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ANALYSIS OF ECOSYSTEM CONSERVATION STAKES IN THE MAIKO TAYNA KAHUZI BIEGA LANDSCAPE FACING THE LAND USE NEEDS

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Abstract
Poor planning and land-use allocation decisions can affect protected species by altering ecosystems. Agriculture, mining, and other human activities significantly threaten biodiversity and natural ecosystems. This research aims to understand the evolution of different microzones of land use and conservation efforts within the Maiko-Tayna-Kahuzi-Biega landscape (MTKB). It involves using time series of remote sensing, combined with existing regional and global remote sensing-based products and GIS, to provide local-specific estimates of land use changes related to deforestation data from 1986 to 2018. The survey identified 4 types of land use: mining, agriculture, rural complex, and conservation. The key results of this research show that forest degradation in the sampling area has an average rate of 8.24%, and 2.74% for deforestation over the past 32 years. Subdivided into three periods, the first period from 1986 to 2000, the period before community-based conservation initiatives were put in place, has a deforestation rate of 2.61% and a forest degradation rate of 7.04%. The period when conservation initiatives began, from 2000 to 2010, is characterized by a deforestation rate of 6.93% and 14.28% for forest degradation. This was also when mineral exploitation was at its peak in the region. The period when conservation is implemented shows (2010 to 2018) progress with a rate of 1.22% for deforestation and 2.77% for forest degradation, and agricultural activities cover 8% of the area, mining 5% (with mining exploitation license covering 30% of the landscape), and 40% for conservation projects. The current policy of community conservation needs to be reviewed and consider the momentum of community reserves that have proven their effectiveness, and reorientation of efforts to consolidate ecological corridors, as the mutation of community reserves seems to fragment the ecological corridor created within this landscape.

Keywords: Biodiversity, Community-based conservation, Deforestation, Ecosystem, MTKB landscape

1. INTRODUCTION

Agriculture, mining, and other human activities pose a significant threat to biodiversity and natural ecosystems (Sonter et al., 2018). Large-scale human activities near protected areas or biodiversity habitats can disrupt the watershed and increase soil erosion (Margaret and Zwick, 2007). Over the past 40 years, the area of global agricultural land has increased by 10%, but in terms of area per capita, the area of agricultural land has decreased. This trend is expected to continue as land becomes more limited and the population increases (WBCSD and IUCN, 2008)

The expansion of agriculture is the most significant driver of global deforestation and accounts for about 73% of tropical deforestation, of which 40 % is due to large-scale commercial agriculture and 33% to small-scale subsistence activities. Other causes include mining, infrastructure and urban expansion. Factors underlying the conversion of forests to agriculture include population growth,

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agricultural development, lack of security of tenure, and poor governance governing land-use change (Sanderson et al. 2002; Consolée et al., 2020). Where subsistence agriculture is the major cause, support for adopting more sustainable production practices needs to be complemented by broader poverty alleviation and rural development interventions, including through the consolidation of land rights. Reducing food loss and waste, restoring productivity to degraded agricultural land, educating consumers, and moving towards healthier diets derived from sustainable food production systems can go a long way towards halting agricultural expansion and associated deforestation (Searchinger et al., 2019).

Human expansion has made agriculture a dominant form of land management worldwide. Human influence on land is accelerating due to rapid population growth and increasing food needs (Radoslava, 2016). Thus, the conversion of forest land to agricultural land (deforestation) is responsible for 15-20% of annual anthropogenic greenhouse gas (GHG) emissions (IPCC, 2007; Bellassen et al., 2008). To provide solutions to reduce the current rate of deforestation, the REDD+ mechanism (Reducing Emissions from Deforestation and Degradation, Enhancing Stocks and Sustainable Management of Forests) was introduced at the 13th session of the Conference of the Parties in 2007 in Bali following intense negotiations. This mechanism involves monitoring the evolution of forest land to measure and verify policies, programs, and projects aimed at conserving or increasing this resource (Verchot and Petkova, 2009).

The Congolese Forest provides a habitat for several of the most endemic species and diverse ecosystems in tropical areas. Indeed, more than 11000 plant species have been identified, of which 3200 species are endemic; over 450 species of mammals (28 endemic) and 929 species of birds (24 endemic) have been identified (Bibby et al., 1992; Debroux et al., 2007; UNEP, 2022). However, unplanned logging combined with slash-and-burn agriculture and other illegal practices such as poaching are likely to contribute significantly to the degradation of these resources as well as the physical environment and environmental quality. These environmental disorders suggest a particular focus on the effectiveness of ecosystem conservation.

The context for ecosystem conservation is generally critical in the Democratic Republic of Congo (DRC) (Yanggen et al., 2010). Poor land-use planning policy has a potential impact on ecosystem management. Ecosystems can be affected by human settlements, by intensive or extensive agriculture, and by mining operations adjacent to them. In addition, failure to deliver clear and effective governance can be a cause of ecosystem loss or degradation (Lockwood, et al., 2006).

Within the DRC and other forestry areas, the demand for arable land is increasing and large areas of forest and/or drained land are newly occupied by fields (Hall et al., 1998). Thus, shifting, or large-scale agriculture around biodiversity habitats can disturb forest habitats. Major habitat changes are the most important factors impacting ecosystem conservation and often result from human settlement and conversion of natural areas to agricultural land. Habitat loss and invasive species are the two greatest current threats to biodiversity, and both will interact significantly with climate change. Estimates of habitat loss indicate that most of the earth's habitable area is now dominated by human activities (Hannah et al., 1994; Sanderson et al,. 2002).

Sometimes a partnership between private landowners and the government can produce initiatives that can reduce habitat and ecosystem loss. A group of landowners can enter into a cooperative see the natural value of their properties and use them as a conservation corridor between two protected areas. One example is the partnership between the Union of Associations for Gorilla Conservation and Development in Eastern Congo (UGADEC) and the Congolese Institute for Nature Conservation (ICCN) (Debroux et al., 2007). Their innovative project was to create a corridor

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between Maiko Park and the Kahuzi-Bièga Park. Community reserves were created, and it is through this approach that the area was constituted as a single landscape now called the Maiko-Tayna-Kahuzi-Biega (MTKB) landscape despite the lack of a management plan (Yanggen et al., 2010). The area is rich in biodiversity, but its natural habitats are threatened and degraded by mining and slash-and-burn agriculture (CI, 2015).

Remote sensing offers us the possibility to gain knowledge on the evolution of forest ecosystems (Köhl et al., 2006). There is a growing interest in current land use and land cover changes, both in the global environmental change community and among researchers working on local environmental issues. Knowledge of current land surface transformations is an important issue for the assessment of the state of the environment, whether their conversions, i.e. the passage from one land use or occupation category to another, or modifications that represent an evolution within the same category following changes affecting its physical or functional attributes (Godoy et al., 2012). Therefore, the aim of this research is to analyse the spatio-temporal evolution of forest ecosystems, agriculture, and other human activities in the MTKB landscape in east DRC. The potential impact of the creation of community reserves on the preservation of natural habitats and identifying the tools already in place to consolidate this landscape in the preservation of natural habitats and biodiversity was depicted. According to the aim of this study, these questions will be answered:

(i) The agrarian policies are well implemented in this area and can enhance the reduction of the rate of forest deforestation and degradation in the landscape?

(ii) Is agriculture the main factor in land conversion within this landscape as most of local people relay to this activity for incomes?

(iii) How have been land cover changes across years especially from 1996 to 2018 within one of the richest landscape in the Congo basin forest?

2. MATERIALS AND METHODS

2.1 Site selection and study area

The MTKB landscape (Figure1) covers more than 106,000 km^2 (Freccia, 2010; Yanggen et al., 2010; Mubonge, 2011; CI, 2015; Mubonge et al., 2016). Unfortunately, the availability of images is not certain over the entire landscape. We agreed to randomly select an area to serve as a model for analysis to illustrate the evolution of land cover change in the area. Our selection criteria were based on the number of community reserves created or planned to be created, the intensity of conservation activities, and the availability of satellite images. Thus, an area of 429,688.36 ha was identified lying to the north at latitude South 0°30'; to the south at latitude South 1°; to the west at longitude East 26°11', and to the east at longitude East 27°05'. The other aspects of the research such as land management policy and ecosystems were taken within the entire landscape area. The landscape is rich in African tropical species of fauna and flora with some specificities of the region such as Gorilla (*Gorilla beringei graueri* Matschie, 1914), Okapi (*Okapia johnstoni* Sclater, 1901), Elephant (*Loxodonta cyclotis* Matschie, 1900), Buffalo (*Syncerus caffer nanus* Boddaert, 1785), Congolese Peacock (*Afropavo congensis* Chapin, 1936), Aardvark (*Orycteropus afer* Pallas, 1766), chimpanzees (*Pan troglodytes* Blumenbach, 1776), many species of antelope, etc. The flora includes high and canopy species, with many of them having an economic value.

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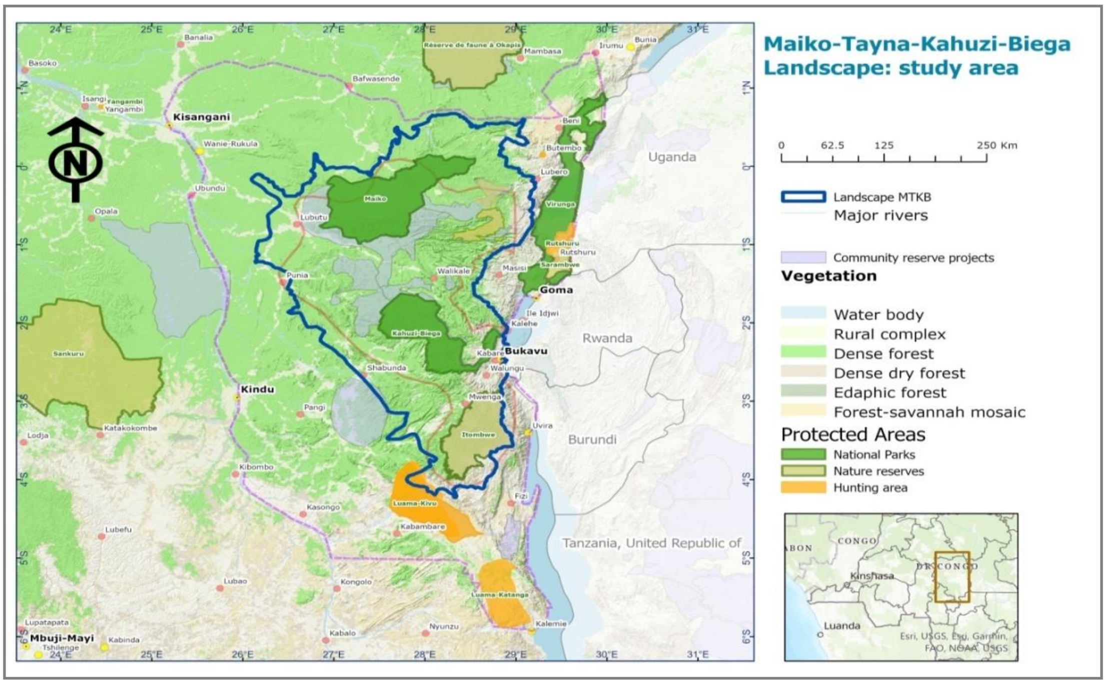

Figure 1. The study area, the MTKB landscape

2.2. Data collection

2.2.1. Image acquisition

We used two ways of acquiring satellite images. Firstly, from existing databases, and secondly through downloading from the NASA website, www.earthexplorer.gouv

2.2.2. Simple surveys

Our simple surveys were undertaken, using observation and interpretation of stakeholders and local populations told us in normal conversation (without any survey guide) to complement the information acquired by remote sensing to identify the different agricultural practices carried out in the region and the different existing projects, and to gain knowledge of the prospects for sustainable management of the MTKB landscape.

2.3. Data analysis

2.3.1. Image analysis and classification

The project was based on the study of spatio-temporal indices of satellite images and/or other remote sensing products. Through data mining, we used a series of images to establish possible changes in the landscape.
The spectral signature of all sample plots was used with a non-parametric classification technique (Figure 2). Temporal model calculations were produced to establish future scenarios and to establish spatio-temporal prediction efforts. In addition, field data were collected to compare and calibrate the remote sensing data.

2.3.2. Calculation of vegetation cover lost

The analysis of images (using standard process of analysis, Figure 2) allowed us to identify changes in forest habitats. The annual deforestation rate is the ratio of the area cleared over a period divided by the initial forest area and the number of years in the period (Menon and Bawa 1997; Ramesh et

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al., 1997; Prasad et al., 2003). However, several publications have recently highlighted that the evolution of forest loss cannot be obtained with this simple ratio. The standardized formula proposed by Puyravaud and Garrigues (2002) was adopted to calculate the annual deforestation rate for this study:

Ø=1/(t2-t1) ln(A2/A1)*100 (Equation 1)

With A1 = forest area of the initial year; A2 = forest area of the final year; t1 = exact acquisition date of the image for the initial year; t2 = exact acquisition date of the image for the final year.

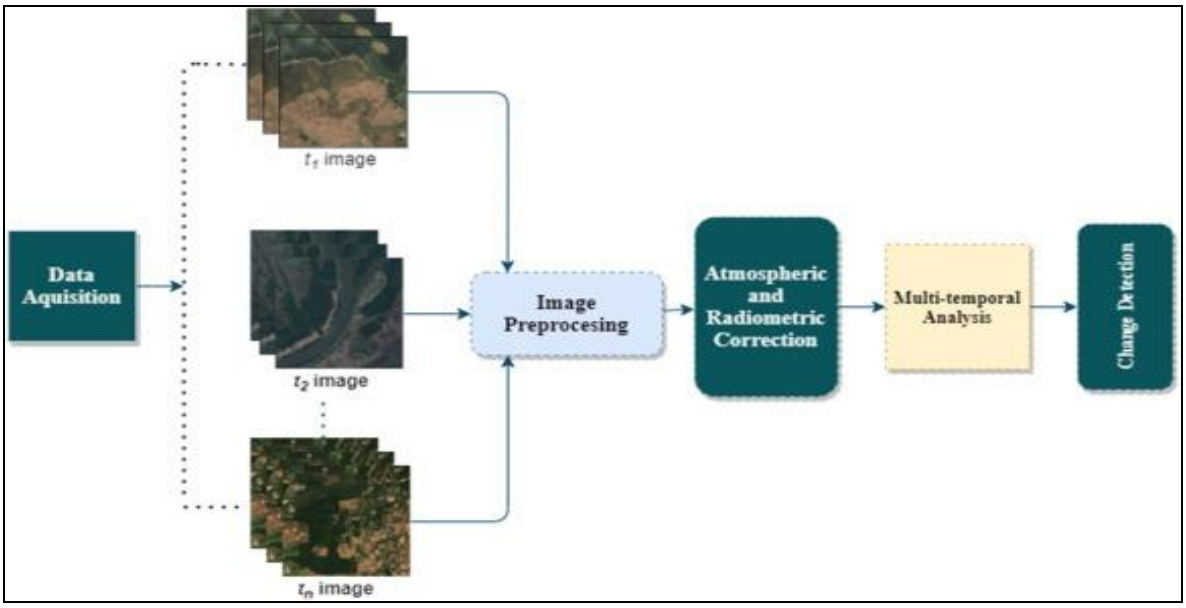

Figure 2. Overview of spatiotemporal process analysis of images for ecosystem monitoring **(MECNT 2015)**

2.3.3. Computing Change Detection

Change detection captures the spatial changes from multi-temporal satellite images due to manmade or natural phenomena. It is of great importance in remote sensing, monitoring environmental changes, and land use-land cover change detection. Remote sensing satellites acquire satellite images at varying resolutions and use these for change detection (Asokan and Anitha, 2019). Change detection is one of the fundamental applications in imagery and remote sensing. It is the comparison of multiple raster datasets, typically collected for one area at different times, to determine the type, magnitude, and location of change. Change can occur because of anthropogenic activity, abrupt natural disturbances, or long-term climatological or environmental trends (ESRI, 2021).

The detection of changes was done by calculating the variation of the weighted values of each pixel through the ArcGIS Pro software according to the following formula (Hountondji, 2008):

Δ (*p*) = [V(*p*) 2018 - V(*p*) 1986]; with:
Δ (*p*): variation of the digital count of pixel *p* between 1986 and 2018.
V(*p*) 1986: the weighted value of pixel *p* in 1986.
V(*p*) 2018: the weighted value of pixel *p* in 2018.

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2.3.4. Forecasting

The least-square linear fit was used to forecast the evolution of the forest over the next 32 years. According to this method, we should look for the equation that passes through the mean points X and Y. Our objective is to predict forest losses, so the difference between the actual observed values and those calculated on the line should be as small as possible.

$$Y = aX + b \text{ (Equation 2)}$$

For this purpose, the directing coefficient of equation (2) should be of the form:

$$A = \frac{\sum Xi.Yi}{\sum Xi2} \qquad \text{and} \qquad b = Y - aX$$

$Xi = xi - x$ $\quad Yi = yi - y \quad x = \frac{\sum xi}{n}$ and $y = \frac{\sum yi}{n}$ with n representing the numbers of years.

3. RESULTS AND DISCUSSIONS

3.1. Main issues

The results of our research found that there are many issues facing ecosystem conservation in the MTKB landscape. Major of these issues are agriculture, mining, population expansion, and lack of ecosystem management practices. Congolese agrarian policies are absent within the landscape.

There is no agricultural policy in the area. People exploit the land according to their own needs. Most farmers (60.4%) use slash-and-burn agriculture to eliminate the tree trunks lying on the ground. Some farmers undertake fallowing (53.2%) or to look for a new field (40.5%) using itinerant agriculture (Table 1). However, pesticides are not yet used to control plant diseases. Only some people use chemicals for fishing in rivers.

Table 1: Different agricultural techniques found in the MTKB landscape

Villages	Slash-and-burn agriculture	Fallowing	Shifting agriculture	Permanent agriculture
Walikale	75%	62%	32%	67%
Mubi	63%	71%	58%	77%
Ndjingala	72%	57%	44%	84%
Makana	65%	54%	32%	65%
Batokolo	58%	43%	26%	46%
Osso	76%	32%	18%	69%
Mungele	83%	65%	76%	84%
Amisi	43%	76%	61%	73%
Lubutu	69%	72%	58%	87%
Total	**60,4%**	**53,2%**	**40,5%**	**65,2%**

Housing in the villages of the MTKB landscape does not comply with any regulations. Although there is a law to respect in housing, here it is ignored. The houses or villages are built according to the people's choice. However, in some villages, according to our survey, people were moved from the forest to the main roads by the colonial settlers. These villages evolve without any regulations or urban planning procedures that respect the objectives of sustainable development.

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There are two dimensions to mining: artisanal and industrial. Artisanal mining is carried out in a coordinated manner through community structures, the mining cooperatives, which carry out their activities in the Artisanal Mining Zones (AMZ). Although defined by the mining law, there is no formal mapping of AMZ. As for industrial exploitation, there are mining licenses covering approximately 55015.37 km^2. Referring to the security context, several mining licenses are in a state of force major or conservation. Thus, several artisanal actors exploit these areas.
This activity is transversal in terms of spatial location. It occurs in all habitat and land use classes. However, in some parts of the landscape, to find a game animal should be to travel many kilometers. There is no well-defined area put apart specifically for hunting activities.
Regulated by the Ministry of the Environment, operators always have a license for exploitation. However, in terms of land-use policy, the sector does not follow any standards and there is no mapping of forest areas for timber exploitation.
Agrarian systems are poorly defined. Nevertheless, new forest and land-use monitoring systems are being developed using more state-of-the-art tools than ever before, facilitating more transparent and accurate forest ecosystem conservation as well (PCF, 2021). This new approach has placed particular emphasis on the evolution of forest habitats and the creation of community reserves and CFCL in the MTKB landscape. The result from that approach demonstrates that to some degree, the trial and error between the two policies of community reserves and CFCL needs to be re-examined and analyzed to define a definitive model that will serve as a policy for the conservation of forest ecosystems in the landscape.

3.2. Conservation efforts in the region

The MTKB landscape has two major national parks: Maiko National Park and Kahuzi-Biega National Park. These protected areas are under armed and police-led conservation.

a. Maiko National Park

The Maiko Park was created in 1970 and covers almost 1,000,000 ha. It is located in the provinces of Tshopo, North Kivu, and Maniema. It is home to three of the country's most spectacular endemic species: the rare okapi, Grauer's gorillas, and the Congolese peacock found only in this part of the country, in addition to a population of forest elephants, chimpanzees, and buffalo. The Maïko Park is a hilly topography and difficult to access, consisting of a block of rainforest. It is a semi-mountainous forest with an average altitude of 1200 meters. It has the highest rainfall in the DRC. It is threatened by mineral extraction and the presence of armed groups.

b. Kahuzi-Biega National Park

The Kahuzi-Biega National Park was created by ordinance n° 70-316 of 30/11/1970 to protect the habitat of Grauer's gorilla; a species endemic to the DRC, the park was later extended to include the lowland forests to the west with a total area of 600 000ha. It was inscribed on the list of World Heritage Sites in 1980. With such a wide altitudinal variation from 600 to 3,300m, this is rare for a national park in Africa. The land around the highest part of the park is heavily populated with densities of up to 300 people/km^2. Slash-and-burn agriculture dominates farming practices, although these are increasingly being replaced by artisanal mining (gold, diamonds, coltan, tin). The main threats are uncontrolled bushfires, logging, artisanal mining, boundary violations, illegal occupation of farms and crops, human-animal conflict, and fuelwood cutting. In 1997 the Kahuzi-Biega Park was placed among the World Heritage Sites in Danger (ICCN, 2017).
Besides 2 national parks (Maiko and Kahuzi-Biega), new protected areas in the MTKB landscape are being established due to the biological richness of the region and its position straddling the Albertine Rift and the Congo basin (Oscar et al., 2012). Efforts have been made by both sides (local

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people and government) to address this need. A network of traditional and scientific leaders in the region created a corporation of nine reserves, known as community reserves. These reserves formed a platform called UGADEC. They covered an area of 15,000 km² (Plumptre et al., 2015), which corresponds to 45% of the protected areas in the MTKB landscape.
The goal of UGADEC is to promote the socio-economic development of the local communities bordering the reserves; with objectives to participate in the conservation of great apes and their natural habitats in eastern DRC, to organize ecotourism after gorilla habituation, to promote the socio-economic development of local communities, to create the ecological corridor between the two national parks, to organize scientific research, and to build a database on the eastern lowland gorillas (Mubonge et al. 2016). This effort put in place two pioneer protected areas with IUCN category IV in the region the Tayna Nature Reserve (RNT) and Kisimba-Ikobo Primate Reserve (RPKI).
The Tayna Nature Reserve, established in 1998 (Godoy et al., 2012), is a model of community conservation in the region. It led to the establishment of 8 other community-based reserves, which subsequently created the UGADEC. It is currently classified as a protected area in the DRC. It covers an area of 927.92 km². The RPKI was created in 2001 following the Tayna model and is classified as a nature reserve in the DRC. It is located in the territory of Walikale and covers an area of 1500 km².
Other proposed community reserves (Mubonge et al. 2016) were created to generate an ecological corridor between protected areas in the MTKB. There are 7, the ones that have remained without recognition as protected areas (Table 2). They were a proposal for the creation of community-managed protected areas in the Tayna model. They are extended to an area of 14310 km². In total, this great apes conservation program covered an area of 29547.92 km².

Table 2. UGADEC Community Reserves

No	Name of reserve	Location	Area	Year of creation
1	Conservation Communautaire pour la Réserve Forestière des Bakano (COCREFOBA)	Walikale Territory, North Kivu Province	957 km²	2002
2	Réserve des Gorilles de Punia (RGPU)	Punia Territory, Province of Maniema	3738 km²	2002
3	Réserve des Gorilles d'Usala (RGU)	Walikale Territory, North Kivu Province	1152 km²	2002
4	Reserve des Gorilles d'Outunda-Wassa (REGOUWA).	Walikale Territory, North Kivu Province	3395 km²	2002
5	Réserve communautaire des Primates et des Forêts de la Lowa (RECOPRIFOL)	Walikale Territory, North Kivu Province	395 km²	2003
6	Réserve de Gorilles de Mokingiti et Kingombe (REGOMOKI)	Lubutu Territory, Maniema Province	2055 km²	2004
7	Réserve de Gorilles de Lubutu (REGOLU)	Lubutu Territory, Maniema Province	2618 km²	2004

Community forestry also appears among the strategic priorities of the Forests and Nature Conservation Project (PFCN) (Maindo & Kapa 2014). Several community forestry projects are being developed in the region. They reinforce conservation projects in the region. The Local

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Community Forest Concessions (CFCL) occupies an area of 2050.80 km^2 (Table 3). Some community reserves are in the process of being partitioned into CFCLs as community forestry is a new policy that most conservation organizations have adopted. However, some existing CFCL projects that conservation objectives are not their first priority have also adopted this model, which integrates biodiversity conservation into forestry activities.

Table 3. Created CFCL

No	Name of CFCL	Location	Area
1	Basengele	Walikale	336,97 Km^2
2	Bananzigha	Walikale	81,81 Km^2
3	Banisamasi	Walikale	458,41 Km^2
4	Kibu	Walikale	325,41 Km^2
5	Kisimbosa Chamakase	Walikale	55,73 Km^2
6	Banamwesi	Walikale	121,96 Km^2
7	Ikamu	Walikale	52,68 Km^2
8	Batiri Nyabayu Biruwi	Walikale	310,63 Km^2
9	Batiri Nyabayu Uchi	Walikale	307,20 Km^2

In addition, as emblematic species are found within this area, conservation needs arise. After Conservation International (CI) handed over the leadership of the Central Africa Forest Ecosystem Conservation (CAFEC) Project to the Wildlife Conservation Society (WCS), a new dynamic for the creation of CFCL was set in motion and some of community reserves were transformed into CFCL. These community reserves were forced to carve out or change to CFCL to access funding. This had a significant impact on the area to be conserved. And 57% of the community reserve's total area, (i.e. 7254.85 km^2) changes status as a result of the new policy of transferring Community Reserves to Local Community Forest Concessions.

The primary purpose of community reserves (Table 2) was to provide an ecological corridor between national parks in the landscape (Freccia 2010, Yanggen et al., 2010, Mubonge 2011, Mubonge et al. 2016), while CFCL aims to meet the economic, social, cultural, and spiritual needs of communities (Kakelengwa et al. 2016). For community reserves, co-management contracts have notably been signed and executed between ICCN and local NGOs (UGADEC) for the Tayna and Kisimba-Ikobo Reserves, which showed the evolution of a formally recognized protected area created from a larger area (Yanggen et al., 2010). CFCLs are not protected areas but rather innovative decentralized and participatory models of forest management (Oyo, 2005), so they can contribute to sustainable natural resource management and biodiversity conservation through land-use planning. They have a local or provincial license whereas community reserves have a national license with protected area status as a nature reserve.

Although an innovative measure, the change in policy to create community reserves as CFCL has not resulted in the protection of the full forest habitats envisaged by the community reserve proposals in the landscape. This community forestry project has led to approximately 7751.2 km^2 of forest being converted to unallocated land and thus connectivity is now fragmented, undermining the idea of creating the corridor. Thus the connectivity is fragmented and the effectiveness of the legal status of CFCLs will always be questioned in the face of mining licenses and other uses by both local people and state structures.

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Forest management is evolving as community conservation reserves were internationally recognized as an effective conservation approach at the 2003 World Parks Congress (Lockwood et al., 2006), and this policy has resulted in the creation of two cited previously (the Tayna Nature Reserve and the Kisimba-Ikobo Primate Reserve), with seven more projects planned. Although local community forest concessions are not protected areas, and no CFCL had ever been produced in these years, NGO actors working in conservation decided to support forestry and convert community conservation projects into CFCL.

3.3. Analysis of land use and forest ecosystem evolution indices

The established vegetation indices allow the identification of trend curves of land use cover evolution with emphasis on ecosystem evolution, hence 2.74% deforestation rates, and 8.24% degradation rates of intact forests are identified through an understanding of the evolution of the farming system in the area and the analysis of satellite images from 1986 to 2018. Thus, the degraded forest class largely encompasses agricultural fields and partially mining activities (Figure 3). The bare soil area is mainly covered by houses and roads.

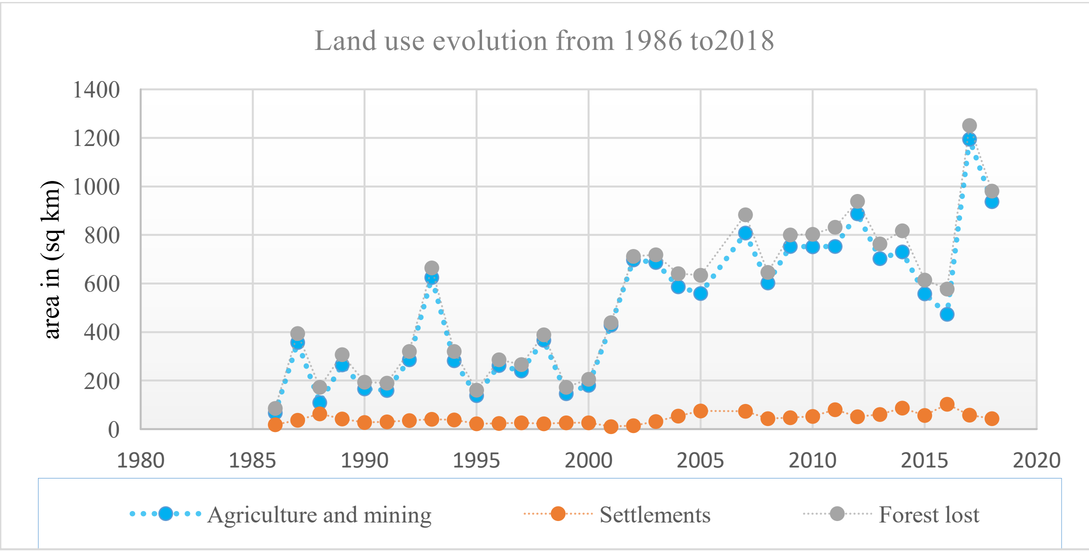

Figure 3. Evolution of forest loss and degradation in the study area from 1986 to 2018

There has been an increase in cultivated and mined areas over the years. Coupled with the agricultural space, the evolution of habitats and bare spaces constitute the loss of forests. We focus on the loss of forests for the analysis of our results because it is proportional to the evolution of agricultural, mining, and housing areas (Figure 3 and Figure 4).

The year 2017 was characterized by large losses of primary forest. According to the evolution of conservation activities, this time series is subdivided into three main periods:

(i) From 1986 to 2000: Before the implementation of community conservation;
(ii) 2001 to 2010: Period of implementation of community conservation projects;
(iii) 2010 to 2018: Peak period of conservation projects

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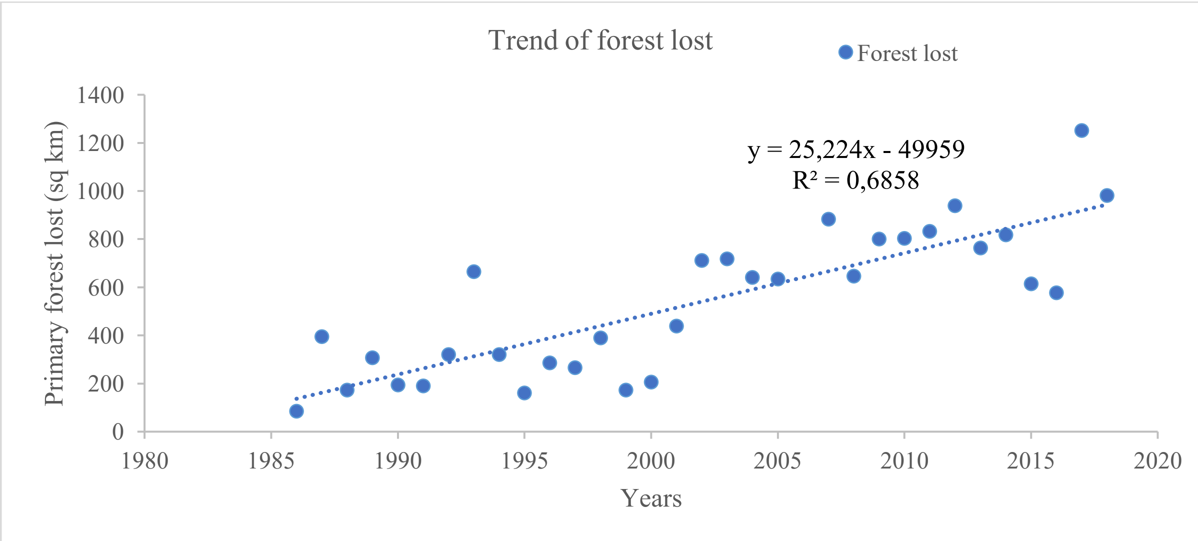

Figure 4. Development curve of primary forest lost from 1986 to 2018

3.3.1. Evolution of forest ecosystems from 19986 to 2000

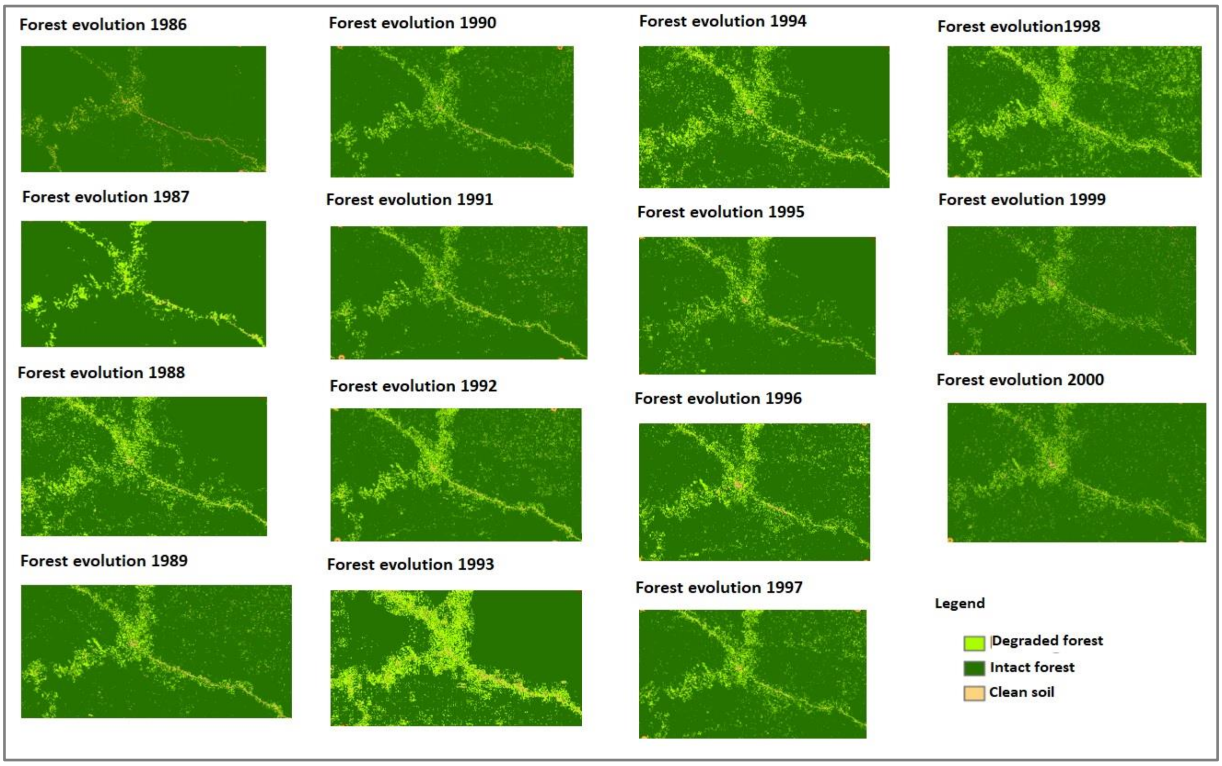

Figure 5. Forest and land cover class changes from 1986 to 2000

The MTKB landscape is characterized by a habitat dominated by primary or intact forest. In the 1980s there was little human activity, which over the years has gradually intensified. In 1993 (Figure 5 and Figure 6), there was a great degradation activity in the intact forests, due to Chinese

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and German road-building activities. This activity has led to an influx of people to these areas to benefit from the related services and opportunities. Also, these companies, in search of gravel and sand for the road, could transport considerable quantities of soil to sample. This process had a visible impact on forest habitats.
Over the 15 years from 1986 to 2000, the deforestation rate is 2.61% with an average annual rate of 7.04% for the degradation of intact forests. The year 1998 was also characterized by the massive arrival of Rwandan refugees and the beginning of coltan and cassiterite exploitation.

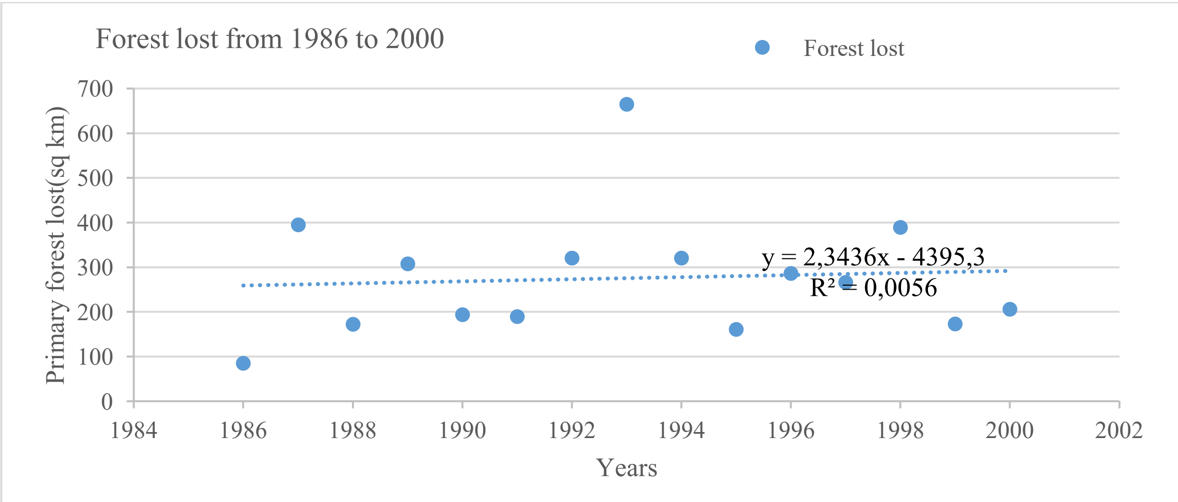

Figure 6. Trends in forest loss from 1986 to 2000

3.3.2. Evolution of forest ecosystems from 2001 to 2010
This period is characterized by the boom in mineral exploitation in the area. This has led to large areas of forest being destroyed (Figure 7 and Figure 8). This is also the period of implementation of community-based conservation in the area. This process of mineral extraction has accelerated the degradation and loss of intact forests, with a deforestation rate of 6.93% and 14.28% of forest degradation in the region (Figure 8).

3.3.3. Evolution of forest ecosystems from 2011 to 2018
During this period, conservation reaches the peak. People receive the conservation message and conservation activities were implemented. There is a decrease in the rate of forest loss (Figure 9). Also, mining activities have decreased (Figure 10), with only 2017 showing a high rate of forest loss. This increase may suggest an in-depth investigation to determine the specific causes. It should be noted that during 2016 and 2017, the company Alphamine Bisighe Mining (ABM) began to build roads and other infrastructure. These activities have had a direct impact on forest habitats.

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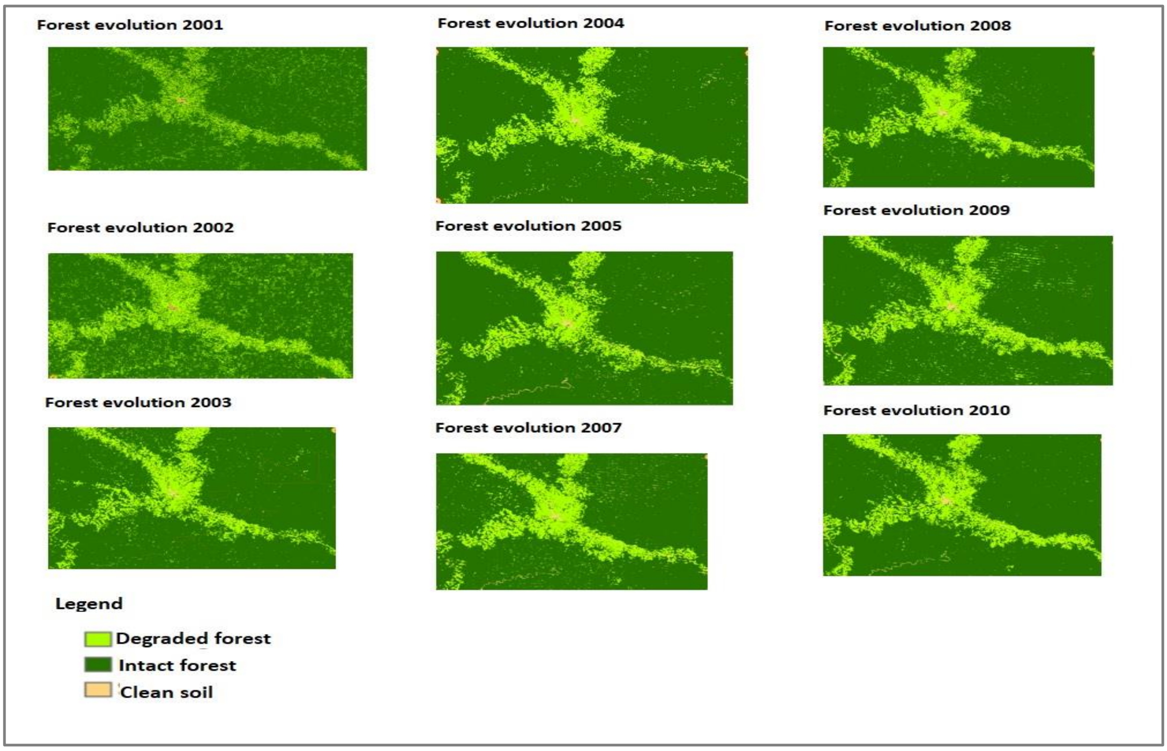

Figure 7. Forest and land cover class changes from 2001 to 2010

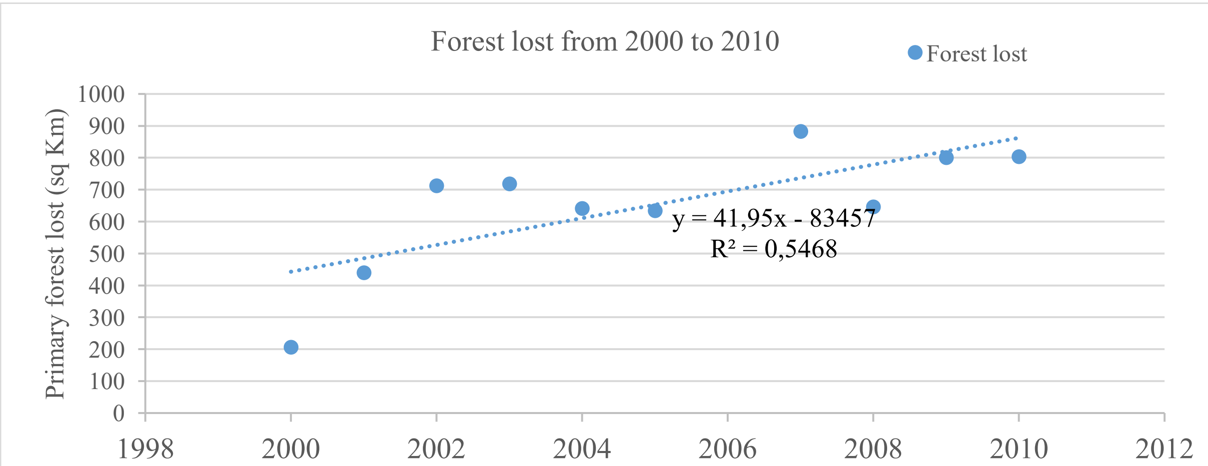

Figure 8. Trends in forest loss from 2001 to 2010

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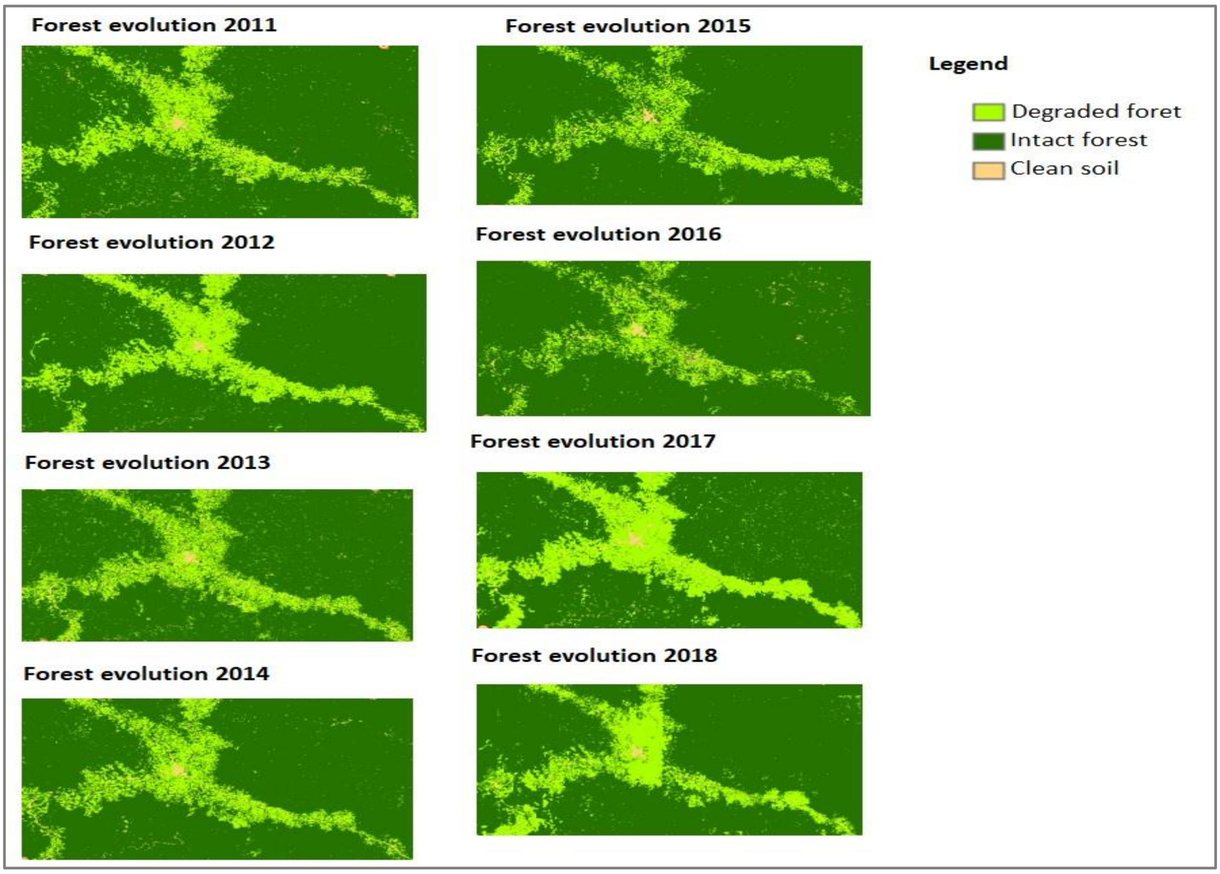

Figure 9. Forest and land cover class changes from 2011 to 2018

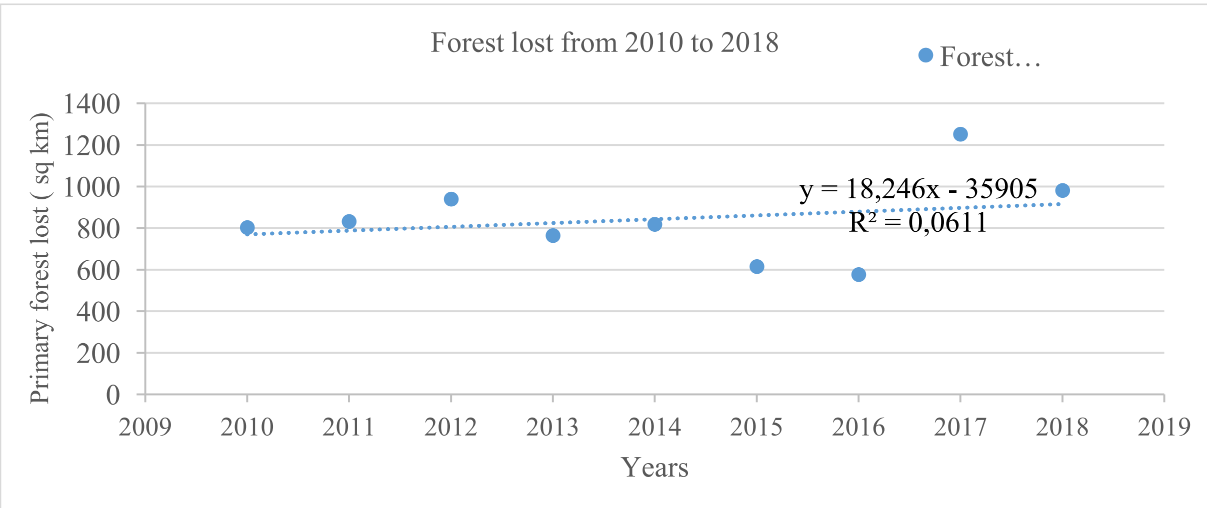

Figure 10. Trends in forest loss from 2011 to 2018

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The 2010-2018 period (conservation is implemented), shows a deforestation rate of 1.22% and forest degradation of 2.77%.

Results show that a low demography also leads to a low rate of deforestation during the period between 1986 and 2018. There are fewer areas for survival (housing and agriculture) and populations do not have significant impacts on forest habitats. Overall, the Congo Basin has low deforestation and degradation rates compared to some regions of the world. However, the rate of net deforestation in the Congo basin increased from 0.09% between 1990 and 2000 to 0.17% between 2000 and 2005. This increase was driven by the DRC as the rate in this country doubled between the two periods, from 0.11% between 1990 and 2000 to 0.22% between 2000 and 2005 (Tchatchou et al. 2015). At the scale of our study area in the MTKB landscape, in contrast, the average deforestation rate over the last 32 years (1986-2018) is 2.74%. And it increased from 6.93% between 2000 and 2010 due mainly to the agriculture, which nevertheless decreased to 1.22% between 2010 and 2018.

3.4. Change detection and Forecasting

Over the past 30 years, forest ecosystems have experienced significant changes due to pressures from agriculture, mineral exploitation, and the influx of refugees from Rwanda. These factors have led to the transformation of 13% of intact forests into degraded forests, while a small portion (1%) of the forest area has been completely cleared (Figure 11). Conversely, 1% of the degraded forest has regenerated into primary forest. Despite these changes, 81% of the original intact forest remains preserved.

Looking ahead over the next 32 years, it is projected that an additional 105 km² of forest could be lost if current land use and management practices continue. In 2050, deforestation rates could reach 1.5%, with a forest degradation rate of 1.87%. As a result, primary forests are expected to be lost at an average rate of 1.85%.

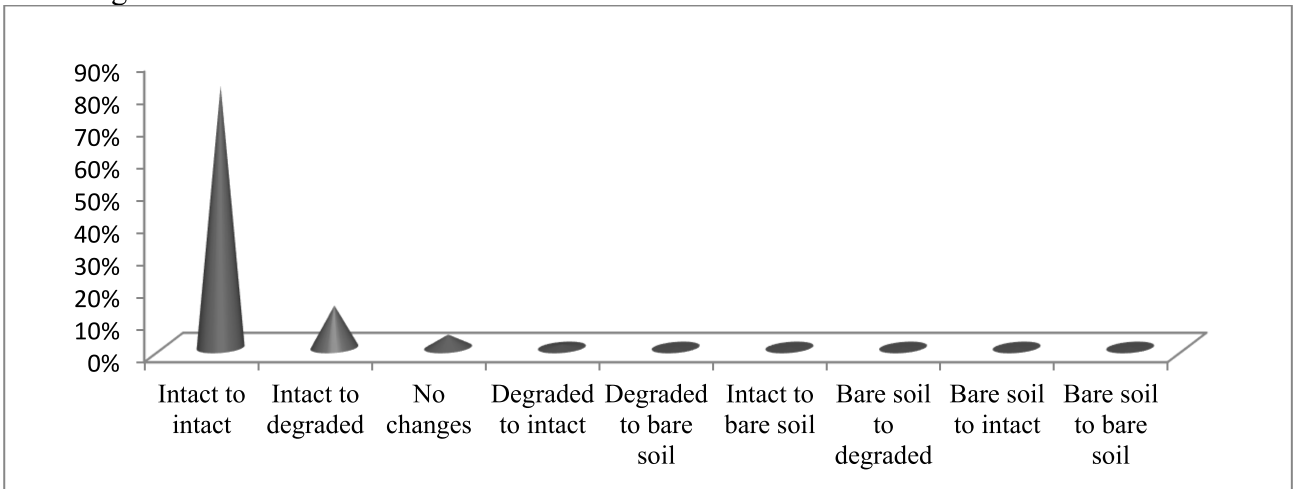

Figure 11. Detection of change between 1986 and 2018 (Degraded to bare soil, intact to bare soil, bare soil to degraded, bare soil to intact and bare soil to bare soil altogether had 1%)

Projecting the result of this analysis into the landscape scale, in the next 32 years (Figure 12) approximately 10074.4 ha of dense forest area will be deforested in the MTKB landscape.

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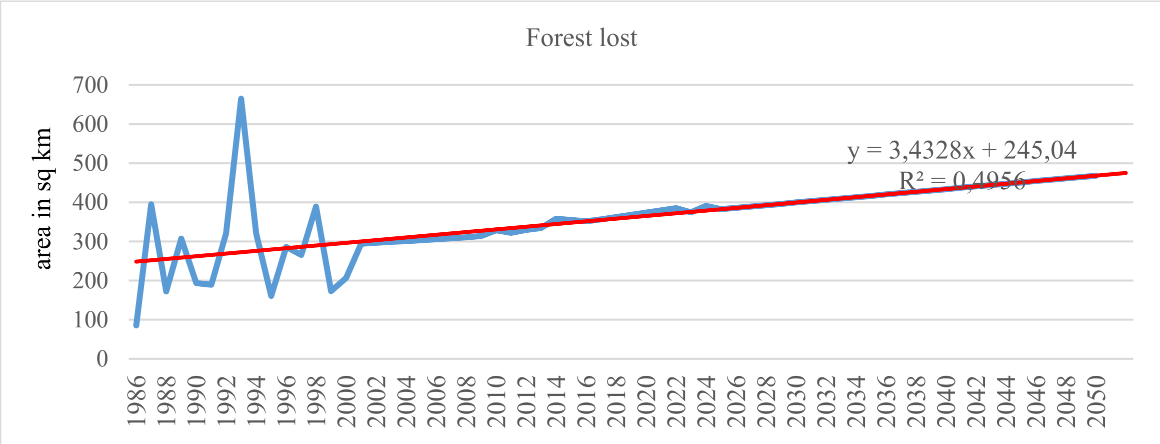

Figure 12. Forecast curve for the evolution of forests to the year 2050

While in developing countries, subsistence agriculture is responsible for 33% of forest degradation (Moniruzzama et al., 2020; Hosonuma et al., 2021), and in some Asian countries, it is the paper and palm oil industries that are responsible for deforestation and forest degradation (Patentreger et al., 2011; Procaccia et al., 2012; Rival and Levang, 2013). In the MTKB Landscape, subsistence agriculture and housing cover 87% of the cause of deforestation and degradation. Certainly, palm cultivation is already practiced in the area and may pose a threat shortly, if some regulations will not be done.

Mining also has a considerable impact on deforestation in the region. The forests of the DRC are threatened by this new form of land allocation. Although most of the mining licenses in the MTKB landscape are not in operation, they cover approximately 55015.37 km2, not including artisanal mining areas.

The major changes were observed in the conversion of intact primary forests to degraded forests in 13% (Figure 11), and with the same land-use pace, without major changes in the land-use system and with current trends, the loss of forests in this area will have an average rate of 1.85% by 2050 or 100.744 km2 on the landscape scale (Figure 12). Our results in the MTKB (Figure 3) landscape show the same global trend found by the World Resource Institute (WRI, 2020) where the year 2016 had more than 12% deforestation (Figure 13)

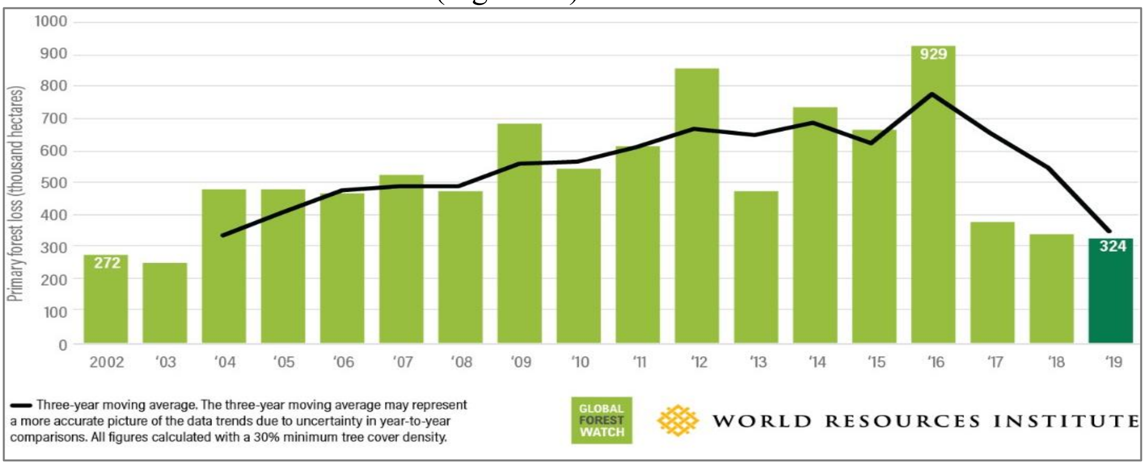

Figure 13. Comparison of WRI statistics from Indonesia (1986-2018) with our results from Figure 3

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The MTKB landscape is rich in biodiversity, with iconic species such as Grauer's gorillas, forest elephants, okapi, Congolese peacocks, chimpanzees, and other protected species. It is the only place in the world where the Grauer's gorilla is found; hence the surname "Grauer's landscape" was given to this landscape. Today, the problems of forest habitat conservation and management are multi-layered and are intimately linked to society's need to measure, preserve, and manage multiple forest values. Population growth and climate change seem likely to create continuous pressure on forests, so that their preservation, even over relatively short periods, seems largely compromised. Human activities threaten the physical existence, biodiversity, and functioning of forests (Franklin, 2001).
These changes occur at a range of spatial scales from local to global and at temporal frequencies from days to millennia (Townshend et al., 1991). Both natural and anthropogenic forces are responsible for these changes. Natural forces, such as continental drift, glaciation, floods, and tsunamis, and anthropogenic forces, such as the conversion of forests to agricultural land, urban sprawl, and forest plantations, have altered the dynamics of land-use and land-cover types worldwide (Giri et al., 2012).
In DRC, protected areas are characterized not only by the richness of their biodiversity but also by subsoil which can be an important reservoir of mineral resources (mining, gas, and oil). The mining is coveted by multinationals in the sector as well as by small-scale miners (Dallmeier et al., 2006, UICN, 2010). Mining is a serious threat to the landscape, as it is always accompanied by related activities (agriculture, hunting, infrastructure construction, etc.). Approximately 55015.37 km2 of space, or 30% of this landscape, is covered by mining licenses, and other areas are considered as AMZ (Artisanal Mining Zones). These AMZ have not yet been mapped and often overlap with protected areas or CFCL.
Overly, It is recognized that the causes of deforestation are multiple (Porrúra et al., 2007, ECOSOC, 1996), ranging from lack of market compassions for conserving forests (market failure) (Panayoutou 1992), to inadequate allocation of property rights (Katrina & Pearce 1994), policy failure, poverty (Otsuka and Place 2001) or poor management practices. All these propositions probably contain some truth that needs to be considered.
The results of this research suggest conservationists, land planners, government officials, and all stakeholders impacting land use need to synchronize their planning to establish efficient strategies for the implementation of conservation activities, and sustainable management of natural resources, and thus avoid rapid habitat loss of the biodiversity of the MTKB Landscape. This survey is the first in such research category in the landscape and could inspire research on monitoring natural habitats in areas where conservation activities are carried out to evaluate conservation efforts and adjust the means to this purpose.

4. CONCLUSIONS

The vegetation indices for the sample from the MTKB landscape for the period between 1986 and 2018 visibly show three land cover classes: intact forest, degraded forest, and bare soil. The bare soil and degraded forest classes converted into land use classes form the classes where human activities are intense or the rural complex. The peak of forest degradation is visible in the years 2015 and 2017. Subsistence agriculture is the major human activity degrading the forest in the MTKB landscape. The population has retained a high rate of slash-and-burn agriculture as a cultivation method, a practice that pollutes the atmosphere and degrades the soil. At the second position, local people claim to practice shifting cultivation. Although regulated, the agricultural

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sector suffers from a lack of supervision and rigorous monitoring of small farmers. Many wooded areas are cleared and used for subsistence shifting cultivation. The loss of fertility of agricultural land also pushes the population to clear more and more forest areas to meet their ever-growing needs.

Sustainable management of ecosystems in the MTKB landscape should be achieved through the development of a land-use policy that takes into account the needs of local people and places particular emphasis on sustainable and intelligent agriculture to promote local economic growth. Rigorous land allocation studies need to take place and an analysis of the effectiveness of biodiversity conservation under different community-based management arrangements needs to follow. A re-visitation of mining licenses in the landscape is needed for those in protected areas and high biological value habitat zones. For efficient forest protection, ecological education is needed, as well as the creation of alternative activities and incentives. The AMZ in this region requires mapping to clarify their distributions and areas to avoid potential conflicts in the future. Such measures will help mitigate ecosystem loss or degradation and enhance the conservation of biodiversity and endangered species in the landscape, as well as combating climate change and promoting local development.

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