Research report

Importance of Ibanda Makera forest restoration on local people livelihoods and environmental conservation in eastern part of Rwanda

Prepared By:

BENIMANA Alice

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Executive summary

Forests are bases of timber, non-timber forest products, ecosystems services and goods that help society as a whole and are essential to rural livelihoods. Forest restoration has been suggested as one an approach to defeat deforestation and manage the production of ecosystem services and goods. The aim of this study was to evaluate the Importance of Ibanda-Makera forest restoration on local people livelihoods and environmental conservation in the eastern part of Rwanda. Both quantitative and qualitative data collection methods were used, including a household Survey (n =300 sample), randomly selected from four villages surrounding Ibanda-Makera forest, personal observation and measurement of leaf temperature for different tree species, leaf mass per area (LMA) for forest productivity, aboveground biomass and soil organic carbon stock. The results showed that forest restoration has positive impact on local people, they got temporary employment, reduction of timber production, the leaf temperature was significantly different among species at $P<0.05$. Highest leaf temperature was observed in *Markamia lutea* had (34.8 ℃) with large leaf size, while the lowest leaf temperature was in *Acacia polyacantha (24 ℃)* with small leaves size. A similar tendency was observed for leaf mass per area (LMA) which was significantly different among species at $P<0.05$. *Markamia lutea* had higher LMA 104.76g/m^2 while the least LMA was observed in *Acacia polyacantha* 63.52g/m$^{2.}$. The results showed that amongst 59 trees recorded per hectare for studying above ground biomass (AGB) that *Acacia polyacantha* had the highest at 6.34t/ha while *Markamia lutea* had lowest about 0.24t/ha. The measurement of soil carbon stock showed that 6.2t/ha was found in the restored part, while in the protected part the soil carbon stock was 9.65t/ha. The restoration of Ibanda-Makera forest improved ecosystem services through, flood regulation and biodiversity conservation.

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Chapter 1. Introduction

1.1. Background of study

Forests are source of timber, fuel wood, and provide ecosystem services that are essential to human wellbeing through the provisioning of food and income generated from non-timber product (Adams et al, 2016). The World Bank (WB) estimates that forest resources improve the directly human well-being of about one billion people in developing countries (Adams et al., 2016)**.** Worldwide forest cover is estimated at 30% of the land surface. In rural zones, of developing countries, it is estimated that five hundred million people depend on a combination of forest resources and agriculture to meet their needs (Adams et al., 2016).

Ecosystem based Adaptation (EbA) integrates the controlling of ecosystems and biodiversity into an general plan to support communities and ecosystems adapt to the adverse impacts of global change (IUCN, 2009). Sustainable conservation and restoration of ecosystem are the way to present EbA that help people to adapt to climate change. It contributes in decreasing vulnerability and increasing resilience to climate and non-climate hazard and offers several benefits to communities and the environment (IUCN, 2009). Ecosystem based adaptation provide numerous economic, social, environmental and cultural benefits such as reduction of disaster risk through infrastructure protection, flood control. It help in food security through poverty reduction, biodiversity conservation, carbon sequestration and sustainable water management (IUCN, 2009).

In relation to their importance, forests provide different goods and ecosystem services that are beneficial to people from ecosystem. Those Ecosystem services include provisioning are product obtained from ecosystem such as food for humans and other animals, medicines, fuelwood, and suitable habitats for other wild plant and animal biodiversity. Regulating services are benefits got from regulation of ecosystem processes such as climate regulation, disease regulation, water regulation, erosion control, pollination and water purification (Hamilton et al, 2003). Supporting services are services essential for the production of all other ecosystem services such as soil formation, nutrients cycling, watersheds protection, biomass production and regulate global climate system (IUCN, 2017). Cultural services are non-material benefits got from ecosystem such as aesthetic, cultural heritage, recreational, educational, spiritual and religious (Hamilton et al, 2003).

They are the storehouse of carbon, and have potentials to capture and store around 30% of carbon dioxide released from fossil fuels and industries, and transform it into living biomass including roots, branches and leaves through photosynthesis (Brack, 2019). Likewise, terrestrial vegetation has important hydrological and biophysical interactions with the atmosphere and thus also affect both local and regional climate (Bonan, 2008). The Bonn Challenge (2011) is a worldwide ambition to restore 350 million hectares of the World has deforested and degraded lands by 2030. In 2011, Rwanda prepared its pledge to the Bonn Challenge to restore 2 million hectares. This characterises equivalently the top national promise to the challenge (MINILAF, 2018). Bonn, 2017 reported that Rwanda is amongst the earliest countries to accept the Bonn Challenge. The Bonn Challenge has sustained Rwanda to bring almost 709,761 ha of land under restoration, which is equal to 29.8% of the total Country area. Rwanda has been one of the main guides for forest landscape restoration. From 2011 to 2019, Rwanda bring 708,628 ha into restoration by development nationwide continuing to accelerate (Oberle, 2020).

Numerous ecosystems such as swamplands, forests and savannahs are present in Rwanda. They offer an extensive range of services including regulating, provisioning, supporting and cultural. These ecosystems enhance the resilience of local peoples to the effects of climate instability and climate change through providing valued services such as food, water regulation and flood protection and erosion control (UNDP-UNEP-IUCN, 2010). Rwanda forest cover area comprises 18% of natural forest (123 538 ha), 39% of shrub-lands (260 569 ha) and 43% (286 811 ha) of forest plantations dominated by eucalyptus tree species (MINILAF, 2017)**.** In Rwanda 12,000 ha of agroforestry and 400 ha of woodlots were restored (Bonn, 2017).

Around 12% of worldwide greenhouse gas emission originate from deforestation and hence contributed to the changes of climate systems, which in turn affect local people through to changes in seasons, rain quality and quantity leading to different borne diseases and food scarcity (Brack, 2019). The major problem faced by forests in Rwanda include deforestation associated with population growth. The main activities contributing to the deforestation include agricultural activities, firewood collection, grazing and tree cutting for fodder (Bizuru et al, 2011). Ibanda-Makera forest is a gallery forest associated with woodland and savannah in the East (Ibanda) and papyrus swamp in the south (Makera). Makera forest is remnant forest, which has endured complete despite pressure from farmers cultivating around it. Currently, Makera forest had a surface area of 74 ha and Ibanda forest has a surface area 89 ha. Ibanda –Makera is crossed by river Nyamporogoma that makes the forest water catchment for local community (Joram et al., 2010) . The Ibanda -Makera natural forest holds different endemic and rare plant species such as *Blighia unijugata (Umuturamugina), Grewia forbeii (*Warty donkey-berry) *and* animal such as *Papio anubis (*Baboon*), Cercopithecus miti dogetti* (Blue Monkey) and *Panthera pardus (*Leopard*)* species. It provided different goods and services to local people such as medicine, firewood food, and fodder and provide shelter (Bizuru et al., 2011).

1.2 Problem statement

The Ibanda-Makera forest has been degraded due to high population pressure searching for firewood, grazing, medicinal plant collection and poaching. Those illegal activities lead to loss of some biodiversity such as buffalo, Wild pig and Impala as well as ecosystem services, loss of habitats for wild animals and cause climate change effects (Bizuru et al., 2011).
From 1984 to 2015 forest loss it size about 88.1% (MINILAF, 2017). Forest was reduced from 169 ha to 163 ha in 2020. Restoration activities were urgently needed and were introduced by REMA in 2018 under the project entitled "Building resilience of communities living in degraded forests, savannahs and wetlands of Rwanda, through the ecosystem-based adaptation (EbA) approach". Restoration activities consisted of restoring of 68 ha of the degraded forests dominated by indigenous species (Nduwamungu, 2019). However, less is known about how local people benefits from the restoration of Ibanda Makera forest, the restoration effects on ecosystem services and forest restoration contribute to local people's adaptation strategies to

climate change. The overall aim of this study is to evaluate the importance of Ibanda Makera forest restoration on local people's livelihoods and environmental conservation in Eastern part of Rwanda.

1.3. **General Objectives**

The goal of this research is to assess the importance of Ibanda-Makera forest restoration on local people's livelihoods and environmental conservation in Eastern part of Rwanda.

1.4. The specific objectives

1. To evaluate the local people benefits from the restoration of Ibanda-Makera forest.
2. To evaluate the restoration effects on ecosystem services essential to local people.
3. To evaluate the role of the restored forest in mitigating climate change effect in region

1.5. Research questions

1. How do local people benefits from the restoration of Ibanda-Makera forest?

2. What are the restoration effects on ecosystem services essential to local people?

3. What are the role of Ibanda-Makera forest restoration in mitigating climate change effects?

Chapter 2. Literature Review

2.1. Concept and definition

Forest are vital ecosystems that provide uncountable goods and services to people and ecosystem around the world. Forests are threaten by illegal activities such as clearing trees for agriculture, ranching, development activities, forest fires, and changes caused by climate change (IUCN, 2017). Restoration has been established in different countries to restore degraded forests. By definition, restoration is a long-term process aiming at recovering environmental functionality and improving human wellbeing across degraded forest (IUCN, 2017). In this regard, forest restoration is a combined method that looks at all features of forest landscape and manage them consequently (Vallauri, 2005). Forest degradation and associated activities such as farming activities, deforestation increase about a quarter of global greenhouse gases (Snilstveit et al., 2016). Forest degradation and deforestation has now cause the loss of species and affect negatively the millions of local people livelihood among the poorest on the earth who rely on forests for survival (Vallauri, 2005). In this regard, restoration is essential to eliminate up to one third of all carbon dioxide emissions from deforestation and land use every year (Snilstveit et al., 2016).

Restoration of destructed landscapes will contribute to improving environmental integrity, which will play a crucial role to plants, animals and human survivorship and well-being. Forest restoration is very important, it can reduced forest use, enhanced tree species richness, improved biomass productivity, carbon sequestration, direct cash, local contribute in land management, training opportunities and improved soil stability (Erbaugh & Oldekop, 2018). In Rwanda, forest cover is estimated at 480 000 ha of country land cover. The Eastern province of Rwanda has gallery forests which covers total land areas of 163 ha mainly in Akagera river-lake system (NBSAP, 2016). Local communities and biodiversity are highly exposed to climate change effect such as drought, floods, fire and loss of species (IUCN, 2017).

2.2. Role of forest restoration on local people's activities

Farmers decide to plant more trees that provide them with food, soil and water retention to adapt for future challenges. Forest restoration provide various product to local people such as fuel wood, construction material, medicine (Langat et al, 2016). Forest restoration bring back the biomass production, organic matter of an area in order to gain any number of benefits for people and the planet. It provides tangible benefits to human wellbeing such as jobs creation, income and carbon sequestration (Resource, 2014). On the other hand, forest restoration with agroforestry species improves household farmer's livelihoods by contributing to nutrition, food security, and sovereignty, allow income generation, and increase farmer self-sufficiency (Miccolis et al, 2019). Forest restoration change farmers livelihood through off-farm service opportunities, income and reduce poverty. Forest landscape restoration provide income, livelihoods change, off-farm employment opportunities, decrease poverty, equity and the provision of timber and energy as ecosystem services (Adams et al., 2016).

2.3. Role of forest restoration on ecosystem maintenance

Restoration activities increase forest cover, hydrological cycle improvement, water availability, and increase ground and surface water regulation and water quality (IUCN, 2017). Forest restoration delivers a wide range of benefits such as increasing biodiversity, creating habitat for and inviting native wildlife like insects, reptiles and birds, stabilizing soil, improve species richness (Ciccarese et al, 2012). Ecological restoration delivers ecosystem services such as soil improvement through holding and delivering nutrients to plants, biomass productivity and increases carbon sequestration. Restoration of degraded ecosystems is among the best important method for improving biodiversity (Padial et al, 2018).

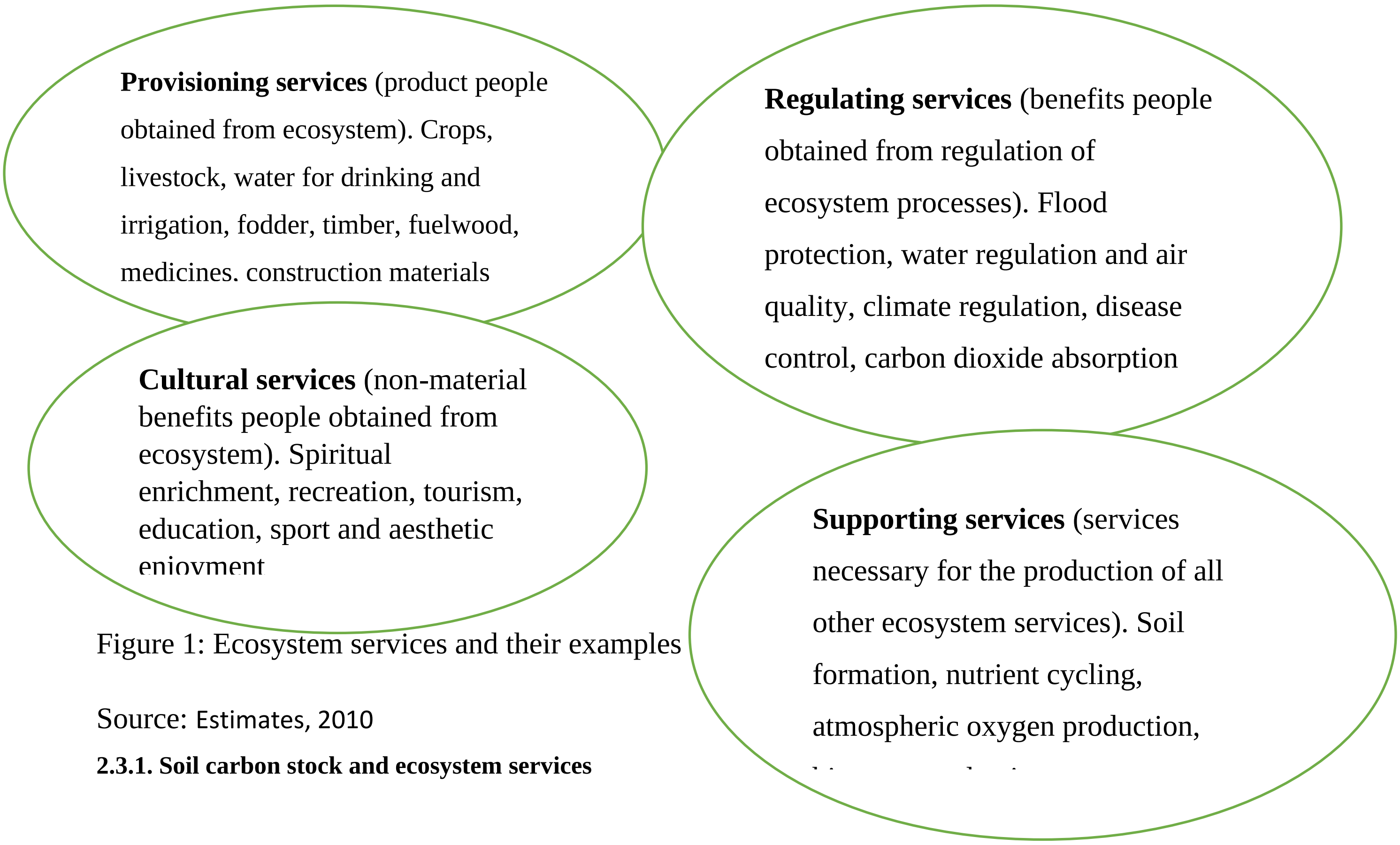

Figure 1: Ecosystem services and their examples

Source: Estimates, 2010

2.3.1. Soil carbon stock and ecosystem services

Ecosystem productivity is level, at which the ecosystem produces biomass and is linked to carbon sequestration. The productivity of ecosystem is related to the effects on carbon stocks and worldwide emissions. High level of productivity show that communities can harvest timber other frequently or get better yields from crops (UNEP, 2014).The Soil Organic Carbon stock is essential for soil quality, fertility, health and productivity. It support ecosystem services such as supporting through nutrient cycling, provisioning through fuelwood, fresh water, and regulating through flood control. Increase in soil carbon stock improve soil organic matter, soil health ,reduce soil erosion through increase infiltration rate, increase soil microorganism, soil health and enhance carbon sequestration (Lorenz et al, 2019).

2.4. Role of forest restoration on climate change effect mitigation

Climate change was found to be the cause of spreading of crop pests and diseases, hence affecting crop production (Verchot et al., 2007). Another study indicated that plant diseases and pest insects population outspread depending on climate variables, mainly temperature and humidity (Verchot et al., 2007). Biological mitigation of effect of greenhouse gases happen through carbon sequestration during afforestation, restoration of natural habitats and reforestation, conservation of current carbon store in avoiding deforestation or protecting wetlands, replacement of fossil fuel energy with technologies founded on biomass (World Bank, 2009)**.** Reforestation of degraded land retain water in soil and provide benefits to the food supply. Further, forest restoration was found to reduce disaster risk and improve coastal of river protection, grassland and forest conservation to prevent soil erosion. Tree buffer along the river protects rivers from flooding. It is also appreciated to increase the vegetation diversity in cities and hence improves the air quality (IUCN, 2017). The supporting services delivered by forest is mainly carbon sequestration from the atmosphere and long-term storing of the carbon in biomass, and dead organic matters in soil. In this regard, it was found that half of carbon produced worldwide is stored in plant biomass (Parrotta et al, 2012).

Chapter 3. Materials and Methods

3.1. Description of the study area

Ibanda-Makera forest located in Eastern Province of Rwanda, Kirehe district, Mpanga sector, Nasho cell at 260179E9767347S and 262104E 9765251S. The soil type of Ibanda Makera forest is loam and highly fertile. Ibanda-Makera has altitude of 1300 m and has mean annual temperature of 23.80 C, mean annual rainfall 1050 mm (Bizuru et al, 2011; Nduwamungu, 2019). It is a gallery forest associated with woodland and savannah in the East (Ibanda) and papyrus swamp in the south (Makera). Makera forest is a remnant forest, which has endured complete despite pressure from farmers cultivating around it. Currently Makera forest had a surface area of 74 ha. Ibanda forest has a surface area 89 ha. Ibanda-Makera is crossed by the River Nyamporogoma that makes the forest water catchment for local community (Joram et al., 2010). The forest covers an area of 163 ha, surrounded by agriculture and livestock rearing. The main source of food and income to local communities. A recent study indicated that around 92% of local people grow beans; around 85% grow maize, while 27% grow sorghum. The main livestock found in the households include cow and goats (Bizuru et al., 2011). Agriculture is the key activity of the region, level of poverty is moderately high: 40-49.9% (REMA, 2019). The population density of Mpanga sector is 128 inhabitants/km^2, average household 4.4 persons, the type of inhabitats 98.5% live in clustered rural settlements (Umudugudu), and 89.6% own a house, 96.1% use firewood as source of energy for cooking (NISR, 2015).

The Ibanda-Makera forest is also dominated by different plants species like *Markamia lutea (*Siala Tree), *Vepris nobilis (*Teclea nobilis), *Ficus vallis choudae, Dracaena afromontana.* Animals' species like *amphibious, primates* like *Papio anubis (*baboon*), Cercopithecus mitis dogetti (*Blue Monkey*)* and birds like rare purple-banded sunbird (*Cinnyris bifasciatus*) and migratory birds such as *Campephaga flava*, *Oxylophus levaillantii* and *Cuculus solitaries* and many reptiles mostly snakes like Python sebae. It contains endemic plant species used in traditional medicine like *Blighia unijugata, Grewia forbesii, Rhus vulgaris, Ficus acuta* and *Ficus thoningii* (Bizuru et al., 2011).

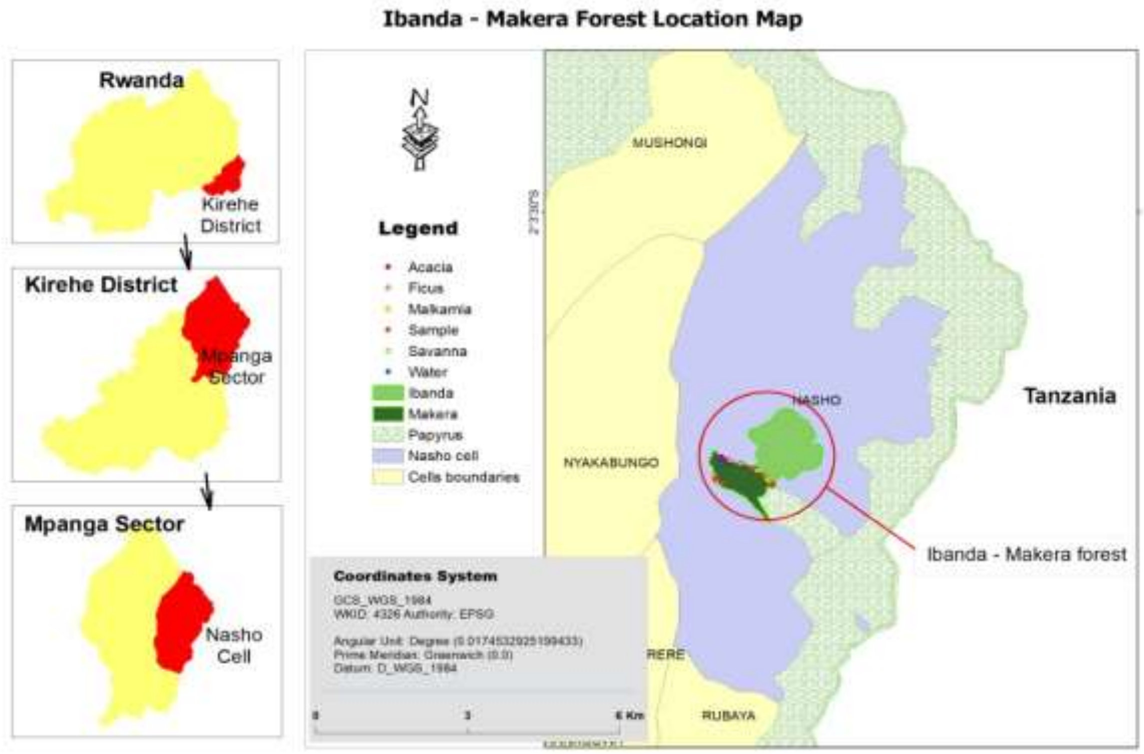

Figure 2. Ibanda-Makera forest location map

3.2. Determining sample size for the household survey

Ibanda Makera located in Nasho cell with the population of 6374. From which the sample size of 300 were calculated using Taro Yamane (1973) formula.

$$n=\frac{N}{1+N(e^2)}$$

Where: n= sample size   N =number of people in the population

e=allowable error (%) +5% and confidence interval of 95%

3.3. Household survey

The study involved informal and formal survey methods. This study has three phases, before each phase the introduction, clarification and aims of study were presented to participants. They were further assured that the information and findings of the study will be confidential and be used for the purpose of this study (Nsengimana et al, 2016). Household surveys were conducted in five villages that surround Ibanda-Makera forest using predesigned survey forms. Around 300 people were selected randomly without replacement. However, to participate in the study, respondent needed to be above 20 years old, and both female and male participated in the study.

3.4. Soil sampling

Soil samples were taken on topsoil (0 - 15cm soil depth) in the lower, middle, and upper part of the forest. Twenty-four samples were randomly collected and put in labelled bags for physical and chemical analysis. The content of organic matter was determined by loss on ignition method. The measured organic matter (OM) was divided by the correction factor 1.72 to obtain the organic carbon content. The dry combustion method was based on the loss on ignition where 2g of soil samples was sieved at 0.5mm and placed in a crucible oven dried at 105℃ and then ignited in a furnace for at least 3 hours at 450°C. The crucible with the sample was cooled in the desiccator for 30 minutes and then weighed. Finally, the organic matter was calculated from the weight loss by using correction factor for clay content. Furthermore, bulk density was determined using the core method. Soil organic carbon stock equation (FAO, 2018).

SOC stock (Mg C ha^{-1}) = OC x BD x ti x 0.1

SOC = Soil organic carbon stock (in Mg C ha^{-1}) of the depth increment

OC= organic carbon content (mg C g soil$^{-1)}$ of the fine soil fraction (< 2 mm) in the depth

ti = thickness (depth, in cm), of the depth increment

0.1 = conversion factor for converting mg C cm^{-2} to Mg C ha^{-1}

3.5. Above ground biomass Measurement

Above ground, biomass was sampled by establishing 1 x 1 km grid inside the forest. Sample plots were recognised at the intersections of a 10 x 20 m. Nine sample plots were randomly selected and trees inside sample plots (200 m^2) were measured. Earlier the non-destructive sampling method was conducted, the diameter at breast height (DBH) (cm) and height (m) of trees were measured using diameter tape. The location of each tree in relation to the plot axis was recoded. The species wood density standards used in the research were mined from the records of FAO (1997). Allometric equation used in dry region, South Asia and Indonesia was used in Ibanda Makera forest. Fifty nine trees were measured (Hairiah et al., 2010).

$$(\mathbf{AGB})\mathbf{est} = \mathbf{0.112} \times (\boldsymbol{rD2H})^{\mathbf{0.916}}$$

AGB) est = Estimated aboveground tree biomass (kg/tree)

DBH= Diameter at Breast Height (cm)

H =Tree height (m)

r = Wood density (g /cm^3)

3.6. Leaf temperature and leaf mass per area measurements

Leaf temperature and leaf mass per area measurements were taken for tree species that have been used for forest restoration namely *Markamia lutea (*Siala Tree), *Acacia polyacantha (*Catechu Tree) and *Ficus thonningii* (Chinese banyan). For each species nine to ten, trees were randomly selected, and healthy early mature leaves were investigated. For *Ficus thonningii* and *Markamia lutea* leaves, the morphological trait measurements were taken. Leaf temperature was taken from the leaves being horizontally exposed to the sun, and measured using Trotec BP10 Infrared Thermometer at a 45° angle and five cm away from the leaf surface. When measuring the leaf temperature, the central main vein of the leaves was avoided. Further, leaf measurements specifically leaf width and length were measured using a ruler, while the leaf mass per area was taken for all three trees species (Ganszky, 2017).

3.7. Data Analysis

Data was analysed using Statistical Package of Social Sciences version 16 (SPSS 16), STATA and Microsoft excel version 16. Open and closed answers from the survey discussion were categorised and coded. Frequencies derived from coded categories were computed and are presented in the bar chat figures where they are further described according to the research objectives. Data from the focus group discussions were qualitatively analysed and compared with those obtained from the household survey. Above ground, biomass was analysed using an Allometric equation and soil carbon stock was analysed using laboratory analysis.

Chapter 4: Results

4.1. Local people benefits from forest restoration

4.1.1. Perception of local people benefits from forest before and after restoration

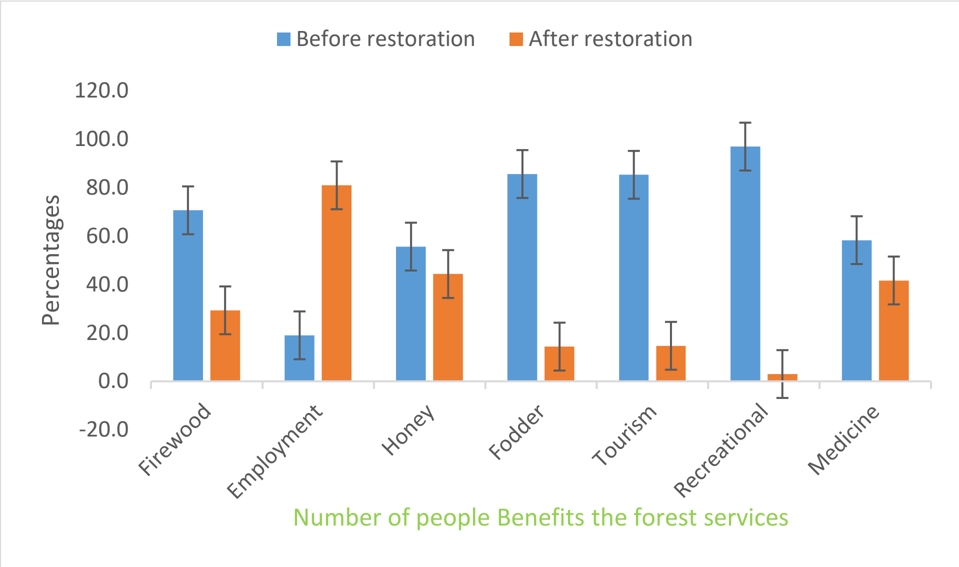

Figure 3. Perception of local people benefits from forest restoration

Table 1: Perception of local people on forest after restoration

Variables	Description
Firewood	Number of people searching firewood in the forest were decreased after forest restoration because people are not allowed to enter in forest
Employment	Number of people got employment during restoration were increased due to activities related to land preparation, nursery development, trees planting and weeding
Timber	Number of people searching timber production in forest was reduce because after forest restoration people are not allowed to enter in the forest
Fodder	Number of people searching fodder were reduced after forest restoration because people are not allowed to enter in forest
Recreational	Number of people entering in forest for recreation activities were reduced after forest restoration because people are not allowed to enter in the forest
Medicine	Number of people searching medicine in forest were reduced after forest restoration because people are not allowed to enter in the forest

Most respondents perceived that forest restoration improved livelihoods of people living around the forest in different ways. First, majority of respondents (81%) obtained an employment during the forest restoration activities. These activities were 2% forest protection, 41.6% land preparation, and 34.3% nursery preparation and forest maintenance. Another 44.3% highlighted the income generation from modern honey production (3000FRW/kg) from the restored forest. The above-mentioned opportunities helped them to improve their standard of living, as they were able to pay health insurance, school fees and secure food from the income generated.

4.1.2. Modelling the key factors reflecting livelihood benefits of communities due to restoration of Ibanda-Makera natural forest

Table 2 shows the results of logistic regression model indicating the factors influencing livelihood benefits of surrounding communities of Ibanda-Makera natural forest during its restoration. The results showed that employment is highly significant at 5 % level. i.e., a high number of population got job. Firewood and tourism is slightly significant, while fodder, medicine and recreation is not significant, but were positively related to the improvement of livelihood indirectly.

Table 2: Representation of logistic regression model Ibanda-Makera forest restoration on livelihood benefits of local people

Key factors implicating Role of forest to improvement of livelihood benefits to local people	Std. Err.	Z	P>z	[95% Conf. Interval]
Employment 3.47802	1.082769	3.21	0.001	1.355833- 5.600208
Firewood 2.187642	1.303311	1.68	0.093	-.3668005 - 4.742085
Fodder 1.464277	.9639187	-1.52	0.129	-3.353523- .4249685
Tourism -2.1291	1.12108	-1.90	0.058	-4.326377 .0681758
Recreational -.2978827	1.665903	-0.18	0.858	-3.562992- 2.967227
Medicine 1.175931	1.00347	1.17	0.241	-.790834- 3.142696

_cons 1.030021	.9315962	1.11	0.269	-.7958737-	2.855916

4.1.3. Challenges met by local farmers before and after restoration

Around 80.3% of respondents mentioned some negative effects of forest restoration on their daily activities. For instance, 66.5% reported that animals from the forest raid their crops before and after restoration. 33.5% stated that trees used during the forest restoration were planted in farmers' land, and they compete with crops. Forest trees also compete with crops. Others reported the lack of firewood that they used to collect from the forest before restoration.

4.2. Assessment of the restoration effects on ecosystem services essential to local people.

4.2.1. The perception of local people on importance of forest before and after restoration on ecosystem service

Results showed that the forest import for ecosystem services before and after restoration (Figure 4) show the perception of local people on ecosystem services.

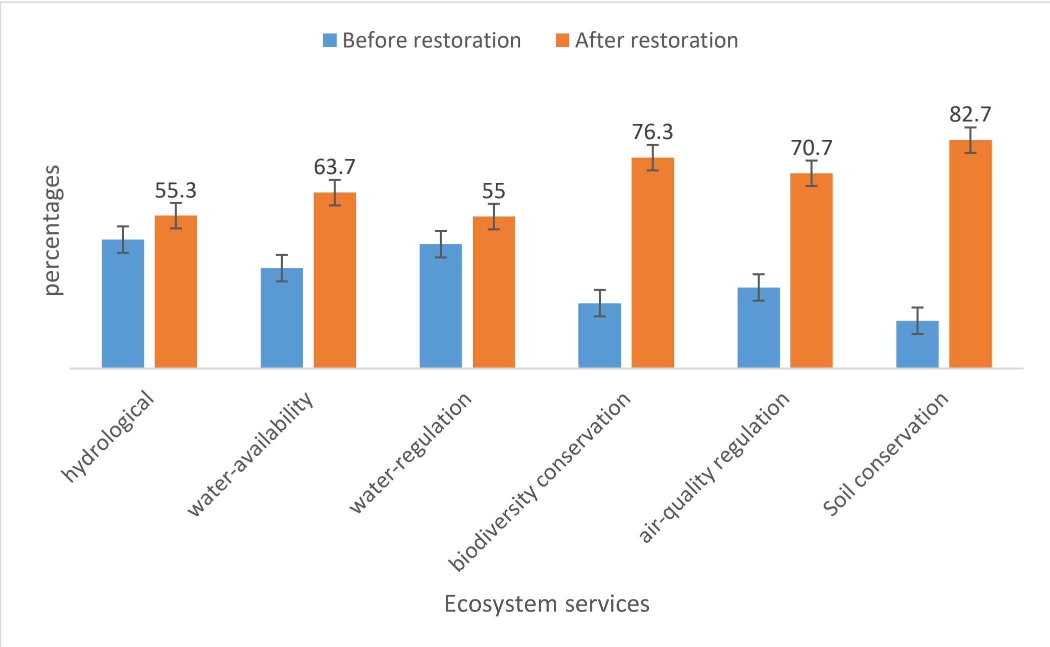

Figure 4: Role of forest before and after restoration

4.2.2. Leaf temperature (T_{leaf})

Results indicated that leaf temperature is significantly different among species at $p<0.05$. Highest leaf temperature was observed in *Markamia lutea* which 34.8 °C T_{leaf}, followed by *Ficus thonningii* had 31.9°C T_{leaf} and the lowest leaf temperature was obtained in *Acacia polyacantha* 24 °C T_{leaf}. Leaf temperature values were much greater for species with large foliage size compared to species with smaller leaf size. Therefore, *Markamia lutea* (large leaves) had the highest measured leaf temperature and *Acacia polyacantha* (small leaves) had the lowest leaf temperature whereas *Ficus thonningii* had middle foliage size and foliage temperature as shown by table 3.

Table 3: Mean leaf temperature

Species	**Mean Temperature (^OC)**
Acacia polyacantha	24
Ficus thonningii	31.9
Markamia lutea	34.8

4.2.3. Leaf mass per area (LMA)

Results show that leaf mass per area was significantly different among species at P<0.05. *Markamia lutea* had higher LMA 104.76 g/m^2. The intermediate LMA was found for *Ficus thonningii* 87.96g/m^2 while the least LMA was observed *Acacia polyacantha* 63.52g/m^2. Leaf width and length of *Markamia lutea* was 8.83 cm and 18.3cm. Leaf width and length of *Ficus thonningii* was 4.8 cm and 10 cm. This leaf trait shows the productivity of different trees species. *Markamia lutea* is highly productive, *Ficus thonningii is* productive rather than *Acacia polyacantha* had low productivity. The higher LMA was found in the species with larger leaf size. Lower LMA was found in the species with smaller leaf size

Table 4: Mean Leaf Mass per Area

Species	**LMA(g/m^2)**	**SEM**
Acacia polyacantha	63.52	±6.07
Ficus thonningii	87.96	±5.04
Markamia lutea	104.76	±6.1

4.2.4. Above Ground Biomass Estimation

The results in table 5 showed that 59 trees were recorded per hectare, representing about 6.34t/ha of above ground biomass. *Acacia polyacantha* had high aboveground biomass 6.1t/ha. *Markamia lutea* had 0.24t/ha. Aboveground biomass is significantly different among species at P<5%. There is a strong correlation between DBH and H, and strong correlation between DBH and Aboveground biomass.

Table 5: Above ground biomass

Species	Number of trees	Mean DBH(cm)	Mean H(m)	AGB(kg)	AGB(t/ha)
Acacia polyacantha	38	12.9	3.4	28.9	6.1
Markamia lutea	18	5.3	2.3	2.45	0.24
Total	59	18.2	5.7	31.35	6.34

4.3. Assessment of impact of Ibanda-Makera forest restoration on climate change mitigation effect

4.3.1. Perception of local people on climate change effect mitigation

Figure 5 below shows the role of forest on climate change mitigation before and after restoration according to survey respondents. The high number of respondent 84%, stabilising and cooling local climate including water flow and rainfall was an important effect and 31.3% of respondents mentioned wetland protection.

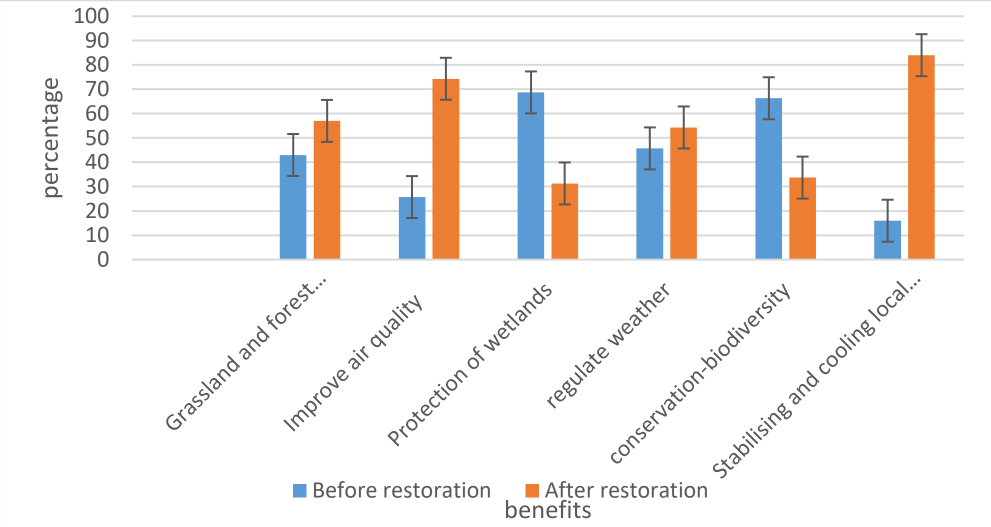

Figure 5: Impact of forest restoration on climate change effect mitigation

4.3.2. Enhancing soil carbon stock

The mean of soil carbon stock in the restored part of the forest was 6.2t/ha while the soil carbon in the protected part is 9.65t/ha. The results indicate that there are significant differences in carbon stock at level of P<5%.

Table 6: Mean of soil depth and variations in soil bulk density, organic carbon and total carbon

Land position	Soil depth	BD	OC	Ct/ha	SEM
Lowland	15	0.79	4.4	5.21	±1.36
Middle land	15	0.9	3.71	5.01	±1.21
Upper land	15	1.05	2.73	4.29	±0.94
Control	15	1.02	6.31	9.65	±2.51

The soil carbon stock showed difference among the different land positions. Soil carbon stock is significantly different at P<0.05 observed in lowland, middle land and upper land compared to control. The results indicate that lowland (low elevation) has high soil carbon stock (as shown by table 6) while low soil carbon stock was seen in the upper land relative to the control. Low bulk density < 1.0 was found in lowland, while high bulk density 1-1.3 was found in upper land. The control has high soil carbon stock compared to the land position lowland, middle land and upper land.

Chapter 5. Discussion

5.1. Role of forest restoration on local people

The results showed that Ibanda-Makera forest restoration brings positive and negative impacts on communities. Forest restoration affects communities positively through the improvement of their livelihood such as employment opportunities and income from honey production. Forest restoration affects communities negatively through wildlife crops foraging because there is no buffer zone around forest. Our results were consistent with the study by Adams et al. (2016) whose socioeconomic results showed there was an increase of income, livelihood variation, temporal employment, decrease of poverty, quality and the establishment of timber and energy as ecosystem services, health, food security and livelihood occasions. In addition, Erbaugh et al. (2018) reported that forest landscape restoration had direct and indirect impacts for improving forest ecosystem function, livelihoods, well-being and resilience. Direct impacts for livelihood was through direct cash, commercial development, occupation security, well-being and resilience. Indirect impact of forest restoration for improving livelihood, well-being and resilience was through decreased forest use, improved directive of forest use, proper and familiar planting, area preparation and other management practices. Land restoration improve food production, soil conservation and biodiversity protection (Erbaugh et al, 2018).

Turner-Skoff et al. (2019) reported that forest restoration helps communities through increase knowledge and skills and that children's access to nature. Health and social well-being, tree cover is powerfully associated to student educational performance. The most benefits of forest for human health is that, the forest capture and decrease air pollution such as carbon monoxide, nitrogen dioxide sulphur dioxide etc. Trees removes heavy metals and other pollutants from the environment (phytoremediation). Our results were similar to Hill (2017) who reported that wildlife foraging crop cultivated by human either by feeding or trampling them (crop raiding). Thus, will affect negatively local people through crop loss and food insecurity that affect negatively livelihoods.

5.2. Role of forest restoration on ecosystem services

Ecosystems provide an extensive range of goods and services to nature and human well –being. Those service including supporting services such as nutrients cycling, regulating such as regulation of water and soil, and cultural service such as recreational and aesthetic values

(Sharma et al., 2019). Erbaugh et al. (2018) reported that forest landscape restoration had indirect impact for improving forest ecosystem function through enhanced trees species richness, occurrence of required biodiversity, enhanced soil stability, fertility, organic matter, decreased soil erosion, combustible materials, enhanced surface water, groundwater, water quality and improved biomass productivity and carbon sequestration. Restoring corrupted forest can be an real result for improving vegetation arrangement, sequestering carbon in vegetation and soil, and improving hydrological cycles and micro-climate (Mekuria et al., 2018; Chirwa, 2014). Trees are certainly important, as they deliver food and environment for birds, invertebrates, mammals, and plants.

5.2.1. Leaf temperature

Results indicated that there is significantly difference among leaf temperature. The highest leaf temperature was observed in species with large leaf size. *Markamia lutea* has a large leaf size followed by *Ficus thonningii* and the lowest leaf temperature was obtained in species with a smaller leaf size *Acacia polyacantha*. The same results was reported in several studies such as (Ntawuhiganayo et al., 2020; Valladares et al, 2008; Vårhammar et al., 2015) that leaf temperature values was higher for the species with large leaves compared to the species with smaller leaves.

5.2.2. Leaf Mass per Area (LMA)

The findings of this study indicated that *Markamia lutea* tree species has higher LMA. The higher LMA was found in species with larger leaf temperature (big leaf size), *Markamia lutea* and lower LMA was found in the species with smaller leaf size. The same results were reported by (Ntawuhiganayo et al., 2020; Vårhammar et al., 2015) that high LMA was found in species that had large leaf size, low LMA were found in species that had smaller leaf size. Both Poorter al et. (2009) and Riva et al. (2016) reported that underwater plants from freshwater environments have the lowest LMA, this occurs because of the low light standards found in these locations.

LMA (leaf mass per area) is highly connected with leaf processes such as maximum photosynthetic rate whole-plant activities such as the species potential growth rate and ecosystem processes such as decomposition rate. The LMA of species is therefore a good indicator of the position of that species along an axis based on resources gaining (Riva et al, 2016). Poorter et al. (2009) reported that species that produce small–LMA with high nutrient content also decompose much earlier, foremost augmenting carbon and nutrient cycling, thus fast moving up ecosystem efficiency in different biomes

5.2.3. Above ground biomass estimation

The results show that restored trees have above ground biomass of 6.4 t/ha. This lower aboveground biomass results from trees still being young, low diversity, firewood collection and grazing of animals. Similar results were found by Shagufta Qasim et al 2017, who reported that above ground biomass was significantly higher in protected area compared to grazed areas. The above ground biomass of protected natural vegetation was ranged between 11.59 and 42.22t/ha. Increasing aboveground biomass could be a feasible opportunity to mitigate and adapt to climate change by decreasing net greenhouse gas releases. Restoration of degraded forests through durable protection methods contribute to carbon sequestration (Mekuria et al., 2018). Atsbha et al. (2019) report that the potential drivers like overgrazing and human interference for firewood collection, tree/shrub cutting for fencing and construction, and charcoal making could lower the carbon stocks in communal grazing land. Free grazing in the communal grazing land aggravates soil and vegetation degradation, which in turn negatively impacts vegetation restoration and accumulation of aboveground biomass.

5.3. Impact of Ibanda-Makera forest restoration on mitigating climate change effect

5.3.1. Soil carbon stock

Soil carbon stock in Ibanda-Makera forest was higher in the protected area at 9.5t/ha than in restored part (6.5t/ha) of the forest. This occurs because of firewood collection, trees being harvested for construction, grazing of animals and young age of trees after restoration. The protected area has a higher diversity than restored part as well. Our results were similar to those obtained by Bikila et al. (2016) and Mekuria (2013) who stated that Soil Organic carbon was highe for Protected Natural Vegetation than exposed grazing areas. Sheikh et al. (2009) also stated that greater SOC quantity was documented the protected areas compared to exposed grazing lands. Native forest permanently had higher SOC content because the existence of foliage that increases the SOC content. Lorenz et al, 2015 reported that the constructive effects of trees on SOC sequestration are that trees change the value and capacity of belowground litter C inputs and change microclimatic situations such as soil moisture and temperature regimes. One of the keyways to limit the impacts of climate change is to decrease the quantity of carbon released into the atmosphere, and tree species are valuable for storage of carbon, the main driver of the climate change effect (Turner & Cavender, 2019).

Recommendation and conclusion

Conclusions

Based on the results of this study, we explore the importance of Ibanda-Makera forest restoration on local people's livelihoods and environmental conservation in the Eastern part of Rwanda. The Ibanda-Makera forest restoration had substantial impacts on local people such as the improvement of living standards. Further, the restoration of Ibanda-Makera forest improved ecosystem functioning through biodiversity conservation and production of above ground biomass of 6.4t/ha. Further, local community members indicated that it had an impact on climate change mitigation through stabilising and cooling the local climate (84%), air quality improvement (74.3%). Carbon sequestration was 6.5 t/ha at restoration site compared to the control 9.5t/ha. It is very important to restore forest because it increase species richness and biodiversity conservation. Ibanda Makera forest restoration has impact on climate change mitigation.

Recommendations

- The study recommends the creation of the buffer zone with the species that benefit to people and not attract animals.to stop encroachment.
- Plant medicinal plant out of forest in order to reduce number of people entering in the forest
- Plant agroforestry species nearby homeland to reduce the impacts on crops, replace goods that used to be collected from the forest such as firewood and increase forest protection
- Encourage people to live in a way that does not hurt the environment
- Legal framework should be developed to prevent and delay illegal activities.
- Other study will focus on the species that can replace *Ficus thoningii* as it is not well adapted in Ibanda Makera forest
- Other study will use soil carbon stock and aboveground biomass as baseline data

Reference

Adams, C., Rodrigues, S. T., Calmon, M., & Kumar, C. (2016). Impacts of large-scale forest restoration on socioeconomic status and local livelihoods: what we know and do not know. *Biotropica*, *48*(6), 731–744. https://doi.org/10.1111/btp.12385

Atsbha, T., Belayneh, A., & Zewdu, T. (2019). Carbon sequestration potential of natural vegetation under grazing in fluence in Southern Tigray , Ethiopia : implication for climate change mitigation. *Heliyon*, *5*(August), e02329. https://doi.org/10.1016/j.heliyon.2019.e02329

B.Bonan, G. (2008). forests and climate change:forcings,feedbacks,and the climate benefits of forests. *European Journal of Gynaecological Oncology*, *25*(6), 752–754.

Bizuru, E., Nyandwi, E., Nshutiyayesu, S., & Kabuyenge, J. P. (2011). *Inventory and mapping of threatened remnant terrestrial ecosystems outside protected areas through Rwanda*.

Brack, D. (2019). *Forests and Climate Change Duncan Brack i the fourteenth session of the United Nations Forum on Forests*.

Ciccarese, L., Mattsson, A., & Pettenella, D. (2012). *Ecosystem services from forest restoration : thinking ahead*. 543–560. https://doi.org/10.1007/s11056-012-9350-8

Erbaugh, J. T., & Oldekop, J. A. (2018). Forest landscape restoration for livelihoods and well-being. *Current Opinion in Environmental Sustainability*, *32*, 76–83. https://doi.org/10.1016/j.cosust.2018.05.007

Estimates, C. (2010). *Ecosystem-based Adaptation in Africa*.

FAO. (2018). Measuring and modelling soil carbon stocks and stock changes in livestock production systems. In *Voprosy Virusologii* (Vol. 53).

IUCN. (2009). Ecosystem-based Adaptation: A natural response to climate change. *Journal of Semitic Studies*, *33*(1), 1–9. https://doi.org/10.1093/jss/XXXIII.1.1

IUCN. (2017). *Enhancing Resilience through Forest Landscape Restoration : Understanding Synergies and Identifying Opportunities*.

Joram, N. S., Marc, N., Loger, G., Theogene, U., Aimable, N., Irakiza, R., … Olive, I. (2010). Eastern Gallery Forest Conservation Project Biodiversity survey A Final Research report. *The RUFFOR Small Grants Fundandation*, (May).

Langat, D. K., Maranga, E. K., Aboud, A. A., & Cheboiwo, J. K. (2016). Role of Forest Resources to Local Livelihoods: The Case of East Mau Forest Ecosystem, Kenya. *International Journal of Forestry Research*, *2016*. https://doi.org/10.1155/2016/4537354

Lorenz, K., Lal, R., Lorenz, K., Lal, R., Lorenz, K., & Lal, R. (2015). *Soil organic carbon* *sequestration in agroforestry systems . A review To cite this version : HAL Id : hal-01234833 Soil organic carbon sequestration in agroforestry systems . A review*. https://doi.org/10.1007/s13593-014-0212-y

Miccolis, A., Peneireiro, F. M., Vieira, D. L. M., Marques, H. R., & Hoffmann, M. R. M. (2017). Restoration through Agroforestry :Optios. *Experimental Agriculture*, *55*(S1), 208–225. https://doi.org/10.1017/S0014479717000138

MINILAF. (2017). Forest Investiment Program for Rwanda. In *Minilaf*.

National Institute of Statistics of Rwanda (NISR). (2015). *Fourth Population and Housing Census, Rwanda, 2012 District Profile Kirehe*. 20–58. Retrieved from http://www.who.int/growthref/tools/en/

NBSAP. (2016). National Biodiversity Strategy Plan. In *National Biodiversity strategy and Action Plan*.

Nsengimana, V., Weihler, S., & Kaplin, B. A. (2016). *Perceptions of Local People on the Use of Nyabarongo River Wetland and Its Conservation in Rwanda*.

Padial, A., Rosa, C. M., & Shimamoto, C. Y. (2018). *Restoration of ecosystem services in tropical forests : A global meta-analysis*. 1–16.

Parrotta, E. J. A., Wildburger, C., & Mansourian, S. (2012). *Understanding Relationships between Biodiversity , Carbon , Forests and People : The Key to Achieving REDD + Objectives* (Vol. 31).

Poorter, H., Poorter, H., Niinemets, Ü., Poorter, L., Wright, I. J., & Villar, R. (2009). *Causes and consequences of variation in leaf mass per area (LMA): a meta-analysis*. 565–588.

Poorter, L., & Bongers, F. (2006). *Leaf traits are good predictors of plant performance across 53 rain forest species Leaf Traits are Good Predictors Of Plant Performance*. *9658*(August). https://doi.org/10.1890/0012-9658(2006)87

Prof Jean Nduwamungu. (2019). *Ministry Of Environment Rwanda Environment Management Authority*.

Resource, M. of natural. (2014). *Republic Of Rwanda Forest Landscape Restoration Opportunity Assessment for Rwanda*.

Riva, E. G. De, Olmo, M., Poorter, H., Ubera, J. L., & Villar, R. (2016). *Leaf Mass per Area (LMA) and Its Relationship with Leaf Structure and Anatomy in 34 Mediterranean Woody Species along a Water Availability Gradient*. 1–18. https://doi.org/10.1371/journal.pone.0148788

Sharma, R., Rimal, B., Baral, H., Nehren, U., Paudyal, K., Sharma, S., … Kandel, P. (2019). Impact of Land Cover Change on Ecosystem Services in a Tropical Forested Landscape. *Resources*, *8*(1), 18. https://doi.org/10.3390/resources8010018

Snilstveit, B., Stevenson, J., Fenton Villar, P., Eyers, J., Harvey, C., Puri, S. J., & Mckinnon, M. C. (2016). Land-use change and forestry programmes: Evidence on the effects on greenhouse gas emissions and food security. In *Evidence Gap Map Report 3*. Retrieved from http://www.3ieimpact.org/media/filer_public/2016/11/17/egm3-landuse-forest.pdf

Turner-Skoff, J. B., & Cavender, N. (2019). The benefits of trees for livable and sustainable communities. *Plants, People, Planet*, *1*(4), 323–335. https://doi.org/10.1002/ppp3.39

Urban, J., Ingwers, M. W., Mcguire, M. A., & Teskey, R. O. (2017). *Increase in leaf temperature opens stomata and decouples net photosynthesis from stomatal conductance in Pinus taeda and Populus deltoides x nigra*. *68*(7), 1757–1767. https://doi.org/10.1093/jxb/erx052

Vallauri, D. (2005). *Overview of Forest Restoration Strategies and Terms Forest Restoration in Landscapes*. https://doi.org/10.1007/0-387-29112-1

Verchot, L. V., Van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., … Palm, C. (2007). Climate change: Linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change*, *12*(5), 901–918. https://doi.org/10.1007/s11027-007-9105-6

World Bank. (2009). Convenient Solutions to an Inconvenient Truth: In *World*.