



**Ecology and Reproductive Biology of *Calotropis procera* (Aiton) W.T in some
parts of Mopani District Limpopo Province**

by

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ABSTRACT

Plant species play a crucial role in maintaining the normal functioning of various ecosystems. However, native species often face decline or extinction due to alien species' invasion and its detrimental impact. One such invasive species, the widespread shrub or medium-sized tree *Calotropis procera* (Aiton) W.T., is encroaching upon several villages and roadside areas in the Limpopo Province of South Africa, where it has been classified as an invasive species. This shrub, ranging from 2.5 to 6 meters in height, has proliferated across various regions of South Africa.

This study was conducted in six villages within the Mopani District, Limpopo Province, to investigate the ecology and reproductive biology of *Calotropis procera* (Aiton) W.T. The findings of this study are critical for devising strategies to manage or eradicate these invasive species in affected areas. Researchers observed and counted the number of *Calotropis procera* (Aiton) W.T. plants alongside roads and villages, measuring the distances between these plants and their nearest neighboring species to assess potential competition.

The present study also involved monitoring the phenological patterns of *Calotropis procera* (Aiton) W.T., including the timing of flower, fruit, and seed production, as well as seed dispersal mechanisms. This information is vital for determining the optimal periods for eradication or control efforts. The distribution pattern of *Calotropis procera* (Aiton) W.T. was analyzed using the Clark and Evans (1954) method, and phenological data were collected through photographic documentation at each site.

The extensive spread of *Calotropis procera* (Aiton) W.T. is attributed to its prolific seed production, wind-dispersed seeds, and stress tolerance, enabling it to thrive in various environments. The study suggests the best time to remove *Calotropis procera* (Aiton) W.T. plants is between February and April before they produce fruits. Understanding the impact of *Calotropis procera* (Aiton) W.T. on the local ecosystem is essential for developing effective management strategies. Overall, this study provides a comprehensive understanding of *Calotropis procera* (Aiton) W.T.'s ecology and reproductive biology and offers valuable insights into potential strategies for managing and eradicating this invasive plant species.

Keywords: *Calotropis procera* (Aiton) W.T., distribution pattern, invasiveness, phenology, road verge, reproductive biology.

Declaration

I, Ratshibvumo Rofhiwa, declared that this project report is my original work and has not been submitted for any degree at any university or institution. The project report does not contain other people's writings unless specifically acknowledged and referenced accordingly.

Student signature.....Date

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Chapter 1- BACKGROUND OF THE STUDY

1.1. Introduction

Plants are often regarded as the foundation of ecosystems due to their critical role in photosynthesis, which enhances oxygen production and is essential for other organisms' survival. Harte (2020) emphasizes that plants act as primary producers and significantly contribute to industries such as pharmaceuticals and textiles while also shaping human behavior and culture. Harte (2020) further observes that native species may decline or become extinct due to invasions by alien species, which can disrupt ecosystems. These invasions are primarily driven by human activities, including the intentional introduction of foreign species and their unintentional spread through intercontinental trade (Thomas et al., 2016).

Keddy (2007) describes plant ecology as a branch of biology that investigates the distribution and abundance of plants, the impact of environmental conditions on plant populations, and the interactions between plants and other organisms. Within plant ecology, plant phenology examines the timing of growth, flowering, and fruiting, revealing how environmental factors and selective pressures influence these processes (Farahat et al., 2016). Farahat et al. (2016) also emphasise the importance of phenology in plant performance under biotic and abiotic constraints, noting that it is a crucial trait shaping life cycle strategies and influencing plant invasions.

Willis et al. (2010) emphasise that non-native species might be more adaptable to climate change than native species, potentially intensifying invasions. They highlight that species capable of modifying their phenology in response to climate change have historically proliferated, with this adaptability playing a crucial role in their success. Menge et al.

(2017) contend that the reproductive success of invasive plant species is vital for their distribution and persistence, emphasizing the intricate relationships between plant fitness, reproductive efficiency, population size, and density.

Despite its importance for conservation and management in the context of climate change, the connection between phenological response and the success of non-native species remains insufficiently explored (Willis et al., 2010). This study aims to examine the ecology and reproductive biology of *C. procera* (Aiton) W.T. in specific regions of the Mopani District to evaluate its invasiveness.

Recent studies have further explored these dynamics. For instance, Ljubojević (2023) discusses how invasive alien species (IAS) adapt to various conditions driven by climate change and their inherent adaptability. Additionally, Bang et al. (2022) highlight the significant environmental and economic impacts of IAS. Theoharides and Dukes (2007) outline the stages of invasion, from introduction to dispersal, emphasizing the traits that enable successful invasions. These findings underscore plant invasions' complexity and the need for ongoing research to understand and manage these processes effectively.

1.2. Problem statement

Invasive alien species threaten biodiversity, endangering native species and causing extensive ecological, environmental, and economic damage (Kaur et al., 2021). These species disrupt nutrient cycles, resulting in financial losses amounting to millions of rands (Milton & Dean, 1998). In South Africa, alien plants are frequently observed along gravel and paved roads, forming belts 10 to 20 meters wide. Milton and Dean (1998) observed that while roadside vegetation may be natural or semi-natural, disturbances and

propagules left by passing vehicles increase the likelihood of alien plant establishment. Roadsides are particularly vulnerable to colonisation by alien plants, as propagules from vehicles, wind, water, or animals can easily establish within road edges. Disturbances and water runoff from roads further influence the growth of weedy plants.

One such species, *C. procera* (Aiton) W.T., is commonly found growing along roadsides in the Limpopo Province. Therefore, it is essential to investigate the distribution pattern, mode of introduction, and reproductive strategies of *C. procera* (Aiton) W.T. as it gradually displaces native vegetation in several areas of the province. This study aims to fill the gaps in understanding this invasive species' ecology and reproductive biology, which is crucial for developing effective management and control strategies to mitigate its impact. By addressing these gaps, the study will contribute to the broader efforts of conserving biodiversity and maintaining ecosystem stability in the face of invasive species.

Recent studies have further explored these dynamics. For instance, the IPBES Thematic Assessment Report on Invasive Alien Species and their Control (2023) provides a comprehensive synthesis of the current knowledge on biological invasions of rangelands and savannahs and impacts on their biodiversity and declining productivity of areas invaded. Schwindt et al. (2023) discuss the global consensus on the need for action against invasive alien species, highlighting the importance of integrating indigenous and local knowledge systems. Additionally, a study by Bang et al. (2022) emphasizes invasive alien species' significant environmental and economic impacts. These recent findings underscore the complexity of plant invasions and the need for ongoing research to understand and manage these processes effectively.

1.3. Rationale of the study

Examining the ecology and reproductive biology of *C. procera* (Aiton) W.T. will deepen our understanding of its introduction mechanisms, distribution patterns, relation with neighbouring plants, and seed production rates. This knowledge is vital for devising effective control strategies before it spreads to become hazardous to other plants, animals, and humankind. Furthermore, the study will shed light on the distribution patterns of *C. procera* (Aiton) W.T. in various regions of the Mopani District. Roadside inspections can act as an early warning system, detecting potential invasions before they become established in other ecosystems. The relative abundance of alien species along roadsides may also signal their potential for naturalisation, especially if local climatic conditions or land use practices are conducive. This information is crucial for proactive management and mitigation efforts to curb the spread of invasive species.

1.4. Research questions

- What is *C. procera* (Aiton) W.T. distribution patterns in different areas of Mopani District?
- What are the impacts of *C. procera* (Aiton) W.T. on their neighboring plants?
- What are the phenological patterns of *C. procera* (Aiton) W.T.?
- What is the seed production rate of *C. procera* (Aiton) W.T. across the six villages of the Mopani District of Limpopo Province, South Africa?

1.5. Objectives

1.5.1 Broad Objective of the Study

- To investigate the distribution patterns, phenology, and mode of reproduction of *C. procera* (Aiton) W.T.

1.5.2 Specific objectives of the study

- To understand the distribution patterns of *C. procera* (Aiton) W.T. in different areas of Mopani District.
- To evaluate the impact of *C. procera* (Aiton) W.T. on its neighboring plants.
- To study the phenology of *C. procera* (Aiton) W.T.
- To quantify the seed production rate of *C. procera* (Aiton) W.T. across the six villages of the Mopani District of Limpopo Province, South Africa.

1.6. Aim

This study aimed to provide insights into the ecological dynamics of *C. procera* (Aiton) W.T. and inform effective management strategies to control its spread.

1.7. Hypothesis

The ecological dynamics of *C. procera* (Aiton) W.T., including its distribution, phenology, seed production rates, and interactions with neighboring plant species, are significantly influenced by environmental conditions.

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Chapter 2- LITERATURE REVIEW

2.1. Origin of *Calotropis procera* (Aiton) W.T

According to Tsala et al. (2015), *C. procera* (Aiton) W.T. first appeared in the Afro-Asian monsoonal regions. In its native habitat, *C. procera* is a common pioneer species found in semi-desert grasslands, scrublands, and eroding sand dunes. It thrives in sandy soil and prefers hot, dry tropical climates. Tsala et al. (2015) also note that *C. procera* spread from Mauritania and Senegal in northwest Africa via the Arabian Peninsula and the Middle East, to the Indian subcontinent. It was brought to dry regions of Australia, the Mascarene Islands, subtropical America, and presumably South-East Asia.

Calotropis procera is a plant that grows in dry areas with sandy soil. It can live in places from sea level up to 1,300 meters high. This plant can handle salty soil and ocean spray. It can also survive with a lot of rain, up to 2,000 mm each year. *Calotropis procera* grows quickly in open places, like along roads and damaged fields. In Australia and Hawaii, people consider it a bad weed. It can take over pastures and fields that are not cared for properly. When the plant is physically destroyed from its stem, it can grow new parts from its roots. To stop it from spreading, it's best to pull it out completely, including the roots. Growing taller plants around it can also help keep it from spreading. In dry areas, seeing this plant usually means that the land is not taken care of well.

As stated by Sharma et al. (2022), the quantity of seeds generated, and the method of dispersal are likely to be more than sufficient to allow persistence and potential

domination. Seeds of *C. procera* (Aiton) W.T. can travel great distances in flood waters and are dispersed by wind and animals (Sharma et al.,2022). *Calotropis procera* (Aiton) W.T.'s extensive environmental adaptation and enhanced reproductive capabilities are responsible for its successful invasion (Sharma et al.,2022). In often disturbed environments, it grows as significantly as an intermediate weed (Sharma et al., 2022).

Kaur et al. (2021) reported that this plant primarily reproduces by producing seeds. Its pollen is green and sticky, and it relies on insects, especially monarch butterflies, for cross-pollination. *Calotropis procera* (Aiton) W.T. has characteristics typical of invasive plants, such as fast growth, quick seed dispersal by wind, a non-specialized pollination system, and a strong ability to thrive in poor soil (Kaur et al., 2021). In Australia, where it is considered an invasive species, experts recommend removal measures (Moustafa & Sarah, 2017). This plant is adaptable in its shape and reproduction and usually blooms throughout the year, which helps it reproduce successfully (Farahat et al., 2016). However, the flowering period decreases during extreme heat and very cold temperatures (Farahat et al., 2016).

2.2. Definition of reproductive biology

Alberts et al. (2000) described reproductive biology as a scientific field focused on the reproductive mechanisms of organisms. This discipline seeks to elucidate the complex processes essential for species survival. In plants, significant areas of investigation include gametogenesis, fertilization, and seed production and development. According to Alberts et al. (2000), plant reproduction is classified into two main types: Sexual reproduction happens when male and female gametes combine to form a zygote. Asexual

reproduction occurs without this combination, allowing offspring to develop from just one parent. occurs without gamete fusion, as seen in vegetative propagation. For example, *Calotropis procera* (Aiton) W.T. reproduces sexually by bearing fruits with seeds easily dispersed by wind, water, or animals. Additionally, this plant demonstrates root-suckering abilities, which enable vegetative reproduction.

2.3. Description of *Calotropis procera* (Aiton) W.T.

Calotropis procera (Aiton) W.T. is one of the invasive alien species in South Africa; its invasive status is listed under category 1B by the National Environmental Management Biodiversity Act (NEMBA) (Government Gazette, 2014). The category 1B illustrates that it possesses characteristics of out-competing native plant species for resources such as light, water, and nutrients, leading to a decline in native biodiversity. Their features also allow them to alter fire regimes by changing the frequency and intensity of fires in an ecosystem, thus causing tremendous harm to the native plant species. For example, most of them have broad leaves and are big in nature, features that may increase the amount of flammable material, leading to more frequent or intense fires. Invasive plants have succulent leaves that can consume large amounts of water, hindering opportunities for water availability for native fauna and flora.

These plants contribute to the soil degradation of the ecosystem as they modify the soil composition and other significant processes, such as nutrient cycling. As a result, the soil becomes less suitable for native species (Bitani et al., 2022; Claassen, 2025). This plant is classified within the Apocynaceae family (Shrivastava et al., 2013; Bukombe et al.,

2024). It is characterized as an erect, xerophytic shrub, commonly found in the tropical and subtropical regions of Asia and Africa (Shrivastava et al., 2013).

Calotropis procera (Aiton) W.T. is described as a shrub or small tree between 2 and 4 meters tall with unique waxy, grey-green leaves (Buerger et al., 2016; Invasive Plant Risk Assessment, 2016; Brandes 2005; Orwa et al., 2009; Kaur et al., 2021). The stems are smooth, bent, and greyish green, covered with soft, thick, corky bark. At its base, the plant frequently branches. The plant releases a milky, sticky fluid when cut or broken. Sessile, glaucous, ovate to obovate, 5–20 cm long, 4–10 cm wide, with six noticeable veins on the underside, and with a short-pointed tip, the leaves are grouped in opposing pairs along the stems. Heart-shaped bases form on leaves. An umbrella-shaped inflorescence with many flowers grows densely and in large numbers. They start as round buds. When fully open, the flowers have a diameter of 2–3 cm and can be white, pink, or purple. Each flower forms a cluster of five blooms, and each bloom has five petals. (Figure 1).

Calotropis procera (Aiton) W.T. is classified as an invasive alien species in South Africa, listed under category 1b by the National Environmental Management Biodiversity Act (NEMBA) (Government Gazette, 2014). This species belongs to the Apocynaceae family (Shrivastava et al., 2013; Bukombe et al., 2024). It is a xerophytic, erect shrub found across tropical and subtropical regions of Asia and Africa (Shrivastava et al., 2013).

According to the 2016 Invasive Plant Risk Assessment, *C. procera* (Aiton) W.T. is a type of shrub or small tree that grows 2 to 4 meters tall. It has unique, waxy leaves that are grey-green. The stems are smooth, bent, and greyish-green, covered in soft, thick bark. The plant often branches from the base and produces a milky, sticky sap when damaged.

The leaves are sessile, glaucous, and shaped like ovals to oblongs, measuring 5 to 20 cm long and 4 to 10 cm wide. They have six noticeable veins on the underside and pointy tips. The leaves grow in pairs along the stems and have heart-shaped bases. The inflorescence is dense and umbrella-shaped, bearing numerous flowers. The flowers have globular buds, and the open corolla is 2–3 cm in diameter, displaying white, pink, or purple hues. Each flower has five petals arranged in umbels of five (Figures 1 and 2).



Figure 1: Features of *Calotropis procera* (Aiton) W.T. (Hassan et al., 2015).

2.4. Reproduction of *Calotropis procera* (Aiton) W.T

Calotropis procera, also known as the Giant Milkweed, is a hardy shrub that belongs to the Apocynaceae family. It grows well in dry and semi-dry areas (Hassan et al., 2015). The plant can reproduce in two ways: sexually, through pollination and seed dispersal, and asexually, by growing new plants from its roots (Hassan et al., 2015; Bebawi et al., 2015) (Figure 2). Its seeds are designed to be carried by the wind, helping them spread

widely. The ability to grow from root suckers allows *C. procera* to create dense groups, which helps it survive in tough conditions (Hassan et al., 2015).

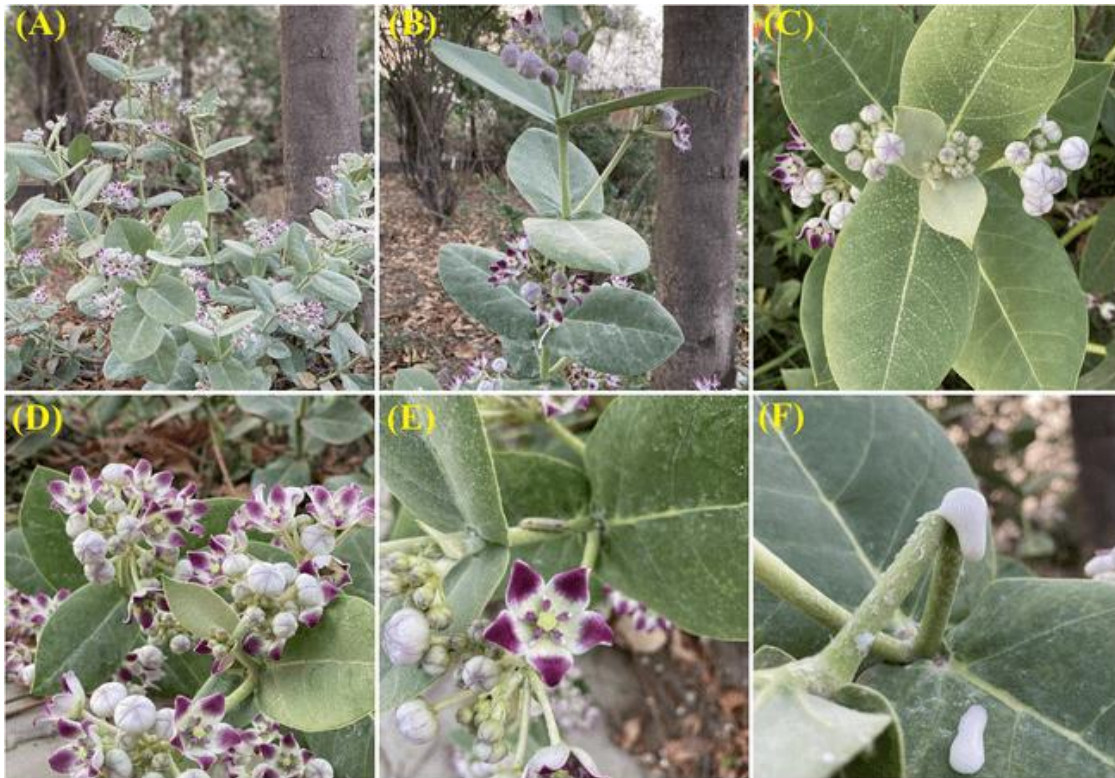


Figure 2: Features of *Calotropis procera* (Aiton) W.T. (Kaur et al., 2021).

2.5 Geographical distribution

This species is commonly found in the dry northern parts of Australia, mainly in Northern Queensland, Northern Western Australia, and the Northern Territory (Biosecurity Queensland Edition, 2016) (Figure 3). In Queensland and the Northern Territory, *C. procera* (Aiton) W.T. is seen as an environmental weed (Biosecurity Queensland Edition, 2016). It grows well in poor soils, especially where overgrazing has removed native grasses that would normally compete with it (Biosecurity Queensland Edition, 2016). This plant can form dense thickets, which outcompete other native plants and change the

appearance of savanna areas (Biosecurity Queensland Edition, 2016). In three Natural Resource Management Regions, it is recognized as a priority environmental weed, and community groups in the northern region are working to control it (Biosecurity Queensland Edition, 2016).

This species is regulated by different states and territorial laws. In the Northern Territory, it is classified as Class B (its spread is restricted) and Class C (it cannot be brought into the territory) (Biosecurity Queensland Edition, 2016). In Western Australia, it is classified under P1-Trade, which prevents its sale or movement into the state (Biosecurity Queensland Edition, 2016). *Calotropis procera* spreads easily due to its wind- and animal-dispersed seeds. It often appears along roads, lagoon edges, and in overgrazed grasslands. Additionally, it is very tolerant of salt and drought. This plant often indicates over-cultivation because it commonly grows in abandoned farmland, especially in sandy soils with low rainfall (Orwa et al., 2009).

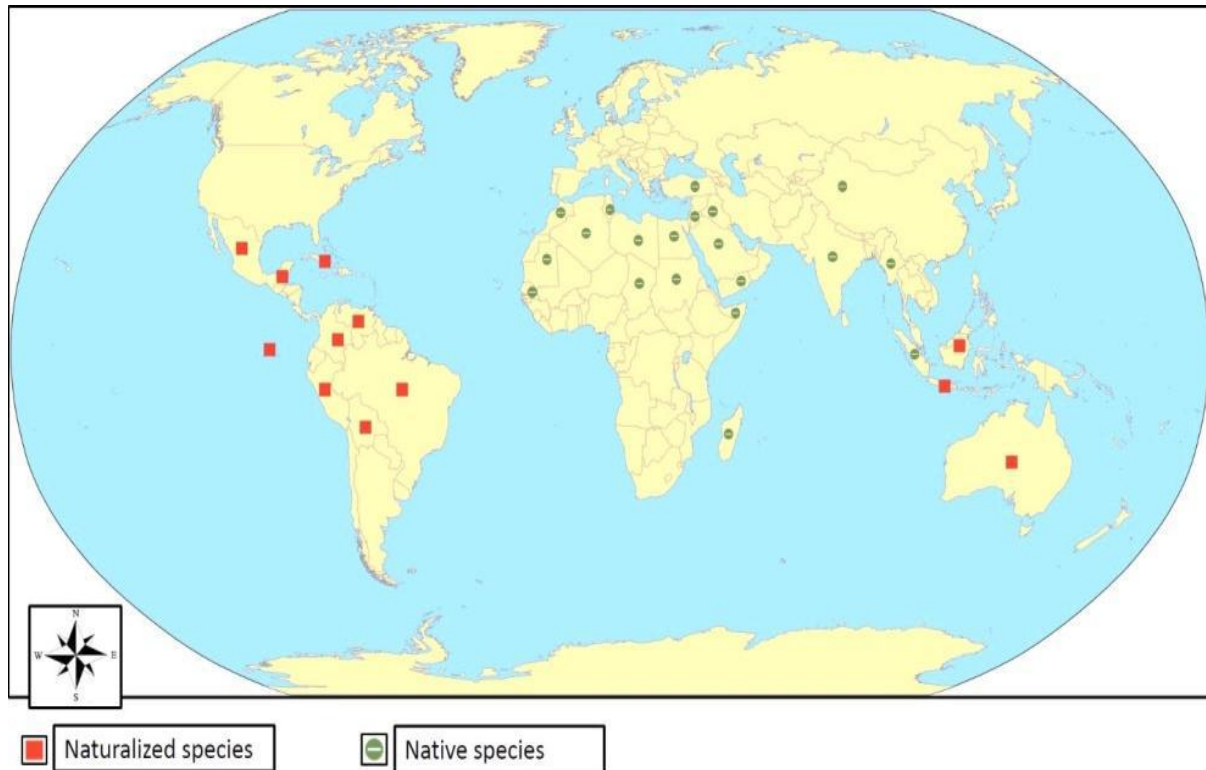


Figure 3: Global distribution of *Calotropis procera* (Aiton) W.T. (Moustafa & Sarah, 2017)

2.6. Pest Susceptibility of *Calotropis procera*

Calotropis procera is more prone to pests (Orwa et al., 2009). Even though it has toxic latex, insects like aphids and grasshoppers still suck sap from its leaves. This plant grows widely in the Tihama coastal plains of Saudi Arabia and is a food source for the larvae of the plain tiger butterfly, *Danaus chrysippus* (Orwa et al., 2009). The poisons from this milkweed are absorbed by the butterfly and help protect it from predators like birds and lizards (Iyadurai et al., 2020).

2.7. Uses of *Calotropis procera* (Aiton) W.T.

A study by Al-Sodany et al. (2016) found that many people use *C. procera* (Aiton) W.T. in traditional medicine because its different parts contain active compounds. The bark, roots, and leaves, especially the milky latex from broken parts, have medicinal qualities. People use *C. procera* to treat problems like ulcers, tumors, leprosy, piles, and issues with the spleen, liver, and abdomen (Al-Sodany et al., 2016). The milky sap is strong and often used as a rubefacient (Orwa et al., 2009). Latex from the plant can treat ringworm, guinea worm blisters, scorpion stings, venereal sores, and eye problems. It is also a laxative (Orwa et al., 2009).

Kumar et al. (2001) noted that people use twigs from *C. procera* to make diuretics, stomach tonics, anti-diarrheals, and asthma remedies. The plant can also help with abortions as a treatment for lice, colic, cough, whooping cough, dysentery, headaches, sore gums, toothaches, sterility, swelling, and ulcers.

This tree produces fibers for making ropes, bags, nets, and paper (Orwa et al., 2009). Its seeds have a white silky floss that can be used as a silk substitute (Orwa et al., 2009). Wood is good for fuel and building (Orwa et al., 2009). In tough times, people can feed young pods and old leaves to goats, camels, and sheep (Orwa et al., 2009). However, the toxic latex can be harmful to livestock (Orwa et al., 2009).

Understanding how plants are distributed helps us learn about the health of ecosystems. Plants are essential for balance and provide benefits to other organisms. Various factors

influence where plants grow, including climate, soil type, terrain, and interactions with other living things. Some plants can only survive in specific environments, while others can thrive in a range of conditions. This ability affects their distribution. Plants also compete for limited resources like light, water, and nutrients, which can prevent some species from existing in certain areas, especially when invasive species replace native ones.

Soil type is important too; different plants need specific soil conditions. Differences in soil can affect where plants grow. Finally, events like wildfires, floods, and human activities can change plant distribution by creating spaces where new species can grow. The frequency and strength of these disturbances can impact the variety of plants in an ecosystem.

2.8 Response of native and invasive plants to moisture stress

According to Simberlof (2021), moisture stress is a significant environmental factor that impacts the growth and survival of plant species. Invasive plant species create a biological imbalance within ecosystems. Invasive species often have higher rates of transpiration, leading to increased water stress on surrounding native flora; this discrepancy in water usage can alter plant community dynamics, causing a decrease in the number of native species as they can adapt to drought. The ability of invasive species to thrive in disturbed environments often allows them to establish themselves in ecosystems where native plants are struggling to survive under the same stressors.

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Chapter 3 - METHODS AND MATERIALS

3.1. Description of the study area

This study was conducted along the roads in six locations within the Mopani District of Limpopo Province, South Africa. The six villages where the study was conducted are Dzumeri (23.5740°S, 30.6981°E), Phikela (23.3287°S, 30.3976°E), Ngove (23.3537°S, 30.7304°E), Nkomo (23.4175°S, 30.7789°E), Noble-Hoek (23.3612°S, 30.4318°E), and Ximausa (23.3741°S, 30.3515°E); all these villages are found in Mopani District in Giyani and others around Tzaneen. Giyani is at the crossroads of R578 and R81 (23.4208°S, 30.7063°E). It is located in the northern region of the former Gazankulu, in the heart of the Limpopo Bushveld, on the north bank of the Klein (Little) Letaba River, to the west of Kruger National Park (see Figure 4). Established in the 1960s, Giyani serves as the

administrative hub for the Tsonga people and also functions as the administrative center for the Mopani District Municipality.

The area is accessible via Tzaneen, the Phalaborwa Gate of the Kruger National Park, and Malamulele, which is approximately 470 kilometers northeast of Johannesburg. Tzaneen is located about 113.5 kilometers from Giyani.. The six different villages of the Mopani District Municipality were chosen because the *C. procera* (Aiton) W.T. was seen growing in relatively large numbers along their roadsides (Figure 6).

3.1.1 Population of the Mopani District Municipality

The total population size of the Mopani District Municipality is 1,372,873, from which the population of the Greater Giyani Local Municipality is 316, 841 (STATS SA, 2022). The nature of this population portrays that most of the inhabitants are black African females, as compared to male inhabitants. 80% of the people in the study area attended educational institutions, and most of them lived in formal settlements. The study area's population is growing because most inhabitants are between the age groups 0 to 19 years for two genders (Figure 5) (STATS SA, 2022).

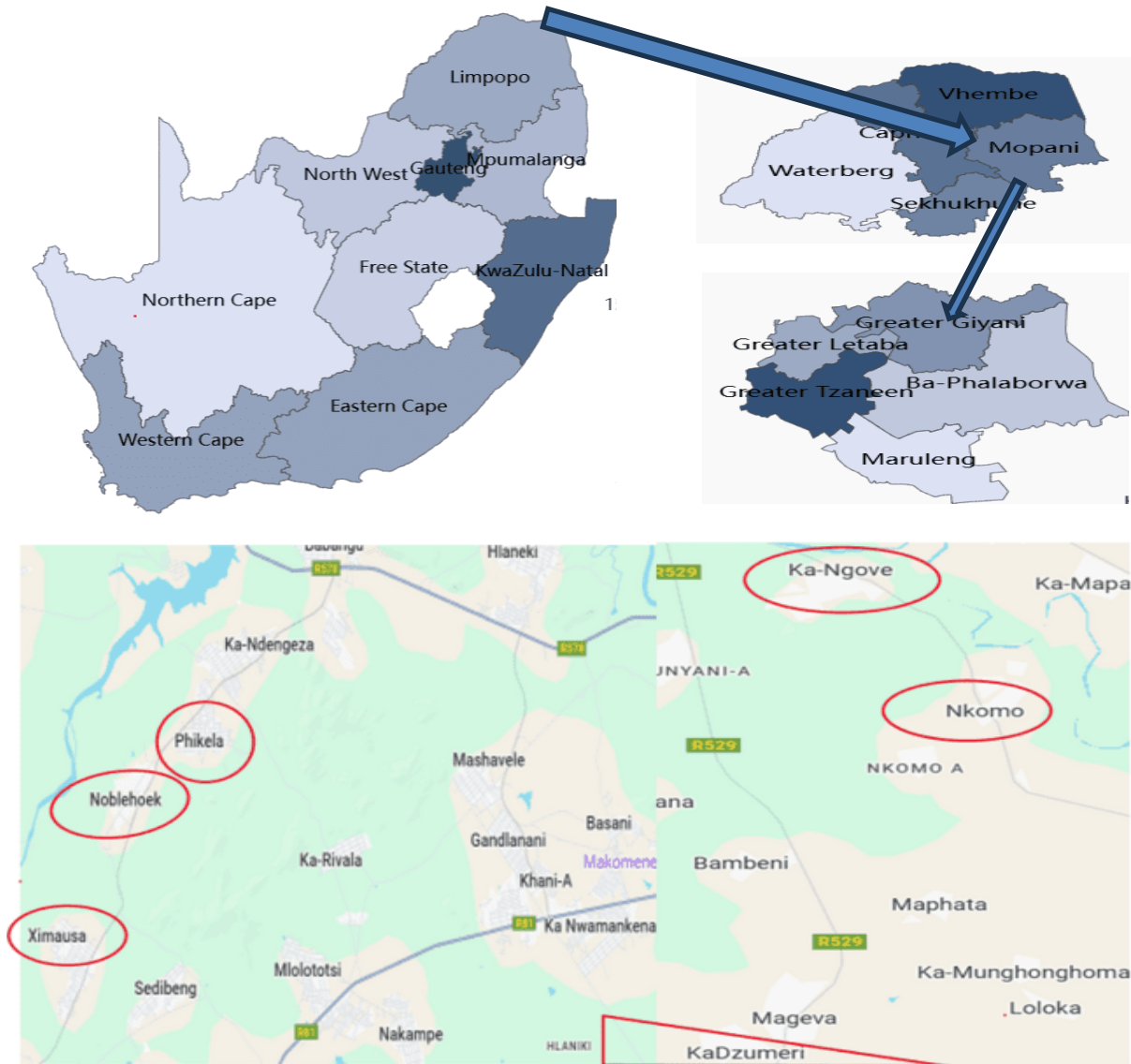


Figure 4: Map of the study area showing the Limpopo Province, Mopani District, Greater Giyani Municipality, and specifically, six data collection sites.

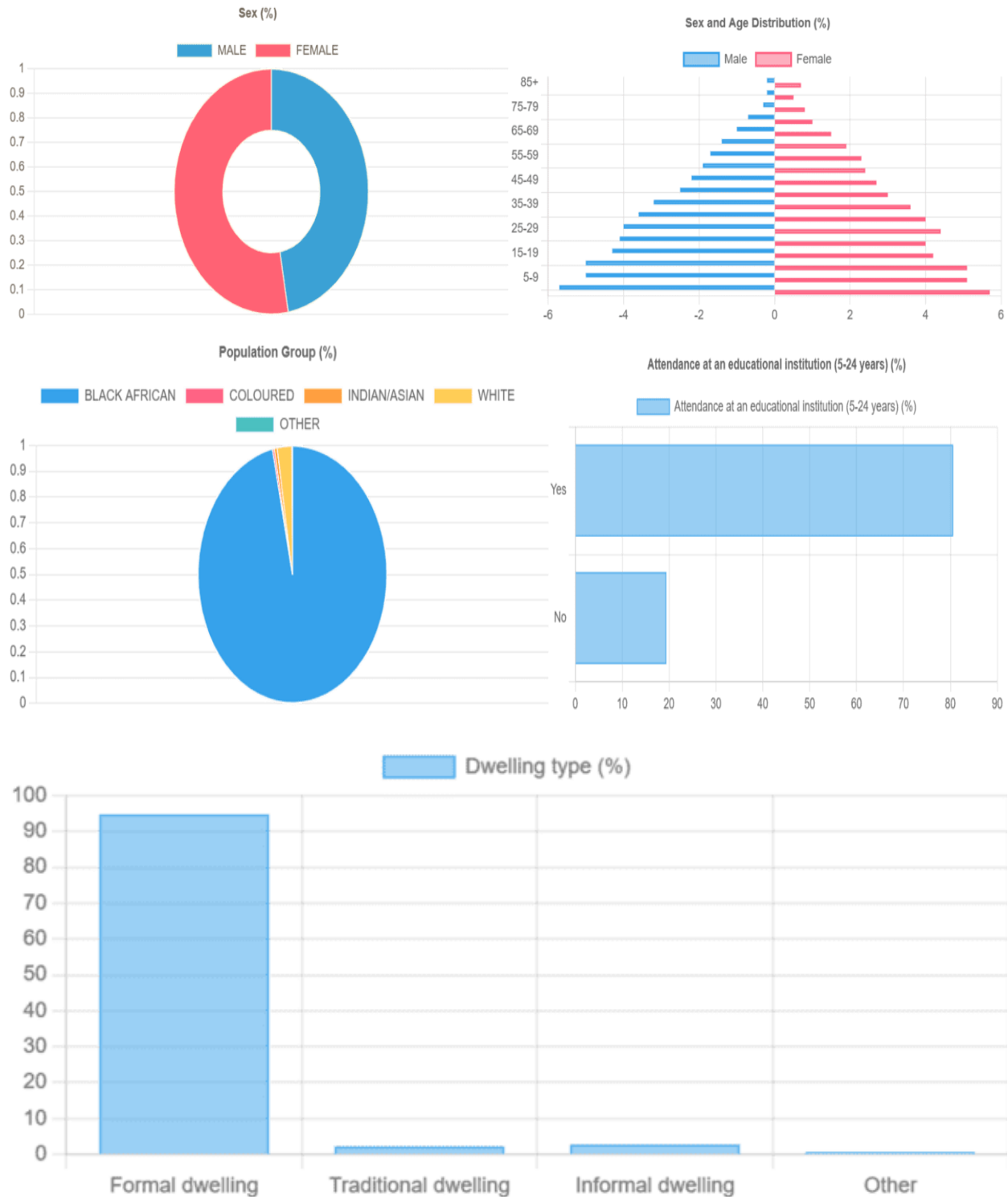


Figure 5: Demographic of the inhabitants of the Mopani District Municipality (STATS SA, 2022)

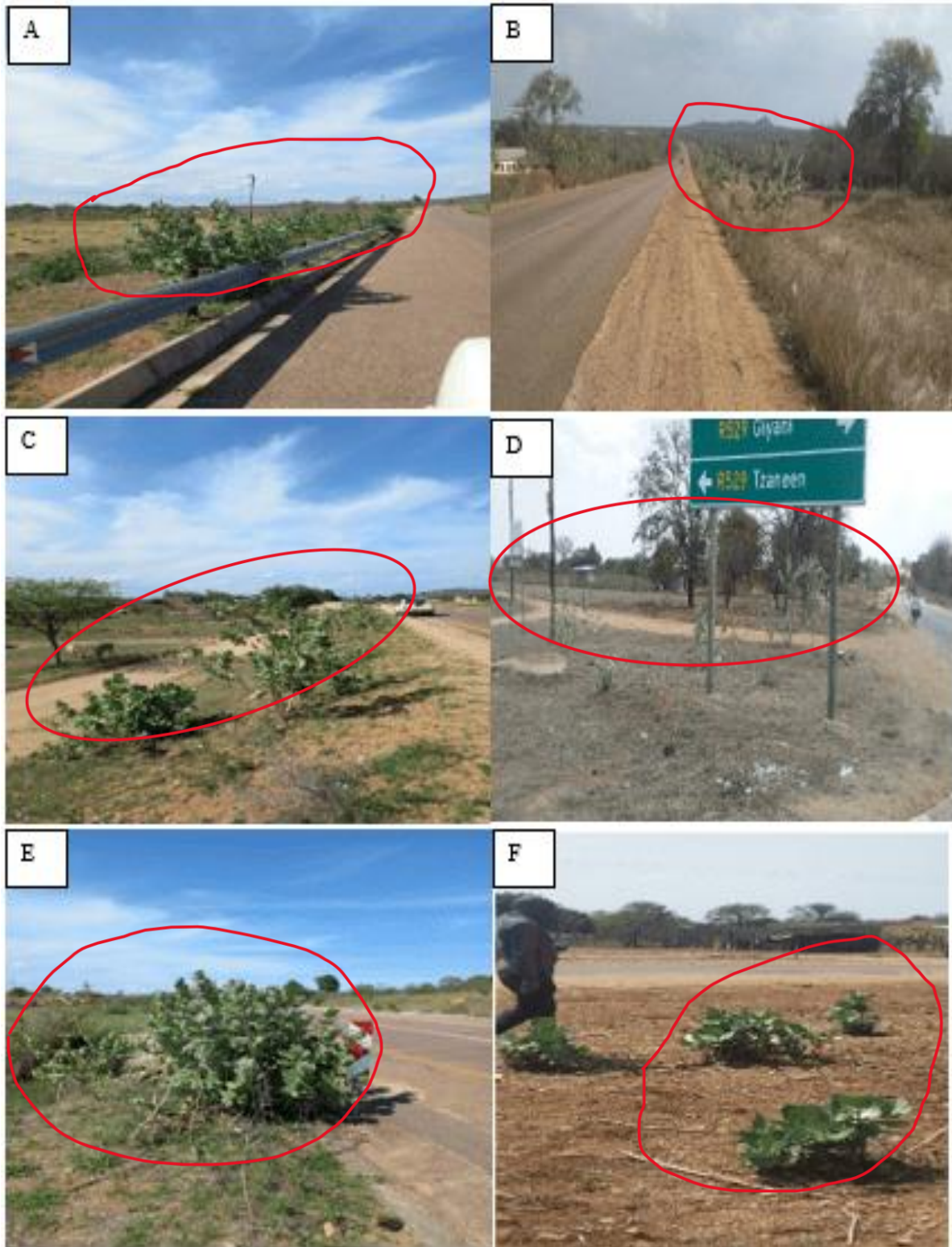


Figure 6: *Calotropis procera* along the roadsides of Noble Hoek (A), Ngove (B), Phikela (C), Nkomo (D), Ximausa (E) and Dzumeri (F) Villages.

3.1.2 Geological information of the study area

Calotropis procera (Aiton) W.T. grows in large numbers along the roads in all six villages we studied (see Figure 6). The soil in the Giyani area is mostly deep and well-drained Oxisols, with less than 30% clay. The irrigation water quality is generally good for farming, though it varies in pH and may sometimes have high nitrate (NO₃) levels, likely because of nearby populated areas. Most agricultural land in the Greater Giyani Municipality is government-owned and managed by local chiefs. Many farms operate under the Permission to Occupy (PTO) land system.

3.1.3 Climatical conditions of the study area

Giyani is in a sub-tropical zone. In summer, temperatures can reach as high as 41°C, while winter temperatures usually drop to about 25°C (Nembilwi et al., 2021) (Figure 7). Days in winter are mild, but nights can be quite cold. The rainy season runs from September to March, and winter lasts from April to August (Mutuwa, 2021) (Figure 8).

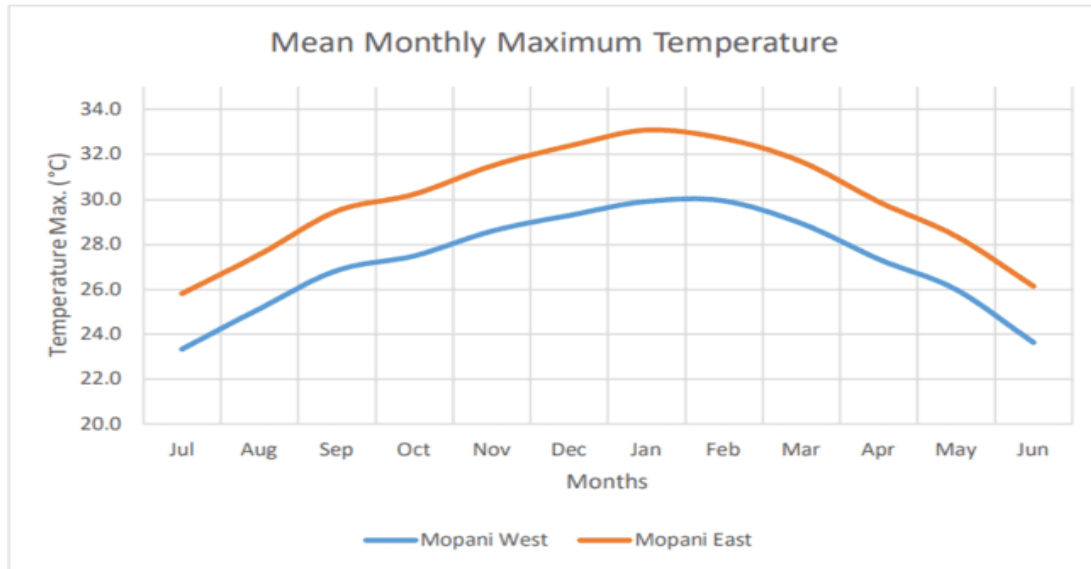


Figure 7: Mean monthly maximum temperature (Nembilwi et al., 2021)

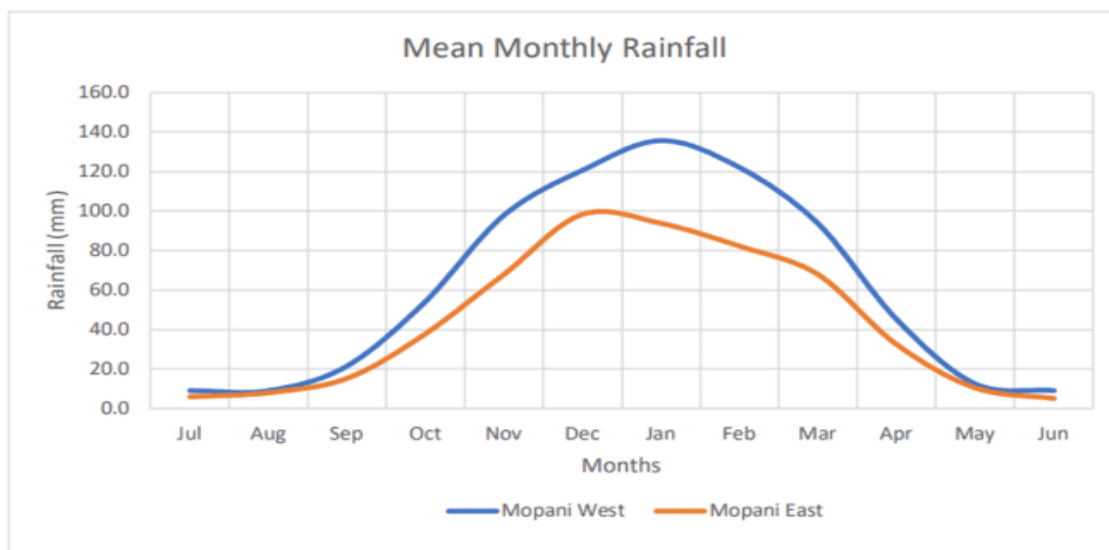


Figure 8: The rainfall season of the study area (Nembilwi et al., 2021)

3.2. Data Collection

3.2.1. Description of research design

The research was quantitative in nature because measurements of parameters such as canopy cover, stem circumference, and tree height were recorded. According to Mutuwa

(2021), quantitative research should be formal, objective, and rigorous, and the deductive approach and systematic strategies should be considered to refine knowledge for solving problems. To attain solutions to problems, the entire design should be either experimental or non-experimental to obtain accurate, valid, and reliable measurements of researched parameters (Das et al., 2008).

3.2.2. Description of the sampling method

Understanding the distribution pattern of *C. procera* (Aiton) W.T. emanated from applying the simple stratified sampling technique to construct the quadrats (Figure 9). This technique was chosen because it allows for a representative selection of the study area, considering the variability in vegetation cover. The study area was divided into strata based on the vegetation cover, and then quadrats were randomly selected from each stratum.

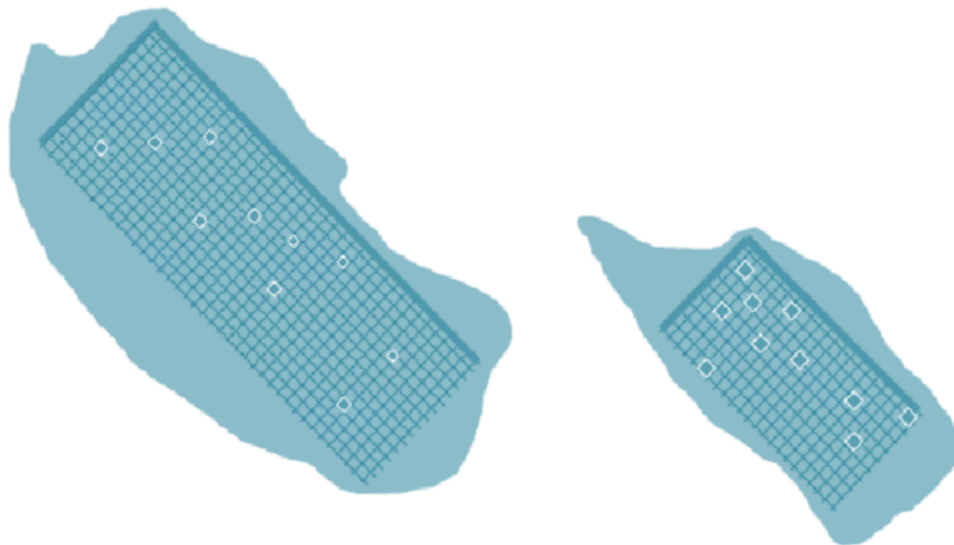


Figure 9: Simple stratified sampling technique employed during this research.
(Hankin et al. 2009; Smith and Jones 2010)

The purposive sampling method considered only plant species within the quadrants (Figure 10). The convenience method was also employed since all ages of the chosen plant species encountered in the quadrats were considered for data collection (Figure 10). These methods were chosen to ensure that the data collected represented the entire study area.

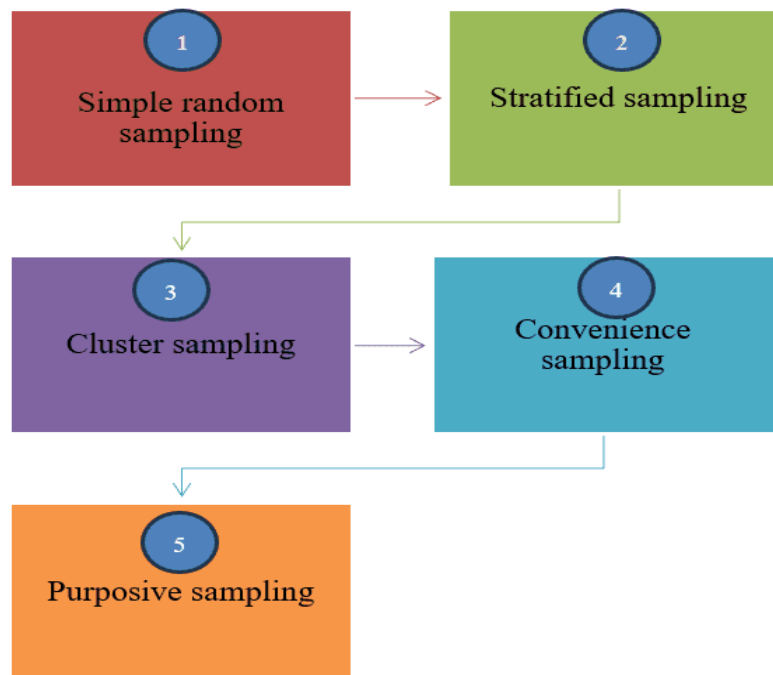


Figure 10: Description of the sampling method for constructing quadrats and selecting plant species for the measurements of parameters (Hankin et al., 2009; Smith and Jones 2010).

3.2.3 Data analysis

We used the Analysis of Variance (ANOVA) single-factor test to see if there are significant differences in the distances between neighboring plants and the distribution of plant populations in the six study sites. To understand how *C. procera* is spread throughout these villages, we applied a method by Clark and Evans (1954). This method helps us

find out if the plants are spread out randomly, spaced evenly, or grouped together. We used a specific formula to determine the distribution pattern.

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

In this analysis, $\bar{r}A$ represents the mean distance to the nearest neighbor, while $\bar{r}E$ represents the mean distance to the nearest neighbor that would be 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 determined by taking the average distance between the *C. procera* (Aiton) W.T. trees and dividing it by half the square root of the total number of trees, as specified by the formula.

If the R-value is equal to 1, it indicates that the population is scattered irregularly. An R-value greater than 1 signifies that the population is scattered regularly, whereas an R-value less than 1 suggests that the population is clustered. ANOVA was utilized to assess whether there were significant differences in the distances between tree populations across all six villages.

3.3 Description of sampling methods, data collection techniques, and data analysis for specific objectives

3.3.1 Sampling method for the determination of the distribution pattern of *Calotropis procera* (Aiton) W.T.

The distribution of *C. procera* (Aiton) W.T. in some parts of the Mopani District was assessed through a study. A straight-line transect of 100 meters was established, and all plants within this transect were counted and measured. The parameters measured included the nearest neighbor distance between pairs of adjacent individuals, plant heights, and the canopy cover of those nearest neighboring plants. Additionally, the number of individuals in each quadrat was recorded.

Tape measures were used to gather all measurements. The nearest neighbor distances were calculated using the Clark and Evans technique (1954) to estimate dispersion indices. Plant heights and canopy sizes were measured to help group individual plants into the same cohorts. In cases where the tape measure was not long enough, the height of the tallest person in the field was measured, and that person stood next to each plant for comparative measurements. The size of the plant was then estimated based on the height of that person. This method of measuring plants was consistently applied throughout data collection in all villages.

3.2.2 Data collection on the interaction between *Calotropis procera* plants

To evaluate the association of *C. procera* (Aiton) W.T. growing alongside each other, hundred meters by hundred-meter quadrats were constructed along and away from the roadsides. Distances, heights, and canopy sizes of a nearest neighbour of *C. procera* (Aiton) W.T. plant individuals were observed and measured to estimate their distances and sizes.

The question of how far apart the pairs of individuals of *C. procera* Aiton (W.T.) of different mixed-size classes were taken into cognisance for measurements; thirty-five pairs of individuals were measured per village to observe how the plants are spaced as per different age classes (Figure 11). The nearest neighbour method employed by Pielou (1960) was utilised for data analysis.



Figure 11: Measuring the distance between the plants.

3.3.3 Data collection on the phenology of *C. procera* (Aiton) W.T.

The photography research method was used in field observations, where pictures of flowering, fruiting, and seeding stages were taken from each site or village visited. Pictures were taken as shown in Figure 12 below. Furthermore, flowering, fruiting, and seeding plants were identified, and some pictures were taken, as seen below. The phenology aspects referred to above were observed seasonally. To avoid the element of bias, the side of the road on which was chosen to be observed was randomly chosen by following the coin-flipping approach. For example, if the coin is flipped to the head side, then the right-hand side of the road is the section of the village considered for data collection, and if it flips to the tail side, then the left side is chosen. Observation around the development of flowers, fruiting and maturity period, and seed dispersal were captured. This was done for 24 months. Pictures were taken of different phases for different seasons: autumn, winter, spring, and summer (Figure 12). Data was analyzed after collection.



Figure 12: Pictures taken at different phenological stages in different seasons.

3.3.3 Data collection for determination of seed production rate of *C. procera* (Aiton) W.T. from the six villages

To achieve this objective, a straight line transect of 100 m was created, and *C. procera* (Aiton) W.T. trees of the same height (1.4 m) were sampled for the evaluation of seed production. This sampling method compelled a sample size of 8,5,6,8,5 and 5 *C. procera* (Aiton) W.T. individuals from Nkomo, Ximausa, Dzumeri, Ngove, Phikela, and Noblehoek, respectively. The final population size for all the villages was 5 tree species for the reason of accommodating the villages with only five samples according to the determined height

of (1.4m). The first five sampled tree species were considered from the villages where there were more than five samples. Furthermore, the random sampling (coin flipping) method was employed to select four fruits from the sampled trees.

This method was necessitated by the four directions of the compass wherein the first head side of the flipped coin instructed the collection of the mature fruit from the southern side of the center of the tree canopy. Subsequently, the second head side of the flipped coin instructed the collection of mature fruit from the northern side of the center of the tree canopy. Conversely, when the coin was flipped to the tail side, the collection of mature fruit was from the eastern and western sides of the tree canopy for the first and second times, respectively. The fruits were then collected, and their lengths were measured using the meter ruler. Fruits were opened, and the seeds were counted individually to understand the insights about the seed production rate.

3.4. References

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Chapter 4- RESULTS

4.1 Distribution patterns of *Calotropis procera* (Aiton) W.T. and its impact on neighbouring plant species

The investigation into the distribution of *C. procera* (Aiton) W.T. reveals distinct patterns across different locations. Ka-Ngove has the highest number of individuals (127) and the greatest sum of neighboring distances (302.51), indicating a more dispersed population. In contrast, Noble-Hoek has the lowest number of individuals (38) and the smallest sum of neighboring distances (100.3), suggesting a more clustered distribution (Table 1). Phikela village stands out with a significantly higher Ra value (44), indicating a higher degree of aggregation compared to other villages. It also has the highest density value (56.8), reflecting a densely populated area. Conversely, Noble-Hoek has the lowest density (16.2) but the highest Re value (65.8), indicating a different distribution pattern, possibly more evenly spaced individuals (Table 1 and Figure 13).

Ka-Ngove's highest distribution ratio (0.3) suggests a more uniform distribution, while Noble-Hoek's lowest ratio (0.01) points to a highly clustered distribution. These variations imply that environmental factors and local conditions significantly influence the distribution patterns of *C. procera* (Aiton) W.T. in these regions (Table 1 and Figure 13). All in all, the dispersion index for all villages was found to be less than 1, implying that the individuals were distributed in an aggregated or clumpish manner in all villages.

Table 1: Total number of individuals from the constructed quadrats per village, the sum of neighboring distance, and the distribution ratios.

Villages	Total Number of Individuals	Sum of Neighboring distance	Ra	Density	Re	Distribution ratio
Ka-Ngove	127	302,51	2,38	19,7	8,8	0,3
Dzumeri	51	123,7	2,4	49,01	14,01	0,2
Nkomo	50	140,11	2,8	50	14,14	0,2
Phikela	40	112,5	44	56,8	15,05	0,16
Noble-Hoek	38	100,3	2,6	16,2	65,8	0,01
Ximausa	60	160,11	2,7	41,7	12,9	0,2

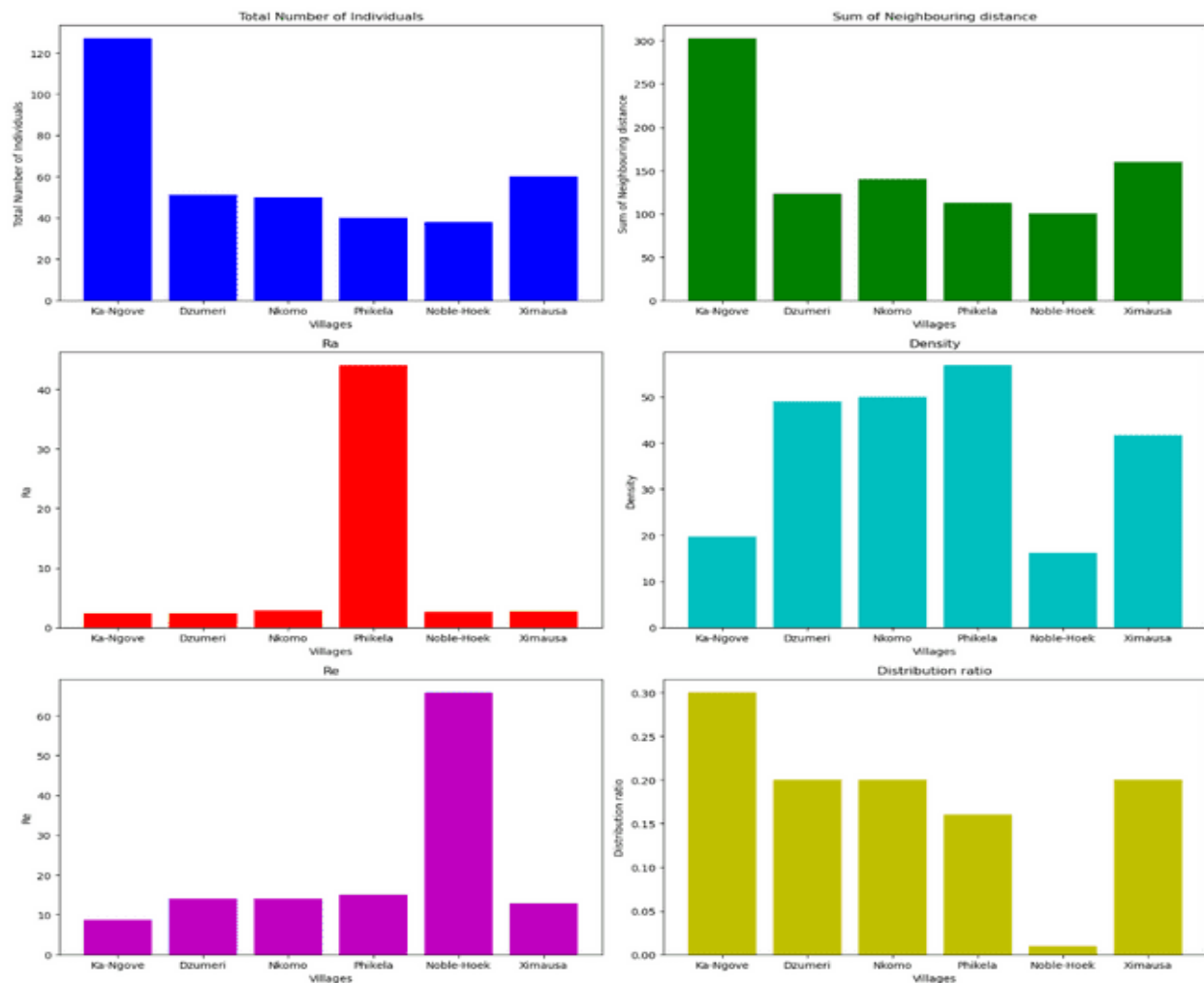


Figure 13: Total number of individuals, Ra value, Re value, sum of neighbouring distance, Density, and distribution ratios of *Calotropis procera* (Aiton) W.T.

4.1.1 Distribution

Plants were generally found distributed in clustered pockets in the villages where they are distributed in semi-arid areas, which might imply that the individual plant species are surviving in semi-arid areas (Figures 14).

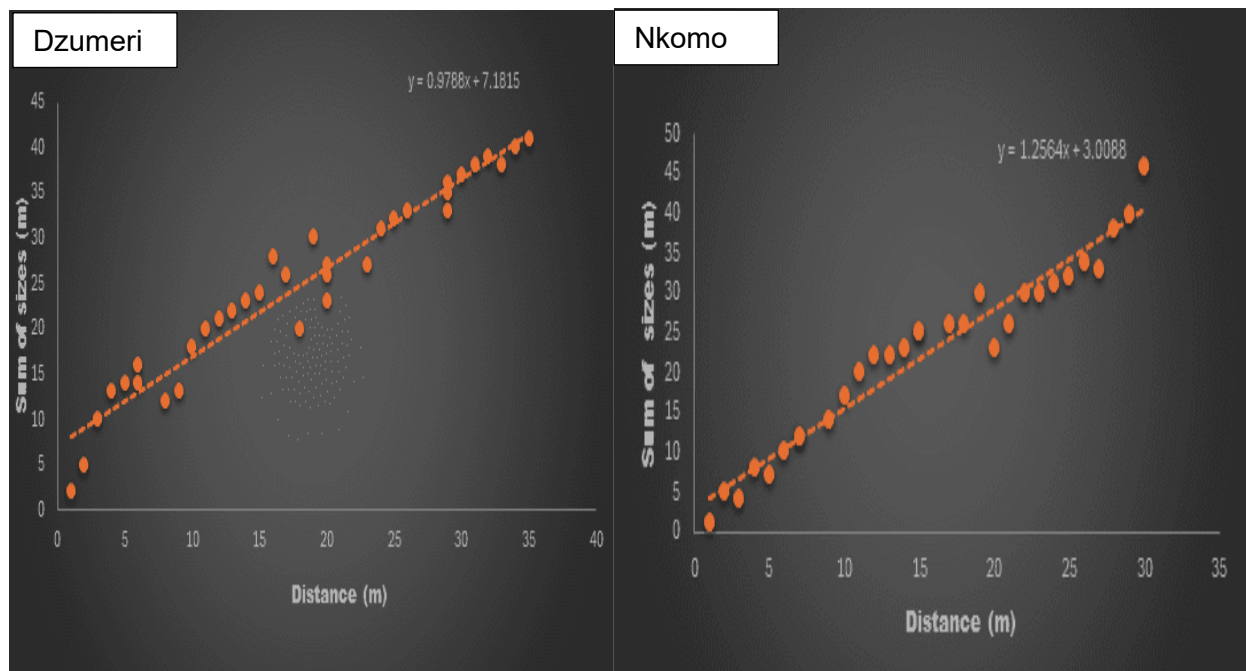


Figure 14: The graph showing the sum of sizes (m) of *C. procera* (Aiton) W.T. and the distance (m) in the nearest neighbour of Dzumeri and Nkomo villages, respectively.

The reason for the clustered distribution in their areas of occurrence is that some of the seeds are seen dispersed together in abundance and fall together, being numerous near each other (Figure 15).

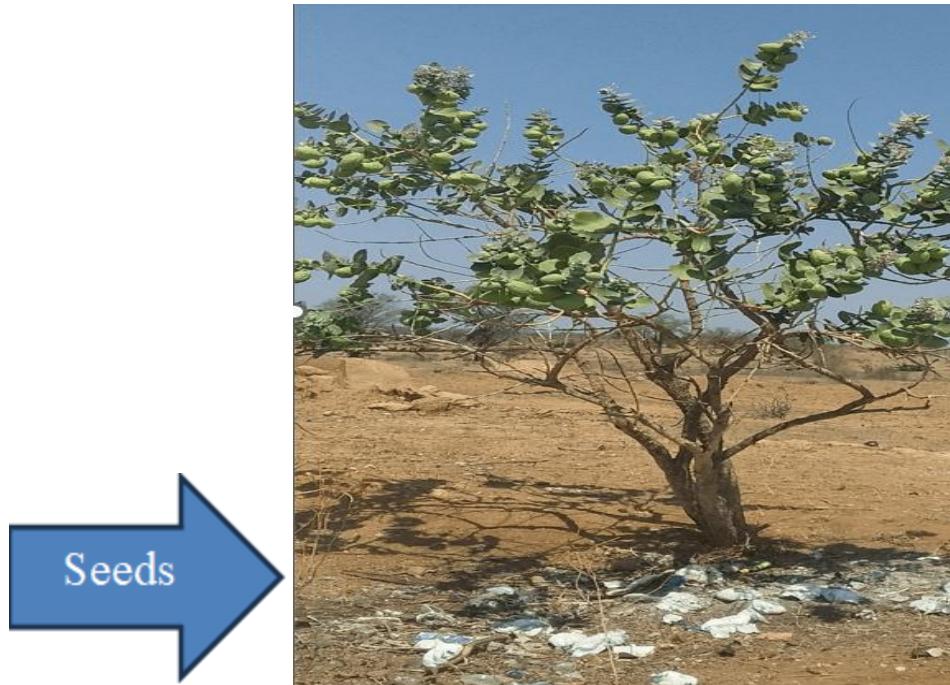


Figure 15: Seeds of *Calotropis procera* Aiton (W.T.) plant dispersed abundantly on the ground.

The soil type of the six villages was found to be hard, red loamy soils. During field observation, the seeds were found to be blown away by wind to a distance away from their parent plants. Also, the seeds can be spread some distances by wind and water. Also, seeds could be seen dispersed in muddy surroundings where they became attached to water-drinking animals and vehicles when driving through the water. This induced the different distribution patterns of *C. procera* (Aiton) W.T. to appear across the 6 villages. In some villages, *C. procera* (Aiton) W.T. was found growing in large numbers, and in other villages, there were fewer. The reason for this might be that in villages like Dzumeri and Nkomo, the introduction was done a bit earlier as the plants were also big in size. On the contrary, *C. procera* (Aiton) W.T. growing in villages like Ximausa, Ngove, and Noble-Hoek appeared scattered (Figure 17), the pattern which is slightly different from the one

seen in Dzumeri, Nkomo, and Phikela. The individuals of this plant looked attractive, were young plants, and occurred in fewer numbers.

The distribution pattern seemed the same in villages like Nkomo, Dzumeri, and Phikela simply because they were many in number and clustered. Probably, this is caused by the earlier introduction of *C. procera* (Aiton) W.T. to the three villages mentioned. On the other hand, the dispersion index for *C. procera* (Aiton) W.T. individuals in the two villages was less than one, meaning that the distribution pattern is clustered (Figure 16).

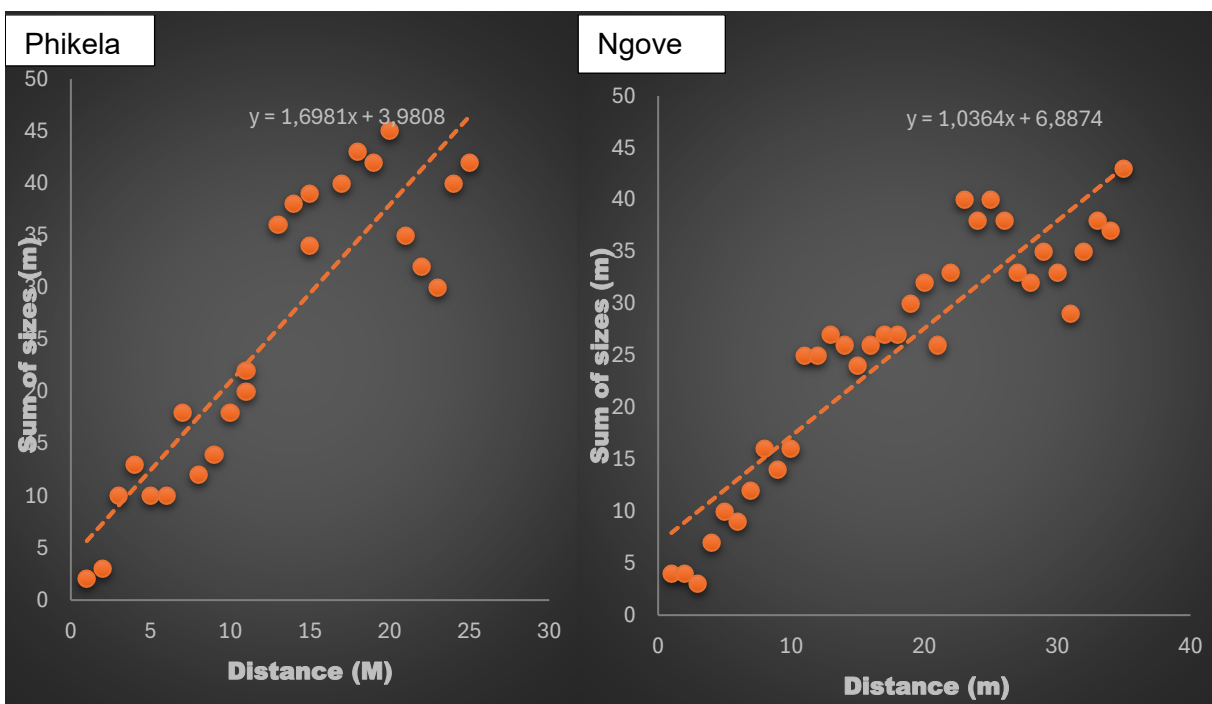


Figure 16: The graph shows the clustering distribution pattern of *Calotropis procera* (Aiton) W.T. individuals growing in Phikela and Ngove villages, respectively.

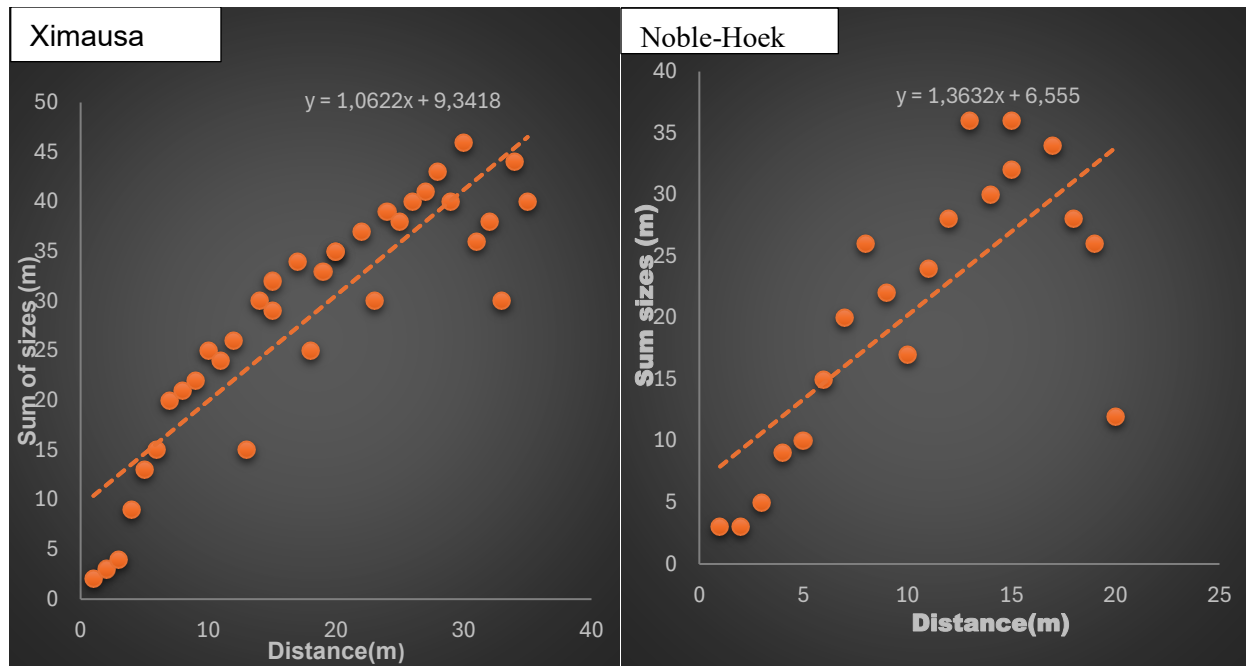


Figure 17: The graph shows the clustering distribution pattern of *Calotropis procera* (Aiton) W.T. individuals growing in Ximausa and Ngove villages, respectively.

The one-way ANOVA test was conducted to determine if there are statistically significant differences in *C. procera* (Aiton) W.T. distribution patterns across different villages. These results (Table 2) were generated from Microsoft Excel, where parameters, including the total number of individuals, the sum of neighbouring distances, Ra, density, Re, and distribution ratio, were analysed. The ANOVA results demonstrate that the distribution pattern of *C. procera* (Aiton) W.T. varies significantly between the villages. This implies that local environmental factors, its resisting strategies, or other ecological variables might be influencing the population density and distribution of this species in different areas. Understanding these differences can help in developing targeted management strategies to control the spread of this invasive species.

Table 2: One-way ANOVA results of the total number of individuals, sum of neighbouring distances, Ra, density, Re, and distribution ratio of *Calotropis procera* (Aiton) W.T. samples from the six villages of the Mopani District Municipality. Results are significantly different at $p < 0.05$.

Parameters		Total number of individuals	The sum of the neighbouring distance	Ra	Re	Density
Statistical values	F-value	12.34	10.56	8.45	9.23	15.67
	P-value	0.0021	0.0035	0.0078	0.0054	0.0012

4.1.2 Seed production of fruits of *Calotropis procera* (Aiton) W.T.

The line graph (Figure 18) shows the average lengths of *C. procera* (Aiton) W.T. 's fruits for the six different villages. These results emanated from the lengths of four fruits sampled from five different tree species in each of the six villages. Overall, the graph indicates that different villages have varying trends across the sampled species, with some showing significantly large sizes while others have more stable values. Additionally, the statistical analysis results showed no significant differences, as the p-value was found to be greater than 0.05 (Table 3).

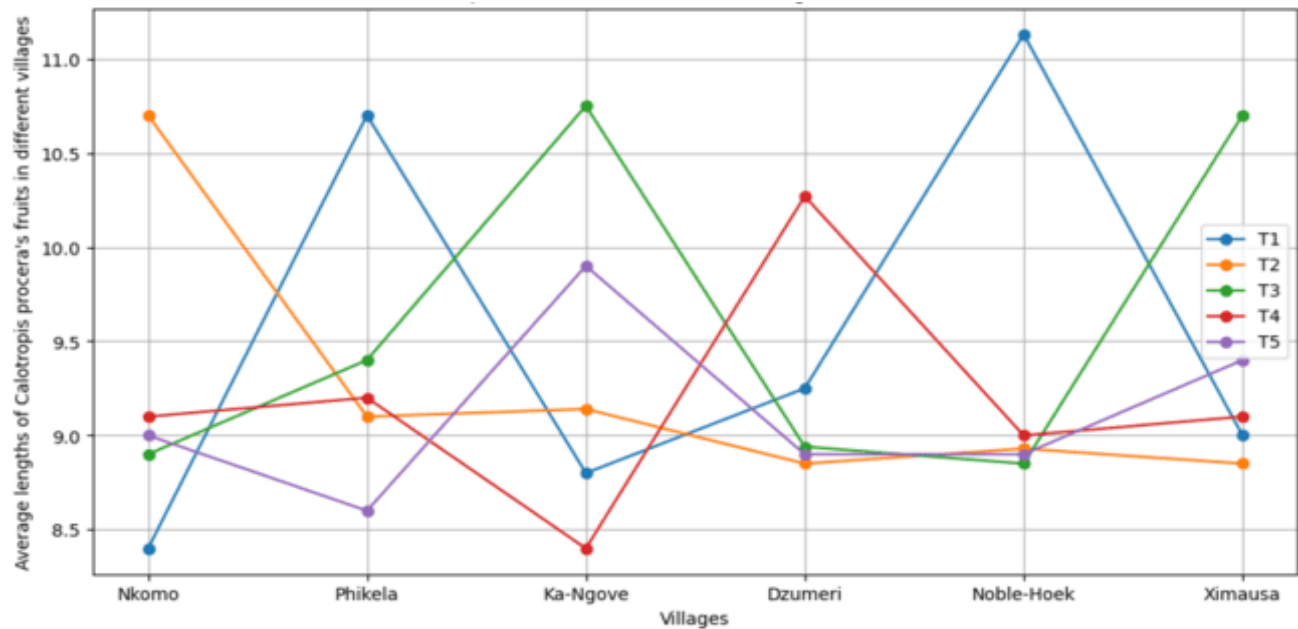


Figure 18: The line graph shows the average lengths of *Calotropis procera* (Aiton) W. T.'s fruits for the six different villages

Table 3: Statistical analysis for *Calotropis procera* (Aiton) W. T. in different villages, $p > 0.05$.

Statistical values	Value
F-value	0.0526
p-value	0.9980

The line graph (Figure 19) shows the average number of seeds in fruits of five *C. procera* (Aiton) W.T. species sampled in six villages. Variations in the number of seeds were observed across the six villages. For example, tree 2 showed a peak of 93 seeds, whereas tree 1 had the lowest (59) seeds at Nkomo village. In the case of Phikela, tree 1 had the highest (97) number of seeds compared to the lowest (61) number of seeds of tree 2. The same trend appeared in other villages where trees 3 and 4 also had the highest number of seeds. Most interestingly, the lowest number of seeds counted from

all the sampled fruits is 59, which exceeds 50% of the production rate. This implies that this plant produces as many seeds as possible to enable its distribution, which will result in the power of its encroachment into local ecosystems.

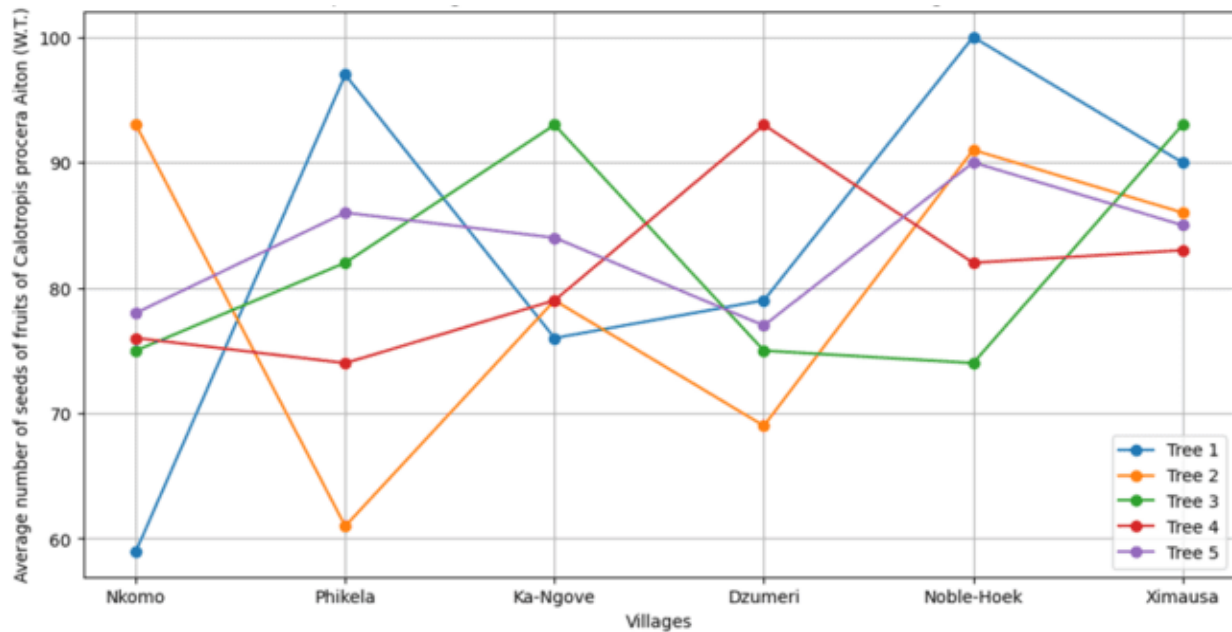


Figure 19: Total number of seeds counted from fruits of five different *Calotropis procera* (Aiton) W.T. species of six different villages of the Mopani District Municipality.

The One-Way ANOVA Test results indicate a p-value greater than 0.05 (Table 4). This indicates that the differences in the average number of seeds in fruits among the different villages are not statistically significant. In other words, there is no significant difference in the average number of seeds in the fruits across the six villages.

Table 4: One-way ANOVA

Statistic	Value
F-value	1.1446
p-value	0.3645

4.1.3 Phenology of *Calotropis procera* (Aiton) W.T. (its flowering, fruiting, and Seed dispersal patterns)

Table 5: Flowering, Fruiting and Seed dispersal of *C procera*

Flowering	Fruiting	Fruit maturity	Seed dispersal
All year round	August	October	November- December
 <i>Calotropis procera</i> (Aiton) W.T. was observed to have flowers every season of the year.	 At this time of the year <i>C. procera</i> (Aiton) W.T. was found fruiting. This scenario was observed at the same time during the data collection period of 24 months.	 The fruits are matured and start to open so that the seeds are exposed for drying purposes.	 The seeds were seen being blown away by the wind from one side of the road to the other side of the road and into the villages; they were collected for clear observation.  During this period, <i>C. procera</i> (Aiton) W.T. shed the dried fruits completely.

Chapter 5- Discussion

5.1. Habitat of *Calotropis procera* (Aiton) W.T.

Calotropis procera is known to invade polluted areas, contaminated sites, and rehabilitated mines. It also has a strong presence near unmanaged crop fields, where it may negatively impact crops through allelopathy, as illustrated in Figure 15. According to Kaur et al. (2021), this plant is commonly found in wastelands, overgrazed pastures, and poorly managed agricultural fields, earning it the designation of "invasive weed" in these environments. *Calotropis procera* demonstrates tolerance to various abiotic stresses such as drought and extreme temperatures, allowing it to colonize and establish itself in degraded habitats. Additionally, *C. procera* (Aiton) W.T. is recognized as a phytoaccumulator of several heavy metals, including manganese, lead, chromium, iron, copper, nickel, strontium, and cadmium (D'Souza et al., 2010).

5.2. Origin

Calotropis procera, commonly known as akanda, is a plant that grows in tropical areas of Asia and Africa. It is found in West Africa and extends south to Angola, as well as in North and East Africa, Madagascar, the Arabian Peninsula, and southern Asia, including Indochina and Malaysia. This plant has also spread to Australia, many Pacific Islands, Mexico, Central and South America, and the Caribbean Islands. In Bangladesh, akanda commonly grows in wastelands and along roadsides, especially in rural areas. In South Africa, *C. procera* is commonly found along roadsides from Giyani to Tzaneen and around villages. This widespread distribution is likely due to the plant's light, hairy seeds, which are easily dispersed by wind, allowing them to travel long distances and establish themselves in various locations, including within and around villages.

The prolific seed production of *C. procera* (Aiton) W.T. contributes to its extensive distribution. Each plant produces multiple fruits, with each fruit containing numerous seeds that are readily dispersed. Navarrete-Sauz et al. (2024) noted that *C. procera* (Aiton) W.T. can produce over 300 seeds per fruit, primarily dispersed by wind, enhancing its ability to colonize large areas.

The presence of *C. procera* (Aiton) W.T. on both roads is attributed to the wind dispersal of seeds from one side to the other. The clustered distribution pattern of these plants is due to the deposition of seeds in large numbers in specific areas. This phenomenon was observed in a village where seeds fell from the parent tree and remained dormant until conditions were favorable for germination.

5.3. Reproduction

Individuals of *C. procera* (Aiton) W.T. were found to produce abundant flowers, fruits, and seeds. Other researchers mentioned that *C. procera* (Aiton) W.T. primarily propagates through seeds, with its green and slightly adhesive pollen being transferred through cross-pollination facilitated by insects, notably the monarch butterfly (*Danaus plexippus*) (Moustafa et al., 2017). The assurance of cross-pollination is also facilitated by its large flowering stalks that attract more pollinators, potentially enhancing pollen transfers more efficiently. The seeds of *C. procera* (Aiton) W.T. are equipped with a silky pappus aiding in wind and animal dispersal, and they can also be transported over long distances by floodwater. Moreover, it reproduces through vegetative means such as half stumps, stems, and root suckers (Moustafa et al., 2017).

The bird's eye-catching phenological characteristic of *C. procera* (Aiton) W.T. is that it produces flowers nearly all year round. This was evident in all villages visited during the study, and these flowers are always attractive in each season of the year. Moreover, they do not lose their attractiveness due to seasonal change, so their pollination occurs at any time of the year. Hassan et al. (2015) attest that the flowers of *C. procera* (Aiton) W.T. increase after rainfall with increasing air temperatures. As alluded to by Nembilwi et al. 2021, the temperatures of the study area can reach a maximum of 33°C, and this climatical condition is a suitable incubator for the establishment and spread of *C. procera* (Aiton) W.T.

Fruiting is limited to the warm months of the year when pollinators are abundant; the fruits are said to be ellipsoid or ovoid, containing 350 and 500 seeds with tufts of white, silky hairs or pappus (Hassan et al., 2015). In all six villages fruits were observed starting from the month of August, a month in which the temperatures of the Mopani District start to rise. The fruits had several seeds ranging from 59 to 100. Even though they had not yet matured, these fruits were thick and spongy. A single tree had approximately 50 fruits, and all these fruits reached the maturity stage since they did not have much disturbance. It was observed that fruits of *C. procera* (Aiton) W.T. open naturally to expose brownish-coloured seeds from October to December, and this pattern was observed in all villages. Navarrete-Sauza *et al.* (2024) reported that the fruit opens completely and inverts when matures, exposing the seeds to dispersed; the fruit starts by drying out, and then the seeds will be exposed before dispersal. Additionally, Navarrete-Sauza *et al.* (2024) observed that the number of seeds per fruit can be related to the number of individuals with potential to establish themselves under adequate conditions. Correspondingly, Kaur

et al. (2021) reiterated that these plants thrive alongside the road because they produce more seeds, which are easily dispersed and germinate. Moreover, the plant has enormous potential to endure stress caused by roadside pollution and contaminated soils (Kaur et al. 2021).

5.4. Interaction of *Calotropis procera* with neighboring plants

General observations indicated a varying abundance of individuals across different sites, with fewer individuals present in some areas due to competition between *C. procera* (Aiton) W.T. and grasses. *Calotropis procera* (Aiton) W.T. struggles to compete with tall weeds, bushes, and grasses, preventing it from invading intact grasslands (Kaur et al., 2021). This explains its proliferation along roadsides, where disturbances from construction create open environments conducive to its growth.

In sites where *C. procera* (Aiton) W.T. was predominant, the species was found in large numbers, suggesting reduced competition with other plant species, such as grasses. Observations within a protected schoolyard revealed that *C. procera* (Aiton) W.T. individuals grew to larger sizes, indicating favorable conditions with minimal competition. The spacing between *C. procera* (Aiton) W.T. plants varied, with larger individuals spaced further apart, likely due to competition for nutrients. Smaller plants were observed growing closer together. This pattern suggests that nutrient competition influences plant size and distribution.

Calotropis procera (Aiton) W.T. appears to be invading the roadsides of Mopani District due to its morphological traits, ability to thrive in semi-arid conditions, and prolific seed production. The species' year-round flowering enhances its reproductive success, leading

to continuous seed production and dispersal. *Calotropis procera* (Aiton) W.T. was observed to grow well alongside the grass, but in areas with larger plant species, only one or two individuals were found, and they did not flourish as they did in open areas with grasses and small herbs. This indicates that *C. procera* (Aiton) W.T., like many invasive species, thrives in open grounds with minimal competition from larger plants.

The biological characteristics of *C. procera* (Aiton) W.T. are typical of invasive plants, including rapid growth, high seed production with efficient wind dispersal, a non-specialised pollination system, and high tolerance to poor soils. In Australia, *C. procera* (Aiton) W.T. has been declared an invasive species, with control strategies recommending mechanical removal of the tree, including its deep tap root and lateral roots, to prevent suckering. Additionally, competition with tall weeds or bushes, particularly grasses, may effectively weaken *C. procera* (Aiton) W.T. and inhibit seed germination. Other studies recommend chemical control for larger colonies (Moustafa, 2017). Observations confirmed that areas with tall weeds, hard grasses, and large trees had fewer *C. procera* (Aiton) W.T. individuals.

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Chapter 6- CONCLUSION

6.1 Conclusion

The study's findings indicate that the phenological processes of *C. procera* (Aiton) W.T. occur consistently during the same season each year. The species produces flowers throughout the year and generates an abundance of seeds dispersed by wind and animals. It is recommended that *C. procera* (Aiton) W.T. be removed between February and April before fruit production begins. During removal, the plants should be dug out, and chemicals should be applied to the area to prevent regrowth.

However, caution is necessary when using chemicals, as they may harm co-occurring grass. Management is advised during colder months when pollinator activity is low, and the plants are not actively producing (Kaur et al., 2021).

In South Africa, *C. procera* (Aiton) W.T. has been classified as an invasive species, particularly in parts of Limpopo Province, including the study areas of the current survey. Local villagers are generally unaware of the plant's invasive status despite its classification as a NEMBA 1B species, which mandates removal. There is a need to educate villagers and municipal authorities on effective removal techniques and the optimal timing for eradicating *C. procera* (Aiton) W.T.

6.2. Recommendations

The Municipality and Environmental Management team should start removing the *C. procera* (Aiton) W.T. plants along the roadsides of Mopani District Municipality before the plants become a bigger problem than they are right now. The villagers also need to know

what it is that is growing in their villages. It was mentioned in other studies that the plant possesses some medicinal properties. Therefore, another recommendation is that more research should be conducted to understand and investigate the possible medicinal uses of *C. procera* (Aiton) W.T., which will, in a way, reduce its existence.

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