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Land cover changes and management effectiveness of protected areas in tropical coastal area of sub-Saharan Africa

Jeffrey Chiwuikem Chiaka [a,b], Gengyuan Liu [a,c,*], Hui Li [a], Wen Zhang [d,e], Mingwan Wu [a], Zhaoman Huo [a], Francesco Gonella [f]

[a] *State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, 100875, Beijing, China*
[b] *Anambra-Imo River Basin Development Authority, Owerri, Nigeria*
[c] *Beijing Engineering Research Center for Watershed Environmental Restoration & Integrated Ecological Regulation, Beijing, 100875, China*
[d] *Key Laboratory for City Cluster Environmental Safety and Green Development of the Ministry of Education, Institute of Environmental and Ecological Engineering, Guangdong University of Technology, Guangzhou, 510006, China*
[e] *Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Guangzhou, 510006, China*
[f] *Department of Molecular Sciences and Nanosystems, Ca' Foscari University of Venice, 30170, Venezia Mestre, Italy*

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ABSTRACT

Nature-based solutions to ecological challenges have continued to draw significant attention, and are connected to the increased establishment of protected areas as a means for climate and ecological crisis mitigation. This study presents an innovative approach that combines spatial and statistical analysis of land cover change and drivers to evaluate land use management and effectiveness of 22 designated protected areas (PAs) across the tropical coastal regions of sub-Saharan Africa. While the results provided insight into land use management and conservation priorities, it highlighted (1) the use of these protected areas for food production is prevalent, irrespective of its designation. Nevertheless, there is evidence of a decline in cropland in some of the protected areas, suggesting a shift in policy towards conservation land use. (2) The occurrence of forest loss suggests that conservation is weak in most of the protected areas, while wetland conservation efforts are stronger due to their land cover expansion. (3) Population density (*human factor)* is the most significant driver of land cover change in these protected areas, followed by elevation (*natural environment)*, precipitation (*climate)*, nighttime light (*socio-economic)*, and slope (*natural environment)*. (4) In terms of Ecosystem value, only 15 of the 22 protected areas exhibited an increase in their total ecosystem service value according to land cover change, indicating sustainable land use and measures effectiveness in these protected areas. However, based on an individual land cover assessment, most protected areas showed signs of loss, especially in forests. Given the projected population growth in Africa, a regular assessment of protected areas should be initiated to enable effective and timely management decisions. Additionally, policies to improve the management effectiveness of African protected areas through funding should be a top priority, while taking into consideration the livelihoods of the indigenous people in the area in order to find a sustainable balance.

1. Introduction

The International Union for Conservation of Nature (IUCN) encourages the establishment and conservation of Protected Areas (PAs) as it is vital to the environment, culture and livelihood of the local communities. As a result, the designation of a land as “protected area" has expanded in recent years to meet conservation targets such as protection of endangered wildlife and forest, but also providing co-benefits for the local people and a source of revenue through tourism (Watson et al., 2014). For effective management, these PAs are divided in categories (I-VI) by the IUCN, though often their descriptions may differ depending on countries and regions (IUCN, 2020) (See Appendix I). For adequate management effectiveness of these PAs, human activities are restricted and controlled to abate the decline in the biodiversity and the environmental degradation (Cazalis et al., 2019), and some of these PAs are administered by government, agencies and communities, with the latter

* Corresponding author. State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, 100875, Beijing, China.
E-mail address: liugengyuan@bnu.edu.cn (G. Liu).

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more noticeable in Kenya and Namibia (IUCN, 2020).

Historically, the first natural protected area was the Yellowstone National Park, in the United States of America, designated in 1872. Subsequently, the next country to designate land as a protected area in the nineteenth century were Australia (Royal National Park) in 1879, Canada (Banff National Park) in 1885, and New Zealand (Tongariro National Park) in 1894. In Africa and Asia, the Etosha National Park in Namibia and the Mount Arayat National Park in the Philippines were the first African and Asian National Park designated in 1907 and 1933, respectively (Yui, 2014). Nevertheless, about 142 countries have established since then protected areas and about 75% of all PAs developed rapidly after 1961 (Yui, 2014).

Since their establishment, emerging literature addressed the poor management of most PAs, both at the local and on a global scale, citing a mere 25% of PAs as receiving an effective management, with known global PAs at different stages of deterioration (Leverington et al., 2010). Indeed, the long-term PA effectiveness was studied for selected major tropical protected areas in 36 countries across Africa, American and Asia-Pacific tropics (Laurance et al., 2012), indicating that half of them are fairly managed, with the rest experiencing declining biodiversity and functionality. The study further linked the declining status of these PAs to human activities, such as wood harvesting and hunting. Another study cited that law enforcement to curb such activities is at the lowest ebb (Blom et al., 2004), and the rate of PA establishment outweighs the resources available to manage them; hence leading to its ineffective management (Matseketsa et al., 2022). Furthermore, a study involving 83 coastal protected areas from Africa (12), Asia (12), Australasia and Oceania (10), Europe (13), Latin America and the Caribbean (13), and North America (23) reported that only 13 out of the 83 PAs received sufficient funding for effective conservation (Balmford et al., 2004).

Actually, 13% of the African continent land is designated as “Protected Areas”, of which about 8000 are formally registered under the World Database of Protected Areas (WDPA) (Miranda et al., 2016; Parks, 2023). The goal is to cover 30% of land and coastal areas (Parks, 2023), but there are reports of poor management and lack of monitoring of existing protected areas within both terrestrial and coastal areas of Africa (Parks, 2023; Failler et al., 2020). Emerging literature indicates that the African coastal environment is highly vulnerable, primarily due to the heavy dependence of coastal communities on their immediate environment (Brito et al., 2020). Furthermore, another study showed that environmental disturbances caused by wood harvesting, agriculture, and mining activities are leading to loss of mangrove forests in places such as the Sherbro River Estuary in Sierra Leone at a rate of 0.5% per annum, and the area is estimated to have lost 20% forest cover over the last fifteen years (Njisuh et al., 2022). These data can be connected to the growing demand for food and livelihood, putting pressure on the land – especially in coastal areas where an estimated one-third of the world’s population lives there or close to them (Barbier et al., 2008). These situations will eventually lead to changes in land use (Foley et al., 2005), and changing environmental conditions are contributory causes of environmental degradation and decline in ecosystem services (Barbier et al., 2008; Olsen et al., 2021; Kinda et al., 2019; Hu et al., 2008); this is especially true for forests, which are under pressure for various land uses (Potapov et al., 2017), thereby slowing down the progress of nature conservation and resilience policies.

While the establishment of PAs reduces deforestation (Yang et al., 2021) and provides adequate ecosystem service values (ESVs), particularly in the tropical forest (MEA, 2005; Filho et al., 2022), literature has also shown how monitoring PAs management effectiveness is the key to conservation efforts and biodiversity protection (Duncanson et al., 2023). In terms of assessment of these PAs, various methods have been utilized to evaluate their significance. A study applied Mahalanobis covariate matching to ascertain whether protected areas can alleviate poverty while promoting forest conservation in the Peruvian Amazon. The result showed that the establishment actually curbed deforestation, yet without significant poverty reduction (Miranda et al., 2016). Moreover, some studies on the role of tropical PAs for forest conservation, using expert knowledge structured questionnaires and land cover change detection, observed how the land cover changes outside of a PA had significant impact within the PA due to a spillover effect, thereby influencing their effectiveness (Laurance et al., 2012; Bailey et al., 2016). Furthermore, a study using weighted least squares regressions of explanatory variables found that forest losses were higher within the PAs compared to their surroundings (Heino et al., 2015). Regarding climate change mitigation, a study found that the aboveground carbon sequestration (AGC) potential of PAs varied depending on biome and continent, with tropical moist forest having the highest aboveground carbon sequestration potential, using the Lidar-derived estimates of AGC from NASA’s Global Ecosystem Dynamics Investigation (GEDI) (Duncanson et al., 2023).

For Africa, preliminary investigations in West Africa involving management assessment through participatory questionnaires to determine the coastal PAs functioning, pointed out lack of expertise, weak institutional policies and conflicts in responsibilities, contributing to ineffective management of the coastal environment (Failler et al., 2020). Another study using human pressure data found that half of the world’s protected areas are under severe human pressure, particularly in Africa, Western Europe, and South Asia (Jones et al., 2018). Hence, the coastal PAs of Africa indicate negative environmental externalities attributed to human factor, but to what extent remains rather vague. Therefore, it appears mandatory to fill this gap in research to holistically monitor the coastal environment. This includes investigating land use changes surrounding existing protected areas along with its consequences, and taking into account the specific features of coastal areas, particularly in terms of human pressures. Moreover, the sustainability of protected areas should be top policy priorities, even for coastal areas as documented in the Aichi Targets 11 and in the resolution passed at the first Africa Protected Areas Congress (APAC) held in Kigali, Rwanda in 2022, which also included prioritizing PAs funding *intra alia* (Bakarr, 2023).

Based on the above, the management effectiveness of the various countries in the tropical coastal areas of sub-Saharan Africa remains uncertain, even considering the intrinsic value of these ecosystems. Furthermore, the coverage of coastal PAs is low compared to their terrestrial counterpart (Watson et al., 2014; Failler et al., 2020), which addresses the uncertainty of the management effectiveness. As a matter of fact, the effectiveness of the ecosystem services value associated with coastal land use change in and around PAs of tropical coast of Africa are still to be assessed, considering the complexity of human, socio-economic and natural environment of these regions. To address these issues, this study assessed the coastal land cover changes, as well as drivers and ecosystem value, for 22 selected protected areas in the tropical coastal region of sub-Saharan Africa. In particular, we considered the land cover change, the drivers and the ecosystem service value assessment as analytical proxies to evaluate the PAs management effectiveness. More important, this study provides an insight and support for the Global Deal for Nature plan (www.globaldealfornature.org), aimed at securing the conservation of terrestrial and coastal areas of African Parks to boost ecosystem services and mitigate climate change impacts (Parks, 2023).

2. Methodology

This study used a comprehensive approach, combining spatial analysis of land cover change, with a global index value coefficients to evaluate ecosystem services and statistical analysis of land cover drivers (Fig. 1). The objective is to assess the management effectiveness of 22 designated protected areas in the tropical coastal regions of sub-Saharan Africa from 2000 to 2020. These protected areas represent 22 countries. The selection of these protected areas was based on several criteria, including their surrounding land use patterns (farming and built-up area – **as an indication of human activities**), designation (Forest, Park, Strict and Natural Reserves – **an indication of PA category**), and

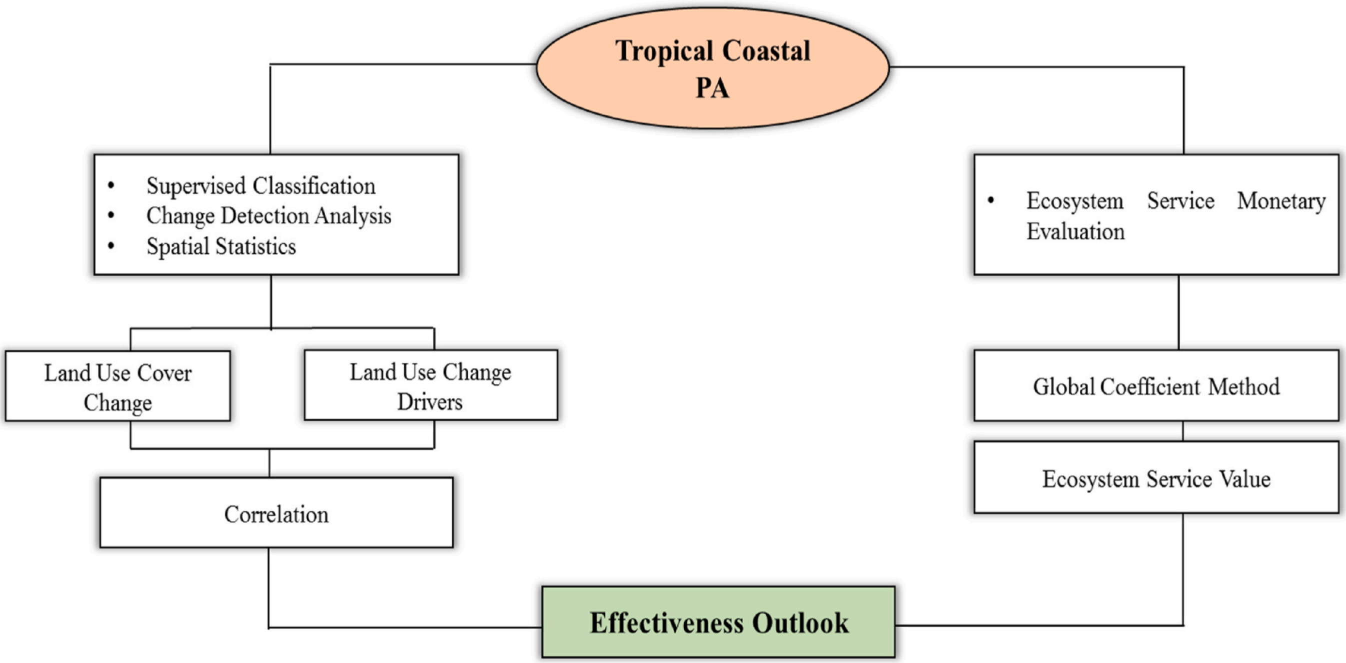

Fig. 1. Diagram illustrating combined methodological approach of the study to assess the management effectiveness of protected areas in Tropical sub-Saharan Africa. *The Orange color represents the 22 protected areas, while the Green offers insights to their various effectiveness outlook*

classification (**21** National and **1** UNESCO – **an indication of management level of the PA**).

To analyze the effectiveness of PAs, a 3 km buffer zone was established around the PA boundary to ascertain the land cover pattern. Thereafter, the land cover inside the PA was also determined after image processing, using supervised classification to delineate the land cover classes. Additionally, a change detection analysis was initiated to define the changes of the land cover in hectares for 2000 and 2020. Moreover, the study performed a statistical analysis on human, social-economic and natural environment drivers to evaluate their individual influence on the land cover and how their interaction leads to land cover changes (Chang et al., 2018).

These data and operations were collated and analyzed using ArcGIS 10.8 software, Statistical Package for the Social Sciences (SPSS) version 27, and Google Earth Engine.

2.1. Assessment of land cover change

A total of 8 land cover classes were used in this study to determine land cover change. The land cover classes are cropland, forest, grassland, shrubland, wetland, settlement, water body and bare land derived from Globeland30, a 30-m resolution global land cover data product (NGCC, 2020) for the years 2000 and 2020.

A 3 km buffer zone was established around the PA boundary to outline the land cover pattern changes. Thereafter, the land cover inside the PA was also determined after image processing using supervised classification to delineate the land cover classes. To determine the change in land cover, a change detection analysis was performed to define the changes of the land cover in hectares within the 3 km buffer of each PA, as well as inside the PAs for 2000 and 2020 using the following equation:

$$LULC = End\ Year_n - Start\ Year_n \tag{1}$$

$$LULC_{\%change} = \left[\frac{End\ year_n}{End\ year_{total_l}} \times 100\right] - \left[\frac{Start\ year_n}{Start\ year_{total_l}} \times 100\right] \tag{2}$$

where, *End year* and *Start year* are land covers for 2020 and 2000, respectively. While '*n*' represents the individual land cover class, and '*l*' is the total area of all the land cover classes in the year under study.

2.2. Assessment of ecosystem service value

To account for ecosystem services in monetary terms, is to provide an overview of their economic value, and contribution to humans' welfare using coefficient values that help policymakers and environmentalist understand the significance of these services in economic terms, while indicating the sustainability of the ecosystem services over time. Hence, to quantify the ecosystem value (ESV), an ecosystem valuation coefficient approach was used following the existing literature (Costanza

Table 1
Ecosystem service valuation coefficient according to land cover classes (Costanza et al., 2014).

Costanza et al. (Costanza et al., 2014) LC classes	Our study LC classes	Ecosystem Service Coefficient (US $ ha^{-1} yr^{-1})
Cropland	Cropland	5567
Tropical Forest	Tropical Forest	5382
Grassland	Grassland	4166
Rangeland	Shrubland	4166
Tidal marsh/mangrove	Wetland	140,174
Lakes/Rivers	Lakes/Rivers	12,512
Urban	Built-up Area	6661
Desert	Bare land	0

et al., 1997; de Groot et al., 2012; Xie et al., 2008). Specifically, this study used the updated data of Costanza global ecosystem value coefficient, which are the summarization drawn from the estimation of the total area of each biome of the ecosystem in USD \$ ha^{-1} yr^{-1} by Costanza et al. (2014) (see Table 1).

To estimate the ESV from the PA individual land cover classes and determine their management effectiveness, the study used the ESV loss and gains due to change in each land cover from 2000 to 2020. The corresponding formula is given by:

$$ESV = A_h \times GC_h \tag{3}$$

$$ESV_{total_h} = \sum (A_h \times GC_h) \tag{4}$$

where ***ESV*** is the Ecosystem Service Value to be estimated. ***A*** is the Area in hectares and ***GC*** is the global coefficient in (USD \$ ha^{-1} yr^{-1}) of the subset ***h*** land cover class.

Furthermore, to estimate the changing ecosystem value due to the land cover changes of the individual land, the formula is

$$ESV_{change} = ESV_{(y+1)n} - ESV_{(y)n} \tag{5}$$

Here, n indicates the individual land cover, y and (y+1) represents the start year (year 2000) and next referenced year (2020), respectively.

The definition of grassland/rangeland is vegetation dominated by grasses, with relatively few woody plants or shrubs. Therefore, in this study, the value for grassland/rangeland used by Costanza et al. (2014) was replaced by that for shrubland, while other tropical land use values were utilized, since the study is located in the tropics.

2.3. Assessment of land cover drivers

The selected drivers of land cover changes for the study were human, socio-economic, climate and natural environment variables to determine their influence on the land cover. Theses drivers are further fragmented into Population density (CIESIN, 2018) (***Human)***, Nighttime light (Román et al., 2018; NOAA, 2000) (***Socio-economic)***, Precipitation (Funk et al., 2015) (***Climate)***, Elevation and Slope (Jarvis et al., 2008) (***Natural environment)***.

To estimate the land cover drivers' impact, their spatial dataset was pre-processed and reprojected to the same coordinate system as the land use cover images. Then, using spatial statistical analysis, the mean values of these driving factors raster - Population density, Nighttime light, Precipitation, Elevation and Slope are extracted for 2000 and 2020, and their difference calculated.

The spatial zonal statistical analysis, which matches pixel-by-pixel value, shows how the human, socio-economic, climate and natural environment variables interact with land cover classes by providing their mean values across the individual variables. Therefore, the

Table 2
Summary of the data source information.

Data Source	Data	Resolution	Year
UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC)	World Database on Protected Areas	Polygon	2023
National Geomatics Center of China (NGCC)	Land Use Land Cover images	30 m	2000 and 2020
NASA Socioeconomic Data and Applications Center (SEDAC)	Population Density	1 km	2000 and 2020
NOAA Defense Meteorological Satellite Program (DMSP)	Nighttime Light	927.67 m	2000
NOAA Visible Infrared Imaging Radiometer Suite (VIIRS)	Nighttime Light	500 m	2020
Climate Hazards Group InfraRed Precipitation Station Data (CHIRPS – Pentad)	Precipitation	5,566 m	2000 and 2020
Consortium for Spatial Information – (CGIAR-CSI)	SRTM Digital Elevation	90 m	2000
Consortium for Spatial Information – (CGIAR-CSI)	Slope	90 m	2000

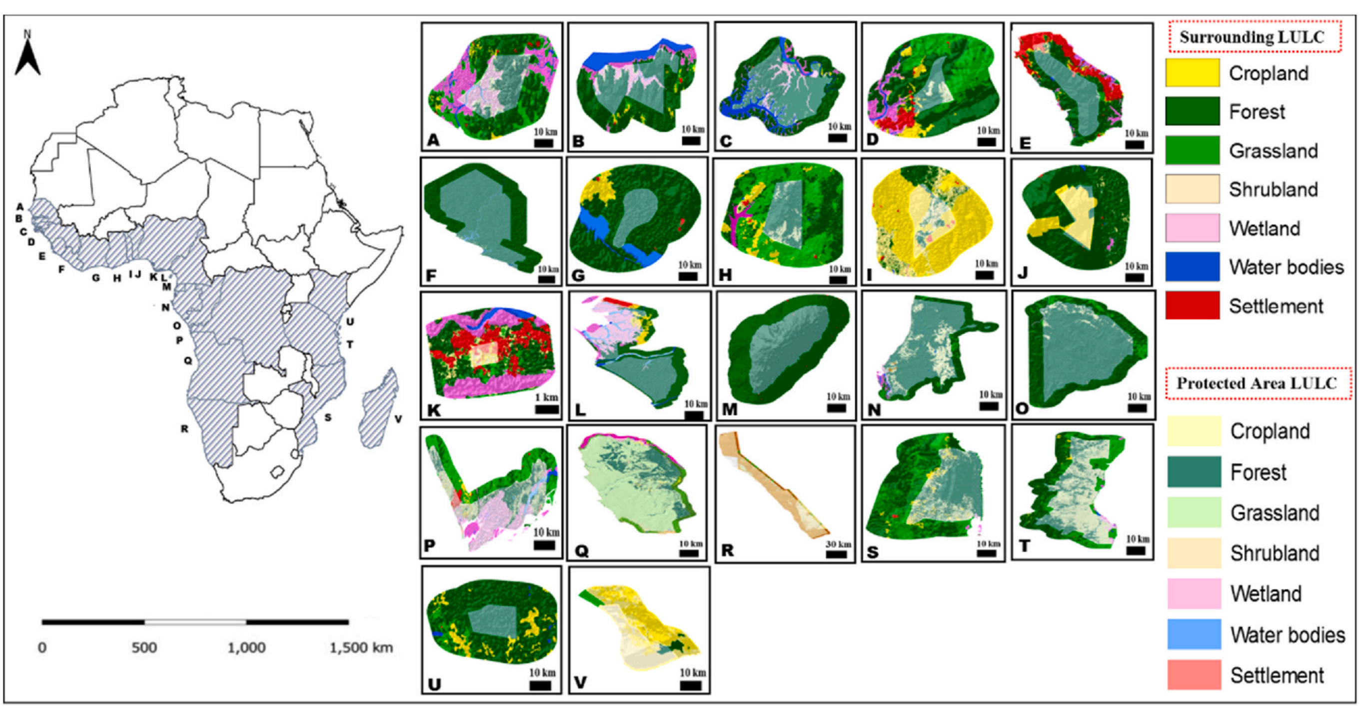

Fig. 2. Location and land cover of the 22 Protected Areas along the Tropical Coast of sub-Saharan Africa. The darker colors represent the surrounding buffer area and lighter colors depict the PAs land cover classes. [A] Senegal [B] Gambia [C] Guinea Bissau [D] Guinea [E] Sierra Leone [F] Liberia [G] Côte d'Ivoire [H] Ghana [I] Togo [J] Benin [K] Nigeria [L] Cameroon [M] Equatorial Guinea [N] Gabon [O] Rep of Congo [P] D.R. Congo [Q] Angola [R] Namibia [S] Mozambique [T] Tanzania [U] Kenya [V] Madagascar

Table 3
Selected protected areas in tropical coastal sub-Saharan Africa.

No.	Tropical Western sub-Saharan Africa Coastal PA			No.	Tropical Central sub-Saharan Africa Coastal PA		
	Country	Name of PA	Classification		Country	Name of PA	Classification
1	Benin Republic	Djigbé	National Forest	13	Angola	Quiçãma	National Park
2	Côte d'Ivoire	Nguechie	National Forest	14	Cameroon	Douala Edéa	National Park
3	Equatorial Guinea	Pico de Basilé	National Park	15	Rep of Congo	Réserve de biosphère de la Dimonika	UNESCO-MAB Réserve de Biosphère
4	Gambia	Kiang West	National Park	16	D.R. Congo	Mangrove Nature Reserve	National Natural Reserve
5	Ghana	Shai Hills PA	Resource Reserve	17	Gabon	Wonga-Wongué	Presidential Reserve
6	Guinea	Dixinn	National Forest		Tropical Eastern sub-Saharan Africa Coastal PA		
7	Guinea-Bissau	Lagoa de Cufada	Natural Park	18	Kenya	Witu	National Forest Reserve
8	Liberia	Cestos-Senkwehn	National Park	19	Tanzania	Saadani	National Park
9	Nigeria	Lekki	Strict Nature Reserve	20	Madagascar	Cap Sainte Marie	National Special Reserve
10	Senegal	Basse-Casamance	National Park	21	Mozambique	Matibane	National Forest Reserve
11	Sierra Leone	Western Area	National Non - Hunting Forest Reserve		Tropical Southern sub-Saharan Africa Coastal PA		
12	Togo	Haho-Baloe	National Forest Reserve	22	Namibia	Skeleton Coast Park	National Park

difference of the mean values of each driving factor within the 3 km buffer around the PA from 2000 to 2020 form the explanatory variables while the change in land use cover within PAs, measured in hectares, serves as the dependent variable. Pearson correlation is then used to assess their influence on land cover change. Fig. 2 illustrates the land cover pattern and study location of the 22 selected countries, Tables 2 and 3 provides the summary of the data source information and details of the selected PAs, respectively.

3. Results and discussion

3.1. Analysis of land cover change

From 2000 to 2020, there has been various land cover changes across the PAs in tropical sub-Saharan Africa, each contributing to their respective ESV. Generally, the land cover pattern within the buffer zone of the PAs indicates loss of forest and presence of cropland across most PAs. Likewise, most of the land cover pattern inside the PAs depict varying degree of forest loss and farming activities. This land use pattern suggests the human presence across most of the PAs. However, **5** out of the **22** PAs were devoid of cropping activities, such as the Nguechie National Forest (Cote d'Ivoire), Pico de Basilé National Park (Equatorial Guinea) and Lekki Strict Nature Reserve (Nigeria) [**West**], Wonga-Wongué Presidential Reserve (Gabon) [**Central**], and Skeleton Coast Park National Park (Namibia) [**South**] despite observed croplands within the surrounding buffer areas as seen in other PAs, especially for Nguechie National Forest (Cote d'Ivoire), and Lekki Strict Nature Reserve (Nigeria) [**West**]. This is a plausible indication of effective PA management policy enforcement to prevent cropland encroachment into their PAs. Fig. 3 shows the spatial patterns and variations of distinct land cover changes inside some selected protected areas to represent our study region. For the percentage land cover changes see (Appendix II).

Consequently, the presence of cropland land use pattern inside a supposedly PA with conservation purposes indicate the country's priority and conservation approach. This style of conservation is referred to as land sharing or land sparing management system, which arguably are dependent upon ones priority, either for conservation purposes or food production (Meli et al., 2019). This study indicated that most of the PAs

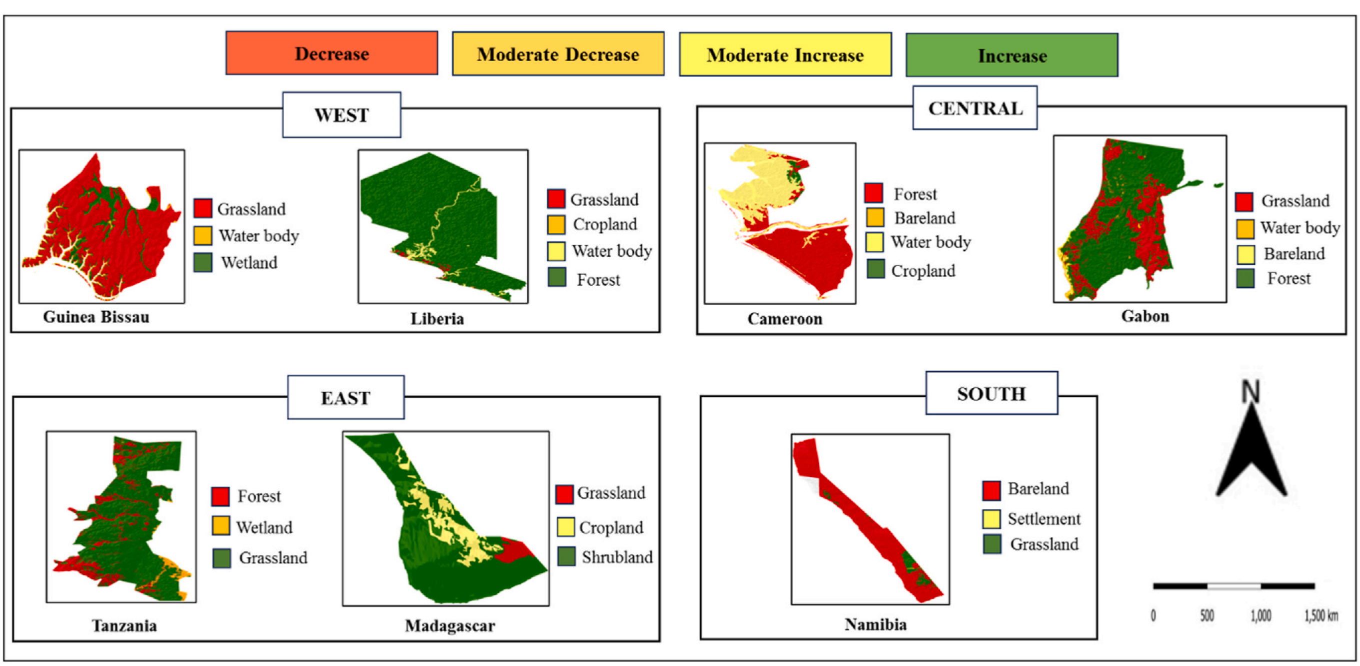

Fig. 3. Cross-section of land cover with significant changes within the selected protected areas.

follow this principle of land use management, with croplands observed within the PAs. This is invariably a leading cause of tropical deforestation (Ceddia et al., 2014), and will ultimately cause PAs to lose their ecosystem functions (Gross et al., 2013) especially in the area of carbon sequestration potential, or in terms of monetary value that can be invested in clean development projects (CDM).

To support the observed land use management practice of the PAs, we therefore considered the hectares used for food production in these PAs as a measure of land sharing/sparing form of land use management. In this sense, PAs that use adequate hectares for cultivation are considered as land sparing, which is indicative of intensive use of land for food production, while the use of much less hectares of the total area for cultivation indicates land sharing, while the absence of cropland indicates that PAs are solely meant for conservation, hence devoid of farming activities. Table 4, illustrates protected areas (PAs) that allocate most of their hectares for food production. These include Benin, Togo (**West**), Angola, Cameroon, D.R Congo (**Central**), Madagascar and Mozambique (**East**). However, 5 PAs show no cropping activities, namely, Côte d'Ivoire, Equatorial Guinea, Nigeria (**West**), Gabon (**Central**) and Namibia (**South**). Nevertheless, most PAs showed a decrease in cropland cover from 2000 to 2020, which may indicate policy consideration for land sharing, aimed at promoting the sustainability of the PAs and the prevention of cropland expansion.

3.2. Evaluation of changes in ESV across the PAs

The study observed that **6** out of the **12** PAs located on the Western coast lost ESV mainly from forest, while the Gambia had the highest ESV total loss of 29 million US \$ ha^{-1} yr^{-1}. The remaining **6** PAs exhibited total gain of ESV as a result of an increase in various land covers, ranging from forest to grassland, wetland and settlement areas, of which Guinea Bissau had the highest ESV gain, contributed mainly from its wetland cover with a total ESV gain of 244 million US \$ ha^{-1} yr^{-1}.

As for the Central coast, wetland cover accounted for **2** PAs massive gains in ESV, particularly in Angola (309 million US \$ ha^{-1} yr^{-1}) and D. R. Congo (238 million US \$ ha^{-1} yr^{-1}). This shows the importance of mangrove conservation in supporting the environment and biodiversity. Looking at the general outcome in Central coast, Angola had the highest ESV total value of 276 million US \$ ha^{-1} yr^{-1}, followed closely by D.R Congo at 224 million US \$ ha^{-1} yr^{-1}, while the Republic of Congo had the least ESV due to decline in water bodies.

On the East coast, only Mozambique and Kenya had total ESV gains, of 1.6 million and 66 thousand US \$ ha^{-1} yr^{-1}, respectively, out of the **4** located in the region. Mozambique gained ESV specifically from cropland and wetland land covers, while Kenya, despite the gains from forest cover, had a huge decline in shrublands. Nevertheless, this reflects their land use management and conservation targets. Tanzania significantly lost ESV of 42 million US \$ ha^{-1} yr^{-1} from wetland cover, while Madagascar had an obvious decline in its forest cover by 15 million US \$ ha^{-1} yr^{-1}, impacting on its total ESV. Interestingly, only the Skeleton Coast Park in Namibia exhibited remarkable gains from all land covers, having an overall total ESV gain of 381 million US \$ ha^{-1} yr^{-1}.

Hence, land cover changes and ESV estimation contributed in assessing the effectiveness of PAs in terms of sustainable land use. Moreover, it provided an insight into PAs priorities as regards to sustainable land use with co-benefits, and this further highlights areas policymakers need to step in to avert further degradation (Trégarot et al., 2020). This is because preserving these PAs leads to economic benefits (Trégarot et al., 2017) and can be used to design sustainable land use (Li et al., 2023).

In sum, only **15** out of **22** PAs had an increased total ESV gains because of the increase of individual land cover area across the tropical sub-Saharan Africa as follows: Benin, Equatorial Guinea, Ghana, Guinea Bissau, Liberia, Senegal, Sierra Leone and Togo (**West**), Angola, Cameroon, D.R Congo, and Gabon (**Central**), Kenya, Mozambique (**East**) and Namibia (**South**). Only the Skeleton Coast Park in Namibia showed signs of a better conservation among the other PAs, considering the land cover area change and its ecosystem services value assessment, while the Saadani National Park in Tanzania underperformed in conservation efforts.

Table 5
The Ecosystem Service Values for individual land cover (US \$ ha^{-1} yr^{-1}).

No.	Country	Name of Protected Area	ESV (US \$ ha^{-1} yr^{-1})
	WEST		
1	Benin Republic	Djigbé	1,267,442
2	Côte d'Ivoire	Nguechie	−20,318
3	Equatorial Guinea	Pico de Basilé	57,491
4	Gambia	Kiang West	−29,717,311
5	Ghana	Shai Hills PA	47,378
6	Guinea	Dixinn	−114,589
7	Guinea-Bissau	Lagoa de Cufada	235,607,732
8	Liberia	Cestos-Senkwehn	949,971
9	Nigeria	Lekki	−70,883
10	Senegal	Basse-Casamance	8,143,858
11	Sierra Leone	Western Area	361,228
12	Togo	Haho-Baloe	99,697
	CENTRAL		
1	Angola	Quiçãma	276,750,120
2	Cameroon	Douala Edéa	47,703,239
3	Rep of Congo	Réserve de biosphère de la Dimonika	−122,828
4	D.R. Congo	Mangrove Nature Reserve	224,368,317
5	Gabon	Wonga-Wongué	2,909,756
	EAST		
1	Kenya	Witu	65,291
2	Tanzania	Saadani	−42,353,928
3	Madagascar	Cap Sainte Marie	−14,087,761
4	Mozambique	Matibane	1,603,936
	SOUTH		
1	Namibia	Skeleton Coastal Park	380,924,468

Table 4
Observation of cropland land use cover across PAs as a proxy of land use management.

PA	Inside (ha)	Total (ha)	Observation	PA	Inside (ha)	Total (ha)	Observation
WEST				CENTRAL			
Djigbé	1652	1974	Land sparing	Quiçãma	3096	438,393	Land sparing
Nguechie	n/a	1197	For conservation	Douala Edéa	2291	83,359	Land sparing
Pico de Basilé	n/a	16,268	For conservation	Réserve de biosphère de la Dimonika	6	66,596	Land sharing
Kiang West	10	9366	Land sharing	Mangrove Nature Reserve	403	33,850	Land sparing
Shai Hills	6	2623	Land sharing	Wonga-Wongué	n/a	140,974	For conservation
Dixinn	39	995	Land sharing	EAST			
Lagoa de Cufada	76	34,236	Land sharing	Witu	4	1161	Land sharing
Cestos-Senkwehn	<1	40,458	Land sharing	Saadani	61	55,451	Land sharing
Lekki	n/a	248	For conservation	Cap Sainte Marie	598	3494	Land sparing
Basse-Casamance	13	4154	Land sharing	Matibane	430	5641	Land sparing
Western Area	152	8348	Land sharing	SOUTH			
Haho-Baloe	1636	2736	Land sparing	Skeleton Coastal Park	n/a	851,325	For conservation

It is worth noting that the changes in ESV within the PAs were observed to be influenced by changes in land cover, plausibly due to management priorities such as the adoption of land sharing or land sparing management strategies, especially in the context of changes in cropland land use patterns. In addition, areas of well-conserved land cover, as indicated by their increased land area, exhibits a positive impact on conservation efforts, particularly in wetlands and forest as they contributed significantly to ESV gains. Overall, more efforts are needed to better conserve and manage the coastal protected areas from deterioration. For a detailed overview, Table 5 shows the total gain/loss in ESV due to land cover area change across the PAs in tropical sub-Saharan Africa.

3.3. Correlation analysis of land cover driving factors

The Pearson correlation analysis highlighted population density as the most contributory driving factor, followed by Elevation, Precipitation, Nighttime Light and Slope, respectively (Table 6). The correlation results indicated that the population density was positively correlated across **17** PAs, Elevation across **15** PAs, Precipitation **14** PAs, Nighttime light **12** PAs and Slope across **9** PAs. Specifically, population density was a more influencing factor in **10** Western African countries, namely, Benin Republic, Côte d'Ivoire, Equatorial Guinea, Ghana, Guinea Bissau, Nigeria, Senegal, Sierra Leone and Togo, albeit weak in some of them. The exceptions, with population density not positively correlated in the West African Countries, was recorded for Gambia and Guinea. Moreover, **3** PAs located in Central Africa, namely, Angola, Cameroon and Rep. of Congo, were influenced strongly by the surrounding population density, except for D.R. Congo and Gabon. Furthermore, all the **4** PAs located on the East were impacted by their population density, while for the South of sub-Saharan Africa, Namibia PA was not influenced by their surrounding population density.

Generally, most of the explanatory variables were positively correlated with the land cover changes inside the PA, albeit weak for some PAs. Population density was the dominant driver of land cover changes inside the PAs, so it is a key factor to land cover changes in African PAs, as documented in a previous study (Jones et al., 2018), as well as an obvious threat to conservation (IPBES, 2018). In addition, population density at the edges of PAs has also been shown to threaten their effectiveness (Filho et al., 2022; Bailey et al., 2016). Furthermore, the positive correlation index of Elevation and Precipitation suggests that the terrain offers a conducive environment, especially for agriculture. This means that the coastal areas are fertile for food production (Singh et al., 2020), and such activities likely exacerbate land use changes. Moreover, the correlation between Nighttime Light, as an indicator of human activities such as settlements and economic activities like tourism observed in coastal areas, was found to be positively associated with land cover changes. Study has opined Nighttime Light influence poses a potential threat to biodiversity and ecosystem functioning in African PAs (Zheng et al., 2021) and even in the coastal region of Sri Lanka, where an increase in economic growth related to oceanic industries was observed to raise several environmental concerns (Wijerathna, 2018).

The Slope of the environment where these PAs are located are more negatively associated with their land cover changes. This makes sense as the geology of most coastal areas are flat and increase in slope will have lesser impact on land cover change.

The establishment of PAs is essential for effective protection based on

Table 6
Pearson correlation outcome of land cover change drivers inside the protected areas.

	Population Density	Nighttime Light	Precipitation	Elevation	Slope
WEST					
Djigbé	0.256	0.045	-0.023	0.301	-0.274
Nguechie	0.267	-0.086	0.085	-0.026	-0.090
Pico de Basilé	0.485	0.775	0.300	0.286	0.308
Kiang West	-0.390	-0.508	-0.516	-0.196	-0.481
Shai Hills	0.282	0.094	0.301	0.139	0.116
Dixinn	-0.207	-0.035	-0.482	-0.608	-0.796
Lagoa de Cufada	0.477	-0.163	0.442	0.527	0.442
Cestos-Senkwehn	0.227	0.164	0.171	0.172	0.622
Lekki	0.013	0.145	0.002	0.038	0.146
Basse-Casamance	0.587	0.558	0.665	0.751	0.762
Western Area	0.869	-0.659	0.028	0.023	0.041
Haho-Baloe	0.688	0.003	0.534	-0.206	-0.257
CENTRAL					
Quiçãma	0.449	0.065	-0.095	-0.712	-0.436
Douala Edéa	0.235	-0.304	-0.280	0.186	-0.251
Réserve de biosphère de la Dimonika	0.541	0.310	0.004	-0.014	- 0.025
Mangrove Nature Reserve	-0.472	-0.186	0.047	0.002	0.006
Wonga-Wongué	-0.250	-0.269	-0.438	0.904	-0.714
EAST					
Witu	0.667	0.119	0.878	0.982	.894
Saadani	0.078	0.000	0.143	0.014	-0.068
Cap Sainte Marie	0.084	-0.058	0.598	0.518	-0.002
Matibane	0.012	0.025	0.004	-0.075	0.263
SOUTH					
Skeleton Coastal Park	-0.019	-0.195	0.123	0.125	0.355

Note: The detailed Pearson correlation results of explanatory variables across the PAs, with Dark Green representing strong positive correlation, Light Green indicates weak positive correlation, Black refers to no correlation, Dark Red and Light Red indicate strong and weak negative correlations, respectively.

their respective designations. Besides, the designation of PAs is based on country's conservation needs or for a specific purpose. However, in this study, it was found that, contrary to their establishment and purpose, most of the PAs designated as natural forest had the highest amount of cropland activities, followed by National parks and resource reserves. Furthermore, PAs designated as "Strict or Presidential" reserve had no cropland activities that may contribute to impacting on the PA effectiveness, as found in Nigeria and Equatorial Guinea. Yet, Ramsar sites are meant to be strict reserves (Donnelly et al., 2022), but the PA in Guinea-Bissau is a designated Ramsar site with cropland activities. Consequently, a study reported that being designated as 'Reserved or Strict' did not stop anthropogenic activities. This indicates weak institutional policies to curb anthropogenic activities observed inside and at the edges of PAs, since they pose a threat to their effectiveness, as reported in a similar study for Ghana and Brazil (Amponsah et al., 2022; Marques et al., 2022). Hence, policy to curtail anthropogenic activities may only exist on paper and not in reality.

The near environment of tropical protected areas are interlinked (Laurance et al., 2012), and the land cover of protected areas are being found to impact on ESV (Belay et al., 2022) and effectiveness. In this study, the land cover changes in the buffer area had a mirror effect, as inside the PA showed similar changes. This type of influence overlapping into the PAs, suggests the possibility of interference with the PAs effectiveness (Laurance et al., 2012; Bailey et al., 2016), which further indicates the inability to control and preserve PAs from external influence. Interestingly, **14** out of the **22** areas had similar land cover changes (with focus on cropland and/or forest cover changes) in the buffer zone, as well as inside the PAs, namely, Gambia, Ghana, Guinea, Guinea Bissau, Nigeria, Senegal, Sierra Leone, Togo (**West**), Angola, Cameroon, D. R Congo (**Central**), Kenya, Madagascar and Tanzania (**East**). None was observed in the South (See Appendix III).

In terms of policy implication, the effectiveness of these protected areas is impacted by changes in the land cover, mainly due to human factors such as overexploitation of resources. This is expected as they provide co-benefits and ecosystem services that play a role to our livelihoods (Bera et al., 2022). Hence, more concerted efforts are needed in terms of adequate funding, monitoring and policy implementation involving the local indigenous natives, as their livelihood largely depends on their near environment and the need to adopt sustainable resource extraction. Strengthening institutions and moving from white papers to reality, by taking proactive steps to curb further deterioration of protected areas, will go a long way to provide resilience and strengthen the protected areas from further degradation, and on track to achieve their conservation goals in a sustainable manner.

4. Conclusion

This study used land cover change to spatially evaluate PAs effectiveness and ecosystem services value, in order to better advocate for a sustainable land use. The following conclusions are drawn:

Land sharing/sparing is prevalent; however, there was an observed decrease in cropland cover in some protected areas, indicating a plausible policy shift towards sustainable land use. Nevertheless, only 5 out of the 22 PAs exhibited no cropland land use patterns, an indication of restricted cropping activities, as there were observed croplands within the buffer areas of some PAs, suggesting effective management control to prevent encroachment.

The analysis of land cover changes reveals that the PA land cover losses commonly occurred in forest, grassland, and shrublands. These losses have a significant impact on their respective ESV. In contrast, wetlands conservation was shown to promote substantial ESV gains. These findings emphasize the importance of conserving these various land cover types for more efficient ecosystem services. Furthermore, the analysis underscores the strengths of most PAs in conservation efforts. However, it also addresses the need for a more robust conservation policy and timely intervention, especially for forest.

Since population is a common driving factor and it is expected to increase in the African continent in the future, periodic assessment and regularization of these PAs should be considered, in order to detect if and when the intended purpose, such as for conservation or multifunctional land use, are impacting on its sustainability.

In sum, PA conservation along the coast of sub-Saharan Africa requires more attention as the drivers of land use/land cover change, and land use management observed across most of the PAs are contributing to the environmental externalities of the PAs. Policy to allocate a percentage from national budget to support PA funding, monitoring and management of African protected areas should be a top priority not only on written pledges but in action steps for sustainability, while creating a balance for the local community's livelihood.

Lastly, some of the PAs had fewer land covers that may have influenced their outcomes. Nevertheless, this study presents the tropical coastal areas of sub-Saharan Africa with representative PAs. Other PAs may differ in the analysis based on their size (area) and designation. We propose therefore to address a further future study to quantify the co-benefits of multifunctional land use in PAs across sub-Saharan Africa.

CRediT authorship contribution statement

Jeffrey Chiwuikem Chiaka: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Gengyuan Liu:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Hui Li:** Resources, Software, Validation. **Wen Zhang:** Data curation, Resources. **Mingwan Wu:** Methodology, Visualization. **Zhaoman Huo:** Software, Validation. **Francesco Gonella:** Project administration, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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