College of Science and Technology

School of Architecture and Built Environment

MSc in Geo-Information Science for Environment and Sustainable Development

Assessment of Growth and Survival Rate of Native Tree Species in COMBIO Project areas in Eastern Province Rwanda.

MSc dissertation submitted in partial fulfilment of the requirements for the award of the Master of Science in Geo-Information for Environment Sustainable and Development.

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October, 2025

DECLARATION

I declare that this MSc dissertation entitled **"Assessment of growth and survival rate of native tree species in COMBIO project areas in Eastern province Rwanda."** submitted for an award of Master's degree in Geo-Information for Environment and Sustainable Development is my own original work and has never been submitted in any higher learning institution or elsewhere.

NSANZIMANA Julien

……………………………. Date: …..../……. /……..

APPROVAL

This is to certify that the study entitled **"Assessment of growth and survival rate of native tree species in COMBIO project areas in Eastern province Rwanda"** was conducted by Julien NSANZIMANA in partial fulfilment of the requirements for the award of the Degree of Master of Science in Geo-Information for Environment and Sustainable Development, in the School of Architecture and Built Environment.

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DEDICATION

This dissertation is dedicated to

My beloved parents

My beloved families, brothers and sisters

ACKNOWLEDGEAMENT

I am humbly thankful for the contributions of different people, who were involved in my research.

I am grateful for having successfully completed my research, thanks to the valuable knowledge and skills I acquired from University of Rwanda (UR), College of Science and Technology (CST), School of Architecture and Built Environment (SABE). It has been great honour to learn more from my lecturers and benefit from the experience they generously shared with me.

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TABLE OF CONTENT

LIST OF ACCRONOMS AND ABBREVIATION

CoEB: Center of Excellence in Biodiversity and Natural Resource Management

COMBIO: Community-based biodiversity conservation project in Eastern Province of Rwanda

CST: College of Science and Technology

DBH: Diameter at Breast Height

DGPS: Differential Global Positioning System

ENABEL: Belgian Development Agency in Rwanda

ES: Early-Successional

FAO: Food and Agriculture Organization of the United Nations

GIS: Geographical Information System

GoR: Government of Rwanda

IDW: Inverse Distance Weighting

IUCN: International Union for Conservation of Nature

LS: Late-Successional

MINAGRI: Ministry of Agriculture and Animal Resources

MoE: Ministry of Environment

NDVI: Normalized Difference Vegetation Index

NLA: National Land Authority

NMDS: Non-Metric Multidimensional Scaling

PH: Potential of Hydrogen

RFA: Rwanda Forest Authority

SABE: School of Architecture and Built Environment

SR: Survival Rate

UR: University of Rwanda

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

The restoration practices of degraded land or deforested forest landscapes using native tree species are increasingly important in addressing global environmental challenges. In Rwanda, COMBIO is among the project that are restoring degraded land and deforested forest in Eastern province using native tree species to enhance ecological resilience and supports community livelihoods. This study assessed the growth and survival rates of one year-old native tree species planted in six sanctuaries with under the COMBIO project areas in Eastern province of Rwanda. Data collection was done by measuring tree height, base-diameter and counting living, dead and missing trees with spatial locations captured using Differential Global Positioning System (DGPS). The study also used interviews and observations to identify factors influencing tree performance and propose best practices. Collected spatial data and physical and environmental variables such as topography, rainfall and temperature related to the project intervention areas were analysed in ArcGIS Pro. Tree growth performance data including average height, base diameter and survival rate were analysed using Ms excel and R software, while the data from both interviews and observation were quoted and interpreted. Results showed significant variation in growth and survival rates across species and sites whereby fast-growing species reached average heights between 1m- 4.8m with base-diameter of 3 cm-8.6 cm, while slow-growing species remained below 1m in the height and 3cm in base-diameter. Survival rates ranged from 60-100% for resilient species, 20 to 60% for less resistant species and below 20% for species introduced from other spatial location, indicating poor adaptation of montane species to the eastern region, which is a lowland and savannah. Key factors influencing growth survival of species included site-species matching, rainfall, temperature, pest and diseases, competition with unwanted trees, topography, livestock grazing, Indirect planting system and lack knowledge among labourers. The study suggests that proper species selection, implementation of Taungya system, protection of plantation against the reach of livestock, application of organic manure, high maintenance practices, use of quality seedlings use of termite resistant trees and enhanced community awareness of tree management are the best practices to ensure successful growth and survival not only in the current sancta but also in further future COMBIO project areas.

Keywords: COMBIO, Native Tree Species, Sancta, Successional Group and Taungya system

1. INTRODUCTION

The introduction provides an overview of the study by presenting the general background information, clearly outlining the research problem, and highlighting the rationale for understanding the study. It further sets out the research objectives, formulates the guiding research questions and hypothesis, and defines the scope and limitations. Finally, it emphasizes the significance of the research, demonstrating its contribution to knowledge, policy and practice.

1.1. General background information

The restoration practices for degraded land or deforested forest landscapes are increasingly important in addressing global environmental challenges. In many countries, the plantation of the native tree species are the most successful restoration initiatives used to recover deforested landscape (Abella & Chiquoine, 2019). Moustakas and Evans (2015, pp. 4-6) argued that the tree plantations are vital for the economic development and serve as the foundation for many other commercial and non-economic assets such as tourism resources, wildlife habitat and water resource preservation.

The perennial tree plantations provide a wide range of benefits including their important role in mitigating climate change through carbon sequestration, provision of habitat for biodiversity, and evapotranspiration contributing to the hydrological cycles. However, various forest resources across the globe have been degraded due to human influences that increase the threats of climate change (Hosonuma et al., 2012). As measures, many countries have been rehabilitating the degraded land using indigenous species which are suited to local environmental conditions (Sorecha, 2017). Sanford et al. (2003) define tree growth rate as the increase in the size, volume or biomass of the tree over a certain period of time while survival rate refers to the proportion of trees that remain alive over period of time mostly expressed in percentage that mostly hinder the growth and survival rate of tree plantation.

Mostly, the trees are typically extremely long-lived and require long-term studies to allow any understanding of the factors that underlie its survival for long time (Fuentes-Ramírez et al., 2011). Ali et al. (2024) state that tree growth and survival is a key factor in forest dynamics and survival probabilities often vary across life stages. However, the success of plantation is hampered by various factors affecting plants survival and growth performance (Gebirehiwot, 2023). For instance, various studies reported that change in survival and growth rate can be attributed to underlying factors including limited light availability, nutritional deficiency, shifting in environmental condition, humidity and water availability (Gemechu & Jiru, 2021). Furthermore, the soil conditions, planting techniques and selection of appropriate species are mainly conserved as an important factors influencing the success or failure of a plantation (Koeser et al., 2014).

In many countries including Rwanda, the native tree species that were maintained by the tradition have been declined due to the global influences of the wealthiest countries hence trends in species diversity in developing countries (Hosonuma et al., 2012). In the last 100 years, the forest plantations in Rwanda have been dominated by monocultures primarily Eucalyptus and Pinus which have negatively impacted the native trees species in Rwanda (Seburanga, 2013, p. 3).

In this context, the Government of Rwanda through Rwanda Forest Authority (RFA) in collaboration of other partners in Rwanda including Belgian Development Agency (ENABEL) and International Union for Conservation of Nature (IUCN) initiated a mass forest restoration known as COMBIO using native tree species in Eastern province of Rwanda (RFA, 2024). The project aims to reduce vulnerability to climate change through enhanced community-based biodiversity conservation by establishment of community biodiversity sancta and development of biodiversity-based enterprises and value chains associated with these sanctuaries in Eastern Province of Rwanda (ENABEL, 2023).

1.2. Problem statement

Globally, deforestation and forest degradation pose serious threats to the environment, largely driven by human activities and environmental stressors (Kumar, 2022). Forest restoration, particularly using native tree species, is seen as a key solution (Lu, 2017). In sub-Saharan Africa and East Africa, deforestation is intensified by agricultural expansion, fuelwood use and climate variability (Ordway, 2017). Regional restoration efforts increasingly focus on drought-tolerant native tree species due to their adaptability and potential for long-term success (Birru, 2014).

In Rwanda particularly in the Eastern province, deforestation and forest degradation are driven by climatic and topographical conditions, particularly low rainfall and lower altitude by limiting water availability, hinders seed germination and leads to poor soil moisture compared to other regions. These conditions negatively impact tree growth and survival (Mirindi, 2022). In this vein, native tree species have been identified as more suitable due to their ability to withstand drought and adapt to poor soil conditions better than non-native species (Buckley & Catford, 2016). Even if native trees persist for draughts and other environmental constraints, the growth and survival vary respecting the type of species, all native tree species are not growing and surviving at equal rate (Stelstra, 2021). In this regard, tracking the tree health in both diameter, height crown size and greenness is important for forest management. The restoration of degraded forest using native tree species has been increasingly recognized as an effective means of restoring ecosystem functions and biodiversity in the degraded areas (Yang Lu, 2017). Therefore, the decline of forest in Eastern province led to the government initiative to restore the degraded areas using native tree species which adapts to local climatic condition (Ngugi et al, 2015).

COMBIO is among the projects that are restoring degraded land and deforested areas in Eastern province of Rwanda using natives tree species. Even though different studies have been conducted on native tree species in Rwanda (Mugunga, 2002; Murekezi, 2013; Hagumubuzima, 2019; Stelstra, 2021; Hagumubuzima, 2022; Ntirugulirwa, 2023; Bosveld, 2023; Cyamweshi, 2023) none of them has assessed specifically the growth and survival rate of native tree species in Eastern province of Rwanda mainly in the areas of interventions of COMBIO project. There is doubt about the growth and survivorship rate of some planted native tree species in the COMBIO intervention areas as this initiative is recent in the area and some seeds were collected far from the Eastern Rwanda.

In this regard, this research assessed the growth and survival rate of native tree species planted one year ago and to determine key underlying factors controlling growth and survival rates in COMBIO intervention areas in Eastern province of Rwanda. The early identification of potential challenges, such as slow growth, low survival rates or environmental constraints will enable timely interventions to mitigate threats and optimize forest restoration efforts in COMBIO project. The research findings will not only enhance the effectiveness of forest restoration programs but also serve a baseline data for the future assessment of growth and survival rate of native trees species planted in the COMBIO project intervention sites in Eastern province of Rwanda.

1.3. Research objectives and research questions

This research is guided by both main and specific research objectives which are outlined as follows:

1.3.1. Main objective

The overall objective of the present study is to assess the growth and survival rate of native tree species in COMBIO project areas in Eastern province of Rwanda.

1.3.2. Specific objectives

To achieve the main objective, four specific objectives have been formulated:

- To assess tree growth (height and base-diameter) of native species in COMBIO intervention areas.
- To explore survival rate of different species across different sites.
- To determine key factors underlying and influencing the growth and survival rates at different sites.
- To propose strategies for ensuring successful growth and survival rate of native tree species.

1.3.3. Research questions

To achieve the specific objective of this research, four key research questions have been addressed:

- How does the growth (height and base diameter) of native tree species vary in COMBIO intervention areas?
- What is the survival rate of different tree species across different sites?
- What are the key factors underlying and influencing the growth and survival rates of native tree species at different sites?
- What are the strategies for ensuring successful growth and survival rate of native tree species?

1.4. Alternative hypothesis

To address the research objectives, four corresponding hypotheses have been formulated based on the research questions and informed by literature and contextual assumptions. First, it is hypothesized that the growth (height and base diameter) of native tree species in COMBIO intervention areas varies significantly across sanctuaries due to differences in environmental conditions such as rainfall, temperature and altitude. Second, the survival rates of native tree species are expected to differ among species, with some showing greater resilience to local environmental stressors. Third, it is assumed that key factors including environmental conditions (eg. Rainfall and temperature), species-specific traits and human activities like grazing and land use practices significantly influence the growth and survival rates of native tree species in the intervention areas. Lastly, the implementation of strategies such as soil management, water conservation techniques, exclusion of grazing, use of quality seedlings, and careful selection of tree species will enhance both growth performance and survival outcomes of native tree species in the COMBIO project areas in Eastern Province of Rwanda.

1.5. Scope of the research

This research focuses on growth and survival rate of native tree species in the COMBIO project areas in Eastern Province of Rwanda. It aims to assess the growth (height and base-diameter), to explore the survival rate of different species, to identify key factors underlying and influencing growth survival, and to propose best practices to control key factor underlying and influencing growth and survival rate of native tree species in the COMBIO project sanctuaries such as Amahoro, Jambo-Beach, Karushuga, Muhazi, Ryarubamba and Shungerezi sancta all located in Eastern Province.

1.6. Significance of the research

Assessing the growth and survival rate of native tree species in the COMBIO project area in Eastern Province of Rwanda is very important for tracking the growth status and survival of one year-old trees to know which species are faster growing, slow growing and high surviving or not surviving in all statuaries. The research is crucial since it highlights the key factors underlying and influencing the tree growth and survival and lately proposing the best practice to put in place to ensure successful growth and survival of native tree species. With low survival rates and slower growing of species in sanctuaries, there is an urgent need to employ recommended best practices for successful growth and survival rate of native tree species. This research uses GIS technology to analyse the underlying factors. Furthermore, this research serves as a baseline data for future growth and survival assessment as well as guiding other future COMBIO project areas to reduce vulnerability to climate change through enhancing community-based biodiversity conservation as the main objective of the COMBIO project.

2. LITERATURE REVIEW

Globally, native tree species have a key advantages that favour natural habitats dues to their adaptations. Gorchov and Trisel (2003) agreed that native tree species are conditionally suitable to local soil, climate and ecological aspects which contribute the their growth and survival rates. Moustakas and Evans (2015) states that native tree species provide support to local biodiversity through providing home and food for indigenous wild animals. Apart from positive contribution of native tree species, they are still various constraints to their growth and survival (Ali et al., 2024). This chapter is focusing on the literatures on tree growth (height and base-diameter) for native species, survival rate among different species, key underlying factors influencing the growth and survival rates, best practices for proper growth and survival rate of native tree species, regulatory and policies regulating natives tree species in Rwanda.

2.1. Tree growth (height and base-diameter) for native species

Tree growth is defined as an increase of height thickness of the tree trunk, branches, and roots (Sumida et al, 2013). The height and diameter at the breast height (DBH) at standardized height of 1.25m above the ground are commonly used measures of tree growth and their relationship (Popoola, 2023). Even if the tree stem diameter, height and crown size are the parameters for measuring tree growth. The crown size measurements have until now been ignored and taken as an optional.

Lu (2017) urges that the mean monthly tree growth vary between species. However, the tree growth is mainly influenced by various key factors. For instance, Coomes and Allen (2007) found that tree growth declined with altitude where trees become stunted and have more open canopies at high altitudes. The height and diameter of some species increase progressively with rainfall like

Eucalyptus siderophloia, *Eucalyptus propingua* and *Laphostemon confertus*. This confirm that tree height and diameter are linearly increases as rainfall increases (Ngugi et al, 2015).

The excellent conditions of location of species leads to the high growth. For example, Ali et al (2023) found that *Dalbergia Sissoo* attained average girth of 19cm and a height of 2.0m due to it nearby to water channels. The diameter and height were higher compared to *Eucalyptus camaldulensis*. Whereby, the *Dalbergia sissoo* had a diameter and height of 6.05cm and 2.8m respectively while *Eucalyptus camaldulensis* had 5.13 cm and 2.93 respectively at 2 years age (Deshmukh and Vishwavidyalaya, 2021). Apart from measuring tree diameter at breast height (DBH), Moustakas (2015) states that it can also be measured at the base (5cm) above the ground by measuring tree circumference for the young trees.

2.2. Survival rate among different species

The most crucial factors determining a plantation's status of being successful or not is its survival rate (Ali et al 2024). Sorecha (2017) define tree survival rate as the percentage of trees that remain alive after a certain period time, typically measured in the first few years. Martin et al (2010) states that poor survival rate may be resulted from insufficient post planting care like mulching and use of manure. The survival rate is measured by counting living trees with comparison of originally planted trees per each species (Dobbertin, 2005).

According to guidelines for agroforestry survivorship in Rwanda, the overall survival rate of species in country is 64.04% where high-altitude regions exhibit the highest survival rate at 67.1%, followed by low-altitude regions at 61.3% and middle altitude region at 56.3% (RFA, 2024). If compared among themselves, the non-native species tend to perform better with an average survival rate of 67.8% than the native species which lag behind at 55.9%. This is supported by the guidelines for agroforestry survivorship in Rwanda.

Murekezi et al. (2013) who point out in his study of investigating survival rate of trees planted in agroforestry and forest plantations in Huye District that native tree species such as *Erythrina abyssinica, Euclea schimperi, Ficus sur, Ficus thonningii, Garcinia buchananii, Galiniera saxifraga, Kigelia africana, Maesa lanceolata, Maesopsis eminii, Markhamia obtusifolia , Markhamia lutea, etc*., have been identified as suitable species that can persist the drought and able to adapt to poor soil conditions.

Ntirugulirwa et al. (2023) founds that the tree survival rate of many species is mainly stimulated by warmer sites compared to the coolest site. Studies have shown that these species can achieve reasonable survival rates when appropriate silvicultural practices, such as mulching and the use of organic fertilizers, are applied. For example, *Acacia senegal* has shown a high growth rate in the dry area of the Eastern Province of Rwanda due to it deep root system that efficiently taps into groundwater resources (Mugunga, 2002). In this research, the living tree species will be counted and compared to the originally planted tree at the beginning.

2.3. Key factors underlying and influencing the growth and survival rates

Nowadays, the native tree species in most countries of Africa are influenced by human footprints that threaten their growth and survival mainly at early stage (Ligot et al., 2022). For instance, in Ethiopia the reduction of native tree species like *Ejersa, Weyirain and Hagenia abyssinica* as common species known locally red to the loss of biodiversity (Megan, 2013). The Ethiopia has started a project rehabilitating the degraded land using the endemic tree especially in Lake Haramaya sub catchment (Gebre et al., 2022). However, the study undertaken to assess the growth and survival rate of the planted endemic tree species in the sub catchment found that *Olea africana* perform well counting 38% of survival rate and 37% of survival rate in Damota and Tinike sub watershed (Sorecha, 2017).

According to Gebirehiwot (2023), the drought and moisture stress, low soil fertility, poor seedlings quality, weak species site matching, termites, livestock grazing, seasonal frost and altitude are the basic factor that hinder the survival and growth of native tree species in the field. For instance, RFA (2024) confirmed that survival rate varies with respect to altitude where *Markhamia lutea* has 70.2% in low, 66% in middle and 0% in high altitude. And, *Maesopsis eminii* has 29.6%, 55% and 56% in high, middle and low altitude respectively.

Kanoti (2005) explains that increasing temperature, changing patterns of precipitation, decrease in moisture influence the growth and survival of native trees mainly at early life stages. Koeser, (2014) urges that on-site irrigation also play a significant role in tree growth and survival. For instance, the study conducting the tree growth indicated that *Virginiana* survived at 97.5% in irrigated land and 94.2% in non-irrigated site. The lack of poor post planting care led to the failure of normal tree growth and survival (Murekezi, 2013).

These species are well-adapted to the local environmental conditions, contributing to their higher survival rates compared to non-native species (Buckley & Catford, 2016). Additionally, the use of agroforestry practices, which integrate native trees with crops, has been shown to enhance soil fertility and moisture retention, further supporting the growth and survival of native trees (Mugunga, 2002).

In Rwanda, native tree species play an important role in the ecosystem. Various studies conducted in Rwanda reported that the growth and survival rates of native tree species is influenced by numerous factors including soil type, climate variability and altitude (Havugimana, 2019). Stelstra (2021) argued that native tree species in Rwanda adapt to the local environmental conditions comparing to the non-native species. And also, the introduction of agroforestry practices by integrating the native tree species with crops contribute to soil fertility and moisture retention which support the growth and survival of native species (Kiyani et al., 2017). (Sorecha, 2017) defined successional group as the tree classification based on how different species establish and grow during various stages of ecological succession. (Ligot et al., 2022) argued that tree successional group facilitate the early or late success growth of tree where early successional group grow well at early stage compare to late successional group.

2.4. Strategies to ensure successful growth and survival rate of native tree species

The decline in tree growth and low survival rate of native tree species can be controlled by employing measures. Munro and Lindenmayer (2011) stated that the in-situ rainwater harvesting structures, fertilizers application, the use of quality seedlings, the right species site matching and exclusion of livestock and grazing animals from planted seedlings are the remedies that must be employed to increase the success of native tree species growth and survival rate in the field.

A continuous long-term monitoring in multi-age provides expected growth and survival for native forest (Micheal, 2015). Narh (2024) indicates that the cultivation of crops in the young forest planation known as Taungya system led to the proper growth of trees. Timely monitoring and evaluation of planted trees is critical to inform the concerned authorities about the present state of plantations and ensuring the effectiveness of the restoration program.

2.5. Regulation and policy regulating natives tree species

Rwanda Forest Authority is mandated to manage forest in Rwanda and establishes regulations relating to the selection of tree species their suitable planting area and their management. The law states that everyone has an obligation to protect, conserve and promote forests (GoR, 2024).

RFA (2024) states that the number of threatened native tree species has decreased down to 10% in 2024. It is recommended that remnant natural forests and native species should be considered in district forest management plans with specific measures for protection. RFA (2024) recommends that trees with values, characteristics or interests for biodiversity including young trees still under management are not recommended for removal. The native tree species must be identified, mapped and will be gazette as protected (MoE, 2018).

RFA (2018) recommends to identify and protecting threatened species as well as managing and maintaining forest resources to ensure biodiversity conservation and sustainable provision of ecosystem goods and services and also rehabilitating degraded forest to improve ecosystem values. In this regard, the Government of Rwanda is putting more efforts to reforest and restore degraded lands by including native species. For example, the reforestation projects in the Gishwati-Mukura National Park have focused on restoring native tree cover, resulting in improved biodiversity and ecosystem services (Nsabimana et al., 2008). These initiatives also extended to Eastern province of Rwanda by focusing on the restoration and conservation of biodiversity through the planting of native tree species to address environmental challenges such as deforestation and soil degradation by promoting the growth of indigenous trees adapted to the region's semi-arid climate and varying soil conditions (Hagumubuzima et al., 2022).

3. RESEARCH METHODOLOGY

This chapter describes methods used for data collection and data analysis. It begins by providing study design, description of study area and data collection methods on each objective that were used to achieve objectives of the study.

3.1. Research design

Research design can be considered as the structure of research. Mainly, this scheme elaborates the arrangements and organisation of the research components such as; general introduction, literature review, research methodology and research findings:

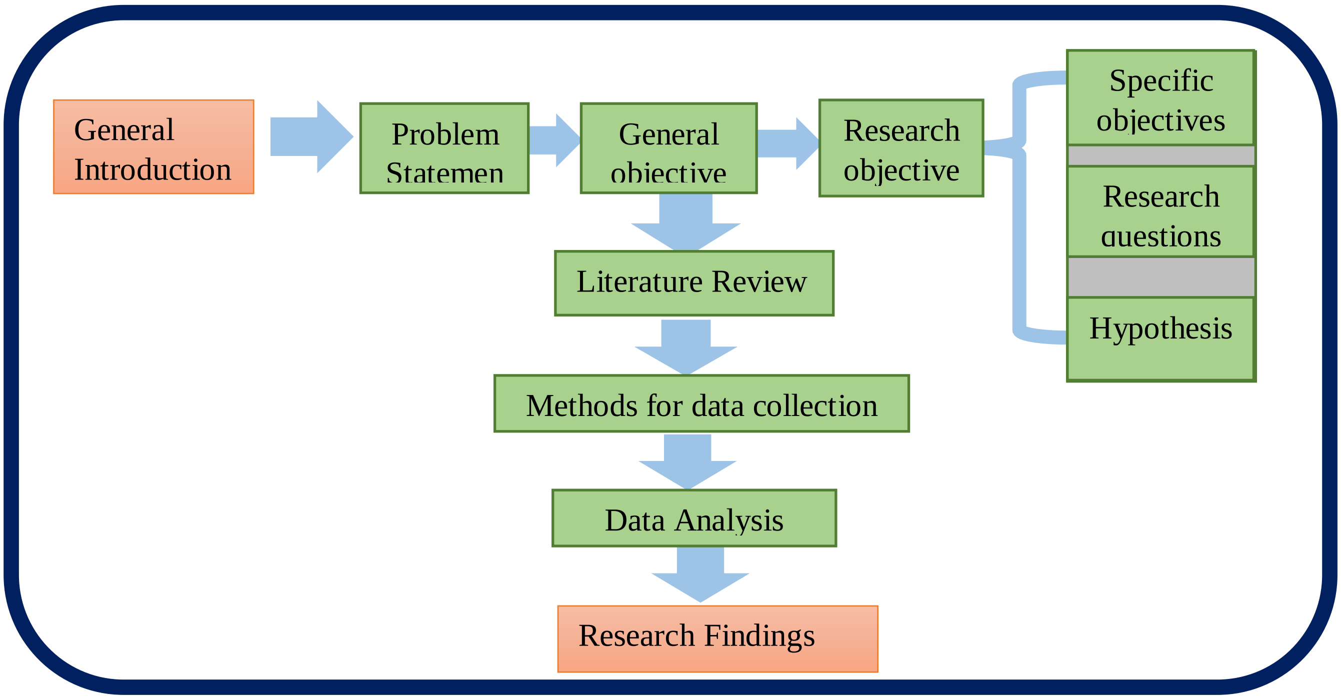

Figure 1. Research Design

3.2. Description of the study area

This study was conducted in six restored sancta of COMBIO project in Eastern province of Rwanda, in the districts of Rwamagana, Kayonza, Ngoma, Kirehe, Gatsibo and Nyagatare. These intervention areas include such Karushuga in Nyagatare District in Nyamiyaga Sector; Ryarubamba in Gatsibo District, Kiziguro Sector; Jambo Beach in Kayonza District, Gahini Sector; Amahoro in Ngoma District, Zaza Sector; Shungerezi in Kirehe District, Kigarama Sector and Muhazi in Rwamagana District, Muhazi Sector.

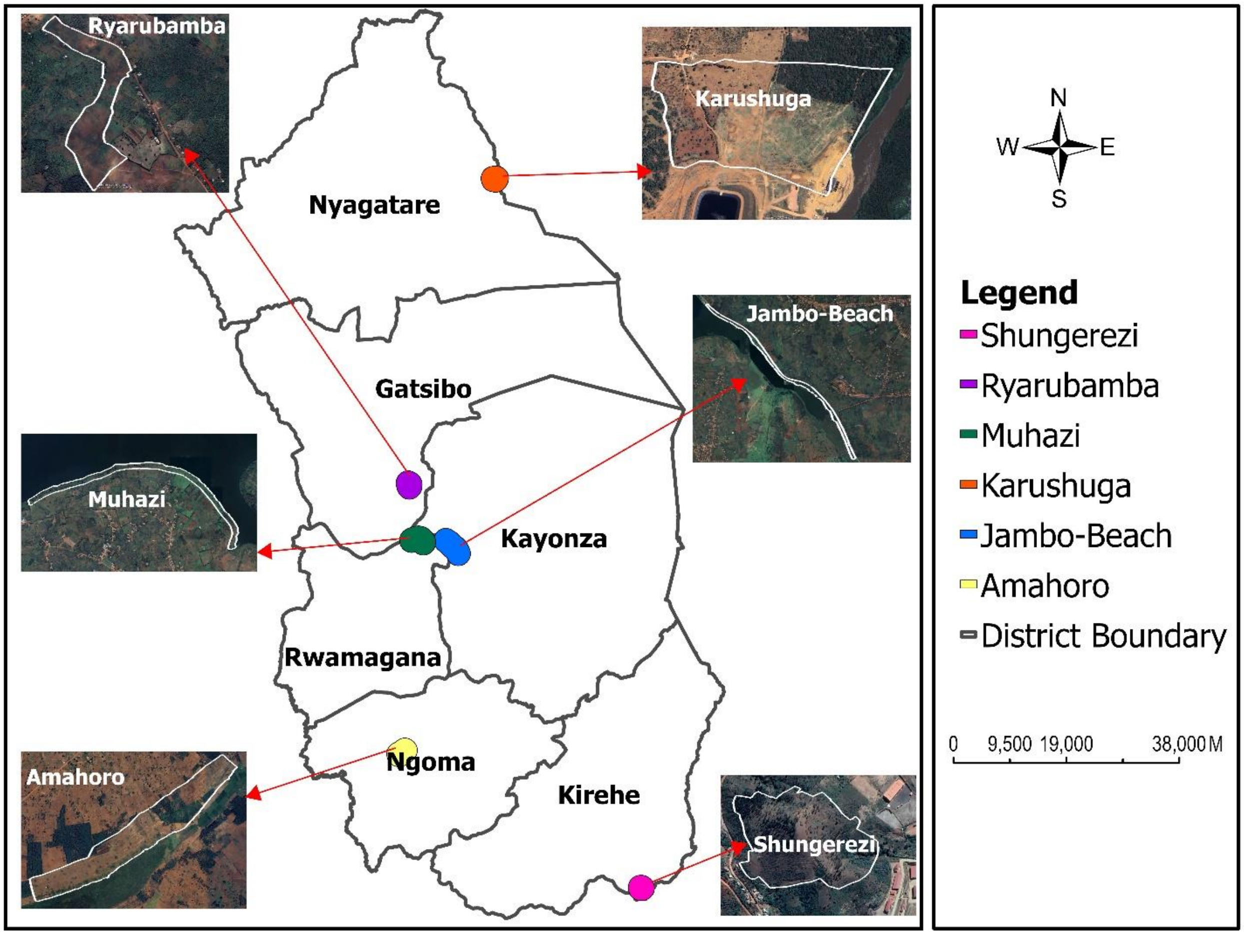

Figure 2. Geographical location of area of intervention for the COMBIO project.

Source: CoEB, (2024).

Following the site boundary and primarily data collected during the field visit in all six sancta, the table below tabulate the location and area of each site in hectares.

Table 1. Size and Administrative location of sancta

Name of Sancta	**Sector**	**District**	**Area in Ha**	**Geo-location (X,Y)**
Amahoro Sancta	Zaza	Ngoma	18.9	(545774.4021, 4759970.6524)
Jambo Beach Sancta	Gahini	Kayonza	12.7	(554081.1187, 4794945.473)
Karushuga Sancta	Rwimiyaga	Nyagatare	14.5	(561590.0189, 4855912.1116)

Muhazi Sancta	Muhazi	Rwamagana	15.3	(549420.3563, 4795547.6432)
Ryarubamba Sancta	Kiziguro	Gatsibo	8.7	(547172.7399, 4804630.269)
Shungerezi Sancta	Kigarama	Kirehe	6.8	(586367.128732, 4737397.84793)

Source: CoEB, (2024)

This study only focused on the area planted with native tree species in December 2023, Area with shrubs and area within tree planted in August 2024 were not assessed.

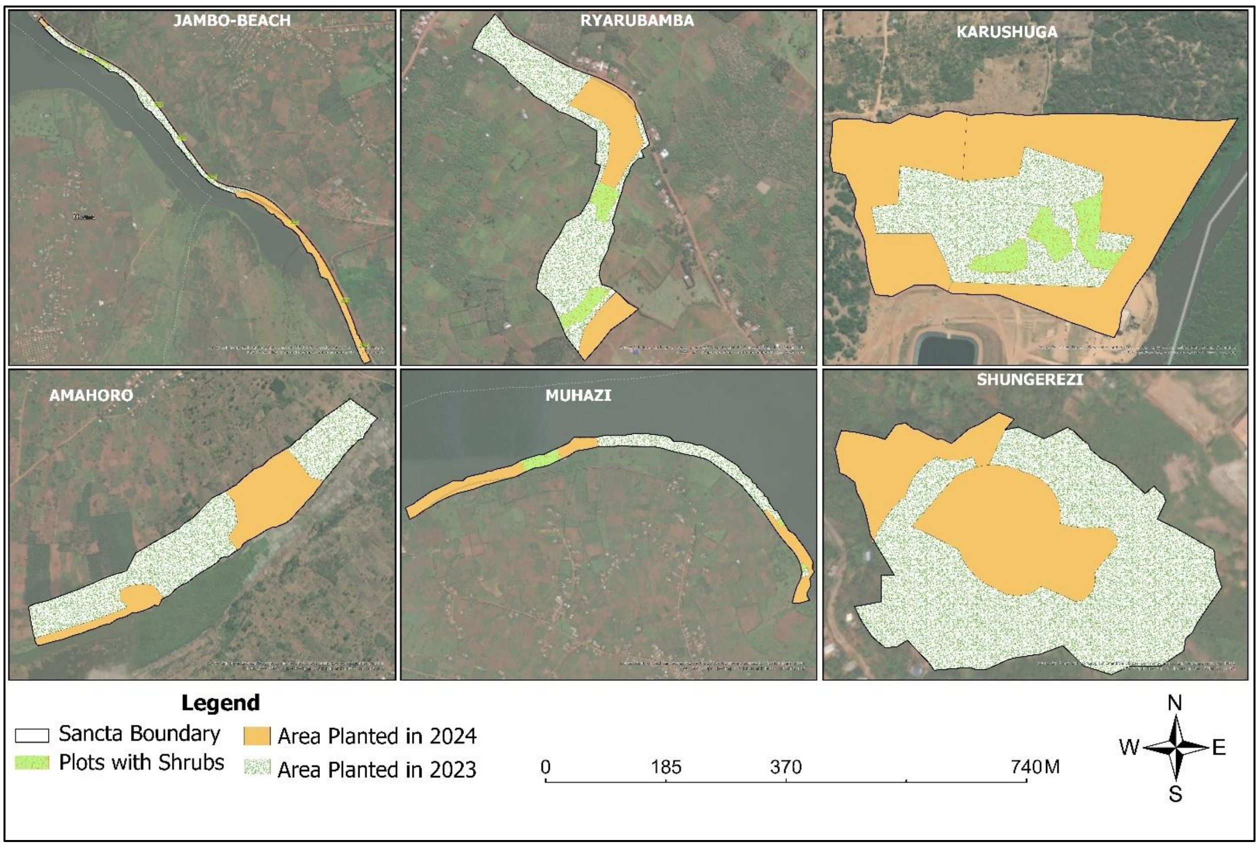

Figure 3. Plots within the sancta in both 2023 and 2024.

Source: CoEB, 2024

3.3. Sampling design

In this research, Cochran's formula used by Joko (2022) in the study of institutional analysis of agroforestry farmers to achieve forest preservation in Bendosari and Ngabab Villages of Pujon, Malang, Indonesia.was used to determine sample size per each sanctum. To ensure the accuracy and reliability of data obtained from sample, the marginal error of 5%, standard normal value of 1.96 and estimated proportion of 0.5 were used. The sample size per each sanctum was distributed with respect to the number of tree species' type planted in Sancta. Stratified random sampling techniques was used to select samples from Sancta and each species were adequately represented. The sample size per each sanctum was calculated using formula adopted from Cochran's formula:

$$n= \frac{N*Z^2*p(1-p)}{d^2 (N-1) + Z2*p(1-p)}$$

Where:

n = Number of trees to measure)

N = Total number of planted trees)

Z = Standard normal value (1.96 for 95% confidence)

d = Marginal error (5%)

p = Estimated proportion (0.5 for maximum variability)

In this research, 2,301 out of 60,335 native tree species were measured in all sancta. Native tree species have been analysed by indicating native tree species found in all six sanctuaries. As a result, only ten native tree species were found in all six sancta of COMBIO project areas. The analysis table is annexed.

The comparison of growth and survival rate of the native tree species focused on ten species available in all sancta which are *Acacia brevispica*, *Acacia polyacantha*, *Combretum molle*, *Entada abyssinica*, *Markhamia obtusifolia*, *Pappea capensis*, *Maesopsis eminnii*, *Ziziphus mucronata*, *Ficus sur* and *Ficus thonningii*. The sample size for each species was determined based on the number of individuals planted.

Table 2. Sample size per species for only ten species available in all sancta

	Species/ Sancta	**Shungerezi**		**Karushuga**		**Ryarubamba**		**Amahoro**		**Muhazi**		**Jambo-Beach**	
S/N		No of trees	Sample	No of trees	Sample	No of trees	Sample	No of trees	Sample	No of trees	Sample	No of trees	Sample
1	*Acacia brevispica*	1221	42	845	40	1006	61	1023	32	1168	47	1337	55
2	*Acacia polyacantha*	1607	55	1327	62	62	4	2050	59	457	18	22	3
3	*Combretum molle*	627	21	201	9	23	3	54	3	113	5	46	3
4	*Entada abyssinica*	486	17	150	7	309	12	80	3	168	7	94	4
5	*Markhamia obtusifolia*	2191	75	300	14	558	34	1910	55	201	8	110	5
6	*Pappea capensis*	618	21	500	23	770	47	720	21	488	19	446	18
7	*Maesopsis eminnii*	1184	41	986	46	252	15	414	12	758	30	816	33
8	*Ziziphus mucronata*	123	4	201	9	171	10	80	3	162	6	34	3
9	*Ficus sur*	273	9	644	30	204	12	100	3	290	12	410	17
10	*Ficus thonningii*	75	3	460	22	397	24	320	10	438	17	119	5
	Total	8405	288	5614	262	3752	222	6751	201	4243	169	3434	146

Source: Enabel (2024)

3.3 Data collection

This section summarises data collection methods and techniques that were used for each specific objective in order achieve general objective of the research, in addition data were either qualitative or quantitative. Primary data were collected using field observation, interview guide, field data measurements and geospatial technology. Whereby, secondary data were collected using online and desk research through analysing the exiting data of COMBIO project in all Sancta and related previously conducted studies.

3.3.1. Marking and tagging

In each sanctum, all measured native tree species were marked using the varnish gel of different colours to allow the researcher to track and monitor the trees measured over time.

Figure 4. Marking and tagging the surveyed trees using varnish gel

Source: Field Survey (2025)

3.3.2. Measurements (height and base-diameter)

In this study, tree diameter has been measured at 5 cm above ground as most trees are shorter than the standard DBH height (1.35 m) making it difficulties to measure the diameter at the breast height (DBH). The trees per each species were measured using meter the tape of 5m lengths to determine the stem height of the tree's species across each sanctum. For the tallest native tree species, Perche was used to measure the height of trees. For the species having several stems or branches, only main stem was measured in this study. Also, ropes and meter measuring tape were used across various sancta to measure the stem base circumference of each living native species.

Figure 5. Field measurement of height and base-diameter of trees

Source: Field Survey (2025)

The base diameter was calculated by dividing circumference by 3.14. The total number of native trees to be measured are 2,301 tree species from six sancta. Since, the roots can cause stem irregularities like swelling, the stem base diameter was measured above 5cm from the ground of all native tree species in six sancta. The google forms were used to collect data from various sancta, then the data were entered in both R software and Ms excel to assess the growth of native tree species in COMBIO project areas in Eastern province of Rwanda.

3.3.2. Counting number of livings, dead, and missing of native trees for survival rate

During the field data collection, total number of planted native tree species, living tree species, dead and missing tree species were counted to accurately record the exact number of living, dead and missing tree species within six sancta per each native tree species. Lately, the numbers living and dead tree species were counted to explore survival rate among different species. To achieve this objective. The survival rate per each native trees were calculated based on the number of living species after planting by adding number of living native trees divided by the total planted native trees across the Sancta multiplied by hundred. The formula below was used to determine the tree survival rate in all sancta, this formula was also used by Khopai et al. (2003, pp. 301-202) to analyze the effects of forest restoration activities on the species diversity of naturally establishing trees and ground flora. Survival rate was calculated as follows:

$$SR = \frac{LS}{PS} * 100$$

Where:

SR =stands for Survival Rate

LS =represent Total Number of Living Species

PS =denotes Total Number of Species Planted

3.3.3. Geospatial technology (GIS)

The geographical coordinates of measured natives' trees species in each sanctum were captured using Differential Geographical Positioning System (DGPS). The spatial locations were joined with tree height and diameter measurements using ArcGIS pro 3.5.2 to correlate growth patterns with underlying environmental factors influencing the tree growth and survival late of native tree species in intervention area of COMBIO in Eastern province of Rwanda.

Geospatial technology was used to analyse the climatic data patterns including temperature and rainfall with growth and survival rate. Climate data were sourced from weather stations in Eastern Province, with accurate records obtained from the Rwanda Meteorological Agency. These datasets were processed using interpolation tools in ArcGIS pro 3.5.2 to examine how climate variations contribute to the growth and survival rates of native trees. By overlaying climate data with tree growth measurements, the study determined the influence of climatic conditions on tree development in the areas of COMBIO project in Eastern province of Rwanda.

Figure 6. Collection of spatial location of surveyed trees

Source: Field Survey (2025)

Geospatial technology was also used to analyse the topographical conditions to estimate the level of water table in six sancta. ArcGIS pro 3.5.2 were used in preparation of maps showing the distribution of growth and survival rate of native tree species for all sancta in relation to environmental factors. These maps illustrated the spatial relationships between environmental factors and tree health, aiding in decision-making for future conservation and reforestation efforts.

3.3.4. Key informant interviews

The interviews were conducted with six agronomists, six technicians assigned to each sanctum, one sancta supervisor from Enabel, two members of cooperative for each sanctum and two representatives of communities living in the settlement nearby each sanctum. The interview with 17 interviewees followed a structured approach while gathering key information including the size and tree species composition of each sanctum, site management practices, initial planting numbers, and the main challenges influencing tree development. Additionally, interviewees were encouraged to share their insights on best practices for improving tree growth and survival rates, and any other relevant observations.

The data collected from these interviews was crucial for understanding the complexities of tree growth and survival in the COMBIO project areas. By identifying the main limiting factors to help the research to develop targeted interventions to enhance restoration efforts. Furthermore, insights from experienced supervisors, technicians, agronomists, cooperative members and communities played an important role in refining strategies that will optimize tree growth and survival rates.

3.3.5. Field observations

This method was used to document tree conditions, environmental influences, and human activities affecting growth and survival through taking detailed notes, photographs, and pattern analysis. It was used to complement interview data to provide a comprehensive understanding of biological, environmental, and human-induced factors influencing tree development.

In this research, the key observations included tree growth characteristics (height, diameter, leaf condition, and overall health), topographic nature and climate factors. Observation was also helped to assess pests and diseases, human activities like deforestation and grazing, the impact of competing vegetation, and the effectiveness of protective measures such as fencing, mulching, and watering systems in enhancing tree survival.

3.4. Data processing

In this research, spatial data were processed using ArcGIS pro 3.5.2, DEM with 10m resolution from NLA were extracted to Eastern province using extract by mask tool while the slope was modelled and calculated using slope tool in spatial analyst tool/surface to create the slope map.

Climatic data such as rainfall and temperature from Rwanda Meteorological Agency (Meteo Rwanda) which includes X,Y coordinates of weather stations located in Eastern Province and its weather records in 2024. The received data were displayed in GIS using display X,Y data and interpolated using IDW tool to create both rainfall and temperature map.

Additionally, the data collected from the field which include X, Y coordinates of each measured tree in six sanctuaries and excel sheets with both heigh and diameter records of each tree measured in cm. The excel sheets were converted to table, spatially joined with its location using join tool to create a dataset of tree measurement and its corresponding spatial location. The created layer was overlayed on each map for comparison between the growth and influencing factors like temperature, rainfall and topographical conditions.

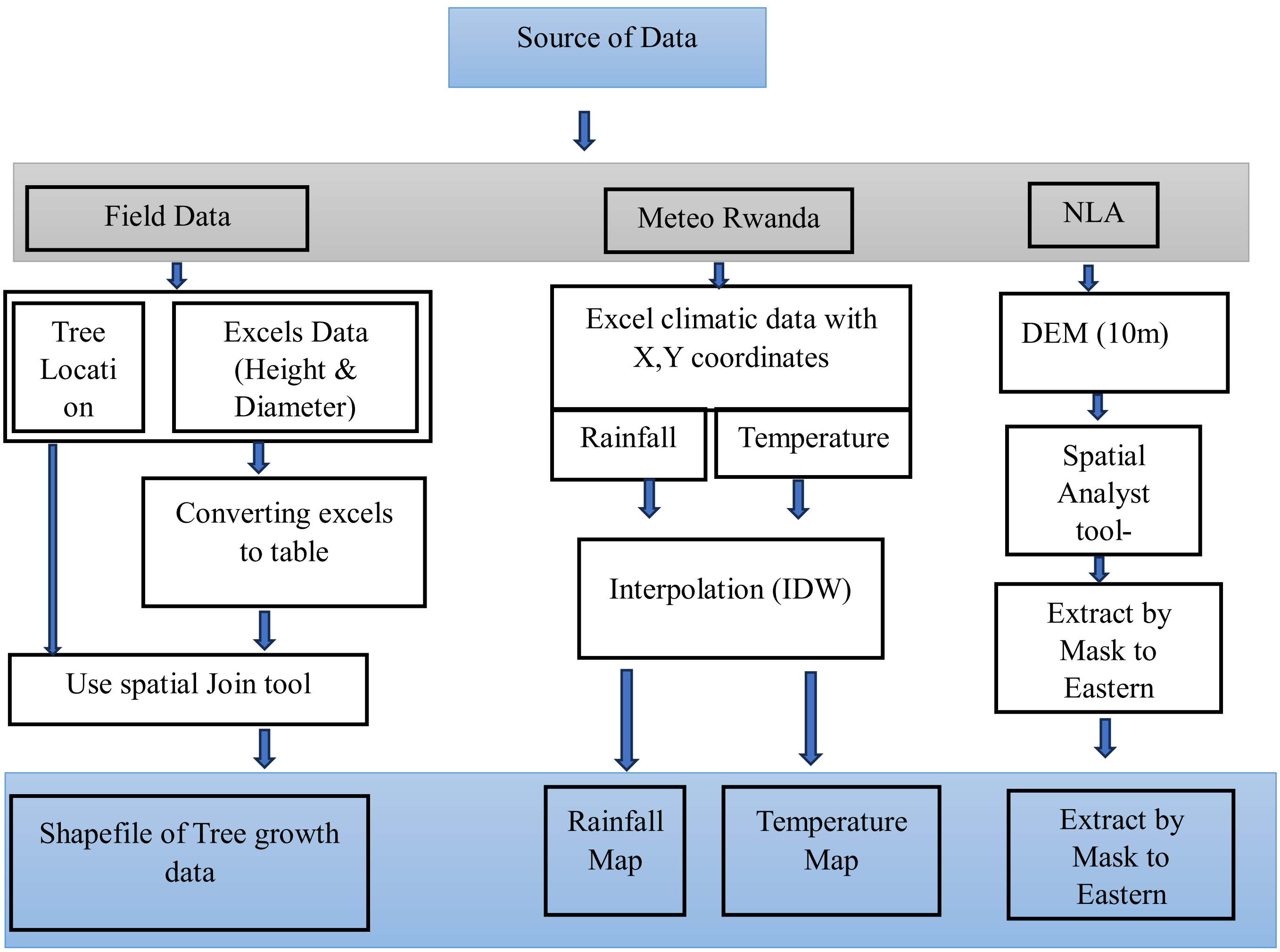

Figure 7. Geospatial Data processing

3.4. Data analysis

The quantitative data including height and base diameter of each tree species, the collected total number of living, dead and missing tree species and total number of planted tree species were entered in Microsoft excel, and statistically analysed using Ms excel and R software. Figures and tables presenting growth performance and survival rate of tree species per each sanctum, across different sancta and NMDS results in R software indicate the influence of environmental factors across the sanctuaries.

In this study, the qualitative data including interview responses and observation notes was categorized into themes related to biological, environmental, and human-induced factors influencing tree growth and survival. Also, repeated ideas, challenges, and recommendations from agronomists, members of cooperatives and communities were grouped together to identify common trends as well as highlight the most frequently mentioned growth challenges, survival strategies, and human activities affecting trees. Then, comparative analysis was used to cross-check interview responses with field observations, ensuring consistency and reliability. Also, ArcGIS Pro 3.5.2 was used to analyse underlying factors that influence the tree growth and survival rate including temperature and precipitation patterns using interpolation methods in spatial analyst tools. Finally, the analysis of both quantitative and qualitative data helped to develop conclusions and recommendations for improving tree growth and survival rates in the COMBIO project areas in Eastern of Rwanda.

3.5. Analytical framework for assessing tree growth and survival rate of native tree species

An analytical framework applied while assessing growth and survival rates during this study was adopted from Senbel et al (2022). It was used in a bid understand and enhance the performance of tree planting initiatives by examining how environmental conditions and management practices influence growth and survival outcomes. It helped in evaluating two main performance indicators: tree growth, measured by height and base diameter, and the survival rate, which reflects the percentage of trees that continue to thrive over time. These two indicators are shaped by a combination of key influencing factors and best practices, both of which play critical roles in determining overall success native tree species in the COMBIO project areas in Eastern province of Rwanda.

Key factors such as climate patterns (including rainfall and temperature), topography significantly affect tree health and development. These environmental conditions can either support or hinder tree growth and survival depending on how well the selected tree species are adapted to them. In parallel, best practices including the application of fertilizers, use of high-quality seedlings, appropriate species-site matching, and the exclusion of livestock and grazing can greatly improve outcomes when implemented effectively. These practices help mitigate adverse environmental effects and support optimal growing conditions.

The interactions between key factors, best practices, and the performance indicators feed into the expected outcomes of the framework. By analysing the relationships among these components, researcher will identify high-performing species that excel in both growth and survival, recognize the most influential environmental and management factors, and develop evidence-based recommendations for future planting strategies. This continuous feedback loop ensures that insights gained from assessing growth and survival can inform improvements in both practices and site selection, ultimately leading to more resilient and productive tree planting efforts in the future in COMBIO project areas. The figure below indicates the analytical framework for assessing growth and survival rate of native tree species in COMBIO project areas:

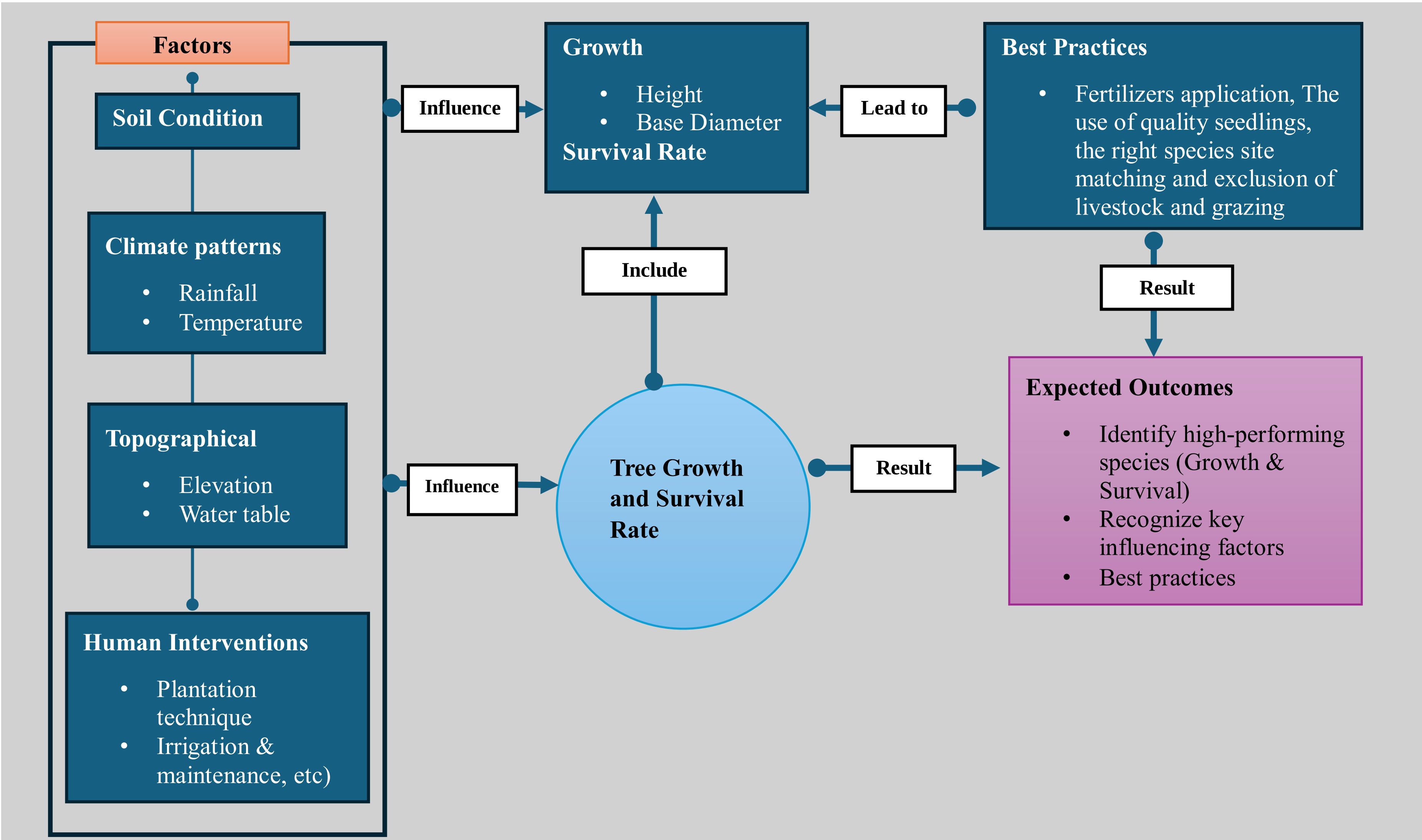

Figure 8. Analytical Framework for Assessing Tree Growth and Survival Rate.

Source: Adapted from *Guédon et al (2007), Ogle (2009)* and *Senbel et al (2022)*

4. RESULT AND DISCUSSIONS

This chapter presents and discusses the performance and survival of native tree species at across six sancta, focusing on both individual and comparative assessments. It begins with the growth performance and survival rate of native tree species at each sanctum; comparison of growth trends and survival rate of ten species commonly found in six sancta. It also includes the key factors underlying and influencing the observed growth and survival patterns as well as relationship between tree growth and survival with environmental factors using NMDS analysis. It ends by proposing key strategies inhibiting the growth and survival of those native tree species in a bid to ensure their good growth in COMBIO project areas.

4.1. Performance of growth of native tree species at each sanctum

This section presents the statistical analysis of growth performance, focusing on the average diameter (cm) and average heights (m) of the trees in relation to influencing factors.

4.1.1. Native tree species average height and diameter in Jambo-Beach Sancta

In Jambo-Beach sancta, a total of 36 native tree species were measured. The collected data were analysed for their average height in centimetres. The result from the measurements reflects a wide variation in heights. The tallest measured species was *Acacia kirkii* with an average height of 4.8 m which indicates an exceptional vertical growth compared to other tree species in that sanctum. Other species with notably high average heights include *Trema orientalis* and *Celtis africana* with 3.4 m and 2.4 m of height respectively.

The species with intermediate heights include *Albizia gummifera*, *Maesopsis eminii* and *Syzygium guineense* with 1.3 m, 1.7 m and 1.6 m average height respectively. Yet, several species have exhibited lower average heights in the same sancta. Those species are such as *Vachelia siebeliana var. woodie* with 0.5 m, *Coffea eugenioides* with 0.3 m and *Mimusops bagashewei* with only 0.2 m of the height.

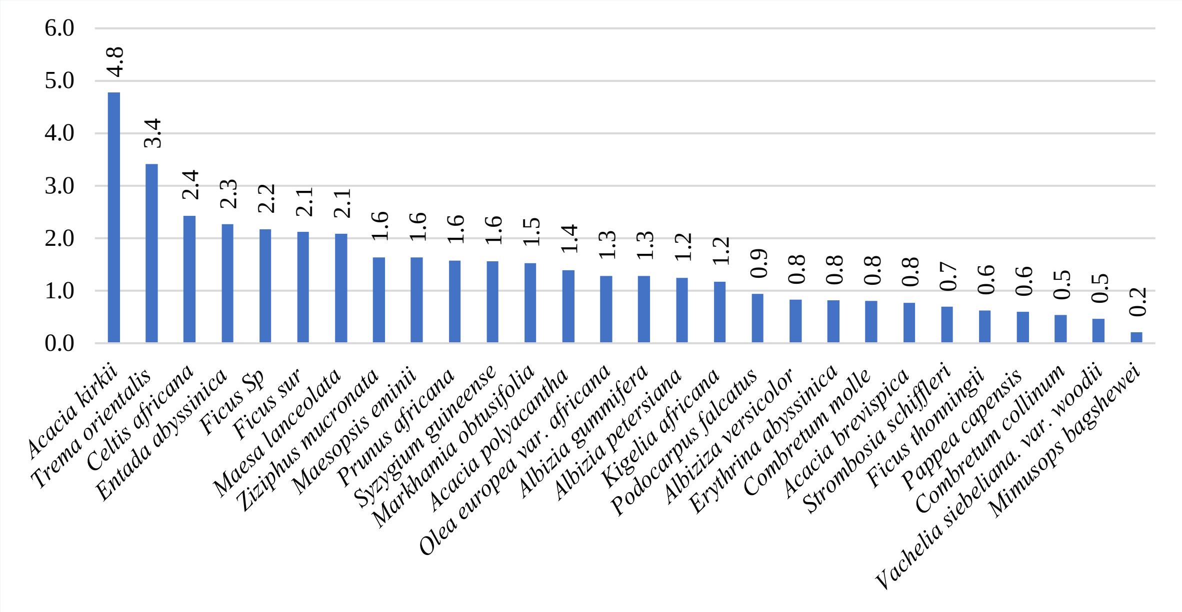

Figure 9. Average height (in m) for the tree species planted in Jambo-Beach sancta

Source: Field Survey (2025)

Among the measured tree species, *Trema orientalis* and *Acacia kirkii* were recorded as the largest average diameter with 6.7 cm and 6.3 cm respectively which indicate diameter growth rather than height driven expansion.

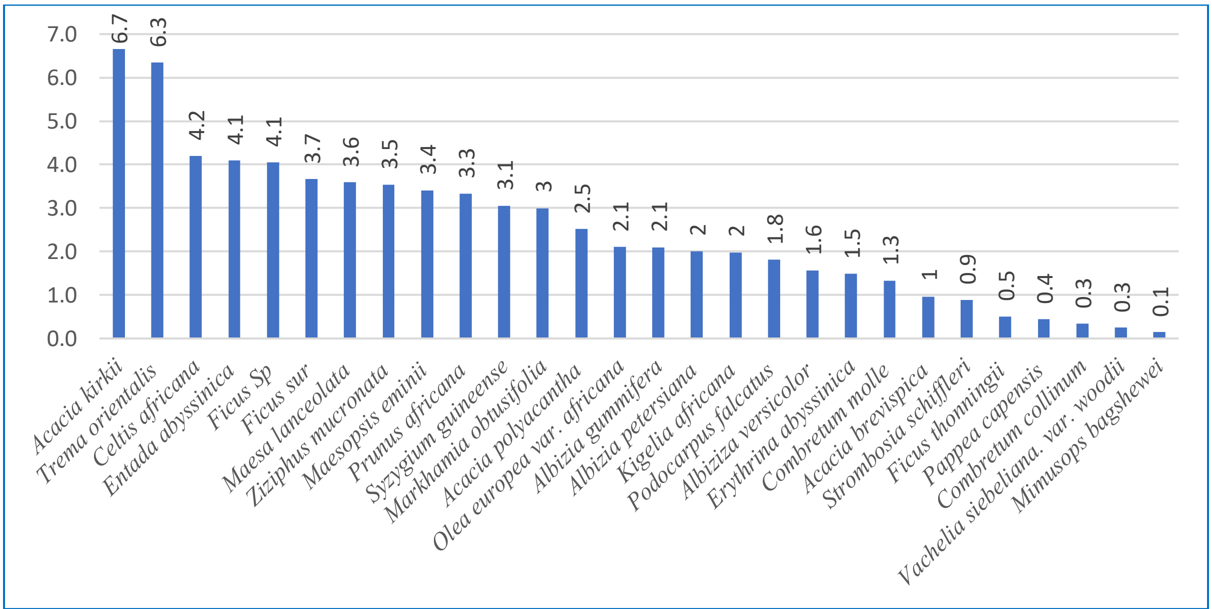

Figure 10. Average diameter (in cm) for the tree species planted in Jambo-Beach sancta

Source: Field Survey (2025)

The species including *Mimusops bagshewei, Pappea capensis, Combretum collinum, Combretum molle, Acacia brevispica, Vachelia siebeliana var. woodie and Strombosia schiffleri* recorded with minimal diameter values of 0.1 cm, 0.3 m, 0.3 cm, 0.9 cm, 1 cm, 0.4

cm and 0.5 cm of the diameter respectively. The study identified that species like *Pappea capensis*, *Combretum collinum* and *coffea eugenioides* belongs to the slower-growing trees while *Vachelia siebeliana var.woodie* slowed down due to unmatched location and conditions at the Sancta.

4.1.2. Native tree species average height and diameter in Ryarubamba sancta

The measurements in the sancta revealed significant differences in tree species average growth. In Ryarubamba sancta, *Acacia polyacantha* was recorded with the greatest average height at 2.5 m, followed by *Prunus africana* at 1.9 m and *Maesopsis eminii* at 1.8 m indicating potential growth in height structure. Conversely, species like *Mimusops bagshewei, Pappea capensis* and *Podocarpus falcatus* displayed the lowest average heights of 0.8 m, 0.5 m and 0.7 m respectively. Meanwhile, other common species exhibited moderate heights which includes *Ficus sur* with 1.5 m, *Olea europaea var. africana* with 1.5 cm and *Syzygium guineense* with 1.3m. The study indicated that species with high and moderate average height belongs to fast growing tress but also Taungya system played a crucial role in successful growth of the native tree species.

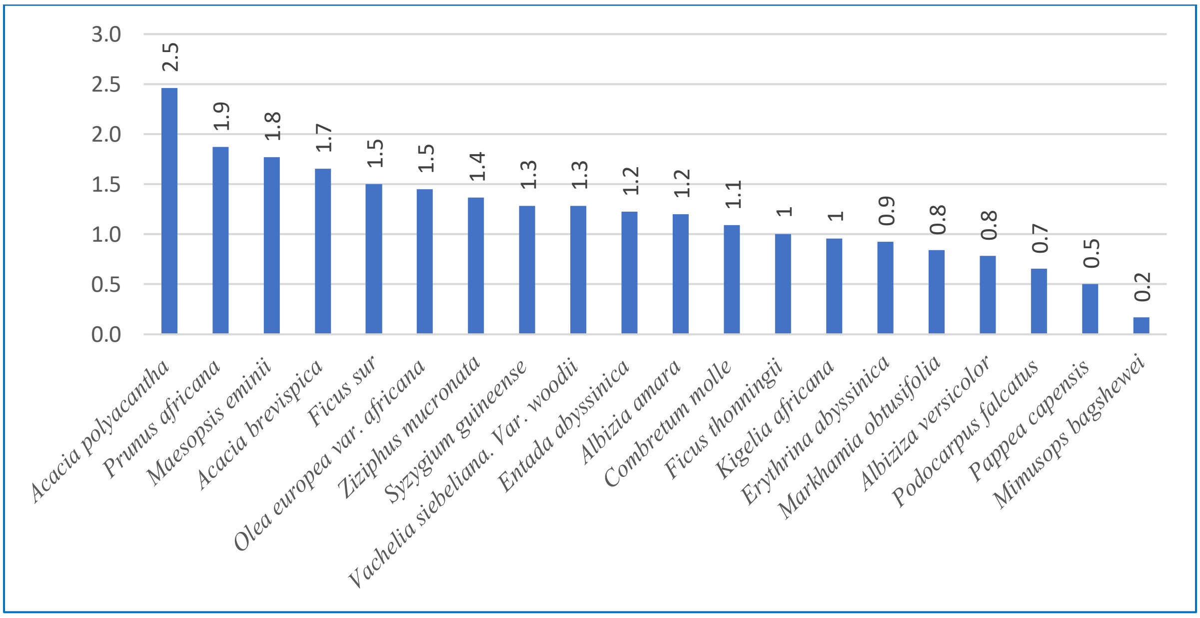

Figure 11. Average height (in m) for the tree species planted in Ryarubamba sancta

Source: Field Survey (2025)

Acacia polyacantha is not only exhibited the greatest height but also substantial base-diameter of 5.6 cm indicating its dominant growth in both parameters. Similarly, species like *Prunus africana*, *Maesopsis eminii* and *Ficus sur* showed significant base-diameter growth of 3.6cm, 5.3 cm and 5.8 cm respectively. In contrast, *Mimusops bagshewei*, *Albizia amara* and *Pappea capensis* had the lowest diameter values of 0.1cm, 0.7 cm and 1 cm. additionally, several other species including *Albizia adianthifolia*, *Entada abyssinica* and *Syzygium guineense* exhibited moderate dimeter growth in the sancta.

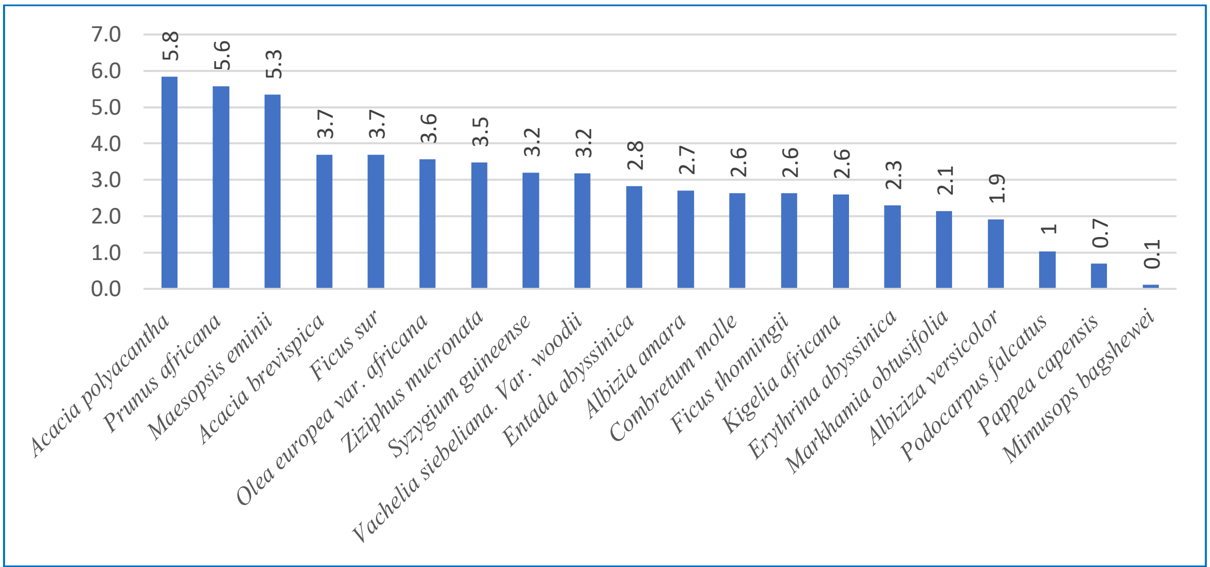

Figure 12. Average diameter (in cm) for the tree species planted in Ryarubamba sancta

Source: Field Survey (2025)

4.1.3. Native tree species average height and diameter in Karushuga sancta

In Karushuga Sancta, the average tree height was measured across 17 different species, the results show notable variation in vertical growth among the measured species. The tallest species was *Albizia petersiana* with an average height of 2.2 m, closely followed by *Acacia polyacantha* and *Entada abyssinica* at 2.1 m and 2m respectively.

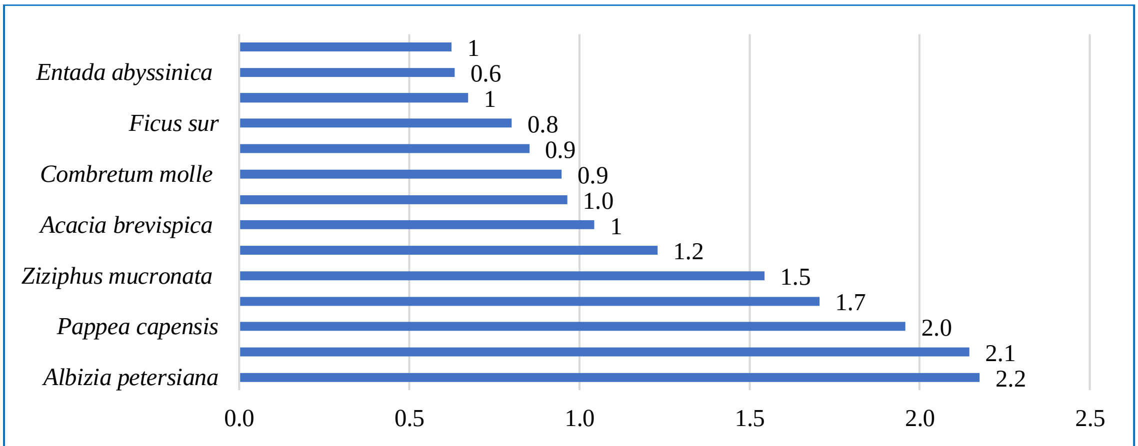

Figure 13. Average height (in m) for the tree species planted in Karushuga sancta

Source: Field Survey (2025)

Moderate heights were observed in species like *Maesopsis eminii* and *Ficus sur* at 1.7 m and 1.5 m each, while *Markhamia obtusifolia* and *Ficus thonningii* measured with average heights of 1.2 m and 1 m respectively. The study denoted that most native tree species with high average height in Karushuga sancta belongs to early successional group like *Maesopsis eminii*, *Ficus sur*, *Entada abyssinica* and *Acacia polyacantha*. However, the species like *Combretum collinum*, *Pappea capensis*, *Ziziphus mucronata* and *Euclea divinorum* recorded with low average height ranging from 0.6 m to 0.8 m in the sancta while species including *Combretum collinum* and *Pappea capensis* grow slowly in nature.

In 17 tree species measured, *Entada abyssinica* and *Acacia polyacantha* were observed as the species with high average diameter of 4cm. *Maesopsis eminii* and *Markhamia obtusifolia* also exhibited dimeter growth of 3.6 cm and 3.2cm individually. Moderately, *Ficus sur and Albizia petersiana* demonstrated a balanced growth of 31.cm and 2.4cm in diameter.

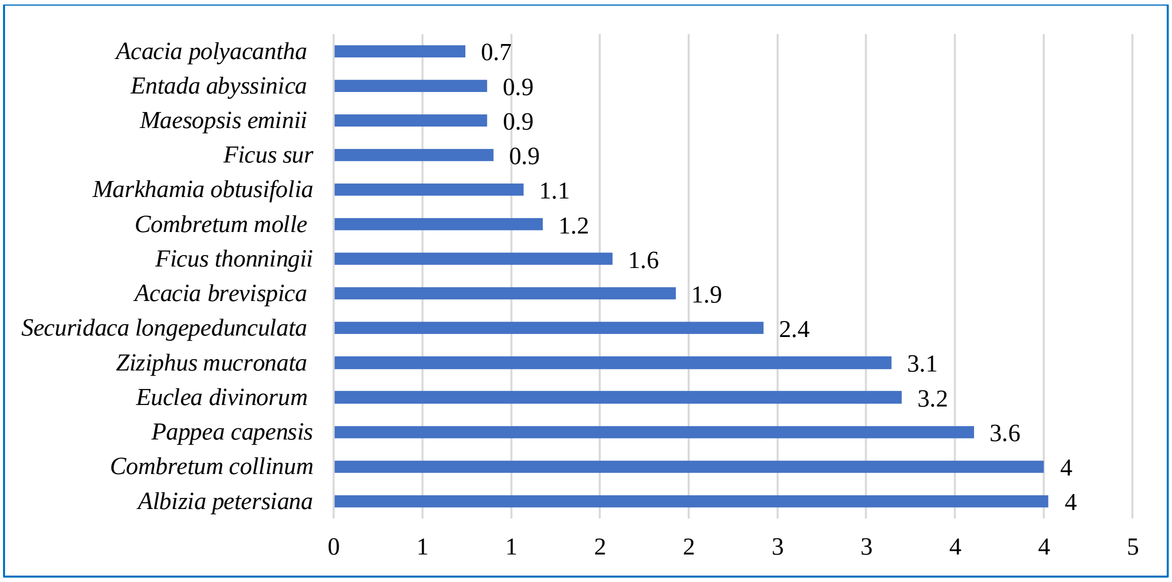

Figure 14. Average diameter (in cm) for the tree species planted in Karushuga Sancta

Source: Field Survey (2025)

In contrast, species including *Combretum collinum, Pappea capensis, Ficus thonningii* and *Euclea divinorum* recorded with a relative limited diameters ranging from 0.9 cm to 1.2 cm. However, the smallest average diameter was recorded for *Acacia brevispica* at 0.7 cm, despite a moderate height of 0.9 m. The study indicated that *Acacia brevispica* and *Ficus thonningii* species have grown slowly in both diameter and height due to that are planted on the fence with irregular maintenance led to high completions. Also, *Ficus thonningii* were affected by paste and diseases which limited its successful growth.

4.1.4. Native tree species average height and diameter in Amahoro sancta

An assessment of the average Height measured in 27 different species planted in Amahoro sancta displayed a considerable variation in their average heights ranging from the shortest of 0.1m for *Mimusops bagshawei* to the tallest of 1.3 m for *Trema orientalis and Albizia gummifera*. Other noted tall species includes *Acacia sieberiana var. kagerensis* and *Combretum molle* with 1.1 m each, *Maesopsis eminii* with 1 m. Conversely, shorter species such as *Syzygium guineense* with 0.3 m, *Kigelia africana* and *Wild coffea* were also measured with 0.2 m each indicating a diverse vertical growth with the sancta. Meanwhile, species like *Ficus sur*, *Acacia polyacantha*, *Acacia brevispica*, *Entada abyssinica*, *Albizia petersiana, Ficus vallis-choudae, Albiziza versicolor* and *Podocarpus falcatus* had a medium growth of height ranging between 0.5-0.1m.

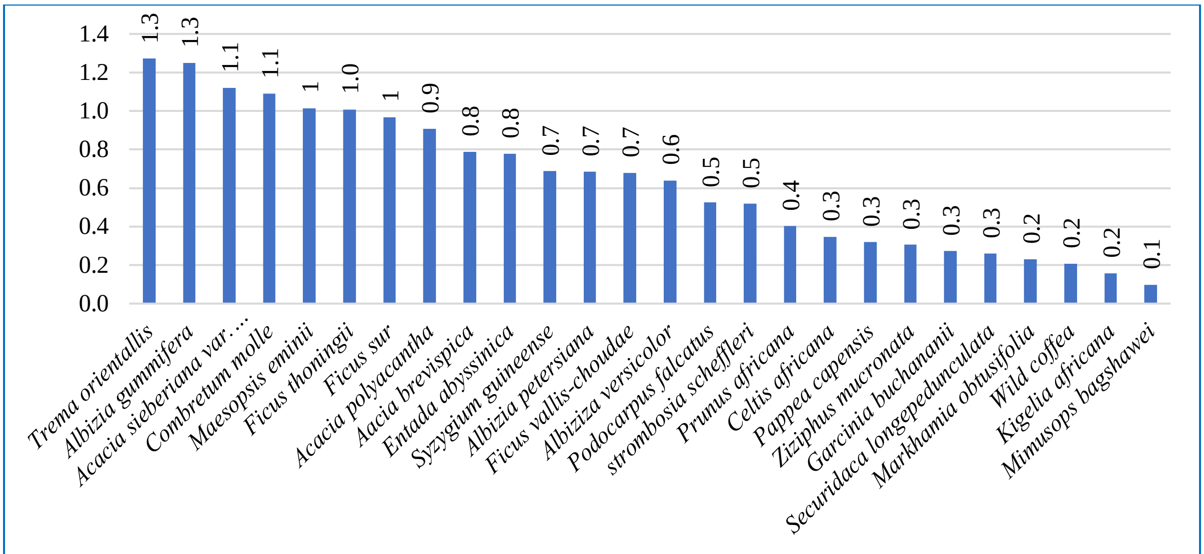

Figure 15. Average height (in m) for the tree species planted in Amahoro sancta

Source: Field Survey (2025)

In 27 tree species measured, the largest average diameter was measured on *Trema orientalis* with 3.4cm, followed by *Maesopsis eminii* with 2.2cm, *Entada abyssinica* and *Ficus sur* both count 2 cm, *Albizia gummifera* with 1.9cm, *Acacia polyacantha* with 1.5 cm, *Acacia sieberiana var. kigerensis* with 1.6cm, *Albiziza versicolor* with 1.5 cm, *Ficus vallis-choudae* with 1.5cm.

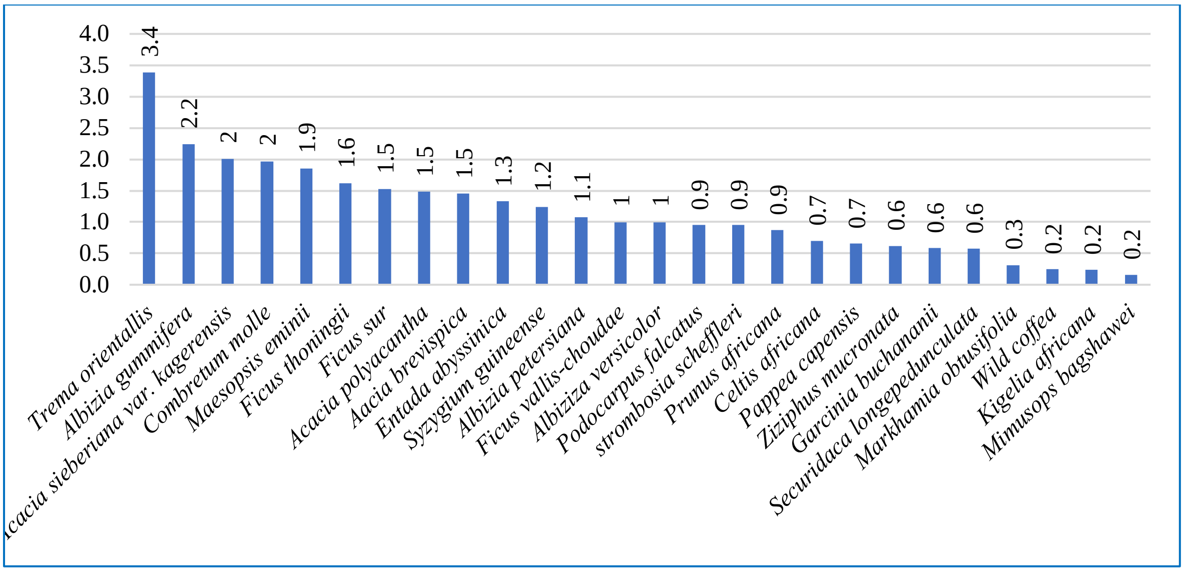

Figure 16. Average diameter (in cm) for the tree species planted in Amahoro Sancta

Source: Field Survey (2025)

However, several species exhibited notably smally average base diameters including *Mimusops bagshawei*, *Wild coffea* and *Securidaca longepedunculata* all with an average of 0.2 cm.

4.1.5. Native tree species average height and diameter in Muhazi sancta

Muhazi as among the sancta nearby the Lake Muhazi, the average height also varies with respect to the tree species. For example, the tallest species recorded was *Acacia polyacantha* with 2.7 m, followed by *Albizia petersiana* with 2.3 m and *Dombeya rotundifolia* with 1.9 m average height. Notably, several mid-height species were recorded including *Ficus sur* and *Syzygium guineense* with 1.7 m each, *Acacia senegal*, *Ziziphus mucronata* and *Vachelia siebeliliana var. woodie* recorded with moderate average height in sancta making them suitable for inclusion in restoration program in the areas with Muhazi sancta's conditions.

In contrast, native tree species such as *Podocarpus falcatus* and *Securidaca longepedunculata* were observed and recorded with relatively low average heights of 0.3 m.

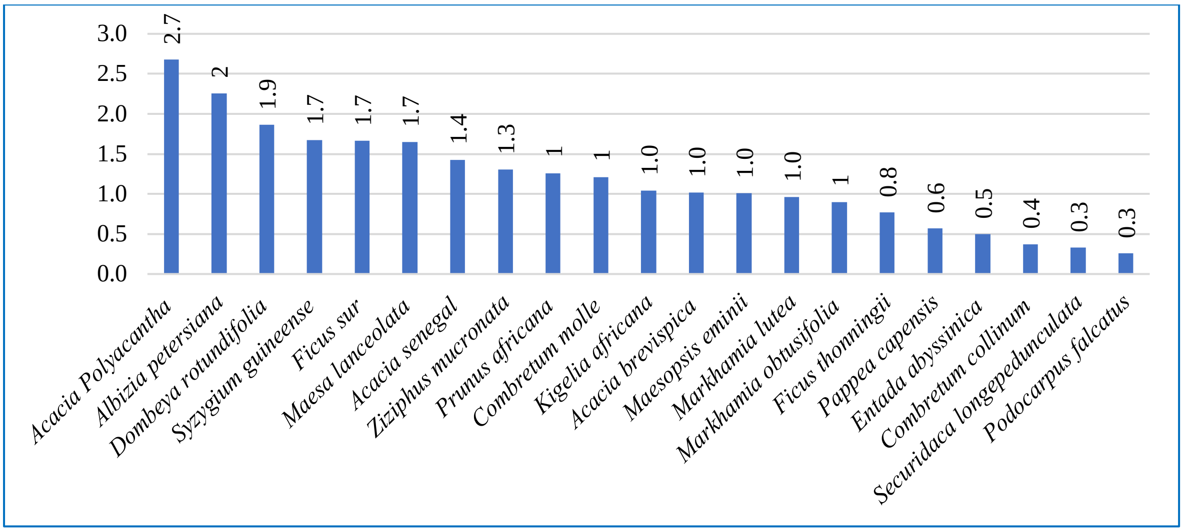

Figure 17. Average height (in m) for the tree species planted in Muhazi sancta

Source: Field Survey (2025)

Similarly to height records, a total of 21 tree species were analysed for their average diameter revealing a wide range of growth and adaptations. The species measured with the largest diameters were *Acacia polyacantha* with 5.3 cm, *Dombeya rotundifolia* with 4.4 cm, *Syzygium guineense* with 4.2 cm. Also, moderate diameters were measured for *Kigelia africana*, *Acacia senegal*, *Ziziphus mucronata* and *Markhamia lutea* with 3.8 cm, 2.8 cm, 2,9cm and 2.5 cm respectively.

Conversely, *Securidaca longepedunculata* was recoded as species with the smallest average diameters with only 0.3cm each. These species also followed closely by *Podocarpus falcatus* and *Combretum collinum* with 0.6 cm each.

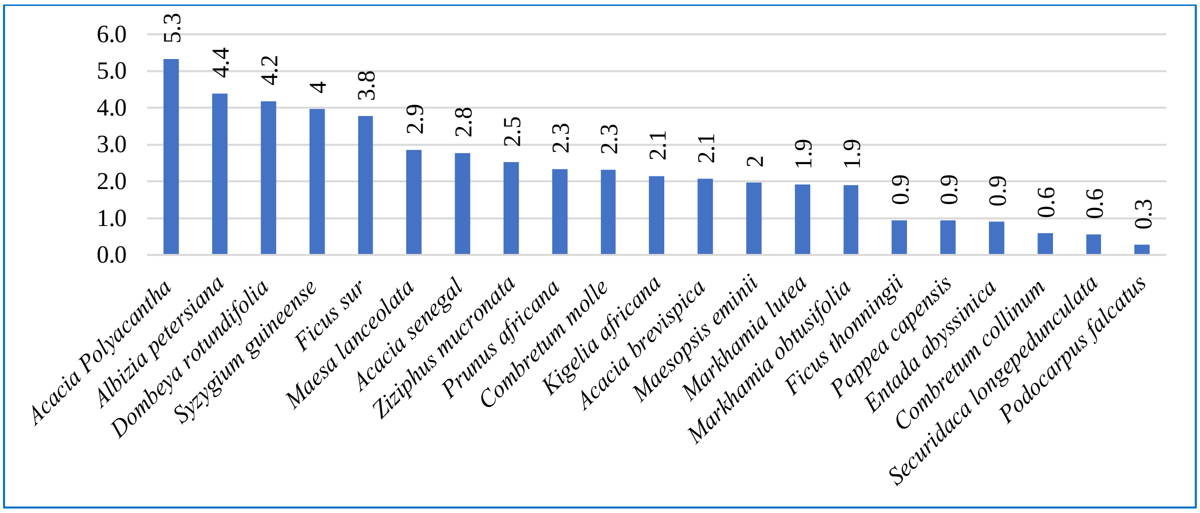

Figure 18. Average diameter (in cm) for the tree species planted in Muhazi sancta

Source: Field Survey (2025)

4.1.6. Native tree species average height and diameter in Shungerezi sancta

The average height measurements of the measured tree species were classified into high, intermediate and low average heights. The species indicated with strong vertical growth in Shungerezi sancta includes *Acacia polyacantha and Trema orientalis* recorded with the highest average height at 1.3 m each, followed by *Acacia sieberiana* at 1.2 m as well as *Maesopsis eminii* and *Syzygium guineense* also showed high average heights of 1.1m each.

The species like *Albizia petersiana, Erythrina abyssinica, albizia amara, Ficus sur* known as "Umukuyu" and *Ficus sur* known as "Umurehe" observed with moderate growth potential under existing sancta conditions with average height of 104.4cm, 93.cm, 90.8cm, 85.9cm, 89cm and 74.7 cm each.

The shortest species in the sancta were observed for *Pappea capensis* with 0.4 m, *Podocarpus falcatus* with 0.5 m, *Ziziphus mucronata* with 0.5 m and *Ficus thonningii* with 0.5 m. Above all, *Markhamia obtusifolia* recorded with the least average height in Shungerezi sancta with only 0.3 m.

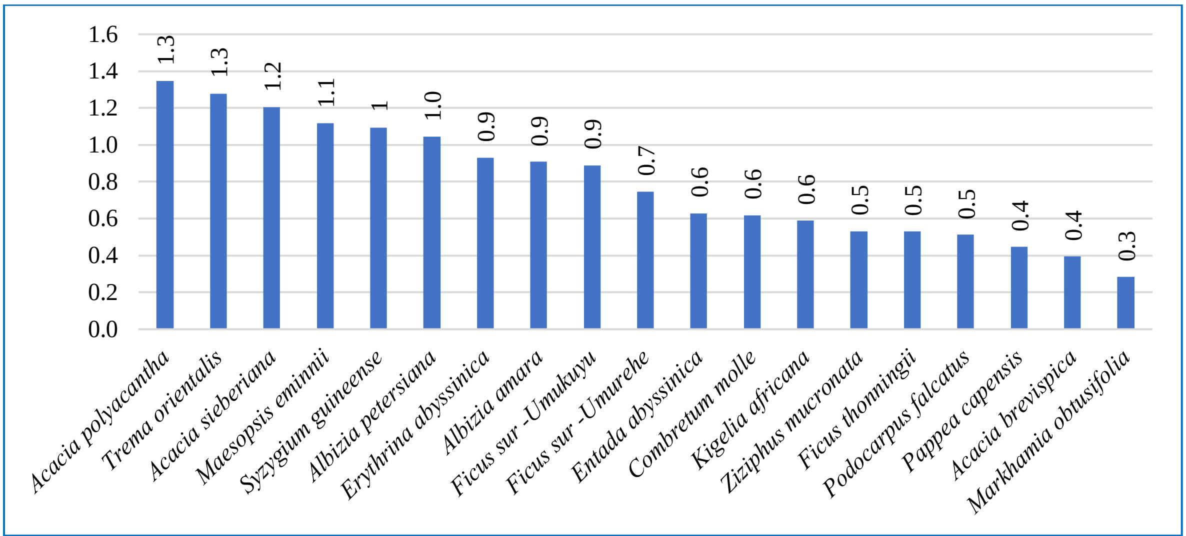

Figure 19. Average height (in m) for the tree species planted in Shungerezi sancta

Source: Field Survey (2025)

Furthermore, the stem base-diameter among the selected tree species were measured where *Acacia polyacantha* exhibited the largest average base-diameter 2.4 cm each. Both *Maesopsis eminii* and *Trema orientalis* averagely had base diameter of 2.3cm. Also, *Syzygium* guineense and *Acacia sieberiana* demonstrated with high average diameter of 1.9cm each.

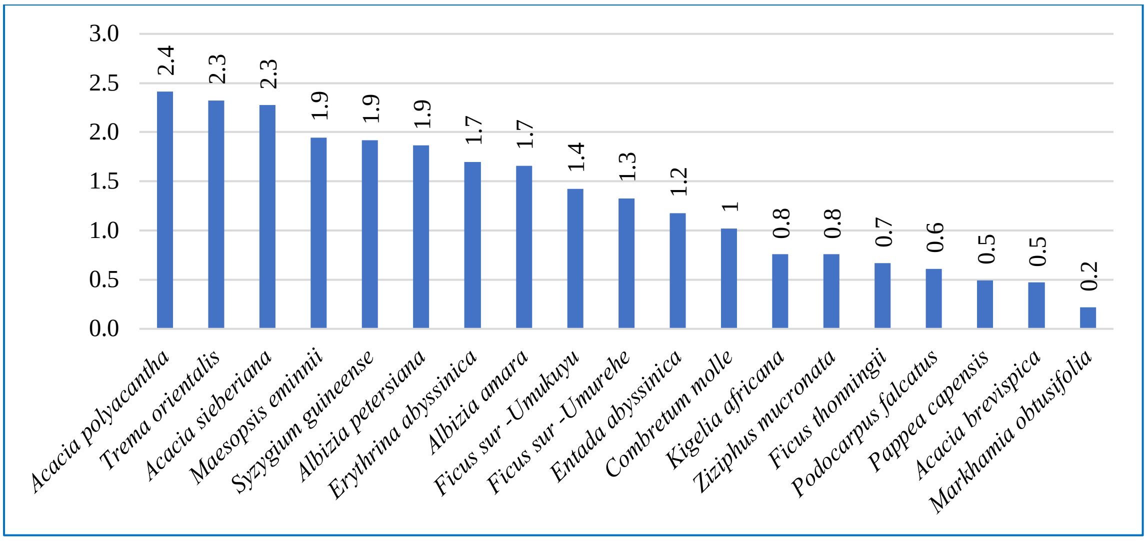

Figure 20. Average diameter (in cm) for the tree species planted in Shungerezi sancta

Source: Field Survey (2025)

On the other hand, moderate base-diameter values were observed for *Kigelia africana*, *Erythrina abyssinica* and *Albizia petersiana* with 1.9cm, 1.7cm and 1cm individually. Nevertheless, species like *Albizia amara*, *Pappea capensis*, *Combretum molle* and *Acacia brevispica* displayed with smaller average diameters ranging from 0.2cm to 0.7cm reflecting minimal early stem-based thickening.

4.2. Survival rate of native tree species at each sanctum

This section presents the statistical analysis of growth performance, focusing on survival rate (in %) of native tree species at each sanctum in relation to influencing factors.

4.2.1. Survival rate at Jambo Beach Sancta

The survival rates in Jambo-Beach sancta varied with respect to tree species. Among the top performing species, *Acacia kirkii* exhibited high survival rate of 96.6% with 114 out 118 trees, *Markhamia lutea* with 53 out of 55 trees surviving at 96.4% and *Kigelia africana* surviving at 96.3% with 79 out of 82 trees proving to be highly adaptable and potentially well suited for human, physical and environmental factors. Additionally, *Acacia brevispica*, *Maesa lanceolata*, *Ficus sp* and *Coffea eugenioides* recorded as high survival species with 1131 out 1337, 130 out of 145, 22 out of 25 and 43 out of 52 trees alive at 84.6%, 89.7%, 88% and 82.4% rates respectively.

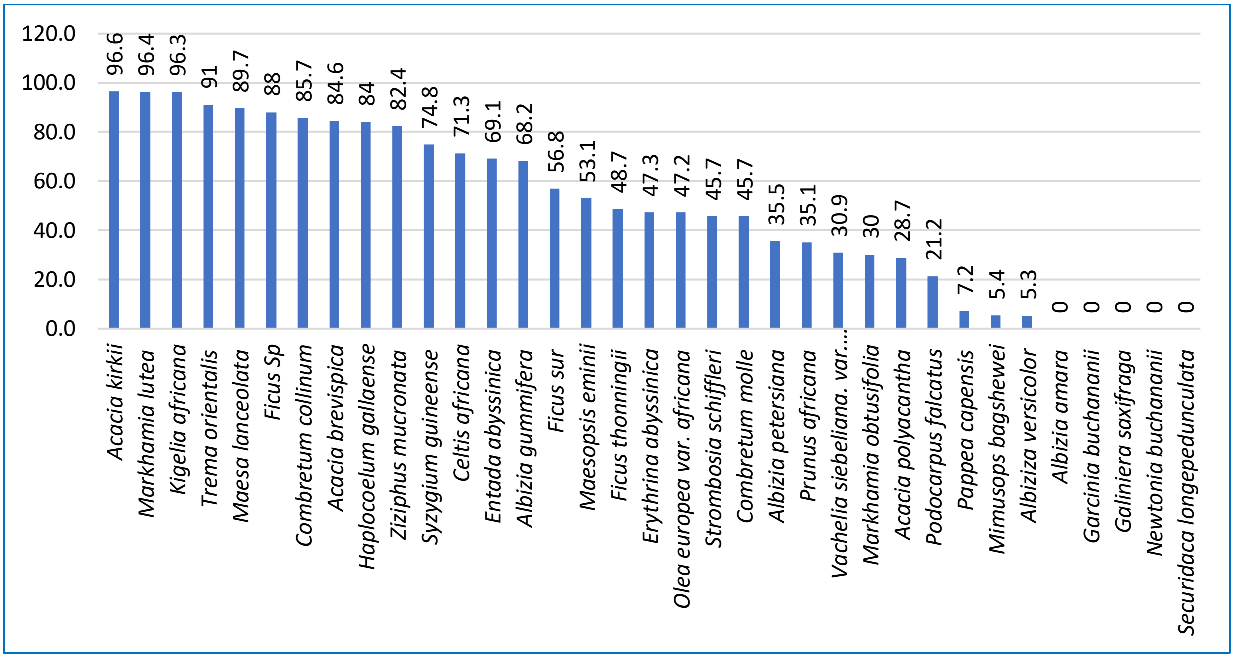

Figure 21. Tree survival rate (in %) at Jambo Beach Sancta

Source: Field Survey (2025)

Several species were recorded with moderate survival rates ranging from 40%-79%, these include *Syzygium guineense* surviving at 74.8% with 116 out of 155 trees, *Celtis africana* with 92 out of 129 trees surviving at 71.3% and *Entada abyssinica* at 69.1% with 65 out 94 trees, *Ficus sur* with 233 out of 410 trees surviving at 56.8% and *Maesopsis eminii* 53.1% with 433 out of 816 trees still alive. While not as strong as top performing group, this species still shows a reasonable potential for integration into restoration programs, especially when ecological diversity is a priority.

Tree species with survival rate below 40% including *Acacia polyacantha*, *Prunus africana*, *Euphorbia candelabrum* and *Vachelia sieberiana var. woodie* with survivorship of 28.7%, 35.1%, 34.6% and 30.9% with 25 out of 87, 397 out of 1130, 36 out of 104 and 217 out 702 trees alive respectively undermines cost-effectiveness and long-term restoration goals. However, species like *Mimusops bagshewei* with 5.4%, *Pappea capensis* with 7.2% and *Albiziza versicolar* with 5.3% may not be viable choices for future planting under current sancta conditions.

In Jambo Beach Sancta, several species experienced a total failure such as *Albizia amara*, *Garcinia buchananii*, *Galiniera saxifraga*, and *Securidaca longepedunculata* recording with 0% survival rates. This survival rate indicates a mismatch between their ecological needs and Jambo-Beach sancta conditions including altitude, rainfall or planting techniques.

4.2.2. Survival rate at Ryarubamba Sancta

Among 21 native tree species planted in Karushuga sancta, five species including *Acacia polyacantha, Combretum molle, Maesopsis eminii, Olea europaea var. African* and *Ziziphus mucronate* achieved a 100% survival rate which indicate strong adaptation to sancta conditions. High survival rate was also observed in *Acacia brevispica* with 1001 out of 1006 trees surviving at 99.6%, *Entada abyssinica* at 99.75 with 308 out 309 trees, *Erythrina abyssinica* with 192 out of 196 trees surviving at 98%, *Ficus sur* at 96.1 with 196 out of 204 trees, *Syzygium guineense* at 96.35 with 26 out of 27 trees, *Vachelia siebeliana. Var. woodie* with 769 out of 825 surviving at 93.2%, *Markhamia obtusifolia* at 92.1 with 514 out 558 trees alive and *Albizia amara* surviving at 92.1 with 152 out of 165 trees alive.

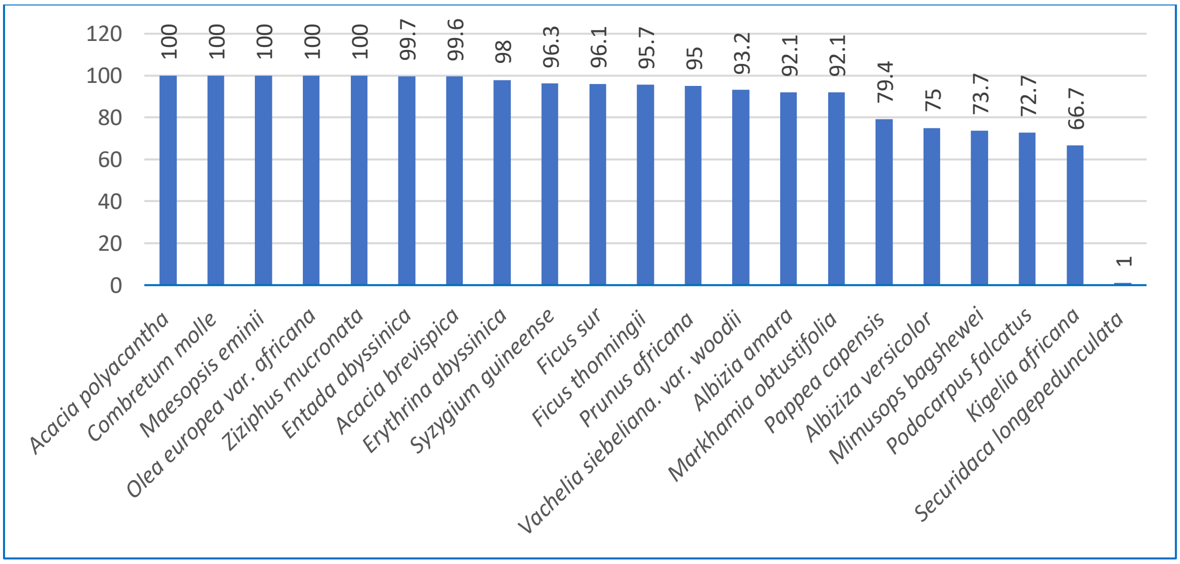

Figure 22. Tree survival rate (in %) at Ryarubamba Sancta

Source: Field Survey (2025)

Contrary to high survival tree species, Species such as *Pappea capensis and Podocarpus falcatus* showed intermediate low survival of 79.4% and 72.7% with 611 out of 770 and 40 out of 55 trees alive respectively. The poorest performance was recorded for *Securidaca longepedunculata* with only 4 out of 391 individuals' survival at 1%.

4.2.3. Survival rate at Karushuga Sancta

In Karushuga sancta, out of 9,419 trees planted from 17 native tree species, the majority demonstrated moderate to high survival rates, although some species experienced substantial mortality. *The* high performing species include *Acacia polyacantha* with 1,302 out of 1,327 trees surviving at 98.1%, *Pappea capensis* with 478 out of 500 trees surviving at 95.6%, *Markhamia obtusifolia* with 285 out of 300 surviving at 95% and *Ficus sur* with 607 out of 644 trees surviving at 94.3%.

Moderate survival rates were observed in species like *Ziziphus mucronata* with 181 out 201 trees surviving at 90%, *Albizia petersiana* surviving at 93.8% with 75 out of 80 trees alive, *Combretum molle* with 196 out of 201 trees surviving at 97.5%, *Acacia brevispica* at 88.2% with 745 out of 845 trees alive while *Euclea divinorum* and *Combretum collinum* counted at 82.1% and 83% with 179 out of 218 and 83 out of 100 tree alive respectively.

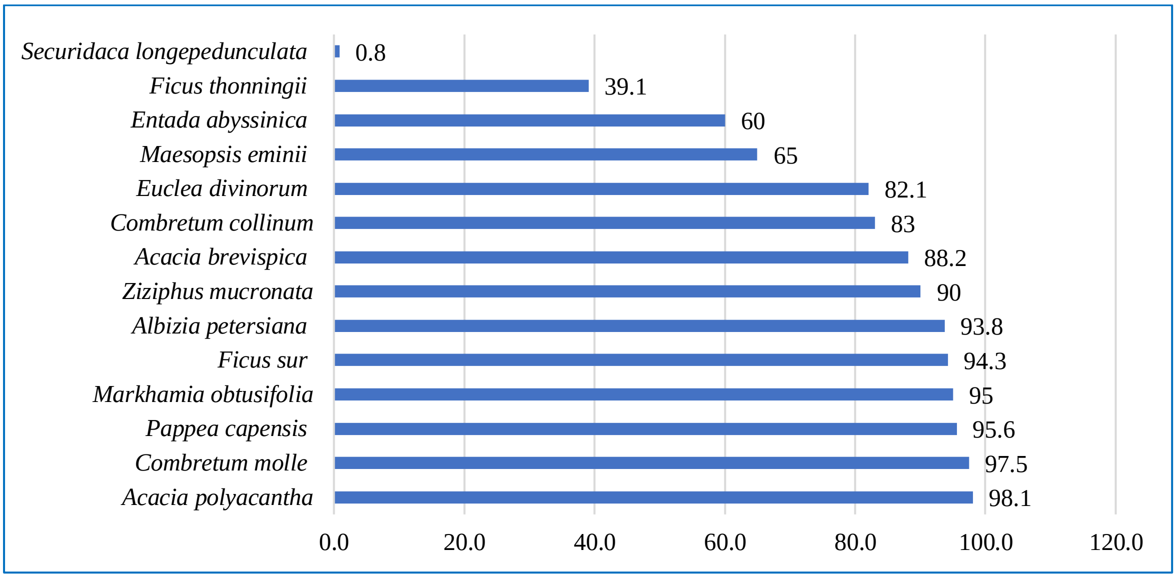

Figure 23. Tree survival rate (in %) at Karushuga sancta

Source: Field Survey (2025)

Nevertheless, *Entada abyssinica* and *Maesopsis eminii* were recorded with lower survival rates of 60% and 65% reflecting the loss of 90 out of 150 and 641 out of 986 trees each. Poor survival performance was also noted for *Ficus thonningii* with 180 out of 460 trees surviving at 39.1%, *Tetradenia riparia* with 33 out of 710 trees surviving at 4.6% and the lowest survival was observed in *Sicuridaca longepedunculata* where only 9 out of 1,067 trees survived rating at 0.8%.

4.2.4. Survival rate at Amahoro Sancta

The survival rates of trees species planted within sancta revealed varying percentages of success across the 27 species counted. Out of 27, 18 species achieved survival rate above 90% indicating strong adaptability and favourable sancta conditions for species. For instance, *Albizia gummifera* and *Combretum molle* achieved a perfect survival rate of 100% while *Ficus Vallis-chuidae* survived at 99.6% with 1096 out of 1100 trees, *Acacia sieberiana var.*

kagerensis at 98.7% with 2191 out of 2220 trees alive, *Garcinia buchananii* with 489 out of 496 trees survived at 98.6%, *Maesopsis eminii* at 97.6% with 404 out of 414 trees, *Pappea capensis* at 97.1% with 699 out of 720 trees and *Acacia brevispica* achieved 96.3% with 1300 out of 1350 trees alive in the sancta.

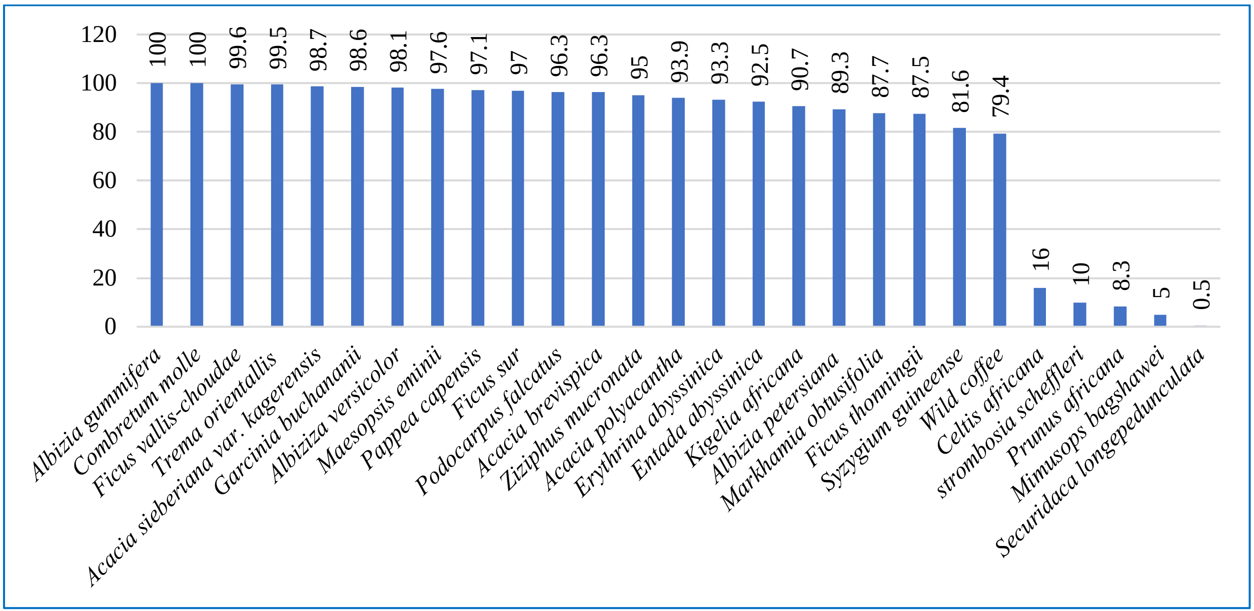

Figure 24. Tree survival rate (in %) at Amahoro sancta

Source: Field Survey (2025)

Several species displayed a moderate survival rate including *Wild coffee* surviving at 79.4% with 135 out of 170 trees, *Syzygium guineense* at 81.6% with 554 out of 679 trees and *Markhamia obtusifolia* with 1675 out of 1910 planted trees leading to survival rate of 87.7%. Nevertheless, low survival rates were also observed, where *Securidaca longepedunculata* demonstrated the lowest survival rate with 1 out of 200 trees surviving at 0.5% rate in the sancta, followed by *Mimusops bagshawei* with 10 out of 200 planted trees surviving at 55, *Prunus africana* at 8.3% with 33 out of 400 trees and *Strombosia scheffleri* with 20 out of 200 trees surviving at 10% rate.

4.2.5. Survival rate at Muhazi Sancta

Among the 30 tree species assessed, *Maesopsis eminii* demonstrated the highest survival rate with 758 trees planted and 741 surviving resulting a survival rate of 97.8%. Also, *Ficus sur* and *Dombeya rotundifolia* survived at 98.6% and 96.6% with 286 out 290 trees and 56 out of 58 trees respectively. These species clearly exhibit strong adaptability to the sancta conditions and should be prioritized in the future afforestation and restoration projects.

In contrast, species like *Acacia brevispica, Ficus thonningii and Securidaca longependunculata* were extremely recorded with low survival rates of 13.2%, 6.4% and 6.9% each. However, species such as *Garcinia buchananii*, *Euclea divinorum* and *Galiniera saxifraga* were purely recorded with 0% survival due to its poor adaptability and post-planting management challenges.

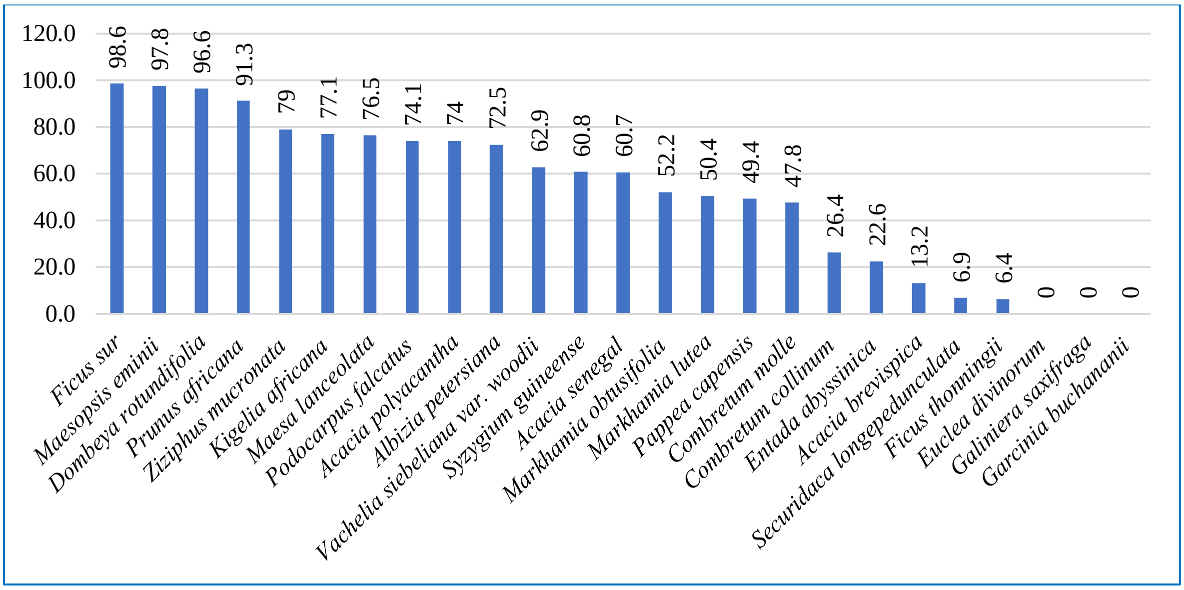

Figure 25. Tree survival rate (in %) at Muhazi sancta

Source: Field Survey (2025)

Additionally, most species including *Acacia polyacantha* which had a 74% survival rate with 338 out of 457 planted trees, *Ziziphus mucronata* at 79% with 128 surviving out of 162 planted, *Albizia petersiana* with 72.5% and *Kigelia africana* surviving at 77.1% also showed high resilience and will serve as the reliable species in degraded forest restoration initiatives.

4.2.6. Survival rate at Shungerezi Sancta

In Shungerezi sancta, the analysis of survival performance was made across 19 native tree species based on both the number of planted and living trees. Species like *Ziziphus mucronata* showed exceptional resilience with 119 out of 123 planted trees surviving at 96.7%. *Ziziphus mucronata* was closely followed by other high performing species including *Acacia sieberiana* surviving at 95.7% with 584 out of 610 trees, *Acacia polyacantha* with 1515 out of 1607 surviving at 94.3% and *Maesopsis eminii* with 1100 surviving trees out of 1184 planted which achieved a 92.9% survival rate.

On the other hand, native tree species including *Syzygium guineense, Kigelia africana, Erythrina abyssinica, Ficus thonningii, Albizia petersiana, Combretum molle, Pappea* *capensis*, *Ficus sur* and *Albizia amara* exhibited a moderate survival rate ranging between 60%-90%. In contrast, *Markhamia obtusifolia*, *Podocarpus falcatus* and *Trema orientalis* recorded with low survival rates of 44%, 34.6 % and 34.8% respectively.

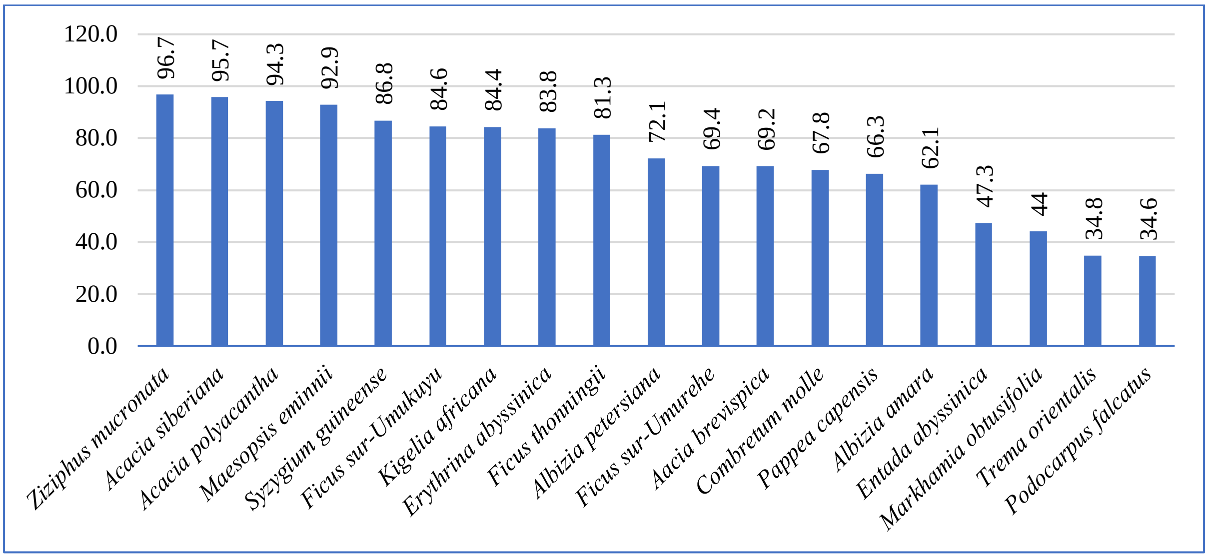

Figure 26. Tree survival rate (in %) at Shungerezi sancta

Source: Field Survey (2025)

4.3. Comparison of growth performance of native tree species across different sancta

This section presents the statistical analysis of comparison of growth performance, focusing on the average diameter (cm) and average heights (m) of the ten trees across available in all sancta in relation to influencing factors. It further reports the comparison of survival rate of ten species across six sancta.

4.3.1. Comparison of heights and diameter of native tree species across different sancta

The analysis of average heights reveals significant spatial variability among the ten species commonly found across six different sanctuaries. *Entada abyssinica* growth portray the greatest spatial variation reaching an average height of 2.3 m at Jambo-Beach sancta. However, the height is very low in Amahoro, Shungerezi and Muhazi sanctuaries with 0.8 m, 1 m and 1 m respectively. Similarly, *Acacia polyacantha* has exhibited exceptional growth in Ryarubamba with 2.5 m and Muhazi 3 m due to favourable ecological conditions like good soil, availability of water, low temperature and moderate rainfall and best management practices, while its height is considerably low in Amahoro sancta with 0.9 m.

Furthermore, *Ficus sur* has shown relative high growth across all sancta with peak values in Jambo-Beach of 2.1 m and Muhazi with 1.7 m due to their proximity to lake Muhazi and other favourable environmental conditions. However, its heights have been low in the sancta of Shungerezi and Amahoro due to high altitude at Shungerezi and climate induced conditions like low rainfall and high temperature in both Shungerezi and Amahoro sancta. Species like *Pappea capensis* and *Ficus thonningii* recorded with consistently low average height across all sancta. For instance, *Ficus thonningii* have been measured with high heights in Ryarubamba, Karushuga and Amahoro Sancta with 1 m each, comparing to 0.5 m, 0.6 m and 0.8 m in Shungerezi, Jambo-Beach and and Muhazi sancta.

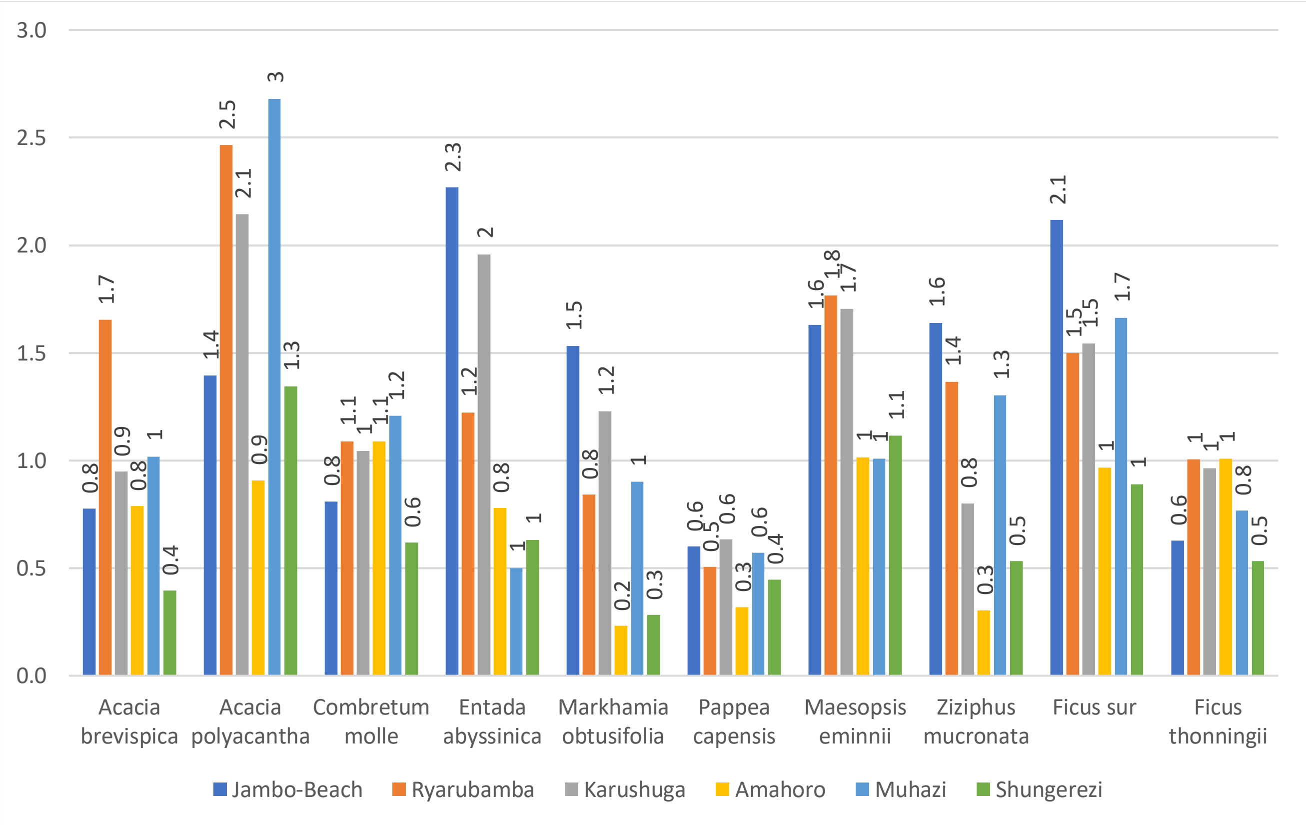

Figure 27. Growth performance (heights in m) for ten native tree species across different sanctuaries

Source: Field Survey (2025)

Native tree species like *Combretum molle* and *Maesopsis eminii* showed a stable average height ranges across all sanctuaries with minimal fluctuation pointing toward their ecological resilience. Meanwhile, the sancta of Ryarubamba often recorded higher average heights for multiple species including *Acacia polyacantha*, *Maesopsis eminii*, *Ficus thonningii* due to its better flat topography, microclimatic conditions with a well-managed anthropogenic disturbance. Conversely, Shungerezi and Amahoro sancta remarkably record the lowest average heights due to high temperature, low rainfall for Shungerezi and Amahoro with steep slope on Shungerezi sancta.

Beside average heights, ten tree species demonstrated a notable difference in diameter growth where *Ficus sur* and *Acacia polyacantha* has been recorded with the highest diameters, particularly in Ryarubamba with 5.8cm and 5.6 cm respectively, in Muhazi with 4cm and 5.3 cm each which indicating that Ryarubamba and Muhazi offer favourable conditions for stem growth for Ficus sur and *Acacia polyacantha* compared to other sanctuaries. *Maesopsis eminii* also has also grown with diameter growth especially in Ryarubamba sancta with 5.3cm confirming its suitability to sancta's conditions.

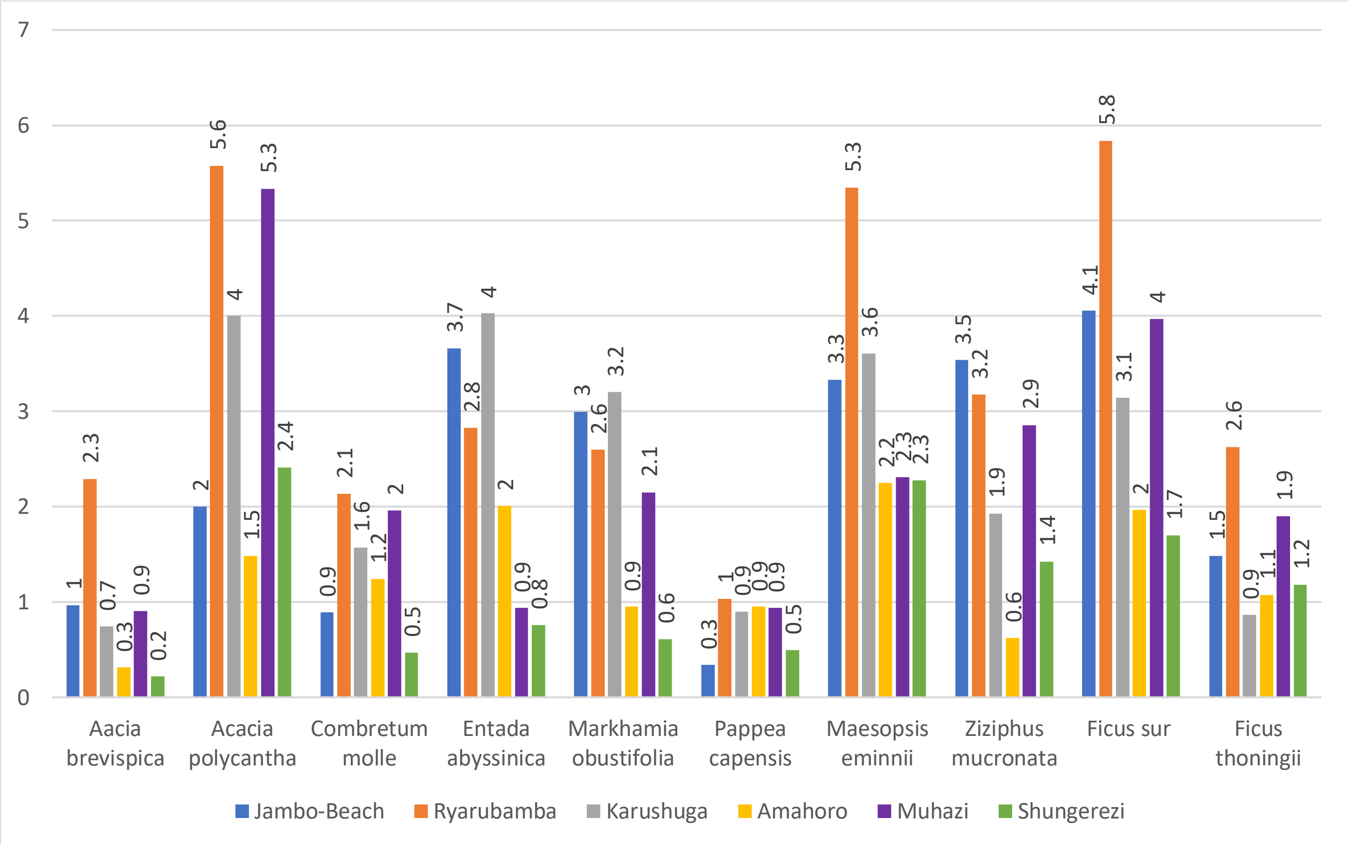

Figure 28. Growth performance (diameter in cm) for ten native tree species across different sanctuaries

Source: Field Survey (2025)

Entada abyssinica observed with a balanced diameter values across sanctuaries with the highest measurement in Jambo-Beach with diameter of 3.7cm and gradually decreasing across the other sanctuaries. Similarly, *Ziziphus mucronata* and *Combretum molle* show similar trends with high performance in Jambo-Beach and Ryarubamba while exhibiting limited growth in Shungerezi sancta. Ultimately, Ryarubamba observed as the sancta with high peak values of base diameter for multiple species, whereas Shungerezi and Amahoro consistently recorded the lowest record.

4.3.2. Comparison of Survival rate of native tree species across different sanctum

A comparative assessment of ten native trees was conducted across six sancta to evaluate their spatial survival performance. The results reveal that survival is highly dependent on both species and sanctum conditions where several species had high survival rates in some sancta with decline in other sanctuaries. For example, *Acacia brevispica* recorded with high survival rate in Ryarubamba and Amahoro at 99.6% and 98.1% each but decline in Muhazi with a survival rate of 13.3 due to anthropogenic constraints. *Acacia polyacantha* achieved 100% in Ryarubamba and 98.1% in Karushuga but performed poorly in Jambo-Beach with 28.7% due to moisture stress.

Combretum molle and *Entada abyssinica* had an optimal survival in Ryarubamba and Amahoro with 99.7% and 92.55 each while experiencing minimal survival in Muhazi with 47.8% and 22.6% respectively. *Markhamia obtusifolia*, despite its adaptability showed weak survival in Jambo-Beach with 39% and Shungerezi with 44%, it performed well in Karushuga with 95% survival rate.

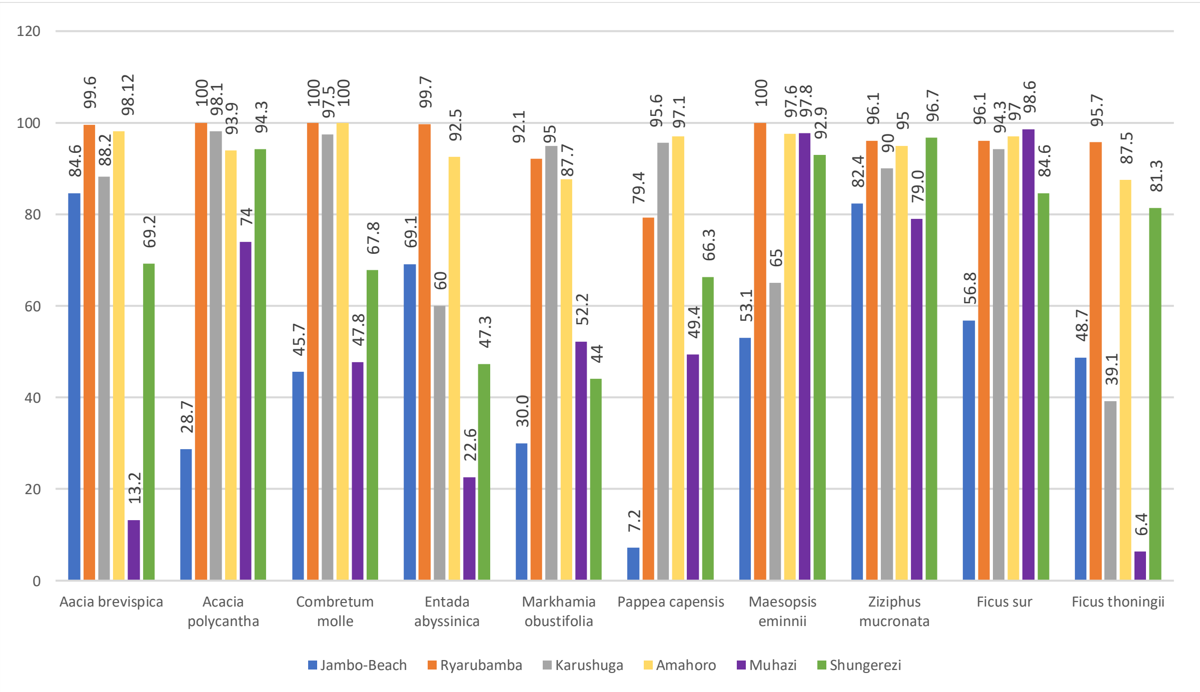

Figure 29. The survival rate (in %) of native tree species across different sanctum

Source: Field Survey (2025)

Pappea capensis also had the lowest survival in Jambo-Beach with 7.2%, yet demonstrated high survivorship in Amahoro and Karushuga with 97.1% and 95.6% respectively. Notably, *Maesopsis eminii* maintained high survival across all sancta proven with 100% in Ryarubamba and 97.8% in Muhazi which indicate a strong adaptability to sanctuaries' conditions. *Ziziphus mucronata* exhibited uniformly high survival rate above 90% in four sancta with the highest of 96.7% in Shungerezi and lowest of 79% in Muhazi. Although, *Ficus thonningii* declined in Muhazi with 6.4 suggesting its incompatibility to sancta condition, it has been survived in Ryarubamba, Amahoro and Shurungerezi sancta at 95.7%, 87.5% and 81.3%. *Ficus sur* had excellent survival with above 80% except in Jambo-Beach declined with 56.8% survival rate.

4.5.Factors underlying and influencing growth and survival of native tree species

This section presents both biotic and abiotic factors underlying and influencing growth and survival of native tree species

4.5.1. Species site matching

During the interview, most interviewees stated that *"planting tree species in location where the environmental condition such as soil, climate, water availability and elevation are well suited to their ecological need's leads to high growth and survival and vice versa"*. For instance, responses from Amahoro sancta monitoring technicians explained that *"species with high average height and diameter in Amahoro sancta including Trema orientallis, maesopsis eminii, Albizia gummifera, Acacia sieberiana var. kagerensis, Combrentum molle and Ficus thonningii were originally existing before COMBIO project which indicate that their ecological need are locally matching with sancta's conditions"*. Nevertheless, except *Securidaca longepedunculata* other species with below 10% survival rate such as *Garcinia buchananii, Galiniera saxifraga, Euclea divinorum* and *Dichrostachys cinerea* were adopted from other special location which mismatch with Amahoro sancta's conditions including high temperature especially from June-September leading to death and low survive rate.

4.5.2. Tree growth rate successional groups

Sancta technicians indicated that *"Trees are classified into two groups based on their growth rate such as fast-growing and slow-growing trees depending on inherent characteristics and biological nature of each tree species"*. For instance, respondents from Karushuga sancta explained that *"Species with average height like Senna singueana, Maesopsis eminii, Ficus* *sur, Entada abyssinica, Albizia petersiana and Acacia polyacantha belongs to the early successional group category*". Meanwhile, responses from Amahoro sancta's technicians stated that *"Species like Pappea capensis, Markhamia obtusifolia, Celtis africana, Ximenia caffra, Prunus africana, Crosoptelex, Strombosia scheffleri and Wild coffea belongs to the late succession group in the nature".*

4.5.3. Plantation timing

In the interview, Sancta agronomists confirmed that *"The time of tree planting plays a vital role in growth performance and survival rate of trees species".* The trees were planted in December 2023 in short rain season which provided initial moisture to support seedling establishment. However, the seedlings faced with limited rainfall from January to February led to the water stress for the young trees which affected root development in different sanctuaries. This period was followed by heavy rainy season from March to May which accelerated the growth of trees especially in Jambo-Beach, Muhazi, Amahoro and Ryarubamba sancta. The agronomists suggested that *"Optimal growth and survival of native tree species would be more successful when trees are planted at the start of rainy seasons either September or March to ensure sustained soil moisture and better rooting for dry condition set in".*

4.5.4. Water availability

During an interview, responses from Enabel supervisors said that *"Proximity of sancta to waterbodies and wetland influenced the growth and survival of the native tree species".* The responses emphasised on the Muhazi and Jambo-Beach sanctuaries which are spatially located on the lake Muhazi shores, Amahoro and Karushuga which are located nearly to Akagera and Nyirabihorwe wetlands respectively, directly influences tree physiological process such as cell expansion, leaf formation and root development. On the other hand, Sancta like Shungerezi and Ryarubamba located far away from natural waterbodies slow down growth and limit the tree's ability to absorb essential nutrients from the soil.

Figure 30. Sancta proximity to lake Muahzi

Source: Field Survey (2025)

4.5.5. Climate variability factors

This section analyses the influence of climatic factors such as temperature and rainfall to the growth and survival rate of native tree species in different sancta.

4.5.5.1. Temperature

In comparison to the temperature patterns for all sancta in 2024, data from Rwanda Meteological Agency show that Amahoro sancta experienced the highest temperatures ranging from 25.9°C to 30.6°C. In contrast, Shungerezi sancta recorded moderate temperatures between 22.3°C and 23.2°C which keeps the soil warm while contributing to limited moisture availability. According to interviews with sancta technicians, the high temperature in both Amahoro and Shungerezi led to soil and leaf drying which slowed tree growth as well as death of some tree species.

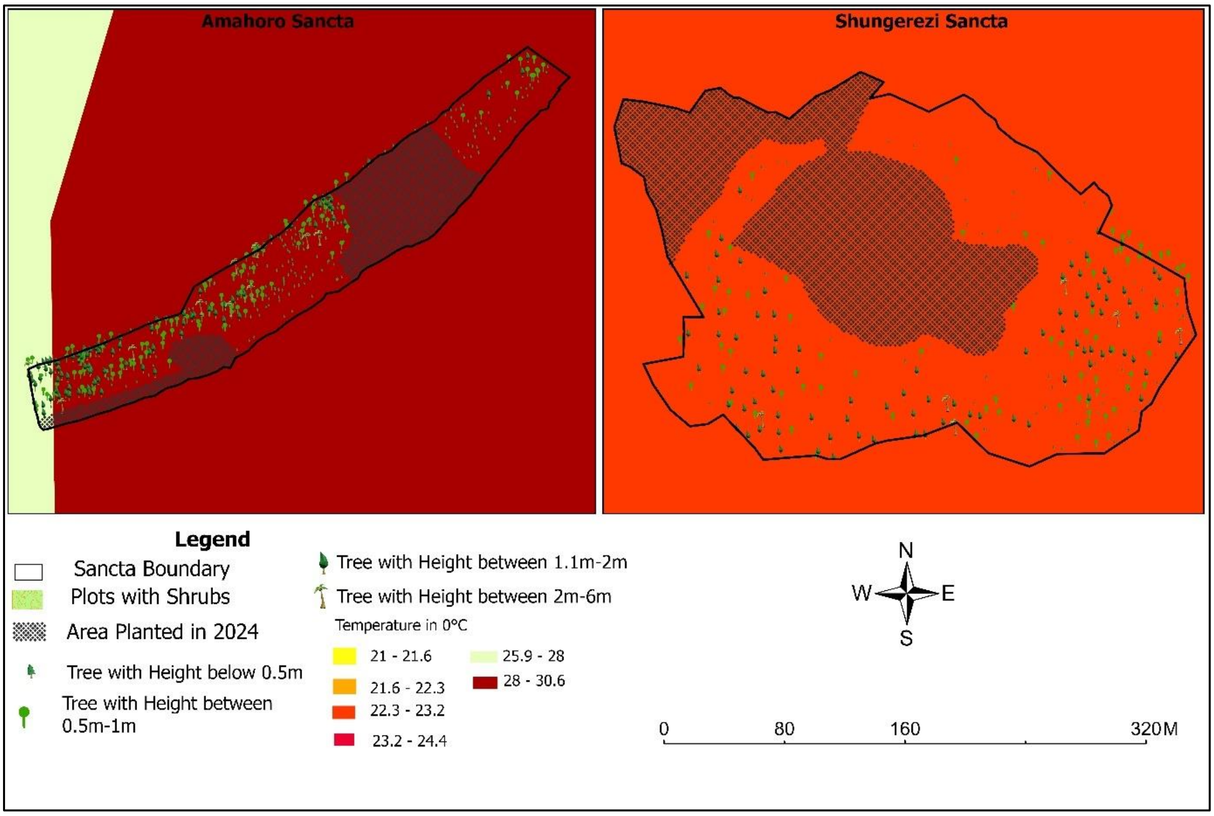

Figure 31. Average annual temperature at Amahoro and Shungerezi sancta in 2024.

Source: Rwanda Meteorological Agency (2025).

The sancta of Ryarubamba and Karushuga experienced moderate temperatures ranging between 22.3°C and 24.4°C, which supported tree growth by enhancing efficient photosynthesis. Height measurements recorded in these sancta indicate that most species attained heights exceeding 1.1m.

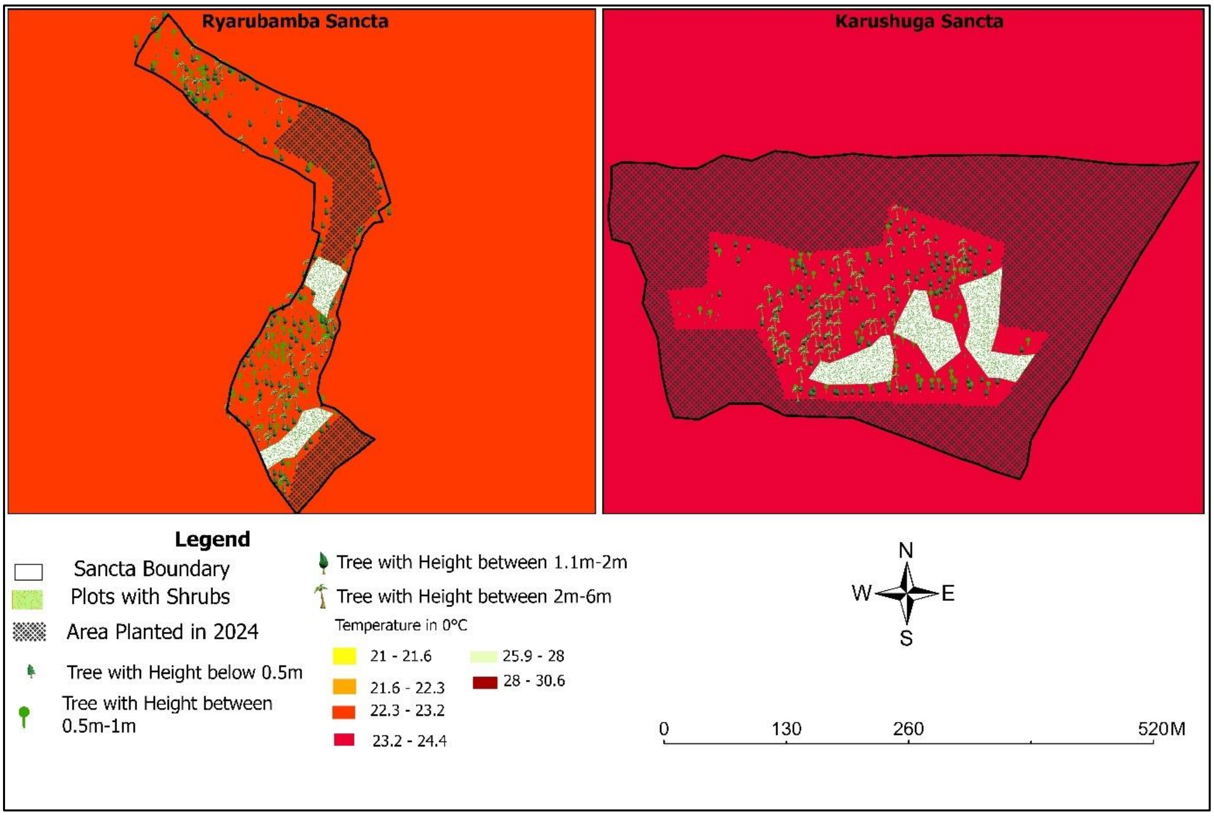

Figure 32. Average annual temperature at Ryarubamba and Karushuga sancta in 2024

Source: Rwanda Meteorological Agency (2025).

Similar to Muhazi sancta, moderate temperatures ranging between 22.3°C and 23.2°C were recorded which facilitated tree growth with most species reaching heights above 1m. Interestingly, the tallest trees reaching heights close to 6m were observed at Jambo-Beach, despite it experiencing lower temperature. This suggests that while moderate temperatures generally support steady growth, other factors such as moisture retention or species adaptability may have contributed to the exceptional tree height at Jambo-Beach.

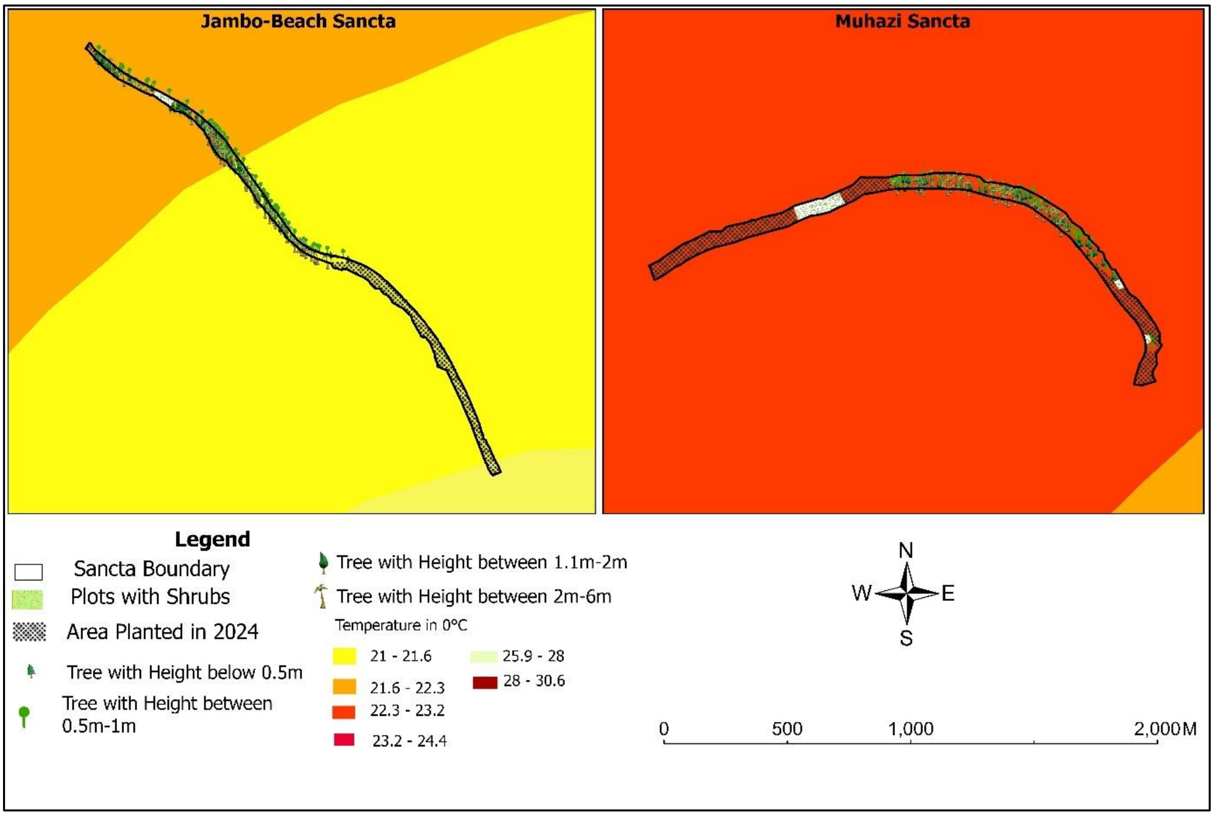

Figure 33. Average annual temperature at Jambo-Beach and Muhazi sancta in 2024.

Source: Rwanda Meteorological Agency (2025).

In contrast, Muhazi and Jambo-Beach sancta experience the low temperature, oscallating between 22.3 ^{0}C-22.7 ^{0}C and 19.6^{0}C and 22.2^{0}C respectively. The low temperature allows for the soil to remain wet with high soil moisture which is favourable for the root and stem development with health leaves and branches through the year. In both sancta where the temperature is low, trees have grown and survived normally. For example, the tree height recorded in both Jambo-Beach and Muhazi are predominantly ranging between 1.1 m and -567cm which proves that low temperature is among the factors influenced positively the growth and survival of native tree species in these sancta.

4.5.5.2. Rainfall

According to the data collected from Rwanda Meteorological Agency, indicated that rainfall at Amahoro sancta were heavy compared to other sanctuaries with rainfall ranging between 846.6 mm-1074.7 mm in 2024. However, the sancta technicians reported that heavy rainfall well counted in winter which was supper imposed by high temperature in the summer from May to September led to root stress and increased the diseases and pest within the sancta. The sequence of heavy rainfall to high temperature negatively affected the young trees through wilting and leaf scorch. Therefore, both rainfall and temperature supper imposed each other where the growth predominantly remained below 0.5 m and within 0.5 m-1m high.

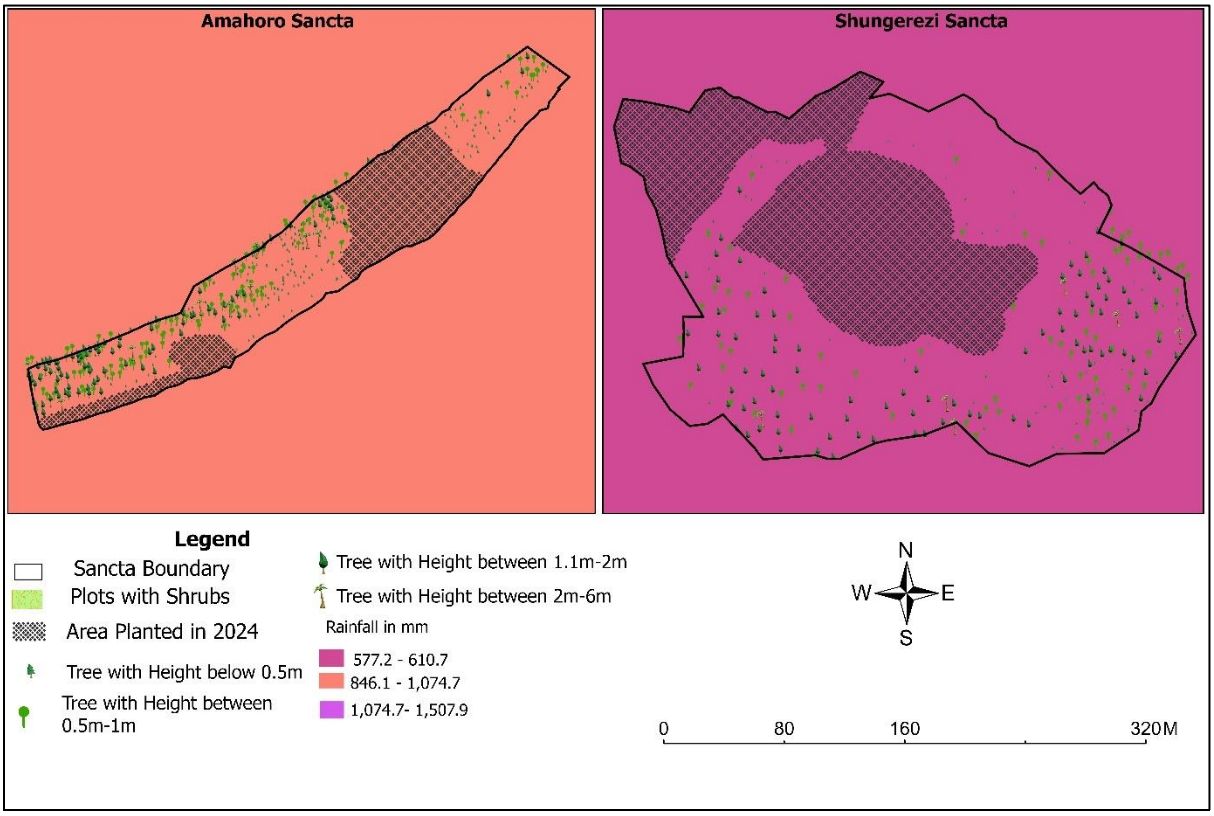

Figure 34. Annual rainfall at Amahoro and Shungerezi sancta in 2024.

Source: Rwanda Meteorological Agency (2025).

Furthermore, the rainfall at Shungerezi was limited in 2024 ranging between 577.2mm-610.7mm which negatively influenced the growth of native tree species with limited height mostly belwo 1m.

Sancta like Karushuga and Ryarubamba experienced with moderate rainfall raning bewtween 577.2 mm-610.7 mm in 2024. The moderate rainfall were supported by regular maintenance and Taungya sytem particulary in Ryarubamba sancta to ensure potential growth of tree. However, the responses from sancta technicians aruged that some species including *Pappea capensis* has not grown well due to the influence of moderate temperature which went alongside with moderate temperature which kept soil neighter warm or wet. This condition limit the growth of species need much water to grow faster.

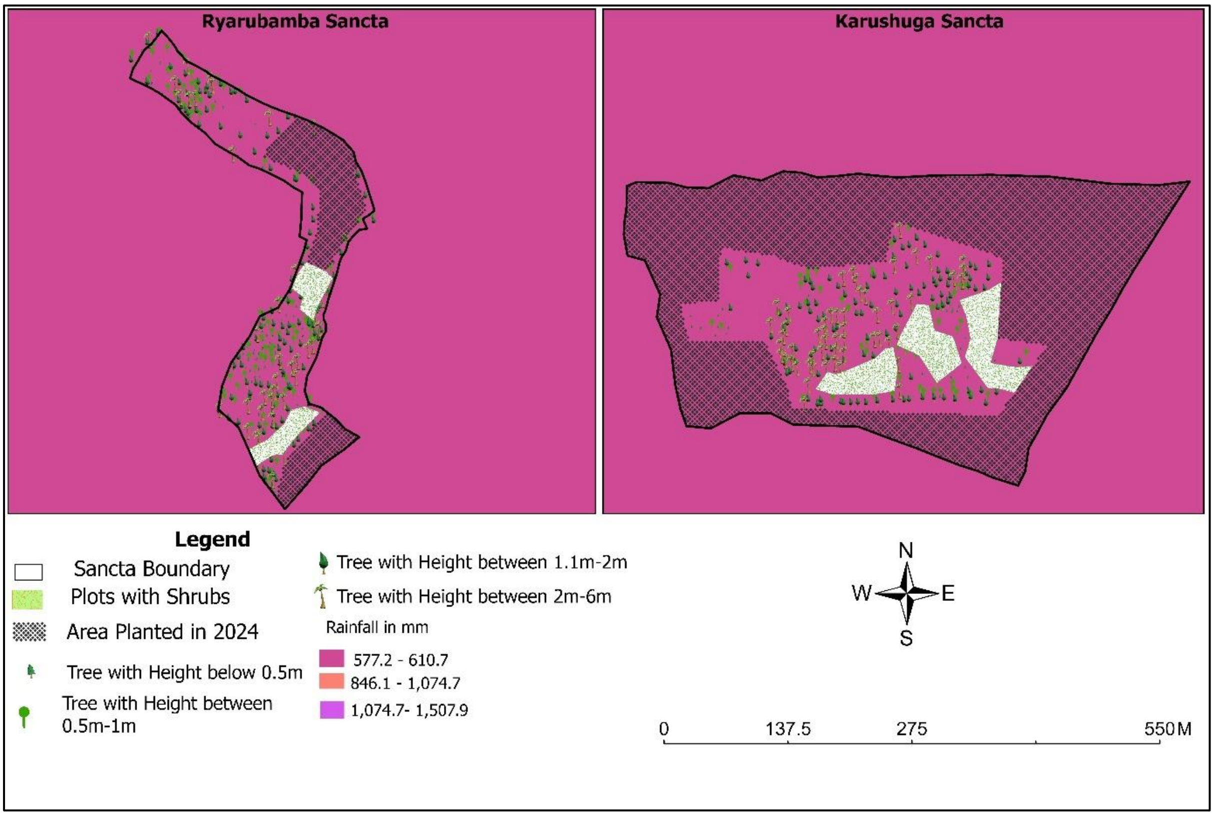

Figure 35. Annual rainfall at Ryarubamba and Karushuga sancta in 2024.

Source: Rwanda Meteorological Agency (2025).

In all sancta, high rainfall has been recored at Jambo-Beach with rainafall beween 1074.7mm-1507.9 mm which facilated the tree growth with height above 1m with trees dominant tree species with height above 2m high. Whilist, Muhazi sancta were also experienced by moderate rainfall ranging between 577.2mm-610.7mm where most trees were recorded with the height between 0.5m-1m as well as few tree with height between 1.1 m-2m high. The agromists stated that the high rainfall was supported by the natural water from lake Muhazi with low temperature in the sancta which kept the soil normaly with high miosture.

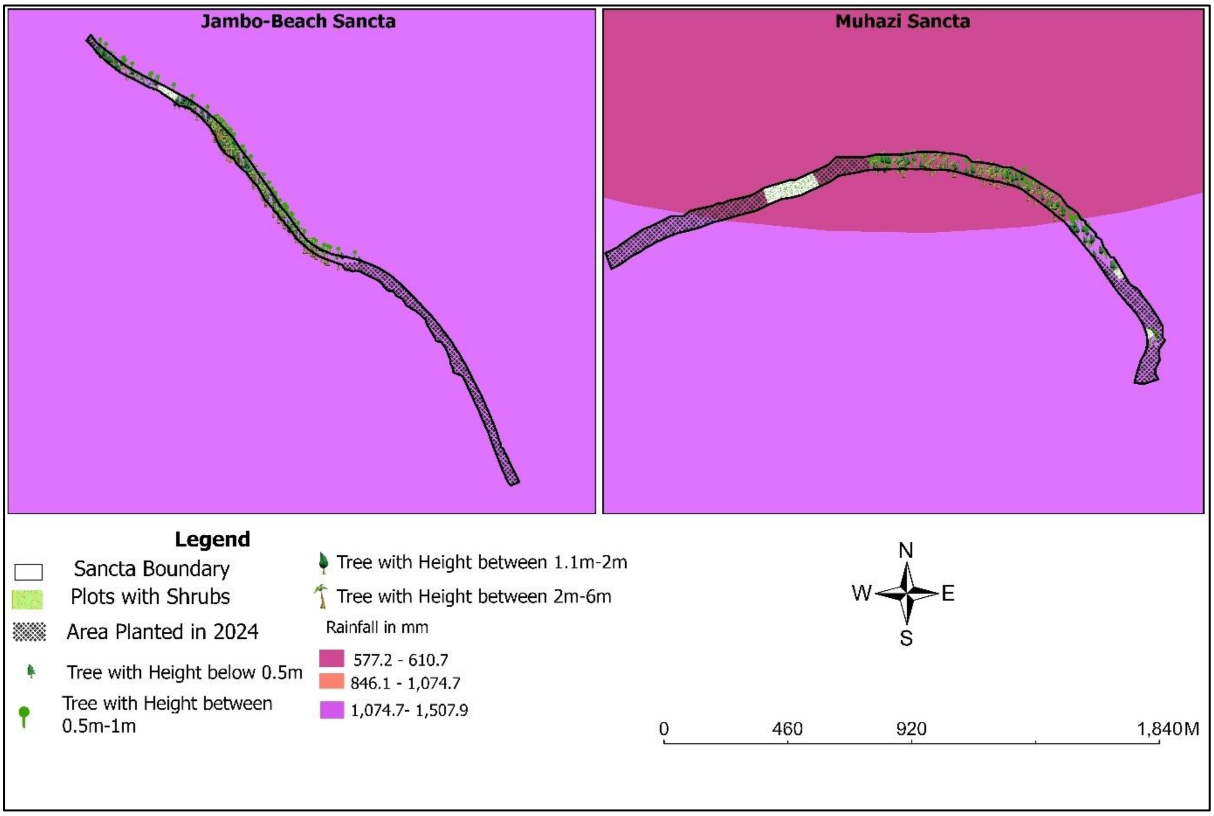

Figure 36. Annual rainfall at Jambo-Beach and Muhazi sancta in 2024.

Source: Rwanda Meteorological Agency (2025).

4.5.6. Pest and diseases

In the interview, Agronomists responded that *"Insects like beetles, aphids and caterpillars affected trees like Markamia abtusifolia, Syzygium guineense and Entada abyssinica mainly in Karushuga sancta"*. On the hand, termites' damages tree roots and weaken trees by disrupting vital processes such as photosynthesis as well as limiting the absorption of water and nutrient. The termites mainly affected Shungerezi, Karushuga and Amahoro sanctuaries.

4.5.7. Competition with weedy species

The response from sancta monitoring technicians during interview indicated *"competition from weedy species hinder the growth and survival of native tree species planted"*. Through observation, Jambo-Beach sancta are experiencing with high competition of unwanted trees than other sanctuaries while Ryarubamba sancta is the least sancta with unwanted trees due to use of the Taungya System where food crops are intercropped with trees in early stages of forest plantation. Sancta Technicians said that *"weedy species mainly within dense canopies* *limit the growth of the seedlings through depleting soil nutrients and water and reduce the photosynthetic capacity of planted native tree species".*

4.5.8. Topographical conditions

The slope model in all sanctuaries indicated that only Shungerezi sancta has a steep slope mostly ranging from 15^0 and above compared to other sanctuaries which indicate that the water table in Shungerezi is deep. During the interview, sancta technicians also reported that *"Trees struggle to access water especially during dry season"*. Members of cooperatives also argued that *"Soil erosion is high due to steepness which led to the removal of nutrient and reduce tree root stability in Shungerezi sancta"*.

Figure 37. Topographic condition of Shungerezi Sancta

Source: Field Survey (2025)

However, the slope of Amahoro sancta is predominantly gentle, ranging between 5^0 -10^0 indicating a relatively shallow water table compared to Shungerezi sancta. In contrast, Shungerezi sancta is characterized by steeper slopes, which can lead to increased runoff and reduced water retention. Despite these differences, both steep slope at Shungerezi and gentle slope at Amahoro appeared to limit tree growth as the majority of tress in both sancta exhibited heights below 1m. This suggests that factors such as poor water retention in steep areas and possibly high surface temperatures or soil compaction in gently slope areas may have constrained optimal tree growth.

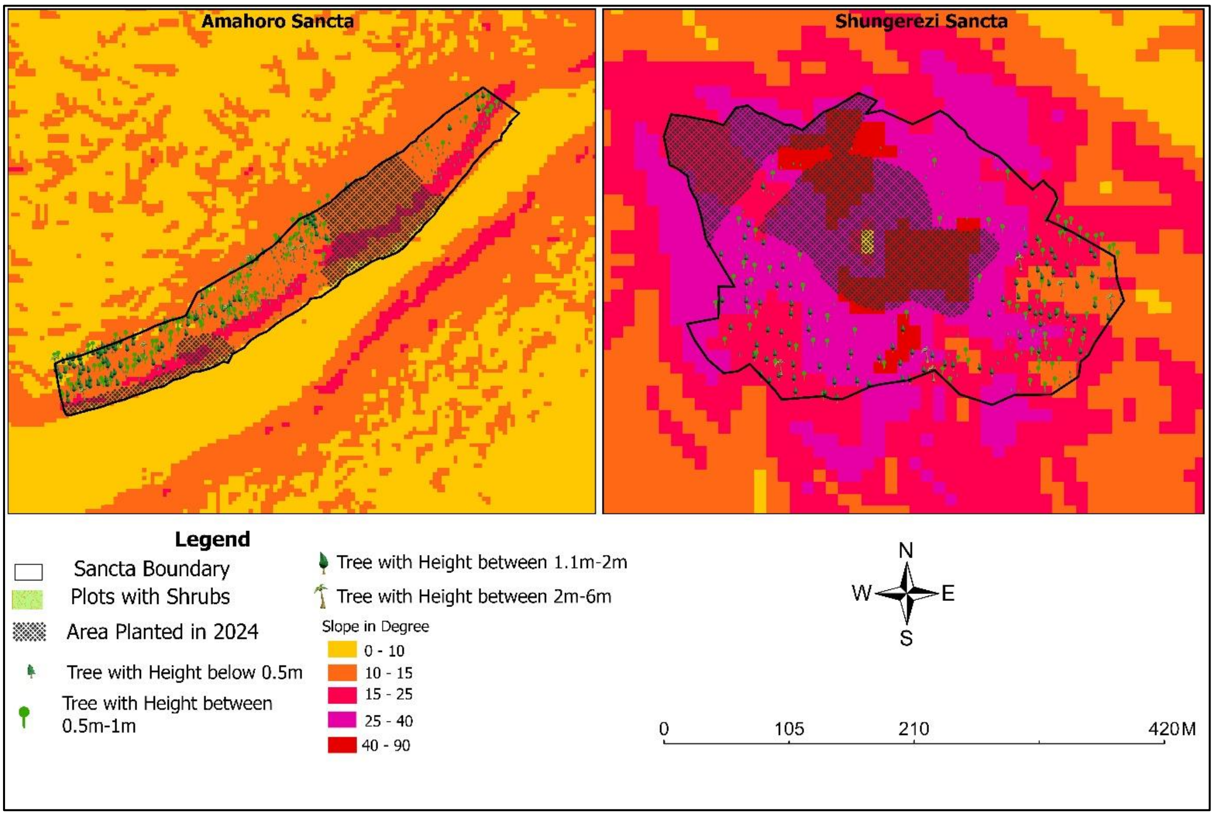

Figure 38. Topographical condition at Amahoro and Shungerezi sancta.

Source: NLA, 2025

Similarly to Jambo-Beach and Muhazi sancta, gentle slope between 5^0-10^0 were modelled which indicate that the water table is relatively close to the surface providing more moisture. In both sancta, most tree species grown with height ranging between 1.1m-2m with a few native tree species reaching between 2m-6m. As results of interview, Agronomists said that *"Sancta with low slopes facilitated easier access to groundwater which supported healthy tree growth and reduce tree loss and mortality"*.

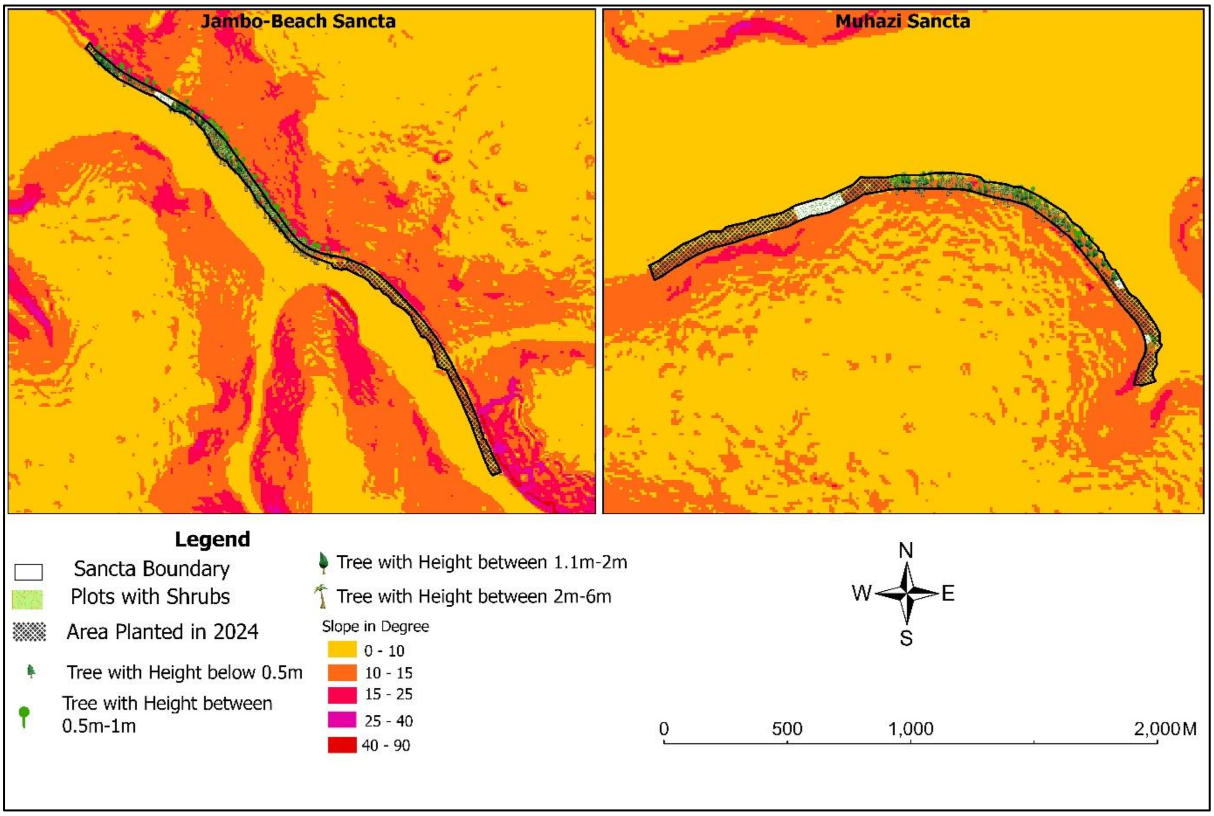

Figure 39. Topographical condition at Jambo-Beach and Muhazi sancta.

Source: NLA, 2025

Lastly, the potential growth of native tree species appears to be influenced by very low altitudes, predominately ranging below 10^0. This is evidenced by the dominance of native tree species in these areas with the tallest species reaching heights between 2m-6m significantly higher compared to those recorded in other sancta.

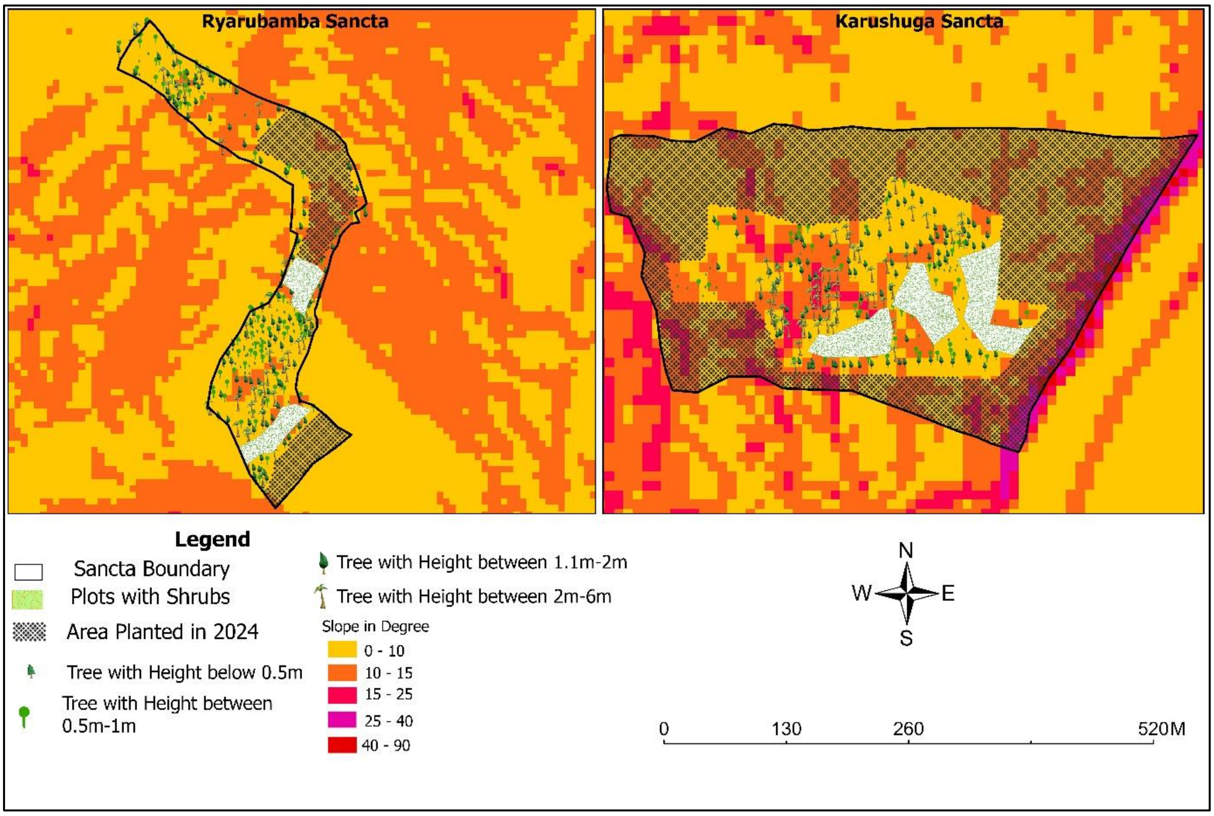

Figure 40. Topographical condition at Ryarubamba and Karushuga sancta.
Source: NLA, 2025

4.5.9. Tree management practices

Members of cooperative agreed that *"Effective management practices like weeding and watering support tree development by minimizing environmental stress and enhancing nutrient availability*". In the interview, sancta technicians also revealed that *"Weeding through removing competing plants around the tree base reduced competition for water, sunlight and soil nutrient which keep tree with normal growth*".

The members of cooperatives also reported that the *"Watering process during the early stages of tree establishment maintained the soil moisture needed for root development and physiological process"*. By observation, sancta including Jambo-Beach, Amahoro and Karushuga are highly affected weeds where regular weeding are required to ensure optimal growth of native tree species.

Figure 41. Weeding in Ryarubamba sancta

Source: Field Survey (2025)

The Enabel sancta supervisors indicated that the *"Taungya System used in Ryarubamba sancta where food crops and trees are intercropped contributed to effective growth and survivorship of planted trees in the sancta"*. This system is not only reducing unwanted weeds but also support economically the member of cooperative and reduces the food insecurity.

4.5.10. Livestock grazing and feeds

Reflecting to the interview responses from the community mainly belongs to cooperatives in charge of maintenance like weeding and pruning of the sancta especially at Jambo-Beach and Muhazi sancta indicated that *"livestock hindered the growth and survival of trees"*. For example, *Entada abyssinica* and *Ficus thonningii* in Muhazi sancta were affected by cows' proximity to the sancta feed leaves and young trees.

The community members reported that *"Areas known as Muhazi sancta was previously used as a livestock farm with many cows"*. In contrast, livestock farmers indicated that *"Before establishment of the sancta, the presence livestock improved soil fertility and accelerate the growth and survival of native trees species through the natural additional of manure"*. The interview with communities resulted that *"Illegal slashing of grasses like Chrolis gayana for livestock purposes in Jambo-Beach in combination lack of awareness among some individuals involved in grass harvesting who are often unable to distinguish between grasses and young planted trees led to unintentionally cut of the new planted trees hence death or slower growth of the native tree species"*.

Figure 42. Livestock grazing in Muhazi sancta
Source: Field Survey (2025)

4.5.11. Indirect planting system

During the interview, Sancta technicians indicated that *"the use of indirect planting where trees are not directly planted in their final growing sancta but rather than growing in nurseries also influence the growth and survival of same native tree species".* Through observation, species like *Securidaca longependunculata* appeared in Shungerezi sancta as wildings which were not planted have high performance rather than seedlings relocated from nurseries to sancta. Based on the finds, several species like planting *Securidaca longependunculata* would be successful once are planted directly in the sancta.

4.5.12. Lack of knowledge of weeding labourers on trees species

During the interviews with cooperative members per sancta, said that *"Lack of knowledge regarding to different trees species led to the loss and low survival of native tree species*". For example, members involving in pruning, weeding and other maintenance activities reported that unable to distinguish between planted tree seedlings and unwanted trees led to intentionally cut not only leading to direct loss of trees but also disturb its growth in terms of height and diameter.

Figure 43. Weeding laborers at Jambo-Beach sancta

Source: Field Survey (2025)

During the interview, Sancta technicians indicated that factors such as species site matching, plantation timing, climate variability, management practices and Taungya System in

Ryarubamba were the primary factors influencing the growth and survival of native trees species in the COMBIO project areas.

4.6. Relationship between tree height with environmental conditions across sanctuaries

The NMDS results in R software, indicated that among the sancta, Karushuga, Ryarubamba and Muhazi are relatively close indicating similar species composition, whereas sancta like Amahoro and Shungerezi are more widely separated, indicating that species are likely influenced by differences in slope and temperature. Jambo-Beach occupies an intermediate position but is separated along NMDS1, suggesting a unique species mix moderately shaped by environmental factors.

Slope showed the strongest relationship with the NMDS (NMDS 1 =-0.78, NMDS2=0.85) indicating that tree species composition is strongly influenced by slope especially at Shungerezi with steeper slope. Temperature was moderately correlated with NMDS1 = -0.70, suggesting that warmer sancta like Amahoro favor certain species. In contrast, rainfall exhibited weak correlations with both NMDS axes which indicates that it is less influential factor for growth and survival rate.

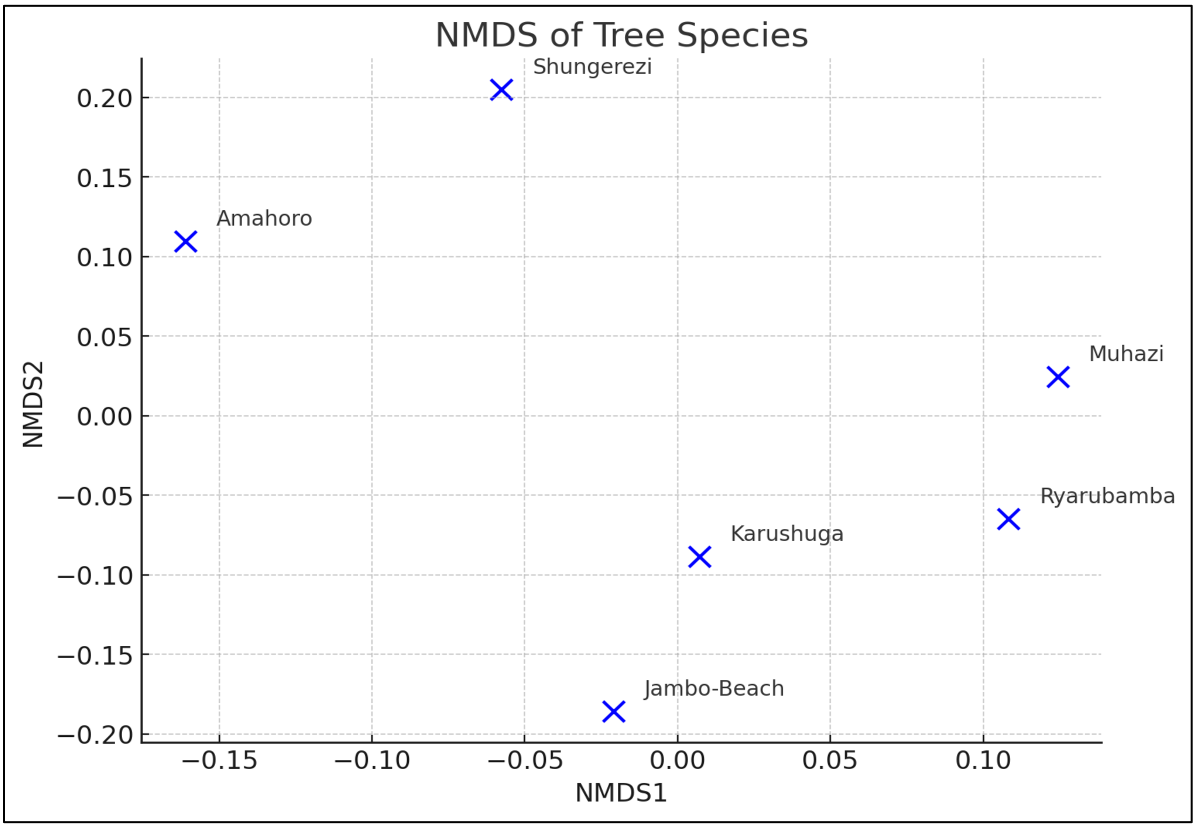

Figure 44. Relationship between tree heights with environmental conditions across sanctuaries

Where: Points represent sites with their positions reflecting similarity in tree species composition. Sites closer together have more similar species distributions.

4.7. Proposed strategies for boosting the growth and survival rate of native tree species

This section presents the strategies for boosting the growth and survival of native tree species in COMBIO project areas.

4.7.1. Site preparation and selection of suitable species

The sancta's monitoring technicians stated that *"Conducting site assessments including test and prepare soil, Considering climate variabilities like rainfall and temperature, slope conditions, climate vulnerability analysis, test and prepare soil, clearing competing vegetation as well as choosing native tree species which are locally adaptive to site conditions rather than adopting other specialise from different spatial location with unsimilar ecological condition is a critical first step to ensure successful growth and long-term of tree species"*.

The practical benefits of this strategy are evident in the experiences of community members of Jambo-Beach sancta. They reported that *"Species like Acacia polyacantha, Vachelia siebeliana var, woodie, Markhamia obtusifolia and Markhamia lutea grown and survived well due to that both were originally wildings in the area prior to the establishment of Jambo-Beach sancta"*. The success of those species suggests that they are well-adapted to local site conditions and that seedlings of the same species sourced from nurseries are also likely to thrive under similar environmental circumstances.

4.6.2. Regular tree maintenance practices

Through the interviews, the sancta technicians pointed out that *"Regular and well implemented tree maintenance practices are essential for ensuring the successful growth and survival of native tee species in all sancta through creating favourable microclimatic and soil condition that support early-stage tree establishment"*. They confirmed that regular weeding strengthens tree development by reducing competition with unwanted trees. They suggested that even if pruning has been never used in all sancta, it removes diseased or poorly formed branches which reduce the risk of pest infestations and enhancing canopy shape.

Sancta Agronomist suggested that *"Regular watering and mulching should be considered as maintenance practices"* where watering is important in the dry season to help the young tree species to overcoming transplant shock and build strong root systems while mulching retains soil m moisture, regulating temperature and suppresses weeding growth which contribute to tree rood development. In the interview, sancta technicians argued that *"Even if watering and mulching have been never applied in all sancta, they agreed that application of these practices could improve the growth and survival rate of native tree species in the COMBIO project areas"*.

4.6.3. Application of organic manure

Members of cooperatives responded that *"The use of organic manure during tree plantation and weeding processes enhance the growth and survival of native tree species"*. They made a reference to Muhazi sancta which was historically a livestock far, they agreed that presence of cow manure played a great role in the successful growth and survival of trees in the sancta.

Some of the agronomists' sancta suggested that *"Due to presence of pineapple prior to established of Amahoro sancta disrupted natural nutrient from the soil*". By observation, high steep slope with infertile sandy soil of Shongerezi sancta slower down the growth and survival of tree species. The agronomists argued that *"Organic manure can supply essential nutrients inclining nitrogen, phosphorus and potassium which promote root development, leaf formation and overall plant Vigor during the critical early growth stages*".

Enabel sancta supervisors agreed that *"The trees planted in December 2023 were planted without manure while the trees planted in August 2024 were planted with cow manure which indicated fast growth and survivorship than the trees planted with no manure*". Conversely, they highlighted that application of manure must be done carefully and in moderation to avoid negative environmental impacts. Whereby, over organic manure can lead to nutrient leaching, soil imbalance as well as damaging native trees that are adapted to low nutrient conditions. Finally, they recommend that soil test should be assessed prior to application of manure in any sancta of the COMBIO project.

4.6.4. Livestock restriction measures

During the interview, agronomists from Muhazi sancta suggested that *"Excluding livestock from tree planting sites is a critical best practice to ensure the healthy growth and survival of native tree species*". They stated that most species including *Albizia petersiana, Ficus thonningii, Rhus natalensis, Tetradenia riparia* and *Vernonia amygdalina* were eaten by cows which are settled in the nearby livestock farm. Apart from feeding leaves of several species, livestock also cause significant damage including trampling young seedlings and compacting soil making it difficult for trees to establish strong root systems. Sancta technicians proposed that implementing protective measures including strong fence and a well community grazing management should create a safe environment for seedlings to mature without livestock disturbance.

4.6.5. Use of quality seedlings

In the interview, sancta agronomist suggested that *"Use of quality seedlings from nurseries is a fundamental best practice for ensuring the successful growth and survival of native tree species"*. To ensure the quality, seedlings should be gown using proper nursery practices, healthy, free from diseases, well-rooted and adapted to local environmental conditions. The cooperatives members said that *"Use of poor seedlings result a high mortality rates, slow growth and vulnerability to diseases and pest which undermines the forest restoration effort*".

4.6.6. Taungya system

Enabel supervisors taken Ryarubamba sancta as a win-win model for how the Taungya system is the best practice to the successful growth and survival of native tree species. They stated that *"The combination of agricultural crops with the tree seedlings especially during early stages of forest establishment offered sustainable land use approach not only offering benefits to seedlings but also supporting local livelihoods*". Agronomist said that when trees are still young and not yet shading the land, cooperative members are allowed to grow short-term food crops such as beans, maize, cassava, etc to ensure that the land is well maintained, weeded and protected as farmers have a direct incentive to care for both the crops and the trees.

Sancta technicians reported that *"Taungya system contributes to successful tree establishment through reducing maintenance costs and increasing soil fertility through crop residue"*. In return, Cooperative members agreed that they benefit from food production and potential income which foster a sense of ownership and responsibility of the seedlings.

4.6.7. Community awareness

Raising community awareness to understand the native tree species planted, its ecological, economic and social benefits is the best practices for the success growth of native tree species in COMBIO project areas. The representatives of sancta's cooperative members reported that *"Most members cannot differentiate the native tree seedlings planted and wildings or unwanted trees which leads to unintentionally cut of newly planted seedlings during weeding*".

Therefore, community engagement can resolve these issues through community workshops, trainings and meetings will lead to proper tree maintenance and the project gain local ownership and social acceptance. As a response from Enabel sancta supervisors, the community awareness will not only enhance the success of tree growth and survival but also ensuring ongoing care and protection of restored landscapes beyond the project's duration.

4.6.8. Use of termite resistant trees

Cooperative members of Amahoro and Shungerezi sancta reported that *"Planting termite-resistant tree species like Euphorbia tirucallii locally known as "Umuyenzi' along the new native tree seedlings is a best practice to ensure high survival rate of native tree species"* especially in termite prone areas. They stated that termite feeds roots and stems of trees species leading to slower growth or total loss. Adiji and Olaniran (2023) agreed that integrating *Euphorbia tirucallii* characterized by its toxic, milky sap and unpalatable properties alongside with native tree seedlings reduce the termites.

5. CONCLUSION AND RECOMMENDATIONS

This section presents the conclusive aspects and key recommendations to ensure the successful growth and survival of native tree species in the COMBIO project areas.

5.1. Conclusion

The study aimed to assess the growth and survival rate of native tree species in the COMBIO project areas in Eastern province of Rwanda by measuring tree height, base-diameter and counting the survival rate across different one year-old native tree species. Additionally, the study analysed the key factors underlying and influencing the growth and survival rate, and finally proposing the best practices to ensure the successful growth and survival of native tree species.

Various methodologies and tools were used to address the research questions including measuring tape used for measuring heights and base-diameter of native trees across the sanctuaries. Survival rate was assessed through counting and marking methods by recording the total number of planted trees, living trees, dead and missing trees. Spatial location of each trees measured was captured using DGPS, lately processed using ArcGIS Pro to join the recorded growth measurements (height and base-diameter) with its spatial location. Furthermore, interview and observation were employed to identify the key factors underlying and influencing the growth and survival of native trees and proposing the best practice to ensure successful growth and survival of native trees species planted in the COMBIO project areas. Temperature, rainfall and topographic factors were analysed using ArcGIS Pro version 3.5 to compare each parameter with growth of trees in the six sanctuaries.

The results reveal that the growth varied with respect to the growth group (fast and Slower growing trees) and uniqueness of each sanctum. The native tree species belongs to fast growing group exhibited high growth with average height ranging between 1m-4.8m with average base-diameter ranging between 3cm -8.6cm while the slowing trees grown at 1m and below with average height with average base-diameter below 3 cm. The survivorship also varied species by species and sancta by sancta, where most resistant trees achieved 60%-100% survival rate while weak resistant trees achieved between 20%-60%. However, native tree species adopted from other spatial location below 10% survival rate in six sancta which indicated that these trees were not matching to the sancta conditions in Eastern province. It revealed that species like *Securidaca longependunculata* survived at law late in all six sanctuaries.

This study found that species site matching, soil quality, tree growth rate classification, rainfall, temperature, pest and diseases, competition with unwanted trees, topography, management practices, livestock grazing, indirect planting system and lack of knowledge of weeding labourers influenced the growth and survival of trees eighter positively or negatively. Lastly, the study proposed that site preparation and selecting suitable species, employing high management practices, application of organic manure, use of quality seedlings, use of the Taungya system, exclusion of livestock, community awareness and use of termite resistant trees should be taken into account in the sancta to ensure successful growth and survival in the current sanctuaries and for the future COMBIO project areas.

5.2. Recommendations

The recommendations from this study are pertinent for COMBIO project team including managers, sancta technicians, supervisors, agronomists, cooperative members at each sanctum and communities around the sancta, for policy makers, researchers and agronomist aiming to restore degraded forest using native tree species, as follows:

- Given that eastern province is characterized by low rainfall and high temperature, it is advisable for COMBIO project team to conduct site assessment and select suitable species matching with sancta condition as well as excluding livestock grazing at each sanctum.

- The COMBIO project team should conduct regular annual assessment of growth and survival of native tree species to track tree health for each species
- Future assessment of the growth and survival should take the study results as the baseline data in the next years.
- Researchers are encouraged to further investigate the tree health beyond height, base-diameter and survival rate through employing GIS and remote sensing technology to assess tree health using various vegetation indices including NDVI

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6. APPENDICES

Appendix 1. List of native tree species planted in all six sancta

Species/Sancta	No. of Sancta	Shungerezi Sancta		Karushuga Sancta		Ryarubamba Sancta		Amahoro Sancta		Muhazi Sancta		Jambo-Beach Sancta	
		No of total trees	No. Tree to be measured	No of total trees	No. Trees to be measured	No of total trees	No. Trees to be measured	No of total trees	No. Trees to be measured	No. of total trees	No. Trees to be measured	No of total trees	No. T to be measu
Acacia brevispica	6	1221	42	845	40	1006	61	1350	34	1168	47	1337	
Acacia polyacantha	6	1607	55	1327	62	62	4	2050	59	457	18	22	
Acacia sieberiana	3	610	21	0	0	0	0	2220	64	0	0	0	
Albizia petersiana	5	725	25	80	4	0	0	1040	30	109	4	487	
Albiziza amara	3	103	4	0	0	165	10	0	0	0	0	9	
Combretum molle	6	627	21	201	9	23	3	54	3	113	8	46	
Entada abyssinica	6	486	17	150	7	309	19	80	3	168	7	94	
Markhamia obtusifolia	6	2191	75	300	14	558	34	1910	55	201	8	110	
Pappea capensis	6	618	21	500	23	770	47	720	21	488	19	446	
Senna singueana	3	255	9	150	7	0	0	0	0	0	0	55	
Kigelia africana	5	147	5	0	0	3	3	150	4	35	3	82	

Maesopsis eminnii	6	1184	41	986	46	252	15	414	12	758	30	816
Ziziphus mucronata	6	1184	4	201	9	171	10	80	3	162	6	34
Syzygium guineense	1	123	6	0	0	0	0	0	0	0	0	0
Podocarpus falcatus	5	127	4	0	0	55	3	300	9	54	3	297
Ficus sur(umukuyu)	6	273	9	644	30	204	12	100	3	290	12	410
Trema orientalis	3	244	8	0	0	0	0	396	11	0	0	100
Ficus sur(umurehe)	2	62	3	0	0	0	0	1100	32	0	0	0
Erythrina abyssinica	4	290	10	0	0	196	12	150	4	0	0	338
Bridelia scleuroneura	1	132	5	0	0	0	0	0	0	0	0	0
Ficus thonningii	6	75	3	460	22	397	24	240	7	438	17	119
Markhamia lutea	2	0	0	0	0	0	0	0	0	230	9	55
Combretum collinum	2	0	0	100	5	0	0	0	0	197	8	14
Euclea divinorum	2	0	0	218	10	0	0	0	0	25	3	0
Securidaca longepedunculata	5	0	0	1067	50	391	24	200	6	261	10	80
Senna singueana	2	0	0	150	7	0	0	0	0	0	0	55

Tetradenia riparia	4	0	0	710	33	420	25	0	0	2335	93	205
Vernonia amygdalina	2	0	0	200	9	0	0	0	0	13	3	0
Albizia adiantifolia	1	0	0	0	0	167	10	0	0	0	0	0
Albiziza versicolor	3	0	0	0	0	16	3	54	2	0	0	47
Mimusops bagshewei	3	0	0	0	0	19	3	200	6	0	0	540
Olea europea var. africana	2	0	0	0	0	2	2	0	0	0	0	31
Prunus africana	4	0	0	0	0	40	3	400	12	200	8	1130
Syzygium guineense (Umugote)	4	0	0	0	0	27	3	679	20	79	3	155
Vachelia siebeliana. var. woodii	3	0	0	0	0	825	50	0	0	442	18	702
Albizia gummifera	1	0	0	0	0	0	0	54	3	0	0	87
GarciniaBuc hananii	2	0	0	0	0	0	0	496	14	0	0	135
Ximenia caffra	1	0	0	0	0	0	0	113	3	0	0	0
Strombosia scheffleri	2	0	0	0	0	0	0	200	6	0	0	94
Crosoptelex	1	0	0	0	0	0	0	160	5	0	0	0
Celtis africana	2	0	0	0	0	0	0	170	5	0	0	129
Acacia senegal (Umukonji)	1	0	0	0	0	0	0	0	0	117	5	0

Artemisia afra	1	0	0	0	0	0	0	0	0	196	8	0
Dichrostachys cinerea	1	0	0	0	0	0	0	0	0	3	3	0
Dombeya rotundifolia	1	0	0	0	0	0	0	0	0	58	3	0
Galiniera saxifraga(ikiryohera)	2	0	0	0	0	0	0	0	0	61	3	6
Garcinia buchananii	1	0	0	0	0	0	0	0	0	616	25	0
Maesa lanceolata	2	0	0	0	0	0	0	0	0	34	3	145
Rhus natalensis	1	0	0	0	0	0	0	0	0	200	8	0
Artimesia sp	1	0	0	0	0	0	0	0	0	0	0	90
Acacia kirkii	1	0	0	0	0	0	0	0	0	0	0	118
Coffea eugenoides	1	0	0	0	0	0	0	0	0	0	0	195
Clausena anisate	1	0	0	0	0	0	0	0	0	0	0	95
Euphorbia candelabrum	1	0	0	0	0	0	0	0	0	0	0	104
Euclea schimperi	1	0	0	0	0	0	0	0	0	0	0	43
Newtonia buchananii	1	0	0	0	0	0	0	0	0	0	0	11
Phoenix reclinata	1	0	0	0	0	0	0	0	0	0	0	3
Haplocoelum gallaense	1	0	0	0	0	0	0	0	0	0	0	25
Total		12284	388	8289	387	6078	380	15080	436	9508	395	9096

Appendix 2. Research Matrix

No	Specific Research Objectives	Research Questions	Data Required	Methods and techniques to be used	Expected output
1	To assess growth (height and base-diameter) of native tree species in COMBIO project areas	How does the growth (height and base diameter) of native tree species vary in COMBIO intervention areas?	Height and base-diameter of tree species across the Sancta Geographical coordinate (x,y) of measured trees in each sanctum	Measuring tape, Perche GPS, R version 4.5.1, Google forms and sheets	A well formulated text, Chart, graphs, tables with statistical tests demonstrating the tree growth (height and base-diameter in COMBIO intervention areas. A well-prepared map and text describing the spatial location of tree growth rate of measured trees.
2	To explore survival rate of different native tree species across different sites	What is the survival rate of different native tree across different sites?	• Numerical data of dead and missed tree species • Numerical data of living tree species • Total number of planted tree species • Geographical coordinate (x,y) of measured trees in each sanctum	Markers, Tags and recording sheets	A well formulated text with Chart, graphs, tables and statistical tests explaining the native species survival rate in COMBIO intervention areas. A well-prepared map and text describing the spatial location of dead or missed trees.

3	To determine key factors underlying and influencing the growth and survival rates at different sites	What are the key factors underlying and influencing the growth and survival rates of native tree species?	Qualitative data Spatial data (Temperature, precipitation, Water table, Humidity, soil and topography/slope)	Interview Observation Geospatial Technology.	A well formulated text of key underlying factors controlling growth and survival rates Comparative factor maps with growth and survival results. A well formulated text explaining each factor maps
4	To propose strategies for ensuring successful growth and survival rate of native tree species	What are the ensuring successful growth and survival rate of native tree species?	Qualitative data	Interview Observation	A well formulated text of strategies ensuring successful growth and survival rate of native tree species

Appendix 3. Interview Guide tool

This interview guide was used to determine the underlying biological, environmental, and human-induced factors influencing the growth and survival rates of native tree species in the COMBIO project in Eastern province of Rwanda. It has been designed for sancta technicians, supervisors, agronomist, member of cooperatives and nearby communities per each sanctum. All responses will remain confidential and will be only used for research purposes.

Objective 3: Determining the key factors underlying and influencing the growth and survival rates in the COMBIO project areas in Eastern province of Rwanda

Objective 4: To propose best practices to control key factors underlying and influencing the growth and survival rate of native tree species in COMBIO project areas in Eastern province of Rwanda

Introductory Part	
Interviewer	**Interviewee**
Introduction to the respondent: (Biography and Purpose of the research)	**Can you briefly introduce yourself? (**Including Names & Role)
Question related to the objective 3 and 4	
Questions	**Answers**
What is the name of sancta and its size?	
What type of native tree species are planted in the sancta?	
How many trees have been initially planted in the sancta (At the biggening)?	
Based on your experience, what are the main factors influencing the growth and survival of the native tree in this sanctum?	
Based on your experience, what are the key strategies for ensuring successful growth and survival rate of native tree species at each sanctum?	
Is there anything else you would like to add regarding the factors influencing tree growth and survival in this sanctum that we haven't covered?	

Appendix 4. Average diameter and height of native tree species in Shungerezi Sancta

Name of Tree Species	Average-Height (in m)	Average-Height (Cm)	Average-Diameter (in Cm)
Acacia polyacantha	1.3	134.6	2.4
Trema orientalis	1.3	127.9	2.3
Acacia sieberiana	1.2	120.3	2.3
Maesopsis eminnii	1.1	111.6	1.9
Syzygium guineense	1	109.4	1.9
Albizia petersiana	1.0	104.4	1.9
Erythrina abyssinica	0.9	93.1	1.7
Albizia amara	0.9	90.8	1.7
Ficus sur -Umukuyu	0.9	89	1.4
Ficus sur -Umurehe	0.7	74.7	1.3
Entada abyssinica	0.6	63	1.2
Combretum molle	0.6	61.9	1
Kigelia africana	0.6	59	0.8
Ziziphus mucronata	0.5	53.3	0.8
Ficus thonningii	0.5	53.2	0.7
Podocarpus falcatus	0.5	51.2	0.6
Pappea capensis	0.4	44.8	0.5
Acacia brevispica	0.4	39.6	0.5
Markhamia obtusifolia	0.3	28.3	0.2

Appendix 5. Tree survival rate in Shungerezi Sancta

Name of Tree Species	**Planted Trees**	Living trees	Missing Trees	Survival Rate (%)
Ziziphus mucronata	123	119	4	96.7
Acacia siberiana	610	584	26	95.7
Acacia polyacantha	1607	1515	92	94.3
Maesopsis eminnii	1184	1100	84	92.9
Syzygium guineense	182	158	24	86.8
Ficus sur-Umukuyu	273	231	42	84.6
Kigelia africana	147	124	23	84.4
Erythrina abyssinica	290	243	47	83.8
Ficus thonningii	75	61	14	81.3
Albizia petersiana	725	523	202	72.1
Ficus sur-Umurehe	62	43	19	69.4
Aacia brevispica	1221	845	376	69.2
Combretum molle	627	425	202	67.8
Pappea capensis	618	410	208	66.3
Albizia amara	103	64	39	62.1
Entada abyssinica	486	230	256	47.3
Markhamia obtusifolia	2191	965	1226	44
Trema orientalis	244	85	159	34.8
Podocarpus falcatus	127	44	83	34.6

Appendix 6. Average diameter and height of native tree species in Ryarubamba sancta

Name of Tree Species	Average-Height (in m)	Average-Height (Cm)	Average-Diameter (in Cm)
Acacia polyacantha	*2.5*	246.5	5.8
Prunus africana	*1.9*	187	5.6
Maesopsis eminii	*1.8*	176.8	5.3
Acacia brevispica	*1.7*	165.3	3.7
Ficus sur	*1.5*	149.9	3.7
Olea europea var. africana	*1.5*	145	3.6
Ziziphus mucronata	*1.4*	136.7	3.5
Syzygium guineense	*1.3*	128.7	3.2
Vachelia siebeliana. Var. woodii	*1.3*	128.5	3.2
Entada abyssinica	*1.2*	122.4	2.8
Albizia amara	*1.2*	119.8	2.7
Combretum molle	*1.1*	109	2.6
Ficus thonningii	*1*	100.5	2.6
Kigelia africana	*1*	96	2.6
Erythrina abyssinica	*0.9*	92.8	2.3
Markhamia obtusifolia	*0.8*	84	2.1
Albiziza versicolor	*0.8*	78.3	1.9
Podocarpus falcatus	*0.7*	65.3	1
Pappea capensis	*0.5*	50.6	0.7
Mimusops bagshewei	*0.2*	17	0.1

Appendix 7. Tree survival rate in Ryarubamba sancta

Name of Tree Species	Planted Tree	Living Trees	Dead/Missing Tree	Survival Rate (%)
Acacia polyacantha	62.0	62.0	0.0	100
Combretum molle	23	23.0	0.0	100
Maesopsis eminii	252	252.0	0.0	100
Olea europea var. africana	2	2.0	0.0	100
Ziziphus mucronata	171.0	171.0	0.0	100
Entada abyssinica	309.0	308.0	1.0	99.7
Acacia brevispica	1006.0	1002.0	4.0	99.6
Erythrina abyssinica	196	192.0	4.0	98
Syzygium guineense	27.0	26.0	1.0	96.3
Ficus sur	204.0	196.0	8.0	96.1
Ficus thonningii	397.0	380.0	17.0	95.7
Prunus africana	40.0	38.0	2.0	95
Vachelia siebeliana. var. woodii	825.0	769.0	56.0	93.2
Albizia amara	165.0	152.0	13.0	92.1
Markhamia obtustifolia	558.0	514.0	44.0	92.1
Pappea capensis	770.0	611.0	159.0	79.4
Albiziza versicolor	16.0	12.0	4.0	75
Mimusops bagshewei	19.0	14.0	5.0	73.7

Podocarpus falcatus	55.0	40.0	15.0	72.7
Kigelia africana	3	2.0	1.0	66.7
Securidaca longepedunculata	391.0	4.0	387.0	1

Appendix 8. Average Diameter and height of native tree species in Muhazi sancta

Name of tree species	Average-Height (in m)	Average-Height (Cm)	Average-Diameter (in Cm)
Acacia Polyacantha	2.7	268	5.3
Albizia petersiana	2	225.3	4.4
Dombeya rotundifolia	1.9	186.3	4.2
Syzygium guineense	1.7	167.3	4
Ficus sur	1.7	166.3	3.8
Maesa lanceolata	1.7	165	2.9
Acacia senegal	1.4	142.7	2.8
Ziziphus mucronata	1.3	130.3	2.5
Prunus africana	1	125.8	2.3
Combretum molle	1	120.7	2.3
Kigelia africana	1.0	104	2.1
Acacia brevispica	1.0	101.7	2.1
Maesopsis eminii	1.0	100.8	2
Markhamia lutea	1.0	96.2	1.9
Markhamia obtusifolia	1	90	1.9
Ficus thonningii	0.8	76.7	0.9
Pappea capensis	0.6	57.1	0.9
Entada abyssinica	0.5	50	0.9
Combretum collinum	0.4	37.4	0.6
Securidaca longepedunculata	0.3	33.1	0.6
Podocarpus falcatus	0.3	25.8	0.3

Appendix 9. Tree Survival rate in Muhazi sancta

Name of tree species	**Planted trees**	**living Tree**	**Dead/missing trees**	**Survival Rate (%)**
Ficus sur	290	286	4	98.6
Maesopsis eminii	758	741	17	97.8
Dombeya rotundifolia	58	56	2	96.6
Prunus africana	320	292	28	91.3
Ziziphus mucronata	162	128	34	79
Kigelia africana	35	27	8	77.1
Maesa lanceolata	34	26	8	76.5
Podocarpus falcatus	54	40	14	74.1
Acacia polyacantha	457	338	119	74
Albizia petersiana	109	79	30	72.5
Vachelia siebeliana var. woodii	442	278	164	62.9
Syzygium guineense	79	48	31	60.8
Acacia senegal	117	71	46	60.7

Markhamia obtusifolia	201	105	96	52.2
Markhamia lutea	230	116	114	50.4
Pappea capensis	488	241	247	49.4
Combretum molle	113	54	59	47.8
Combretum collinum	197	52	145	26.4
Entada abyssinica	168	38	130	22.6
Acacia brevispica	1168	154	1014	13.2
Securidaca longepedunculata	261	18	243	6.9
Ficus thonningii	438	28	410	6.4
Euclea divinorum	25	0	25	0
Galiniera saxifraga	61	0	61	0
Garcinia buchananii	616	0	616	0

Appendix 10. Average diameter and height of native tree species in Jambo-Beach sancta

Name of tree species	Average-Height (in m)	Average-Height (Cm)	Average-Diameter (in Cm)
Acacia kirkii	4.8	478.2	6.7
Trema orientalis	3.4	341.8	6.3
Celtis africana	2.4	243.3	4.2
Entada abyssinica	2.3	226.8	4.1
Ficus Sp	2.2	217.7	4.1
Ficus sur	2.1	211.7	3.7
Maesa lanceolata	2.1	208.9	3.6
Ziziphus mucronata	1.6	164	3.5
Maesopsis eminii	1.6	162.9	3.4
Prunus africana	1.6	157.5	3.3
Syzygium guineense	1.6	156.4	3.1
Markhamia obtusifolia	1.5	153	3
Acacia polyacantha	1.4	139.5	2.5
Olea europea var. africana	1.3	128.3	2.1
Albizia gummifera	1.3	127.8	2.1
Albizia petersiana	1.2	124.9	2
Kigelia africana	1.2	117.1	2
Podocarpus falcatus	0.9	94.2	1.8
Albiziza versicolor	0.8	82.7	1.6
Erythrina abyssinica	0.8	81.78	1.5
Combretum molle	0.8	81.1	1.3
Acacia brevispica	0.8	77.6	1
Strombosia schiffleri	0.7	69.4	0.9
Ficus thonningii	0.6	62.7	0.5
Pappea capensis	0.6	60.1	0.4
Combretum collinum	0.5	54	0.3
Vachelia siebeliana. var. woodii	0.5	46.8	0.3
Mimusops bagshewei	0.2	21.3	0.1

Appendix 11. Tree survival rate in Jambo-Beach sancta

Name of tree species	Planted Trees	Living trees	Dead/missing trees	Survival Rate
Acacia kirkii	118	114.00	4.00	96.6
Markhamia lutea	55	53	2.00	96.4
Kigelia africana	82.0	79.0	3.00	96.3
Trema orientalis	100.0	91.0	9.00	91
Maesa lanceolata	145.0	130.0	15.00	89.7
Ficus Sp	25.0	22.0	3.00	88
Combretum collinum	14	12.0	2.00	85.7
Acacia brevispica	1337.0	1131.00	206.00	84.6
Haplocoelum gallaense	25	21	4.00	84
Ziziphus mucronata	34.0	28.0	6.00	82.4
Syzygium guineense	155.0	116.0	39.00	74.8
Celtis africana	129.0	92.0	37.00	71.3
Entada abyssinica	94.0	65.0	29.00	69.1
Albizia gummifera	22.0	15.00	7.00	68.2
Ficus sur	410.0	233.0	177.00	56.8
Maesopsis eminii	816.0	433.0	383.00	53.1
Ficus thonningii	119.0	58.0	61.00	48.7
Erythrina abyssinica	338	160.0	178.00	47.3
Olea europea var. africana	89.0	42.0	47.00	47.2
Strombosia schiffleri	94.0	43.0	51.00	45.7
Combretum molle	46.0	21.00	25.00	45.7
Albizia petersiana	487.0	173.00	314.00	35.5
Prunus africana	1130.0	397.0	733.00	35.1
Vachelia siebeliana. var. woodii	702.0	217.0	485.00	30.9
Markhamia obtusifolia	110	33	77.00	30
Acacia polyacantha	87.0	25.00	62.00	28.7
Podocarpus falcatus	297.0	63.0	234.00	21.2
Pappea capensis	446.0	32.0	414.00	7.2
Mimusops bagshewei	540.0	29.0	511.00	5.4
Albiziza versicolor	76.0	4.0	72.00	5.3
Albizia amara	9	0	9.00	0
Garcinia buchananii	135	0	135.00	0
Galiniera saxifraga	6	0	6.00	0
Newtonia buchananii	11	0	11.00	0
Securidaca longepedunculata	80	0	80.00	0

Appendix 12. Average diameter and height of native tree species in Karushuga

Name of tree species	Average-Height (in m)	Average-Height (Cm)	Average-Diameter (in Cm)
Albizia petersiana	2.2	217.6	4
Combretum collinum	2.1	215	4
Pappea capensis	2.0	195.8	3.6
Euclea divinorum	1.7	170.5	3.2
Ziziphus mucronata	1.5	154.3	3.1
Securidaca longepedunculata	1.2	122.9	2.4
Acacia brevispica	1	104.4	1.9
Ficus thonningii	1.0	96.4	1.6
Combretum molle	0.9	94.8	1.2
Markhamia obtusifolia	0.9	85.3	1.1
Ficus sur	0.8	80.1	0.9
Maesopsis eminii	1	67.3	0.9
Entada abyssinica	0.6	63.4	0.9
Acacia polyacantha	1	62.4	0.7

Appendix 13. Tree survival rate in Karushuga

Name of tree species	Planted trees	Living Trees	Dead/Missing	Survival Rate (%)
Acacia polyacantha	1327	1302	25.0	98.1
Combretum molle	201	196.0	5.0	97.5
Pappea capensis	500	478.0	22.0	95.6
Markhamia obtusifolia	300	285.0	15.0	95
Ficus sur	644	607.0	37.0	94.3
Albizia petersiana	80	75.0	5.0	93.8
Ziziphus mucronata	201	181.0	20.0	90
Acacia brevispica	845	745.0	100.0	88.2
Combretum collinum	100	83.0	17.0	83
Euclea divinorum	218	179.0	39.0	82.1
Maesopsis eminii	986	641.0	345.0	65
Entada abyssinica	150	90.0	60.0	60
Ficus thonningii	460	180.0	280.0	39.1
Securidaca longepedunculata	1067	9.0	1058.0	0.8

Appendix 14. Average diameter and height of native tree species in Amahoro sancta

Name of tree species	Average-Height (in m)	Average-Height (Cm)	Average-Diameter (Cm)
Trema orientallis	1.3	127.1	3.4
Albizia gummifera	1.3	125	2.2
Acacia sieberiana var. kagerensis	1.1	112.1	2
Combretum molle	1.1	109	2
Maesopsis eminii	1	101.5	1.9

Ficus thoningii	1.0	100.8	1.6
Ficus sur	1	96.7	1.5
Acacia polyacantha	0.9	90.8	1.5
Aacia brevispica	0.8	78.9	1.5
Entada abyssinica	0.8	77.8	1.3
Syzygium guineense	0.7	68.7	1.2
Albizia petersiana	0.7	68.4	1.1
Ficus vallis-choudae	0.7	67.9	1
Albiziza versicolor	0.6	64	1
Podocarpus falcatus	0.5	52.4	0.9
strombosia scheffleri	0.5	52	0.9
Prunus africana	0.4	40.2	0.9
Celtis africana	0.3	34.7	0.7
Pappea capensis	0.3	32	0.7
Ziziphus mucronata	0.3	30.5	0.6
Garcinia buchananii	0.3	27.2	0.6
Securidaca longepedunculata	0.3	26	0.6
Markhamia obtusifolia	0.2	23.1	0.3
Wild coffea	0.2	20.8	0.2
Kigelia africana	0.2	15.8	0.2
Mimusops bagshawei	0.1	9.8	0.2

Appendix 15. Tree survival rate in Amahoro sancta

Name of tree species	Planted Tree	Number of living tree	Dead/Missing	Survival Rate (%)
Albizia gummifera	54	54	0	100
Combretum molle	54	54	0	100
Ficus vallis-choudae	1100	1096	4	99.6
Trema orientallis	396	394	2	99.5
Acacia sieberiana var. kagerensis	2220	2191	29	98.7
Garcinia buchananii	496	489	7	98.6
Albiziza versicolor	54	53	1	98.1
Maesopsis eminii	414	404	10	97.6
Pappea capensis	720	699	21	97.1
Ficus sur	100	97	3	97
Podocarpus falcatus	300	289	11	96.3
Acacia brevispica	1350	1300	50	96.3
Ziziphus mucronata	80	76	4	95
Acacia polyacantha	2050	1925	125	93.9
Erythrina abyssinica	150	140	10	93.3
Entada abyssinica	80	74	6	92.5
Kigelia africana	150	136	14	90.7
Albizia petersiana	1040	929	111	89.3
Markhamia obtusifolia	1910	1675	235	87.7
Ficus thonningii	240	210	30	87.5
Syzygium guineense	679	554	125	81.6

Wild coffee	170	135	35	79.4
Celtis africana	50	8	42	16
strombosia scheffleri	200	20	180	10
Prunus africana	400	33	367	8.3
Mimusops bagshawei	200	10	190	5
Securidaca longepedunculata	200	1	199	0.5

Appendix 16. Average height of 10 native tree species across six sancta

Name Tree	Jambo-Beach	Ryarubamba	Karushuga	Amahoro	Muhazi	Shungerezi
Acacia brevispica	0.8	1.7	0.9	0.8	1	0.4
Acacia polyacantha	1.4	2.5	2.1	0.9	3	1.3
Combretum molle	0.8	1.1	1	1.1	1.2	0.6
Entada abyssinica	2.3	1.2	2	0.8	1	1
Markhamia obtusifolia	1.5	0.8	1.2	0.2	1	0.3
Pappea capensis	0.6	0.5	0.6	0.3	0.6	0.4
Maesopsis eminnii	1.6	1.8	1.7	1	1	1.1
Ziziphus mucronata	1.6	1.4	0.8	0.3	1.3	0.5
Ficus sur	2.1	1.5	1.5	1	1.7	1
Ficus thonningii	0.6	1	1	1	0.8	0.5

Appendix 17. Average diameter of 10 native tree species across six sancta

Name Tree	Jambo-Beach	Ryarubamba	Karushuga	Amahoro	Muhazi	Shungerezi
Aacia brevispica	1	2.3	0.7	0.3	0.9	0.2
Acacia polyacantha	2	5.6	4	1.5	5.3	2.4
Combretum molle	0.9	2.1	1.6	1.2	2	0.5
Entada abyssinica	3.7	2.8	4	2	0.9	0.8
Markhamia obtusifolia	3	2.6	3.2	0.9	2.1	0.6
Pappea capensis	0.3	1	0.9	0.9	0.9	0.5
Maesopsis eminnii	3.3	5.3	3.6	2.2	2.3	2.3
Ziziphus mucronata	3.5	3.2	1.9	0.6	2.9	1.4
Ficus sur	4.1	5.8	3.1	2	4	1.7
Ficus thonningii	1.5	2.6	0.9	1.1	1.9	1.2

Appendix 18. Survival rate of 10 native tree species across six sancta

Name Tree	Jambo-Beach	Ryarubamba	Karushuga	Amahoro	Muhazi	Shungerezi
Aacia brevispica	84.6	99.6	88.2	98.12	13.2	69.2
Acacia polyacantha	28.7	100	98.1	93.9	74	94.3
Combretum molle	45.7	100	97.5	100	47.8	67.8
Entada abyssinica	69.1	99.7	60	92.5	22.6	47.3
Markhamia obtusifolia	30.0	92.1	95	87.7	52.2	44
Pappea capensis	7.2	79.4	95.6	97.1	49.4	66.3
Maesopsis eminnii	53.1	100	65	97.6	97.8	92.9
Ziziphus mucronata	82.4	96.1	90	95	79.0	96.7
Ficus sur	56.8	96.1	94.3	97	98.6	84.6
Ficus thonningii	48.7	95.7	39.1	87.5	6.4	81.3