ECOLOGY AND PHENOLOGY OF *Melia Azedarach* Linn. ON AND OFF THE RIVERINE AREAS

By

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DEDICATION

This research is dedicated to my lovely family which is my wife Makungo Mulalo Agreement and my sons Masia Vhuthu Terence and Masia Vhuhone Theo for appreciating time without me and being patient with me. Your support and love are highly appreciated. I extend my sincere gratitude to my father Masia Tshitokisi, my mother Mathonsi Mihloti Eunice, my brother Masia Timothy and my sister Masia Vuledzani Tshitokisi for their unconditional love. I send my deepest condolences to my late auntie “Mashau Mashudu” I always remember your words “once you have registered, consider that done.” Your presence will always be missed.

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DECLARATION

I, khathutshelo Victor Masia of 11640864, declare that this dissertation is my original work and has not been submitted for any degree at any other university or institution. The dissertation does not contain any other persons` writing unless specifically acknowledged and referenced accordingly.

Signed : KV Masia Date: 12/12/2023

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ABSTRACT

Noteworthy, *Melia azedarach Linn.* is an indispensable tree species that is utilised in various forms. It can be used in craft industries as a substitute for teak wood when the supply is reduced. Simultaneously, its leaves, roots, bark, and flowers are used as medicines and natural pesticides. *Melia azedarach Linn.* is traditionally used as medicine to treat astringents and furthermore can be used against intestinal worms, skin diseases, stomachaches, uterine illnesses, and as a diuretic and febrifuge. In addition, it has been reported to possess anticancer, antimalarial, analgesic, and anti-inflammatory, antifungal, antibacterial and antioxidant activities.

This tree can adapt to different environmental conditions so that it can grow well in extensive areas. *Melia azedarach Linn.* is a plant that grows both on and off the riparian zones. Communities in South Africa see less value attached to it to the extent that in many places where these trees are found growing, the majority are cut for no good reason. Sometimes, the plant species is cut for the construction of fences, kraals, or firewood. The main reason for this practice is that much is not known about the plant; it could be found de-vegetated anytime.

The study was conducted at Ha-Tshikonelo, Thulamela Local Municipality, Limpopo Province, South Africa. Plant phenology and distribution have gained increased interest because climatic change is sensitive to phenological traits and their consequences for ecosystem function. It is made possible to gather information on spatial and ecological scales because of new technologies innovative technologies.

Temperature, photoperiod, and winter chilling are examples of plant phenology drivers, and competition is included. A smartphone (Huawei Nova Y60) camera was used to take pictures of phenological changes when visiting the on and off riparian zones from August 2019 to December 2021. The research aimed to determine the different phenophases and distribution patterns of Melia azedarach in riparian zones. The Nearest-neighbour method of sampling individuals within a population of plants was used for data collection.

The collected data was then analysed using Analysis of Variance (ANOVA). It was found that *Melia azedarach* Linn. is regularly distributed for both on and off-riparian areas. Phenophase occurring off riparian zones was found to be occurring earlier than in riparian zones. It was found that *Melia azedarach* Linn. is surviving and flourishing in both off and on the riparian zones. On riparian zone individuals were growing bigger than those found off the riparian zones because of the abundant supply of resources such as water and nutrients.

Keywords: *Melia azedarach* Linn., phenology, phenophases, riparian areas, distribution.

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CHAPTER 1. INTRODUCTION

1.1. Species description

Melia azedarach Linn species was selected because it was seen flourishing on both on and off-riparian zones at Ha-Tshikonelo village. Traditional healers were seen harvesting this plant for medicinal purposes and for shade, ornamental, and lastly timber. It was also seen as a food supplement to live stocks during drought season around the village and surrounding areas. *Melia azedarach* Linn. is a member of the Meliceae family and attracts traditional healers for their well-known limonoids or meliacins and other bitter and biological activities (Oyedeji-Amusa *et al*., 2021).

Melia azedarach Linn. is native to tropical Asia belongs to the Meliaceae family and is also native to many other countries. It is widely spread in the tropics and subtropics (Al-Rubae *et al*., 2009). Deciduous *Melia azedarach* Linn. is fast-growing and shade-intolerant with leaves and fruits that have insecticide compounds. It is harvested for its high-quality wood properties, making it a popular species to cultivate. According to (Jhou *et al*., 2017) *Melia azedarach* Linn. possesses a shallow root system. Due to the notion of owning a shallow root system, the plant species is found to be hard and drought resistant.

In terms of height, *Melia azedarach* Linn*.* can grow to heights of 5 - 15 m and a stem diameter of 110 m^2. Some of the attributes of *Melia azedarach* Linn. are that it is an ornamental tree and provides shade with lateral branching. Ferny foliage turns yellow in autumn. Leaves are dark green (Figure 1.1(b)) on the upper surface and pale green underneath. When these leaves are crushed, they produce a pungent smell. Flowers are lilac coloured and fragrant (Figure 1.1(a)). Fruits are green and turn yellow when ripe (Figure 1.1(c)) (Voigt *et al*., 2019).

Figure 1.1(a,b,c): Lilac flowers, green leaves, and green and brown ripening fruits of *Melia azedarach* Linn.

Melia azedarach Linn. has 5 to 6 ovaries, with small fruits of not more than 2 cm in length, the inflorescence length is often of leaf length (figure 1.2(a)). Fruits are large but not more than 3 cm in size. It is distributed in mixed evergreen, broad-leaved, and deciduous forests and sparse forests, field margins, and alongside roads (Chen and Xu, 2012). It is monoclinous, and the first flower occurs 2 to 3 years after germination. Wind and animals are the pollination agents of these seed dispersal is promoted by birds or by gravity (Chen and Xu, 2012).

In most of the publications, it is called China berry, Persian lilac, Pride of India, White Cedar, cinamomo in Brazil (Cavusoglu & Sulusoglu, 2015), Zanzalacht in Jordan (AL-Rubae, 2009) and Mindi in Indonesia (Syamsuwida *et al*., 2012). Phenological and morphological features are expected to change in climatically and geographically different areas because of the wide range of distribution (Cavusoglu & Sulusoglu, 2015). *Melia azedarach* Linn. is adaptable to all types of soil. It can survive in the tropics and warm temperate areas (Florido *et al*., 2002).

Melia azedarach Linn. is used in craft industries as a substitute for teak wood when the supply is reduced. However, its leaves, roots, bark, and flowers are used as medicines and natural pesticides. This tree can adapt to different environmental conditions so that it can grow well in extensive areas (Chen *et al*., 2012). All parts of the plant, namely leaves, roots, stems, barks, fruits, seeds, and flowers have traditional uses (Mishra *et al*., 2013).

Melia azedarach Linn. is traditionally used as medicine to treat astringent (Sen *et al*., 2012), and used against intestinal worms, skin diseases, stomachache, uterine illness, and as a diuretic and febrifuge (Khan *et al*., 2001). It has been reported that it owns anticancer, antimalarial, analgesic, and anti-inflammatory activities (Vishnukanta & Rana, 2010), as well as antifungal, antibacterial, and antioxidant activities (Sukirtha *et al*., 2012).

It is widely distributed and has an economic value in the development of botanical pesticides, timber, bioremediation in urban industrial districts, and a combination of forestry and agricultural uses (Xu *et al*., 2010). In China, it has an economic value concerning the development of botanical pesticides, timber, and a combination of forestry and agricultural uses (Sharma *et al*., 2012). *Melia azedarach* Linn is an ornamental plant (Figure 1.2) and furthermore, can be used as a windbreaker for agricultural purposes and reforestation projects. The leaf extracts have insecticidal properties that repel insects in clothing. The leaves can be used as a source of food for the goats. Seed oils are used to treat antiseptic sores, ringworms, and ulcers which show no tendency to heal (Florido *et al*., 2002).

Chen and Xu (2012) showed that the change in the rate and direction of plant phenology in response to climate change are diverse, depending on geographical locations, time scales, and species. Zheng *et al*. (2004) describe phenology as the sensitive and easily observable indicator of climate change and as having different ecological implications. According to Dai *et al*. (2012) phenological study helps us to understand the interaction between vegetation dynamics and climate systems not only by measuring the effects of global climate change on the phenology of plants. The natural distribution of *Melia azedarach Linn*. is uncertain but is thought to be native to Asia but has long been cultivated throughout the Middle East. It is widely extended from northern Queensland to new southern Wales, mostly within 100 km of the coast (Turnbull & Doran, 1997). The habitat of this species is the lowland and highland rainforest.

The distribution of *Melia azedarach* Linn*.* in Thailand is associated with mixed deciduous forests. In Australia, it is mostly distributed as single and scattered trees in or on the margins of rainforests (Turnbull & Doran, 1997). In South Africa, it is the invader of savanna, wastelands, riparian corridors, and urban open spaces (Voigt, 2019). It is also found in the episodic riverbank, sandy areas, moist drainage lines, and mining areas (Brown *et al*., 1986). In Tanzania, it is naturalized in lowland tropical forests. Alongside the roads, fences, floodplain woodlands, and upland woods were reported in the USA (Langeland & Burks, 1998).

Melia azedarach Linn. is associated with seasonal forests, not excluding thickets and woodlands (Ahmed and Idris,1997). It is widely distributed as single and scattered trees in or on the margin of a closed forest. In Queensland, it is found in rain forests while in Wales it is commonly found in riverine, dry and rain forests (Turnbull and Doran*,* 1997).

Figure 1.2: Picture showing *Melia azedarach* species.

1.2. Problem statement

The majority of *Melia azedarach* Linn. species were found chopped for the construction of fences, cattle, and goat kraals, and some were stacked behind the houses, ready to be utilised as firewood. Most alarmingly, this frightening problem triggered the study of the distribution of *Melia azedarach* Linn. on and off riparian zones of the selected study area. It is vital to understand their distribution and their phenological pattern because the tree is seen flourishing at the riparian zones as compared to the off-riparian zones. Researchers have used numerous techniques to observe how phenology shifted in recent decades such as species-level observation

(Cleland *et al*., 2006), satellite remote-sensing of ecosystem production (Zhou *et al*., 2001), atmospheric monitoring of carbon dioxide (Randerson *et al*., 1999). Most of these techniques found a correlation between summer phenology and rising temperatures in recent decades but different results in the growing season (Estrella & Menzel, 2006). Phenology is a dominant and overlooked aspect of plant ecology, from the scale of the individual to the whole ecosystem (Cleland *et al*., 2006). The timing of phenological changes is a major determinant of species distribution and plant production (Vitasse *et a*l., 2011). The temperature changes that are relevant to the distinct phases of plant development are represented by phenoclimatic measures. In tropical ecosystems, phenology might be less sensitive due to temperature and more tuned to shifts in precipitation (Morellato *et a*l., 2010).

According to Convertino *et al*. (2014), species are declining due to habitat degradation and loss for recreational activities and infrastructure development, and this possibly enhances the variation of adverse biological processes in a particular ecosystem.

It is important to check what could be the drivers and the influence of their phenology and distribution. Despite many reports that clear the important uses of *Melia azedarach* Linn., people in the current study area are unaware of such indispensable uses. Therefore, education on their uses is necessary to mitigate the de-vegetation of this plant species.

1.3. Research questions

Three research questions were drawn during this study:

- What are the distribution patterns of *Melia azedarach* Linn. found on and off the riparian zones of Ha-Tshikonelo village?
- What are phenological behaviours of *Melia azedarach* Linn. found on and off the riparian zones of Ha-Tshikonelo village?
- Are there any similarities or variations of the phenophases of *Melia azedarach* Linn. growing on and off the riparian zones of Ha-Tshikonelo village?

1.4. Study Objectives

- To determine the distribution *pattern of Melia azedarach* Linn. on and off the riparian zones.
- To establish the phenological behaviours of *Melia azedarach* Linn. on and off the riparian zones.
- To investigate any variations or similarities of the phenophases of *Melia azedarach* Linn. on and off the riparian zones.

CHAPTER 2. LITERATURE SURVEY

2.1 Theories on species distribution

Melia genus of the Meliceae family is composed of about 20 distinct species in the world and is mostly distributed in the eastern hemisphere in tropical and subtropical regions. According to Liu (*et al.,* 2010) *Melia azedarach* L., *Melia azedarach* var. japonica, *Melia volkensi*, Gurke and *Melia toosendan* sieb et Zucc had received more attention because of their medicinal and ornamental uses.

The natural distribution of *Melia azedarach* Linn. is uncertain but is thought to be native to Asia but has long been cultivated throughout the Middle East. It is widely extended from northern Queensland to new southern Wales, mostly within 100 km of the coast. The habitat of this species is the lowland and highland rainforest. The distribution of *Melia azedarach* Linn*.* in Thailand is associated with mixed deciduous forests. In Australia, it is mostly distributed as single and scattered trees in or on the margins of rainforests (*Thakur et al*., 2016). In South Africa, it is the invader of savanna, wetlands, riparian corridors, and urban open spaces (Voigt, 2019). It is also found in the episodic riverbank, sandy areas, moist drainage lines, and mining areas (Brown *et al*., 1986). In Tanzania, it is naturalised in lowland tropical forest. Occurrences of this species were reported alongside the roads, fences, floodplain woodlands, and upland woods in the United States of America (USA). *Melia azedarach* Linn*.* is associated with seasonal forests, not excluding thickets and woodlands (AL Rubae, 2009: Maciel et al., 2006).

There are vast anthropogenic drivers that contribute to species distribution, such as eutrophication and habitat loss in oceans, disturbance, fire regimes, and mining in terrestrials (Brown et al., 2011). Tree growth and distribution are indicators of climatic variables that are driving tree phenology and their sensitivity (Vitasse *et al*., 2011). The growing season of the tree species depends on temperature (Zhang *et al*., 2004). It is assumed that spring temperature plays a key role in tree species bud bursts in boreal and temperate zones (Vitasse *et al.,* 2011). On the other hand, geomorphological modification of some parts of the plants will influence species in terms of distribution and abundance. However, these changes will alter how animal and plant biodiversity distribution patterns behave in both terrestrial and marine ecosystems.

2.2 Measurement of species distribution

Plant community appearance is critical to the coexistence of different plant species of different forms and the maintenance of biodiversity. The notion of plant community aggregation has been debated by ecologists from all over the world for more than a century (Jiang et al., 2021) to address the involved contributing factors. Most importantly, a more accurate understanding of the mechanisms of plant community distributions involves consideration of multiple factors in the discussion of their effects (Jiang et al., 2021).

The so-called species Beta diversity mechanism which simply indicates variations in plant community composition in a particular space or time (McCain and Beck, 2016; Ulrich *et al*., 2017) is useful in determining species distribution in an ecosystem. Furthermore, the species Beta diversity provides a clear understanding of species aggregation within a community. Presently, environmental factors such as niche processes and neutral processes individually affect the species distributions (Jiang et al., 2021). Climate change is one of the natural factors that influence the distribution of plant species (Dormann, 2007) (Figure 2.1), however, the measurement of species distribution should be based on most extreme individuals rather than variables that present the distribution of individuals in a population because this may lead to very different estimates of climate change response rates (Dormann, 2007).

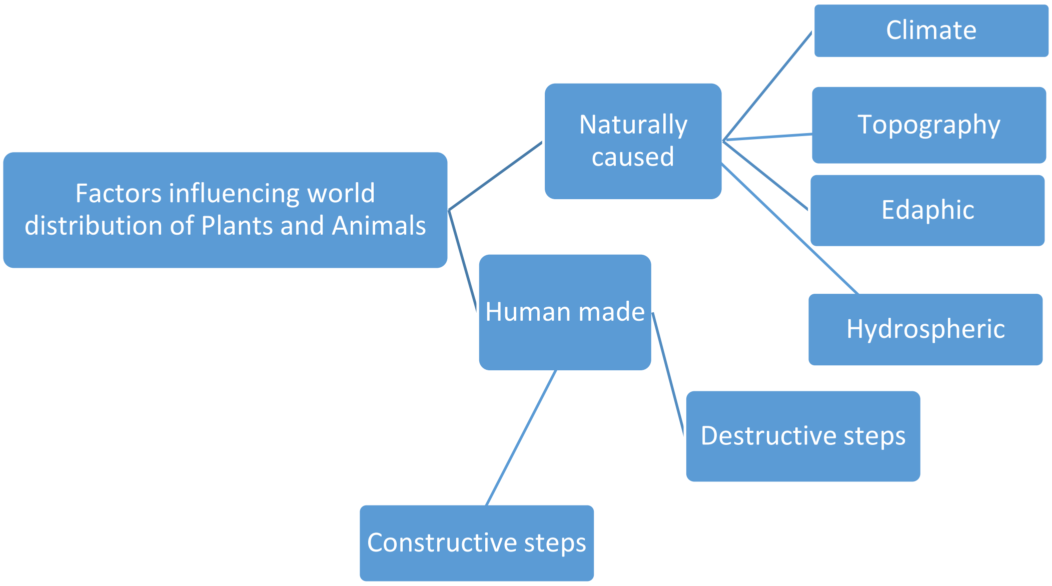

Figure 2.1: Some of the factors affecting distribution of plant species (Arise, 2021 accessed on the 31 July 2023).

Other species distribution models available presently are built on site-specific population characteristics across a large area under assumptions of genetic uniformity (Chuine *et al*., 2003). Additionally, Wang *et al*. (2006) reported that coastal populations respond hugely in diverse ways because they are affected by most biological processes of marine, terrestrial and riverine ecosystems.

2.3. Drivers of species distribution

Human-induced climatic change is one of the most major influenceable drivers of change in the distribution of timing of biological events and biodiversity (Parmeson & Yohe, 2003). Phenology is affected by global climatic change in the environment.

2.3.1. Factors affecting tree phenology

Global climate change is reported to affect the aspect of plant life strategies (Walther, 2003). Zhang *et al*. (2004) highlighted that more focus should be on phenology because it is a sensitive, easily observable, and integrated indicator of changes. Energy, moisture exchange, and seasonal carbon exchange are caused by seasonal shifts of phenophases and next changes in growing season length (Dai *et al*., 2012). Williams *et al*. (2021) describe phenology as the timing of seasonal events such as flowering, leafing, and fruiting in plants, and seasonal migration in animals.

Chen and Xu (2012) proved that the change in the rate and direction of plant phenology in response to climate change are diverse, depending on geographical locations, time scales, and species. According to Dai *et al*. (2012) phenological study helps us to understand the interaction between vegetation dynamics and climate system not only by measuring the effects of global climate change on the phenology of plants. Zhu *et al*. (2006) explain phenotypic plasticity as the ability of a genotype to produce distinct phenotypes when exposed to different environments during its ontogeny. Plants respond to variations in resource availability by changing their morphology and growth characteristics (Maherali *et al*., 2001). An understanding of phenological shift occurrence is needed (Dunnell & Travers, 2011) as it will aid with knowledge about the understanding of species distribution. Changes in morphology and growth traits that occur in plants in response to variations in resource availability are known to be vast (Zhang *et al*., 2004), hence resulting in distribution variations.

2.3.2. Measurement of tree phenology

Phenology can be measured by censusing a population throughout a season to determine the peak of the season in that population. Measures of phenology based on most individuals rather than variables present distribution of individuals within a population may lead to different estimates of climate change response. Single individuals may by chance have extreme responses and measurements using a single individual are susceptible to detection of biasness (Brown et *al*, 2006).

The phenology of deciduous is sensitive to variations in inter-annual climate and are useful indicators of climate change impacts. From regional to global extent, satellite remote sensing data has been effectively used to capture terrestrial phenology over time. Land surface phenology is viewed as the cumulative response of many individual organisms within each remote sensing pixel in combination with other land surface changes and different than field-based observation of individuals (Elmore *et al*., 2016). Satellite remote sensing at moderate resolution is used to provide daily observation of land surface properties at a spatial scale compatible with the size of the footprint of the eddy covariance observation site. Consequently, it has become a more vital data source for the study of the phenology of vegetation (Brown *et al*., 2011).

CHAPTER 3. METHODOLOGY

3.1. Description of the study area, location, municipality, latitudes, longitudes, and maps

The study was conducted at Ha-Tshikonelo, Thulamela municipality, Limpopo, South Africa. Thulamela municipality is one of the four local municipalities in the Vhembe district of the Limpopo Province. (Figure: 3.1.) shows the province of Limpopo, Vhembe district, and Thulamela municipality boundaries within South Africa. Light grey shows Limpopo province from South Africa (bottom map), brown shows Vhembe district (middle map), green borders (top map) show Thulamela municipality and on the left, the dot shows Ha-Tshikonelo village and Luvuvhu river is shown by blue lines. The municipality is situated in the eastern subtropical region of the province and the climatic conditions are generally hot and humid. It receives much of its rainfall in summer from November to March (Kabanda, 2004). The study site is characterised by the dry season in the months of March to September. The average temperature ranges from 35°C in summer and 18°C in winter (Nethengwe, 2007). The considered riverine study area was a riparian zone on perennial river called Luvuvhu and off riparian area was far away from the river towards Tshikonelo homestead with GP co-ordinates 22°53`40.2”S 30°44`14.4”E. Vegetation is a tropical dry deciduous forest dominated by many savannah big trees such as *Burkea africana*, *Dichrostachys cineria, Ficus sycromorus,* and *Combretum imberbe*. The soil found in riparian areas is sandy and black clay whereas the one found in the off-riparian area is loamy.

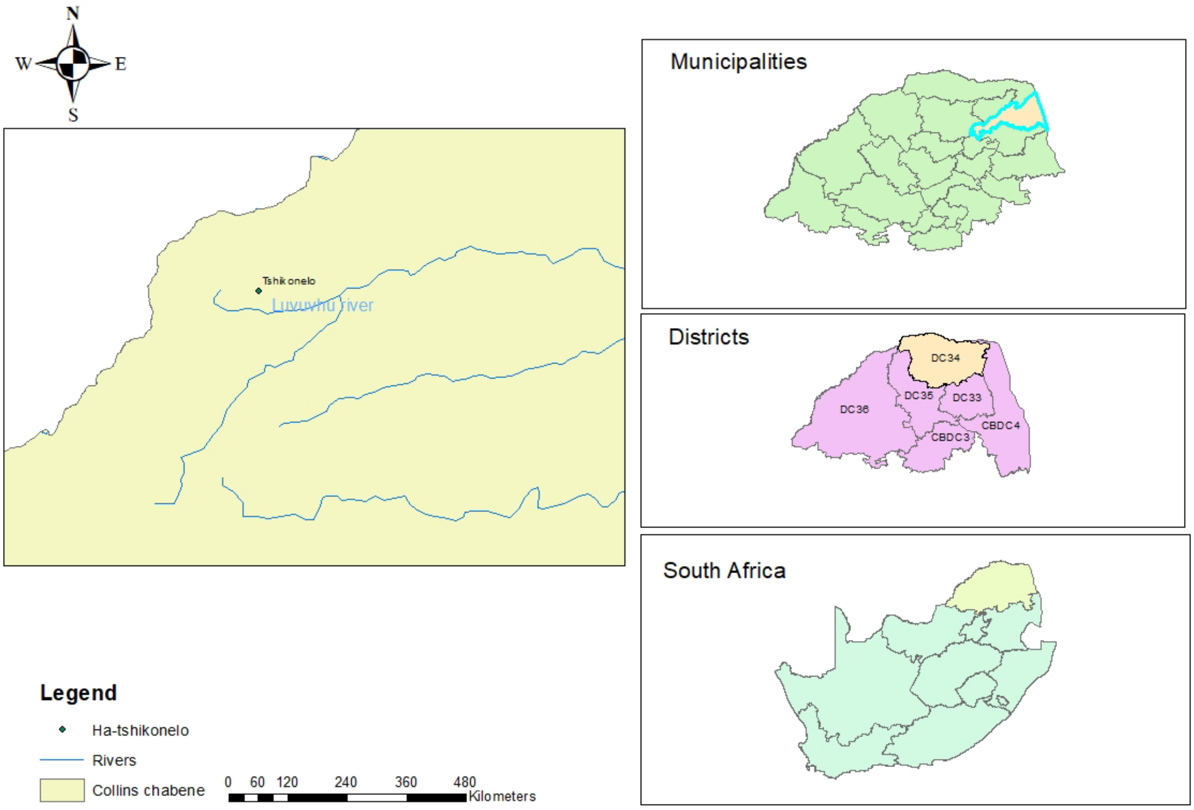

Figure 3.1: Map showing the study area of the research.

3.2. Vegetation types

The current research was conducted in a Savanna biome characterized by trees and grasses. The land is mostly flat with a transitional climate. The prevailing climate is said to be transitional because sometimes it switches between wet periods and dry periods. The rainfall is seasonal, and the study area receives more rain during the summer season. The land is very dry during winter due to the scarcity of rainfall.

Figure 3.2: A picture showing savanna biome. Source: (https://www.google.com/search?q=savanna%biome)

3.3. Data collection methods.

3.3.1. Description of research design

The research is quantitative because measurements of parameters such as canopy cover, stem circumference, and tree height were recorded. According to Burns and Grove (2005), quantitative research should be formal, objective, and rigorous and consider the deductive approach as well as systematic strategies to refine knowledge for solving problems. To reach solutions to problems, the design of the entire should be either experimental or non-experimental to obtain correct, valid, and reliable measurements of researched parameters (Rahman, 2017).

3.3.2. Sampling of individual tree species

Random sampling was used on riparian zones of the Luvuvhu River, while a purposive approach was employed for sampling individuals growing away from the riverine zone. The reason for the purposive sampling approach for away riverine zones is that plants were found scattered in homesteads because of human disturbances. The quadrats technique was used to measure the species distribution and other parameters. Random sampling was utilised to avoid bias. Ten 20x20m quadrats were constructed to measure parameters such as canopy cover, stem circumference, and heights. For the construction of the remaining quadrats, a 10m distance was the distance between all the 10 quadrats of this study. A coin was used to decide the direction of the next quadrant. The head side of the coin stood in the west direction, and the tail side stood in the east direction. During the sampling of *Melia azedarach* Linn. for both on and off-riparian zones, all *Melia azedarach* Linn. species met in the quadrats were measured, however, only 40 individual *Melia azedarach* Linn. species were marked for further investigation in each study site.

As mentioned before, the parameters considered for this study were canopy cover, stem circumference, and heights, therefore, the measuring tape and height meter rod were used, respectively. The stem circumference was measured at 1.2 m above the ground and the heights of the plant individuals were measured using a height meter rod placed next to the tree. Two people, one at one end of the canopy and the other at the other end of the canopy, extended the tape and recorded the length of the canopy cover. Two measurements were recorded and then averaged to determine the canopy cover. The data was used to determine whether the tree members were scattered irregularly, scattered regularly, or they are in clusters.

Furthermore, the nearest neighbour approach was employed to determine the distribution patterns of *Melia azedarach* Linn. in two study regions of the study area. Plant species were chosen at random and tagged for future reference from the on and off riparian zones, and the distance between the two closest neighbours was measured. The diameters of their stems, heights, and canopy coverings were also measured. The study was conducted at Ha-Tshikonelo, Collins Chabane, Vhembe district, Luvuvhu River, which is on a riparian zone, and Tshikonelo homesteads were off riparian. 40 trees were selected for each study area. Ten 20x20m quadrats were laid down to gain quantitative information randomly across each study area. Stem circumference, height, and canopy cover for each species were calculated as per Curtis (1950).

3.3.1. Description of research design

The research is quantitative because data collection methods were used in the field to obtain data for the research such as canopy cover, stem circumference, and tree heights.

3.3.2. Sampling of individual tree species

3.3.2.1 Construction of quadrats

On riparian zones of the Luvuvhu river, random sampling was used. Quadrats were created and 10m was considered as a distance between all the constructed quadrats of this study. Shortest distances from the quadrat’s edges were considered for the choice of 40 individual tree species which were marked for further data collection. Finally, a total of four individuals were marked in each of the ten constructed quadrats. A purposive approach was followed in the off-riparian zones since the plant species were not found in all the homesteads of the study area. The feasibility of this approach depended on the willingness of the homestead owners as some were not interested in cooperating with the researchers during the first visits.

3.3.2.2 Determination of the distribution pattern of Melia azedarach Linn.

The distribution patterns of *Melia azedarach* Linn. in the study region were determined using the nearest neighbour approach. Plant species growing outside and inside the 15 homesteads of Ha-Tshikonelo village were selected randomly and the distance between the two closest neighbours was measured. The stem diameters, heights, and canopy covers were also measured using a measuring tape and a height rod.

The stem diameters were measured using the diameter tape at 1.2 m above the ground, and the heights of the plant individuals were measured using a height meter rod placed next to the tree. Two measurements of the diameter of the tree canopy were averaged to obtain the length of the canopy cover. The data was used to determine whether the tree members were scattered randomly, regularly, or in clumps.

3.3.3. Phenological observation

The forty tree species that were selected for measurements of stem circumference, canopy cover, and heights were used to check the phenological aspects. The phenology of fruiting, flowering, budding, abscission, and leaf yellowing was studied during different seasons. During the observation period, phenological data were collected using the photography research method, in which pictures of plant phenophases were captured using a smartphone (Huawei Nova Y60) for every visit to the two study sites. The notion of using photographs for a better understanding of tree phenology has been supported by Vierling et al,.1996 in Jonsson 2012 who stated that for the past three decades, remote sensing using satellite and aerial photographs has been a popular technique to study phenological events of plant species.

Subsequently, for further and objective understanding of periods of leaf emergence, start of senescence, and dormancy proper monitoring using digital repeat photography with its high temporal resolution (Ahrends *et al*., 2009) is needed. Photographical research methods aid researchers in having a higher understanding of complex and extended activity chains, events flow firsthand, and reproduce further information and discussion (Buchanan, 2001). So, Crimmins and Crimmins (2008) argued that repeated photography is effective in capturing traditional phenological events information such as first date of flowering and senescence.

3.3.4. Data analysis

The Analysis of Variance (ANOVA) single factor was used to compare if there are any significant differences between canopy cover, heights, and stem circumferences of plant population growing from the two study sites. To decide the distribution pattern of

Melia azedarach Linn. of the two study sites, a method applied by Clark and Evans (1954) was used. The distribution ratio coined by Clark and Evans (1954) was used to determine whether the plant individuals are scattered irregularly, scattered regularly, or appear in clusters. The formula used to determine the distribution pattern is:

$$R = \frac{\bar{r}A}{\bar{r}E}$$

Where $\bar{r}A$ is the mean of series distance to the nearest neighbour and $\bar{r}E$ is the mean distance to the nearest neighbour expected in an infinitely large random distribution of density.

The density was calculated as the number of individuals per unit area. The distribution ratio is equal to the mean or average between the *Melia azedarach* Linn. tree divided by half the square root of the total numbers of the tree as repeated by the formula. In cases where the R-value is equal to 1, the population is scattered irregularly; if R is greater than 1, the population is scattered regularly; and if R is less than 1, the population is distributed in clusters. ANOVA was used to determine if there were any significant differences among the distances between tree population individuals in both study sites.

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Distribution of *Melia azedarach*

4.1.1. Determining the structure of *Melia azedarach* by measuring the canopy cover, stem circumference, and height.

The results showed that stem circumferences for riparian trees are thicker than those off riparian zones. The difference in circumference sizes could probably be due to variations in soil moisture supply between the two areas (Table 4.1.1.a and Figure 4.1.1). In areas where soil moisture supply is favourable plants would generally be found to be surviving well than where soil moisture is limited.

Stem circumference and tree height of plant individuals are vital when examining the species distribution in disturbed areas (Helm & Witkowski, 2012). Stem circumference is more useful than height because fire and herbivory cannot damage the height tree sizes. Abundant seedlings and juveniles compared to adults are interpreted as a healthy or stable potentially growing population while scarcity of seedlings and juveniles shows a declining or unstable plant population (Condit *et al.*,1998).

Table 4.1.1.a: A summary of the statistical analysis of the stem circumferences between *M. azedarach* Linn. individual on and off riparian zones.

Study area	**Count**	**Sum**	**Average**	**variance**	**F**	**P**
On riparian	40	2034,4	49,61951	1,90911	42,59	p<0,05**
Off riparian	40	1868,7	45,57805	0,762256		

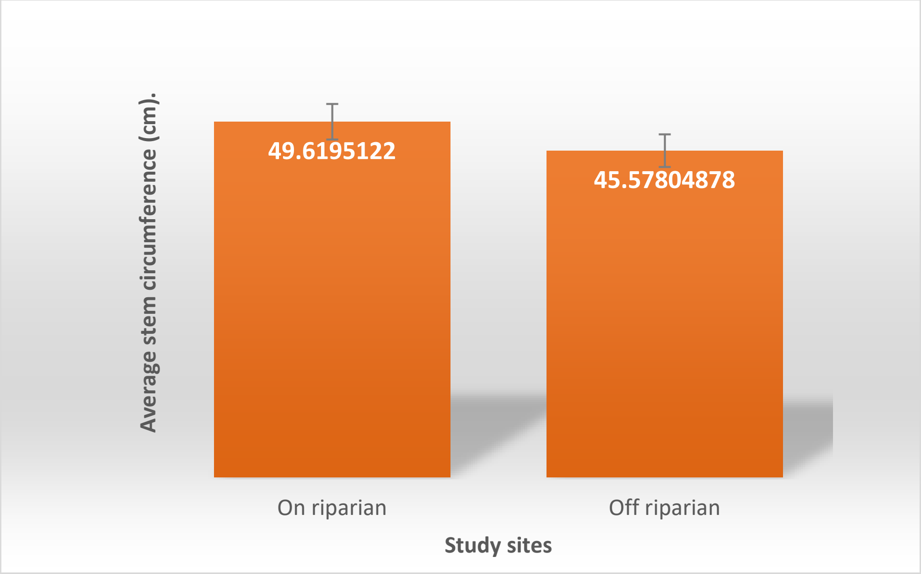

Figure 4.1.1: Comparison of average stem circumference of *M. azedarach* Linn. on and off riparian zone

The heights of *Melia azedarach* Linn*.* plant population in riparian zones were much taller than those found in the off-riparian zones, this was probably due to sufficient water supply to the riverine plants than those on the off-riverine areas. Possibly, the dense nature of the riparian zone vegetation could stimulate or lead to *Melia azedarach* Linn. individuals to grow taller so that it becomes easy to have access to sunlight which is necessary for photosynthesis (Table 4.1.1b and Figure 4.2).

Tree heights of different species are affected by the vertical gradient in light availability, vapour pressure deficit, air temperature, hydraulic resistance, and gravity on water transportation (Ambrose *et al.,*2016), temperature, rooting depth, precipitation, and soil type are key factors that determine plant heights across biomass (Rueda *et al.,*2016) Tropical Forest trees increase area based photosynthetic capacity to increase tree heights. Taller trees are associated with greater hydraulic stress, higher water-use efficiency, and an elevated level of thermal tolerance (Fauset *et al.,* 2018).

The difference in tree heights between various regions is influenced by hydraulic limitations. Natural disturbance (wind throw, drought and anthropogenic action increases mortality and limits available time for tree to grow taller (Almeida *et al.,* 2019).

Table 4.1.1.b: A summary of the statistical analysis of the tree heights between *M. azedarach* Linn. individual on and off riparian zones.

Study area	count	sum	average	variance	F	P
On riparian	40	354,1	8,636585	0,883378	17,37	p<0,05**
Off riparian	40	300,3	7,32439	0,26089		

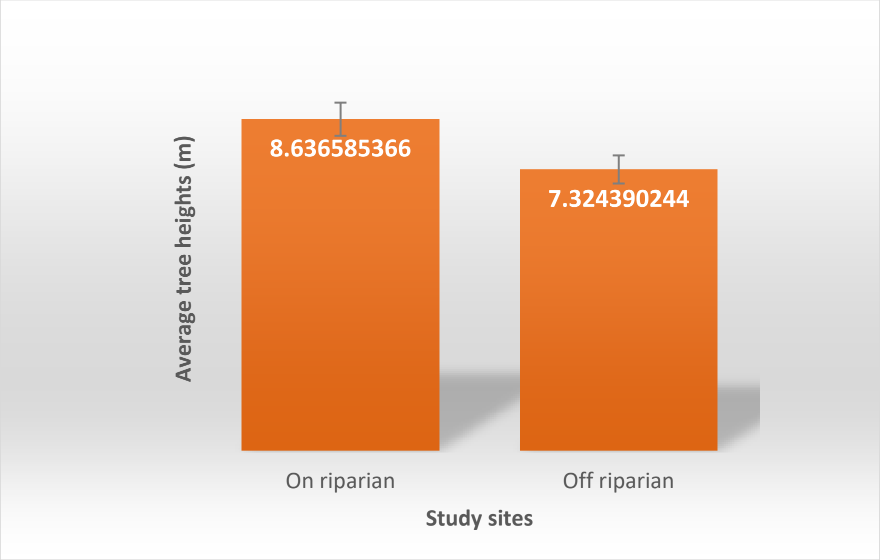

Figure 4.1.2: Comparison of average heights of *M. azedarach* Linn. on and off riparian zones.

Canopy covers were found to be broader on the riverine areas than away riverine areas and the same argument of more water supply near the riverine areas than further away from the riverine areas is apparent (Table 4.1.1.c and Figure 4.1.3). The factor of nutrient availability was not investigated but because along riverine areas the vegetation was dense with substantial number of debris, it may be possible that nutrients were more on the riverine areas than further away riverine areas and hence this could have contributed to the bigger-sized canopy covers of *Melia azedarach* Linn. growing thereof.

Holdo and Arnorld (2012) is in concurrence with this observation as they reported the directly proportional relationship between nutrient amounts and plant canopy size covers. The latter implies that nutrients availability could be one of the plant population structure determinants. It was found that tree canopy covers across amazon were related to various environmental variables. Amount of cloud free days, wind speed, clay soil content elevation and seasonal temperatures are most relevant to the canopy covers (Gorgens *et al.,* 2020).

Table 4.1.1.c: A summary of the statistical analysis of the canopy cover between *M. azedarach* individual on and off riparian zones.

study area	**count**	**sum**	**Average**	**variance**	**F**	**P**
On riparian	40	448,7	10,9439	0,748524	31,36	p<0,05**
Off riparian	40	340,3	8,3	0,303		

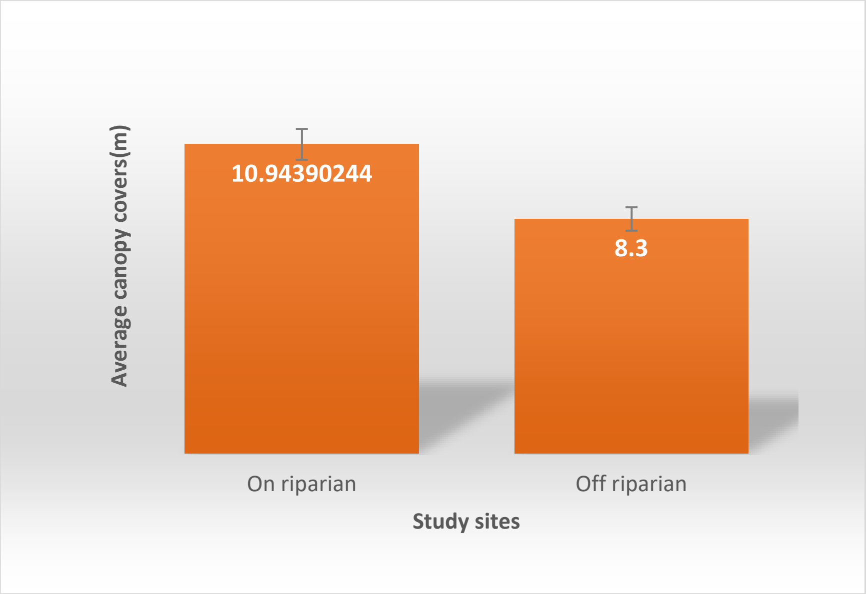

Figure 4.1.3: Comparison of average canopy covers of *M. azedarach* Linn. on and off riparian zone.

Canopy covers, basal circumferences, and tree heights differ in soil nutrient availability. Biotic and abiotic factors that have acted on the past and present individuals of the population had an impact on the size structure of the plant population (Bullock *et al*.,2012). The knowledge of species population size structure gives information about the relationship between the species and its environment.

4.1.2. Determining the distribution pattern of *Melia azedarach* Linn. of on and off riparian areas using the nearest neighbour method.

When determining the distribution pattern of *Melia azedarach* Linn. plant population of the two study sites on and off the riparian zones, the results showed that the populations are regularly distributed since the distribution ratio (R) was found to be greater than 1. The distribution ratios of distances between neighbours of the on and off riverine zones were found to be 1.25 and 2.36 respectively (Table 4.1.2a).

Table 4.1.2a: Table showing average distances of *Melia azedarach Linn.* between tree trunks and R value of both study sites.

Study Area	N	Average(m)	R	P
On riparian	39	12,70976	1.25	$p<0.05$**
Off riparian	39	17,13171	2.36	

The results in both study areas (on and off the riparian zones) showed that the *Melia azedarach* Linn. population is regularly distributed, and it could be due to the individual plant sizes of the trees that were studied. The distribution pattern of plant species can be determined by competition between species and such causes stress between them (Craine & Dybzinsky, 2013).

The temperature of the study area is relatively high during the dry periods of the year, and such may not be favourable to allow plant species to grow in a clumped fashion. Hence, their regular distribution should be expected (Hamidou *et al*., 2014).

Even though the distribution indexes of on and off riparian zones revealed that the populations are normally distributed statistical results revealed substantial variations in plant population distances (Table 4.1.2b).

4.2. Phenological behavior of M. *azedarach*.

4.2.1 Phenophase occurred in the riparian area and off riparian areas during different seasons (winter, autumn, summer, and spring).

Spring season (August-September)

The phenohases of the on and off-riverine areas are presented in Table 4.2.1. The phenophase of regeneration occurred during the spring season from early August to September, and the peak of the regeneration season occurred in August (shown by X in Table 4.2.1). Some of *Melia azedarach* Linn. individuals had already shed all the leaves during the spring season for both the study areas. During this period most of the *Melia azedarach* Linn. individuals were seen releasing shoots, and the development of small leaves was also apparent (Figure 4.2.1). Even though leaf regeneration was seen in spring, some of the scholars illustrate an overlap in the phenophases of the same plant species. For example, Zhang *et al*. (2014) studied the phenological events of *Melia azedarach* Linn. and reported that the production of leaf buds happens during late winter and early spring.

Furthermore, folded flowers started to show on *Melia azedarach* Linn. Individual plants that were sampled from both the on and off -riparian zones (Figure 4.2.2). However, the flowering times differed slightly because riverine samples started to flower in the month of August whereas the off-riparian area samples started flowering in July. Most of the off-riparian *Melia azedarach* Linn. Samples retained fruits from the previous year, while all *Melia azedarach* Linn. individuals of the riparian areas had shed fruits. It is not astonishing to observe this pattern simply because the riparian zone promotes the well-being of diverse organisms including birds and small rodents that may rely on the fruits of *Melia azedarach* Linn. for nutritional purposes. Individuals that are growing off-riparian zones are more advantageous or are conserved because herbivores and other organisms that might want to feed on edible parts of the species are prevented by human beings.

Table 4.2.1: Principal growth stages (phenophases event) of *Melia azedarach* Linn. on and off the riparian zones and the timelines of the year at Ha-Tshikonelo.

	March	April	May	June	July	August	Septem ber	October	Novemb er	Decemb er	January	Februar y
Seasons				month of the year								
Regeneration					▨	X	▨					
Flowering phase						X	▨	▨				
Fruiting phase							▨	▨	x	x	▨	
Fruits ripening	x	X										

Leaf yellowing	x	X										■
Leafshedding	■	X	x	■								
Senescences			x	■	■							
Beginning of dormancy		■	x	x	■							
Full canopy cover								x	x	■		
Leaf greening								x	x	■		

on the riparian zones

	March	April	May	June	July	August	September	October	November	December	January	February
Regeneration						■	X					
Flowering					■	X	X					
Fruiting							■	x	x	■		
Fruits ripening	x	X										■
Leaf yellowing	x	X	■									■
Leafshedding		X	x	■								
Senescences			x	x	■							
Dormancy		■	x	x								
Full canopy cover							■	x	x	■		
Leaf greening							■	x	x	■		

Figure: 4.2.1: Regeneration of new shoot on *Melia azedarach* Linn. growing on the off-riparian zone.

Figure:4.2.2: Indication of folded flowers of *Melia azedarach* Linn. growing on riverine zone.

Melia azedarach Linn individuals on the riverine areas started fruiting in late spring compared to the off-riparian *Melia azedarach* Linn. individuals. In some other instances, phenological events can be dependent on climatic conditions. This notion is also echoed by Wolkovich (2012) when indicating the numerous effects of climate change on the spring phenology of temperate plants. On the other hand, a temperature rise resulted in earlier leafing, flowering of plants, fruit ripening, and earlier emergence of migration insects (Menzel, 2006). Since there is a direct proportional relation between an increase in light intensity and an increase in temperature. Menzel, (2006)'s argument of an increment of leaf bud bursting in spring is valid. A similar trend was observed with the results of this study because the leaf bud bursting increased with an increase in day temperatures.

Additionally, Williams *et al*. (2021), alluded to the fact that phenological response across a variety of plants has resulted from an increase in temperature and often has led to the early onset of spring events such as earlier flowering. However, these environmental conditions do not affect all species since some species have shown delays (CaraDonna *et al*., 2014) due to different tolerance strategies. Similarly, the rising spring temperature outweighs the possibility of delaying the impact of winter warming cases because a substantial proportion of plants have shown advanced phenology (Yu *et al*., 2010).

The newly emerged leaves took about one to two months to the full maturity. The average length and width of the fully-grown leaves on the riparian zones were 4,81cm and 1,91cm respectively, while off the riparian zones were 3,97cm and 1,79, respectively. Variations in plant leaf sizes growing between on and off-riverine areas could be ascribable to the differences in the amount of water and leaf litter between the two study sites. An abundant water supply and nutrient amount in the form of litter is necessary in determining different plant parts' growth and development.

Overall, both the on and off-riparian zone samples took two to three months to complete the reproductive process (i.e., flowering, pollination, and fruiting). These results are in concurrence with the results of the study conducted by Menzel *et al*. (2012) which indicated that *Melia azedarach* Linn. spent two to three months to complete its reproductive cycle which comprises the development of flower bud and fruit formation. Moreover, the results of the study by Bajpai *et al*. (2012) reported similar responses of a distinct species (i.e., *Shorea robusta*) which also took three to four months until completion of the reproductive cycle. Nevertheless, a slight difference was observed because the reproductive period for this species happened between March and June whereas the reproductive months for the species of the current study were from July to September. Spring phenology of both plants and insects can be affected by winter temperature and duration (Stalhandske *et al*., 2015). Echoing the discrepancies shown from the two species indicated in the above argument, Borchert *et al*. (2004), argue that flowering phenophases differ from one species to the other and various environmental cues such as periodic rainfall and soil water availability trigger the flowering process (Borchert, 2000) resulting to a certain pattern of the entire reproductive cycle of a particular plant species.

Summer (November-February)

During the summer season, leaf greening and full canopy covers phenophase dominated the season ranging from November to February, during November and December leaves were fully green in all *Melia azedarach* Linn. on both on and off riparian zones (indicated by X). A full canopy covers of *Melia azedarach* Linn. individuals were observed for both on-riparian and off-riparian zones (Figure:4.2.3). There were no fruits from previous years found on the trees and the ground from the riparian zone trees, whilst on the off riparian yellow fruits from previous years still hanging on the *Melia azedarach* Linn. individuals.

Melia azedarach Linn. of the riparian zones were mostly green and very few yellow leaves (Figure 4.2.4) during mid-summer in December. Fruits were fully green and fully grown and still on the tree (Figure 4.2.5). During late summer in February, fruits were starting to get ripe (yellowing) (Figure 4.2.4), and leaves were yellowing in the on-and-off riparian zone.

4.2.3: Full canopy cover *Melia azedarach* Linn. Observed on the off riparian zones

Figure: 4.2.4: Leaf yellowing of *Melia azedarach* Linn. the on riparian zones

Figure: 4.2.5: Fully green and fully grown fruits and leaves of *Melia azedarch* Linn. of the off riparian zones.

The current research findings showed the emergence of bud bursting, blooming, leafing, and canopy formation to occur in summer which is in line with what Chen and Xu (2012) observed in their study. The canopies in both on and off-riverine zones were fully covered with green leaves during the summer months which was probably because it was a rainy season favouring regeneration and full growth of vegetation in both zones.

Autumn (March- May)

During the autumn season, ripe fruits were observed (Figure 4.2.6) of the *Melia azedarach Linn.* individual for both on-riparian and off-riparian areas. Leaf yellowing was observed in all *Melia azedarach* Linn. individuals for both study sites and was at its peak during March and April (Figure:4.2.7). Most of the leaves were still green in juveniles, while few leaves were shed on the ground on both on and off riparian zones.

Figure 4.2.6: Ripe fruits observed from *Melia azedarach* Linn. for both on and off riparian zones.

Figure 4.2.7: Peak of yellowing phenophases of the *Melia azedarach* Linn. On the on riparian zones.

Leaves' colour changed from dark green to yellow or red in autumn, and most leaves and fruits had fallen to the ground probably signaling the approach of winter. Most individuals were seen losing all their leaves a sign of having entered a state of dormancy. The loss of all the leaves is preceded by leaf senescence, which is a process of degrading the leaf cells, leading to their death and ultimately leaf shedding. Leaf senescence is a successive functional and structural change that prepares plants to adapt to the winter season (Estiarte and Nuelas, 2015). *Melia azedarach* Linn. also underwent this process during winter and all the leaves of these plants were shed during winter. Autumn events are hugely important ecologically and evolutionarily. In autumn, there is a delay in leaf senescence because of an increase in temperature (Ibanez *et al*., 2010).

Leaves and fruit shedding during the autumn season and late occurrence of the spring season, such as flowering and budburst phenologies, affect the length of the growing season and the productivity of the forest. Estiarte and Nuelas (2015) argued that late budburst and delayed senescences during winter prolong the growing season.

Winter (May-July)

During the winter season, *Melia azedarach* Linn. few individuals for the off-riparian zones were mostly green and very few yellow leaves while most yellowing or yellow leaves were observed in the riparian areas (Figure 4.2.8). Senescences and dormancy were the phenophases that occurred during the winter season and were at their peak in June and July for off riparian areas, whilst on riparian area senescences and dormancy occurred early during late May and June (Figure:4.2.9). Most of the fruits were shed to the ground and very few were still hanging from the *Melia azedarach* Linn. Individuals for both study sites. The phenological calendar and maximising competitive ability is the way plants adjust the phenology of leaf unfolding and senescent, but also maximising winter survival and adaptation to climate change (Soolanayakanahally *et al*., 2013). Different plants have adapted their life cycle to different seasons, in winter developing dormancy that activates the growth period and photosynthesis with a dormant period in unfavourable conditions. Evergreen species maintain their leaves throughout the year, while deciduous species shed all their foliage because species manage their foliage differently during dormancy in woody plants in temperate and boreal ecosystems (Estiarte & Nuelas, 2015).

Figure: 4.2.8: Full yellowing canopy of *Melia azedarach* Linn. Observed on the on riparian zones.

Figure: 4.2.9: Dormancy and senescences phase of *Melia azedarach* Linn. on the off-riparian areas.

Growth cessation (Soolanayakanahally *et al*., 2013), leaf senescence (Puda *et al*., 2008), bud set, dormancy (Ruuhola *et al*.,2011), cold hardiness and environmental cues, and photoperiod are suggested to be the selection pressure for winter phenology at different latitudes. Additionally, plant phenology is mostly driven by temperature in temperate climates (Vitasse *et al*., 2011). The rise in temperature in past decades mostly affected the Northern hemisphere from temperate to boreal latitudes, and there was a strong shift in phenological stages (Linderholm, 2006). The timing of transitions between active and dormant stages has been changing, and these changes are caused by climate change and the rise in temperature. Phenological records of phenological stages from different phenological techniques such as satellite have been used and records have allowed study trends in different plants individuals (Zhang *et al*., 2014), Phenological transitions between distinct stages are easily detected in deciduous species such as leaf fall, leaf yellowing, fruit ripening (Figure 4.2.10), and greening during budburst (Estiarte and Nuesal, 2015).

Figure 4.2.10: Picture showing fruits ripening and leaf yellowing in deciduous trees.

4.2.2. The similarities and differences of *Melia azedarach* Linn. Observed on the on and off riparian areas.

During the autumn season, in both on and off-riparian areas, most of the leaves were already yellowing, and leaves had fallen to the ground while most of the off-riparian area Melia azedarach Linn. were still keeping the fruits from previous years while on the on-riparian-zones, plants did not have any single fruits. The assumption was that the fruits thereof were fed upon by birds.

The growing season and senescence phase were dominant in both riparian areas because all the *Melia azedarach* Linn. had shed all their leaves on the ground. It was observed it took about six weeks from budburst to fully grown leaves for both on and off-riparian areas but spouting on the on-riparian area Melia azedarach Linn. started late July, and on the off-riparian areas started in early August. Fruiting was detected earlier in the off-riparian areas than in the on-riparian areas.

During the summer season, all *Melia azedarach* Linn. individual fruits were fully grown, and leaves were fully matured. Canopy cover for *Melia azedarach* Linn. individual on the on and off riparian areas were fully developed. Yellowing of leaves and fruit ripening were detected during late summer months in off-riparian areas. Fruit shedding was observed on the off-riparian *Melia azedarach* Linn. individual during the last month of the season.

Nature has already set each species the life stages such as budding, flowering, fruiting, seeding, germination, and growth. Environmental factors such as rise in temperature and rainfall influence all stages in the life cycle of plant species (Tiwari & Chandra, 2016). Apparently, tropical trees respond variously to changes in rainfall and rise in temperature because adaptation to drought, cues for bud break, flower budding and leaf budding are different. In tropical forests, global climatic change forces variation in duration, timing, and phenological events (flowering and leaf bud break) (Singh *et al*., 2005).

CHAPTER 5. GENERAL CONCLUSION

Results of this study attested that *Melia azedarach* Linn. plants survive in both off and on the riparian zones. In riparian zones, individuals were growing bigger than those found off the riparian zones because of the availability of resources such as the abundant supply of water and nutrients. However, phenological changes will always be the short-term results of rapid climate change and a sign of the shift in plant phenology on the globe. Tree species will respond differently to temperature change and can cause long-term consequences on geographic distribution (Singh *et al*., 2005). There is a difference in canopy cover, stem circumferences, and height between individuals of the two study sites where on riparian zone has high average values of data compared to off-riparian zones. Phenological differences were observed in such that budburst and sprouting occurred earlier in the on-riparian areas while leaf yellowing and shedding occurred earlier in the off-riparian areas compared to the on-riparian areas.

Phenological changes have been very convincing evidence of species response to climatic changes (Williams *et al*., 2021). It can be concluded that water availability and abundant nutrient supply in the riparian areas led to high values of canopy cover, stem diameter, and tree heights compared to off-riparian areas. Even though all distribution patterns showed random distribution for both study sites, it is believed that birds are the distributing mechanism because it was observed that some seeds were fed on while there are still on the trees in the riparian areas. Additionally, in the off-riparian zone, heavy rains are believed to be a distributing factor when they wash away the seeds and intense winds for dispersal. Most literature highlights phenological change in Eurasia, Central and South America (76), and a limited number of studies and literature are found in the southern Hemisphere (16), I therefore encourage more phenological research studies to be done in southern Africa because very few are found from Africa.

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