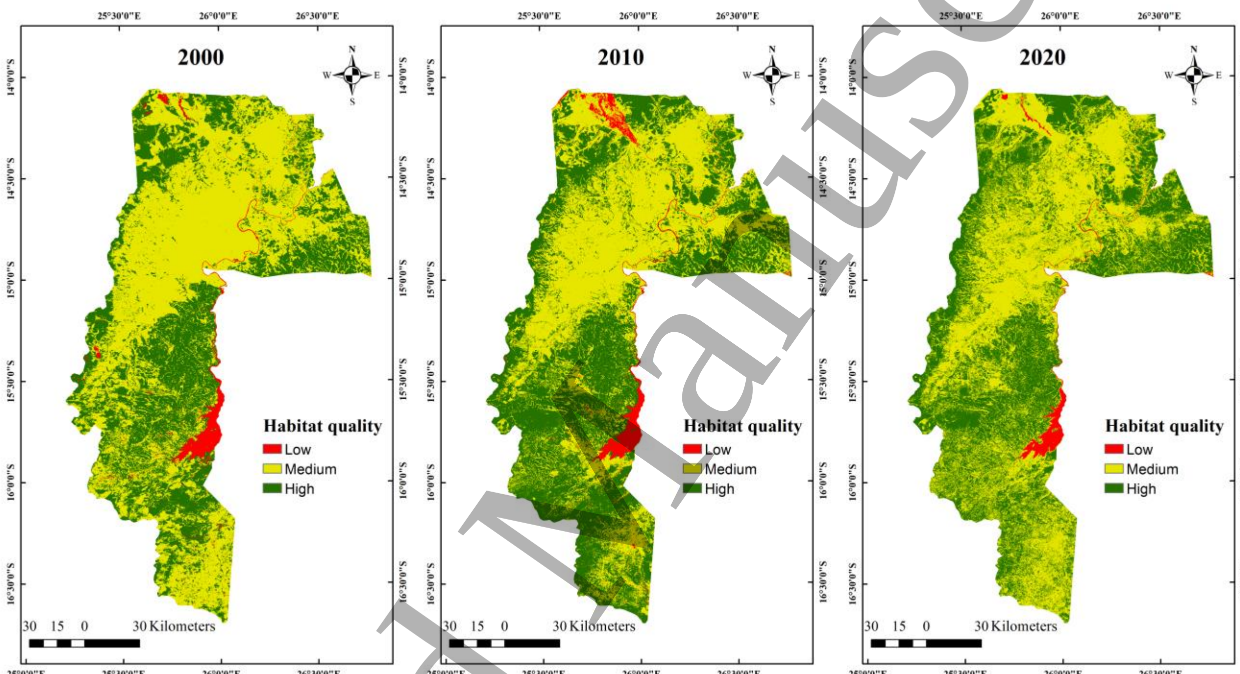

Figure 7. Spatial distribution pattern of trumpeter hornbill's habitat quality in KNP, in 2000, 2010, and 2020

Table 4. Area and percentage of trumpeter hornbill's habitat quality in KNP and Kalomo (km^2,%)

Areas	Classes	2000	2010	2020	Changes (2000-2020)
	Low	578.83 (2.59) *	709.07 (3.18)	370.19 (1.66)	-208.64 (-0.94)
KNP	Medium	13245.31 (59.37)	10832.21 (48.56)	11867.94 (53.20)	-1377.37(-6.17)
	High	8484.36 (38.03)	10767.21 (48.27)	10070.34 (45.14)	1585.98 (7.11)
Kalomo	Low	1277.71 (15.82)	4076.92 (50.49)	2175.36 (26.94)	897.65 (11.12)
District	Medium	4683.71 (58.00)	2684.47 (33.24)	5355.42 (66.32)	671.71 (8.32)
	High	2113.80 (26.18)	1313.63 (16.27)	544.38 (6.74)	-1569.42 (-19.44)

Note: (2.59) *: Percentage of each habitat quality class (%), others as same. The total area of the KNP and Kalomo district is 22,308. 85 km² and 8,075.32 km², respectively.

Kalomo. Overall, the habitat quality for the trumpeter hornbill in the Kalomo district was poor and dominated by low and medium grades. The average habitat quality scores were 0.44, 0.26, and 0.27 in 2000, 2010, and 2020, respectively. These values indicated that the trumpeter hornbill's habitat degraded between 2000 and 2020. The three groups of habitat quality in Kalomo are shown in Table 4. A total of 1569 km^2 of high habitat quality were lost from 2000 to 2020, representing 19.44% of the total area. From the spatial distribution maps (Figure 8), the habitat quality distribution was highly consistent with the distribution characteristics of land use types. High habitat quality was mainly concentrated in the central and southwestern areas in 2000, accounting for 2114 km^2 (26.18%), because these were areas with a concentrated distribution of forest. However, poor habitat quality was distributed in the central and northeastern regions, which were occupied by agriculture, accounting for 1278 km^2 (15.82%). Medium habitat quality was evenly distributed in the rest of the areas, with 4684km^2, accounting for 58.00% of the total area. From 2000 to 2010, the habitat quality degraded from east to west, and most areas of high habitat quality were replaced by poor habitat quality. The limited high habitat quality was distributed in the northwestern and southwestern regions, with 1314 km^2, only accounting for 16.27 %. While poor habitat quality dominated in 2010, occupying half of the area (50.49%) with 4077 km^2. These changes were caused by agricultural expansion between 2000 and 2010. From 2010 to 2020, the area of high habitat quality continually decreased, and only a small portion of high habitat quality located in the southwestern regions was retained, with 544km^2(6.74%). The poor habitat quality decreased from 4076 km^2 (50.49%) in 2010 to 2175 km^2 (26.94%) in 2020, but the medium habitat quality increased from 2684 km^2(33.24%) in 2010 to 5355 km^2(66.32%).

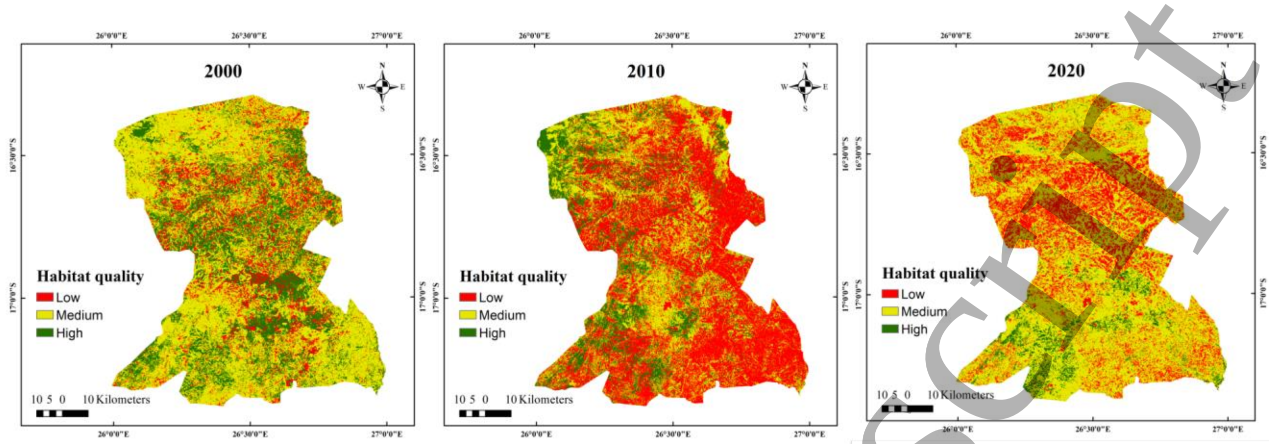

Figure 8. Spatial distribution pattern of trumpeter hornbill's habitat quality in Kalomo, in 2000, 2010, 2020

4. Discussion

This study pioneers the examination of the impacts of diverse land cover changes on ES in southern Zambia over a period of 20 years. It introduced an effective methodology for monitoring land-use changes' influence on carbon storage and habitat quality in two contrasting environments: the agricultural landscape of Kalomo district and the protected area of KNP. The results indicated that KNP has effectively maintained its forest and grassland ecosystems by preventing substantial land-use transitions between 2000 and 2020. However, Kalomo district has undergone a rapid and dramatic transformation, with forests being converted into cropland due to the surging demands of agriculture, accompanied by shifts in grassland and settlement patterns. These transitions were primarily influenced by disparate management strategies. While KNP has remained under stringent protection measures to deter human interference, agricultural activities have witnessed substantial growth in the Kalomo region over the past two decades. The study also found that carbon storage and overall habitat quality, as evidenced by the distribution of the trumpeter hornbill, have been enhanced in KNP but degraded in Kalomo district. These results indicate that LULC changes impacted carbon stock and habitat quality, and this conclusion is supported by further evidence (Solomon et al 2018, Fusco et al 2021).

4.1 Analysis of land-use change

The results of this study indicate that KNP avoided deforestation between 2000 and 2020, and forest areas significantly increased from 38% (8484 km^2) in 2000 to 45% (10070 km^2) in

2020. This finding differs from common conclusions about the effectiveness of PAs in Africa. Some scholars state that establishing PAs cannot prevent habitat loss but could reduce forest loss to mitigate such loss (Cazalis et al 2020, Riggio et al 2019), Rosa et al 2018, Bowker et al 2017). In contrast to these studies, our results show opposing trends of land cover change at the single-park scale and support that land transition could be prevented and vegetation cover could increase due to the effects of conservation implementation. The cropland in KNP represented less than 1%, decreasing from 0.34% (76 km^2) in 2000 to 0.02% (4.56 km^2) in 2020. This reduction can be attributed to restricted cultivation activities within the park, emphasizing its commitment to conservation, as noted by Mwima in (2001).

However, land-use change in the Kalomo has undergone a typical trajectory from forest conversion to cropland for commercial crops. The forest area continually decreased from 26% (2115 km^2) in 2000 to 7% (544 km^2) in 2020, while cropland sharply increased from 15% (1263 km^2) in 2000 to 27% (2158 km^2) in 2020. These changes can be attributed to various factors, including leakage from KNP and the escalating demand for food and charcoal from neighbouring provinces. The establishment of KNP resulted in the forced relocation of at least five chiefdoms, and these communities heavily rely on natural resources for their livelihoods (Namukonde and Kachali 2015). Such displacement has led to intensified pressure on resources outside the park. Studies have demonstrated significant LULC change in GMAs and found that a total of 125,108 ha of forest being converted into cropland (Dietz 2021). Kalomo district is in proximity to KNP and its nine GMAs, so it's plausible to infer that deforestation in Kalomo is closely linked to leakage from the park. Furthermore, the rampant deforestation in Kalomo district is fueled by agricultural expansion and charcoal production. Policy initiatives such as the establishment of farm blocks in Zambia, including Kalomo district, have stimulated investment in agriculture, exacerbating land conversion (Chilombo 2021). Urbanization, a prominent trend in Zambia, has heightened the demand for charcoal, particularly in densely populated areas like Lusaka and Copperbelt, which heavily rely on imports from other provinces (USAID 2017). This is a general trend elsewhere due to population dynamics, rising inequality, migration, agricultural commodity expansion, legal and illegal extraction of natural resources, urbanization, and poor and overlapping or incompatible governance structures (Moombe et al 2020, Reed et al 2022).

There are no settlements within KNP, but the area of settlements in Kalomo district has consistently increased from 2000 to 2020. The primary factors behind the relocation of communities from KNP for conservation purposes were identified by Mwima in (2001). However, it is worth noting that the population of the Kalomo is experiencing a growth rate of 4.4% (CSO, 2010). The water bodies and wetlands in both regions exhibited a persistent decline from 2000 to 2020. Specifically, in KNP, the area of water bodies and wetlands decreased by 67 km^2 and 66 km^2, respectively. The wetlands of the Kalomo district disappeared in 2020. The primary cause of these alterations can be traced to the impact of drought. Climate change has caused many extreme environmental events in Zambia, including more frequent and intense seasonal droughts, increased valley temperature and extended periods of drought (Rosen et al 2021). Musonda et al (2020) stated that the drought trend in Zambia significantly increased between 1981 and 2017, and twice severe droughts in 2005-2006 and 2015-2016, leading to serious concern for agricultural and hydrological sectors in drought-prone areas of southern Zambia (Musonda et al 2020). In addition, Kalomo district is situated in one of the most arid areas of Zambia, characterized by ephemeral and non-perennial streams and rivers that rapidly diminish after the rainy season (Republic-of-Zambia 2021). Deforestation in Kalomo has resulted in the loss of vegetation cover along riparian zones, accelerating the depletion of water sources (Republic-of-Zambia 2021). The district, predominantly inhabited by smallholder farmers, witnesses unsustainable agricultural practices, including direct extraction of water from rivers and streams for agriculture and livestock. These practices exacerbate the drying process of these vital water sources (Upla et al 2022).

4.2 Analysis of Carbon Storage Change

Carbon storage increased in KNP but declined in Kalomo from 2000–2020. The dynamics of LULC crucially impact ecosystem service provision (Rai et al 2018), with forestland playing a significant role in carbon sequestration and storage in the miombo woodlands (Pelletier et al 2018). Therefore, changes in forest land significantly impact carbon storage. In KNP, the growth of forest land significantly enhanced carbon storage. The increase in forest cover is the key to improving carbon sequestration due to trees role as carbon sinks (Nunes et al 2019). This finding is consistent with previous studies that showed that increased vegetation cover in PAs is effective at preventing carbon loss (Lobora et al 2017). In Kalomo district, the decrease in the forest during 2000–2020 was attributed to deforestation caused by agricultural expansion and charcoal production driven by rapid urbanization and as a response to environmental shocks such as droughts, both locally and nationally. Between 2000 and 2010, many miombo forests were cleared for agriculture and charcoal production, contributing to carbon loss. This is also consistent with previous findings. Williams et al (2008) stated that the clearance for agriculture could reduce the loss of stem wood carbon stocks. Also, Bulusu et al (2021) and Gumbo et al (2018) found that deforestation in miombo woodlands was driven by land clearance, and grassland and forest were cleared for agriculture and wood extraction for energy. These land transitions led to a decrease in carbon stored across miombo woodlands (Jew et al 2016).

4.3 Analysis of Habitat Quality Change

The habitat quality of trumpeter hornbills has been enhanced in KNP but degraded in Kalomo district. Trumpeter hornbill is a forest-dependent species that feeds on fruits (Chibesa and Downs 2017). Grassland can also provide food resources for the trumpeter hornbill, as this species adds other food resources to meet their food requirements, such as insects and small reptiles (Lenz et al 2015). Therefore, habitat quality change is related to forest and grassland changes. In KNP, the predominant land-use change was an increase in forests during 2000-2020, with the increased forest cover providing more habitat and food for trumpeter hornbills, effectively improving the habitat quality of this species. This finding is consistent with Cazalis et al (2020), who showed that PAs were effective at conserving forest-dependent bird species. In the Kalomo district, the Kalomo Hills Local Forest Reserve was destroyed by agricultural encroachment following settlement (Moombe et al 2020, Mbanga et al 2021). The settlement of more than 12,700 farmers in the reserve has led to an increased demand for agricultural production, resulting in the conversion of forests and grasslands into productive land for crops, particularly maize, to meet household income needs through sales (Mbanga et al 2021), leading to a decline in the habitat quality of trumpeter hornbill. Increased charcoal production to satisfy urban demand has further and significantly contributed to forest loss.

4.4 Analysis of the Impact of Land Management Policies

KNP is a national asset that brings benefits at the national level and is important for the conservation of unique biodiversity (Vezina et al 2020). This park is surrounded by nine GMAs which provide economic and ecological buffer zones for KNP (Dietz 2021, Agnes 2015). Meanwhile, KNP has attracted significant investment in conservation initiatives. A notable example is that the United Nations Development Programme launched a conservation project to support the management of KNP (United Nations Development Programme 2011, African Parks 2021). KNP is the oldest and largest national park in Zambia, and the Zambia Wildlife Authority (ZAWA) is solely responsible for the management of KNP (Chanda 2007). This dedicated management, backed by the strong support of the Zambian Government, ensures the effective protection of the KNP. Hence, the prevention of deforestation in KNP is a result of the combined efforts of conservation initiatives.

In contrast to KNP, the Kalomo region prioritizes economic development over ecological conservation. The Kalomo district, known for its strong tradition of maize and livestock farming, is largely acknowledged as the agricultural hub of Zambia (Moombe et al 2020). The implementation of measures promoting the cultivation of maize has significantly contributed to the economic development of the Kalomo district (Amondo et al 2019). The government supported through the Fertilizer Support Program (FSP), has generated a significant increase in maize production in Zambia since 2002/03, increasing the number of smallholder farmers, and the maize area cultivated by smallholders also increased from about 750,000 hectares in 2002/03 to 1,300,000 hectares in 2010/11 (Chamberlin et al 2014). The significant promotion of maize production between 2000 and 2010 has led to Kalomo being one area with a major maize surplus (USAID 2017).

Despite operating under separate land management policies, KNP and Kalomo encounter distinct difficulties. KNP appears to be a classic case of strict, yet repressive, conservation in practice in Zambia. Its substantial restrictions on access to natural resources bear profound socio-economic consequences for the adjacent GMA communities (Vezina et al 2020). Communities proximate to the KNP are heavily dependent on natural resources for their livelihoods but are excluded from the park to the extent that most people in these communities (erroneously) consider visiting the park to be illegal (Watson et al 2014, Namukonde and Kachali 2015, Milupi et al 2021). These limitations have resulted in a lack of access to food and heightened strain on resources, which in turn undermines the effectiveness of KNP's conservation endeavours beyond the park's boundaries. In addition, the demand for land in the GMAs can rise due to ongoing population expansion, and open spaces are expected to grow in the next few years, which could undermine KNP's conservation efficacy. Indeed, evidence of settlements is already visible at the border of KNP (Dietz 2021). Therefore, it is evident that a sectoral approach to conservation within KNP, that fails to consider local socio-economic needs, while conserving biodiversity within the park, is perpetuating environmental collapse beyond the park barriers. To address this issue, a more rigorous approach is needed, including awareness and education programmes to engage local communities and improve their access to the parks, as well as a more equitable share of the benefits generated by the park.

Conversely, the Kalomo district stands as a typical case where economic development is achieved at the expense of environmental sacrifice, and the uncoordinated governance on land has enlarged environmental problems. Agriculture development has contributed to livelihoods and economic growth but led to severe deforestation in Kalomo (Moombe et al 2020, Mbanga et al 2021). In addition, Mbanga et al (2021) stated that agricultural land is expanding without proper monitoring and planning. Furthermore, forest resource management was centralized, and local communities and other stakeholders were excluded from the forest management and forest-resource-utilization systems (Wang et al 2022a). This region is facing increasing pressure on the land due to uncoordinated governance (Upla et al 2022), and rapid population growth, heavy reliance on agriculture for the economy, and declining soil fertility may further exacerbate this pressure. Hence, it is essential to develop more coordinated landscape management plans that harmonize local livelihood concerns with conservation targets and promote sustainable agricultural practices that enhance productivity while minimizing the negative impact on the environment. We provide more specific recommendations for improving landscape management in southern Zambia below.

5. Recommendations

5.1 Recommendation for the management of PAs

In Zambia, PAs cover a significant portion of the land (40%), with 20 national parks (64,000km^2) and 36 GMAs (167,000km^2) established for the primary goal of conserving biodiversity (Lindsey et al 2014, Hou-Jones et al 2019, Lecina-Diaz et al 2019), with Zambian national parks regarded as strict PAs where human settlement is not permitted (Lindsey et al 2014). However, the traditional approach of establishing strict PAs has been criticized for inadequately considering the needs of local communities (Mfune 2014, Vasquez and Sunderland 2023), leading to conflicts over resources and increasing pressure on the surrounding landscapes (Vezina et al 2020). A sectoral approach to strict PAs to protect biodiversity and ecosystem services that disregard local well-being needs is unlikely to be successful over the long term in Zambia (Batáry et al 2011). The effectiveness of PAs is strongly related to conservation governance and policy frameworks, and the most positive results can be seen when Indigenous Peoples and local communities play a central role in decision-making and have clear lines of authority (Dehmel et al 2022). Therefore, a more holistic landscape approach that integrates the management of national parks and GMAs and considers broader landscape socio-cultural and political-economic dynamics should be prioritized to better harmonize conservation and development objectives.

To achieve the long-term conservation and sustainability of PAs, several recommendations can be made. Firstly, involving local communities in decision-making processes related to the management of PAs and broader land-use planning processes is crucial to better understand their perceptions, incorporate their knowledge and needs, and ensure their support for specific, contextually appropriate types of conservation efforts; the long-term success of conservation is largely dependent on their support. Secondly, increasing commitments to monitoring land-use change and strengthening cross-scale and multi-sector dialogue can contribute to preventing the expansion of settlements closer to PAs and preserving biodiversity and ecosystem services through clarification of rights, responsibilities, and access to information and resources. Finally, exploration of alternative culturally appropriate livelihood strategies that are pro-environment or sustainably used, rather than simply depleting the natural resource base can help reduce environmental pressure and improve local well-being. Such an integrated approach can significantly contribute towards the goals and targets of the Global Biodiversity Framework by seeking to conserve existing PAs but also enhance ecosystem connectivity, support restoration of surrounding degraded areas, strengthen landscape resilience, and ensure the viability and sustainability of livelihood activities, particularly in neighbouring communities with high natural resource dependence.

5.2 Recommendations for the management of agricultural landscapes

Zambia has suffered high rates of deforestation, driven largely by agricultural expansion (Richardson et al 2021), resulting in an annual deforestation rate of 250,000 to 300,000 hectares per year (Phiri et al 2022). In addition, rainfed agricultural systems are susceptible to extreme climatic events, such as more frequent, intense, and extended droughts (Black et al 2016, Ngoma et al 2021). To address these challenges, it is necessary to pursue more sustainable and diversified agricultural production that avoids contributing to further land clearing, thereby promoting agriculture development and biodiversity conservation while responding to the impacts of climate change.

Agri-environmental management (AEM) has been identified as a crucial strategy for biodiversity conservation in cropland (Batáry et al 2011, Mfune 2014, Batáry et al 2015), with agricultural landscapes increasingly recognized as domains for conserving biodiversity and managing ES (Leakey 2012, Reed et al 2016). Conservation agriculture (CA) is one of the significant measures of AEM (Mfune 2014), and has the potential to resolve conflicts between biodiversity conservation and economic development by increasing crop yields and diversifying crop types, thereby improving the livelihoods of farmers while reducing environmental risks (Mfune 2014, FAO and UNDP 2020). Therefore, CA could be promoted in agricultural landscapes in southern Zambia, and recent research suggested that there is local demand to increase the capacity for such approaches in Kalomo (Reed et al 2022). Meanwhile, incorporating Indigenous and local perspectives within such processes can further strengthen integrated landscape management due to their role as holders of specific place-based social-ecological knowledge. In Zambia, the traditional knowledge of the Tonga people has contributed to the development of sustainable livelihood practices and agricultural methods, enabling them to live sustainably (Yanou et al 2023). Therefore, promoting the engagement of multiple stakeholder groups, including Indigenous People and the local community, in land-use planning and natural resource management can help to generate more suitable land management solutions that satisfy the needs of humanity (food and energy production), while mitigating environmental harm (deforestation) within agricultural landscapes.

6. Conclusion

This study employed both quantitative and qualitative methods to assess the impacts of LULC changes on the ecosystem functionality of tropical landscapes in southern Zambia between 2000 and 2020. We used the most reliable and recent datasets to spatially assess LULC change, carbon storage, and the trumpeter hornbill's habitat quality. We visualized these changes on 30-meter resolution maps, providing an important resource for decision-makers and managers for future contextualized natural resource management and land-use planning interventions. Our assessment involved a comparative analysis of ES changes in two distinct landscapes: a protected area (KNP) and an agricultural landscape (Kalomo) over time. The results revealed the direct influence of policy implementation on LULC, thereby significantly affecting the functionality of landscapes that provide ES.

In summary, our study offers valuable insights into the spatial distribution of carbon storage and the habitat of the trumpeter hornbill. The practical assessment of carbon stock and habitat quality of specific species could guide how these carbon and biodiversity targets can be incorporated into national policies and implemented in climate change mitigation and adaptation (Soto-Navarro et al 2020, Munang et al 2013, Sintayehu 2018). In addition, the conservation of trumpeter hornbill is important and closely tied to forest management practices in Zambia, as this species can facilitate functional connectivity of the landscapes. By assessing the trumpeter hornbill's habitat quality, our research empowers governments and stakeholders to specifically express their conservation and restoration objectives for ecosystem services in geospatial.

Our study highlights a crucial contrast: while strict enforcement measures have succeeded in conserving biodiversity habitats within KNP, a mix of pressures has led to rapid environmental degradation outside the park and across the Kalomo district. To move towards more sustainable and equitable landscape management that responds to the goals of the Global Biodiversity Framework, we suggest a need for a more holistic approach in the region that better accounts for local livelihood needs and broader political-economic and social dynamics.

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