

MAKERERE



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**TREE SPECIES TRAITS AND POPULATION STRUCTURE OF NATURAL
REGENERATION IN THE 66-YEAR OLD ARBORETUM AT NYABYEYA
FORESTRY COLLEGE, MASINDI DISTRICT, WESTERN UGANDA**

BY

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DECLARATION

I, **AINE NICKSON** hereby affirm that this research dissertation entitled “tree species traits and population structure of natural regeneration in the 66-year old arboretum at Nyabyeya Forestry College” is entirely my work to my effort and it has never been presented and submitted before for any degree in Makerere University or in any other academic institution for any academic reward.


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ABSTRACT

Arboreta and botanical gardens have been focused on as better opportunity to monitor and study regeneration, the establishment of young trees, under controlled conditions, shedding more light on special requirements of various trees. Forest regeneration is a critical process for maintaining biodiversity, ecosystem stability, and sustainable forestry practices. This study examined the traits and population structure of tree species undergoing natural regeneration within the 66-year-old arboretum in Masindi, western Uganda. Specifically, the study compared the stem density of regenerating plants between habitat types, successional guilds, dispersal modes, and examined the size class distribution of regenerating plants. The study utilized systematic sampling methods across the entire arboretum. 75 plots of 10×10 m were used to sample regenerating plants. Data were analyzed using linear regression models in R software. The results revealed a higher density of forest-dependent than forest nondependent species; dominant non-pioneer light-demanding species compared to pioneers and shade-tolerant species. Abiotic dispersal modes were found to significantly influence seed distribution contributing to higher stem density than biotic dispersal. There was a high seedling density indicating strong regenerative potential within the arboretum crucial for sustaining biodiversity. The study provides critical insights into effective arboreta management and tree conservation strategies contributing to broader efforts to combat Uganda's declining forest cover and biodiversity.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

In the 21st century, Uganda's forest cover area has reduced to 4.9 m ha which constitutes to 24% of the entire land (Esaete et al., 2023). 1.9 m ha are designated as a permanent forest estate for the country and the rest of the area is set aside for conservation of biodiversity, protection of the environment services and the sustainable production of the forestry products (MWE, 2016). The rest of the area set aside incorporates the arboreta and botanical gardens. These have played a role in exsitu and insitu conservation of the most threatened species (Seibert, 1956), education and awareness, scientific research, preservation of tree species, citizen science and popularization (Chen & Sun, 2018). Reduction in the forest cover is attributed to numerous threats including deforestation, land use changes and the encroachment of invasive species. Due to these threats, there has been a significant impact on the regeneration of tree species, as many of these woodland areas are no longer available for seed dispersal and germination. Rising temperatures and changing precipitation in Uganda have also altered the distribution and abundance of tree species making it more difficult for them to regenerate (Walck et al., 2011). In addition, human activities such as grazing and wood harvesting have also impacted tree species regeneration. Over grazing has reduced the availability of seedlings and increased the risk of seed predation (Mochi et al., 2022) as wood harvesting has also contributed to the removal of mature and mother trees that are a potential for seed sources for regeneration.

Following the regeneration decline in the natural and permanent forest estates, there has been a demand for monitoring in order to account for the negative effects. Addressing forest loss and promoting regeneration require a multifaceted approach that combines both proactive measures and community engagement (Verma et al., 2023). Implementing strict regulations against illegal logging and deforestation is crucial, coupled with incentives for sustainable forestry practices (Mukul et al., 2014). Additionally, community-based initiatives focusing on education and awareness can empower local residents to become stewards of their forests (Mamun & Natcher, 2023). Supporting agroforestry projects that integrate trees into agricultural landscapes promotes biodiversity while providing economic benefits to communities. Furthermore, reforestation efforts, including the strategic planting of native tree species, can accelerate the regeneration process (Elliott et al., 2023).

Arboreta and botanical gardens have been focused on as better opportunity to monitor and study regeneration under controlled conditions, shedding more light on special requirements of various trees (Xu & Zang, 2023). Extensive efforts are being made to create an environment conducive to the study of plant diversity and conservation, with interpretive signage and guided tours which have also been developed to enhance public awareness. The arboreta are being designed to serve as a hub for scientific research, with data on tree species which are systematically documented and shared with the broader research community. Moreover, partnerships with educational institutions and community outreach programs have been established, ensuring that the arboretum's objectives are met not only through academic pursuits but also by actively engaging the public in the importance of preserving and appreciating the diverse beauty of our forests (Day & Day, 2023).

Arboretums are being managed at a global level through collaborative efforts and initiatives aimed at biodiversity conservation and research (Raschke et al., 2022). International organizations, governmental bodies, and environmental agencies have played key roles in establishing and sustaining arboretums as centers for botanical research and education. Global partnerships, such as those facilitated by organizations like the International Union for Conservation of Nature (IUCN) and the United Nations Environment Programme (UNEP), have promoted the sharing of knowledge, resources, and best practices in arboretum management (Miah et al., 2023). Advances in technology have also contributed to the global management of arboretums, allowing for the exchange of data and research findings among institutions worldwide. In Uganda, NFA has promoted and protected arboreta e.g. Nyabyeya forestry college arboretum and botanical gardens e.g. the botanical gardens in Kabanyolo and Entebbe with significant efforts to embrace conservation of key species (MWE, 2016). This has been done by involving communities, creating public awareness of biodiversity and advocating policies favorable to ex situ biodiversity conservation.

Several studies that have been carried out on arboreta and botanical gardens identify priority sites and species for restoration, opportunities and constraints in the use of indigenous and endangered tree species in forest restoration (Mulugo et al., 2020), identifying tree and shrubs and exploring their diversity (Mugunga et al., 2022). An arboretum has a forest character with a typical mixed forest undergrowth (Sggw, 2009) which brings in an understanding of regeneration though it still

remains half uprooted. Regeneration more like in any other forested area has been fuel to sustainability and biodiversity conservation.

Factors that hinder regeneration of trees in a natural forest are more similar to those that affect trees in the arboretum. Some of the factors are; average annual precipitation, ecosystem complexity, species density, species richness and diversity and soil temperature (Gan et al., 2023). Succession of tree species depends on the factors outlined above. Understanding regeneration doesn't only focus on the native tree species but also the non-native species. Therefore, extra efforts are always needed to consider the newly arising species, the drivers of those plant introductions and the extent of invasiveness. Species diversity and distribution of the woody plants in the arboretum also depend on the mechanisms of dispersal (Piano et al., 2023). Free agents in the dispersal in the forests include; mammals, birds and wind (Estrada-Villegas et al., 2023). Different species are prone to different mechanisms of dispersal and this has accounted for uneven distribution of the woody communities in the forest. Characteristics of regenerating woody plant species in the arboretum compare the understory with the overstory plant structure (Chae et al., 2023). Therefore, to understand regeneration of the woody communities, there is a need for a clear analysis of the species traits (habitat preference, the successional guilds of the woody plants and the dispersal modes) that affect the population structure.

1.2 Problem statement

The reduction of Uganda's forest cover to 24% of the land raises significant concerns about the regeneration of the tree species (Opedes et al., 2023). With 1.9 m ha designated as a permanent forest estate including arboreta and botanical gardens serve critical roles in ex situ and in situ conservation (Ren & Antonelli, 2023). However, these threats such as deforestation, invasive species and human activities like grazing and wood harvesting pose substantial challenges to regeneration (Williams et al., 2023). Climate change, influencing temperature and precipitation patterns further compounds these challenges disrupting the distribution and abundance of tree species and hindering their regeneration. Overgrazing would also pose decline in seedling availability, while wood harvesting removes mature trees crucial for seed sources.

The decline in natural and permanent forest estates necessitates comprehensive monitoring and multifaceted strategies for addressing forest loss and promoting regeneration. To counteract these

issues, there is need to focus on the arboreta to address the reducing forest cover. However, the nature of the plant communities that colonize the arboreta(tree species and populations)is not clearly understood. This hinders scaling up and effective management of the arboreta as an opportunity to combating the degraded forest cover. The proposed study aims to contribute to scaling up and effective management of the arboreta as strategies for combating the woody plant communities. By comprehensively understanding these aspects, the study seeks to contribute valuable insights to the development of effective conservation strategies for sustaining biodiversity in Uganda’s forests.

1.3 Objectives of the study

1.3.1 Main objective

To contribute to scaling up and effective management of the arboreta as strategies for combating tree species loss.

1.3.2 Specific objectives

The specific objectives of the study are;

1. To determine the habitat preference of the woody plants in the arboretum.
2. To assess the successional guilds of the woody plants in the arboretum.
3. To assess the dispersal modes of the woody plants in the arboretum.
4. To examine the size class distribution of the woody plants in the arboretum

1.3.3 Hypotheses

Ho: there is no significant difference in the relative abundance between habitat preferences of the woody plants.

Ho: there is no significant difference in the relative abundance between successional guilds.

Ho: there is no significant difference in the relative abundance between the wind and animal dispersed woody plants.

1.4 Significance of the study

The study holds paramount significance in addressing the urgent conservation challenges faced by Uganda’s forest ecosystem as outlined in the introduction. By focusing on the scaling up and

effective management of the arboreta as strategies for combating tree species loss, the study aims to contribute to insights for the preservation of the country's declining forest cover. The findings promise to mitigate the threats posed by deforestation, invasive species and human interventions offering a targeted approach to ensure sustainability of both natural and permanent forest estates.

Furthermore, the research contributes to scientific advancements in the arboretum management, shedding light on habitat preferences, successional guilds, dispersal modes and size class distribution. This knowledge will inform global efforts in managing arboreta and botanical gardens for biodiversity conservation and scientific research. Additionally, the study holds potential for policy advocacy, providing evidence to support regulations against illegal logging and deforestation and promotion of sustainable practices. Lastly, the education outreach facilitated by the study will enhance public awareness about the complexities of tree species regeneration, fostering a deeper understanding of the challenges and opportunities in preserving Uganda's forest biodiversity.

1.5 Justification of the study

This study aims to assess the current status of the tree species regeneration within the arboretum by evaluating the factors such as habitat preferences, successional guilds, dispersal modes and size-class distributions. The study also seeks to identify potential areas for improvement to enhance the regenerative processes if at all they stand. This seeks to contribute to the valuable insights into effective strategies for maintaining healthy forest ecosystems and promoting biodiversity both locally and globally. With the intense knowledge from the study, potential threats to regeneration are to be identified and addressed in order to facilitate further regeneration in the arboreal ecosystems.

CHAPTER TWO: LITERATURE REVIEW

2.1 Tropical forest loss

Various drivers of tree loss are described, such as subsistence agriculture, commercial agriculture (Tom-Dery et al., 2023), commercial oil palm and other palm plantations, pasture, managed forest/forestry, roads/trails/buildings, mining and crude oil extraction, wild fire (Busch & Ferretti-Gallon, 2023), and other natural disturbances or no visible tree loss driver. Each category is detailed with distinctive features, including field size, land use, and specific examples (Laso Bayas et al., 2022). The tree loss drivers are generalized into broader categories, including agriculture/pasture (encompassing both commercial and subsistence agriculture, pasture, and commercial oil palm and other palm plantations) (He et al., 2019), managed forest/forestry (covering logging, timber plantations, managed and replanted forests, and rubber plantations), roads/trails/buildings (encompassing built-up areas, infrastructure, roads, trails, and mining and crude oil extraction), and natural disturbances (including wildfire and other natural disturbances) (Laso Bayas et al., 2022). In Ghana, a study spanning 2013 to 2020 examined the impact of logging, mining, agriculture, and wildfires on tropical forests. Using Landsat imagery and VIIRS fire data, researchers found that 3562 km² of forest reserves were disturbed—17% by fire and 83% by non-fire causes. Degradation from closed to open forests comprised 68% of disturbances, open forest loss was 28%, and closed forest loss was 4%. Over the same period, 2702 km² recovered, with 1948 km² returning to closed-canopy forests Boamah (2020). Fire disturbances correlated with drought, while non-fire disturbances showed weaker precipitation connections. Closed forest disturbances occurred where cover was already low, while open forest disturbances were common in areas with moderate population pressure and proximity to non-forest land. The study suggests Ghana's forest disturbance involves a multi-stage process, emphasizing the importance of targeted conservation and restoration efforts in identified high-risk locations (Wanyama et al., 2023).

Various drivers contribute to LULCC in tropical forests (Asif et al., 2023), including large-scale agriculture, livestock activities, and socio-economic factors such as poverty. Topographical and distance-related measures are identified as significant factors influencing the likelihood of LULCC. Shifting cultivation emerges as a major driver in Mexico's TDFs (Gao et al., 2023),

particularly in the southern region, where cycles of clearing, cultivation, and fallow periods are practiced. Shifting cultivation creates a mosaic landscape of cropped and fallow patches, impacting biomass density (Gao et al., 2023). 27% of global forest loss is attributable to permanent deforestation for commodity production. The remaining areas experiencing loss maintained the same land use over 15 years i.e. 2001 to 2015, with forestry (26%), shifting agriculture (24%), and wildfire (23%) identified as significant contributors. Despite corporate commitments, the rate of commodity-driven deforestation has not decreased (Lyons et al., 2019).

2.2 The importance of arboreta in forest conservation

Botanical gardens and arboreta play a crucial role as conservation centers, serving as effective strategies for safeguarding forest resources (Diribsa & Scholar, 2024). These institutions are instrumental in environmental education, research, and botanical knowledge training at various levels. They are particularly valuable when preserving forest areas within agricultural or urban landscapes (Rinaldi, 2023), botanical gardens and arboreta function as habitats and corridors, aiding in the conservation of flora and fauna (Esparza Olguín et al., 2020).

Trees serve as the foundation of numerous terrestrial ecosystems, playing a vital role in offering essential benefits to both humanity and the planet (Rivers et al., 2023). This distinct life form necessitates specific expertise in horticulture, management, and conservation to foster its growth and flourishing. In response to these needs, ArbNet a global and interactive community of arboreta, was established in 2011. The primary objectives of ArbNet include identifying arboreta, establishing industry standards, elevating professionalism, supporting tree planting and proper care, fostering collaborations, and advancing tree research and conservation. ArbNet has played a pivotal role in the establishment, growth, and networking of arboreta worldwide, creating awareness about the crucial significance of trees (WD Blanchard, 2023). These opportunities aim to further fortify the global network of arboreta and professionals dedicated to trees, ensuring the health and sustainability of trees for the well-being of future generations and the planet at large (Turner-Skoff et al., 2022). The predominant form of Forest Genetic Resource conservation in Serbia is in situ, which is mainly applied through the establishment of seed stands, but different types of ex situ conservation are also applied, through seed orchards, progeny tests, and provenance trials. An important gene pool is kept in the arboreta and botanical gardens (Nonic & Milovanovic, 2020).

2.3 Natural regeneration

Natural regeneration is the process by which juvenile plants and coppice that have established naturally replace plants which have died or have been killed. Over time, following a disturbance, the growth of natural regeneration will reestablish canopy trees. This natural recovery process can be exploited in tropical forest management systems to create a new stand (Brown, 2004). Natural regeneration is the establishment of young trees through natural seeding, sprouting, suckering, or layering (Ribeiro et al., 2022). Under suitable conditions, natural regeneration (secondary succession) of tropical forests occurs on its own (Rosenfield et al., 2023), following ecological processes of species colonization and community assembly. Forest regrowth begins with the spontaneous reestablishment of plant and animal species following disturbances (Guariguata, 2016).

2.3.1 Role in forest sustainability

The self-organizing processes that create naturally regenerating forests and natural regeneration in planted forests promote local genetic adaptation, foster native species with known traditional uses, create spatial and temporal heterogeneity, and sustain local biodiversity and biotic interactions (Guariguata, 2016). Natural regeneration is best viewed as a gradual process of recovery of the structure, function, and composition of the pre-disturbance ecosystem (Hong et al., 2024). Changes in vegetation are accompanied by changes in soil microbes and fauna (Dong et al., 2023). In tropical regions, insects and vertebrates play critically important roles in pollination, seed dispersal, and other biotic interactions affecting dynamics of plant populations (Guariguata, 2016). Natural regeneration plays an essential role in achieving the ambitious goals that motivate global restoration initiatives as an approach to forest restoration that aims to regain ecological integrity and enhance human wellbeing in deforested or degraded forest landscapes (Chazdon & Uriarte, 2016).

2.3.2 Sources of natural regeneration

Natural regeneration is defined as the renewal of a forest crop by self-sown seeds or by coppice or root suckers (Hoffman, 2020). Natural regeneration may thus be obtained from the following two sources. Natural regeneration of forests is a critical process for maintaining biodiversity, ecosystem stability, and sustainable forestry practices (Ssekuubwa et al., 2023). This process can

be categorized into two primary sources: regeneration from seed and regeneration from vegetative parts.

Regeneration from seed, also known as 'high forest' or 'seedling crop,' represents the sexual method of forest renewal (Calama et al., 2017). This method relies on the natural dispersal and germination of seeds, resulting in new plant individuals with genetic diversity from both parent trees (Fischer et al., 2015). Seeds are dispersed by wind, animals, water, or gravity. Each dispersal mechanism affects the distribution and density of seedlings (Jongejans et al., 2015). For example, wind-dispersed seeds may cover large areas but in lower densities, while animal-dispersed seeds are more likely to cluster around the parent tree (Hruska et al., 2014). Once seeds reach a suitable site, germination is influenced by factors such as soil conditions, moisture, temperature, and light availability (Rao et al., 2017). The success of seedling establishment is critical for the development of a new forest cohort (Gondo & Mbaiwa, 2022). Seedling crops benefit from genetic variation, which can enhance resilience to pests, diseases, and environmental changes (Tepley et al., 2014). High genetic diversity in seedling populations is associated with greater adaptability and stability of forest ecosystems (Cavers, 2015).

Regeneration from vegetative parts is an asexual method, where new plants arise from parts of the parent plant, such as roots, stems, or coppice shoots (Stuepp et al., 2018). The same author noted that this process ensures that the new individuals are genetically identical to the parent plant.

Coppicing involves periodically cutting trees down to ground level to encourage the growth of multiple new shoots (Loushambamet al. (2021). This method is commonly used in traditional woodland management and is beneficial for species that have evolved to regenerate through coppice shoots (Nimpa et al., 2017). Coppice forests are managed to produce a continuous supply of wood while maintaining the ecological integrity of the forest (Mairota et al., 2016).

Some tree species regenerate through root suckers, where new shoots emerge from the root system of a mature tree. This method is particularly common in species adapted to disturbed or stressed environments (Mostacedo et al., 2009).

2.3.3 Factors influencing natural regeneration

Regeneration, encompassing processes from flowering to seedling establishment, is influenced by various factors (Landhäusser et al., 2007). Seed production, a crucial aspect, is affected by tree resources, genetics, hormones, and social position within the stand (Zwolak, 2018). Resource allocation for growth and reproduction results in internal variability in seed production, with higher availability leading to increased flowering and fruit yield (Hulshof et al., 2012). Pollen quantity is influenced by factors such as phenological synchrony, weather, and genetic regulation, impacting fruit production (Bogdziewicz et al., 2020).

Genetics also play a role in fruit development, with tree social position affecting crown dimension and light availability (Bacelar et al., 2024). Trees in the upper canopy layers tend to have higher seed yields. Regeneration often correlates with masting years, characterized by abundant seed/fruit production (Gonçalves & Fonseca, 2023). However, Masting frequency varies among species (Kelly et al., 2016). Seed/fruit production is further influenced by factors like fungi, invertebrates, predation, and weather Prado (2012). Losses due to these factors can reduce the amount of available seed or affect germination capacity.

Natural regeneration involves seed dispersal, influenced by seed traits, predation, and weather conditions. Fauna can act as predators or disseminators, impacting seed dispersal distances (Kim et al., 2022). Seed predation is more pronounced in low-production years, affecting regeneration success. Serotinity, observed in some species, ties seed release to specific triggers like fire or high temperatures (Llanos-Guerrero et al., 2024). Seed germination depends on species traits, predation, seed banks, and environmental conditions. Site suitability, seedbed conditions, and germination rates are critical (Gardarin et al., 2012).

Seedling survival is influenced by browsing, site conditions, soil fungi, and plantation stress. Browsing can alter seedling growth patterns, with species-specific responses to browsing pressure (Ameztegui & Coll, 2015). Frosts, droughts, and fires can impact seedlings, with some species exhibiting adaptation mechanisms like sprouting. Fungal communities in the soil can have varied effects on seedlings (Keeley & Pausas, 2022). Seedling establishment depends on environmental, biological, and silvicultural factors. Shade tolerance, crown cover, and silvicultural systems play crucial roles. Spontaneous vegetation can either compete with or

facilitate regeneration. Tree age influences seed production and seedling characteristics, contributing to forest system sustainability (Gonçalves & Fonseca, 2023).

2.4 Sources of propagules

2.4.1 Soil

Soil serves as a vital reservoir for plant regeneration, primarily through soil seed banks. Soil seed banks consist of viable seeds that are stored within the soil, often for extended periods (Anju et al., 2022). These seeds can remain dormant until conditions are favorable for germination (Penfield, 2017). Soil seed banks are critical for the persistence of plant species, particularly in environments that experience disturbances such as fires, floods, or human activities (Walck et al., 2011). Among the different types of seed banks, short-term persistent and long-term persistent soil seed banks often store the most germinable species. These seeds contribute to the resilience and recovery of plant communities by providing a ready source of new plants when conditions are optimal for germination and growth (Borsali et al., 2017).

2.4.2 Leaf Litter

Leaf litter, composed of fallen leaves, twigs, and other organic matter, also plays a crucial role in the regeneration of woody species (Giweta, 2020). It acts as a protective layer that retains moisture and moderates soil temperature, creating a favorable microenvironment for seed germination (Tan et al., 2021). Additionally, leaf litter stores germinable propagules such as seeds and spores that are essential for the regeneration of woody vegetation (Kingra & Kaur, 2017).

2.4.3 Animal scats

Animal scats, or faeces, are another significant source of propagules, particularly through the process of endozoochory, where seeds are dispersed by animals after passing through their digestive systems (Lepková, 2023). Many native animals, including birds, mammals, and reptiles, consume fruits and other plant materials containing seeds (Corlett, 2017). These seeds often remain viable after digestion and are deposited in new locations through the animals' scats (Corlett, 2017). This method of seed dispersal plays a crucial role in maintaining plant diversity and facilitating the spread of plant species across different landscapes. In ecosystems where animal activity is prevalent, scats can be a primary means of seed dispersal, aiding in the regeneration and expansion of plant populations (Zivec et al., 2023).

2.4.4 Hydrochory

Hydrochory is a method of seed dispersal that involves the transportation of seeds through water (Hyslop & Trowsdale, 2012). This process is particularly common in plants that inhabit riparian areas, wetlands, or other aquatic environments (Tolkkinen et al., 2020). Seeds dispersed by water can travel significant distances from their parent plants, often landing in new, suitable habitats where they can germinate and establish. Hydrochory is a vital mechanism for the regeneration of plant species in aquatic and semi-aquatic ecosystems, allowing plants to colonize new areas, maintain genetic diversity, and adapt to changing environmental conditions. This dispersal method is especially important for species that rely on water as a medium to overcome barriers such as dry land or inhospitable terrain, ensuring their survival and propagation in dynamic ecosystems (Flores-Galicia & Trejo, 2023)

2.5 Microclimate

The microclimate of a particular location can be defined as the distinctive climate of a small-scale area (Met Office, 2019). Microclimate is the suite of climatic conditions measured in localized areas near the earth's surface. These environmental variables, which include temperature, light, wind speed, and moisture, have been critical throughout human history, providing meaningful indicators for habitat selection and other activities (Coutts et al., 2013). Several studies have emphasized microclimate as a determinant of ecological patterns in both plant and animal communities and a driver of such processes as the growth and mortality of organisms (Kempainen et al., 2024). The importance of microclimate in influencing ecological processes such as plant regeneration and growth, soil respiration, nutrient cycling, and wildlife habitat selection has become an essential component of current ecological research *Erika Marín-Spiotta* (2019).

Forest disturbances alter microclimatic conditions, particularly increasing light availability in gaps as well as local temperatures during the growing season while reducing humidity (De Frenne et al., 2021). Alterations of understory microclimate caused by canopy openings are most pronounced close to the forest floor. Thus, seedlings are particularly exposed to changing microclimatic conditions (Valladares et al., 2016). In addition, as the roots of seedlings are short and their storage capacity is low, they are more sensitive to drought conditions than canopy trees

(Markesteijn & Poorter, 2009). Hence, as climate change intensifies and changing disturbance regimes increasingly reduce the microclimatic buffering capacity of the forest canopy (i.e., the capacity to dampen fluctuations in temperature and air humidity, regeneration success (i.e., the density and diversity of tree regeneration) could be threatened. Regeneration failure constitutes a great challenge to forestry as regime shifts (e.g., from forest to shrub land) or the loss of important tree species likely have negative consequences for ecosystem services and biodiversity (Zellweger et al., 2020). In contrast, canopy disturbances can be important drivers of tree regeneration by increasing the availability of light for photosynthesis and by reducing competition for water between overstory and understory trees (Balandier et al., 2022). In particular, medium-sized gaps created by disturbance increase the heterogeneity in conditions close to the forest floor, favoring diversity in tree regeneration (Thom et al., 2023).

2.6 Edaphic conditions

Edaphic factors which include soil chemistry, soil texture and topography have strong and deterministic effects on community composition. Availability of different levels of soil resources can filter out species as communities assemble throughout succession, creating predictable changes in forest composition. The direction and magnitude of the effects of edaphic factors depend on how sites differ in soil chemistry. Topography is also expected to have a predictable effect in structuring forests undergoing succession. In old growth forests, topography affects soil formation, soil water content and nutrient concentration which in turn determine the abundance of regenerating species. Therefore, both soil nutrients and topography can affect the structure and trajectories of successional communities (Villegas et al., 2020). Tree species may have different edaphic requirements. Tree species occurrence has been predicted with individual soil nutrients, while other studies show that complex edaphic requirements explain habitat associations.

2.7 Tree species traits

2.7.1 Relevance in biodiversity conservation

Plant functional traits are described as attributes of individual plants that impact fitness through carbon, water and nutrient uptake as well as defence, stress tolerance, growth and reproduction (Cavender-Bares et al., 2022). The significance of biodiversity research is to understand the structure and function of the community, and then to protect and monitor the community. The metric of biodiversity is the base of biodiversity conservation (Magurran et al., 2010). Species

traits have much to offer in conservation science because the trait data is used in describing different conservation strategies globally. Traits can influence the performance of populations, communities, and ecosystems processes such as pollination, seed dispersal (Gallagher et al., 2021). Tree species traits describe distribution, germination, establishment, reproduction and survival as acknowledged by different traits both categorical and continuous (Ssekuubwa et al., 2023).

2.7.2 Population structure

Population structure also known as the age structure is essential in conveying the regeneration status of a forest. Population structures characterized by the presence of a sufficient population of seedlings, saplings and young trees indicate a successful regeneration of tree species (Borsali et al., 2017).

Significance of population structure to forest conservation

A diverse age structure shows a healthy forest ecosystem. It indicates that tree species are successfully regenerating, which is critical for maintaining forest cover and biodiversity (Kuuluvainen & Gauthier, 2018). The same authors further noted that a forest lacking younger age classes may be at risk of decline, making conservation efforts necessary to promote regeneration. Different age classes support various species of flora and fauna. For instance, older trees provide habitats for certain bird species, while younger trees support different insect populations.

Protecting forests with a balanced age structure helps preserve overall biodiversity Lindenmayer (2017). Forests with a mix of ages are more resilient to disturbances, such as pests, diseases, or extreme weather events (Bryant et al., 2019). A diverse population can recover more effectively, as some species or age classes may be better suited to withstand changes CBD (2009). Understanding the age structure also helps in the sustainable management of forest resources. It allows for better planning of logging activities, ensuring that not too many mature trees are removed at once, which could disrupt regeneration (Savari et al., 2020). Sustainable practices help ensure that forests continue to provide resources for future generations (J. Parrotta et al., 2016). Forests provide essential services like carbon sequestration, water filtration, and soil protection. A healthy age distribution maximizes these services, supporting climate change mitigation and adaptation efforts (Ebi et al., 2020).

Significance of population structure to wildlife

Different age classes of trees provide varying habitats and resources for wildlife for instance, older trees often have more cavities suitable for birds and mammals, while younger trees may provide browse for herbivores (Banks et al., 2013). Maintaining a diverse age structure ensures that a range of habitats is available for different wildlife species (Hixon et al., 2014). Forests with a healthy age structure also offer diverse food sources year-round. This was explained by (Powell et al., 2013) who noted that Seedlings and saplings support herbivores, while mature trees produce fruits and nuts crucial for different species.

Population structure affects species assemblages and interactions within a forest. For example, certain bird species prefer nesting in mature trees, while others might prefer younger growth for foraging (Basile et al., 2021). The presence of multiple age classes can support a greater diversity of wildlife, promoting intricate ecological interactions (Stein et al., 2014). Wildlife plays a critical role in forest regeneration processes (J. A. Parrotta et al., 1997). Seed dispersers, such as birds and small mammals, often depend on the presence of diverse tree ages to find food and shelter (Garcia et al., 2010). An age-structured forest facilitates these interactions, thereby enhancing natural regeneration and maintaining forest health (Forget et al., 2005).

CHAPTER THREE: STUDY AREA AND METHODS

3.1 Study area

The study was conducted in Nyabyeya Forestry College arboretum which is located in western Uganda, Masindi district, Bujenje County, Budongo. It covers an area of 0.06 Km². It is situated nearby to the villages Kyempunu, Nyabyeya 1 and Maramu. The forest lies between the coordinates 1° 40' 28" north and 31° 32' 11" east. It is located about 500 meters away from the bigger Budongo Central Forest Reserve. It is a semi deciduous mixed forest with diverse vegetation types.

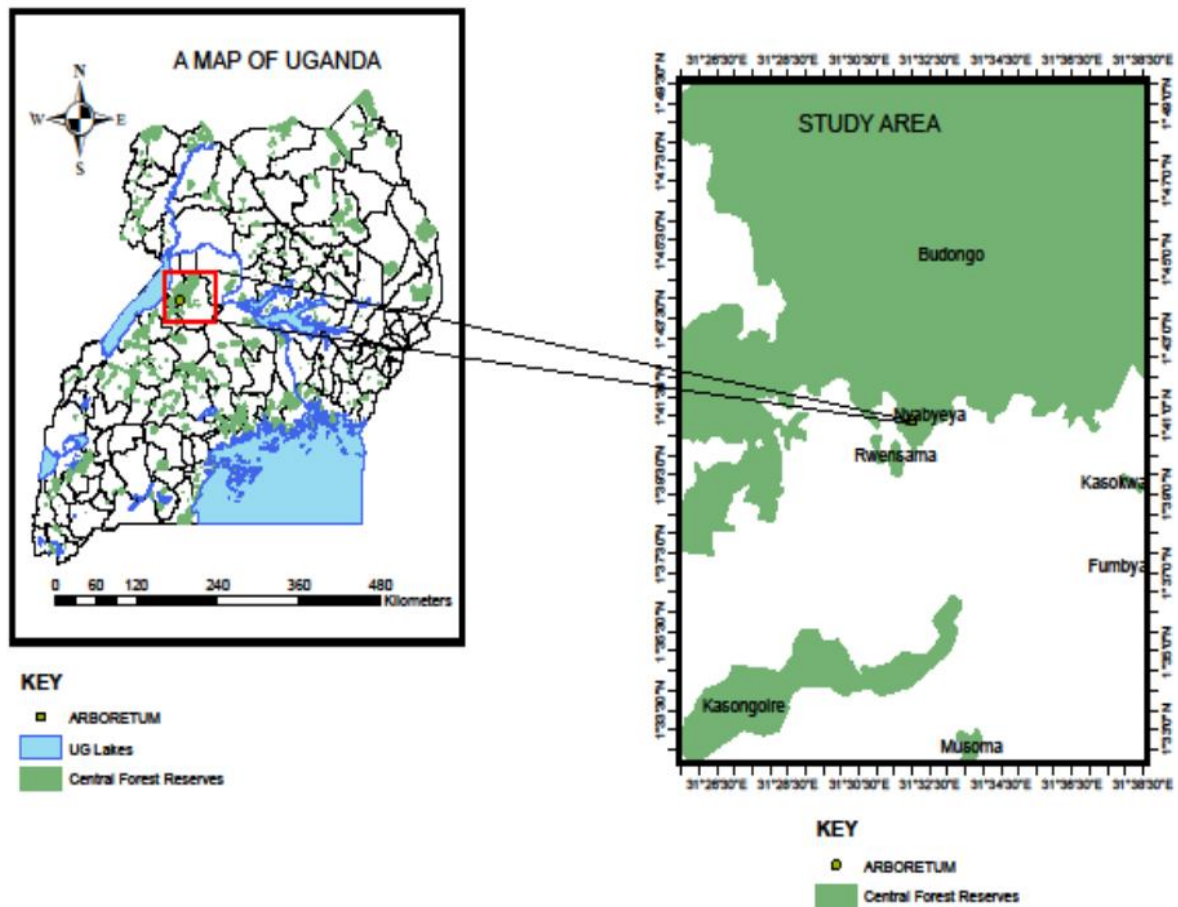


Figure 1: Location of Nyabyeya Forestry College in western Uganda.



Figure 2: The different parts of the arboretum at Nyabyeya Forestry College, Masindi district.

3.2 Sampling design

A systematic sampling procedure was used to collect the data on vegetation characteristics; habitat preference, successional guilds, dispersal modes and size class distribution. Parallel transects that were separated from each other at an equal interval of 10 m were systematically laid to run across the arboretum. The first transect was established 15m away from the road line and the rest ran at equidistant intervals. Within every transect, main plots of 100 m² for the mature tree characteristics were laid systematically at every interval of 15 m starting from the edge of the arboretum. Sub plots of sizes 25 m² and 1 m² to study understory characteristics were embedded within the main plots.

3.3 Vegetation assessments

Vegetation data collection was carried out using similar plots/transects as established. Trees of dbh \geq 10cm were enumerated in plots of 100m², diameter were recorded at breast height. Sprouts, coppices or multi-stemmed individuals of these trees were also counted as separate individuals if the branching was below 1.3 m from the ground. The dbh of each tree was measured at 1.3 m above the ground using a tree caliper and a diameter tape. Saplings were enumerated in plots of 25 m² and recorded. Tree seedlings were also enumerated in the 1 m² plots and also recorded.

3.4 Species traits

Four categorical traits were studied (i.e. habitat preference, dispersal mode, successional guilds, and size class distribution). Habitat preference was used because it shows optimum species distribution in relation to environmental gradients. Dispersal mode was also used because it influences a species ability to reach suitable sites for germination. Successional guilds also determine the species ability to establish and grow in a particular site (Ssekuubwa et al., 2023).

Table 1: Description of the tree species traits in the arboretum at Nyabyeya Forestry College.

Traits	States	Description
Habitat	Open habitat	Occurs in woodland, grassland, rocky places, bush/thickets or swamp
	Forest-dependent	occurs in forest interior, edge, and/or riverine forest
	Forest non-dependent	Occurs in at least one of the open habitats and at least one of the forested habitats
Dispersal	Biotic	dispersed by animals such as birds and mammals
	Abiotic	Dispersed by wind or other abiotic vector
Successional group	Pioneer	Unable to establish in closed forest shade
	Non-pioneer light demander	Seedlings are present in the understory but require higher light environments to reach adult size
	Shade-tolerant	Able to establish in closed forest shade
	Swamp species	Able to survive and grow in waterlogged soils.

3.5 Data analysis

Statistical analysis was done using R software version 3.3.2 for Windows (R Core Team 2016). Mean values were computed for stem density (stems/ha) of the different habitat preferences, successional guilds, dispersal modes as well as different tree sizes (seedlings, saplings and trees). Linear regression models were also used to test for mean difference in the stem density between habitat types (i.e. forest-dependent, forest nondependent and open habitat), successional guilds (pioneer, non-pioneer light demander, shade-tolerant species) and dispersal modes (abiotic, biotic). To examine the size class distribution, linear regression models were also used to test for mean difference in the stem density between seedlings, saplings and trees. For all analyses,

Tukeys HSD was used to separate means where differences were significant. All models were checked for normality, independence and homogeneity assumptions of linear regression(Crawley, 2013). Values were considered statistically significant when $p < 0.05$. Interval plots were used to visualize mean values of stem density of habitat preferences, successional guilds, dispersal modes as well as different tree sizes (Crawley, 2013).

CHAPTER FOUR: RESULTS

4.1 Tree species in the arboretum

The dataset revealed a diverse array of tree species, each with varying levels of abundance. *Cedrela odorata* was the most abundant species with a significant count of 366 individuals, indicating its successful establishment and dominance within the arboretum. *Canthium vulgare* and *Senna spectabilis* also had a high number of individuals, 98 and 93 species respectively. Lesser abundant species included *Albizia glaberrimes* (1 individual) and *Antidesma membranaceae* (1 individual), indicating that these species were either rare or have not been established as successfully as others. The other species in the arboretum are also indicated as shown in the table below.

Table 2: Tree species in Nyabyeya Forestry College arboretum, Masindi district.

Tree species	Number	Tree species	Number
<i>Acalypha spp</i>	8	<i>Glyphaea brevis</i>	6
<i>Albizia glaberrimes</i>	1	<i>Guarea cedrata</i>	1
<i>Albizia zygia</i>	16	<i>Khaya anthotheca</i>	19
<i>Alchornea laxiflora</i>	11	<i>Lannea welwitschii</i>	1
<i>Allophylus dummeri</i>	2	<i>Lovoa trichilioides</i>	9
<i>Alstonia boonei</i>	4	<i>Lychnodiscus cerospermus</i>	2
<i>Aningeria altissima</i>	21	<i>Maesopsis eminii</i>	11
<i>Annona senegalensis</i>	3	<i>Mangifera indica</i>	7
<i>Antiaris toxicaria</i>	47	<i>Markhamia platycalyx</i>	6
<i>Antidesma membranaceae</i>	1	<i>Mildbraediodendron excelsum</i>	7
<i>Araucaria columnaris</i>	3	<i>Milletia spp</i>	1
<i>Araucaria spp</i>	2	<i>Mitragyna stipulosa</i>	4
<i>Argomuelleria macrophylla</i>	13	<i>Monodora angolensis</i>	5
<i>Morus lactea</i>	15		
<i>Artocarpus heterophyllus</i>	7	<i>Pachystela brevipes</i>	3
<i>Balanites aegyptiaca</i>	5	<i>Parkia filicoidea</i>	1
<i>Blighia unijugata</i>	38	<i>Psidium guajava</i>	5
<i>Bridelia brideliifolia</i>	12	<i>Pycnanthus angolensis</i>	2
<i>Broussonetia papyrifera</i>	32	<i>Scolopia spp</i>	1
<i>Caloncoba schweinfurthii</i>	5	<i>Senna spectabilis</i>	93
<i>Canarium schweinfurthii</i>	11	<i>Spathodea campanulata</i>	5
<i>Canthium vulgare</i>	98	<i>Stereospermum kunthianum</i>	1
<i>Cedrela odorata</i>	366	<i>Syzygium guineense</i>	26

<i>Chaetachme aristata</i>	1	<i>Tabernaemontana holstii</i>	3
<i>Coffea canephora</i>	9	<i>Teclea nobilis</i>	2
<i>Cola gigantea</i>	62	<i>Teclea noblis</i>	2
<i>Combretum collinum</i>	4	<i>Terminalia brownii</i>	28
<i>Combretum spp</i>	1	<i>Trichilia prieuriana</i>	5
<i>Cordia millenii</i>	7	<i>Vitex doniana</i>	1
<i>Craterispermum schweinfurthii</i>	12	<i>Ficus asperifolia</i>	58
<i>Croton macrostbachus</i>	1	<i>Ficus exasperata</i>	21
<i>Croton megalocarpus</i>	2	<i>Ficus nantalensis</i>	1
<i>Diopyros abyssinica</i>	3	<i>Ficus sur</i>	1
<i>Dombeya mukole</i>	5	<i>Funtumia africana</i>	13
<i>Erythroypleum suaveolens</i>	3	<i>Funtumia elastica</i>	14
<i>Fagaropsis angolensis</i>	6	<i>Funtumia exasperata</i>	1
Grand Total	1203		

4.2 Habitat preference of the woody plants in the arboretum

An interval plot was used to show the descriptive statistics describing the different habitat preferences namely; open habitat, forest and forest non-dependent habitats. It was observed that the relative abundance of woody plants as measured using the stem density (stem/ha) was highest in forest-dependent species (70 stems/ha) followed by forest non-dependent species (60 stems/ha) whereas open habitat species (5 stems/ha) had the lowest density of woody plants (Fig.3, Table 3). However, the stem density of forest non-dependent species was not significantly different from that of forest dependent species (Fig.3, Table 3). Tukeys HSD showed that the forest non-dependent species had higher stem density than open habitat species ($Z = 4.391$, $SE = 0.57$, $p < 0.001$).

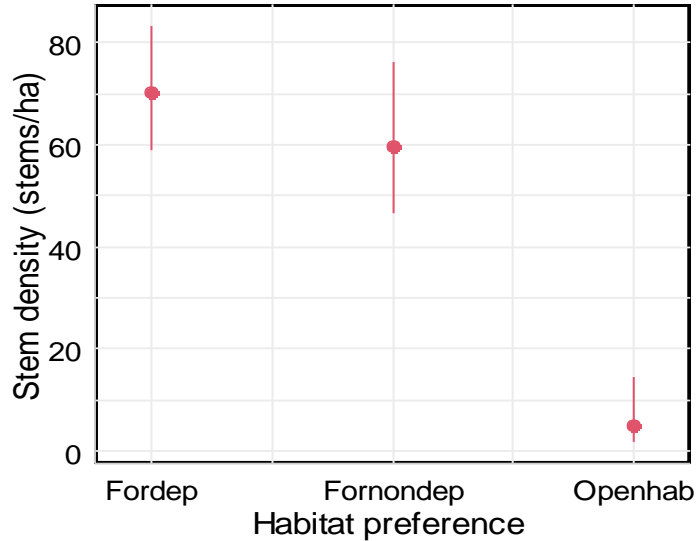


Figure 3: Interval plot showing descriptive statistics for relative abundance in different habitat types; forest dependent (Fordep), forest nondependent (Fornondep) and open habitat (Openhab).

Table 3: Linear regression model for the variation of stem density across different habitat preferences. forest dependent (Fordep), forest nondependent (Fornondep) and open habitat (Openhab).

Coefficients	Estimate	SE	z value	Pr(> z)
Intercept	4.25	0.09	48.034	<0.001
Habitat (Forest non-dependent vs Forest dependent)	-0.16	0.15	-1.058	0.290
Habitat (Openhabitat vs Forest dependent)	-2.68	0.57	-4.735	< 0.001

4.3 Successional guilds of the woody plants in the arboretum.

The interval plot was used to show stem density for pioneer, non-pioneer demander and shade-tolerant succession guilds (Fig. 4). It was observed that the average stem density was highest in the non-pioneer demander species followed by the shade-tolerant category (Fig.4, Table 4). There was no significant difference in the stem density of shade-tolerant species and pioneers ($Z = -0.706$, $SE = 0.23$, $p = 0.480$); shade-tolerant species and swamp species ($Z = -0.096$, $SE = 1.23$, $p = 0.924$); pioneer species and swamp species ($Z = 0.034$, $SE = 1.22$, $p = 0.9725$; Fig.4).

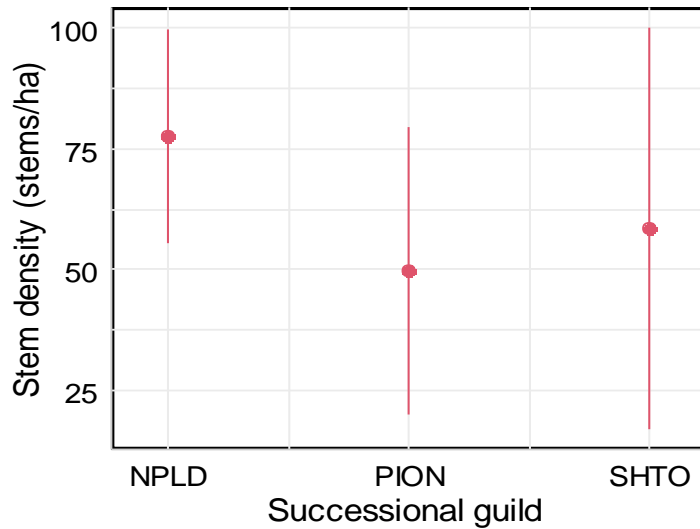


Figure 4: Interval plot showing descriptive statistics for stem density of different successional guilds; non-pioneer light demanders (NPLD), pioneer species (PION), shade tolerant species (SHTO).

Table 4: Linear regression model for the variation of stem density across succession guilds. Non-pioneer light demanders (NPLD), pioneer species (PION), shade tolerant species (SHTO).

Coefficients	Estimate	SE	z value	Pr(> z)
(Intercept)	4.35	0.01	669.310	< 0.001
Guild (PION-NPLD)	-0.44	0.01	-34.682	< 0.001
Guild (SHTO-NPLD)	-0.28	0.02	-18.105	< 0.001
Guild (SWSP-NPLD)	-0.40	0.10	-4.048	< 0.001

4.4 Dispersal modes of the woody plants in the arboretum

An interval plot was used to determine the descriptive statistics of stem density in dispersal modes of biotic and abiotic categories. The abiotic mode of dispersal had a higher mean stem density of 80 stems/ha compared to 52 stems/ha of biotic modes of dispersal (Fig. 5, Table 5).

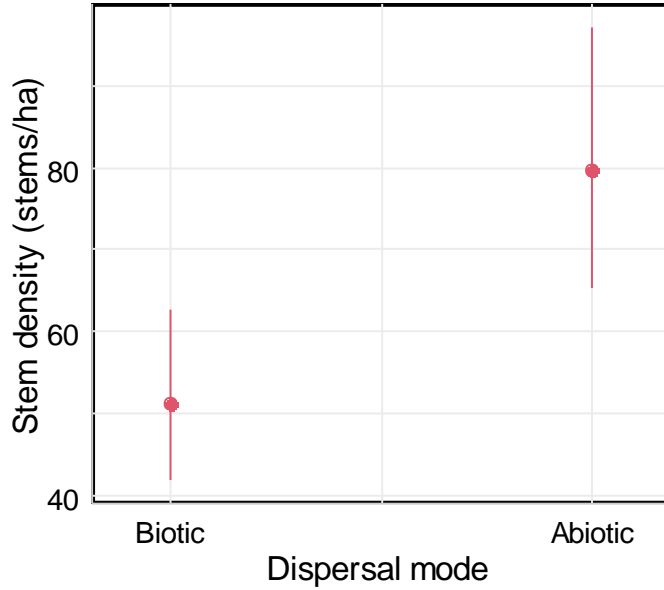


Figure 5: Interval plot showing stem density in biotic and abiotic dispersal modes.

Table 5: Linear regression model for the variation of stem density between biotic and abiotic dispersal categories.

Coefficients:	Estimate	SE	z value	Pr(> z)
Intercept	4.378	0.007	663.32	< 0.001
Dispersal mode (Biotic-Abiotic)	-0.444	0.011	-41.62	< 0.001

4.5 Size class distribution of the woody plants in the arboretum

The size class distribution of woody species was assessed by evaluating the stem density of seedlings, saplings and trees. An interval plot was used to determine the descriptive statistics of these three classes. It was observed that the stem density of seedlings was significantly higher with an average of 300 stems per hectare. This value was far higher than the stem density values of saplings and trees which were 10 and 5 stems /ha respectively. The high density of seedlings signifies the high potential of the arboretum to support regeneration and therefore sustainability and conservation (Fig.6, Table 6).

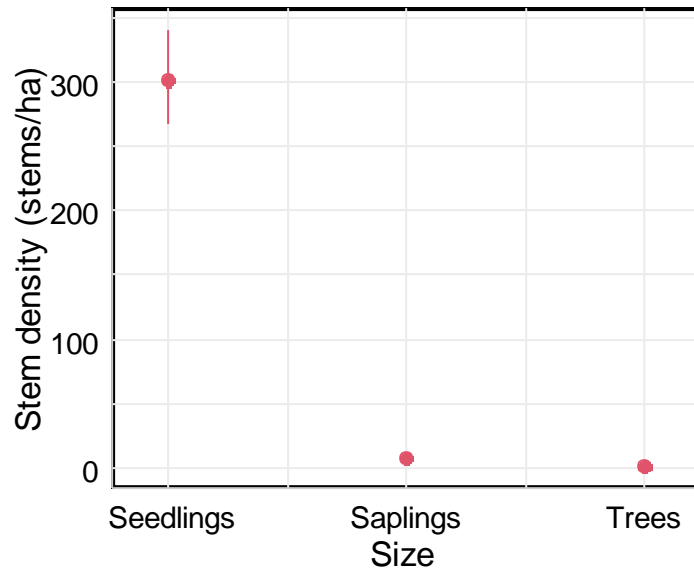


Figure 6: Interval plot of size class distribution of woody plants

Table 6: Linear regression model for the variation of stem density between different tree sizes.

Coefficients	Estimate	SE	z value	Pr(> z)
Intercept	2.06	0.02	105.58	< 0.001
Size (Seedlings- Saplings)	3.65	0.02	179.74	< 0.001
Size (Tree- Saplings)	-1.54	0.07	-21.19	< 0.001

CHAPTER FIVE: DISCUSSION

5.1 Assessment of habitat preference of the woody plants in the arboretum

The study revealed that woody plants in the arboretum exhibited distinct habitat preferences, with the highest relative abundance (as indicated by stem density) observed in forest-dependent species, followed by forest non-dependent species, and the lowest in open habitat species. This pattern aligns with ecological theories and previous studies on woody plant distribution, offering insights into the factors influencing these preferences. The dominance of woody plants in forest-dependent habitats can be attributed to the favourable microclimatic conditions provided by the forest environment (Rembold et al., 2017). Another study by De Frenne et al. (2021) also indicates that forest-dependent habitats offer shade, moisture retention, and protection from wind, all of which are conducive to the growth and survival of many forest species. The canopy cover in these areas reduces the competition from herbaceous plants, which might otherwise dominate in more open environments. The lower stem density of forest nondependent species and open habitat species suggests that the arboretum has attained typical characteristics of a forest interior environment (e.g. dense canopy, microclimate) that potentially do not favour these species (Ssekuubwa et al., 2023).

5.2 Assessment of successional guilds of the woody plants in the arboretum.

The analysis showed that the non-pioneer light demanders (NPLD) guild had the highest average stem density among the successional guilds. The high density of NPLD species indicates their dominance in the arboretum, suggesting that the environment favoured species that thrive in stable, well-lit conditions. According to Luambua et al. (2021), this group is often composed of species that establish themselves after the pioneer species have created a more hospitable environment, making them crucial for the long-term stability and diversity of the ecosystem. Shade-tolerant species (SHTO) followed NPLD in terms of stem density, reflecting their ability to persist under canopy cover and lower light conditions. However, these species are typically found in more mature forest stages, where they play a critical role in maintaining forest structure and biodiversity (Avalos, 2019). Their presence in significant numbers suggests that the arboretum is progressing towards a more mature successional stage. Pioneer species (PION) were observed to have a low average stem density as compared to light demanders and shade-tolerant

species. This lower density is consistent with the typical lifecycle of pioneer species, which are usually the first to colonize disturbed or open areas but are gradually outcompeted by more shade-tolerant and light-demanding species as the ecosystem matures. The low density of PION species suggested that the arboretum has moved beyond the early successional stages, where pioneers are dominant. The swampy species (SWSP) guild also exhibited lower stem density, which could be due to the specific microhabitat requirements of these species. Their distribution is likely confined to certain wet areas within the arboretum, limiting their overall density compared to the other guilds. The relatively lower densities of pioneer and swampy species indicate that the arboretum is moving away from early successional stages and that wetland-specific habitats may be limited.

5.3 Dispersal modes of the woody plants in the arboretum

The mean stem density of abiotic dispersal modes is significantly higher than that of biotic dispersal. This difference suggests that abiotic dispersal mechanisms, such as wind or water, might be more effective in distributing and establishing seedlings across the arboretum (Piano et al., 2023). Indeed, field observations revealed that the middle stratum was relatively more open which could promote abiotic dispersal. Arboretum is surrounded by human settlements and a tree nursery so human activities could limit biotic dispersal (Kim et al. (2022) which could also explain the predominance of abiotic dispersal. The larger interquartile range in abiotic dispersal areas indicates greater variability in stem density. This could be because abiotic dispersal mechanisms are less selective compared to biotic ones. Abiotic factors like wind can scatter seeds over a wider range of conditions, leading to more heterogeneous distribution patterns (McConkey et al., 2012).

5.4 Size class distribution of the woody plants in the arboretum

The size class distribution in the 66-year-old arboretum at Nyabyeya Forestry College reveals significant insights into the population structure and regeneration potential of woody plants. The higher stem density of seedlings, compared to saplings and trees is indicative of a robust regenerative capacity within the arboretum. This result aligns with the concept of natural regeneration, where the abundance of seedlings is a critical indicator of a healthy, self-sustaining ecosystem (Wallace et al., 2022).

The significant stem density mean difference observed between the size classes further highlights the distinct stages of growth in the arboretum, with seedlings being more abundant. This finding can be attributed to the favorable conditions provided by the arboretum, such as protection from disturbances, ample light, and nutrients, which facilitate seedling establishment and growth. These results are consistent with findings from other studies on forest regeneration. For instance, studies in similar tropical forest settings have reported higher seedling densities due to favorable microclimatic conditions and low disturbance levels, which are crucial for regeneration (Zermeño-Hernández et al., 2015). The species composition within the arboretum also provides insights into the population structure. Species like *Cedrela odorata* and *Senna spectabilis* dominated the arboretum, with the highest recorded numbers, which could be indicative of their competitive advantage in this environment.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The findings indicate that;

1. There is a higher distribution of forest dependent species in the arboretum compared to the forest non-dependent species and open habitat species an indicator that the arboretum is shifting to a typical forest habitat.
2. There is a higher proportionality of non-pioneer light demanders compared to the shade tolerant and pioneer species due to their competitive ability to thrive in lower light conditions as the arboretum is shifting to its mature stage.
3. There is a higher distribution of abiotically dispersed woody plant species compared to the biotically dispersed woody plant communities.
4. The arboretum is a healthy and self-sustainable ecosystem because of the higher proportionality of seedlings compared to saplings and matures trees.

6.2 Recommendations

- In order to increase the proportionality between the abiotic and biotically dispersed woody plant communities, there is need for enrichment planting of biotically-dispersed species.
- There is need for further research on other scientific aspects like soils and ecological networks within the arboretum to understand its contribution to ecosystem functions in the landscape where larger forests are embedded.
- The management of the arboretum needs to retain the different habitat types, successional guilds, dispersal modes revealed by this study in order to sustain the diverse species assemblage

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