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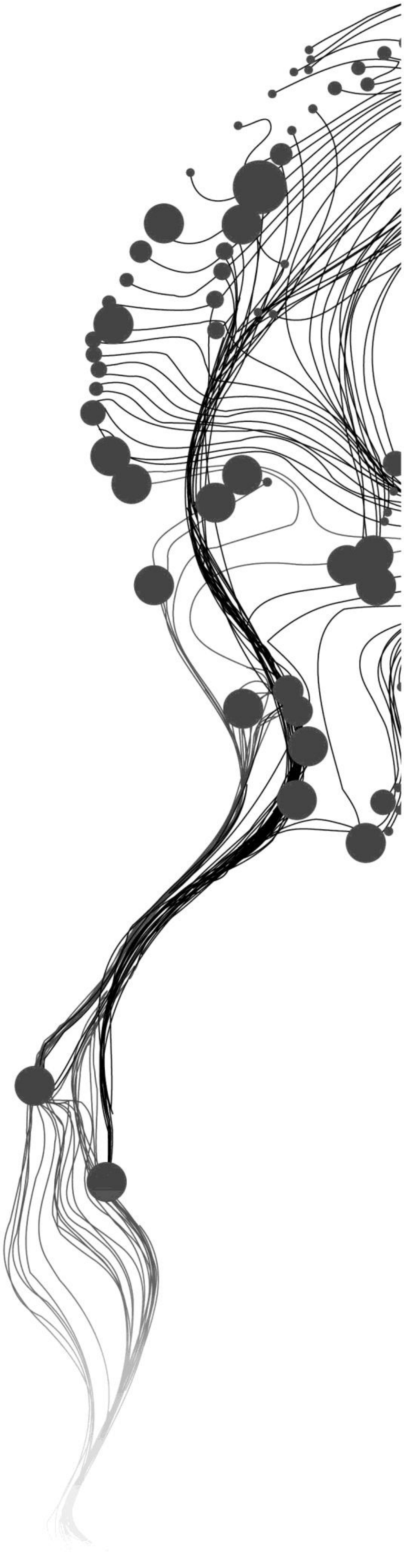

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ABSTRACT

Habitat fragmentation, arising from anthropogenic activities, is one of the main threat to biological diversity and primates in particular. However, primate species differ from each other in responding to fragmentation vulnerability. The chimpanzees considered as endangered and rare species, with low fecundity have been identified to be much more affected by fragmentation and habitat degradation. This study aimed to assess the chimpanzee habitat fragmentation within and around the Cyamudongo forest patch in the perspective of identifying where future potentially chimpanzee habitat can be restored to connect isolated forest patches with the contiguous forest of Nyungwe in Rwanda.

This study used remote sensing data to map and detect land cover change in the landscape located between Cyamudongo and Nyungwe National Park through 1989, 2005 to 2013 and then quantify spatial patterns changes in forest cover in 1989, 2005 and 2013 with FRAGSTATS™. This research defined areas suitable for chimpanzee habitat as well as the areas biophysically suitable for the establishment of ecological corridor. The results showed the total forest area in 1989, 2005 and 2013. Forest degradation increased during the period of 1989-2005, but decreased as from 2005 to 2013. The number of forest patches increased in 1989-2005 indicating more fragmented landscape and decreased during the period of 2005-2013. This research pointed out areas that are most suitable for reforestation efforts based biophysical variables, namely land cover, forest patches, protected areas, slope, distance to settlements, distance to roads, distance to rivers. The application of least cost path analysis with corridor design and ArcGIS software produced three corridors path, the corridor path 4 has potential to connect several fragmented forest patches between Cyamudongo and Nyungwe National Park.

This research generated baseline data against which long term impact of fragmentation on chimpanzee in Rwanda can be assessed for better conservation and protection of chimpanzee population in their natural habitat in Rwanda.

Key words: Remote Sensing, habitat fragmentation, Chimpanzee, habitat suitability, corridor modelling, Cyamudongo forest

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To my beloved wife Mrs Yvone Akimana and my son Igeno Yvan Harris and to all conservation scientists who care about prrimates protection and conservation.

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ABBREVIATION AND ACRONYMS

APES: Ape Populations Environments Surveys
CAR: Central African Republic
CI: Conservation International
CITES: the Convention on International Trade in Endangered Species
CMS: Migratory Species of Wild Animals
DRC: Democratic Republic of Congo
FFI: Fauna and Flora International
GRASP: The Great Apes Survival Partnership
IUCN: International Union for Conservation of Nature
JGI: The Jane Goodall Institute
MINIRENA: Ministry of Natural Resources
NNP: Nyungwe National Park
REMA: Rwanda Environment Management Authority
TACARE: Lake Tanganyika Catchment Reforestation and Education
WCS: Wildlife Conservation Society
WWF: World Wildlife Fund

1. INTRODUCTION

1.1. Distribution, status and conservation of the chimpanzee

Together with the gorilla (*Gorilla gorilla sp.),* bonobo (*Pan paniscus*) and orangutan (*Pongo sp.*) the chimpanzee (Pan troglodytes) makes up a group of four great apes species. The chimpanzee, close relatives to human being, are divided into four subspecies and widespread of all species of great apes in 24 African countries as follows: *P. t. Schweinfurthii* (Eastern Africa), *P. t. ellioti* (Cameroon and Nigeria), *P. t. verus* (Western Africa), *P. t. troglodytes* (Central Africa). The population size of chimpanzees has dramatically declined in the last decades and disappeared in the wild in some Western African Countries such as Benin, Togo, Gambia and probably in Burkinafaso due to improper management regulations, habitat loss and hunting (Kormos et al. 2003). Moreover, the number of chimpanzees has reduced from 1,000,000 in 1900 to around 300,000 individuals surveyed in 2003 (JGI 2014a). As a result, these creatures are classified as an endangered species on the IUCN Red list of threatened species and considered as species of global concern (Plumptre et al. 2010).

Chimpanzee natural habitat is under pressure across Africa. Human activities such as mineral extraction, illegal logging, charcoal production, agricultural expansion, hunting for bushmeat and illegal trades of infants are mentioned to gravely threatening chimpanzees. Although the four subspecies of chimpanzees face similar threats, some local threats are found. A survey conducted by IUCN in 2010 reported that Eastern chimpanzees and their habitat are particularly threatened by habitat loss and fragmentation in Uganda, Tanzania, Burundi and Rwanda (Plumptre et al. 2010). In the Republic Democratic of Congo (DRC), a large number of chimpanzees have disappeared in the last decades due hunting, trade of infant, diseases such as Ebola epidemic which killed a large number of chimpanzee population (Beudels-Jamar et al. 2008). In the Central African Republic (CAR), chimpanzee are target for bush meat which is aggravated by armed Sudanese poachers, refugees, militia, poor law implementation and high level of human suffering (Plumptre et al. 2010; A.P.E.S 2014).

International awareness on chimpanzees conservation and protection has been growing progressively since 1960's started in Gombe National Park in Tanzania. Under the financial support from Leakey Foundation, Jane Goodall came to Gombe to study chimpanzees in July 1960. She was the first to closely study chimpanzees in their natural habitat. She became world famous by discovering that chimpanzees are capable of making and using tools (Goodall 1990). Moreover, Jane Goodall, learned that chimpanzees and their habitat are threatened from human related activities namely agriculture, hunting, etc. She decided to stay in Gombe and started speaking to the world on the importance of protecting chimpanzees. Later 1980's, she created the Jane Goodall Institute, a famous institute dedicated to the conservation of chimpanzees and protection their habitat with the aim of improving the global understanding and treatment of great apes through education, advocacy and research (Goodall 1990).

Despite the effort of the global community in protecting chimpanzees, the conservation struggle continues to reduce human pressure on chimpanzee habitat. Today, similar initiatives or projects have been launched in different part of the continent where chimpanzee are vulnerable. The Tai Chimpanzee project in Cote d'Ivoire (Tai et al. 1995), The Budongo Conservation Field Station in Uganda (Babweteera and Reynolds 2014) and The chimpanzee Conservation Centre in Guinea Bissaou (Slayback et al. 2011). Moreover, a large number of conservation agencies and organization are jointly working together to address the urgent conservation problems facing the chimpanzees. Some of them signed protocols to ensure the long term conservation and management of chimpanzees habitat. Among them WWF, CITES, FFI, CMS, CI, GRASP, etc. Primatologist, conservation biologists and ecologists decided to build databases to facilitate access, information sharing, education and research on chimpanzee and it's conservation (A.P.E.S 2014).

1.2. Habitat fragmentation

In order to better understanding the concept of habitat fragmentation and its effects, the term habitat must be clearly explained. The term habitat has been defined by many conservation scientist but that term has been most of the time been confused with the term vegetation type (Franklin et al. 2002). He defined the term habitat as an as an assemblage of resources and conditions required for an animal species to survive; or a set of environmental conditions such vegetative association, cover type that an animal may use to survive. According to Franklin et al. (2002) habitat fragmentation can also be defined as 1. The reduction and isolation of patches of natural habitat 2. an alteration of the spatial configuration of natural habitats 3. a landscape transformation that includes the breaking of large habitat into many smaller pieces, 4. when a large, fairly continuous tract of a vegetation type is converted to other vegetation types such that only scattered fragments. Generally, the habitat fragmentation is an ecological process in which a large patch of habitat is divided into smaller patches of habitat (Arroyo-rodríguez et al. 2013).

Fragmentation has become a major subject of research and debate among conservation scientists (Franklin et al. 2002). Habitat fragmentation is a major factors that contribute to the decline of many wildlife species including carnivores (Anitha et al. 2013), plants (Hadley and Betts 2012), invertebrate (Leidner and Haddad 2011), reptiles (Lehtinen and Ramanamanjato 2006), birds (Andren 1994) and primates(Chancellor et al. 2012; Chapman et al. 2007). Among various species, the most affected are those with low fecundity, wide ranging species, species with low population density, endemic species and species with natural rare status. Therefore, among the critically impacted species we include the chimpanzee as they exhibit all the above listed characteristics (Plumptre et al. 2010). In the case of chimpanzee, habitat consists mainly of forest vegetation. A large number of them can also live in rain forests, most preferably in primary forest with high trees (Basabose 2005). Chimpanzees live in social communities that range from 5 to 150 individuals while searching for food and nesting (Basabose et al. 2002). Chimpanzees feed on ripe fruits, they spend 80% of the time feeding and their food sources comprised around 56 different plant species of which 94% (Tweheyo et al. 2004). Chimpanzees home ranges varies between 5-20km2 per community in Gombe and up to 30-40 km2 in other forest site (Pintea 2007).

In Rwanda, chimpanzees are found in three nature reserves Nyungwe National Park, Cyamudongo forest and Gishwati natural forest. These reserves are mainly composed of mountain rainforest. They are part of the Albertin Rift afro-mountain and are considered as home to a large number of endemic fauna and flora species such as Birds, primates and plant species (Barakabuye et al. 2007). However, rainforest in Rwanda are facing rapid degradation, loss and change following deforestation for settlement, farming, agricultural activities and soil erosion. As a result the forest vegetation, the primary habitat of chimpanzees, is cleared.

A status survey conducted by Wildlife Conservation Society (WCS) in Nyungwe National Park (NNP), showed that chimpanzee population has been decreasing from 382 individuals in 2004-2005 to 306 individuals in 2009 due to fires occurred in the year 2000s where almost 13% of the park was burned(Barakabuye et al. 2007; Plumptre et al. 2010). Gishwati forest reserve is also home to 9-19 chimpanzees (Chancellor et al. 2012). This reserve was once the largest forest in Rwanda, but has significantly decreased in size over the last 30 years. This forest has been deforested and reduced in size from 280km2 to 6 km2 remaining today. This extreme deforestation was due to the use of woody resources for farming and agricultural activities and the 1994 genocide (Guinness et al. 2014). A small population of 37-41 chimpanzees currently reside in the Cyamudongo forest (Chimpanzee trackers, personal communication, October 10 2014) is isolated from other population in the NNP. Although habitat loss, hunting, and disease are threats to isolated populations, inbreeding poses a long-term threat to the survival of a small isolated population. The genetic diversity of the community appears to be similar to larger, less isolated communities in the same region, susggesting that inbreeding has not become a significant issue yet (Chancellor et al. 2012). Though this community has not experienced significant genetic diversity reduction, it has been predicted that if such a small population remains isolated, inbreeding is inevitable and will cause a bottleneck of genetic diversity (Chancellor et al. 2012).

1.3. Remote sensing of chimpanzee habitat change

Remote sensing techniques have proven to be a good spatial tools for acquire data to map land cover changes. Many other researchers (Alqurashi and Kumar 2014; Dewan and Yamaguchi 2009; Fichera et al. 2012; Pintea 2007; Pintea et al. 2003; Wasige et al. 2013) used Landsat data for land cover mapping and change detection purposes. Pintea (2007) used Landsat imageries to detect and monitor changes of forest structures at the landscape. He also investigated the use of Landsat data to map chimpanzee habitat in Gombe National Park between 1972-1999. Pintea outlined three types of information that can be accurately generated with the aid of remotely sensed data, namely forest extent, the type of forest, forest cover and forest biophysical properties. He also stated that remote sensing can provide baseline information that can help in assessing deforestation and supporting conservation related activities. It can also help to identify areas of interventions to improve livelihoods of the population living around protected areas and encouraging them to reduce threats to protected areas. Reinartz et al. 2008 used Landsat TM images to investigate the habitat use bonobos in the Democratic Republic of Congo. He found that the images with 30 meters resolution can be used to map the generalized forest structure.

Chimpanzee habitat can be fragmented due to human related activities. This resulted in the conversion of natural habitat into farmland, and other land use types. Several methods and techniques have been developed and applied to quantify fragmentation. Landscape spatial pattern analysis software FRAGSTAT is used to analyse spatial pattern at three different scales namely patch, class and landscape scales and nearly 40 kinds of spatial metrics can be calculated. Hickey et al. 2012 developed and applied four landscape metrics edge density, cohesion, contagion and Class area, to characterize potential suitable habitat of Bonobos and found all of them performing better especially Edge Density (ED) which was the best predictor with 72.1% in mapping bonobo habitat. They conducted a moving in FRAGSTATS software (Mcgarigal et al. 2002) to calculate the above mentioned metrics on each of the forest cover layers.

By applying habitat suitability models, a destroyed chimp habitat that perhaps can be restored into suitable chimp habitat could be mapped. Different habitat factors namely, land cover, protected areas, distance to roads, distance to villages and can be used to determine the best suitable areas. For example, riverbanks of wetlands which are protected by country's wetlands Organic Law N° 04/2005 (REMA 2011) could be used to connect different patches. This law recommend 20 meters from river banks to remain free of human made activities. Agro-forestry and tree planting activities could also be another potential action that could involve local community to take action to the restoration of degraded habitat. In Tanzania, Lake Tanganyika Catchment Reforestation and Education (TACARE) Progam initiated in 1994 is a good example. People around lake Tanganyika and Gombe national reserve are encouraged to actively protect chimpanzee habitat through reforestation (JGI 2014b)

In Rwanda (Saad et al. 2013) elaborated a reforestation suitability map and an ecological corridor that would be beneficial for national parks managers for future plans to connect Nyungwe forest, Mukura Forest and Gishhwati to enable free mobility of chimpanzees. A similar study in Uganda, considered chimpanzees habitat specific required to build a corridor model that will enable mammals including chimpanzees to move across many patches of the Murchison-Semliki landscape (Nangendo et al. 2010). Therefore, this research seeks to assess the forest cover changes over the last 30 years, to examine the fragmentation of the forest between Cyamudongo and Nyungwe forest, to assess habitat suitability in the study area and determine the most promising location of an ecological corridor when habitat restoration is considered to take place.

1.4. Problem statement

A small population of chimpanzees currently resides in the Cyamudongo forest patch , isolated from other populations in the big forest of Nyungwe National Park. Although diseases, farming, agricultural practices, hunting and habitat loss are serious threats to chimpanzees (Plumptre et al. 2010), inbreeding also poses a long-term threat to the long term survival of a small isolated population, such as these chimpanzees. Additionally, there is a lack of baseline data and information about chimpanzee habitat and restoration in Rwanda. Up to date, no study attempted to analyze fragmentation in chimpanzee habitat in relation to the spatial configuration of forested landscapes such as forest patch size, patch isolation, etc. and this gap rises serious concern on long term viability of the chimpanzee population inhabiting fragmented areas like Cyamudongo forest. The research findings will serve as baseline data against which short and long term impacts of fragmentation on chimpanzee population can be assessed and conservation and restoration measures can be considered. In this way this study hopefully contributes to better conservation and ensuring long term survival of these endangered animals in their natural habitat in Rwanda.

1.5. Research objectives

Overall objective

To assess the chimpanzee habitat fragmentation within and around the Cyamudongo forest patch in the perspective of identifying where future potentially chimpanzee habitat can be restored to connect isolated forest patches.

Specific objectives

To analyze the chimpanzee habitat within and around the Cyamudongo forest patch over the last 25 years;
To map and detect changes within and around the Cyamudongo forest patch over the last 25 years;
To assess the suitability of chimpanzee habitat within and around the Cyamudongo forest patch;
To quantify fragmentation patterns of chimpanzee habitat within and around the Cyamudongo forest patch over the last 25 years;
To identify areas best suited for the corridor establishment to expand chimpanzee habitat in the future.

Research questions

What is the current distribution of forest patches around the Cyamudongo forest and how did this develop in the past?
What were the changes in forest fragmentation over the last 25 years?
What are the areas suitable for chimpanzee habitat?
Which areas are biophysically suitable for expansion of chimp habitat in view of connecting the isolated forest patch to the main forest area?

2. MATERIALS AND METHODS

2.1. Study Area

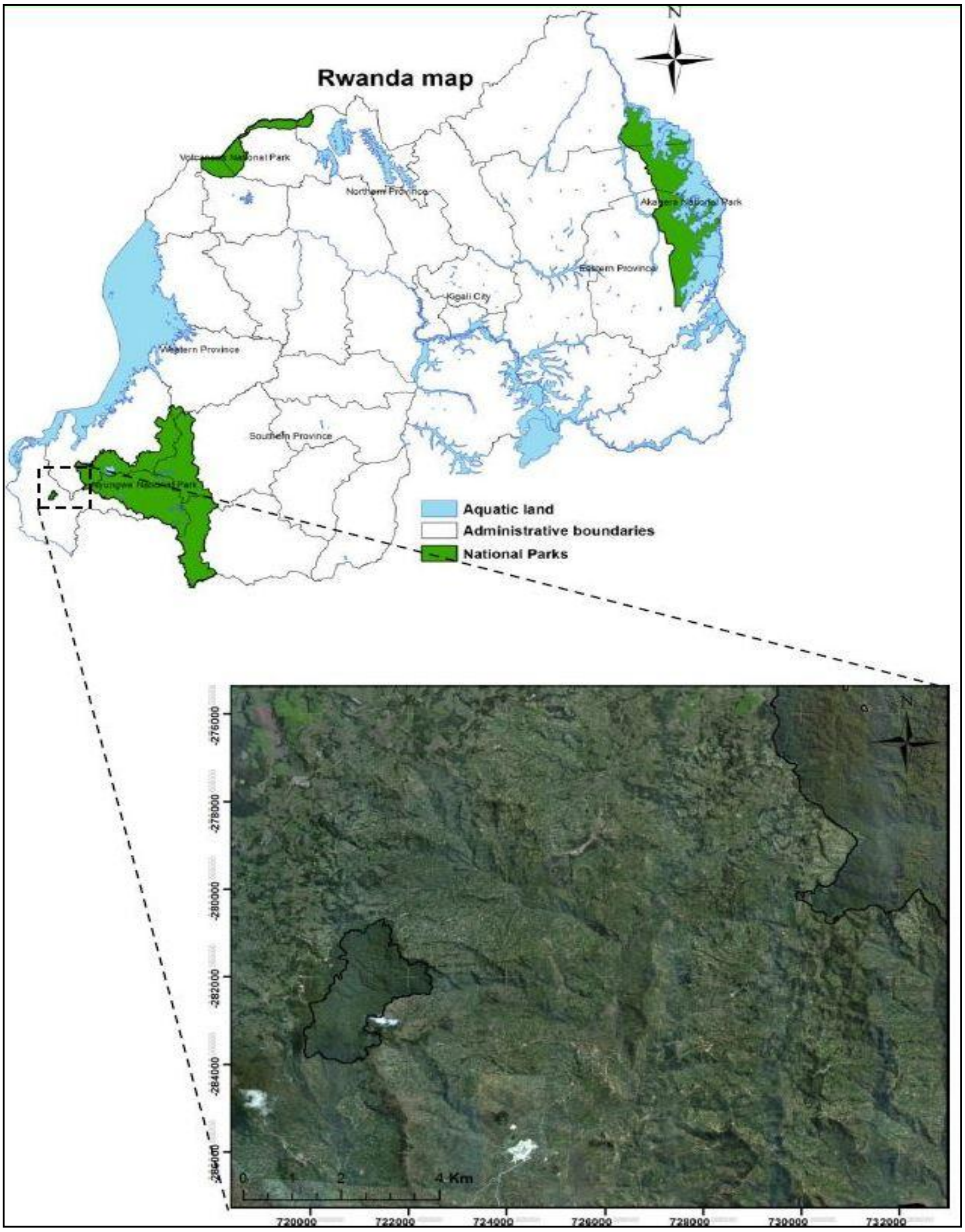

Figure 1: Geographic location the Cyamudongo-Nyungwe landscape

The image in (figure 1) is an high resolution aerial photographs which was taken in 2008 in an aeral survey mission conducted by Swedesurvey and was acquired from Center of Geographic Information System and Remote Sensing of the University of Rwanda (CGIS/UR).

The study area includes the landscape extended between Cyamudongo forest, a small forest patch and Nyungwe National Park. It shows landscape and boundaries of natural forests. The Cyamudongo forest patch in the southwest and Nyungwe forest in the north east corner.

Nyungwe National Park is a high-altitude, mountainous tropical rainforest situated in the South-western of Rwanda between the latitude of 02°15'-02°55'S and longitude 29°00'-29°30'E. Nyungwe was established in 1933 as a natural forest reserve and gazetted as a national park in 2005. It covers a total area of 970 km and together with neighbouring Kibira National Park in North of Burundi, it forms one of the largest tropical mountain forests in Africa (Plumptre et al. 2002). As a tropical rainforest, the climate in Nyungwe is general cool, with annual precipitation average of 1744 mm (Kaplin et al. 1998). The daily temperatures vary throughout the year with average minimum of 10.9^{0}C and maximum of 19.6^{0}C. Nyungwe is home to a wide range of mosaic types vegetation (Sun et al. 1996). Apart of being a tropical montane rainforest, various and unique vegetation types are found in in Nyungwe namely, high altitude wetland, bamboo, acacia woodland, savanna grassland and this mosaic make the forest a habitat to many wildlife species.

Nyungwe counts more than 265 plant tree species with at least 24 species that are endemic to the Albertine Rift. Various tree species are found therein including *Philippia benguelensis, Agauria salicifolia, Faurea saligna* and *Hagenia abyssinica* and so many others (Gapusi 2007). Nyungwe forest is also home the world's most threatened primate species makinf the forest one of the montane rainforest rich in primate communities in Africa (Kanyamibwa 2013). Of particular interest are the spectacular association of more than 300 black-and-white Colobus monkey *(Colobus angolensis ruwenzorii)*, an estimated 500 chimpanzees population *(Pan troglodytes schweinfurthii)*, the owl-faced monkey *(Cercopithecus hamlyni)*, golden monkey (*Cercopithecus mitis kandti*) and so many others (USAID 2008, Masozera 2002; Plumptre et al. 2002). Nyungwe is very rich in birds species and ranked second only to Itombwe Massif in the Democratic Republic of Congo (DRC) to hold a large number of various birds species that are known endemic in the Albertine Rift region (Plumptre et al. 2002).

Cyamudongo forest is a small forest of 410ha located in the south-western of Rwanda (02°33.12'S 28°59.49'E) in eight km away from Nyungwe National Park (NNP). Its altitude ranges between 1,700 to 2,000 m above sea level. Cyamudongo forest is home to a wide range of fauna and flora species. These include a group 41 chimpanzees *(Pan troglodytes schweinfurthii)*, baboons, mona monkeys, important bird species and so many plants species. The vegetation of the forest is dense with some common different tree species like *Chrysophyllum gorungosanum, Croton spp., Newtonia buchananii, Alangium chinense and Leptonychia melanocarpa* (BirdLifeInternational 2014). Historically, Cyamudongo forest was connected to Nyungwe in its northeastern side. However, due to human population increase, forest conversion into farmlands and agricultural lands as well as into tea plantation, Cyamudongo forest was progressively reduced in size up to 410 ha of its natural forest remaining today.

Various man made and illegal activities area still threatening the forest namely, encroachment, trees logging for housing construction, agricultural support and for making bricks. Native people in the area who actually depend on forest resources to survive are usually cutting trees in the core and buffer zones as well as collecting firewood. These actions are sources of conflict between native people and park managers whose primary responsibility is to make sure the remaining forest of Cyamudongo is well protected against any human related activities.

Due to its richness in unique wildlife such as chimpanzees, Cyamudongo was officially annexed to Nyungwe National Park in 2005 to enhance its management and protection. Because of its small size, Cyamudongo forest has been considered a natural reserve that needs much attention in conservation and involve local community in it's protection. In this perspective, tourism and research activities were initiated therein to provide revenues to the local communities so that they feel in conservation practices.

Being smaller, it is much easier for tourists and researchers to track chimpanzee in their limited home range of Cyamudongo.The chimpanzee attracts many researchers and tourists. As as result, research and tourism activities provide daily income to the local population to sustain their families. According to Mr Télésphore Ngoga, Conservation Division manager, who has management and conservation of natural parks in his attributes, tourism was initiated in Cyamudongo to particularly offer guarantee and long term protection to remain chimpanzee population. Other possible attractions in that forest are hot springs, bird watching, nature walks, cultural tourism, and a cave with cultural myth to it.

2.2. Materials

The following equipments were used in this research (table1)

Table 1: List of equipment

Equipments		Used for:
1.	GPS Garmin Etrex	To collect and locate GPS points of variables (% cover, tress species and height
2.	Mobile GIS	To navigate to selected sample point To collect and locate GPS points of variables (% cover, tress species and height)
3.	Binocular	To visualize chimpanzees in the trees and tree species recognition
4.	Digital camera	To take photos during field work and recording interviews.
5.	Data collection form	To collect vegetation structure data (% cover, tress species and height)
6.	50 meters tape measure	To measure the plot size
7.	High resolution image from Google Earth	To select and recognize sample plots To define field classes
8.	Topographic map	Georeferencing Landsat images to the coordinate system of Rwanda (WGS84, projection: UTM zone 35)
9.	Orthophoto of 2008	To select and recognize sample plots To define field classes

The following software were used in this research (table2)

Table 2: List of software:

	Software	Use for:
1	ERDAS Imagine 10.1	Image classification
2	ArcGIS 10.1	Data preparation, map productions
3	ILWIS3.8	Image processing and analysis
4	FRAGSTAT	Landscape metrics calculation
5	Corridor Design	Habitat suitability and corridor modelling
6	Microsoft Excel	Data entering, preparation and statistical analysis
7	Microsoft word	Reporting
8	Microsoft Visio	Flowchart

The following are different data types used in this research (table3):

Table 3: List of data

Data		Source
1.	Landsat data TM 1989 & 2005 and ETM+ 2013	http://glovis.usgs.gov/
2.	Topographic map 1988	CGIS/UR
3.	Aerial photograph 2008	RNRA
4.	High resolution image (Google Earth)	Geodata Warehouse-ITC
5.	Vegetation structure data (% trees cover, tree species and height)	Field work
6.	Digital Elevation (DEM) data	Geodata Warehouse - ITC
7.	Roads, rivers, villages, protected Areas shapefiles	RNRA

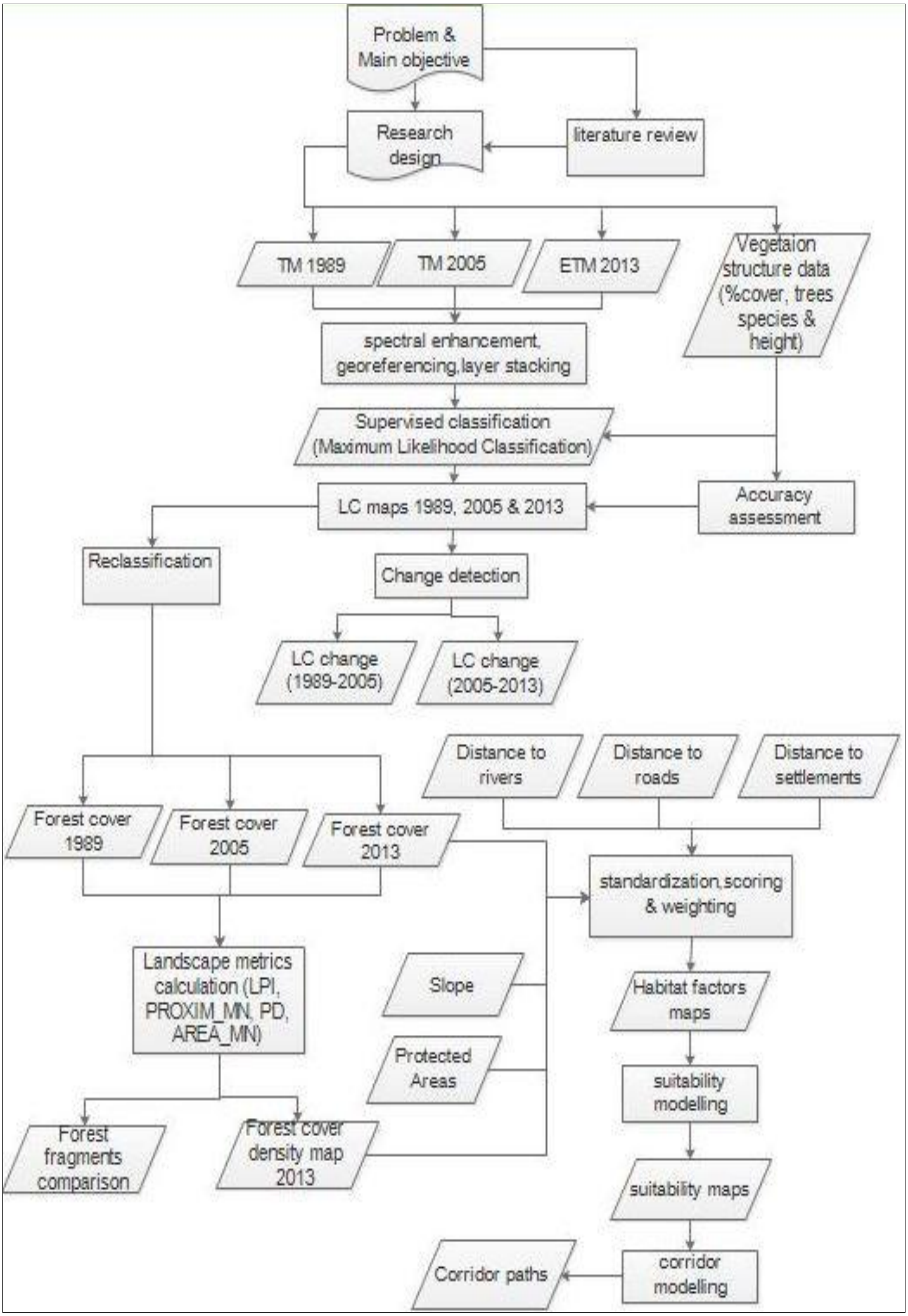

Figure 2: Research approach to analyse chimpanzee habitat fragmentation in view of conservation and habitat restoration

2.3. Land cover change mapping

2.3.1. Field Sampling:

Stratified clustered sampling method was used for field observation. In stratified sampling, the land cover types are grouped together based on similarities of spectral characteristics. Stratified sampling is necessary and aid to make sure that small but important land cover are included in the collected samples (Congalton & Green 1999). With the aid of aerial photo of 2008, 150 representative sample points distributed within the study area boundary were selected. The selection of these samples points depends different characteristics of land cover (pattern, color, texture, etc). Taking into consideration the easy accessibility of some location of the study area, a cluster of 4 (four) sample points were settled around each of the selected sampling units in East, West, South and North direction at an estimated distance of 150 meters each. A sample plot of 20m of radius was applied and for each sample point a data collection form (appendix) was used to fill in the relevant data observed.

To describe the composition and structure of the land cover types, sample plots were visited in the field and predominant land cover type was sampled first based on different variables such as estimated percentage cover, trees species, trees height. Handheld mobile GIS and GPS were used to navigate to each selected sample point. Others field equipments were also used during fieldwork among them digital camera, 50 meters tape measure, binocular, topographic map, high resolution image from Googgle Earth, orthophoto of 2008, false color composite of TM, ETM+ satellite images. Based on the satellite image and field observation, a list of map classes which could be distinguished on the satellite image was elaborated. As a results (4) four land cover types were identified within the defined study area (table4). These classes are forest, tea shrubs, crops and bareland & settlements. To obtain information about the forest cover change local leaders, park authorities and elderly people in the villages located in between the Cyamudongo and Nyungwe forests were interviewed. The interviews were conducted through video recording.

Table 4: Description of land cover classes

LC Classes	General description
Forest	Natural and private (plantation) forest. Those are trees with open and close canopies. Those trees includes nesting and food tress of chimpanzees in Cyamudongo and Nyungwe forest such as: *Cymphonia groblefela, Syzygium guineensis, Dombea gotseenii, Ficus sp., Carapa grandiflora*, etc., trees in the buffer zone: pinus, grevillea and cypress and trees owned by local population such as eucalyptus.
Crops	Farmlands, horticultural farms and areas covered by various crops that are grown in the region namely: banana plantation, beans, soya, coffee, cassava, irish potatoes, etc.
Tea shrubs	The tea-plant, in their natural state, grows either in the small or medium sized tree.
Bareland+ settlements	Area with sand plains, unpaved roads, excavation site. It also include human settlement or residential site, commercial and business, public centers such as schools, health centers and churches, etc.

2.3.2. Image classification:

The Landsat images TM 1989 & 2005 and ETM+ 2013 were downloaded from the USGS Global Visualization View (http://glovis.usgs.gov/). The cloud free images were chosen and georeferenced to the coordinates system of Rwanda (WGS84, projection: UTM zone 35) using a topographic map which was generated in 1988. Their main characteristics of the Landsat images (appendix) are summarized in (table 5).

Table 5 Landsat images used in forest cover classification

Satellite Type & Sensor	No. of Bands	Pixel resolution (M)	Observation date	Source
Landsat5 TM	6	30*30	August, 1989	http://glovis.usgs.gov/
Landsat7 ETM	6	30*30	July, 2005	http://glovis.usgs.gov/
Landsat8	7	30*30	July, 2013	http://glovis.usgs.gov/

The downloaded landsat images were enhanced before using them. Spatial enhancement and spectral enhancement techniques were applied in ERDAS Imagine ™ 10.1. The downloaded images are separate TIFF files bands which covered the large area and go beyond my study area. In first instance, the image combination of all bands, starting from band 1 up to band 7 except band 6 and 8 was performed into ERDAS Imagine™ 10.1. The layer stack tool was used for bands combination. Supervised classification with Maximum Likelihood Classification (MLC) algorithm techniques in ERDAS imagine10.1 software were employed to classify the digital images into the defined land cover types: forest, tea shrubs, crops, bareland & settlements. A hundred and fifty (150) samples collected during field work were used to classify and valiate the images. A hundred and five (105) samples were used as training samples to classify the landsat images; forty five (45) were used as testing samples to validate the classified images. The MLC algorithm assigns a pixel to a particular land cover based on covariance information. A 3x3 majority filter has been applied to the classified images to eliminate and replace isolated pixel with values of their surroundings (Wasige et al. 2013)

The classification accuracy of classified images of 1989, 2005 and 2013 was assessed and an error matrix tables were elaborated. The Kappa coefficient was used to statisticall compare the classification accuracies of classified images of 1989, 2005 and 2013 using the (equation 1). The Z test value was also used to test if there a significant difference between two pairs of classified images. If the z-value is greater than or equal to 1.96, it means a statistically significant difference at 95% confidence between two Kappa statistics. This corresponds to a P value less than or equal to 0.05 (Wang et al. 2009).

$$k = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+} X_{+i}}{N - \sum_{i=1}^{r} X_{i+} X_{+i}} = \frac{\theta 1 - \theta 2}{1 - \theta 2}$$ -------------Equation 1

$$\theta 1 = \sum_{i=1}^{r} \frac{X_{ii}}{N} \qquad \theta 2 = \sum_{i=1}^{r} \frac{X_{i+} X_{+i}}{N^2}$$

Where and "r" is the numbe rof rows in the error matrix, "xii" is the number of observations in row i and column i, and Xi+ and X+i represents the marginal totals for column i and row respectively, and N the total number of observation.

To define two classes: Foret and Non forest, the land cover classes of images of 1989, 2005 and 2013 were reclassified. Therfore, Forest class remained as forest whereas tea shrubs, crops and bareland & settlemets classes were combined into non forest class. These two classes served as input for further analysis of fragmentation analysis

2.3.3. Change Detection:

To identify the land cover change that occurred during the years 1989-2005 and 2005-2013, a post classification comparison approach of the land cover maps from the years 1989, 2005 and 2013 was applied in ArcGIS 10.2 overlay tools..

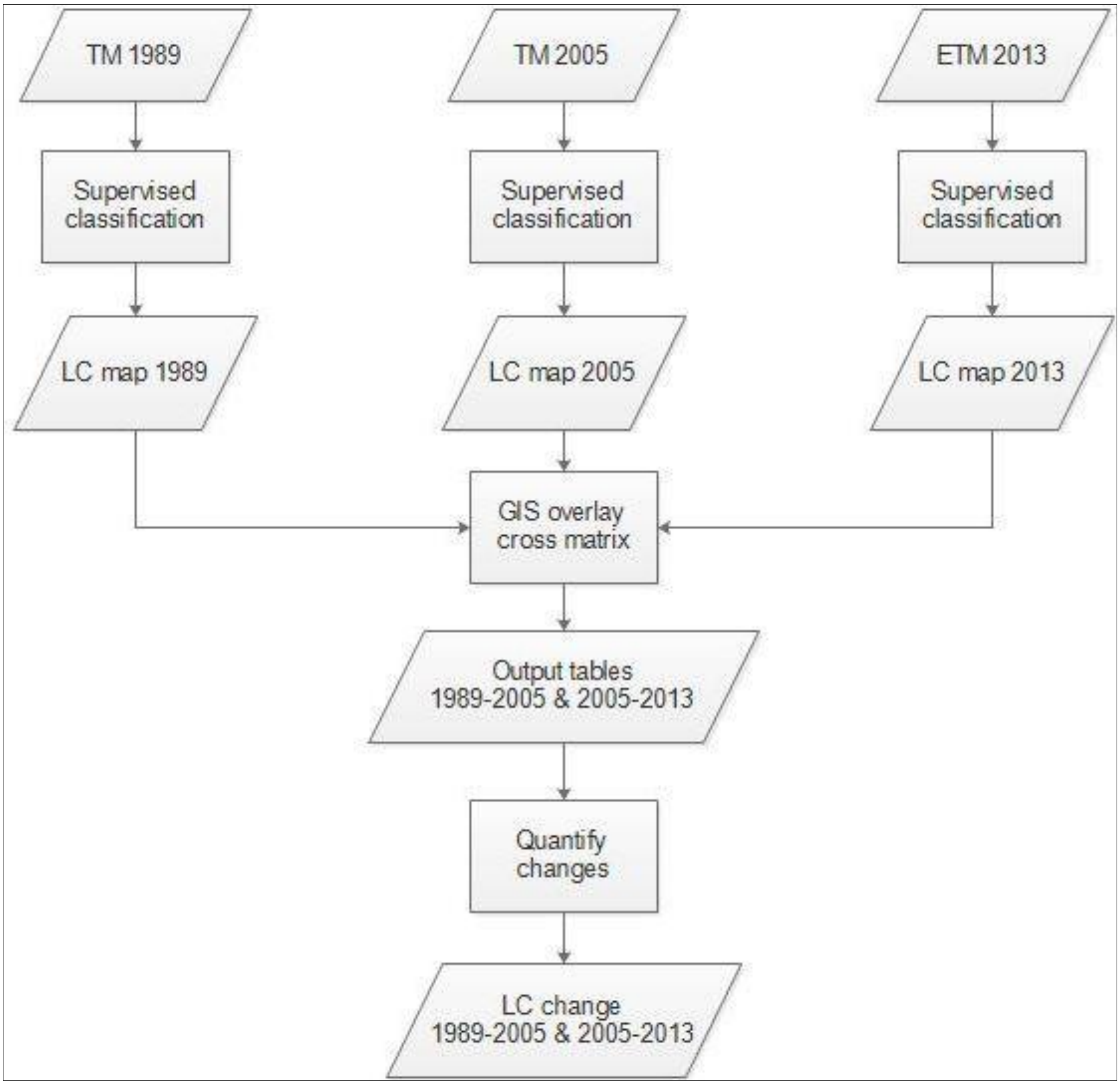

Figure 3: Post classification land cover change detection

2.4. Fragmentation analysis

A software package called FRAGSTATS was applied to quantify fragmentation patterns. FRAGSTATS was developed by a team of conservation scientists, ecologists, forest managers of the Department of Forest Science of Oregon State Univeristy, USA (Mcgarigal 1994). Two versions of FRAGSTAT have been developed and are currently used to calculate and analyse landscape metrics, Raster (Image maps) and Vector (ARC/INFO) versions.

In this research, the raster version was employed to compute metrics with a constant spatial unit and to create a continuous landscape metrics surface for statistical analysis, by using a square moving window computing technique. Within each window, each selected metric is computed. By selecting moving window mode, the following parameters of that window should be specified: shape and size in meters and then the moving window is passed over the grid until every positively valued cell containing a full window is assessed. The output is a new grid for each selected metric. FRAGSTAT is useful, appropriate and helpful to analyse landscape fragmentation or provide detailed characteristics of landscape as well as components of those landscapes at different levels (Mcgarigal 2014; Çak et al. 2008). Three kinds of scales exist: patch, class and landscape (Mcgarigal 2014) and nearly 40 landscape indexes could be quantified. The descriptions of landscape metrics and their corresponding scales are found in the user's guide of FRAGSTATS (Mcgarigal 2014). In this research, forest cover maps of 1989, 2005 and 2013 were used for fragmentation analysis. Due to the shortage of publication on fragmentation analysis for primates, other publications on Panda (Tong 2011, Sun 2011) and bonobos in DRC (Hickey et al. 2012) were used to identify landscape metrics that best describe the habitat fragmentation for chimpanzees. Therefore, the relevant metrics were selected and used in this research. These metrics are (1) Patch density: PD (2) Mean patch area index: Area MN (3) largest patch index: LPI and (4) Mean proximity index: PROX_MN. A short description of these metrics are provided in table 5 and more details on them are found in (Mcgarigal 2014; Kele et al. 2008; McGarigal et al. 2012)

Table 6: Landscape pattern metrics description

Index (unit)	Description
LPI (%)	The percentage of the landscape comprised by the largest patch
AREA_MN (ha)	Average size of patches
PROX_MN (m)	Average proximity index for all patches in a class
PD	Number of corresponding patches divided by total landscape area

With the aid of FRAGSTAT software interface (figure4) these spatial metrics were computed through the following steps: 1. selecting input layers, (2) specifying common tables (3) setting analysis parameters (4) selecting and parameterizing class metrics (5) executing FRAGSTAT (6) browsing and saving the results. The results were thereafter processed and analysed in excel software. More details on the above mentioned steps are found in the FRAGSTAT user guide (Mcgarigal 2014)

2.5. Habitat suitability modelling:

Based on chimpanzee ecology profile (Koops et al. 2012; Basabobe 2002; Pintea 2007), previous habitat suitability and corridor modelling practices (Nangendo et al. 2010; Saad et al. 2013) biophysical variables that describe habitat requirements of chimpanzee were selected. These variables are land cover, protected areas, slope, distance to rivers, distance to roads, distance to villages and forest patches. The selected variables were standardized and assigned a suitability score based on their resistance to the chimpanzee movement and then assigned weights based on how each variable is important to the chimpanzee (Nangendo et al. 2010). A high score of 100 was given to the best habitat or suitable and a score of 0 was assigned to a class of variable which does not correspond to the habitat requirement or unsuitable. To calculate the suitability value of each pixel, the weighting system was used to assign weight to different habitat factors. Four different scenarios were considered and the weights for different habitat was assigned based the publications (Nangendo et al. 2010; Saad et al. 2013), species expert, park managers and reseachers offices, laws, regulations and policies in Rwanda.

Scenario 1 lead to the creation of habitat suitability map 1. The habitat suitability map A was produced based on publication (Nangendo et al. 2010) through a combination of the following factors: land cover, protected areas, distance to roads, distance to rivers, distance to settlements.

Scenario 2 and 3 were basically the same in term of relative importance of the different factors and lead to the creation of habitat suitability maps 2 and 3 respectively were generated based on two different standardizations of slope steepness. The map 2, was based on another publication (Saad et al. 2013) during which steeper slope was given high suitability score with the fact that chimpanzees typically reside in areas with steeper slopes.

However, on the other hand, chimpanzee may be found on steeper slope not because they prefer to reside there but because human activities pushed them to the to hogher slope, areas which are considered less suitable for agriculture and more susceptible to soil erosion. Therefore, another Scenario was created to generate a habitat suitability maps 3 by giving lower suitability score to steeper slope. The two suitability maps 2 and 3 were compared to evaluate the differences.

Scenario 4: since forest patches are highly valuable for habitat restoration, layer of forest in the surrounding areas of 300 x 300 m was created abd assigned suitability scores and weight to evaluate its influence to the habitat suitability. To make 23% weight for forest patches layer, 10 %, 3% and 10% were respectively removed from land cover, protected areas and slope layers. As a result, the suitability map 4 was created.

In the ArcGIS software, the following tools were respectively used to assign scores to biophysical variables:

- **Arc toolbox>Spatial analyst tool>surface>slope and distance to road**
- **Arc toolbox>Spatial analyst tool>distance> Euclidean distance**

In ArcGIS software, the following tools were used to assign weight to biophysical variables

- **Arc toolbox>Spatial analyst tool>overlay>weight overlay.**

The suitability maps were obtained through the following equation (Favilli et al. 2013).

$$\text{Suitability} = \prod_{i=1}^{n}\left(S_i^{W_i}\right) \qquad \text{Equation2}$$

Where and $\prod$ is the product to combine "n " habitat factors classes "i" with their scores "Si" and their habitat factors weight "Wi". The results of suitability modelling are presented in figure in the results section.

All variables were prepared and overlaid in ArcGIS software to generate all the four habitat suitability maps. Raster images, scores and weights of all variables are respectively presented in figure 4, table 7 and table 8.

Table 7: Criteria of suitability assessment for the habitat factors

Land cover	Protected areas	Slope set 1	set 2	Distance to roads	Forest in surrounding area (300 x 300 m)	Distance to rivers	Distance to settlements
Forest	Protected	0 – 10		0 – 50	0 – 10	0–50	0 –100
100	**100**	**10**	**50**	**10**	**10**	**100**	**0**
Tea	Non protected	11 – 20		51 –100	11 – 20	51–100	101-500
0	**0**	**20**	**75**	**20**	**20**	**90**	**20**
Crops		21 – 30		101–500	21 – 30	> 100	501-1000
0		**30**	**100**	**30**	**30**	**80**	**40**
Bare		31 – 40		501 – 1000	31 – 40		1001 – 5000
0		**40**	**100**	**40**	**40**		**60**
		41 – 50		> 1000	41 – 50		> 5000
		50	**100**	**100**	**50**		**100**
		51 – 60			51 – 60		
		60	**100**		**60**		
		61 – 70			61 – 70		
		70	**100**		**70**		
		71 – 80			71 – 80		
		80	**75**		**80**		
		81 – 90			81 – 90		
		90	**50**		**90**		
		91–100			91 – 100		
		100	**0**		**100**		

Table 8: Weighting of habitat factors

Factors	Scenario 1 Based publication	Scenario 2 based on other publication Standardisation 1	Scenario 3 Based on other publication Standardisation 2	Scenario 4 Including slope and amount of nearby forest
Land cover	0.51%	0.40%	0.40%	0.30%
Protected Areas	0.31%	0.13%	0.13%	0.10%
Slope	-----	0.20%	0.20%	0.10%
Dist. to roads	0.04%	0.04%	0.04%	0.04%
Dist. to rivers	0.11%	0.20%	0.20%	0.20%
Dist. to settlements	0.03%	0.03%	0.03%	0.03%
Forest patches	-----	-------	-------	0.23%

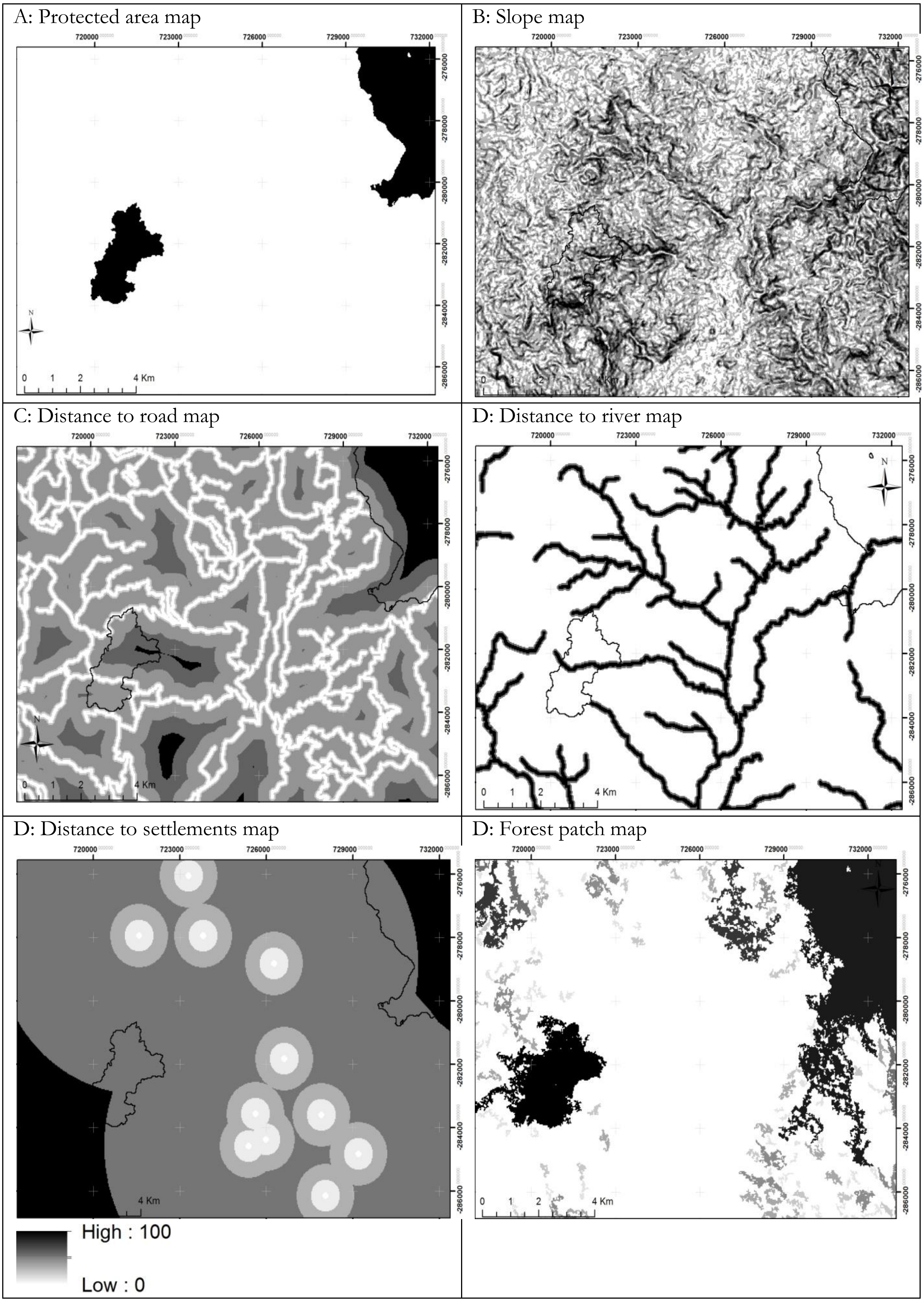

Figure 4: Maps of biophysical variables used in suitability modelling

2.6. Ecological corridor modelling

The suitability maps produced in the previous section served as inputs to model the eco-corridor path. To undertake this process, a software called "corridor designer" was applied (Beier et al. 2007). This software was downloaded and added to ArcGIS toolbox. By double clicking on the extension called create a corridor model (figure 5), a window appears where the following inputs and parameters were loaded. Refer to (Nangendo et al. 2010) other parameters that are relevant to eco-corridor modelling for chimpanzees such as corridor width of 200m were applied. The wildland block 1 and wildland block 2 which are respectively Cyamudongo and Nyungwe natural forests were defined and included in the model. In ArcGIS software, the following tools are respectively used to design an eco-corridor: Arc toolbox>corridor design>corridor modelling>create corridor model.

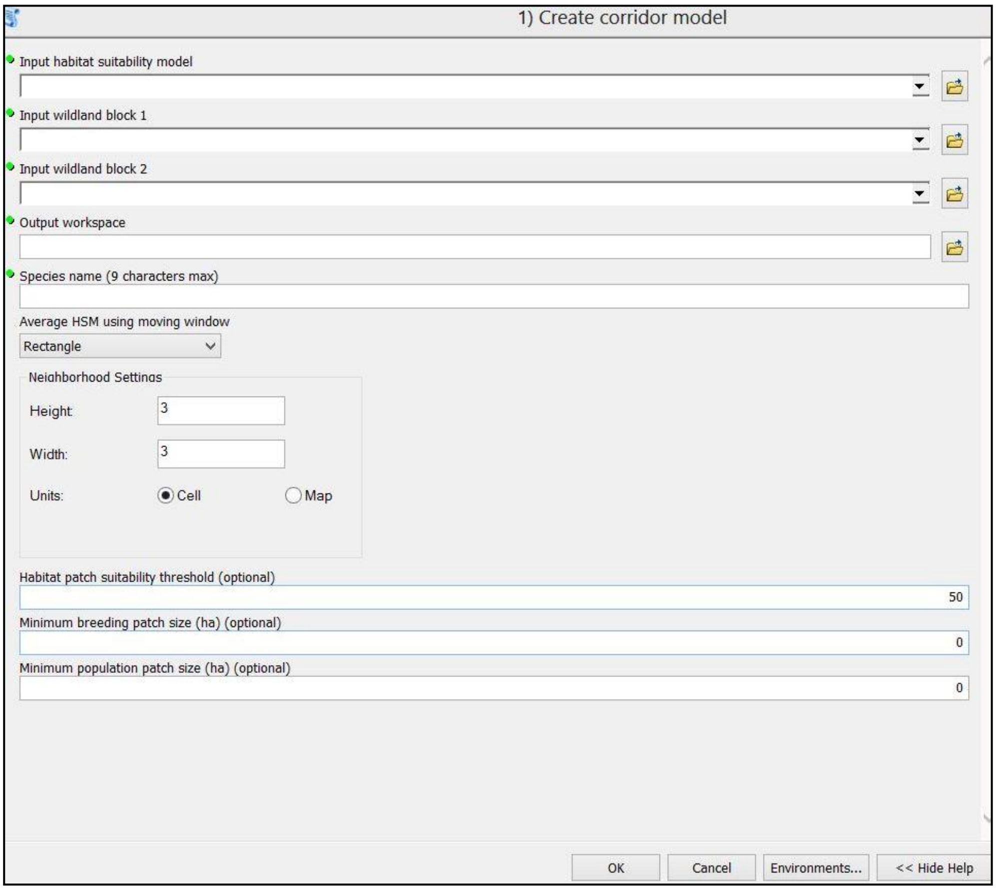

Figure 5: The creation of an ecological corridor

3. RESULTS

3.1. Land cover maps

The three thematic maps presented in figure 6 show land cover types of the study area in years 1989, 2005 and 2013. A total of 4 (four) land cover classes are displayed namely, forest, crops, tea shrubs and bareland and settlements.

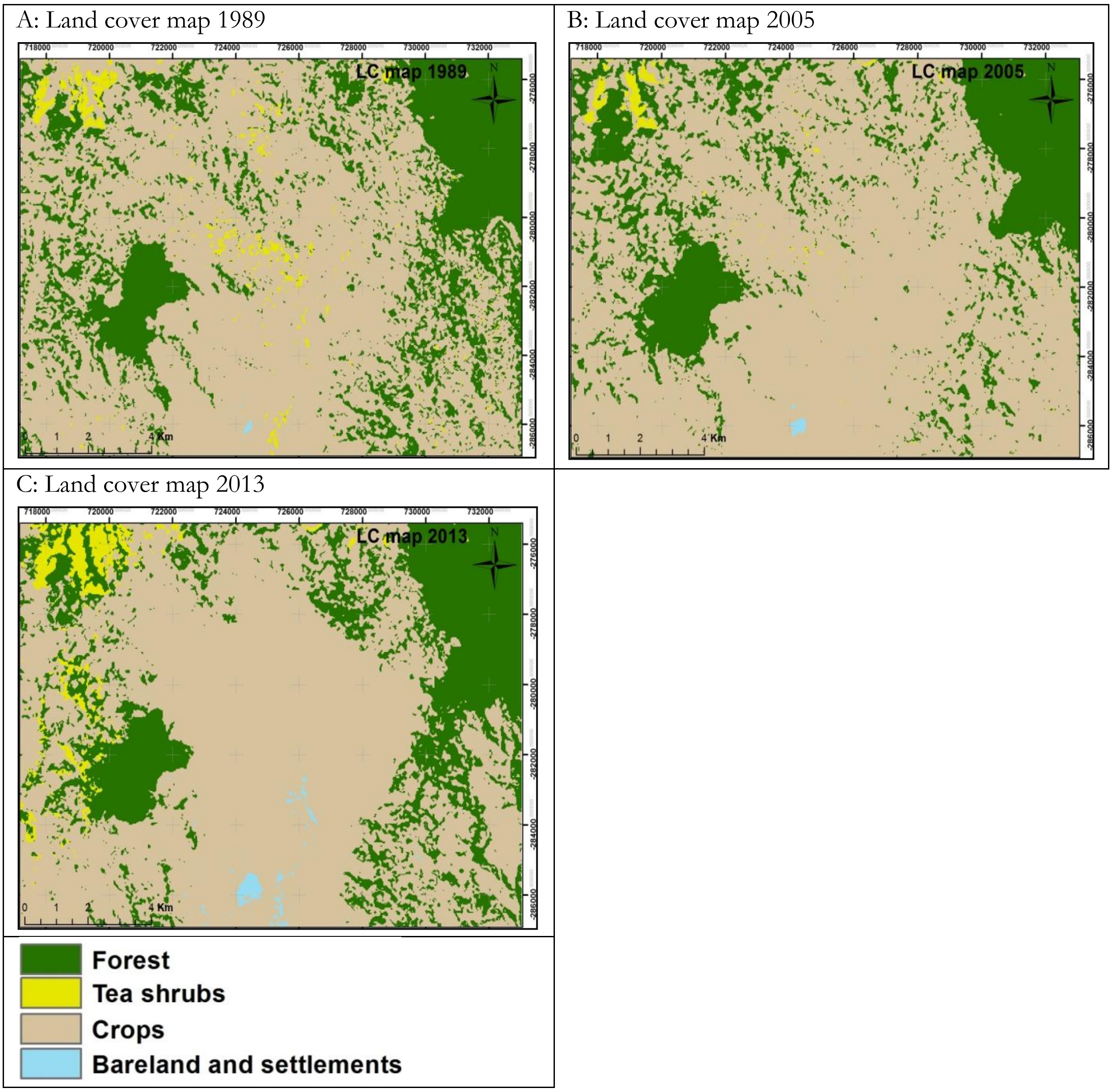

Figure 6: Land cover maps of 1989, 2005 and 2013

The figure 7 shows the distribution patterns of reclassified maps of 1989, 2005 and 2013. In general, non forest class covers a large area than forest class. The results show the trends changes of forest coverage in hectare in 1989, 2005 and 2013. The forest coverage has been reduced in the periods of 1989 to 2005 and started increasing in 2005 to 2013.

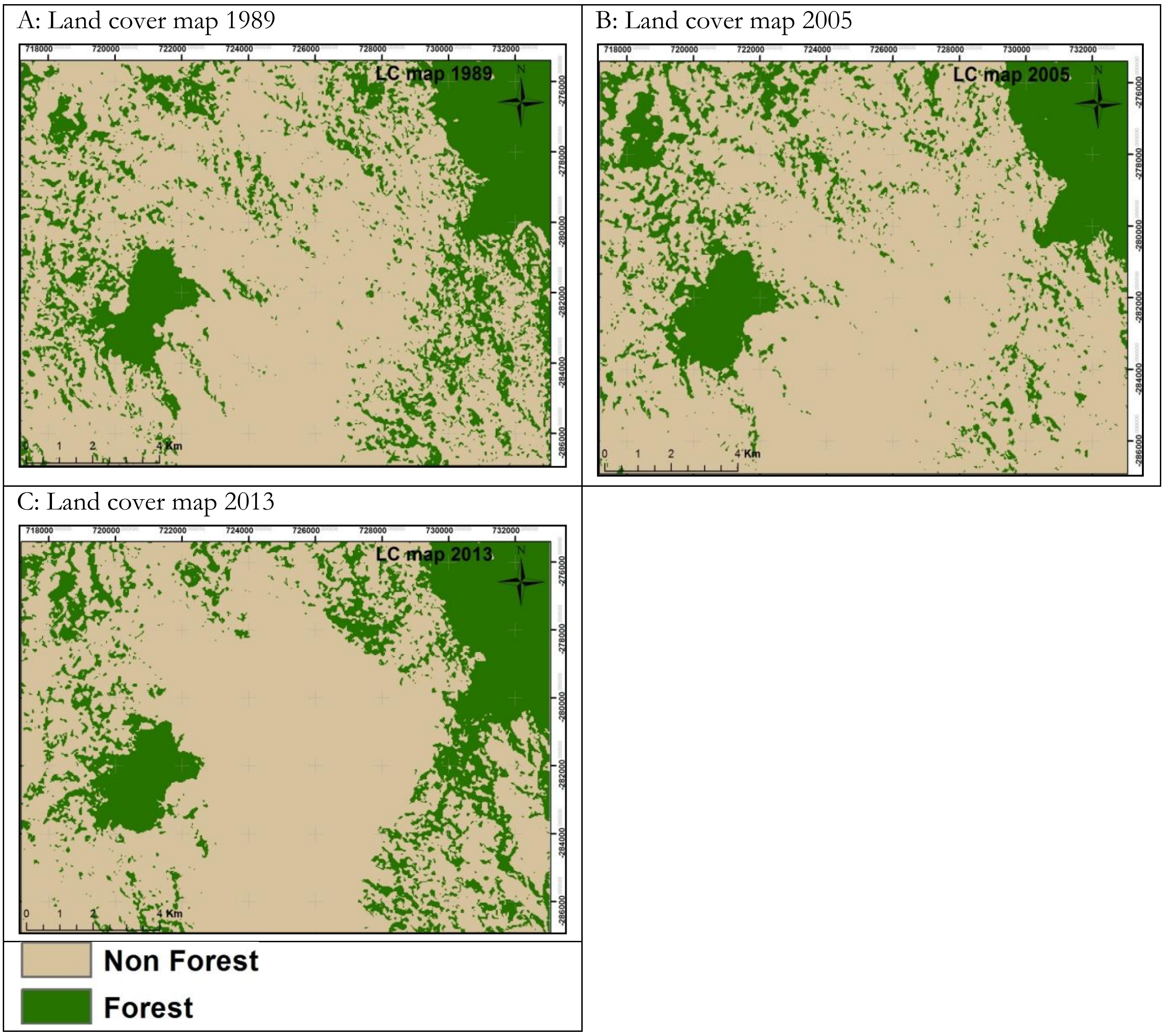

Figure 7: Maps forest and non forest in 1989, 2005 and 2013

Table 9: Areas of land cover types in 1989, 2005 and 2013

Land cover classes	1989	%	2005	%	2013	%
Forest	54100	29.4	47786	26.0	49972	27.2
Tea shrubs	5235	2.8	2191	1.2	6026	3.3
Crops	124317	97.5	133882	75.4	126429	98.8
Bareland&settlements	471	0.3	262	0.1	1347	0.7
Total Area in Ha	184122		184122		184122	

Accuracy assessment for land cover maps (figure6) generated with 1989, 2005 and 2013 landsat image was performed based on error matrix table. The overall accuracy of classification was 87.25% for the 1989 TM image, 88.24% for 2005 TM image, and 91.18% for the 2013 ETM+ image (table 10) and the Kappa coefficient was 0.78, 0.79 and 0.85 respectively (table 10). All three kappa statistical values are greater than 0.6, an indication that the mapping was accurate. The Z-value for pairs of land cover classified images was calculated as follows: 1989-2005: 1.67, 1989-2013: 0.32 and 2005-2013: 1.36. The Z-values are presented in table (11).

Table 10: Accuracy assessments of classification results

Land cover maps	Overall Accuracy	Kappa
1989	87.25%	0.78
2005	88.24%	0.79
2013	91.18%	0.85

Table 11: The results of two classes Z test

Pair of Land cover maps	Z Value
1989-2005	1.67
1989-2013	0.32
2005-2013	1.36

3.2. Land cover change

The classified land cover maps revealed estimates of changes in land cover during 1989 to 2005 and 2005 up to 2013. The land cover change shows a decrease forest from 1989 to 2005 years due to increase in crops and bareland & settlements areas (table 12). The surrounding areas formerly dominated mainly by crops changed partly to forest during the years 2005-2013. This increment in forest coverage indicated that no much more forest land converted into new areas, rather it is the removal of crops to the forest.

Table 12: Magnitude of change in land cover types between 1989-2005 and 2005-2013

To			Forest	Tea shrubs	Crops	Bareland
	Forest	1989-2005	34337	151.2	19609	1.8
		2005-2013	34196	1006.2	12369	6.3
	Tea shrubs	1989-2005	345.6	1096.2	3793.5	0
From		2005-2013	214.2	1137.6	837	1.8
	Crops	1989-2005	13099	943.2	110075	199.8
		2005-2013	15562	3882.6	113113	1188
	Bareland	1989-2005	5.4	0.9	404.1	60.3
		2005-2013	0	0	110.7	151.2

3.3. Fragmentation analysis:

The fragmentation varies among the forest coverage of the area, as highlighted in table 13. The statistics indexes showed that the forest patch density remained almost the same with 19.98 in 1989 and 16.32 in 2005. The patch density decreased from 16.32 to 8.369 during period of 2005 to 2013. The LPI decreased from 10.85 to 8.61 from 1989 to 2005 and increased from 8.61 to 12. 50 during 2005 up to 2013. The reduction of forest patches was identified in areas extended between Cyamudongo to Nyungwe forest. This area is currently dominated by agricultural land, human settlements and other physical infrastructures.

Table 13: Four landscape metrics values calculations

Years	LULC	PD	LPI	AREA_MN	PROX_MN
1989	Forest	16.98	10.85	1.73	349.91
2005	Forest	16.3218	8.61	1.59	123.23
2013	Forest	8.369	12.50	3.24	107.68

Where **PD:** Patch density, **LPI**: Largest patch index, **AREA_MN**: Mean patch area and **PROX_MN:** Proximity mean

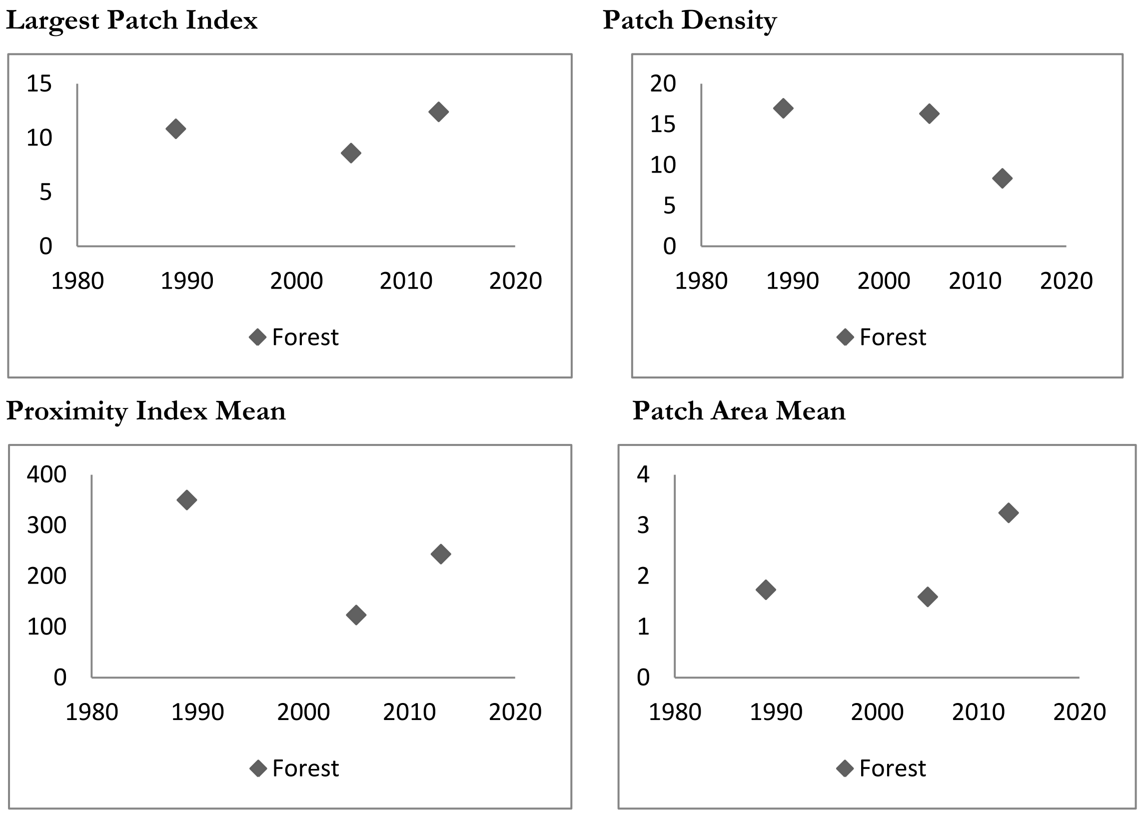

Figure 8: Four landscape metrics plots

3.4. Habitat suitability modelling

Four suitability maps were maps were created and are presented in figure 9. Natural reserves were highly suitable whereas tea shrubs and settlements appeared to be unsuitable for all the four maps. Agricultural land became moderately suitable with high contrast on the suitability map 2 and compared to suitability maps 3 and 4. Again, rivers traces are clearly shown on the suitability map 2 compared to suitability map 3 and 4 where rivers contrast is very low. Forest patches are distributed in the landscape with very low contrast on the suitability map 1 compared to other maps in areas close to tea shrubs and Nyungwe and west of Cyamudongo forest.

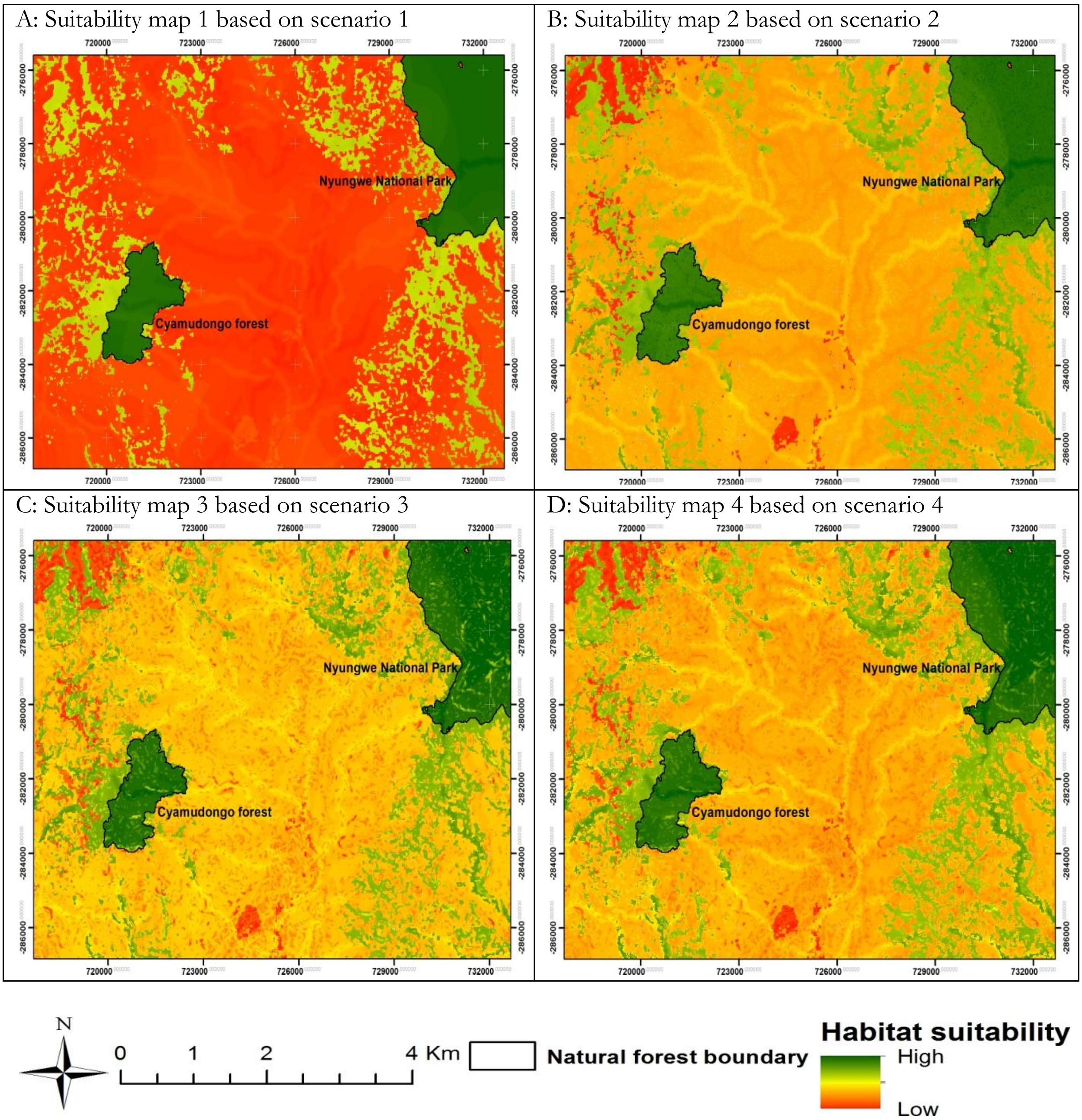

Figure 9: Habitat suitability maps based on different suitability calculations

3.1. Ecological corridor modelling

Three proposed corridor paths were created from suitability maps 2, 3 and 4 (figure 8) and are presented in figure 9. The width of each of the corridors is 200 meters. Corridor paths of 50 meters were also created for comparison. The corridor path 4 was the longest with 9.98km, followed by corridor path 2 and corridor path 3 with 8.44 km and 8.49 km, respectively. The corridors path 2 and 3 appeared to pass in the central parts of the landscape through the agricultural land and follow the river traces at the entrance of Nyungwe National Park. Corridor path 4 traverses through agricultural land towards north direction of the landscape, areas with forest patches close to Nyungwe National Park. All corridors did not avoid human settlements, roads and rivers. The corridor path C looks very different from others. This corridor followed forest patches at the entrance of Nyungwe National Park.

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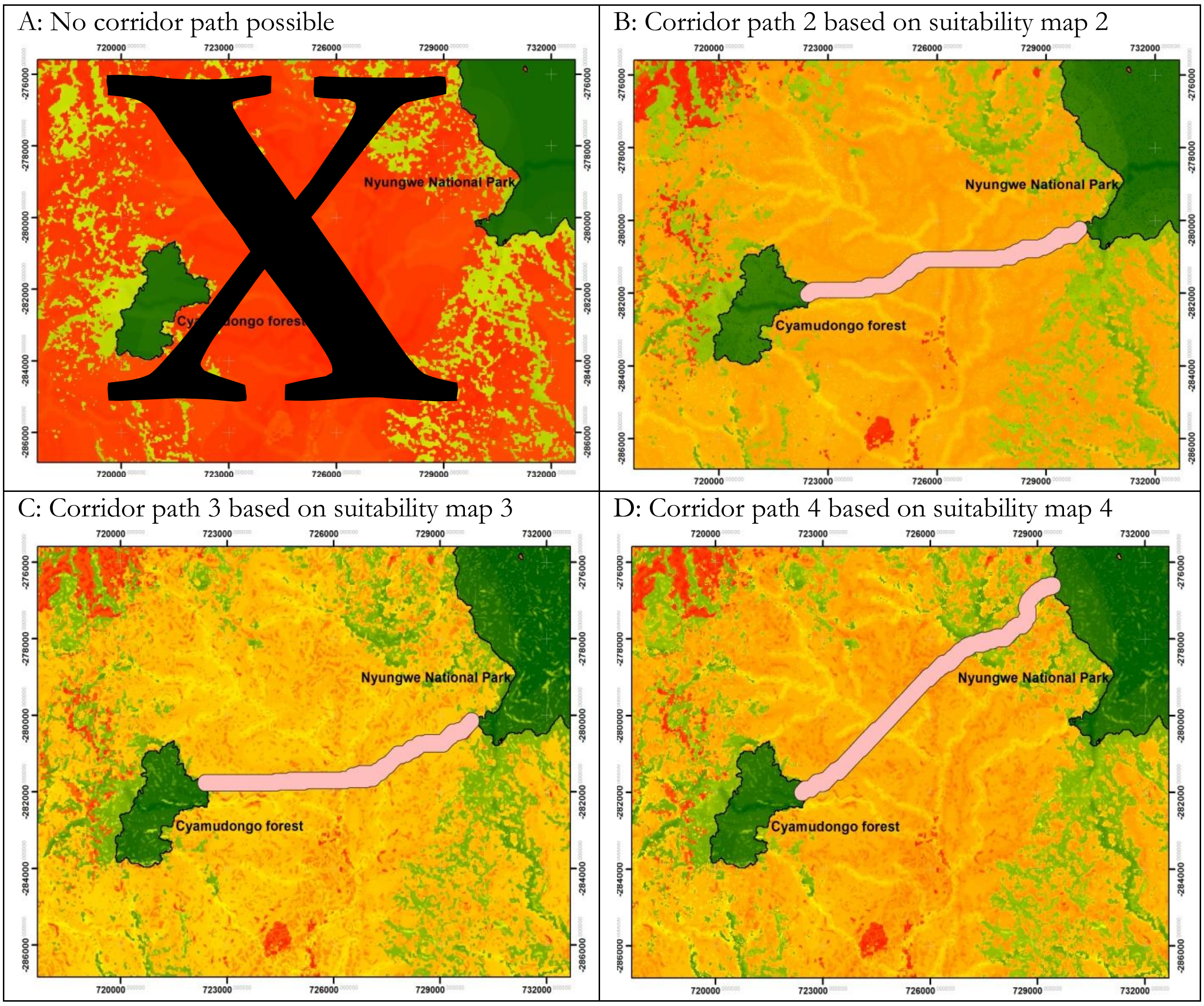

Figure 10: Corridor paths based on different suitability maps

4. DISCUSSION

4.1. Ecological corridor

In this research suitable path for establishing an ecological corridor was assessed. The created suitability maps were used to propose suitable corridor paths for chimpanzees mobility and dispersal from Cyamudongo to Nyungwe and vice-versa. These corridor paths are referred as corridor path 1, 2 and 3 (figure 10) and they are generated from habitat suitability map 2, 3 and 4 respectively (figure9). There is no corridor path 1 as the habitat suitability map 1 did not allow creating corridor path. The corridor paths 2 and 3 pass through the central part of the landscape, areas with steeper slopes. The corridor path 4 appears to pass in the north direction, areas with forest patches close to Nyungwe National Park. All corridor paths 2, 3, and 4 did not avoid roads, human settlements and rivers.

The corridor path 4 looks more promising to be more suitable for chimpanzees habitat restoration because of two main reasons: (1) This corridor passes through different forest patches which could be considered as starting point to connect most forest patches to Nyungwe National Park (2) It follows the rivers at the entrance of the park. Mclennan (2008) found that chimpanzees of Hoima in Western Uganda use forest patches along water course throughout this region. Some of those forest patches belong to government, private and community land. Similar approach can be applied for forest patches and rivers which are found in the Cyamudongo-Nyungwe landscape. Chimpanzees cannot cross wide rivers unless there is a bridge as they cannot swim (JGI 2014a). However, rivers are an opportunity to design ecological as river banks are protected by laws (Mclennan 2008).

According to Saad et al. (2013) corridors paths did not avoid roads crossing between the Nyungwe forest and Mukura forest in Rwanda. Therefore roads became a constraint to the dispersal and free movement of chimpanzees between these two forests. As the roads are paved, Saad et al. (2013) proposed an infrastructure solution to the Government of Rwanda to ensure the safe crossing of chimpanzees. Moreover, in the Netherlands, eco-corridors are used to enable animals to cross the roads. In this sense, they used fauna bridge or fauna tunnel to let animals cross safely (Jongman 2008)). However, these techniques are not necessary in the Cyamudongo-Nyungwe landscape as the roads are not paved. As they're travelling throughout the corridor, chimpanzees might not be concerned much how narrow or bigger is the width of the corridor. In Murchison-Semliki landascape, Nangendo et al. (2010), used 200m width corridor to enable free movement of chimpanzees. With consultation of park managers in Rwanda, the same width of 200 meters would be sufficient for the corridor path 4 of 8 km from Cyamudongo to Nyungwe National Park. Another corridor width of 50 meters (appendix) was created for comparison. The comparison did not reveal any change to the location of the corridor path, only the width changed.

4.2. Habitat suitability

Four habitat suitability maps were generated and are referred to as habitat suitability map 1, 2, 3 and 4 (figure 9). Habitat suitability depends on various factors. Different arguments were used to standardize suitability values for each of the different factors. Some arguments came from literature (Saad et al. 2013; Nangendo et al. 2010) other arguments came from discussion with expert (park managers, research officers in Rwanda and Executive Director of Jane Goodall Institute in the Netherlands, etc).

Although the suitability map 1 used the same biophysical variables, scores and weights as Murchison-Semliki landascape in Uganda (Nangendo et al. 2010) to run the suitability model, the results of suitability map 1 showed that the large areas extended between Cyamudongo and Nyungwe forests was unsuitable and only natural forests and forest patches were suitable. The difference in suitability was due probably to (1) the low scores of crops which covers a large part of the landscape (2) the differences of topographic conditions between the landscapes considered by Murchison-Semliki and Cyamudongo-Nyungwe landscape. For instance, the Murchison-Semliki landscape has an elevation that ranges between 619-1,291m (Prinsloo et al. 2012). Moreover, the scores and weights of different factors that have been used to run their suitability and corridor were undoubtedly related to the real condition of their landscape. Contrary, Nyungwe is a high-altitude, tropical rainforest with an elevation ranges between 1,600 meters and 2,950 meters (Gross-camp and Kaplin, 2005). If it is for this research to estimate the suitability of the landscape, the real topographic conditions should be considered and taken into consideration. Therefore, habitat factors and weights from Murchison-Semliki should not be applied to estimate chimpanzee habitat suitability in Rwanda as they do not reflect the real situation of the landscape.

Slope is an important factor that characterises the chimpanzee habitat. Many researchers revealed that steeper slope is favourable habitat for chimpanzee especially for nesting (Koops et al. 2012; Saad et al. 2013, Ukpong et al. 2013). Saad et al. (2013) explained that it is preferable to establish the eco-corridor in areas with steeper slopes which are less suitable for farming and agriculture because they are more susceptible to soil erosion, and therefore likely to minimize conflict with farmers. He used the argument for habitat suitability in terms of slope "the steeper, the better". So flat areas is unsuitable and very steep areas is highly suitable. Therefore, the same approach was applied by including slope data in suitability model. The suitability maps 2 showed that flatter areas in Southern part of Cyamudongo were less suitable.

This standardization seems to be not realistic as chimpanzee can live in flat areas. Ukpong et al. (2013) findings indicated that chimpanzees can construct nests on flat lands ranging from angles of class interval $6^{\circ} \leq 20^{\circ}$. Again, in Rwanda, steeper slope and high altitude in the mountainous landscape areas are not suitable for human activities such as farming and agricultural activities because there are susceptible to soil erosion. Therefore, the preference for steeper slopes or high altitude for chimpanzee populations might be linked to the avoidance of human activities or presence and not because they preferred to reside in high altitude. The suitability map 3 considered the fact that steeper slope might not be suitable for chimpanzee by adjusting suitability scores for slopes. In this sense, steeper slopes were given low score. The results revealed that some steep areas of the landscape became less suitable especially areas extended straight between Cyamudongo and Nyungwe forest. Overall, there was no big difference between map 2 and 3, although both maps were influenced by slope data.

Mclennan (2008) highlighted that chimpanzees use small forest fragment and rivers in their habitat. So, forest patches data were added in our model to produce the suitability map 4. The outcome of the map revealed a change in contrast of different factors involved. This indicates that forest patches have an influence to the suitability map that led to the changes of value map.

In her research Saad et al. (2013) found that reforestation suitability maps and corridors paths were influenced by weighting methods. Similarly, the four suitability maps were influenced by standardisation and weighting methods and this had an impact to the suitability maps and corridor paths. For instance, the methods used Murchison-Semliki landscape did not work in Rwanda. Therefore, it was not an appropriate method for Cyamudongo-Nyungwe landscape. The maps 2 and 3 were influenced by slope data and rivers which were assigned higher weights. The standardization method seemed to work well for suitability map 4. This method pointed out forest patches which were weighted higher and this influenced much the location of corridor path 4 as it appeared to follow forest patches and rivers close to Nyungwe National Park. Overall, this suitability maps 4 looks much more promising with potential opportunities for future restoration of chimpanzees habitat compared to suitability maps 2 and 3.

The quality of input suitability maps was satisfactory as they came from well classified land cover maps of 2013 with a satisfactory accuracy of 91.18% (Treitz & Rogan 2004). This may indicates also that corridor paths outputs were satisfactory.

4.3. Land cover change mapping

The overall accuracy of classified images of 1989, 2005 and 2013 was satisfactory (table10). According to (Treitz & Rogan 2004) a good accuracy in land cover mapping practices is justified with values range between 80%-85%. Kappa statistics (table10) showed that there was no significant difference between the classified images of 1989, 2005 and 2013 and the real situation of the landscape (Viera & Garrett 2005). Landsat data with 30 meters resolution was not sufficient to accurately classify and distinguish some features uncounted on the ground. For instance, forest plantation to natural forest, crops to bareland. This might be linked to the season. The landsat images used in this research was acquired in the months of July and August which correspond to the harvesting period in Rwanda. Therefore, pixels of cropland and bareland classes could be mixed in classification since both classes appeared to have the same colors on the satellite images.

The results of reclassified maps of 1989, 2005 and 2013 (figure7) showed that the forest coverage decreased during the years 1989-2005 followed by an increase in forest from 2005-2013. The result obtained in this research regarding forest extent, forest cover and historical changes agree with my personal observation and information acquired from interviwees namely, park managers, farmers and local authorities. Before 1990, there was no proper forest protection and management plans in the country. These periods were characterized by extreme deforestation in areas adjacent to Nyungwe National Park. After, 1994 the Government of Rwanda and their partners, namely Wildlife Conservation Society, UGZ (Unite de Gestion de la Zone) initiated various programs and policies to protect Nyungwe forest. Local communities were encouraged to plant exotic plantations, trees suitable for buffer zone to better protect the Cyamudongo natural forest such as Eucaltptus, Pinus and Grevellia (Gapusi 2007). The disturbed areas of Cyamudongo forest and buffer areas can be identified of reclassified forest maps of 1989, 2005 and 2013 on the western part of the Cyamudongo forest (figure7).

4.4. Fragmentation Analysis

To understand forest dynamics in Cyamundongo and Nyungwe forest, we need to understand the spatial and temporal configuration of forest landscape changes. Fragmentation, habitat loss due to forest cover change is a major cause for the declining of biological diversity. The most important indicators of habitat fragmentation are the number of patches, patch density and the increase in smaller patches (Karahalil et al. 2009). Therefore, spatial metrics were computed to evaluate the level of fragmentation of the forest coverage. The results revealed that the number of patches was higher between 1989 to 2005 and reduced from 2005 to 2013.

More patches and less forest areas between 1989-2005 and less patches and large forest coverage between 2005-2013 indicating respectively degrading and restoring chimpanzees habitat. The total area covered by forest was much higher in 1989 compared to 2005 and increased in 2013. This indicates that the forest was degraded during the year 80's and 90's, a period during which there was no proper regulation and laws to protect forests. However, after the forest was gazetted and attached to Nyungwe national park in 2005, forest coverage increased, especially in areas adjacent to the natural forest. As a result, this is basically good as it indicates the efforts of the Government forest restoration and this gives hope to the bright future of chimpanzees habitat in Rwanda.

4.5. The way forward

If the corridor path is to be established, there will be necessity of laws, regulations and policy involvment. In this sense, forestry and wetlands policy already established in Rwanda could be followed. The country's wetlands are protected by Organic Law N°04/2005 highlighting modalities of conservation and protection of the environment. The law recommend a creation of 20 meters free buffer zone from river banks to ensure the protection of wetlands and it's biodiversity (REMA, 2011). Therefore, the law could be applied to delineate areas where the corridor path is suitable. For example, to reserve the 20 meters suggested by the law as a free zone for chimpanzees habitat restoration and movement especially to the areas close to Nyungwe National Park where corridors appeared to follow the river banks. However, Indonesian law (Keputusan Presiden No 32/1990) requires a 50 meters buffer zones on both side along small rivers. This law was applied to designing an eco-corridor for Borneo Orangutan ((Persey, 2011). Therefore, it would be a good suggestion to expand the buffer suggested by the law from 20 meters to 50 meters to enable safe mobility of chimpanzees.

In 2004, Government of Rwanda put in place a forestry policy with the aim of increasing forest cover up to 30% of national total area (MINIRENA, 2010). This policy could help in forest restoration alongside of the corridor path 4. To improve the suitability of chimpanzees habitat, forest restoration initiative should be implemented alongside the corridor path 4. According to Plumptre et al. (2010), restoration of degraded habitat and encourage agroforestry are among the top priorities to protect chimpanzees in Rwanda and were included in the National Action Plan for great apes. Moreover, Chen et al. (2008) stated that to transform unsuitable habitat into suitable and to improve the landscape connectivity, could be done by the vegetation restoration. In this sense, the forest restoration should include fast growing trees which are identified as chimpanzees food and nesting tress. Therefore, three levels of intervention can be applied in Rwanda: (1) Involving local community to undertake agro-forestry practices by planting trees such as Grevillea trees which provide fuel wood and timber to local community (2) Planting fast growing trees of their preferences such fruit trees: avocado, papaya, orange and citrus providing fruits (3) to plant nesting and food tress for chimpanzees such as *Tabernaemontana stapfiana, Prunus africana, Schefflera goetzenii, Salacia erecta, Coccinea mildbraedii, Cleistanthus polystachyus, Croton megalocarpus, Casearia runssorica, Ekebergia* *capensis, Macaranga kilimandschalica Cymphonia groblefela, Syzygium guineensis, Dombea gotseenii, Ficus sp., Carapa grandiflora,* etc (Gross-camp et al. 2009).

Similar initiatives have been applied successuly in different countries to protect chimpanzee and their natural habitat such as Tanzania, Congo Braza and Uganda. In Congo Braza, the program encourages students to plant fruit trees between forest patches and enable free mobility of chimpanzees from one forest patch to another (JGI, 2010). In Tanzania the project is called": TACARE project (Lake Tanganyika Catchment Reforestation and Education). It was initiated in 1994 with the addressing poverty and support livelihoods in villages around Lake Tanganyika and Gombe National Park while arresting forest degradation especially chimpanzees natural habitat. TACARE focuses on community socio-economic development and provide trainings and education program to local community to increase their knowledge in forest conservation and natural resources in general (JGI, 2014c). In Uganda the program is called 'The chimpanzee Conservation corridor". With this project, local community are paid for ecosystem services. This project initiated a payments for environmental services to provide incentives local farmers to encourage conservation and restoration natural habitat which are home to wild chimpanzees (CSWCT, 2007). Overall, experience and success stories in forest restoration can have an added value in Rwanda during implementation of reforestation program in Cyamudongo-Nyungwe landscape.

5. CONCLUSION

In this research, the temporal and spatial land cover change of landscape between Cyamudongo and Nyungwe forest was performed. Different land cover types as well the changes from one land cover type to another was determined to evaluate the scale of the changes. The fragmentation patterns of a period of 25 years were calculated and analyzed. The most suitable and unsuitable areas for reforestation purpose as well as potential corridor establishment was evaluated. The corridor paths to connect both Cyamudongo and Nyungwe forest were suggested in the hope that these corridors will facilitate in the future movement of populations of chimpanzees from one reserve to another to avoid the loss of genetic diversity and reduce inbreeding. The paths were modelled based on a set of biophyisical variables, namely land cover, protected areas, slope, distance to rivers, distance to settlements, forest patches, distance to roads were selected based on publication and chimpanzees habitat preferences. Each of these factors was taken into consideration and different maps were created to evaluate the most appropriate corridor paths. The final suitability maps effectively indicate a clear path for the proposed corridor. The most realistic suitability map from this study (suitability map 4) can serve as a base for further planning a chimpanzee habiat corridor. The suitability maps will be shared with different stakeholders, namely: Rwanda Development Board/Tourism and Conservation department, District land use planning committees, Ministry of Agriculture and Rwanda Environment Management Authority (REMA) to assist and collaborate in identifying areas to target for corridor building efforts. Overall, given the shortage of studies on landscape-scale fragmentation metrics, habitat suitability modelling related to primates in Rwanda, I beleive the outcomes of this research will serve as input and approach for further related research to other fauna species.

6. RECOMMENDATION

Further Research should be conducted to improve the ability of remote sensing data to accurately classify different land cover types within the area. By using high resolution images such as GeoEye and/or IKONOS, various features such crops, bareland, settlements, natural forest and forest plantation could be accurately classified and distinguished.

Satellite and remote sensed data could also be used to assist the government of Rwanda to survey the land and demarcate land which is suitable agricultural and identifying risk zones that can be reserved for conservation practices as forestry zone.

Multi-criteria analysis could be a good method to use for further research to test the similarities and differences in suitability modelling compared to the method used in this research.

Lastly, programs intended to increase the living conditions of local communities around Cyamudongo forest should be initiated. Creation of non-agriculture income generating activities to reduce forest resources dependency and to increase their knowledge in conservation and protection of the natural resources including forest. For example: Biogas, cultural tourism development as it was suggested by interviewees.

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8. APPENDIX

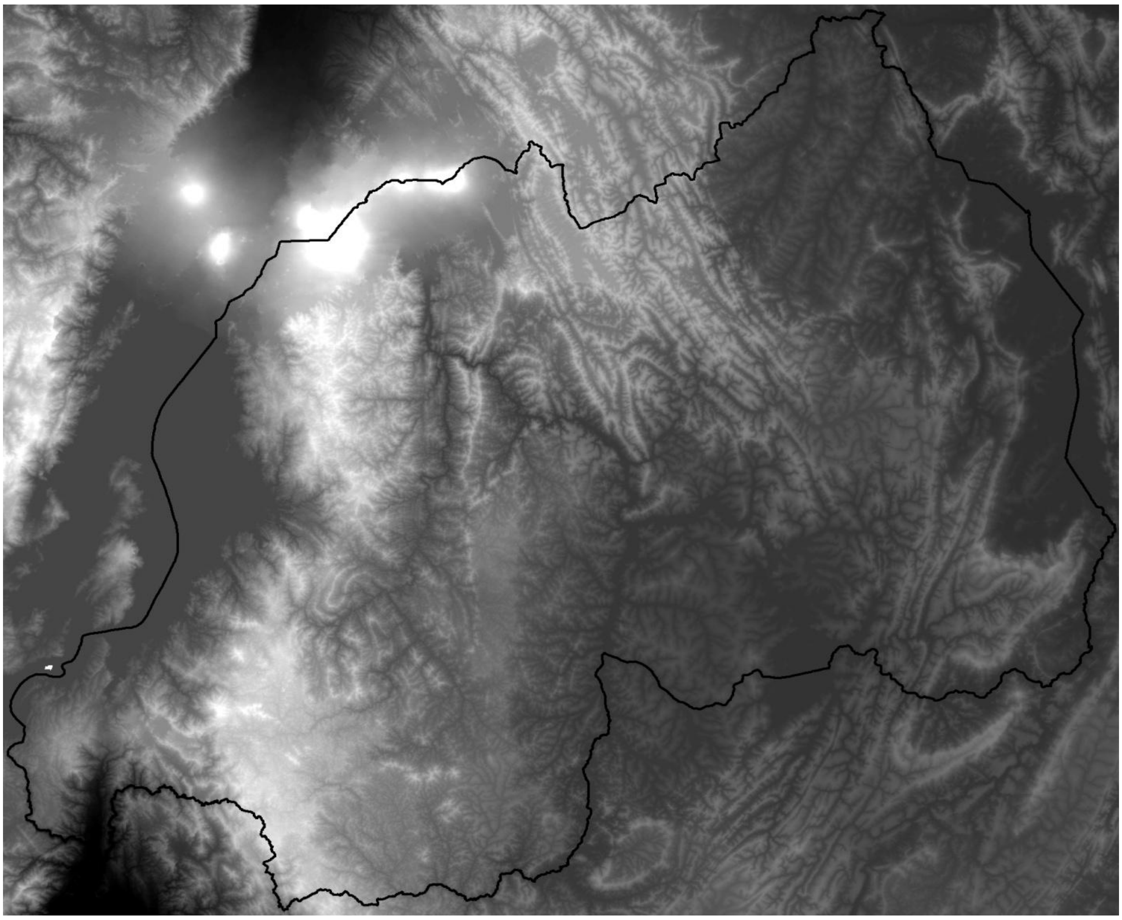


Figure 11 Digital Elevation model (DEM) of the country

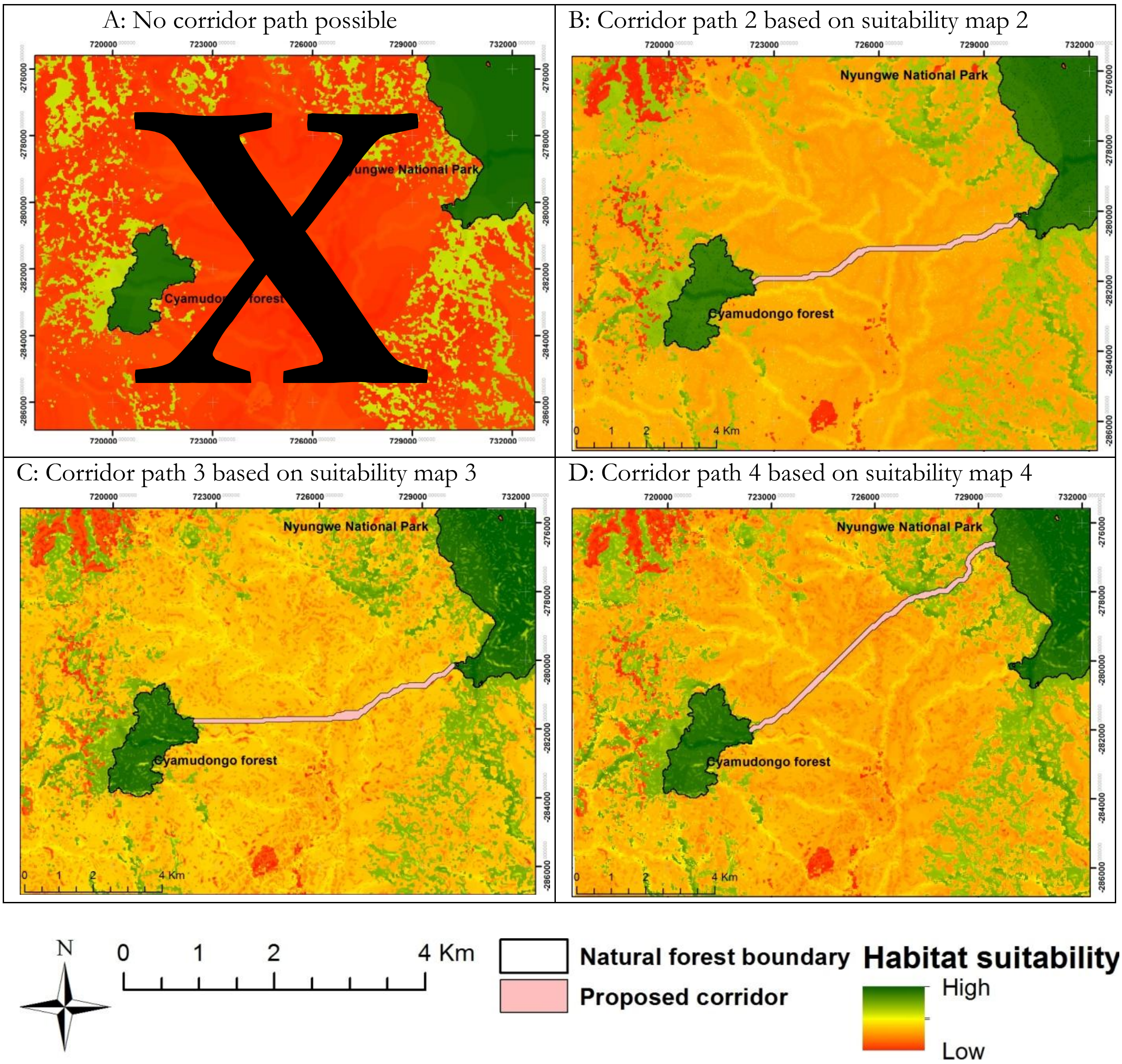
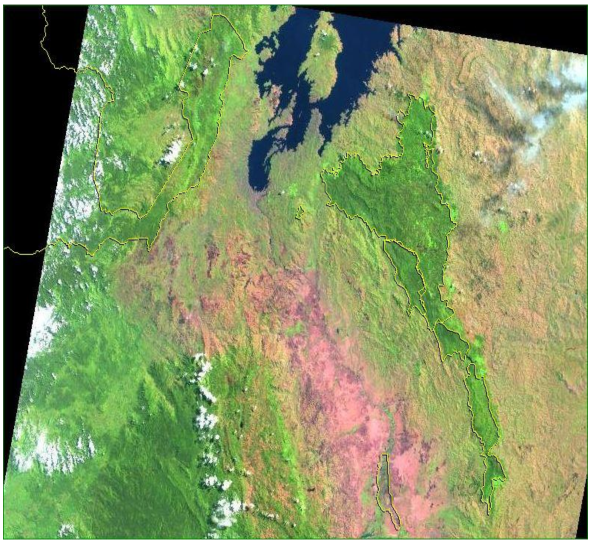
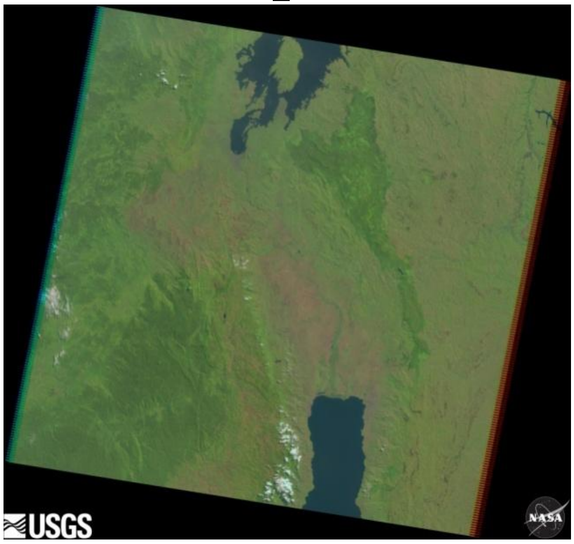


Figure 12 Corridor paths of 50 meters width

Landsat ETM^{+} 2013



Landsat _TM 2005



Landsat _TM 1989

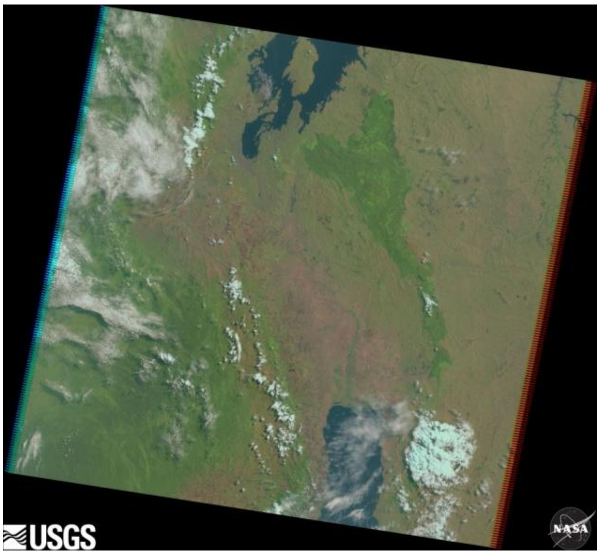


Figure 13: Landsat images (TM 1989, 2005 and ETM+ 2013)

Table 14 :Field data collection form

Data Sheet for vegetation cover in Nyungwe National Park (NNP)									Sample#:
Plot #: Plot size: Altitude:									Location:
Date: /10/2014	GPS	X							Observer:
	UTM	Y							

LC type	LU type	Structure	% Cover	Height in meters
		High tree layer		
		Med. tree layer		
		Low tree layer		

Dominant species	Food trees		Nesting trees		Additional information/Observations
	In	out	In	Out	
1. *Tril. mad.*					
2. *Meme. wal.*					
3. *Musa. leo.*					
4. *Ficus or.*					
5. *Ficus au.*					
6. *Myri. hols.*					
7. *Piper umb.*					
8. *Sola. nig.*					
9. *Casp. gum.*					
10. *Pter. aqu.*					
11. *Triu. cor.*					
12. *Syzy. gui.*					
13. *Domb. got.*					
14. *Cyat. man.*					
15. *Ekeb. cap.*					
16. *Mim. exc.*					
17. *Ure. hyp.*					
18. *Tab. sta.*					
19. *Gyn. sca.*					
20. *Sal. ere.*					
21. *Tri. cord.*					
22. *Ekeb. cap.*					
23. *Mae. lanc.*					
24. *Symp. glob.*					
25. *Urer. hyps.*					

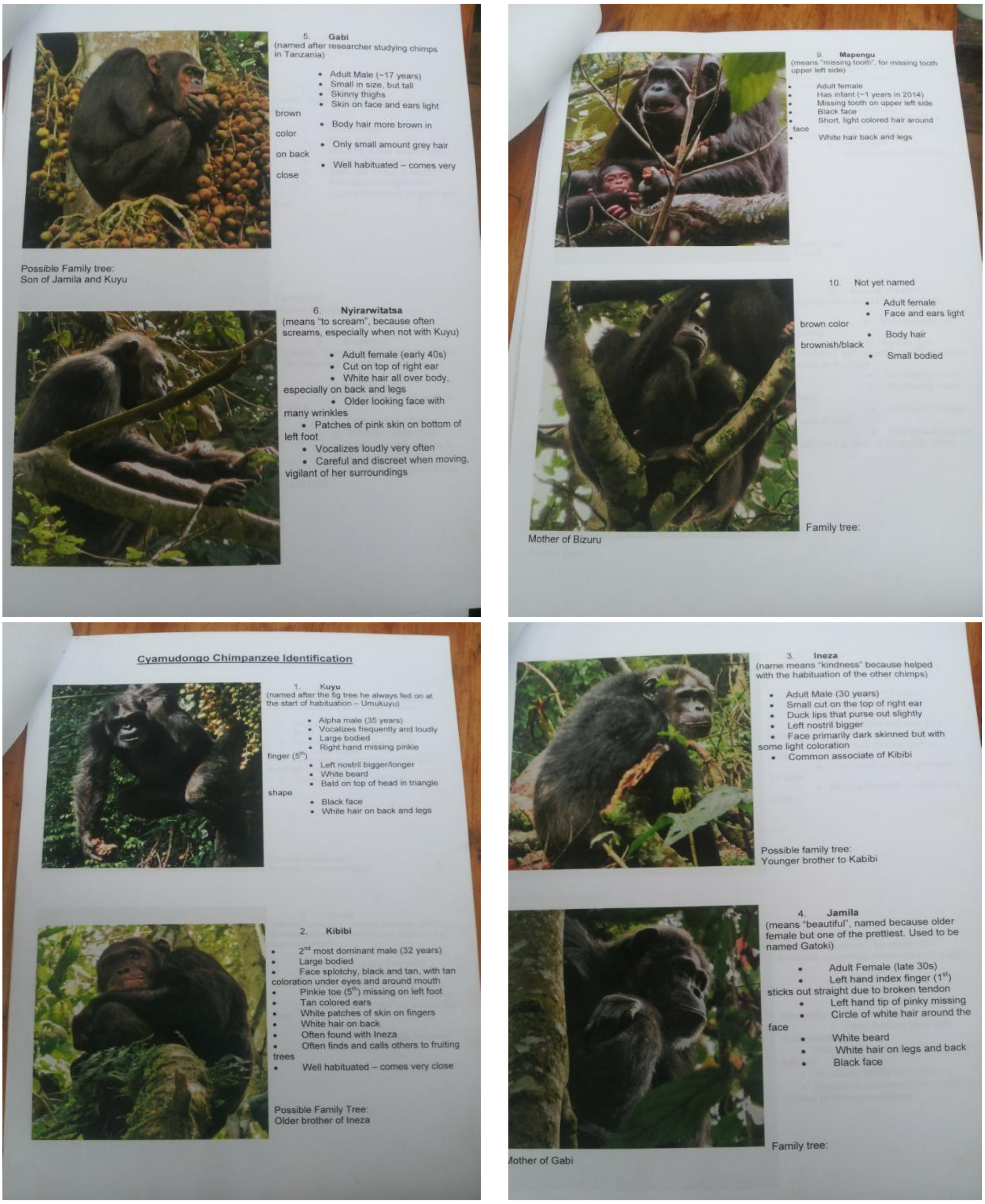


Figure 14: Cyamudongo chimpanzee identification

Source: Archive of Cyamudongo Natural forest chimpanzees tracking records

Together with Conservation Division Manager at RDB

Interviews with indigenous people around Cyamudongo forest

Chimpanzees species in Cyamudongo forest

Data collection with Mobile

Crops adjacent to the forest buffer

Recording GPS points in the forest

Figure 15: Other pictures from study Area