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Two decades of land cover change and anthropogenic pressure around Bontioli Nature Reserve in Burkina Faso

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ABSTRACT

Protected areas (PAs) are critical for ecosystem maintenance and providing services that benefit both wildlife and people. Nevertheless, climate change and anthropogenic pressures are posing an increasing challenge. Surrounded by high human population densities, there is still a paucity of information on how the land cover in Burkina Faso's PAs is changing, and what kinds of human activities are the main drivers. In this study, we examined the change in land use and land cover (LULC) in the Bontioli Nature Reserve (NR), one of Burkina Faso's most important protected areas, and assessed anthropogenic pressure within and around. Landsat imagery (ETM+ and OLI-TIRS) is used to categorise and estimate the change in LULC in 2000, 2010, and 2022 with the Random Forest algorithm on the Google Earth Engine platform. Regression analysis was applied to examine the relationship between the LULC categories and population increase. We found significant changes and correlations in LULC trends and population growth over time. From 2000 to 2022, wooded savanna, tree savanna, and shrub savanna decreased by 20.8 %, 6.8 %, and 4.5 %, respectively, while cropland increased by 26.3 %, along with grass savanna by 5 %. Population growth correlated with increased agriculture and decreased vegetative area with R^2 of 0.903 and 0.793, respectively. Efforts should be made to create harmony between humans and nature through various approaches such as nature-based solutions to enable efforts for the reserve sustainable management (SDG15).

1. Introduction

Protected areas (PAs) are integral to global conservation strategies, preserving biodiversity, maintaining critical habitats, and sustaining ecosystem services that benefit both wildlife and the surrounding human population (Dimobe et al., 2022; Etiendem et al., 2013). Yet, these reserves are under increasing threat from climate change and anthropogenic pressures, which compromise their integrity and functionality (IPBES-IPCC, 2021; Kiribou et al., 2024b; Sala et al., 2000). Inadequate monitoring of the PAs, which is often linked to insufficient funding, further exacerbates the situation by making it possible for illicit activities to occur within the PA boundaries, such as logging, mining, poaching, and farming encroachment (UNEP-WCMC, 2023). These activities subsequently pose a threat to the ecological health and biodiversity of the PAs (Hoffmann and Sven Schmeller, 2021).

PAs in Africa face specific challenges that are typically more pronounced or distinct compared to other continents. Many of these PAs are surrounded by high human population densities (Fuente et al., 2020). This proximity increases the likelihood of conflicts between humans and wildlife, illegal activities, and territorial encroachments into PAs for agriculture and settlements (Mekonen, 2020). Poverty further contributes to increased pressure on natural resources, such as firewood and grazing land, leading to unsustainable exploitation (Tchobsala et al., 2022). In some regions, political instability may undermine effective

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governance and law enforcement within PAs management (Amano et al., 2018). Limited resources, and hence the capacity to patrol and monitor vast and remote areas further strains limited conservation ressources, make it challenging to combat illegal activities which can lead to significant biodiversity decline and loss (Rija et al., 2020).

Remote sensing offers a powerful tool for filling this gap in monitoring anthropogenic pressure on forests and natural habitats. Advanced satellite imagery provide data with comprehensive spatial and temporal coverage, facilitating the detection of land use changes and illegal activities in the forest that traditional ground-based surveillance might miss (USGS, 2023; Zhu et al., 2022). The integration of remote sensing data with Geographic Information Systems (GIS) enables precise, real-time analysis of ecological changes and human impacts on PAs. This technological approach is particularly relevant in Burkina Faso, where diverse ecosystems and significant environmental pressures pose unique challenges for conservation.

Located in West Africa, Burkina Faso is known for its diverse ecosystems, including savannas, forests, and wetlands (Thiombiano et al., 2012). Large herbivores and predators roam the country's savannas, and many bird species utilize the country as a stopover or wintering ground, making it an important migratory route (Cambridge University, 2022). PAs cover 14 % of the country's land area, and many of these PAs are experiencing significant anthropogenic pressure (Thiombiano and Kampmann, 2010). Demand for food, fuelwood, and settlement has stimulated agricultural activity, grazing, and woodcutting near these PAs (Akodéwou et al., 2020; Dimobe et al., 2015; Munaz et al., 2018). A recent report by the Ministry of Environment and Ecology showed that the country's cropland has doubled over the last thirty years, while forest area reduced by an annual rate of 0.87 % (FAO and UNEP, 2020). Smallholder rainfed farming dominates the country's agriculture for subsistence purposes, and low land productivity has led farmers to expand their cultivated area, placing pressure on PAs (Fritz et al., 2015; Knauer et al., 2017). Despite this trend, there is still a paucity of information on how the land cover in Burkina Faso's PAs is changing, much less what kinds of agricultural activities—such as conversion to logging, grazing, or cropland are the key drivers of this change. Comprehensive monitoring of the land use and land cover (LULC) dynamics inside PAs is still needed to gauge the potential impact on species and ecosystems and to inform suitable conservation actions and sustainable land management (UNEP-WCMC, 2023).

In this study, we investigated the LULC changes in one of Burkina Faso's key PAs, the Bontioli Nature Reserve (NR). The reserve serves as a wildlife refuge and is an important part of the West African Savannah's extensive *''Forêt Classée de Bontioli''*. We used remote sensing data to estimate changes in vegetation cover over the last twenty years, alongside the population increase surrounding the reserve. More specifically, we seek to answer three research questions: (1) How much has LULC changed in the Bontioli NR in the last two decades, as determined by satellite data from 2000, 2010, and 2022? (2) How is the shift in LULC within the reserve correlated with demographic changes around the reserve? and (3) what are the effective conservation challenges in Bontioli NR? Thus, this study underlines the value of remote sensing data in enhancing our understanding of LULC dynamics within PAs. Our examination of the key factors contributing to LULC within the Bontioli NR is crucial to help inform more targeted conservation efforts. These efforts aim to contribute towards the achievement of Sustainable Development Goal 15 (SDG15), involving relevant stakeholders in sustainable management of natural ecosystems.

2. Methods

2.1. Study area

The Bontioli NR is situated in Burkina Faso's South-West Region (Fig. 1). The reserve covers 46,764 ha, divided into 13,797 ha of Total Reserve and 32,967 ha of Partial Reserve. The Total Reserve belongs to the IUCN Category I strict protected area with limited human access, whereas the Partial Reserve belongs to the Category IV species

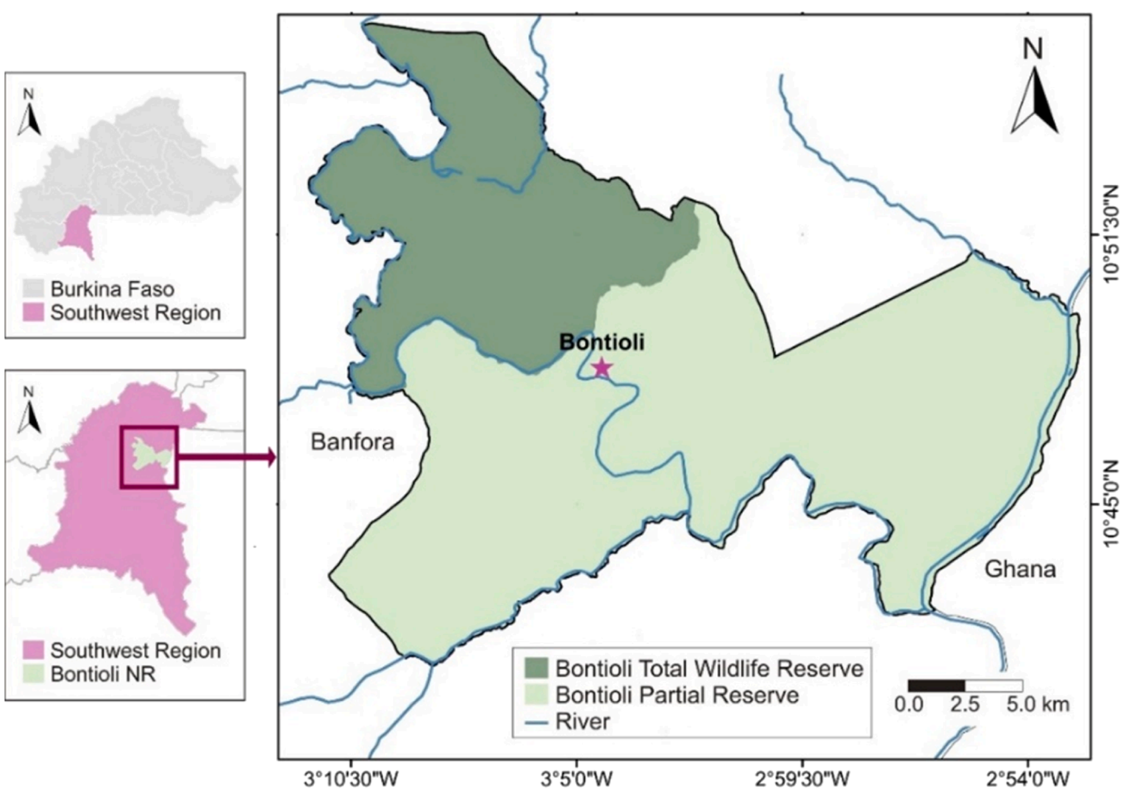

Fig. 1. Map of the Bontioli Nature Reserve (46,764 ha) in Southwest Region of Burkina Faso. The reserve is divided into Total Wildlife Reserve (IUCN Category I strict protected area) and Partial Reserve (IUCN Category IV species management area).

management area. Like other protected areas in Burkina Faso, the reserve was established during the colonial era in 1957. It serves as a transitional zone between Sudanese savannahs and Guinean forests, thus positioning it as an important humid zone in Burkina Faso. This NR is situated entirely within the South Sudanese phytogeographical zone, which has an estimated annual average rainfall of 900 to 1000 mm. The vegetation is dominated by trees and wooded savanna (Dimobe et al., 2015). The duration of the dry season is almost 6 months. It runs from November to April, with monthly average temperatures ranging from 26 to 32 °C.

2.2. Remote sensing and human population datasets

We used satellite images from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for 2000 and 2010 and Landsat 8 Operational Land Imager (OLI) for 2022 (USGS/NASA, 2023). These images generated by the United States Geological Survey (USGS) were obtained from the Google Earth Engine (GEE) data archive, a cloud-based platform that houses a large collection of satellite images and allows for geospatial analysis. The datasets utilized were Landsat 8 and 7 Level 2, Collection 2, Tier 1 classifications with a spatial resolution of 30 m (Roy et al., 2016). In addition to Landsat images, we utilized digital elevation data from the Shuttle Radar Topography Mission (SRTM) (USGS, 2018) to improve the image classification accuracy. We obtained the Bontioli NR shapefile from Burkina Faso's National Geographic Institute (IGB). All spatial datasets were georeferenced according to the Universal Transverse Mercator (UTM) projection, WGS84 zone 30 north, EPSG:4326. A data extraction technique was carried out within the GEE interface using a shapefile that defined the study area. Table 1 describes all the remote sensing datasets we used (Table 1).

Besides remote sensing data, we utilised demographic data to investigate the link between LULC changes and anthropogenic pressures. Human population dynamics were estimated using data from national censuses conducted in 1996, 2006, and 2019 including the projection to 2022. The data were obtained from Burkina Faso's National Institute of Statistics and Demography (INSD) (Burkina Faso Data Portal, 2023).

Moreover, we used QGIS software 3.20 for map visualisation (QGIS Development Team, 2021) and R software version 4.2.1 for statistical analysis and plotting (R Core Team, 2023).

2.3. Pre-processing and selection of remote sensing images

Remote sensing images often contain distortions or noise, such as clouds, cloud shadows, and haze. Data pre-processing must therefore be performed to provide clear and accurate images that are readily compatible over time. For each image, we detected pixels with clouds and shadows and then replaced them with values predicted from neighbouring pixels. We used a median filter approach for pixel replacement, which involves replacing individual cloudy pixels with the median of neighbouring pixels (Draz et al., 2023).

Table 1
Remote sensing datasets used in this study.

Satellite types	Image spatiotemporal resolution	Number of images	Selected bands	Satellite image scenes (Path/ Row)	Image acquisition period (month, year)
ETM+	30 m, 16 days	20	2,3,4,5,7	195,196 / 52, 53	1 to 12, 2000
ETM+	30 m, 16 days	20	2,3,4,5,7	195,196 / 52, 53	1 to 12, 2010
OLI-TIRS	30 m, 16 days	36	2,3,4,5,6,7	195,196 / 52, 53	1 to 12, 2022
SRTM	30 m	1	ASTER	195,196 / 52, 53	3, 2000

In regions where cloud-free images are rare, identifying the optimal temporal window for high-quality image classification is crucial. Previous studies in this area indicate that the best images for classification occurred during the dry season, which spans from October to May (Dimobe et al., 2022; Zoungrana et al., 2015). Consistent with our preliminary investigation, we found that clouds significantly affected images from June to September, and images from March were impaired by dust. Consequently, we focused our further analysis on images from April and May, in addition to those from October to February.

2.4. LULC classification

We classified satellite imagery into eight LULC categories. The classifications follow the nomenclature of African vegetation types defined in the Yangambi Agreement (Aubreville, 1957) and have been used in an earlier study on Bontioli by Dimobe et al. (2015). These LULC classes include: (1) gallery forest, (2) wooded savanna, (3) trees savanna, (4) shrub savanna, (5) grass savanna, (6) croplands, (7) bare soil, and (8) waterbody (Table 2).

We used a total of 736 ground samples for the years 2000, 2010, and 2022 to train the image's spectral signature to these LULC classes (**Table S1**). The 10-year interval is consistent with the recommendations of the national LULC database. It provides a balanced framework for assessing medium-term changes such as forest regrowth, anthropogenic impacts, or ecosystem recovery following disturbances. The LULC databases of the National Geographic Institute (IGB) of Burkina Faso and the Directorate of Environment and Forestry of the Southwest area provided a total of 253 training samples for 2000 and 222 samples for 2010 respectively. Using a handheld GPS, 261 training samples for 2022 were gathered from field surveys conducted inside the reserve.

Because land cover and vegetation vary with the seasons, it is crucial to determine the optimal month when the image's spectral signature matches each of the LULC categories. We proceed with a composite index after the combination of satellite spectral bands including certain mathematical methods for a particular purpose (DeFries, 2013). This technique is used to highlight the occurrence of some materials or to minimize the representation of other elements or features. Many remote sensing studies applied the index of NDVI (Normalised Difference

Table 2
Eight LULC classes used in this study and their characteristics, following the nomenclature of African vegetation types defined in the Yangambi Agreement (Aubreville, 1957).

LULC class	Class description
Gallery forest	Gallery forest is defined as discontinuous ensembles of closed canopy forest along main streams and in some headwater basins and occurs on the landscape throughout the year.
Wooded savanna	The wooded savanna has an uneven mix of flora, with native tree species ≥7 m tall and 20–70 % tree cover, including *Anogeissus leiocarpa, Diospyros mespiliformis, Isoberlinia doka, Burkea africana, Vitellaria paradoxa, Afzelia africana, Lannea acida, Pterocarjpus erinaceus,* and *Combretum nigricans.*
Tree savanna	The term tree savanna refers to a vegetation area with native tree species ≥7 m tall and 2–20 % tree cover, such as *Vitellaria paradoxa, Detarium microcarpum, Isoberlinia doka, Crossopteryx febrifuga, Terminalia laxiflora*. It is a landscape structure that resembles a forested savanna and is made up of sporadic individual trees.
Shrub savanna	A shrub savanna is an ecosystem with widely scattered shrubs and grass savanna, with few trees present. The vegetation structure is often somewhat open to the closed canopy, with uneven horizontal canopy spacing and varying height, but typically ≤5 m. Shrub and herb growth types cover the bulk of the vegetation.
Grass savanna	A grass savanna is a habitat dominated by grasses and low-growing plant cover of non-wooded species.
Cropland	Cropland is cultivated land with tree cover <10 %.
Bare soil	Bare soil is defined as cleared land, rocks, and land surface without vegetation, buildings, or water.
Waterbody	Waterbody is an area dominated by rivers, lakes, or dams.

Vegetation Index) as a measure of vegetation greenness (Pepe and Parente, 2018). The index ranges between −1 and 1 where a higher value indicates a high degree of greenness. Among the seven months with free cloud images, October had the highest NDVI (Fig. 2). This suggests that the spectral signature in this month best captures the degree of vegetation greenness, which might help characterize the various LULC categories. Before using the NDVI, the composite indices consisted of evaluating the surface reflectance of each LULC unit across different image bands (Fig. S1).

To perform the LULC classification, we partitioned the dataset into training and testing subsets, constituting 70 % and 30 % of the total ground truth points, respectively. Supervised machine learning method Random Forest (RF) was used in the classification. RF is a well-regarded method widely used in satellite data classification (Oskar Gislason et al., 2004). The method generates multiple decision trees where each decision tree is constructed from a bootup sample of the training data. During the tree-building process, a one-shot randomly selected subclass of the variables is considered for splitting at each node (Biau and Scornet, 2016; Breiman, 2001; Rodriguez-Galiano et al., 2012). For the LULC classification for years 2010 and 2000, bands 2 to 5 and 7 of the Landsat 7 were used (Table 1). For 2022, six bands including bands 2 to 7 of Landsat 8 OLI sensor were used. The thermal bands (Band 10 of OLI and Band 6 of ETM+) were excluded from the classification because of their coarse spatial resolution (i.e. 120 m for ETM+ and 100 m for OLI). To improve the assessment of vegetation in the classification scheme, false colour compositions were used in combination with the ground truth points (**Fig. S2**).

The classification accuracy was subsequently assessed by computing the Cohen's kappa indices on the prediction and test data confusion matrices (**Table S2**). Kappa values range from −1 to 1, where values greater than 0.75 indicate strong performance. We found that the Kappa indices for 2000, 2010, and 2022 were 0.96, 0.92, and 0.89, respectively, indicating superior classification performance.

2.5. LULC change and its relation to anthropogenic pressure

We examined the change in the extent of each LULC class within the reserve every ten years between 2000 and 2022. This is achieved by calculating the difference in the proportion of LULC class across the study area from one period to the next, i.e.

$$\Delta \boldsymbol{LU}_{i,t} = \boldsymbol{LU}_{i,t} - - \boldsymbol{LU}_{i,t} + 1 \quad (1)$$

for each $\boldsymbol{i} \in$ {gallery forest, wooded savanna, …, waterbody} and $t \in$ {2000, 2010} where $\mathbf{LU}_{i,t}$ denotes the proportion of LULC class $\boldsymbol{i}$ at time $\boldsymbol{t}$, and $LU_{i,t+1}$ denotes the proportion of LULC class i in the next time period.

To analyse the change in LULC in relation to anthropogenic pressure, the study area is divided into grid cells with a resolution of 2.5 km and used these grid cells as our unit of analysis. This allowed us to include the population density within the NR boundary. For external human pressure analysis around the NR, the surrounding cities located within the 10 km boundary are considered.

We focused the analysis on changes in the extent of land uses that are deemed to be primarily influenced by human activities, such as cropland and vegetation classes. Vegetation classes were broadly classified into two: dense vegetation (comprising gallery forest and wooded and tree savanna) and sparse vegetation (comprising shrub and grass savanna). We applied an Ordinary Least Square (OLS) regression to model the relationship between the change in population and the extent of each anthropogenic land use, i.e.

$$\boldsymbol{LU}_{i,t} = \boldsymbol{\beta}_{0,i} + \boldsymbol{\beta}_{1,i}\,\boldsymbol{POP}_t \quad (2)$$

for each $i \in$ {cropland, dense vegetation, sparse vegetation} where $LU_{i,t}$ denotes the extent of anthropogenic land use i at time t, and POP_t is the total population at time t. Parameters $\beta_{0,i,}$ and $\beta_{1,i}$ are to be estimated from the OLS model for each land use i.

3. Results

3.1. Change in LULC between 2000 and 2022

The LULC maps generated from the three time periods between 2000, 2010, and 2022 show how the landscape has changed over time within the Bontioli NR *(*Fig. 3*)*. The spatial and temporal LULC dynamic revealed that the landscape has changed dramatically from 2000 to 2022 with the wooded savanna and tree savanna being the most negatively impacted (Fig. 3). The extent of wooded savanna reduced from 15,019 ha in 2000 to 5668 ha in 2022. The extent of tree savanna decreased from 9809 ha in 2000 to 6745 ha in 2022. The LULC share change dynamic shows a decline of wooded savanna from 33.3 % in 2000 to 12.5 % in 2022, or a loss of 20.8 % during the past 22 years. The same trend is observed with tree savanna which passed from 21.7 % in 2000 to 14.9 % in 2022 equating to a 6.8 % decline *(*Fig. 4*)*. Moreover, the loss of trees appears to coincide with the fall in waterbodies, which diminished by 104 ha over the same period. On the other hand, the cropland area expanded fourfold from 3975 ha to 16,274 ha, whereas the extent of grass savanna increased more than double from 1683 ha to 3881 ha. This represents an increase from 8.5 % in 2000 to 34.8 % in 2022 for cropland and 3.6 % in 2000 to 8.6 % in 2022 for grass savanna.

The rate of land use change in the first period of 2000–2010, as

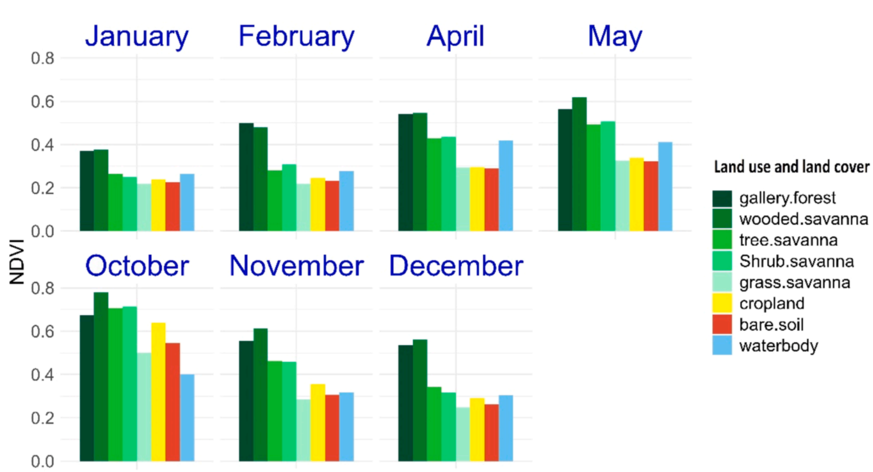

Fig. 2. Vegetation reflectance of each land use category in the Bontioli NR in 2022.

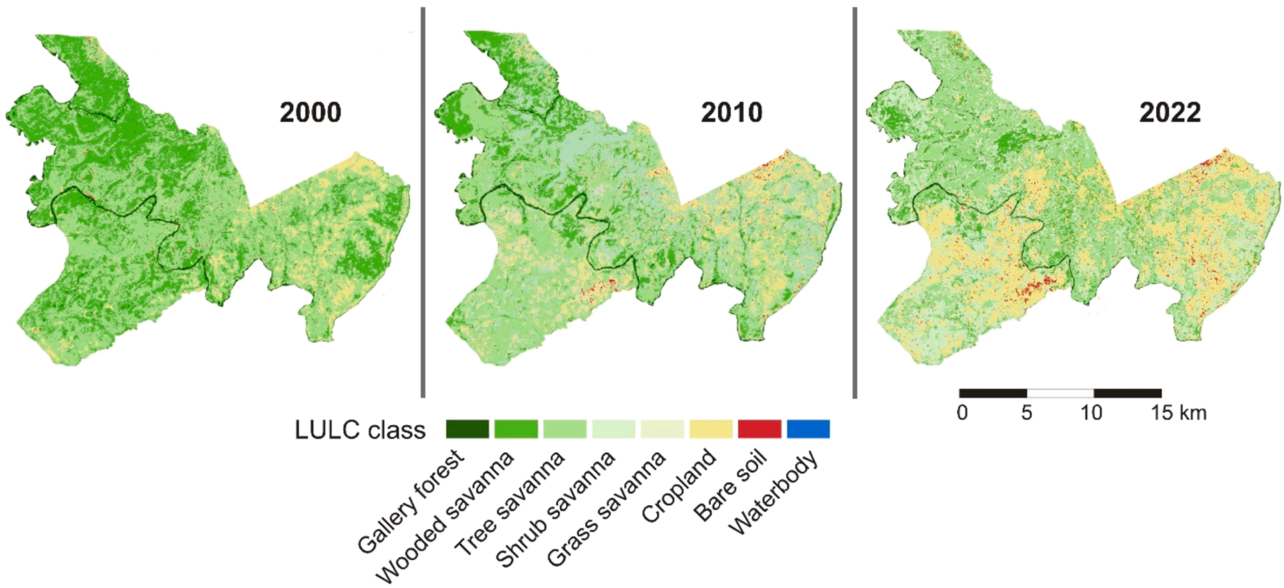

Fig. 3. Map of the changes in land use and land cover within the Bontioli Nature Reserve for the years 2000, 2010, and 2022.

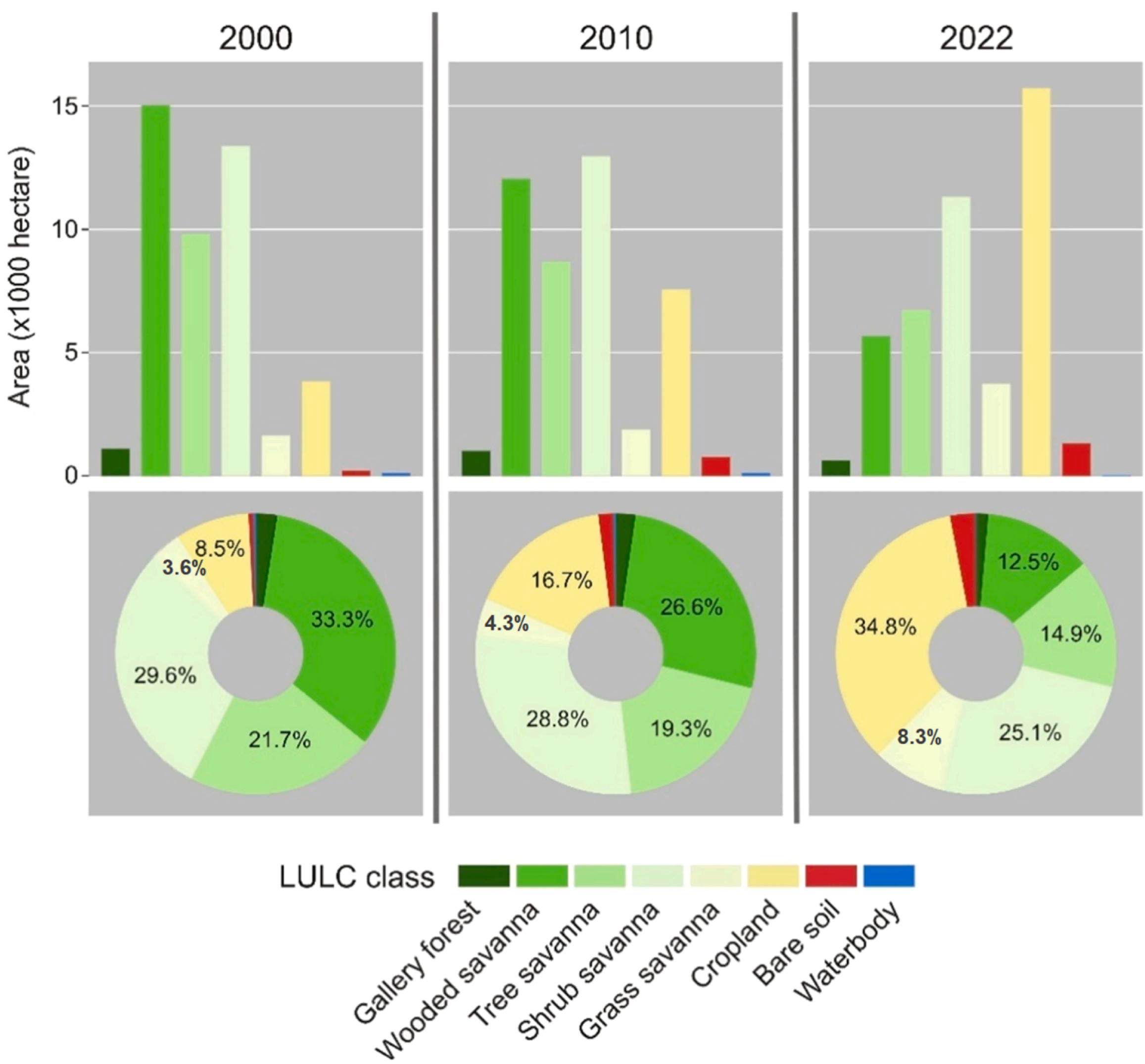

Fig. 4. The changes in land use and land cover extent and proportion within the Bontioli Nature Reserve for the years 2000, 2010, and 2022.

measured by the difference in the proportion of LULC classes between 2000 and 2010, was 2.5 % on average. Comparatively, the average rate of land use change in the second period of 2010–2022, as measured by the difference in the proportion of LULC classes between 2010 and 2022, was 6 % (Fig. 5). This demonstrates that land use change was faster in the second period than in the first, meaning that it has accelerated with time. Cropland as well as Wooded savannas were found to be the LULC classes with the fastest rate of change, indicating a significant human population impact on agriculture activities in the region.

3.2. LULC change and anthropogenic pressure

The population of the Bontioli NR and the surrounding area increased significantly between 2000 and 2022 (Fig. 6). Over this time, the human population increased from 1126.88 to 1255.55 inhabitants within the reserve boundaries, but it increased from 72,604 to 85,784 inhabitants, within 10 km of the reserve boundaries. The primary location of the human population growth within the NR boundary is Bontioli, whose name is attributed to the NR. The location within the 10 km boundary with a high population (11,637 inhabitants in 2022) is Dissin, which is the second regional city in Burkina Faso's South-West Region. The variation of population density over time revealed the spatial dynamic of the human settlement within the Bontioli NR boundary. The same population increase dynamic is observed within the 10 km of the NR. This therefore confirms the anthropogenic pressure on the Bontioli NR over the two decades. The spatial and temporal dynamic of the population revealed the change in the NR population density between 2000 and 2022, as well as the population number increases within the reserve and the surrounding villages and towns in the buffer of 10 km *(*Fig. 6*)*.

The regression analysis revealed the relationship between population growth and the LULC change between 2000 and 2022. Increased human population density was linked to dense vegetation (gallery forest, woodland, and tree savanna) (R^2=0.665) and more sparse vegetation (shrub and grass savanna) (R^2=0.788) (Fig. 7a, b). In contrast, the increased population density was highly associated with increased cropland area (R^2=0.903) and bare soil (R^2=0.793) (Fig. 7c, d). The more the population increases, the more the vegetation decreases, explaining therefore the effectiveness of deforestation in the Bontioli NR. The increase in cropland associated with the population density revealed that how the land is utilized is linked to the number of populations living within and surrounding the Bontioli NR. This situation can therefore lead to environmental stress and the maintenance of the ecological balance challenges in the Bontioli NR.

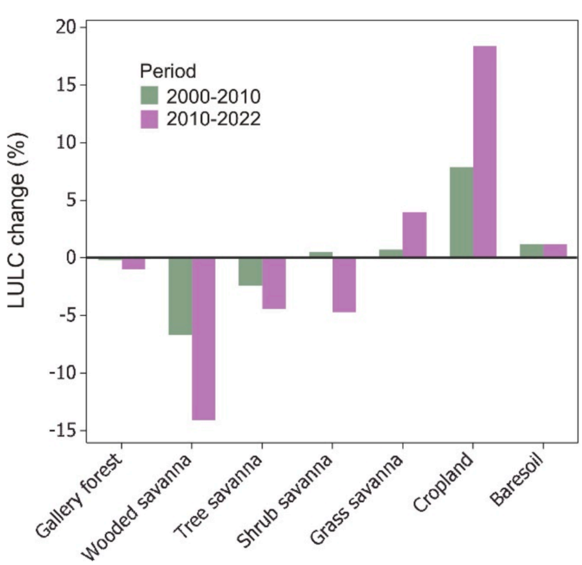

Fig. 5. Rate of change in the *land use land cover change* extent within the Bontioli Nature Reserve for the periods 2000–2010 and 2010–2022.

3.3. Bontioli NR LULC implication for effective conservation challenges

Since it was established in 1957, the Bontioli NR has suffered continued degradation. The anthropogenic forces play a key role in the reserve land cover change dynamics. The cropland expansion is the main driver of land use change that repetitively shaping the landscape of the reserve. As the human population increases, human-environmental interaction also increases, as shown considering the 10 km boundary around the reserve. This explains the demand for more cropland and the overuse of the Bontioli NR resources in the face of population density increases from 2000 to 2022. Additionally, the juxtaposition between the total and the partial reserve, makes Bontioli NR vulnerable to anthropogenic pressure. The total reserve belongs to the IUCN category I strict protection zone with limited human access, while the partial reserve belongs to the category IV species management zone. The partial reserve is the corridor of the spatial dynamic of anthropogenic pressure on the Bontioli NR. It therefore highlights an absence of effective conservation intervention in addition to the lack of the local population implication in the Bontioli NR management.

Furthermore, the couple's socioeconomic and environmental interactions revealed how distant human density dynamics and socioeconomic development exacerbate the anthropogenic pressure on the Bontioli NR. For instance, the highest population density within the 10 km boundary around the Bontioli NR reserve is urbanized. The main energy source in the region's metropolitan areas is still wood and charcoal, which explains the decrease of vegetation (gallery forest, woody savanna, and shrub savanna) by 32.1 % in two decades. Therefore, the regional urban growth has negative feedback and flows on the Bontioli NR resources. Another factor jeopardizing the sustainable management of the reserve is the regional population migration and resettlement due to the insecurity that affects the region. The Southwest region of Burkina Faso has registered more than 96,204 migrants (Forcibly displaced people) in January 2023. This population flow influences local environmental and human interaction. The high positive correlation between the increased population density with increased cropland area (R2=0.903) confirmed these interactions. Therefore, there is a teleconnectivity between urban development, population migration due to the regional conflict, and the Bontioli NR degradation. The natural resources are used to support mass migrations and the need for cropland affects the reserve. This change in land cover under human pressure presents the greatest immediate threat to biodiversity and could affect the reserve ecosystems' function and species' extinctions as the reserve is the transition area of migratory bird species.

Recognizing these broader challenges, it becomes imperative to adapt and implement tailored conservation strategies at the local level to effectively manage and protect the Bontioli Natural Reserve. In light of our findings, it is crucial for local government authorities and conservation organizations to adopt strategic interventions to mitigate the ecological pressures on Bontioli NR. We recommend implementing stricter land use regulations inspired by Costa Rica's Payment for Ecosystem Services program (Brownson et al., 2020), which has effectively reduced deforestation by financially incentivizing landowners to maintain forest cover. Additionally, promoting sustainable agricultural practices such as agroforestry and controlled grazing, similar to those used in Namibia's Community-based Natural Resource Management (Naidoo et al., 2011), can enhance biodiversity and reduce environmental impact. Initiatives like the Great Green Wall in the Sahel, which combat desertification through large-scale reforestation (Gadzama, 2017), could serve as a model for reforestation projects within the reserve. Engaging local communities through education about the benefits of conservation, and adapting conservation strategies to local conditions are essential for the success of these initiatives (Dimobe et al., 2015). Addressing those potential implementation challenges will

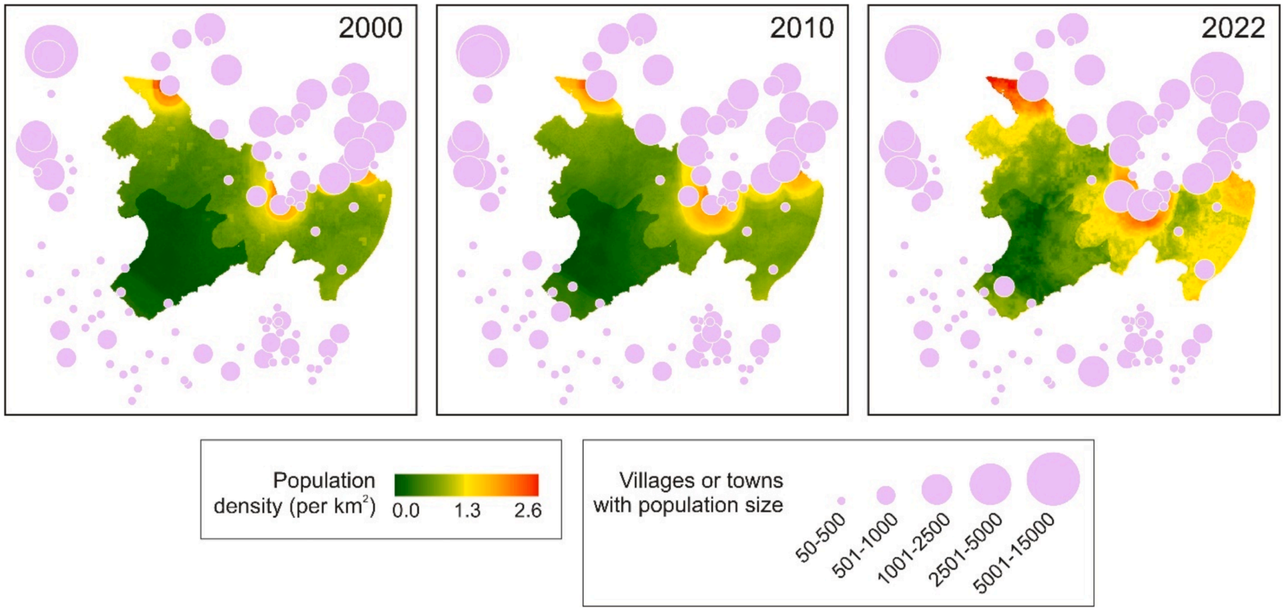

Fig. 6. Change in the Bontioli Nature Reserve's population density between 2000 and 2022, as well as the increasing number of people living within the reserve and the surrounding villages and towns.

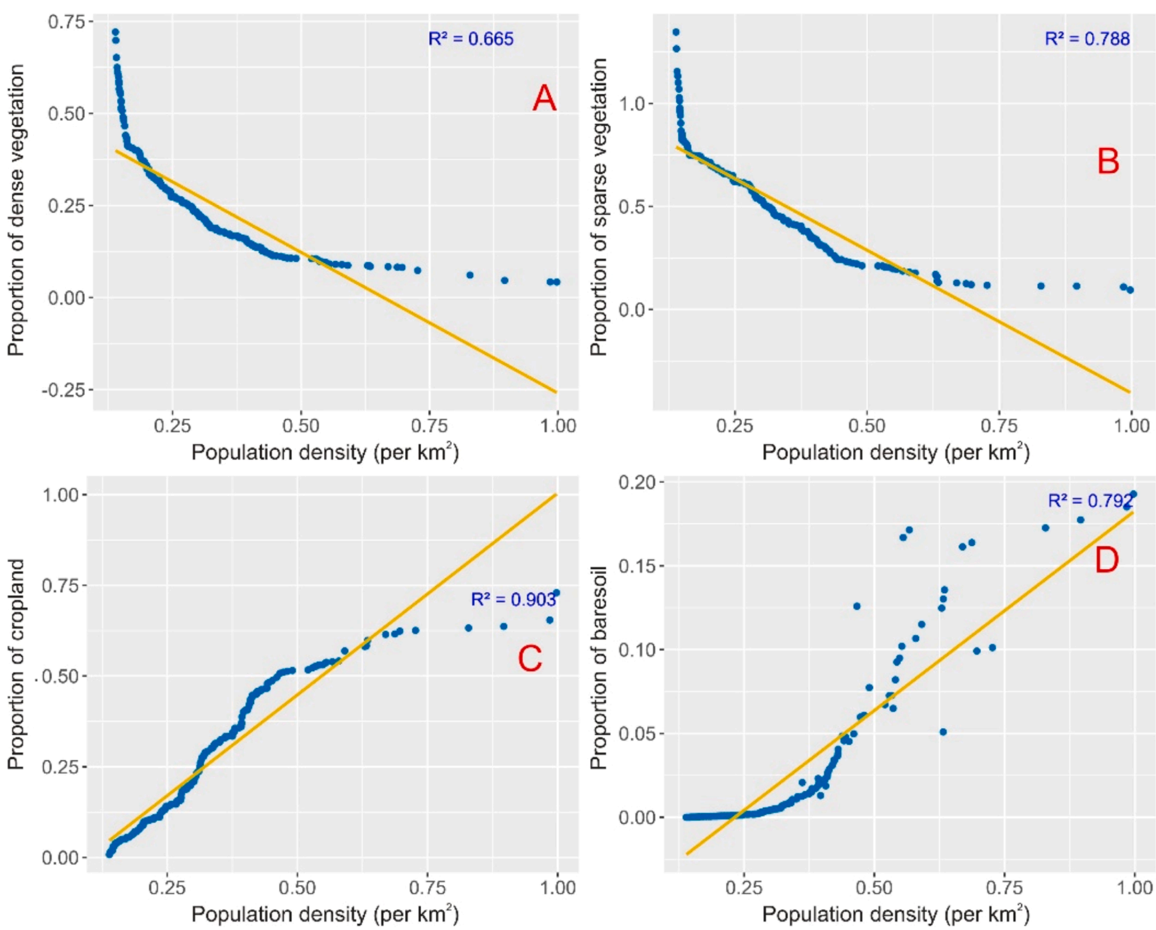

Fig. 7. The relationship between changes in population density and LULC within the Bontioli NR.

require stakeholder engagement, international funding, and public-private partnerships to ensure the sustainability of conservation efforts.

4. Discussion

With the growing situation on climate and environmental alteration worldwide, land use systems have appeared to be one of the main components of research areas for addressing these challenges and issues (Turner et al., 2007). To assess the complex interaction between land, and human action, remote sensing has developed a powerful device appropriate for long-term land use and change monitoring and diachronic analysis as we used in this study. The main challenges with remote sensing data are cloud, noise removal, and the variation of land cover and vegetation over seasons which can lead to high uncertainties (Fuladlu, 2022; Karnieli et al., 2014). To overcome these challenges, we determine the optimal months when the image's spectral signature matches each of the LULC categories during the year. This technique uses surface reflectance such as NDVI and, revealed that clouds had significant effects on the images from June to November, including March where the image was impaired by dust. We therefore focused on April and May in addition to those from October to February for further analysis. The previous studies in the same region faced similar challenges and their findings revealed the months of April, May, and October to February images were free from clouds (Dimobe et al., 2022; Zoungrana et al., 2015; Yangouliba et al., 2023). It also revealed that the particular month of October has the most vegetation greenness confirming our results. This therefore allowed us to get significant results of the LULC dynamic in the Bontioli NR.

The temporal and spatial analysis of the land cover change shows the vegetation cover change over time in the Bontioli NR. Between 2000 and 2022, vegetation cover has reduced while cropland area has significantly increased. Most studies on other natural reserve areas in West Africa have revealed the same results (Dimobe et al., 2015, 2022). Many of these findings discovered land degradation within the Natural Reserve boundary, biodiversity loss, and destruction of tree species. The main drivers of this ecological disturbance are farming, energy-related threats with charcoal, logging, and mining (Abukari and Mwalyosi, 2020; Dimobe et al., 2022; Luckeneder et al., 2021). This situation explains the local communities' need for the use of forests to extract fuel wood, and agricultural production within and around the NR confirming the anthropogenic pressure as highlighted in this study. Thus, anthropogenic pressure seems to be one of the core drivers of the NR land change dynamic and its vegetation degradation within the Bontioli NR.

The strong correlation between population density with vegetation decrease and cropland increase illustrates this human pressure on Bontioli NR. Thus, land or natural resources becoming scarcer in the face of rapid population increase, which explains the need of local farmers for land to cultivate intensively have led to cropland extension to the Bontioli NR area. This describes the high decreased rate of dense vegetation and the increased rate in cropland from 2000 to 2022. Regional decision-makers together with the local communities might not act rapidly to develop approaches for efficient farming to ensure Bontioli NR sustainable management. This lack of adequate actions results in protected area degradation with biodiversity decline (National Academies Press, 1993; Polyakov and Zhang, 2008; Turner et al., 2007). Additionally, the waterbody area of the reserve which is gradually reduced can be explained by the crop system including the conversion of wetlands for agricultural use. This farming stands out as one of the largest consumers of surface water, particularly through extensive irrigation, especially in arid regions. The reduction in water flow in rivers can therefore be linked to anthropogenic pressure and could negatively impact the ecological balance on Bontioli NR as well as the increases of climate change impact. The 2022 scientific reports, revealed the influence of land use in waterbodies as well as plant species composition (Szpakowska et al., 2022).

Despite the association or linking analysis amid population dynamics and LULC revealed a significant result, it is limited by many challenges. Those challenges are the adequate matching of population and environmental or ecological data that are not generally gathered in the same period (Jolly, 1993). Many environmental impact studies to understand human population growth effects on natural resources have yielded positive results. Environmental data including LULC data are often collected in a particular ecosystem or landscape, which cannot correspond to the political or administrative boundaries. As no area is a closed system, population migration challenges the demographic data accuracy even if it's gathered with land use data on the same area. It has been demonstrated that people migration complicates population dynamics, whereas climate change complicates land use dynamics (National Academies Press, 1993; Zhang et al., 2022). Thus, to reduce these challenges, the study area is divided into grid cells with a resolution of 2.5 km, and used these grid cells as our unit to perform the relationship analysis between LULC and anthropogenic pressure. The world population census data have been converted into gridded data sets references with a uniform coordinate system rather than irregular administrative units by NASA Socioeconomic Data and Applications Center (SEDAC) with the same approach. This procedure can allow to performance of certain types of analyses for cross-disciplinary studies (CIESIN, 2018; Deichmann et al., 2001).

Moreover, the absence of effective conservation intervention and the lack of clear land use policies have demonstrated that natural reserve governance is an ineffective protected area land use system. Natural reserve management in the face of human population increase, pose many challenges. As demonstrated by Wittemyer et al. (2008), Protected areas are human settlements attracted instead of repelling (Wittemyer et al., 2008). He found evidence of higher population growth on PAs boundaries crosswise regions. This human resettlement can be explained by the natural reserve ecosystem service and can therefore lead to anthropogenic pressure on natural resources. This is the case of Bontioli NR where the human density is highly correlated with the reserve vegetation decrease and the increase in cropland. Furthermore, many factors far away can effectively contribute to the PAs degradation. For example, the indirect forces with complex and significant impacts on land change can be conflict, urbanization development, or other socioeconomic growth of the region. Since land systems play a crucial role in conflict due to the competition for natural resources, conflict creates mass movement of people into resettlements which typically increases pressure on nearby natural resources (Glew and Hudson, 2007). This is the case with the southwest region that received many forcibly displaced people due to last decade's terrorist attacks in other rural areas of Burkina Faso (OCHA, 2023) In the face of human population growth, migration, and resettlement, urban development could have severe implications for Natural Reserves and biodiversity conservation (Mcdonald et al., 2008). The case here with Bontioli NR is a regional urban development that indirectly affects the reserve. This teleconnectivity between local land use dynamics and urbanization exposes Bontioli NR where the anthropogenic pressure is highly correlated with dense vegetation decrease as well as the increase of cropland

Furthermore, it is clear that land use dynamics crosswise distant places remain increasingly affected by human activities such as agricultural trade, coupled with environment-human interactions (Dou et al., 2019). For instance, it revealed that 52 % of the global reforestation between 2003 and 2007 in 7 countries that had forest transition is based on the displacement of land use through the import of forest products from other countries (Meyfroidt et al., 2010). This situation of forest displacement mostly exports negative externalities to countries with weak land governance systems, which can therefore affect their natural reserve (Global Land Programme, 2024). For effective natural resources and protected areas management, it is recommended to develop an approach including technologies in cropland management. This can limit negative feedback in conservation nature systems (Butsic and Kuemmerle, 2015). Additionally, the nature-based solution with local population implications can assist in effective conservation (Kiribou et al., 2024a). The interaction of a coupled human-environmental system in a telecoupled world with Bontioli NR has to be more explored as its implication for biodiversity conservation since the area is a route of migratory birds. Thus, conservation actions such as awareness campaigns and participatory activities among local populations can help restore Bontioli NR. This has been successfully implemented in Tanzania's Ngorongoro conservation which integrates local population activities with wildlife conservation that supports both pastoralist communities and biodiversity protection through a controlled land use approach (Boone et al., 2006)

5. Conclusion

The Bontioli NR is under high anthropogenic pressure. From 2000 to 2022, the dense vegetation decrease is highly correlated to the population density as well as the increase of cropland within the reserve boundary. LULC dynamic analysis revealed that the landscape has changed dramatically from 2000 to 2022 with the wooded savanna and tree savanna being the most negatively impacted. The rate of land use in the first period of 2000–2010, as measured by the difference in the proportion of LULC classes between 2000 and 2010, was 2.5 % on average. Comparatively, the average rate of land use in the second period of 2010–2022, was 6 %. This dynamic in LULC highlights the lack of effective conservation of the Bontioli NR. The main drivers of this change are agricultural activities—such as conversion to logging, grazing, or cropland. In addition to the population density increase, it revealed that the challenges of the reserve conservation could be driven by distant events such as conflicts that affect the region and lead to people's migration toward the area where the reserve is located. Therefore, these findings exposed the need to incorporate local communities into the Bontioli National Reserve's long-term management. Our findings highlight the importance of incorporating local population dynamics and community participation into the Natural Reserve's long-term management. Further research is needed to evaluate the impacts on land use change systems and its interrelated drivers of conflict, and climate change, which are not yet understood. Understanding this interrelationship can effectively contribute to the achievement of SDG15.

CRediT authorship contribution statement

Razak Kiribou: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Kangbéni Dimobe:** Writing – review & editing, Visualization, Validation, Supervision, Methodology. **Lassane Yameogo:** Writing – review & editing, Methodology. **Huiyi Yang:** Writing – review & editing, Visualization, Supervision, Methodology. **Truly Santika:** Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation. **Sintayehu W. Dejene:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology.

Declaration of competing interest

Not applicable, no funds received out of the academic research support and there are no competing interests included.

Data availability

The data are freely available on Google Earth Engine archive for satellite image and the population data at Burkin Faso open data archive site.

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Supplementary materials

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