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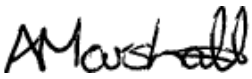
The complex socio-ecological system of the lowveld marula bioeconomy catchment

Amy Marshall Blair

A thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

1 February, 2021 in Johannesburg, South Africa

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



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Amy Marshall Blair

Submitted for examination on 20 April 2020

Abstract

The iconic species *Sclerocarya birrea* subsp. caffra, locally known as marula, is an ecologically important savanna tree, valued as much culturally as it is economically. Marula is a keystone species and vital natural resource with limited demographic data on the current population status outside of conservation areas. Communities harvest marula within non-conservation area communal lands in the lowveld region of far north-east South Africa. Across these non-conservative savannas, marula is an important source of non-timber forest products (NTFP), with populations affected by a range of socio-economic factors. Specifically, marula products provide livelihood sustenance for local communities in these savanna woodlands of southern Africa. However, the fruit products are increasingly being commercialized, which in addition to heavy reliance on fuelwood, is increasing resource pressure and starting to degrade this resource. As an ecologically important savanna species, it is imperative to understand if this resource use is sustainable. Understanding environmental degradation requires examining landscape changes over multiple spatial and temporal scales.

Landscape ecology emphasises patterns, processes and scales that result from combined ecological and social drivers of change. Addressing environmental degradation within complex socio-ecological systems (SES) necessitates the coupling of ecological and social sciences in order to interrogate the mutual interactions between the social and environmental elements of the system. Applying a socio-economic lens to environmental degradation further links social meaning and symbolism to physical findings, allowing social ecologists to comprehend SES contexts where ecological data alone tells an incomplete story. With increasing environmental degradation, the imperative to combine quantitative data with qualitative research, in order to address the underlying causes of SES change, has never been more pertinent. Considering the context of the complex SES of the lowveld marula bioeconomy, marula trees are utilised for a variety of socio-economic reasons across different land-use types in these non-conservation areas. Understanding if resource use is sustainable requires therefore interrogating population demography across different land-use types.

The aim of this study was to provide an updated inventory of marula population demographics linked to resource utilisation practices. As a heavily utilised natural resource, marula demographic data is used as a key indicator of population changes across not only land-use types, but also geographical zones. The key ecological indicators of marula density, gender ratios, mortality, tree damage, maturity ratios and size-class distributions were used to gauge marula population demographics within the lowveld areas of Phalaborwa and Bushbuckridge. Additionally, temporal comparisons are provided for the Bushbuckridge area, where a previous data set exists, allowing for a 15-year comparison. Ecological data from 5832 surveyed marula trees coupled with 240 individual household interviews and numerous informal focus groups were combined to understand the marula bioeconomy catchment. Social data for different behaviour patterns were used to provide context and explain anomalies in the population demographic data.

Marula tree population data were gathered in rangeland transects and randomly selected fields and yards from eight human settlements, divided equally between the Bushbuckridge and Ba-Phalaborwa municipalities. Population structures can be gauged by comparing tree density and size-class distribution (SCD) profiles across the three land-use types (homestead yards, fields and rangelands) prevalent in these savanna socio-ecological systems. When combining density

data with SCD profiling, it is apparent that land-use and harvesting practices are sustainable at present and that marula population structures are stable. However, certain trends in the ecological data suggest that there is cause for concern. In both Bushbuckridge (mean = 25.7±4.1 trees/ha) and Phalaborwa (mean = 13.9±1.9 trees/ha), overall density was highest in yards. While this would appear to reject the hypothesis of decreasing density with increasing anthropogenic interference, the ecological data alone only tells part of the story. Juvenile populations comprising large numbers of seedlings were common in yards, which the social data revealed was the direct result of discarded kernels from marula beer making. These seedling populations caused elevated overall mean densities in yards. Respondents indicated that these individuals are usually removed after a season, meaning that the majority do not recruit through to adulthood. While comparisons with previous studies showed that overall marula densities have increased in homestead yards, they have been rapidly decreasing in rangelands over a 15-year period, suggesting intense resource use, particularly for fuelwood.

Female densities were higher than male densities in yards in both Bushbuckridge and Phalabarwa but not in either fields or rangelands, with the social data once again revealing that this selection is due to the prioritisation of female trees as the fruit producers. Male trees will therefore be selectively cut when land is cleared for residential plots. The preference for the female tree with it's valuable fruit has resulted in a departure from the 1:1 ratio expected in dioecious species, specifically in yards where the female tree is maintained for it's combined cultural and economic status. These findings are important as they indicate that value attribution can lead to species conservation where the cultural capital of a specific natural resource is high. Due to the numerous seedlings in homesteads, yards had negative size-class distributions (SCD) in both locations, indicating strong recruitment, whereas rangelands displayed positive slopes in both locations, indicating the opposite. This suggests possible overharvesting in rangelands, with the collection of all available fruit under the parent tree as a likely key-contributing factor to diminished recruitment. In both locations, adult and large adult populations were highest in rangelands with the social surveys indicating that the larger trees are chopped down in yards due to the concern that marula's extensive branch and root systems might destroy roofs and building foundations respectively. Furthermore, according to the social accounts provided by respondents, the declining large trees across land-use types are attributed to extended drought conditions. Mortality increased across the land-use types from yards to rangelands in Phalaborwa, while the opposite trend occurred in Bushbuckridge with mortality increasing from rangelands to yards. In both locations, primary damage increased along the gradient from yards to rangelands. While instances of mortality and tree damage were minimal, complete removal of chopped trees in yards and rangelands means that there is likely insufficient evidence to create an accurate overall picture of negative resource practices.

Understanding the causes of resource conservation and degradation in the context of important NTFPs is a key knowledge challenge. In light of demographic changes from increased resource use in recent years, this study serves as an updated inventory benchmark for marula populations in the area. Important lessons learned here can be applied to socio-ecological contexts where key natural resources are responsible for sustaining livelihoods. By linking marula population demographic data with the specific social behaviour patterns that shape these data, it is possible to provide new insights regarding the use of a key non-timber forest product (NTFP) within the complex socio-ecological system of the lowveld marula bioeconomy catchment.

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"It is the journey, not the destination" — Ralph Waldo Emerson

For many, a PhD is about the destination. For me, it has been about the journey. I set out to explore a topic that I was passionate about. Along the way, I have learnt an immeasurable amount about myself, about life and about marula trees. While I set out to achieve a Doctorate in Science, it has been the numerous little lessons along the way that have enriched this experience in ways I could never have imagined when I set out on this journey.

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List of Abbreviations

Community-Based Natural Resource Management (CBNRM)
Common property resource (CPR)
Cooperative Conservation (CC)
Cooperative Community Custodian Model (CCCM)
Department of Environmental Affairs (DEA)
Driver, Pressure, Impact, State, Response (DPISR)
Ecosystem Services (ES)
Ecosystem-based Adaptation (EbA)
Environmental Protection and Infrastructure Programme (EPIP)
Human-Environment System (HES)
Kruger National Park (KNP)
Kruger to Canyons Biosphere Reserve (K2C)
Meters above sea level (m a.s.l)
Mpumalanga Tourism and Parks Agency (MPTA)
Non-Timber Forest Product (NTFP)
Non-Protected Area (Non-PA)
Participatory Forest Management (PFM)
Payment for Ecosystem Services (PES)
Protected Area (PA)
Traditional Environmental Knowledge (TEK)
Small, Medium and Micro Enterprises (SMMEs)
Socio-Ecological System (SES)
Socio-Ecological Systems Framework (SESF)
South African National Biodiversity Network (SANBI)
South African Environmental Observation Network (SAEON)
Sustainable Livelihoods Approach (SLA)

Glossary of Important Terms

Bioeconomy – Local or regional economy based on biological products or resources

Dioecious – A plant or invertebrate animal where the male and female reproductive organs are located in separate individuals

Induna – The traditional leader or headman of a village or settlement

Kuphahla – Cultural ceremony where the practitioner communicates with the ancestors

Socio-Ecological System – A system comprising both social and ecological elements

Tribal/Traditional Authority – Customary law governance structure

Xikuha – The traditional sharing of marula beer with the Induna at the beginning of marula season

Xirhwalo – The customary sharing of marula beer during special occasions

1. Overview

1.1 Introduction

The marula tree (*Sclerocarya birrea* (A.Rich.) Hochst. subsp. *caffra* (Sond.) Kokwaro) is an ecologically important, economically valuable and socially significant species. In savanna socio-ecological systems (SES) of the South African lowveld, this tripartite value nexus is particularly prominent. As a medium to large tree, S. birrea, commonly known as marula, plays an important role in ecosystem functioning, while generating cultural and economic value for local communities (Shackleton, 2000; Nwonwu, 2006). The fruit is brewed into marula beer, which is shared socially and used in cultural ceremonies (Shackleton, 2004). Increasingly, marula beer is sold informally for much needed subsistence income (Shackleton & Shackleton, 2005). Marula tree sites are used for cultural ceremonies, such as *kuphahla* (communicating with the ancestors), while bark is used as an ethnobotanical medicine to treat stomach ailments (Shackleton et al., 2002). Juice and jam are made from marula fruit, while kernels are eaten whole or added to a variety of food dishes (Shackleton & Shackleton, 2005). Marula fruit pulp forms the primary ingredient in an internationally marketed liqueur (Shackleton et al., 2002; Mariod & Abdelwahab, 2012). In addition, there is increasing commercial demand for marula oil, extracted from the kernel, as an ingredient in numerous cosmetic products (Wynberg et al., 2002).

The marula tree has a wide value nexus based on its multiple uses, making it a multi-use common property resource (CPR) in communal lands and an important source of non-timber forest products (NTFPs) (Shackleton et al., 2003). Increasing resource demands, combined with many large tree fuelwood options being depleted across the landscape, have escalated fuelwood harvesting of marula (Matsika et al., 2012; Mograbi et al., 2015). Fuelwood demands are no longer being met through the collection of dead wood, with live trees being harvested (Mograbi et al., 2017). This is despite marula being a protected species under national legislation (National Forest Act, 84 of 1998). In addition, it is taboo locally to cut marula due to its cultural value (Madubansi & Shackleton, 2007). Such overharvesting in strongly coppicing species can lead to over-representation in the smaller height classes (1-3 m) (Chidumayo et al., 2002). This gives the impression that the resource is recovering, but on-going harvesting at this level may become unsustainable (Kaschula et al., 2005; Neke et al., 2006). Repeated cutting of coppicing individuals, in woody species such as marula, leads to changes in tree morphology and demographics (O'Connor & Goodall, 2017).

Currently, the greatest threat to marula populations is the harvesting of wood from live marula trees for fuelwood markets and home-use purposes, such as cooking and heating (Emanuel et al., 2005; Wessels et al., 2011; Wessels et al., 2013). This fuelwood harvesting is currently the major driver of savanna ecosystem degradation in non-conservation areas (Matsika et al., 2012; Bailis et al., 2015; Specht et al., 2015; Chaudhary et al., 2016). Demographic changes of marula trees, as a consequence of fuelwood harvesting, include decreased overall densities, alterations in size-class distributions and scarcity of reproductive adults coupled with lower seedling densities (Djossa et al., 2002; Neke et al., 2006; Matsika et al., 2012). However, there are limited data on the long-term effects of continuous harvesting and coppicing cycles on woody tree

species. Given the dioecious nature of marula trees, selective cutting of male trees for fuelwood occurs, with the fruit-bearing females being protected from chopping (Nghitoolwa et al., 2003). This results in potential imbalances in the male to female ratios required for effective pollination (Ticktin, 2004). The varied impacts of harvesting on marula trees highlight the importance of understanding the current status of the resource.

Gauging current marula resource sustainability requires understanding marula demographics, in addition to understanding the underlying socio-economic drivers shaping resource use. The impact of land-use choices on tree populations can be understood through plant population dynamics. These include changes in density, population structure and age distribution by land-use type.

Shackleton et al. (2005) produced an inventory of marula in the rural municipality of Bushbuckridge, South Africa. At the time, the authors concluded that densities of fruit-bearing trees were adequate to support both domestic and commercial demands locally. However, marula tree densities had declined over the previous decade (1995 – 2005) and all indices suggested on-going degradation of the resource (Shackleton et al., 2005).

With nearly 15 years having passed since the Shackleton et al. (2005) study, an updated inventory for this important NTFP resource was overdue. Fundamentally, what needs to be understood is whether the current socio-ecological system is sustainable and more importantly, if it is likely to remain so into the future. Yet the data needed to answer these questions currently is insufficient, or altogether lacking. To this end, the aim is to provide an updated inventory of marula populations in two areas of the north-eastern South African lowveld, the Bushbuckridge and Ba-Phalaborwa municipalities.

This study applies an interdisciplinary approach, combining quantitative ecological data with qualitative social data to interrogate how human resource choices impact marula tree populations in complex socio-ecological systems (SES).

1.1.1 Socio-ecological systems (SES)

Ecosystems do not exist in isolation but rather co-exist alongside social systems, both of which co-evolve over time, creating complex socio-ecological systems (Ostrom, 2009; Schluter et al., 2012; McGinnis & Ostrom, 2014; Biggs, 2015). Biodiversity conservation is a top priority on the environmental agenda, with widespread ecosystem degradation threatening millions of species (Carpenter et al., 2009). Compounded by the diverse consequences of climate change, negative implications for biodiversity conservation and ecosystem services are now widely accepted (Twine, 2005; Young et al., 2006; Liu, 2007; Binder et al., 2013; Scholes et al., 2013). The inherent value of natural resources, as sources of natural capital, are determined by the social and institutional capital that coexist as a result of the value attributed to the resource (Deutsch et al., 2003; Rolfe, 2006; de Sherbinin, 2008). This interdependence means that improving resilience and adaptive capacity within systems requires viewing these contexts through both ecological and social lenses (Crews & Young, 2013, del Castillo, 2015).

Research on human resilience in response to ecosystem degradation aims to understand capabilities of individuals and communities to effectively respond to significant shocks, adversity or stress factors (Rolfe, 2006). Only by integrating the bio-geophysical elements, including the actors and institutions that operate locally, can future resilience and thus sustainability of socio-ecological systems be ensured (Ohl et al., 2007; Polasky, 2008; Partelow,

2016). This requires sustainable development approaches that recognise the ecological limits to growth from the perspective of natural capital (Rees, 1990). While certain examples of natural capital are considered renewable, other resources are considered essential, scarce and depletable (O'Connor, 1993). At present, anthropogenic factors are driving ever more socio-ecological systems into this critical bracket of being scarce and depleted.

Considering the various anthropogenic drivers of ecosystem degradation as a component of global change, the driver that has potentially caused the most damage is land-cover change. In particular, the widespread removal of trees in forests, woodlands and across savanna ecosystems as a result of particular land-use and resource use practices (Li et al., 2019). Accelerated loss of tree cover is linked to overharvesting and other resource use practices. In turn, these practices result in the degradation of crucial ecosystems, which are pivotal for all life on earth, not least of all for human survival. Trees play a crucial role in not only sequestering carbon, but also providing a plethora of fundamental ecosystem services for people as well as habitats and food for countless species (Lopez & Moran, 2016; Li et al., 2019).

Socio-ecological systems (SES) are complex, adaptive systems entailing multiple scale interactions and linkages. In addition, SES are characterised by numerous feedback-loops between the social and ecological components of these systems, resulting in the reorganisation of the system as a consequence (Giannecchini et al., 2007; Biggs et al., 2015; Melnykovych, 2018). Environments that provide the specific ecosystem services necessary for food security and economic sustenance are often directly affected by poor resource management practices (Mooney et al., 2009). Due to the complex nature of SES, contemporary research in this area is continually evolving to incorporate innovative inter- and trans-disciplinary approaches. These approaches can be used to analyse complex interactions and find meaningful sustainability solutions (Kaschula et al., 2005; Biggs et al., 2015; Partelow, 2016). Central to the SES research agenda is using "empirical and comparative analytical contributions to understand transformative change processes" (Partelow & Winkler, 2016:403). Kaschula et al. (2005) advocate the importance of combining hard-system scientific approaches with soft-system methodologies for tackling human complexity. In other words, it is important to embed environmental issues within the immediate social context in order to satisfactorily explore fundamentally disturbed environments. Specifically, those environments that remain potentially productive despite disturbance activities degrading the overall system. Binder et al. (2013) highlight the plethora of frameworks utilised for addressing the complexity inherent in SES. Two of the approaches that stand out in academic circles are the Ecosystem Services (ES) framework and Socio-Ecological Systems Framework (SESF) (Partelow & Winkler, 2016). Due to the complex, non-linear and pluralistic nature of SES, most approaches concede that no one framework can capture all aspects of the system (Poppy et al., 2014; Partelow & Winkler, 2016). The ES framework provides a more eco-centric analysis of the SES while the SESF is more anthropocentric in terms of the system knowledge that it generates (Rissman & Gillon, 2017).

In order to facilitate and encourage multidisciplinary scientific approaches to connect and communicate in a common language, Ostrom (2009) conceptualized the Socio-Ecological Systems Framework (SESF). The SESF is a diagnostic checklist of interacting SES components (Partelow & Winkler, 2016). Central to the SES framework is the presumption that humans, either individually or collectively, are capable of making decisions or choices that significantly affect the outcomes of the system (McGinnis & Ostrom, 2014). Ostrom envisioned complex SES as a combination of i) subsystems, ii) resource units, iii) governance systems and iv) users,

which not only interact to produce changes at the SES level, but also feedback to affect the subsystem and its various components (Ostrom, 2009). The SES framework is a useful tool in the context of this research project as the resource being evaluated, the marula tree, is part of a complex system of interlinking social and ecological components. Applying this theoretical framework to the complex SES of the marula bioeconomy catchment, the i) resource subsystem is the savanna communal landscape, the ii) resource units are the individual marula trees, the iii) governance system includes traditional, local, provincial & national government and the iv) users are the communities and companies benefitting from the resource use.

Two key aspects of applying the SES approach are observing spatial and temporal scales, in order to track changes over space and time within the system. This requires identifying the ecological and human drivers of changes over space and time, as well as the linkages between the two sets of variables (Liu et al., 2007; Crews & Young, 2013; Schluter et al., 2014). In short, this means focussing on the interactions that occur at the eco-social interface between the social and ecological components of the system (Redman, 2004). Social and ecological processes do not always occur at the same scales or may occur over multiple scales, necessitating linkages that connect across different scales (Redman, 2004, Scholes et al., 2013). Socio-ecological methodologies are important for interrogating the impacts of resource use in multi-functional landscapes (landscapes utilised for a variety of purposes and functions) in order to gauge simultaneous implications for conservation as well as livelihoods (Biggs et al., 2015; Sunderland et al., 2017). This is especially true for ecosystems where natural resource use is a key component of the land-use changes taking place locally. And in particular, how these changes impact the different species existing across the coupled social and ecological landscape (Liu et al., 2007).

1.1.2 Natural resources: communities and conservation

Natural resources have historically been viewed as a solution to both development and conservation objectives (Richards, 1993; Arnold & Perez, 2001). Contexts where communities and natural resources coexist within a common property resource (CPR) system of adaptive management have proven to be the most effective for meeting both development and conservation objectives (Ramachandra et al., 2017). However, governance of open access resources is both complex and contested. Berkes (2007) explains how two features usually define communities and commons: the exclusion problem or the subtraction problem. Exclusion details the issue of control or access to the resource and subtraction highlights how each user has the ability to decrease the overall welfare of the system. Dependency on natural resources is usually determined by socio-ecological factors including: location, wealth status, gender, education and seasonality (Timko et al., 2010). Understanding how these factors interlink with the ecological system that is being utilised is fundamental for unlocking sustainable approaches. Shackleton et al. (2007) classify the uses of natural resources into three distinct classes: 1) a source of basic needs such as nutrition, 2) cash saving on purchased resources and 3) a safety-net in times of shock. Utilisation of a natural resource for the purposes of development is only said to be sustainable if "the sum of the capitals (i.e. financial, social and natural) does not decrease as a result of the action" (Scholes, 2009:114). Considering the multi-purpose value generated by natural resources within ecosystems, the true value of ecosystem services is grossly underestimated, leading to poor management practices of these key resources (Ramachandra et al., 2017).

1.1.2.1 Traditional management of common property resources

Rural settlements in South Africa generally fall under customary land tenure, whereby local traditional authorities zone the villages into three different land-use types. These land-use types include residential areas for housing, arable plots for fields and communal savanna, which is used as rangeland for livestock as well as resource harvesting (Matsika et al., 2012). According to Kirkland et al. (2007), transitioning to democracy in post-apartheid South Africa after 1994 helped to formulate a culture of individualism and personal or household-level rights. This was in opposition to the previous more inclusive mind-set of community-level values. Located in the communal rangelands surrounding local villages, natural resources are considered a common property resource, under the jurisdiction of the village Headman (Induna) and at a higher level, the Chief of the wider area. While previously being quite successful at regulating the use of common property resources, the authority of traditional leaders has been continually eroding since the onset of democracy in South Africa. Importantly, traditional leaders were previously given a budget to hire crucial 'tree police' who could enforce local rules pertaining to tree chopping and harvesting natural resources (Kirkland et al., 2007). With the cessation of these budgets, the regulation of local customary rules and adherence to customary laws has begun to erode (Findlay & Twine, 2018).

Kirkland et al. (2007) explain how the legitimacy of the tribal authority was first challenged by the youth under Apartheid, with local leaders often criticised as being the puppets of the Apartheid apparatus. Later, with the onset of democracy, the breakdown in management of communal savannas has been attributed to a declining respect for local traditional authority amplified by confusion as to what role traditional leaders actually play in the new democracy. Traditional authorities share leadership with local governance structures, including municipalities and provincial authorities, but the lines of authority are not always clearly lineated (Kirkland et al., 2007). This has further been diluted by a combination of policy approaches, which further blur the lines between local leaders as figureheads and actual legitimate rulers, with government endorsed authority. Marula is protected from being cut under the National Forests Act of 1998 (Act 84 of 1998), in addition to the cultural prohibition under customary law against cutting live trees for wood, in particular fruit trees. Despite these regulations, many people chop not only dead trees, but also live marula trees for fuelwood. This may in part be due to an attrition in respect for local traditional authorities who forbid the cutting of live trees, but also in part due to the necessity caused by depleting natural resources and increasing population numbers (Kirkland, 2007). As village boundaries merge and traditional authority erodes, marula sustainability is further challenged by outside communities as well as commercial fuelwood harvesters, turning to one of the last large and relatively abundant trees remaining in the communal savanna landscape. Understanding the crucial role that common property resources, such as marula, play within these ecosystems is fundamental for securing the future sustainability of NTFPs in communal savanna systems.

1.1.3 Non-timber forest products (NTFPs)

Non-Timber Forest Products (NTFPs) are all natural resource items of biological origin, excluding commercial timber (Pandey, 2016). NTFPs originally referred to natural resources of forest origin only, but the definition was later expanded to include non-timber resources from savanna systems (Belcher & Vantomme, 2003). NTFPs are an example of a key ecological capital input, with millions of individuals in some of the poorest rural communities across the planet relying on these resources for livelihood sustenance (Shackleton et al., 2007; Dovie, 2009;

Heubach et al., 2011; Shackleton et al., 2011; Shackleton et al. 2011). Within the South African context, NTFPs contribute to rural daily livelihoods, specifically products from savanna ecosystems, South Africa's largest biome (Shackleton et al., 2002, Shackleton et al., 2007).

As with other natural resources in most rural contexts, NTFPs are utilised in order to mitigate poverty as a daily livelihood strategy, while also serving as a safety net in times of emergency or livelihood crisis (Belcher, 2005; Rolfe, 2006). Often, product reliance begins as a safety net but then evolves into a livelihood income strategy. Livelihood income strategies can either be subsistence or supplementary (Belcher & Ruiz-Perez, 2005). A subsistence strategy provides most of the household's livelihood, whereas a supplementary strategy is a secondary livelihood source, which supplements the main source of income. Where either strategy is successful, the next level of poverty alleviation is the actual reduction of overall poverty, whereby the resource user is able to improve their circumstances through the commercial value of the natural resource (Belcher, 2005). While access to export markets is often a key aspect of livelihood support, Shackleton et al. (2007) highlight the importance of viable local markets for NTFPs, in order to bolster local livelihoods. While it is assumed that commercialisation of a resource will further improve the livelihoods of the poor, this is not always the case. A growing body of literature, in particular research focussing on parts of Africa, Brazil's Amazon Rainforest and India's tropical deciduous forests, has demonstrated that the previous thesis of "conservation through commercialisation" (Arnold & Perez, 1993: 437) needs revising (Marshall et al., 2003; Sunderland et al., 2004; Shackleton et al., 2005; Shackleton et al., 2007; Dovie, 2009; Shackleton et al., 2011).

Poverty reduction based on the conservation through commercialisation narrative requires not only interrogation, but also possibly part or whole substitution, for local systems that incorporate indigenous knowledge and local ways of utilising a natural resource (Arnold & Perez, 2001, Kaschula et al., 2005; Belcher & Schreckenberg, 2007). The 'Tragedy of the Commons' theory suggests that without intervention, open access areas such as rangeland savanna, will continue to be unsustainably depleted of natural resources until the landscape can no longer recover (Hardin, 1968). While this outcome is thought to be inevitable in any open access system, this is not always the end result (Beresford et al., 2018). While contemporary resource depletion due to population pressure may not serve conservation goals, proper institutional organisation can lead to 'win-lose' compromises that balance resource depletion with poverty alleviation. However, these 'win-lose' management approaches require some form of acceptance of an imbalance in the natural system within which the resource is embedded (DeFries et al., 2007). A key problem with the resource commercialisation approach is that resource harvesting is based specifically on market demand, which hampers the ecological objective of conserving the resource, specifically from a biodiversity perspective (Arnold & Perez, 2001). While the premise of conservation through commercialisation is that the higher the commercial value of a NTFP, the more likely it being conserved, this is seldom the reality (Arnold & Perez, 2001, Belcher & Schreckenberg, 2007).

In order to address some of the contradictions inherent in NTFP usage and biodiversity conservation, more nuanced management approaches to both harvesting and resource utilisation are required. These approaches include studies to accurately understand the actual harvesting and management practices applied by local communities in various contexts (Ticktin, 2004; Ndangalasi et al., 2007). This includes the incorporation of the national policy context as well as integrated supply chain approaches into proposed solutions (Belcher & Schreckenberg,

2007). To this end, alternative value allocation methods need to be applied, in order to adequately understand the true impact of these products on both livelihoods, as well as national economic productivity, in developing nations (Chopra, 1993). Initiatives and governance approaches which rely on economic instruments, such as Payment for Ecosystem Services (PES), have proven to not always be entirely effective, especially in the face of a resource that has deeper cultural ties and traditional meaning for the respective community (Berkes, 2007; Khalid et al., 2013). Understanding how local resources are valued, harvested and utilised in situ is therefore crucial for understanding the sustainability of the resource. In particular, this requires understanding the wider socio-ecological system in which the resource is embedded, such as savanna communal rangelands.

1.1.4 Savanna communal rangelands: NTFPs in non-conservation areas

Savanna is the largest biome in South Africa, characterised by co-dominant trees and grasses (Shackleton et al., 2007). The savanna biome accounts for approximately 42 million hectares of land-cover, the bulk of the wooded land surface in South Africa (Shackleton et al., 2007). This biome is zoned into various land-use types including communal rangeland, where over 70% of the former Apartheid regime homelands were located (Shackleton, 2007). Communal rangelands cover over 6 million hectares alone and are home to approximately 2.4 million households (Shackleton, 2001; Twine, 2005). The savanna biome can be classified further into conservation and non-conservation areas, with communal rangelands falling into the latter. The former are either private reserves or national parks. Communal rangelands are of mixed land-use, with settlements usually under an assortment of governance structures, including traditional authority and land tenure, which differ from privately owned commercial cattle or game ranching land-use types. Traditional authorities have historically demarcated the available land into three land-use types: residential zones (homestead yards), arable plots (fields) and communal rangeland (rangelands). Across rural areas of South Africa, communities live on these mixed ecosystems, which provide numerous natural resources as well as grazing for livestock (Twine, 2005; Khalid et al., 2013). Across communal savanna systems, woody species in particular are harvested for a range of crucial livelihood resources.

While providing key natural resources for livelihoods, communal rangelands are increasingly becoming severely degraded due to drivers such as over-harvesting of resources and poor land-use management. These drivers are further compounded by factors such as high human densities and the accompanying livestock numbers, which in turn lead to a loss of grass cover (particularly palatable grazing species) and associated severe soil erosion, increased run-off as well as poor water infiltration (Khalid et al., 2013). It is therefore important to understand the impact of multiple resource demands on modified savanna systems, such as communal savanna landscapes, which are essentially "complex, disturbance driven, socio-ecological systems, in which humans are the main agents of structural and functional change" (Matsika et al., 2012:71). Humans therefore perform a similar function to elephants as ecosystem engineers (Jones et al., 1994), altering vegetation structure and composition through tree removal for wood (Mograbi et al., 2017). Understanding the extent to which humans act as change agents within these systems is therefore fundamental. As human population density increases and resources are depleted, the species composition of savanna regions change across different land-use gradients, often leading to what is described in ecological terms as fragmented landscapes (Castillo, 2015). The ecology of fragmented landscapes details how the landscape is in constant flux, from wooded savanna on one end of the spectrum through to homestead yards

on the other end, as the most human altered land-use. This continuum across the landscape creates a mosaic of land-use types. Conversion of wooded savanna to arable plots or residential yards is common practice in the savanna landscapes of the communal rangelands of South Africa. This conversion of the landscape is not unique to South Africa, with Sunderland et al. (2017) illustrating how transitions along the forest to field continuum occur in other parts of the world, including Zambia, Burkina Faso, Cameroon, Ethiopia, Indonesia and Bangladesh.

Higgins et al. (1999) confirm that communal grazing management substantially changes both the composition, as well as the overall structure, of woody plant communities. The authors conclude that the vegetation of savanna ecosystems is severely impacted by land-use change at the landscape level, including clearing, burning and chopping of individual trees (Higgins et al., 1999). Significant differences in stem density are attributable to land tenure and land-use, with greater stem densities in communal rangelands often as a result of land clearing and chopping activities (Chidumayo, 2002). These activities result in an increase in stems in the smaller size classes, either linked to regrowth (through regeneration) or smaller individuals taking the place of the larger individuals, which have been removed, burnt or chopped down. Shackleton (2000) compared land-use impacts on vegetation within rural savanna contexts in the lowveld region of South Africa, finding at the time that while communal areas demonstrated disturbance, they did not display the expected species paucity. In addition, these communal areas were not significantly different in terms of species richness when compared to adjacent conservation areas (Shackleton, 2000). This finding could be attributable to the high elephant densities in the adjacent conservation areas at the time and speaks to the resilience of these systems (Shackleton, 2000). Nearly 20 years later, the relative and absolute impact of elephants compared to humans within these contexts requires further investigation.

1.1.4.1 Fuelwood and resource harvesting

Each year, approximately 9-11 million tons of wood is used for fuel per year in South Africa, of which 6.6 million tons are estimated to be harvested from natural wood (Kirkland et al., 2007). In rural areas, these wood sources are usually located in the surrounding savanna rangelands belonging to each village. Annual average household consumption of fuelwood in the Bushbuckridge region of South Africa is approximately 3.8 tons (Madubansi & Shackleton, 2007). The increase in access to electricity for the general population went up from 36% in 1994, to 74% in 2007 (Matsika et al., 2013). Despite this increase, dependence on fuelwood remains over 90%, possibly even as high as 95% of electricity-connected rural households (Madubansi & Shackleton, 2007; Matsika et al., 2013). It is concerning that currently only 7% of fuelwood demand is being met by the collection of dead wood (Mograbi et al., 2015). Thus, live wood harvesting is driving the major degradation of semi-arid ecosystems, particularly the lowveld communal savanna systems (Madubansi & Shackleton, 2007; Matsika et al., 2013). Kirkland et al. (2007) highlight the importance of natural resource use as a form of subsistence income, with fuelwood being attributed a high direct annual use value. This has implications for sustainable harvesting in areas where resources are under pressure in terms of supply and demand.

The cutting of live stems coupled with coppice regrowth has led to changes in not just tree morphology, but also the demographics of woody species, such as marula. Despite being a protected tree, the marula is under increasing pressure as an option for fuelwood harvesting as other choices are depleted (Madubansi & Shackleton, 2007; Mograbi et al., 2015). Fuelwood harvesting is considered ecologically unsustainable when it results in permanent changes to the

woodland structure. In addition, harvesting is considered socially unsustainable when the decline in the natural capital results in higher opportunity costs, adversely affecting both social and economic capital (Matsika et al., 2012). Essentially, the decline in the resource base requires increased time to be invested in activities such as searching for trees to harvest, which not only takes time away from other economic and social activities, but can result in a lower financial return on the time invested. According to Matsika et al. (2012), fuelwood availability can be gauged using three demographic parameters, namely woody stem density, size class distribution and harvestable resource area. Overharvesting can lead to a spike in coppicing and re-sprouting, resulting in increases in stems in the smaller size classes (1-3m height classes). This gives the impression that the resource is not being depleted, when in fact harvesting levels may be unsustainable (Chidumayo, 2002).

Coppicing and regrowth rates can be manipulated to reduce rotation periods between harvesting, depending on the cutting height, the size of the tree and the root/shoot ratio after felling (Shackleton, 2001). Neke et al. (2006) show how harvesters tend to target species that are good at coppicing, or with relatively large re-sprout shoots. In addition to this, cut height is also a factor with re-sprout originating from the stem instead of the root crown, resulting in taller stumps (Shackleton, 2000; Neke et al., 2006). Shackleton (2000) found that taller tree species would have fewer regrowth shoots in order to reduce competition, as a bid to regain as much height as possible. In reality, selective or considered harvesting is the ideal. However, with limited time and resources, people will likely cut whatever tree is easiest and most accessible, sometimes removing the whole plant in the case of smaller individuals (Ticktin, 2004). Mograbi et al. (2015) explored the implications of extensive harvesting on canopy cover, concluding that harvesting in species with strong regenerative capacity can paradoxically result in bush thickening due to coppice, while extraction practices may fundamentally affect overall population structure. Increases in woody biomass are therefore not necessarily a good indication of the impacts of fuelwood harvesting (Mograbi et al., 2015).

Importantly, with increased resource pressure communities will continue to harvest at the same levels due to necessity, instead switching to alternative species, such as marula to make up the deficit. Other ways in which communities diversify their fuelwood utilisation options are by opting to use smaller size classes in species that are already overharvested, travelling further afield to harvest wood, making more frequent trips and dedicating more time per trip to harvesting (Matsika et al., 2013). In addition to this, using wheelbarrows and donkey carts allows for greater quantities to be collected. Other strategies include utilising neighbouring communal or private land, in addition to local rangelands. A last resort may entail purchasing wood by turning to fuelwood markets, which use vehicles and therefore harvest resources from larger areas to meet demand (Madubansi & Shackleton, 2007; Matsika et al., 2012; Mograbi et al., 2015). The range of strategies utilised in relation to fuelwood harvesting, highlights the need to understand the impacts on individual resources, as part of a larger landscape of resource demands.

1.1.5 Introduction to the study species: marula (*Sclerocarya birrea* subsp. *caffra*)

Marula is a medium-sized (10-17 m) deciduous tree that flowers between September – December and fruits between January – March (Shackleton, 2002). The male and female flowers grow on separate trees, although occasionally a tree with male flowers may bear a few female flowers (Shackleton, 2002). Individual marula trees are known to exceed 300 years in age, assuming there is no disturbance due to harvesting in non-conservation areas and elephants in

conservation areas. In addition, fruiting first occurs between 7-10 years of age, with fire acting as a limiting factor to flowering and fruiting in conservation areas (Shackleton, 2002, Helm et al., 2009). The fruit is about 3.5 cm in diameter and green in colour on the tree, but changes to a pale yellow and usually only falls to the ground once ripe (Shackleton, 2005). The leaves are imparipinnate and alternate, with 3-18 pairs of leaflets (Hall, 2002). Marula is usually single stemmed and branches at 3-4 m above the ground, with a spreading elliptical crown and a silvery mottled bark (Palmer & Pitman, 1972). Marula trees grow in a variety of soils but prefer well drained soils, growing at altitudes ranging from sea level to approximately 1800 m above sea level, where mean annual rainfall ranges from 200-1500 mm (Mariod & Abdelwahab, 2012).

As a medium to large tree, marula plays an important role in ecosystem functioning by providing a cool sub-canopy environment, as well as a habitat for small vertebrates and invertebrates (Shackleton et al., 2002). In conservation areas, the canopy provides browse material for a variety of game, while mammals such as elephants, monkeys and kudu (antelope) all eat the fruit, with elephants also utilising the bark (van Wyk and van Wyk, 2009). In non-conservation areas, livestock such as cattle utilise the tree for browse with goats and sheep preferring seedlings (Shackleton et al., 2003).

Marula has a geographical range throughout much of Africa; *Sclerocarya birrea* subsp. *birrea* is dispersed across West to East Africa, with a relatively small pocket of *Sclerocarya birrea* subsp. *multifoliolata* found in parts of East Africa. *Sclerocarya birrea* subsp*. caffra* is found throughout much of southern Africa, including Madagascar. Marula has also been introduced to Israel where 7 hectares was planted in the Arava region, which yielded abundant fruit (Nerd & Mizrahi, 1993). Marula has apparently also been introduced to India and Australia (Mokgolodi et al., 2011). The distribution of *Sclerocarya birrea* subsp. *caffra* throughout southern Africa means that much of the data and studies that exist on this specific subspecies are drawn from the region. Marula has been a protected tree in South Africa since 1962 (Hall, 2002; Shackleton, 2005) and is also protected as an indigenous tree in Namibia and Botswana (Chikamai & Tchatat, 2004). In Swaziland, marula is used in numerous cultural and traditional ceremonies, as well as hosting two processing plants for marula based products, Swazi Secrets and Swaziland Marula (Murye & Pelser, 2018). Marula is considered a preferred fruit tree in Mozambique and promoted in agroforestry in Botswana, but is less frequently used in Malawi (Bandeira et al., 2009; Nakafeero et al., 2007; Ngulube, 2000).

Examples of marula studies include research on the fruit specifically, including the domestication potential of marula, as well as the phenotypic variations in nut kernel traits in Namibia (Leakey, 2005; Leakey et al., 2005). Leakey et al. (2005) compared trees in Bushbuckridge (South Africa) to trees from the north central region of Namibia in terms of domestication potential. While the authors concluded that there is significant potential for the development of cultivars, more importantly, differences in kernel mass in farmed fields suggested anthropogenic selection and a form of domestication. Shackleton et al. (2003) came to a similar conclusion for the Bushbuckridge area, citing the positive relationship between tree size and number of fruits produced in homesteads and fields, as an indication of historical selection of trees based on fruit production. In the South African context, marula trees are not currently planted or cultivated at scale, except for individual cases of domestication through selection of trees with larger fruit mass in homestead yards in rural areas (Leakey et al., 2005). As a result, indigenous marula populations are still considered to be wild, with population ranges and reproduction occurring largely without human intervention, except for examples in

rural human settlements, which are the exception (Shackleton et al., 2003).

Nghitoolwa et al. (2003) investigated the population status of marula trees in Namibia, taking into account gender imbalances, and found that the populations may not be self-sustaining due to factors such as dispersal, which can impact gene flow. Gender biases have implications for management practices, if aspects such as adequate pollen flow are to be ensured. Other recent studies have explored the phytochemistry, pharmacology and toxicology of marula (Ojewole et al., 2010) and its medicinal properties (Mariod et al., 2012) as a significant indigenous tree across southern Africa, specifically South Africa, Botswana and Namibia (Nghitoolwa et al., 2003). Jaenicke & Thiong'o (1999) examined the nutritional value of Kenyan based *Sclerocarya birrea* subsp*. birrea,* concluding that the Kenyan fruit is of equal quality to that produced in Southern Africa.

1.1.6 Savanna dynamics and marula demography

Woody plants are an important component of savannas, with woody communities being directly affected by a myriad of abiotic factors including soil nutrients, temperature, rainfall, fire regimes and topographic positioning, in addition to biotic processes such as herbivory. Understanding demographic changes requires focussing on life stages of the population from recruitment, life stage transitions through to mortality. Midgley & Bond (2001) provide a comprehensive framework for classifying demographic hurdles, starting with seed-set limitations (linked to pollination), seed limitation due to predation, seed dispersal and germination limitations as well as seedling establishment limitations through to fire mortality and fire damage limitations, herbivory and adult mortality linked to life-span and senescence. Two of the most important drivers of woody plant dynamics in savannas are the interactions between fire and herbivory (Staver et al., 2009; Midgley et al., 2010). The combined impacts of elephants and fire on marula populations have shown increases in morbidity, specifically in the size classes utilised by elephants (Helm et al., 2011; Mograbi et al., 2017; O'Connor & Goodall, 2017). Due to the dioecious nature of marula, female trees have also been shown to demonstrate greater damage due to elephant impact, with female trees targeted for their fruit (Hemborg & Bond, 2007). Elephant–fire synergy also specifically increases mortality in large trees (Moncrieff et al., 2008; Helm, 2011). Fire frequency and intensity are key factors in terms of damage, with winter burns (August) having the greatest impact on seedling structure, while higher fire intensities result in the development of a multi-stemmed morphology in marula (Jacobs & Biggs, 2001). In addition, atmospheric CO_2 can influence tree cover by altering post-burn recovery rates with slow sapling recovery at low CO_2 rates favouring the spread of grasses, which leads to reduced tree cover (Bond et al., 2003). Fire and herbivory interactions are also important due to the fact that their combined impact acts as a strong limitation to recruitment, resulting in a lethal combination for woody plant recruitment and transitions (Helm et al., 2011). However, in some cases, herbivory alone, notably by elephant and impala, can be more of a limiting factor than fire (Midgley et al., 2010).

While fire and herbivory have a key impact on mortality, they also directly impact recruitment and thus transitions to larger size classes. Survival and growth at the seedling stage presents a major bottleneck in the recruitment of woody species (Sanchez-Gomez et al. 2006). This includes how marula saplings survive and out-grow this damage, mainly through height, but also bark thickness and stem diameter growth to a certain degree (Midgley et al., 2010). Defence versus growth trade-offs are therefore an important aspect of woody plant survival strategies (Helm, 2011). Recruitment can often be considered a bottleneck, since resprouting is generally a

trade-off against recruitment (Bond and Midgley 2001). While the demography of each species is unique, given the prevalence of resprouting in species such as marula, this is a key cause of the recruitment bottlenecks and affects the transition of juveniles to fire-proof or herbivore-proof size classes (Higgins et al.2000; Midgley and Bond 2001; Bond 2008). Escaping the so-called fire-trap requires juveniles to reach an 'escape height' of typically 2–3m in order to avoid top-kill (Higgins et al. 2000). There is a similar correlation with the browse-trap, which results in recruitment bottlenecks through heavy herbivory of seedlings by species such as impala, which acts as a limiting factor to both recruitment and transitions into higher size classes (Staver & Bond, 2014). Escaping the browse-trap, or release from browsing, results in increases in tree sizes (Staver & Bond, 2014). It is for these reasons that size-class distributions stem diameter slopes are considered to be a good indicator of population structure at a specific point in time (Condit et al., 1998; Lykke, 1998; Obiri et al., 2000). However, these data must be combined with additional demographic information, in order to make predictions about future population structures (Condit et al., 1998). In response to fire, marula seedlings appear highly adapted, with high allocation to below-ground biomass and starch storage, very thick bark from very small stem diameters and a well developed resprouting response from very young (Helm, 2011).

Understanding how fire and herbivory impact marula is therefore a key consideration in conservation areas. Browsing and fires interact to supress tree density in conserved savanna systems (Staver et al., 2009). In non-conservation areas, land-use areas such as homestead yards and fields do not experience regular burning. Rangelands experience very erratic burning but due to the low biomass from overgrazing by cattle, the impact of fire on woody vegetation is slight to negligible. While it is important to understand the fire response strategies of different savanna woody plants in conservation areas, in non-conservation areas, the impact of human damage is far more of a concern. While land-use practices, such as widespread tree removal has a detrimental impact on tree cover, when comparing different land tenure (conservation, commercial farms and communal rangeland), global drivers such as atmospheric CO_2 and nitrogen deposition were found to have a greater impact on tree increases in grassy biomes, rather than the local land-use practices (Wigley et al., 2010).

Due to the dioecious nature of marula, with separate male and female trees, community demographics are important to consider, meaning that the neighbourhood size has an impact on both pollination potential as well as intensity (Van Drunen & Dorken, 2012). However, pollen loads can be maintained with fewer males to females in the population provided the distances between these males are not too far for key pollinators, such as bees and wasps, to fly between trees (Nghitoolwa et al., 2003). Recruitment bottlenecks can be addressed through the storage effect, whereby woody plants such as marula will establish a cohort of juveniles when conditions are favourable, which allows these individuals time to flourish and thus, once established, these individuals are able to persist in adverse conditions (Helm, 2011). The ability for woody plants to accumulate excess carbohydrates during favourable conditions and then deplete these stores for regrowth after a disturbance, is another key survival strategy. Marula's thick taproot and subtending widely distributed lateral roots, comprise a significant storage site, a useful response strategy to dryland conditions (Hall et al. 2002). Woody plants in drier environments are predicted to have larger root to shoot ratios (Chapin et al. 1993). This biological response allows marula trees to survive in semi-arid conditions and sandy soils with low moisture content.

While marula has a small persistent seed bank, recruitment appears to be reliant on the current season's fruit crop, which can remain dormant in the soil for up to 6 months, until sufficient rainfall the next rainy season (Helm, 2011). Recruitment bottlenecks can occur due to the marula endocarps (the dispersal unit of marula seeds) having an operculum that restricts germination until it is removed (von Teichman et al., 1986). Due to this hard endocarp, marula seeds do not readily germinate in the same season in which they were produced. However, mammalian ingestion not only serves as a key dispersal agent, but may also speed up germination due to acid digestion (Lewis, 1987). Recruitment bottlenecks can also occur due to severe rodent predation of the seeds (Helm, 2011). While water availability and temperature are key factors influencing the onset of germination, water requirements for germination and successful seedling establishment in marula are very low (Helm, 2011). Water stress is however, another key factor leading to seedling mortality and is considered more detrimental than burning, although water stress and fire combined result in the highest cases of mortality (Midgley et al., 2010). The fractional conversion of mean annual rainfall to plant available water is based on the existing vegetation cover as well as abiotic factors such as soil texture and topography (Tietjen, 2016). Utilising stored water in the soil is therefore a key survival strategy, especially for woody vegetation in semi-arid savanna ecosystems, emphasising the importance of marula's root system.

1.1.7 Marula in South African savanna socio-ecological systems

While the biophysical interactions, such as the impacts of fire and herbivory on savanna dynamics are relatively well understood, studies combining these variables with the socio-economic impacts of humans are not as common (Fisher, 2012). As a natural resource, marula fruit contributes to two potentially competing spheres: the formal and informal industries operating in the Phalaborwa and Bushbuckridge areas of the South African lowveld. As a commercial product utilised by the formal industry, marula forms the basis of many commercial products, with the Distell Group Limited currently as the largest off-taker. Within the informal industry, marula fruit contributes towards the production of marula beer as well as other products such as jam and juice, with the sale of the fruit and fruit-based products providing a crucial income stream for many households in the region. In particular, this income forms vital supplementary funds for the lowest income households (Shackleton et al., 2000; Shackleton et al., 2002). In addition to this income, the tree also provides a resource base for various medicinal purposes. Marula is also an important cultural keystone species with a central role in local tradition and customs. As a key NTFP, with its highly prized golden fruit, marula is at risk of over-exploitation unless adequately controlled at an institutional level (Solomon, 2016).

1.1.7.1 Marula as a non-timber forest product in non-conservation areas

Marula fruiting season at the beginning of each year is a time when cash reserves are particularly low after the Christmas season but demand is high for school related items such as books, uniforms and fees (Shackleton, 2002). Although generally modest, the sales from marula beer form a key contribution to subsistence income as a bridging amount at the beginning of a new year. This income allows for livelihood diversification and often even the provision of a financial safety net (Shackleton, 2004). In addition to income provision for local households, through the sale of various marula based products, the vitamin and nutrient rich fruit is consumed by individuals of all ages, including children and the elderly (Shackleton et al., 2000). Shackleton et al. (2002) found that marula is one of the most commonly used wild fruit species in the Bushbuckridge area, with 59-77% of households consuming marula fruits four to five

times per week during fruiting season. Marula beer is particularly interesting as it performs a dual function. The beer is simultaneously a commodity for sale and income generation and a key component in cultural practices. Marula's cultural value made it previously taboo to sell the beer under local customary law (Shackleton & Shackleton, 2005). Specifically, the brewing and sharing of marula beer is a key component in building and maintaining social networks and hierarchies, through its central role in a variety of local ceremonies and customs (Shackleton et al., 2002). Women perform a central role in these practices, as well as the trade in marula products.

Traditionally, it was also taboo to cut a marula tree, but this has changed as local customary systems have broken down in recent decades (Wynberg et al., 2002). Despite the prohibition on felling marula trees according to customary law, male trees are more commonly felled due to their lack of fruit (Shackleton et al., 2003). However, even the felling of female trees has become more common with the disintegration of local customary laws and authorities (Shackleton et al., 2002; Wynberg & Laird, 2007). Tensions exist in terms of local authority and application of the law, specifically between traditional and modern authority figures (Kirkland et al., 2007; Findlay & Twine, 2018). In addition, as commercialisation of marula increases, the disconnect between policy at the national level and application at the local level becomes more problematic, with national policies promoting sustainable resource extraction but unsustainable practices continuing to occur locally (Kirkland et al., 2007). Regardless, the marula tree holds great cultural and ritual significance for local communities, comprising a central component of many fundamental traditional aspects of community life.

Marula is thus a multiple use and value natural resource, which provides a range of capitals including human (empowerment of women and local skills/knowledge), social (cultural and spiritual significance), financial (supplementary income), natural (biological diversity) and physical (community level investments). The varied qualities and characteristics of marula use create a unique bioeconomy, located within the catchment area of this resource. In other words, marula use and reliance has created a local resource based economy, defined by the use of marula within its current natural range and biological niche. Understanding the current nature of marula use, specifically whether there is sufficient supply to meet the demands of the local communities that constitute the informal marula industry is necessary. Understanding the current nature of marula use helps to ascertain whether the current levels of harvesting are sustainable.

1.1.7.2 Marula trees in conservation areas of the lowveld

Helm (2011) conducted extensive research on the life history strategies of marula in the conservation areas of Kruger National Park (KNP) and Associated Private Nature Reserves (APNR). Helm and Witkowski (2012) monitored marula populations across conservation sites in and around Kruger National Park in South Africa, concluding that there was a general trend of decreasing adult density with decreasing rainfall across the KNP sites. This would suggest that going into the future, marula densities are likely to decrease in the more western parts of their current South African range, which is projected to get hotter and drier (Tshiala et al., 2011; Dedekind et al., 2016). The authors detail how up to 40.2% of the variability in total tree densities could be accounted for through a combination of rainfall, elephant presence and soil type, including their two-way interactions (Helm & Witkowski, 2012). Interestingly, however, elephant have less impact on density and a greater effect on size class distributions (Helm, 2011; Helm et al., 2011).

Helm et al. (2009, 2011) also conducted extensive research on the mortality rates of marula in the conservation area of the Kruger National Park. Data were collected as a resurvey of a previous sample, allowing for data from 2001–2008 to be analysed. The study found that mortality rates varied from 2.6% per annum for individuals under 5 m to a concerning 7.1% for individuals in the 5-8 m class (Helm et al., 2009). In addition to this, minimal recruitment into the seedling class was observed at the time (Helm et al., 2009). It was concluded that due to an increasing elephant population and changes to the KNP fire policy, that the sampled population was not self-sustaining (Helm et al., 2009). Examining mortality data for adult trees in southern KNP from 2001-2010, Helm & Witkowski (2012) concluded that the loss of adult marula trees in some parts of the park over the preceding ten years was in excess of a quarter of the overall population. The work of Helm et al. (2011) and Helm & Witkowski (2012) details the implications of elephants and fire on marula in conservation areas, concluding that the unstable population structures observed do not bode well for the persistence of marula as a dominant canopy species. The authors found that rainfall had a strong influence on mortality (Helm & Witkowski, 2012). While it is not yet clear how temperature variability either from year to year, or with climate change over the long-term, will affect these populations, there is increasing evidence that recent human-induced environmental changes have already triggered species' range shifts, including changes in phenology (Thuiller et al., 2008).

1.1.7.3 Marula in conservation versus non-conservation areas of the lowveld

The Kruger to Canyons (K2C) biosphere reserve is an area encompassing parts of the Mpumalanga and Limpopo provinces of South Africa, approximately 2.6 million hectares in size (Coetzer et al., 2010). The K2C biosphere reserve incorporates the Kruger National Park, a range of conservation areas and numerous transition zones, which are open access non-protected areas central to communities and conservation. The management paradigm of the Kruger National Park has shifted in recent years to incorporate the communities on the periphery of the park as part of the greater Kruger National Park ecosystem (Venter et al., 2008; McHale et al., 2013). This means that management actions on both sides of the fence line are now considered equally important for conservation of the wider socio-ecological system (Venter et al., 2008). Due to the high human densities in the transition zones of the K2C biosphere reserve, sometimes exceeding 300 people/km^2 (Coetzer et al., 2010), with low economic opportunities and high levels of poverty, a huge strain is placed on the natural resources which households depend on for their livelihoods. In addition to this, settlements in the area have not only expanded but have also become more densely populated, resulting in accelerated land-cover change (Coetzer et al., 2010; Giliba et al., 2011). This mosaic landscape is therefore spatially defined by a complicated political, economic and social history (Coetzer et al., 2013).

Changes in vegetation are controlled by a balance of the interacting forces of climate, fire, herbivory and human utilisation (Gaugris & van Rooyen, 2010). Comparing these four factors, Gaugris & van Rooyen (2010) found that human utilisation, followed by herbivory, had the most distinctive as well as rapid impact on vegetation structure. While Midgley & Bond (2001) provide an excellent framework for analysing demographic bottlenecks in savanna tree species in conservation areas, in non-conservation areas, many of the key factors contributing to bottlenecks, such as fire and herbivory (especially by elephants), do not apply to either seedlings, saplings or adults in these contexts. Seed dispersal in non-conservation areas is also not primarily linked to mammalian herbivores, as per Midgley & Bond's framework, but rather to human behavioural practices (such as fruit collection and the discarding of kernels after

making marula beer). In addition, germination linked to water, fire and mammalian herbivores are also considerably different in non-conservation areas where fire is almost entirely absent (except for intermittently in rangelands) and herbivory is almost negligible in land-use types such as yards and fields due to fences. Water is also more readily available in yards meaning this is not always a limiting factor as is the case in conservation areas.

While marula trees may be vulnerable to overharvesting of fruit and fuelwood in non-conservation areas, in conservation areas containing elephants, humans are not the main threat (Cook et al., 2017; Mograbi et al., 2017). Elephants heavily utilise marula for the fruit and bark, stripping the bark or pushing over trees to reach the fruit, particularly in the summer months when the tree is fruiting (Helm et al., 2009). Anthropogenic and elephant disturbance on *Acacia xanthophloea* (fever tree) populations in the lowveld were compared by Botha et al. (2002), contrasting the negative implications of both change agents on the species. The authors found that the densities of harvested and protected populations were similar, but that stem damage (bark stripping and breakage) by elephants was significantly higher and that over time, elephant impact was the more severe disturbance (Botha et al., 2002).

Mograbi et al. (2017) compared humans and elephants as the main drivers of treefall in the communal rangelands of Bushbuckridge Municipality, with the conservation reserve of the Sabi Sands. The authors found that while elephant-mediated treefall was higher than that caused by humans, the pattern was heterogeneous and largely associated with geology and surface water. In contrast, human treefall patterns related to wood harvesting and settlement expansion. Mograbi et al. (2017) highlight the paucity of data on humans as important ecosystem components and key determinants of woody cover in non-conservation areas. Helm et al. (2009) surveyed changes to marula populations in Kruger National Park over 7 years, finding that elephants specifically targeted marula trees, particularly the 5-8 m height class, where the highest rates of mortality occurred. Similar findings were recorded in the Jejane Private Nature Reserve (Cook et al., 2017), which was previously devoid of elephants until 2013, when the shared fences with Kruger National Park were taken down. Highest annual mortality rates, as well as elephant impact scores, were also recorded for the 5-8 m height class in this study (Cook et al., 2017). Humans, like elephant browsing, encourage the re-sprouting of savanna species (such as marula) through continual harvesting (Mograbi et al., 2017).

Elephant bark stripping combined with too frequent burning, contributes to increased large tree mortality in conservation areas (Helm, 2011). In addition to elephants, seedlings in protected areas are heavily predated by impala antelope and other herbivores and often remain in the 'fire trap' (Mograbi et al., 2017). In comparison, humans are often responsible for burning in non-protected areas in order to clear land for crops or improve seasonal livestock grazing. Seedlings in the open rangelands are also at risk of being browsed by domestic livestock such as cattle and goats (Mograbi et al., 2017). In protected areas, elephants play a key role in seed dispersal, while in non-protected areas livestock such as cattle play a minor role, with humans having the biggest impact in terms of seed dispersal through tree planting practices (Mokgolodi et al., 2011). However, humans also clear vast tracks of land to expand settlements (Coetzer et al., 2010). Wessels et al. (2013) found that the impact of human-induced fuelwood extraction resulted in a far greater reduction in biomass, on savanna woody cover, than elephants and fire combined. The clear pattern that elephants and humans share is that as their densities increase, woody vegetation such as marula tree density decreases. Elephants have historically been given a bad reputation for their impact on marula populations, which lends itself to an interesting

comparison with humans as change agents. While elephants tend to target female trees for their fruit (Hemborg & Bond, 2007), human wood harvesters favour male trees as these are viewed as 'barren' and not of the same economic or cultural value as the female trees (Shackleton et al., 2003). Considering the large ecological footprint of the greater Kruger Park socio-ecological system, these behaviour patterns can lead to interesting outcomes. While male trees decline in communal rangelands where they are targeted for wood, elephants in conservation areas may more regularly target female trees. Over time, by understanding these dynamics on both 'sides of the fence', it is possible to better understand the complete status of the marula resource base.

1.2 Rationale and Motivation

1.2.1 Closing the knowledge gap

Considering the geographical range of marula, the current depth and breadth of information on this iconic tree is fragmented. Studies have been conducted on the marula tree in terms of its ecology and biology in conservation areas, as well as from the perspective of the fruit and its uses in non-conservation areas (Molelekoa et al., 2018). However, there is a paucity of information on recent natural population demographics, specifically recent surveys in relation to population demographics in non-conservation areas of southern Africa. The key gap that exists in the knowledge base is therefore updated marula demographic data, in order to understand marula population ecology in non-conservation areas of South Africa at present. In addition to a lack of recent demographic data, knowledge gaps also exist concerning marula in non-conservation areas from the standpoint of combined ecological and social perspectives. These perspectives are needed in order to understand the long-term sustainability of this ecological and cultural keystone species. To this end, the potential impact of resource use patterns and practices on marula population demographics, across non-conservation areas of the South African lowveld, is both critical and poorly understood.

At the start of the millennium, Shackleton (2002) noted a deficit in marula demographic data in the Bushbuckridge region of Limpopo. This included density data other than those collected coincidentally as part of vegetation mapping studies. Shackleton et al. (2002; 2003; 2004; 2005) embarked on a marula-focussed research campaign over the following years, generating extensive data on marula demographics, uses, values and cultural importance. In short, the work created a complete inventory of marula, which contained the ecological, social and economic status of the marula resource at the time.

Unfortunately, these valuable data have not been fully updated since, leaving a deficit in updated marula population demographics. In particular, an updated inventory of marula from an ecological as well as cultural perspective is thus required. One of the main reasons an updated inventory is so important, is to understand vulnerability of the species to harvesting pressure, which is projected to have increased over the past decade. It is therefore fundamental to also compare land-use types where human utilisation is high, with areas where there is no human access. Conservation areas in the lowveld region are not generally utilised for resources by humans, other than isolated exceptions. This means conservation areas could act as a control for this study in terms of human induced changes in non-conservation areas. This is especially important because changes to the system are variable in both space and time. This variability highlights the need to understand the resultant impacts on the complete socio-ecological system of the marula bioeconomy catchment that this key subspecies supports. To address this deficit, this study explored marula population demographic variations in terms of both spatial as well

as temporal changes, across various land-use types in non-conservation areas.

The lowveld marula bioeconomy context represents a multi-dimensional problem considering how highly prized the fruit is, both as a commercial product, but also in terms of its traditional and cultural uses for the rural communities harvesting marula fruit (Shackleton et al., 2000; Shackleton et al., 2002; Wynberg et al., 2003). As marula becomes increasingly commercialised, the financial benefits of such need to be weighed against the various social, cultural and economic costs that may arise as a result (Shackleton & Shackleton, 2005). Considering this tree is utilised for a variety of resources by a range of actors, the various vested interests and the corresponding impacts need to be carefully tracked and traced. In addition, applying a socio-economic framework in this study allows the utility of this ecosystem good to be divided into use values (the informal marula industry and ecosystem services) and non-use values (cultural significance). Fundamentally, understanding how marula is valued and utilised as a resource helps to uncover whether the current socio-ecological system is sustainable.

The data required to answer these question were previously either insufficient, or altogether lacking for parts of the lowveld region, with the information gathered under this study aimed at assisting in answering these crucial questions. Without this information, it is impossible to map resilience and develop mitigation or adaptation approaches that may serve to ensure the future sustainability of this social-ecological system, centred on marula as a source of NTFPs (Wynberg & Laird, 2007). A key aspect of understanding the innate sustainability of the system is investigating the cultural practices and processes that either promote or demote the conservation of marula, which this study explored in detail.

Whether the marula bioeconomy context is sustainable was a key focal area of this study, as well as whether it is likely to be sustainable in the long-term. These are particularly pressing issues for non-conservation savanna systems across South Africa, where resource use, reliance and depletion are intertwined with species conservation based on shared cultural values. The classification of marula as a protected tree under the National Forest Act of 1998 (Act 84 of 1998), means that technically the tree species may not be cut down or otherwise damaged or destroyed, nor products removed, except under license. However, the reality of the resource use is not in line with the prescribed legislation. This required further interrogation at the local level in this study to understand the contributing factors, including gauging how robust local customary authorities are in protecting marula as a key resource.

As an important livelihood strategy and safety net for poor local communities, marula use and reliance is a key aspect of resilience in the lowveld context. Shackleton et al. (2005) stressed the dangers of commercial over-harvesting and resource viability in terms of compromising long-term sustainability of the fruit supply. Understanding current marula resource supply and demand is therefore crucial for understanding the long-term sustainability of current resource use practices. Shackleton et al. (2002) noted that the supply of marula fruit appeared sufficient for both domestic as well as commercial use at the time of the study. However, use of the tree for other purposes such as fuelwood, were of greater concern to the long-term sustainability of the species (Shackleton, 2005). Under the context of increasing commercialisation, Shackleton (2002) recommended that i) on-going monitoring of density, recruitment and size class profiles needed to occur and ii) a sustainable harvesting strategy must be developed to ensure adequate gender ratios and fruit availability for recruitment. To speak to these objectives, as well as provide a current stock-take of marula demographics, three data chapters in this thesis dealt

with the ecological indicators of density, recruitment and size class distributions respectively. At the local level, uncovering this information requires examining the current social-ecological landscape and natural resource extraction under local governance and resources management systems. Importantly, this involves an understanding of the role and behaviour of the resource users, the impact on the resource, as well as the specific outcomes of these two inter-linking factors (Tallis and Kareiva, 2006). This information was used to map the co-dependency of social and ecological systems, highlighting what solutions are needed to ensure future sustainability.

The varied use and reliance on marula trees and their fruit highlights the importance of understanding the nexus between the ecological, social and economic values across the marula bioeconomy. Ecological findings alone can be misleading without understanding the social context and behaviour patterns that have helped to shape the specific socio-ecological landscape. Due to these complexities, the research focus and methodological approach applied in this study aimed to unpack and address the complex, multi-disciplinary issues that exist around a fundamental resource such as marula (Smit, 2006; Young et al., 2006). In particular, this includes the implications for the various actors and institutions affected by a changing socio-economic system Fruit yield modelling in this region by Emanuel et al. (2005) indicated that 92% of the fruit could be removed from the system, without impacting the current population profile. However, the authors noted that more intensive marula resource uses, such as fuelwood or bark harvesting, needed to be carefully monitored (Emanuel et al., 2005). Understanding the current impacts of these more intensive resource use practices is therefore critical for assessing sustainability going forward and was examined in this study. However, on-going research in the long-term will be needed to understand if the current system remains sustainable and when a tipping point in relation to the resource status might be reached. These findings may be geographically specific to South Africa, but lessons learnt from a social-ecological context such as this can be analysed and applied elsewhere, allowing the scaling up of workable solutions and outcomes.

Considering the large-scale impact of NTFPs in both poverty alleviation and conservation initiatives, limited quantitative data exist on the resources used, amounts required and frequencies of harvesting deemed necessary. Understanding the extent of community reliance on a NTFP, particularly as a natural resource that forms part of a larger population, is therefore an important knowledge challenge. The long-term impacts of NTFP dependency are concerning, in particular when considering the backdrop of a changing climate. Climate change and the impacts of temperature and rainfall variability are likely to adversely affect sensitive social-ecological systems in South Africa, specifically where a particular natural resource forms the basis of the bioeconomy of an area (Ohl et al., 2007; Mace et al., 2011). Vegetation and soil type, as well as inter-annual temperature and rainfall variability, play active roles in shaping ecosystems dynamics, such as those within the subtropical savanna biome in which marula trees thrive (Zeng et al., 2000). This is of key concern in relation to marula, especially considering the projected drier and hotter weather for the lowveld region of South Africa (Tishiala et al., 2011; Dedekind et al., 2016). The likely consequences are longer and more frequent droughts, which are likely to adversely affect key natural resources, such as marula in savanna ecosystems (Tshiala et al., 2011; Engelbrecht et al., 2013; MacKellar, 2014; Malherbe et al., 2014; van Wilgen et al., 2016; Engelbrecht & Engelbrecht, 2016). North-eastern South Africa represents the southernmost distribution limit for marula's (*Sclerocarrya birrea* subspecies

caffra) range. As is typical of edge-of-range provenance, especially at the temperature extreme of an otherwise tropical distribution, marula is likely highly sensitive to climate change and variability. Understanding current utilisation of marula, in terms of both wood as well as fruit harvesting within this climatic zone, is important for gauging the current status of the resource. This is a key knowledge challenge that this study aimed to address.

The dioecious nature of marula makes understanding selective tree harvesting, in terms of gender ratios, particularly important (Hall et al., 2002). This includes understanding changes as a part of larger population demographics, as well as how this is linked to fruit production (Hall et al., 2002). The ratio of male to female trees is an important contributing factor to overall population stability (Nghitoolwa et al., 2003). To provide this data, gender ratios were explored in this study, as well as the densities of male and female marula trees. Due to the impact of biased gender ratios on recruitment potential, juvenile ratios and densities were scrutinised in this study. Recruitment specifically can be diminished based on the average distance main pollinators, such as bees, can fly between male and female plants in order to pollinate females. However, fruit harvesting is less of a concern in terms of population stability, as the kernels are usually discarded after the pulp has been extracted. This allows for germination to take place, in comparison to more harmful practices, such as chopping of trees for fuelwood purposes, leading to increased damage and mortality (Matsika et al., 2012). With the erosion of customary laws, the chopping of male trees (non-fruit bearing) has increased in recent times (Kirkland et al., 2007). To understand population demographic outcomes, resource extraction and land-use practices needed to be explored across the marula bioeconomy catchment. In particular, a greater understanding of how resource and land-use practices have impacted the overall regeneration of the species was needed. The combination of resource utilisation and barriers to recruitment were therefore strategic areas explored in this study from the perspective of population structure (large adult, adult and juvenile ratios) and the density of trees falling into these demographic categories across the various land-use types.

This PhD study thus aimed to explore current population demographics, including structure and composition of marula within the bioeconomy of the lowveld region, exploring the potential long-term impacts of resource use and over-harvesting on marula as an important NTFP. Land-use types along a gradient from homestead yards, to arable plots (fields) and communal rangelands were compared and contrasted for two sites across a rainfall gradient, with differing natural marula densities at each site. These land-use categories were selected for two reasons. The first is that historically, traditional authorities designated these categories of available land, dividing villages into space for residential yards, areas on the outskirts for arable fields, and beyond that, the open access rangelands. The second reason is that Shackleton's research from 2000 investigated densities and population dynamics across these three land-use types thereby allowing certain high-level comparisons to his findings. This allowed for an overall comparison in relation to the population demographics and structure of this species across non-conservation areas, the latter including communal rangeland, arable fields and homestead yard trees in local communities.

1.3 Aims and Objectives

1.3.1 Aim

To explore changes in marula population demographics (ecological indicators) within the complex socio-ecological system of the lowveld marula bioeconomy, specifically how resource use patterns across land-uses (social drivers) are responsible for variations in marula population demographics.

Data was collected to understand the impact of community utilisation and management practices on the marula resource, as well as the reciprocal impact of varying resource availability (marula fruit and fuelwood) on the resource reliant communities within the study context. In particular, this involved exploring the context-specific drivers affecting marula populations and what this means for the marula bioeconomy catchment as a whole. Reciprocal impacts were explored through the utilisation of a combined socio-ecological and high-level livelihoods framework approach. The chosen geographical region included four rural and four peri-urban villages across the Limpopo and Mpumalanga lowveld region of South Africa.

1.3.2 Objectives

Within a complex socio-ecological system centred on marula, this research was conducted with three primary objectives:

1.3.2.1 To explore the current status of marula populations in the lowveld marula bioeconomy catchment

The current status of marula populations in non-conservation areas, comprising three land-use types (homestead yards, arable fields and communal rangeland), across two settlement types (rural and peri-urban) was investigated. The current status of the resource was explored from the perspective of marula population demographics, focussing on: density changes, adult to juvenile ratios, size class distributions, male to female tree ratios, evidence of damage and mortality.

1.3.2.2 To understand the interactions between the social and ecological components of the marula socio-ecological system as drivers of population demographic change and the resultant impacts across the bioeconomy catchment

In particular, the impacts of resource utilisation and land-use management practices as dominant drivers of change were explored. This included examining the positive and negative implications of these factors on marula populations.

The three areas where drivers of change are considered to be instrumental are:

Ecological: Understanding how population demographic changes, as denoted by ecological indicators such as density, recruitment, size-class distributions, gender and maturity ratios convey key shifts within the system. In addition, tracing how the ecological traits of marula contribute towards, or detract, from the conservation of the species as a whole.

Social (economic and cultural): Analysing how varying marula population demographics impact the informal marula bioeconomy that relies upon and uses this resource and in turn, how the economic and cultural drivers of change impact this complex socio-ecological system.

Socio-ecological: Exploring how variations in marula population demographics impact the communities who rely upon and use this resource and in turn how the communities, as social drivers of change, impact ecological elements of the socio-ecological system.

1.3.2.3 To examine the possible compounded implications of environmental change, as a consequence of resource use and reliance, including current resource management practices on the local marula bioeconomy in the lowveld

The compounded impacts of both the risks to the system and the current resource status are explored in relation to the impacts (positive or negative) to the communities who utilise marula. This includes understanding what long-term solutions exist for securing the sustainability and resilience of the system under conditions of environmental degradation.

1.3.3 Research questions

Objective 1 (resource status) research questions:

What is the current status of marula tree populations in areas that are classified as non-conservation savanna ecosystems (settlements divided into rural and peri-urban and comprising three land-use types: homestead plots, arable fields and communal rangeland)?

1. What is the current overall population density as well as the densities of male/female, adult/large adult and adult/juvenile trees?

    a. How do densities in non-conservation areas compare across land-use and settlement types?

2. What are the levels of adult tree mortality and overall population regeneration? (based on size class structure and recruitment from seedlings).

    a. What visible damage/impact/mortality is observed within the sampled populations?
    b. What are the maturity ratios, in terms of adult and juvenile as well as adult and large adult trees, across marula populations and how do these compare?
    c. How do maturity ratios and size-class distributions compare across location, land-use and settlement types?

3. What proportion of the population that comprises fruit-bearing adults are male and female, and what is the gender balance-ratio of male versus female trees in the population?

    a. How do gender ratios compare across location, land-use and settlement types?

Objective 2 (drivers/controllers) research questions:

1. What are the possible impacts of current resource utilisation, land-use and management practices on marula populations?

    a. What resource utilisation, land-use choices and stewardship practices (or lack thereof) affect marula densities, size-class distributions and gender and age-class ratios?

Land-use and management practices include behaviours such as tree ownership/ stewardship and pruning or utilising parts of the tree, including chopping trees for fuelwood and using different parts of the tree for marula products or medicinal applications.

2. How is marula valued as a cultural commodity and does this value impact how communities utilise the resource?

3. What are community perceptions of climate change and how this has potentially impacted marula as a key subsistence resource?

    a. How do communities view changes in local climate and weather patterns over recent years, and have they been able to adapt their livelihoods strategies to meet these changes?
    b. What response do communities have to climate change potentially impacting marula, as an important commodity and cultural asset?

Objective 3 (bioeconomy) research questions:

1. What are the possible implications (positive and negative) of changing marula availability and access (fruit and wood) for the communities across the marula bioeconomy catchment areas of Limpopo and Mpumalanga from the perspective of household income and financial reliance on these specific resources?

2. What are the local economic drivers maintaining or undermining the current patterns of reliance and resource use based on marula's socio-ecological footprint?

3. What social-economic factors increase or decrease local resilience and how are these likely to affect the current marula socio-ecological system?

1.4 Study Approach and Structure of the Thesis

1.4.1 Study approach

The research undertaken in this study utilises a multidisciplinary approach to obtain current tree population demographic data on tree density, basal circumference, size class distributions, gender and maturity ratios. In addition, local social data on the cultural and economic value of the tree are provided in order to contextualise these ecological indicators. The socio-cultural and socio-economic data are important due to the social landscape within which marula trees are embedded. This includes the patterns of resource use that directly impact the resource base, which are revealed through the ecological indicators. This information can then be used to understand the implications of resource use, and in particular, any overutilization of the resource by the communities that constitute the informal marula industry. Potential overutilisation can be gauged from the current tree population structures combined with maturity, gender ratios and densities. Finally, by linking social and ecological data, it is possible to map resilience and capabilities in order to inform the long-term sustainable development of this complex social-ecological system which is strategically centred on marula.

Considering the complexity of this socio-ecological system, a high-level SES lens was applied in order to investigate the various components of the system. There is extensive literature on SES models and approaches comparing the top frameworks for analysing social-ecological systems (Tallis and Kareiva, 2006; Young et al., 2006; Ohl et al., 2007; Binder et al., 2013). While there are numerous SES approaches, the most applicable in the current research context was deemed to be the Social-Ecological Systems Framework (SESF), which includes a Livelihoods Framework. The SESF can be used to explain contextual findings based on the reciprocity between the ecological and social elements of the system. Based on guidance by Binder et al. (2013), the SESF framework is also considered useful for this study as it interrogates the social system in terms of not just the resource users (the actors) but also the governance systems that influence actions, with a specific focus on harvesting rates. Understanding the drivers motivating resource users, as well as the wider socio-economic marula landscape, specifically in terms of resource harvesting, are three crucial elements of this study. Additionally, the SESF incorporates feedback loops by exploring environmental changes in relation to human actions, as well as environmental awareness regarding these behaviour patterns (Binder et al., 2013). The implications of land-use choices and resource practices are examined in this study with the key additional step of understanding how perceptions about key changes in the system may impact resource use behaviours.

Three layers of data are required to assess the reality of marula populations within these areas. The first being a more expansive understanding of gender ratios and the implications of the dioecious nature of the species, the second is size class distribution data to qualify if large juvenile populations are recruiting through to adulthood and the third is social data to detail how resource users are likely to behave towards the resource. In addition to exploring gender ratios, the ecological indicators of damage, bark removal and mortality data help to explain the resource use patterns around marula in more detail in Chapter 4. An assessment of size class distribution is used to tell a complete story of marula use across land-use types in Chapter 5. Social data on the cultural and economic value of marula are then provided in Chapters 6 and 7 respectively. While current marula densities suggest that the populations are not severely degraded in either location, on-going stressors on the system, such as high levels of resource utilisation, combined with a changing climate need to be investigated further. Changes in density over the 15-year period help to clarify current population trends and speak to the pervasive value of longer-term studies that are able to benchmark and then track species change over extended time periods. As the commercialisation of marula based products continues to expand across southern Africa, understanding future tipping points in terms of population responses to key stressors is fundamental. Specifically, future studies which track marula population trends in terms of key climatic variations in temperature and rainfall are crucial. Finally, incorporating the social elements of marula resource reliance into population trends will be invaluable, in determining the on-going future sustainability of marula, as a keystone species.

The first three data chapters of the thesis comprise ecological data, detailing changes in marula population demographics. In order to understand changes within the ecological system, six ecological indicators were selected for the comparison across the three land-use types (yards, fields and rangelands) as well as two settlement types (rural and peri-urban) as shown in Figure 1.1.

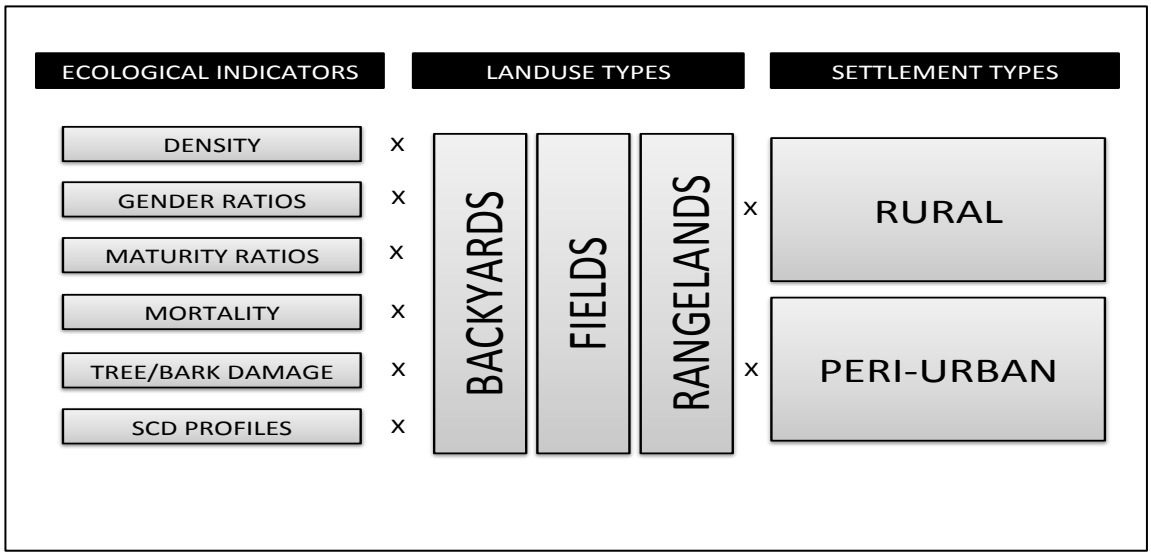


Figure 1.1: Diagram of the project design in terms of ecological indicators and 'replicates' by land-use and settlement types

The focus of the ecological data chapters are based on Shackleton's key suggestions for important on-going research themes in terms of marula studies. Shackleton's (2002) study recommended long-term monitoring of density, recruitment and size-class profiles as well as the development of a sustainable harvesting strategy to ensure adequate gender ratios and fruit availability for recruitment. In order to answer these objectives, as well as provide updated inventory data, the three ecological data chapters deal with the ecological indicators of density, recruitment (including gender ratios) and size-classes respectively. In addition, there are two key social chapters, which provide contextual data in order to understand the resource and land-use practices that have contributed to the changes revealed by the ecological indicators. The social components are divided into socio-cultural and socio-economic aspects. Combined, these social and ecological chapters aim to generate a complete picture of marula use and reliance in the lowveld region.

This study has been designed as a 'comparative measurative' experiment of different marula population sites along a land-use gradient in a specified region, with replicates per 'treatment' at the level of land-use and settlement type for two locations (Phalaborwa & Bushbuckridge). Across these municipalities, the villages were selected in order to ensure two representing peri-urban and the other two, rural villages. In addition to this, the research design ensured that half of the villages sampled were communities from which Distell (largest commercial off-takers of marula fruit at the time and makers of marula-based liqueur Amarula Cream) were purchasing fruit, with the other two not being fruit suppliers to Distell. The intention is to make direct comparisons between locations by drawing inductive conclusions about the two-way interactions between the ecological and social components of the overall system.

Changes in the socio-ecological system were compared across spatial and temporal scales. The spatial component relates to changes in marula population demographics and structure (ecological indicators) as well as resource utilisation and land-use management (social factors) across the various land-use types (non-conservation areas). Across the different treatments, the temporal scale was applied by exploring changes based on published data from two important marula focussed past studies (Shackleton, 2002; Helm, 2011) to the present context. The three different land-use types of yards, fields and rangelands are displayed in Figure 1.2.



Figure 1.2: Images of the three land-use types compared during the course of this study: A) Homestead yards, B) Arable fields and C) Communal rangelands

Within socio-ecological systems, many of the changes in resource population demographics and structure occur as a direct result of the two-way interactions between the resource users and the resource. While many scientific or social studies utilise one methodological approach, this study incorporates the underlying principles inherent in the inter-disciplinary paradigm shift occurring over the past decade. This paradigm shift promotes multiple methodologies for understanding complex socio-ecological systems. While Traditional Ecological Knowledge (TEK) and scientific observation are often regarded as mutually exclusive methodologies, combining these two forms of knowledge acquisition, specifically in relation to understanding ecosystem degradation, can actually help to reduce uncertainty (Huntington et al., 2004).

After the three ecological chapters, the methodology shifts to a social narrative for the next two chapters, which include social resource use and reliance data. These are presented in the form of Traditional Environmental Knowledge (TEK), which have been added to provide insights into the cultural and economic value supposition surrounding marula. This requires premising the ecological changes within the context of resource use choices by the resource users, which in turn involves interrogating the resource value narrative, as this directly determines resource use (Figure 1.3).

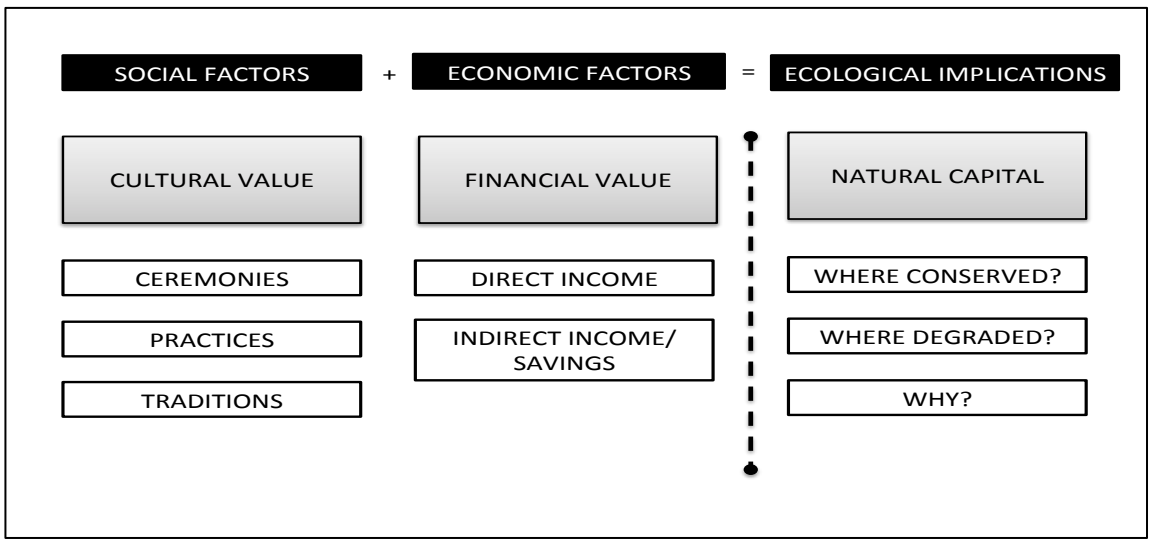


Figure 1.3: Diagram detailing the social factors (cultural value) and economic factors (financial) value which result in changes to the natural capital (ecological implications)

Applying the above research design to the project, data were collected and analysed, applying a quantitative approach to the ecological data components and a semi-qualitative approach to the social data sections. The three ecological chapters explore overall density, size-class distributions, mortality and tree/bark damage in the first chapter, with gender ratios and density in a second chapter. Maturity ratios and juvenile, adult and large adult densities are examined in the third ecological chapter. The social data are used as a narrative to embed as well as premise ecological findings. The two social chapters are a socio-cultural chapter (cultural capital), that includes perceptions on cultural fragmentation, linked to potential climate change impacts on marula. The second social chapter is a socio-economic chapter (financial capital) that explores the direct and indirect economic value of marula. The final step involved linking the datasets so that the interactions between the ecological and social components (eco-social interface) of the system could be explored in the final chapter of the thesis. These outcomes are profiled in the synthesis chapter in terms of the overall impacts on the status of marula (natural capital).

1.4.2 Structure of the thesis

This thesis has been written as a research dissertation with an introductory chapter, methodology and context chapter, five data chapters and a synthesis chapter at the end. The thesis is divided into four parts, with eight chapters overall. Information from the various chapters are complementary in building an overall picture of the ecological and social drivers affecting marula, meaning that some repetition is inevitable. In order to reduce repetition as far as possible, cross-referencing is made to the various chapters containing the more detailed information on a specific topic, pattern or trend.

Part A: General introduction and background, including:

- Literature review
- Conceptual frameworks
- Species characteristics
- Rationale and objectives
- Research questions
- Introduction to thesis layout
- Study site descriptions
- Ethical clearance
- Methodology overview

Chapter 1: A general introduction, which contextualises the study within the relevant literature, reviews the conceptual frameworks applied, details the study species, provides the rationale and objectives and contextualises the research questions against the backdrop of the thesis to indicate how the aims of the research will be addressed.

Chapter 2: Provides the study site descriptions, including background as to why these specific sites were selected, with detail regarding the various quantitative and qualitative research methodologies as well as data assessment approaches, including detail on the ethical clearance process followed in order to obtain clearance to interview human subjects.

Part B: Marula population demographics, as illustrated by the following ecological indicators:

- Density,
- Gender ratios,
- Mortality,
- Tree and bark damage,
- Maturity ratios and
- Size-class distributions (SCDs)

Chapter 3: Spatial comparison of marula demographic changes in terms of overall marula density, size-class distributions, damage and mortality across three land-use types (homestead yards, fields and rangelands) as well as two settlement types (rural and peri-urban). In addition, a high-level comparison is made in the final section with published findings from two previous studies allowing for a 15-year temporal comparison in the Bushbuckridge context, with conservation and non-conservation densities being contrasted for a fence-line comparison.

Chapter 4: Changes in the ratios of male to female (male:female) individuals, as well as their densities, are compared across yards, fields and rangelands as well as rural and peri-urban contexts to gauge differences in densities between the genders as well as any departure from Fisher (1930) 1:1 ratio for undisturbed dioecious populations.

Chapter 5: Variations in maturity ratios as well the densities of juvenile, adult and large adult individuals are compared across yards, fields and rangelands as well as rural and peri-urban contexts to gauge recruitment as well as regeneration of the population. Juveniles are split into seedlings and saplings, with adults split into intermediate adults and large adults. This is done because these two ends of the continuum, seedlings and large adults, are critical life history stages (recruitment bottlenecks and fruit (seed) productivity).

Part C: Social drivers of marula population changes as a result of resource use and harvesting practices, explored in terms of:

- Economic (financial capital) value of marula as subsistance income
- Cultural (social capital) value of marula in terms of ceremonies and customs

Chapter 6: Exploration of the economic value of marula as a source of important financial capital for community members who rely on marula as a key form of supplementary subsistence income. The income generated from the sale of marula fruit, beer and jam are compared to income generation in the same context 15 years prior.

Chapter 7: The cultural value of marula as an important tree in local customs and rites is examined, as well as the cultural usage of the beer in three main ceremonies. Local involvement in these cultural practices are compared with findings from 15 years prior to gauge current engagement in customary practices, as well as the possible causes of any changes over this time-frame.

Part D: Uncovering the eco-social interface, combining the social and ecological elements:

- Synthesis of social and ecological drivers and outcomes

Chapter 8: Provides an overview of how the social and ecological factors interact and interconnect to impact marula populations across the lowveld, as illustrated by the variability in the demographic data (ecological) and contextualised through the social data and personal narratives of the marula resource users.

2. Environmental Context, Study Region & Research Methods

2.1 Study Sites

2.1.1 Greater study area

The greater area within which this research is situated is the north–eastern low altitude savanna (lowveld) region of South Africa. The region is called the lowveld due to the low elevation of the plain (below 900 m a.s.l), which stretches from the Greater Drakensburg Escarpment in the west to the Mozambican coastal plain to the east (Shackleton, 2000; Pfukenyi et al., 2007). The overall topography is generally flat to slightly undulating relief, resulting in relatively slow flowing rivers and mainly human-engineered dams, which provide water for livestock in rural areas and wildlife in conservation areas (Pfukenyi et al., 2007). The region is known for its granitoid rocks, specifically potassic granites and grandiorite (Shackleton et al., 2003; Helm, 2011). Soils are generally shallow sandy lithosols, with deep apedal soils closer to the Drakensburg Escarpment (Shackleton, 2000).

Under the Apartheid Regime in South Africa, indigenous black communities were relocated into much of this region from the 1960s onwards, under the Apartheid Government's Promotion of Bantu Self-Government Act of 1959. These areas were orignally designated under colonial rule but formalised under apartheid and constituted just 13% of the total land in South Africa, yet were created to house the bulk of the black population at the time (Yawitch, 1988). It is estimated that around 12.7 million people, approximately 32% of the national total, live in these areas (Bennett & Barrett, 2007). Prior to 1960, communities lived in dispersed homesteads on arable land, with migrant labour supplementing a mainly agricultural economy (Stadler, 2003). However, under the apartheid regime from the 1950s onwards, many communities in the area were relocated into the designated homelands, with each village being allocated a surrounding communal rangeland area of approximately 1000- 2000 ha in size for agriculture, grazing and resource harvesting.

The unfairly biased restrictions on the land, which was made available for these activities, were intended to control land tenure by further disenfranchising local communities (Niehaus, 2007; Helm, 2011). The poor quality of the shallow sandy lithosols is one of the main historic reasons why these areas were designated into the so-called 'Homelands.' In comparison, the best agricultural land with the most productive soils, were reserved for white-owned commercial farms in the region. This meant that homelands were usually situated on poor agricultural land, and with limited access to grazing for cattle (Stadler, 2003). The consequences of this historical legacy are poor agricultural yields as well as restricted land availability, due to the various demarcated land-use zones. This has in turn resulted in ever increasing pressure on the already heavily utilised land, which needs to be made available for on-going housing and agricultural expansion (Mograbi et al., 2015; Coetzer-Hanack et al., 2016).

The lowveld region has historically been characterised by a range of mixed land-use types creating a patchwork of distinct land-use zones (Coetzer-Hanack et al., 2016). This mixed land-

use region forms part of the declared UNESCO Kruger to Canyons Biosphere Reserve. The landscape today ranges from the human inhabited communal rangelands, which form the focus of this study, through to conservation areas (private and provincial game reserves as well as the Kruger National Park) with commercial and subsistence agricultural land, plantation forestry, mining and human settlements dominating the remaining non-conservation land (Coetzer et al., 2010; Helm 2011).

The region is characterized by a west to east gradient in terms of topography and climate, with the Drakensberg escarpment in the west receiving a mean annual rainfall (MAR) of 1200 mm, which decreases to around 550 mm towards the east (Shackleton et al., 2002; Shackleton et al., 2003; Shackleton & Shackleton, 2005; Helm, 2011). The climate of the wider area is tropical to subtropical with hot humid conditions and summer rainfall (October –May) averaging 500-700 mm while winters are generally mild and frost free (South African Weather Service, 2020). Drought in the region is endemic and prolonged, occurring at least once every 10 years (South African Weather Service, 2020).

The average temperatures for the region range from 17.3-24.4°C; minimum temperatures range between 9.5-20.4°C, and maximum temperatures are in the range of 26.1-32.4°C. The three years preceding this study from 2014 - 2016, were classified as below average annual rainfall for the region, which resulted in severe drought conditions (Archer et al., 2017; Siderius et al., 2018). Due to the rainfall gradient of the region, two main types of vegetation are evident: Granite Lowveld towards the east, grading into Legogote sour bushveld at the foot of the escarpment in the west (Mucina & Rutherford, 2006). These vegetation types are underlain by granitic geology giving rise to sandy soils. Patches of Gabbro Grassy Bushveld occurs in thick vertic clays on a gabbro dyke in the east (Mucina & Rutherford, 2006). Fuelwood is the dominant energy source in the rural areas with between 85-95% of household relying on wood for cooking and heating purposes (Shackleton, 2002).

2.1.2 Specific study sites

2.1.2.1 Explanation of study areas

The Limpopo and Mpumalanga regions are considered the 'home' of the marula industry in South Africa, due to Phalaborwa and Bushbuckridge being at the epicentre of marula's geographic range in South Africa. Phalaborwa and Bushbuckridge have been specifically selected due to their positioning as key marula related hubs, with the Distell processing plant, the largest commercial off-taker of marula, being located in Phalaborwa until 2019. The Distell processing facility and Amarula Lapa were located in Phalaborwa, which enabled the fruit pulp to be extracted from the marula fruit before being sent to the Distell distillery in Stellenbosch to make the final Amarula Liqueur product. In addition, the various communities of the Bushbuckridge region have constituted the focus of many of the most pivotal marula related studies to date, which have been discussed in the introduction, including the work done by Shackleton et al. (2002) in compiling a complete marula inventory.

This project therefore incorporates these two study areas, the Phalaborwa and Bushbuckridge municipalities, with four villages selected in each area. These were used as the basis for collecting quantitative data on marula population demographics and structure, as well as qualitative data collection on community resource utilisation, reliance and resilience patterns. A baseline tree population data set exists for Bushbuckridge (Shackleton et al. (2002; 2003; 2005),

but due to a lack of previous studies, the same data is not available for Phalaborwa. Due to geographical and cultural differences, the Phalaborwa and Bushbuckridge communities are compared or contrasted to interrogate differences and are not intended to be grouped statistically. However, when combined, they form the established marula industry around which deductions can be made regarding high-level marula use and reliance within the bioeconomy catchment. The location of the two research areas by province is detailed in the study site map (Figure 2.1), showing the Limpopo and Mpumalanga village sites at Phalaborwa and Bushbuckridge. The location of the eight villages (four in each location) are shown on maps detailing geographical features in Figure 2.2. In addition, the sampling methodology is illustrated using the Phalaborwa village of Lulekani as an example (Figure 2.2).

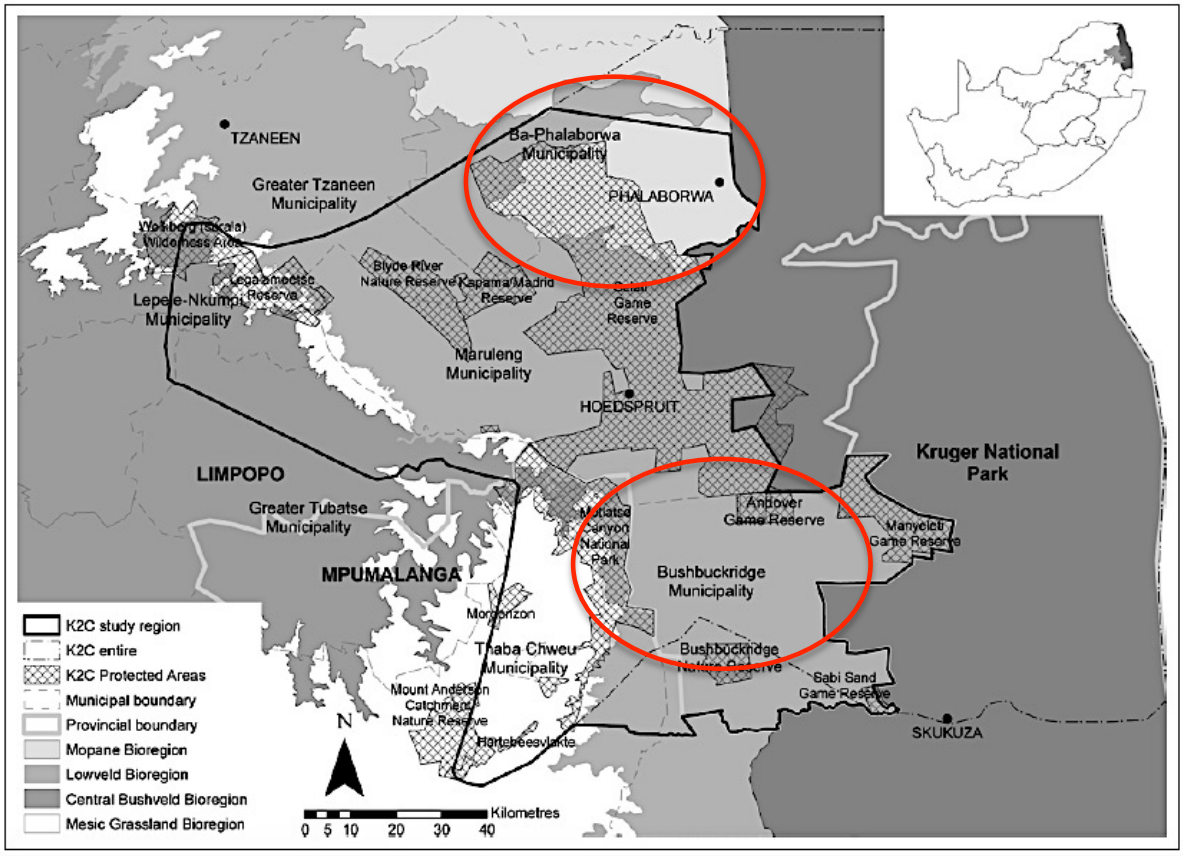


Figure 2.1: Regional location of the Kruger to Canyons Biosphere Reserve (K2C), including protected areas, vegetation bioregions and municipal districts, including Ba-Phalaborwa (top circle) and Bushbuckridge (bottom circle) (~Coetzer, 2016)

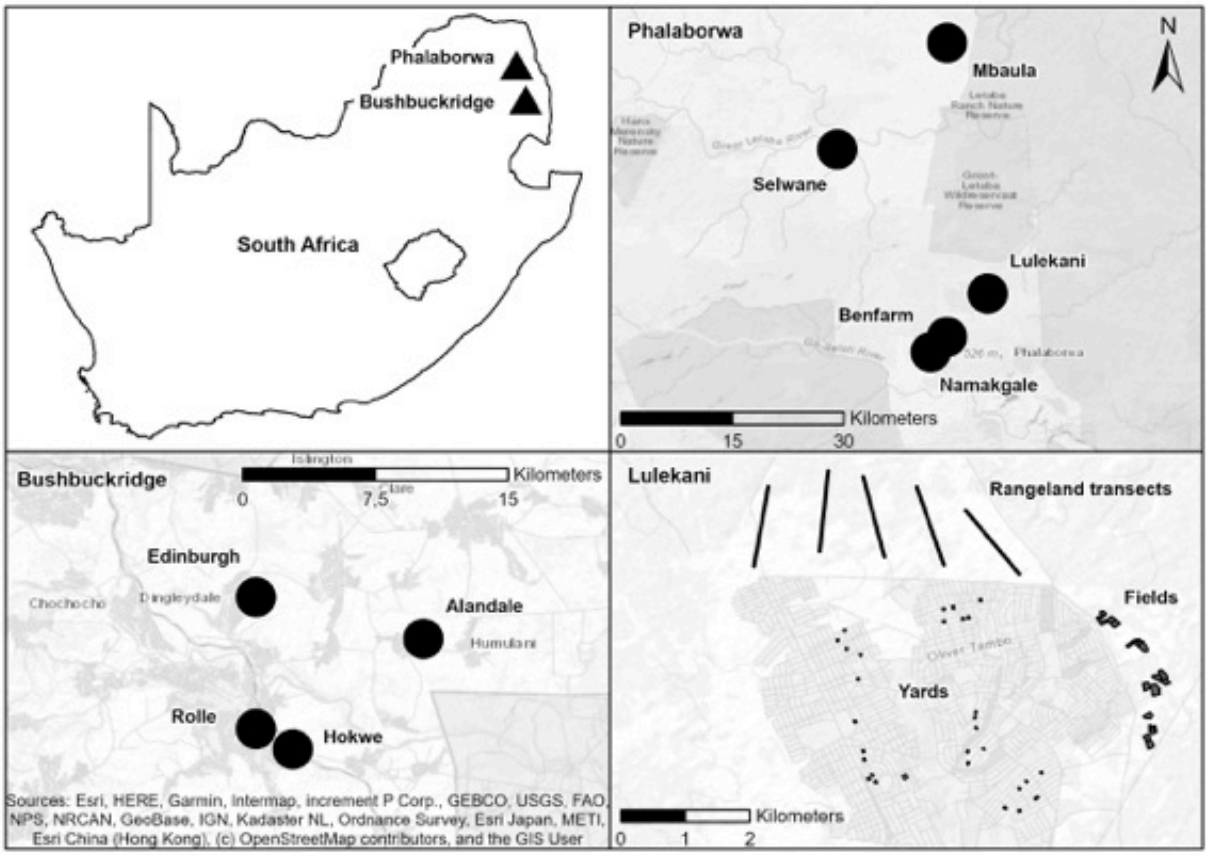


Figure 2.2: Map of the study sites in the north-eastern corner of South Africa, detailing the four Bushbuckridge (Allandale, Edinburgh, Hokwe and Rolle) and Phalaborwa (Mbaula, Selwane, Lulekani & Benfarm/Namakgale) villages, as well as the sampling methodology of yards, fields and rangelands

2.1.2.2 Bushbuckridge municipality (Mpumalanga)

2.1.2.2.1 Bushbuckridge area

The Bushbuckridge municipality is located in the southernmost section of South Africa's Mpumalanga province and was named after the large numbers of Bushbuck antelope found in the area in the 1880s. The Bushbuckridge region is approximately 2600 km^2 and is comprised of two of the former homelands, Mhala in Gazankulu and Mapulaneng in Lebowa, both demarcated according to the previous Apartheid Government's political boundaries (Giannecchini, 2007). Due to forced mass relocations under the previous disposition, Bushbuckridge is characterised by high human densities of up to 300 people/km^2 in places, which were exacerbated by an influx of refugees from Mozambique during the civil war in the 1980s (Shackleton, 2000; Mograbi et al., 2015). The forced removals to the Lebowa and Gazankulu homelands during apartheid resulted in relatively high-density rural villages with low levels of infrastructure and high unemployment and mortality rates (Niehaus, 2007). In accordance with the rainfall gradient of the region, two types of vegetation are evident, the Lowveld Sour Bushveld is dominant in the wetter west grading towards the eastern sweetveld Savanna Grasslands (Shackleton et al., 2003). In the Lowveld Bioregion, SANBI classifies the vegetation around Bushbuckridge as Legogote Sour Bushveld (Mucina & Rutherford, 2006). Hemmed in by protected areas, both private and state owned, there is increased pressure on available land in Bushbuckridge for both livestock grazing and harvesting of natural resources (Mograbi et al.,

2015). After the democratic transition in 1994, Bushbuckridge become a unified municipality. Bushbuckridge is characterised by underdevelopment, poor service delivery and high unemployment rates (Shackleton et al, 2002). Bushbuckridge Local Municipality consists of 135 settlements and is divided into 34 wards (StatsSA, 2011). Human population density is estimated to be around 150-200 persons per km^2 in the east and 300-400 persons per km^2 in the west (Shackleton et al., 2003; Emanuel et al., 2005), although Statistics South Africa places the average density far lower at 53 people per km^2 (StatsSA, 2011). Unemployment remains high with an estimated 60-70% of the potentially economically active population unemployed at the time Shackleton et al. (2002) conducted their research. At the time, Shackleton (2002) found approximately half the households cultivated demarcated arable land on the periphery of the villages with land shortages preventing further involvement. The remaining land is classified as communal grazing land with most households harvesting resources, including NTFPs, from these communal lands (Emanuel et al., 2005).

The overall population for the area was 541,248 people according to the last national census (StatsSA, 2011), with approximately 80 000 households collecting marula fruit each season, according to Emanuel et al. (2005). Livelihood income options range from micro-trade to home-based micro-enterprises and subsistence farming, with a small percentage involved in formal employment (Shackleton & Shackleton, 2005). Of the overall 134,197 households in the area in 2011, approximately one third (53,204) were found to be agricultural households according to the StatsSA census (2011). The average household size at the time was four people with 53.3% female-headed households (StatsSA, 2011). Shackleton & Shackleton (2005) placed the mean household size between 6-7 people.

Frequently occurring tree species are *Sclerocarya birrea* subsp. *caffra* (marula)*, Lannea schweinfurthii, Ziziphus mucronata, Dalbergia melanoxylon, Peltophorum africanum and Pterocarpus rotundifolius* subsp. *rotundifolius*. The majority of the woody biomass in the region is contributed by *S. birrea, Pterocarpus angolensis and Senegalia [*previously *Acacia] nigrescens* (Mograbi et al., 2015).

2.1.2.3 Ba-Phalaborwa municipality (Limpopo)

2.1.2.3.1 Phalaborwa area

The Phalaborwa municipality, situated in the eastern part of the Limpopo Province, is to the north of Bushbuckridge. Historically, the land-use in the area has been mining, dating back to the Sotho tribes who both mined and smelted copper and iron in the area as far back as 400 AD (Moore, 1974). These Sotho tribes named the area Ba-Phalaborwa, which means 'better than the south.' Phalaborwa remains a mining town today with Palabora Copper [previously Phalaborwa Mining Company] still in operation. The vegetation is Phalaborwa-Timbavati Mopaneveld (Mucina & Rutherford, 2006). Despite Phalaborwa being at the lower end of the rainfall gradient, MAR of 543 mm when compared to Bushbuckridge with an MAR of 650 mm, a large number of tree species occur in the area (Shackleton et al, 2000; Munnik et al, 2013).

The landscape around Phalaborwa is mostly dominated by *Combretum apiculatum*, *Terminalia sericea* and *Colophospermum mopane* trees. While not one of the most dominant trees, marula tends to dominate the landscape alongside main roads and in villages across the area, where they are one of the larger trees in the ecosystem. Unlike Bushbuckridge, the lower rainfall means that overall, marula trees are less abundant in Phalaborwa, with water acting as a

limiting factor in relation to planting and tree care of domesticated trees. Phalaborwa was selected as the second site for this study due to its identification as a second marula 'hub' in the lowveld. In addition to Bushbuckridge, where the majority of marula studies on community and conservation have focussed, Phalaborwa was the site of Distell's Amarula distillery until 2019. The presence of the distillery meant that communities in the area could sell the fruit directly to the company at the factory gates, in addition to utilising it for a variety of livelihood purposes.

Phalaborwa is also characterised by poor service delivery, poverty and high unemployment, specifically in the more remote rural villages. According to the Census 2011, Ba-Phalaborwa Local Municipality had a total population of 150 637 people with 95% of the population residing within a 15 km radius of Phalaborwa Town (StatsSA, 2011). Phalaborwa displays a very clear rural and peri-urban division between settlements, with a number of villages located more than 50 km from the town. This allowed for a clear comparison between the rural and peri-urban contexts to be made for this area. Population density was low at the last census at 20 persons per km^2 (StatsSA, 2011). The unemployment rate for the area was 37.4%, with youth unemployment at 50.2% at the time (StatsSA, 2011). Of the approximately 41,115 households located in the area, 10,628 were agricultural households in 2011 (StatsSA, 2011). The average household size was 3.6 people, with 39.5% female-headed households at the last census count (StatsSA, 2011).

The main geographical differences between the municipalities of Ba-Phalaborwa and Bushbuckridge are highlighted in Table 2.1.

Table 2:1: Comparison of the main environmental and socio-economic differences between Phalaborwa and Bushbuckridge

	Phalaborwa	Bushbuckridge
Mean Annual Rainfall	543 mm	650 mm
Mean Annual Temperature	22.1°C	21°C
Soil Type	Sandy Lithosols	Mainly sandy Lithsols with some deep apedal soils
Vegetation Type	Phalaborwa-Timbavati Mopaneveld	Legogote Sour Bushveld
Dominant Vegetation	Combretum apiculatum, Terminalia sericea and Colophospermum mopane	S. birrea, Pterocarpus angolensis and Senegalia [previously Acacia] nigrescens
Human Population	150 637	541 248
Human Density	20 people/km^2	53 people/ km^2
Number of Households	41 115	134 197
Average Household Size	3.6	4
Unemployment Rate	37.4%	65%
Female-Headed Households	39.5%	53.3%

2.1.2.4 The eight study villages

This study was conducted in eight rural and peri-urban villages, four located in Bushbuckridge municipality (Mpumalanga Province) and four in Ba-Phalaborwa municipality (Limpopo Province). The four Bushbuckridge villages are Allandale (24° 42'S 31° 16'E), Edinburgh (24° 40'S 31° 13'E), Hokwe (24° 45'S 31° 15'E) and Rolle A (24° 44'S 31° 14'E). Selwane (23° 41'S 30°

55'E), Mbaula (23° 36'S 31° 01'E), Lulekani (23° 51'S 30° 04'E) and Benfarm (23° 41'S 54° 02'E) are located in the second location of the greater Ba-Phalaborwa region. In Phalaborwa, the rangeland near Benfarm technically belonged to the neighbouring village, Namakgale. This meant yards and fields were sampled in Benfarm but rangelands technically fell under Namakgale jurisdiction. However, Benfarm residents share these rangelands with Namakgale in terms of harvesting resources. All of the selected villages fall under the authority of local traditional authorities, with each village led by an Induna (Headman). The Bushbuckridge villages were selected based on previous studies conducted by Shackleton over the years 2000–2005, so as to replicate the methods and the site in order to compare findings. Geographical differences in terms of the three land-use (homestead yards, fields and rangelands) and two settlement types (rural and peri-urban) were compared and contrasted through replication of the current Bushbuckridge study in a different part of the lowveld, the second site comprising the four villages in the Phalaborwa area. Across the Ba-Phalaborwa local municipality, the villages were selected in order to ensure two classified as peri-urban and the other two as rural villages, as was the case in Bushbuckridge. Peri-urban and rural classifications were ascertained based on village distance to the nearest largest town. For Ba-Phalaborwa this was Phalaborwa Town (Phalaborwa) and Thulamahashe for the Bushbuckridge municipality. The two villages furthest away were classified as rural and the two closest classified as peri-urban in each location. In the Phalaborwa context, this division was more distinct with two villages being located approximately 12 km from the town and the second two almost 60 km away. In Bushbuckridge, the distances are not as obvious, with the more rural villages (Edinburgh and Allandale) being 9.8 km and 12.1 km from Thulamahashe and the more peri-urban (Howke and Rolle A) located 7.4 km and 3.6 km away. Despite these smaller distances, Howke and Rolle A are located south of Thulamahashe where available land is at a premium, whereas Edinburgh and Allandale are north and north-east of Thulamahashe, with more available rangeland and greater distances between villages.

In addition to this, the research design ensured that half of the villages sampled were communities from which Distell (largest commercial off-takers of marula fruit at the time and makers of marula-based liqueur Amarula Cream) were purchasing fruit, with the other two not being fruit suppliers to Distell. Conveniently, at the time of this study, the four Bushbuckridge villages that Shackleton had worked in 15 years before met all the specified criteria. The two-way comparison of both past to present population demographics in Bushbuckridge, as well as geographical changes from one location (Bushbuckridge) to another (Phalaborwa), allowed for a temporal as well as spatial assessment of changes in marula demographics and resource practices.

2.2 Methodology

2.2.1 Research design

Over two fieldwork seasons during 2017 and 2018, marula trees were surveyed in yards, fields and rangelands, across the eight villages in Phalaborwa and Bushbuckridge. These data were used to establish different demographic categories of marula density (trees/ha) as well as the ratios of male:female, adult:juvenile adult:large adult and dead:alive trees. In addition to this, tree and bark damage recordings were taken and tree size class distributions were established based on basal stem diameter at 30 cm above ground level as per Helm (2011). Seedlings were measured 2 cm above ground.

In order to ascertain differences in density, data were categorised into six density categories and analysed per land-use type: overall density, male density, female density, adult density, large adult density and juvenile density. Juveniles were classified as individuals below 14 cm basal stem diameter as per the methodology used by Helm (2011), adults were individuals greater than 14 cm and large adult were adults greater than 43 cm, as per Shackleton et al. (2002). These density categories were compared across land-use and settlement types as well as geographically between locations (Ba-Phalaborwa and Bushbuckridge). In addition to this, density changes in Bushbuckridge were compared temporally for the same four villages over a 15-year period, drawing on the findings of Shackleton (2002). Aggregated data from this study (non-conservation area) was compared to published density data in conservation areas using findings from the comprehensive study by Helm (2009-2011) in Kruger Park, in order to gauge changes on both sides of the fence line.

Social data were added through 240 individual household surveys, divided equally between the two locations, as well as semi-formal focus groups in each of the eight villages. The social data serve two main purposes in terms of the project design. The first purpose is to provide contextual details to help explain the density demographics, gender, maturity and mortality ratios as well as the size-class distribution findings, by highlighting the social and cultural processes and practices that drive human behaviour as agents of change within this landscape. The second purpose is to provide linkages at the interface where the ecological and socio-cultural/socio-economic components of the system intersect. The three key areas of intersection for the purposes of this project were identified as the utilisation of marula fruit, the harvesting of marula branches for fuelwood and the removal of trees for various reasons across all three land-use types. The social behaviours associated with these particular practices are therefore discussed as the eco-social interface between the ecological and social components of the system in the synthesis chapter.

2.2.1.1 Ethical clearance procedures and processes

Permission to work in all the communities was obtained from the relevant traditional authorities. The first fieldwork season involved the gathering of ecological data from rangelands and fields, meaning that there was no interaction with human subjects. The second fieldwork season involved measuring trees in yards and simultaneously conducting an interview with a relevant household member. Before this process commenced, an application to the University of the Witwatersrand's Human Ethics Research Committee (Non-Medical) was made. A certificate of ethical clearance to conduct this research was granted on 17 November 2017 (Protocol Number: H17/11/30).

Access to communal rangelands, fields and yards was obtained through the local tribal authority for each village with local Environmental Monitors acting as gatekeepers and translators. Environmental Monitors are appointed through the Department of Environmental Affairs (DEA's) Environmental Protection and Infrastructure Programme (EPIP) and are members of each community. In the Bushbuckridge area, the University of the Witwatersrand has a long-standing arrangement with the communities adjacent to the Wits Rural Facility, which allows students to do research in these communities, as long as the local traditional authority and community development forum is notified in advance. Fieldwork in each community would commence and end with a meeting with the local Induna (Headman) to inform him/her of where work was taking place, the purpose of the research and to provide feedback at the end of each segment of

work in the village. In Phalaborwa, local Environmental Monitors from each village also acted as gatekeepers and set up meetings with the relevant traditional authorities and Indunas. At these meetings, the project purpose and timelines were presented in order to gain access and permission to work in this context.

2.2.1.2 Ecological marula data gathered across yards, fields & rangelands

Ecological data for marula trees growing in yards, fields and rangelands were collected over two consecutive fieldwork seasons, from January to July of 2017 and 2018. These data were used to ascertain marula population demographics. The marula fruiting season extends from January – April, so working during this period assisted with identification of tree gender. Outside of the fruiting season, persistent endocarps found under trees were used to indicate gender.

Marula trees in communal rangelands were surveyed by means of belt transects. Google Earth Pro (version 7.1.8.3036 (32-bit)) was used to obtain satellite images of each of the villages. Transects were 1250 m in length and 40 m in width (5 ha in area), as per the previous study conducted by Helm (2009 - 2011). As far as possible, it was endeavoured that transects be placed a couple of hundred meters from the village periphery (where the last houses ended) radiating outwards into the rangelands, located equidistantly around the village. Five transects, totalling 25 ha, were located around each of the eight villages, taking into account access issues such as roads, as well as geographical features such as rivers or dams, which might affect walking a transect. This resulted in a total of 40 transects across all 8 villages. In two instances, man-made features, such as fences were not visible in the satellite imagery, meaning these transects had to be moved once on site.

In more peri-urban villages where communal rangeland was at a premium due to 'urban' (village) encroachment, more transects had to be placed on a particular side of the village than the other, depending where the available land was situated. This meant that transects were not always evenly spaced around the villages. Transects could not always radiate out from the village in a straight line either but needed to either lie parallel to the village or in particular cases, bend to accommodate the available rangeland as shown by transect line MT4 (Mbaula Transect 4) in Figure 2.3. The transect lines in Figure 2.3 are an example of one of the surveyed villages, Mbaula, where a few of the described difficulties were encountered.

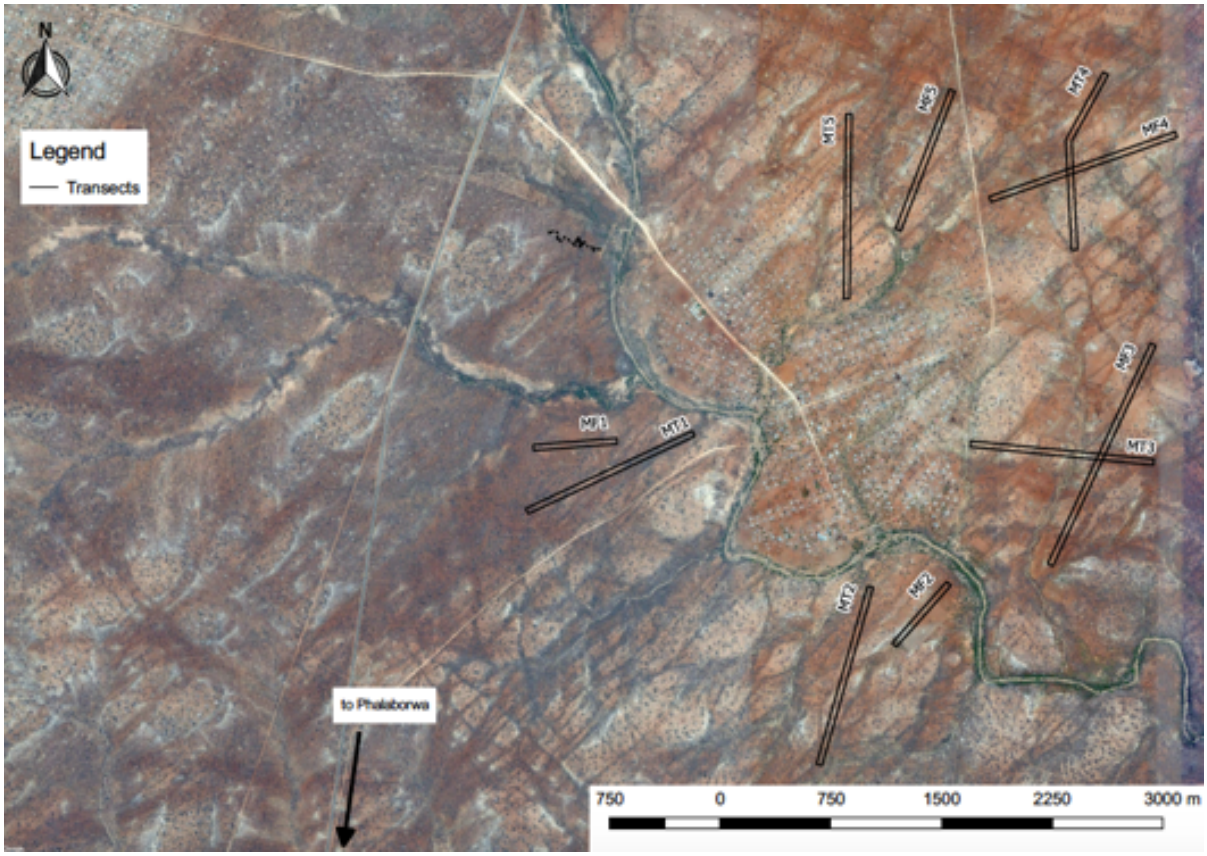


Figure 2.3: Map from ArcGIS of the Mbaula study site (Phalaborwa) showing the placements of the five transects (MT1-MT5) around the village using lines and buffers in ArcGIS as well as the corresponding field sites (MF1-MF5)

Once all the transects had been positioned, the files were converted to lines and buffers using ArcGIS and then loaded onto the Garmin (GPSmap 62sc) GPS using Garmin Bootcamp (version 4.6.3). The GPS was then used to navigate to the start of each individual transect. The transect was then walked from the start to finish points and every individual marula tree located inside the 40 m buffer measured (20m each side of the centre line), as per Helm (2011). The following measurements/classifications were recorded for each tree encountered: GPS co-ordinate; basal stem diameter at 30 cm above ground height using a tape measure or callipers; tree height using a clinometer; crown dimensions measured horizontally along two perpendicular axes using a tape measure; male or female classification based on visible fruit or endocarps from fallen fruit; adult or juvenile classification based on basal stem diameter (as per Helm (2011), with trees ≤14 cm classified as juveniles (Shackleton et al., 2005; Helm, 2011), which could not be ascribed a gender.

Stem and branch damage, bark removal and mortality were also recorded. The diameter of cut stumps were also recorded and the individual marked as dead, or alive, if there was evidence of coppicing. In certain transects, a field was encountered, the largest taking up 250 m of the transect and the smallest only omitting a few meters of the transect. Trees located in the field segment of a particular transect were not counted as part of that transect's tree quota and the overall size of the transect was recalculated, so as not to affect density results. Overall, 1223 trees were surveyed from twenty transects surrounding Bushbuckridge, and 677 in the twenty transects surrounding Phalaborwa villages. The area of the cumulative transects in Phalaborwa

was 98.57 ha and for Bushbuckridge it was 91.23 ha. The final Bushbuckridge transect area was slightly lower than Phalaborwa, as there were more fields that needed to be removed from the transect area in this location, due to space being at a premium in this context.

Areas with arable fields in close proximity to the five transect lines at each village site were also marked on Google Earth Pro so that these areas could be located with the GPS. Once on site, individual fields were randomly selected until 20 fields had been surveyed surrounding each village. It was not always possible to gain access to pre-selected fields. Access was determined by each community, which involved attendance at a preliminary meeting with the relevant tribal authority. In certain cases, it was not feasible to go to individual community members to ask for access to a specific field that was locked or not accessible due to fences. Once access to a field was gained, all marula trees within that field were surveyed in order to obtain the same measurements/classifications as outlined for the rangeland transects. The area of each field was calculated by placing area polygons around the periphery of each field in Google Earth Pro (Figure 2.4). Established fields are usually kept by a family for extended periods of time. Therefore, despite the Google Earth imagery being slightly dated in some instances, the fields utilised in the study were all clearly demarcated, suggesting a degree of longevity in terms of their establishment. This would suggest that in terms of field peripheries or boundaries, there were no recent changes in field designation. Overall, 476 trees were surveyed in fields in Bushbuckridge and 542 in fields in Phalaborwa. The overall field area in Phalaborwa was larger than Bushbuckridge due to larger fields being located in the rural context in Phalaborwa. The overall field area in Phalaborwa was 96.64 ha and 69.86 ha in Bushbuckridge.



Figure 2.4: Google Earth Pro image showing examples of the marula trees (red markers) logged in Lulekani (Phalaborwa) fields surrounded by white polygons used to calculate field area

Homestead yards were randomly selected by starting on one side of a village, avoiding the first street and then walking along the next street choosing every third house, alternating to the left and right, until the street had been surveyed. Where it was not possible to conduct an interview, for any particular reason, that house would be skipped and the one next to it selected instead. The methodology was repeated until a total of 30 households per village had been surveyed, taking care not to survey neighbours by avoiding adjacent streets. Any marula trees present in the yard of the selected houses were measured/classified as outlined previously. Interviews with a household member were conducted at the same time. Using the GPS markers for the trees surveyed, the areas of the individual yards were calculated using area polygons in Google Earth Pro as per the methodology used for fields. In terms of the accuracy of the satellite imagery, all participants were asked how long they had resided at their current address and all of the respondents indicated that it had been numerous years. This would suggest that yard peripheries were established at the time that the imagery was taken the year prior to the study. The overall area of yards in Phalaborwa was 20.69 ha, with larger yards in the Bushbuckridge resulting in an overall yard area of 31.37 ha.

Tree density was calculated as trees/ha using yard and field areas gleaned from Google Earth Pro, and transect dimensions for the communal rangelands. The data was statistically analysed using SPSS Statistics Version 26.

2.2.1.3 Socio-economic marula data gathered in household interviews

Semi-structured interviews were conducted with individuals in 240 households, divided equally between the eight Bushbuckridge (n=120) and Phalaborwa (n=120) villages. Unfortunately, it was not possible to gain a completely random sample of respondents as each household indicated which member would be interviewed, based on the person collecting marula. As this is determined by cultural norms, this resulted in a skewed sample in terms of gender, with more females being interviewed, although a range of ages were accommodated. However, where tested statistically, the data was checked for skewness. All interviews were conducted with the assistance of an interpreter over a 6-month period from January to June 2018. Yard trees were measured, as detailed above, once each interview was complete. In Bushbuckridge, all exchanges were conducted in Shangaan (Tsonga) while in Phalaborwa the interpreter was able to conduct the interviews equally efficiently in either Sepedi or Shangaan. Interview times ranged between 45-60 minutes, although some took up to 90 minutes where the individual respondent had more information to share. The survey instrument was semi-structured with a combination of binary as well as open-ended questions, allowing for definitive answers combined with the flexibility to obtain in-depth responses. The questionnaire was specifically divided into eight sections, with the purpose of obtaining categories of data necessary to answer the specific research questions (Appendix 10.2: Research Instrument). The eight sections of the survey were: 1) socio-demographic data, 2) marula fruit collection data, 3) marula tree use data, 4) economic value of marula data, 5) cultural value of marula data, 6) marula access and land tenure issues data, 7) marula management and stewardship data and 8) resource availability and climate change perceptions data.

A thematic analysis methodology was applied to the social data in order to ensure a robust approach to identifying, analysing, organising, describing and reporting themes found within the social data set (Braun & Clarke, 2006; Nowell et al., 2017). Thematic analysis is a useful methodology for examining the perspectives of different research respondents, highlighting similarities and differences and thereby generating insights by noting key trends in the

outcomes (King, 2004; Nowell et al., 2017). Due to the large nature of the data set, this allowed for a structured and methodical approach for identifying key trends in the data, allowing the main themes to emerge with reduced interpreter bias. Interpreter bias can be further reduced by assuming a clear epistemological position that underpins the study's empirical claims (Holloway & Todres, 2003). In this case, the social data was used to verify ecological findings and vice versa. In order to meet the requirements of credibility, transferability and dependability, data was captured into spreadsheets and coded by category and then aggregated by research question in order to allow patterns to emerge by village and settlement type (rural and peri-urban). These were then further aggregated at the location level (Bushbuckridge and Phalaborwa) for the purposes of discussing high-level socio-economic and socio-cultural trends in Chapters 6 and 7.

The first step involved coding the descriptive data for thematic responses. Coding simplifies the data and enables specific characteristics of the data to emerge (Morse & Richards, 2002). During coding, important sections of text are identified, labelled and indexed according to how they relate to a theme or issue in the data (King, 2004; Nowell et al., 2017). The second step involved overlying the quantitative outputs (including those that were statistically analysed) with the descriptive responses, cross referencing key findings with recurring descriptive themes. Finally, the key themes emerging from the descriptive data were independently crosschecked with the statistical outcomes from the ecological data to confirm if the anecdotal evidence supported the significant quantitative outputs.

Interviews were conducted with only one member of each household. However, in each village there were certain households where more than one person wanted to be interviewed. Where possible, these situations were used to conduct informal focus groups, where a group discussion would be facilitated after the main interview, focussing on themes in the data that needed further clarification, or where more detail was deemed useful. One informal focus group was held in each village.

Statistical analysis of social data

Cross-tabulations for data on cultural practices, resource perceptions, stewardship practices, resource use and economic contributions to household income were performed in SPSS using Chi-Square Tests ($p<0.05$) with Fisher's Exact Test and a Phi Effect Size for tables in a 2 by 2 cross-tabulation and Pearson's Chi-Square, with a Cramer's V Effect Size, for larger than 2 by 2 cross-tabulations. Analyses were performed on all questionnaire responses excluding 2 by 2 binary cross-tabulations such as Yes/No responses by Location (Phalaborwa/Bushbuckridge).

With a 2 by 2 table, SPSS provides the Yates Correction for Continuity, designed to compensate for an overestimation of the Chi-Square value, which was provided with the statistical outputs for the Chi-Square value. With Chi-Square tests it is important to check that the assumption for 'minimum expected cell frequency' has not been violated. In order to not violate the assumption, at least 80% of cells need to have a frequency of 5 or more, otherwise it is not possible to provide a significance value for the cross-tabulation.

Logistic regression analysis

Logistic regressions were used in SPSS to tests models to ascertain variables contributing to marula fruit collection, fuelwood use, yard marula damage & changes in marula's importance over time. The independent variables included in the models were tested for collinearity, with

high tolerance values indicating low correlations between variables. The predictor variables were tested for 'goodness of fit' with the Omnibus Tests of Model Coefficients. The Hosmer-Lemeshow Goodness of Fit test was used to indicate if the models were worthwhile. The Cox and Snell R Square as well as Nagelkerke R Square were both calculated in order to indicate the range of variability explained by the chosen set of variables in each model. The Classification Table for the model indicated the number of correctly classified cases. Finally, the Variables in the Equation Table were included with the results, which provide information about the importance or contribution of each of the predictor variables. The significance values indicated which of the predictors provided a significant contribution. Two of the most important statistics included the B values (probability of a case falling into a specific category - with a positive or negative result indicating the direction of the relationship) and the Odds Ratios. Finally, each variable in the models had an odds ratio, which is a 95% confidence interval with a lower and upper value.

Multiple regression analysis for total marula income

A multiple regression analysis was used to analyse the continuous dependent variable of total marula income. A multiple regression is able to ascertain how well a set of variables is able to predict a particular outcome. Preliminary analyses were performed to ensure there were no violations of the assumptions in terms of sample size, normality, outliers linearity, multicollinearity and homoscedacity. The cases that were outliers were removed from the model, using the chi-square values, which were calculated based on the number of independent variables and degrees of freedom. The R Square, Degrees of Freedom, Residual, F statistic and significance values for the model were all reported. When evaluating each of the independent variables, the Beta value under the Standard Coefficients was provided with the largest Beta values making the strongest unique contribution to explaining the dependent variable (Pallant, 2007). Finally, the significance value indicated if the variable made a statistically significant unique contribution to the prediction of the dependent variable.

2.2.1.4 Linking ecological and social components to identify the eco-social interface

Once the quantitative and qualitative data had been logged, a matrix of linkages was created to see which social and ecological components were likely to be most interconnected (two-way interactions) and therefore useful for explaining specific outcomes in the data. This was ascertained by degrees of relevance, by rating which social practices are likely responsible for identified ecological outcomes. In terms of changes in the ecological data, the social practices that most clearly resulted in increased or decreased marula densities, changes in male and female ratios, adult and juvenile ratios, adult and large adult ratios, mortality, damage and altered size-class distributions were those decisions around land-use choices (building in yards or planting in fields) and fuelwood harvesting in rangelands. Land-use choices were selected as being prominent due to these sets of practices directly resulting in stem cutting or removal of the whole individual. The next most relevant social practices involved activities around resource harvesting for economic or cultural purposes as well as medicinal uses. In addition, the attribution of value to female trees through cultural practices involving beer or using the tree to communicate with the ancestors were also identified as having a prominent, although less direct impact on marula trees. These activities had the next strongest bearing on whether a tree is likely chopped, damaged or left untouched, resulting in increased or decreased densities, ratios and ultimately size class distributions depending on the outcome. Social data from the sections

of the questionnaire that dealt with these practices were thus extracted and used as the descriptive focus for the ecological data findings.

Key aspects of the eco-social interface of marula are captured in a series of images (Figure 2.5 – 2.8). Images illustrating the socio-economic aspects of marula as a natural resource, including how it is collected and sold as fruit, beer and nuts are shown in Figure 2.5. The socio-ecological landscape of marula, across the land-use types of yards, fields and rangelands in non-conservation areas, are captured in Figure 2.6. Seedling populations display unique characteristics in non-conservation area, these differences are highlighted in Figure 2.7, including the 'forests' of marula seedlings in fenced yards and fields. Finally, marula trees experience specific types of damage due to the use and value nexus associated with these trees. The various types of damage inflicted on marula are captured in images in Figure 2.8.



Green marula fruit is collected to be sold



The edible marula fruit pulp



Marula nut kernels which are sold and eaten



Ripe marula fruit is made into marula beer



Ripe (yellow) and unripe (green) marula fruit



The 80 kg maize meal bags used to collect marula fruit



Customers can taste marula beer before buying a 1L or 2L bottle



Fruit sellers waiting for the Distell trucks to buy the bags of collected fruit



Marula nuts for sale, usually sold in 20ml jars or small packets

Figure 2.5: Images illustrating the various economic activities associated with marula, including the sale of the fruit, beer and nuts



Marula trees in yards showing proximity to houses

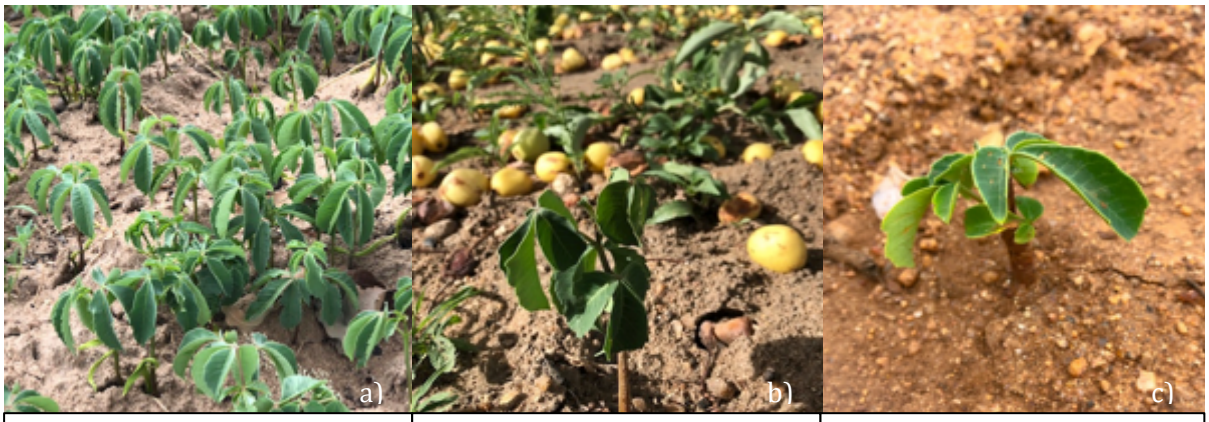


Marula trees in fields showing a range of field types



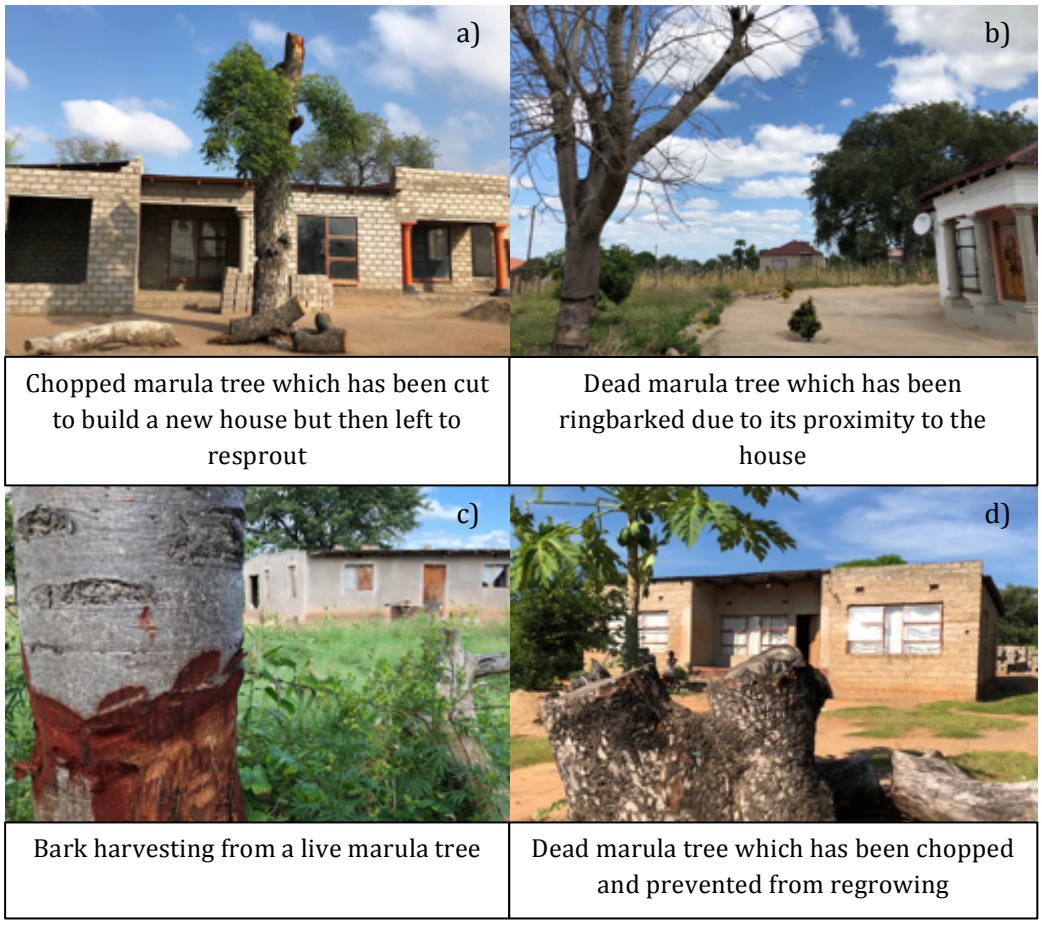
Marula trees in communal rangelands showing different vegetation types

Figure 2.6: Images illustrating the three land-use types: (a) yards, b) fields and c) rangelands, across which marula trees are prevalent



"Forests" of marula seedlings growing in yards	Numerous marula seedlings in fields which have germinated from uncollected fallen fruit	Lone marula seedling in the communal rangelands

Figure 2.7: Images illustrating the differences in marula seedling populations across the three land-use types of a) yards, b) fields & c) rangelands



Chopped marula tree which has been cut to build a new house but then left to resprout	Dead marula tree which has been ringbarked due to its proximity to the house
Bark harvesting from a live marula tree	Dead marula tree which has been chopped and prevented from regrowing

Figure 2.8: Images illustrating the types of damage inflicted on marula including: a) chopped and resprouted, b) ring-barked and died, c) bark harvested and d) chopped and died

3. Redefining 'Protected': Marula Population Demographics in Non-Conservation Areas of the Lowveld

3.1 Introduction

Habitat destruction and land-cover conversion are threatening biodiversity at a concerning rate and scale. Fundamental to solving this problem is identifying how anthropogenic damage to ecological systems can be mitigated through altering certain human behaviour patterns in relation to the environment. Understanding the knowledge systems and worldviews of the communities living closest to natural environments, in any given context, has to be a key aspect of any proposed solutions (Rolfe, 2006; Deutsch, 2003). Across Africa, this requires actively including the numerous rural communities, who have relied on natural resources for centuries, into solution driven processes. The majority of South Africa's rural population reside on communal rangelands, with these communities characterised by poor service delivery and extreme poverty (Shackleton & Shackleton, 2004; King & McCusker, 2007). Households in these mainly rural communities have highly diversified livelihood strategies, with significant reliance on natural resources from the savanna ecosystem (King & Peralvo, 2010). Within these savanna ecosystems, marula trees (*Sclerocarya birrea* subsp. *caffra*) provide key natural resources, which are utilised for both livelihood support and sustenance. Increasingly, these ecosystems are being over utilised due to land-use pressures, including settlement expansion and limited space for arable land, as well as resource limitations leading to fuelwood harvesting of live trees (Shackleton, 2005; Matsika, 2012).

3.1.1 Marula population profiles in non-conservation areas

Size-class distributions (SCDs) are a useful tool for understanding population structure at a given point in time and when combined with demographic information, can be used to make predictions about future population structures (Condit et al., 1998). Negative SCD slopes indicate more individuals in smaller size classes, while positive slopes indicate very few individuals in smaller classes, signifying a lack of recruitment (Condit et al., 1998; Lykke, 1998; Obiri et al., 2002; O'Connor & Goodall, 2017). It is therefore important to ascertain how anthropogenic land-use practices, which either conserve or deplete a natural resource such as marula, impact population structure across the landscape.

A pivotal study, which has been replicated numerous times in terms of the SCD methodology, is that of Obiri et al. (2002). This methodology linked SCDs to local attitudes regarding the conservation of key, high-value tree species to understand harvesting guidelines in Pondoland (Eastern Cape, South Africa). The questionnaire in this particular study focussed on four key areas: what species were harvested and used, household to forest distances, perceptions of availability and willingness to plant indigenous trees. The authors found that harvesting usually took place within a 5 km radius of the home and that those trees in the size classes 10-20 cm were selected regardless of species (Obiri et al., 2002). Shackleton (1993b) made a similar finding with fuelwood choices in Bushbuckridge, indicating that size and distance were more important selection criteria than tree species, with 11-25 cm size classes most frequently utilised. While dry wood was indicated as preferred, due to supply outstripping demand, live

trees would be cut and only if possible the species and stem size selected. In addition to this, trees that were perceived to be abundant were more likely to be utilised than those perceived to be declining (Obiri et al., 2002). Furthermore, in overharvested contexts, the density gradient is eroded with density no longer relating to distance from village, suggesting uniform harvesting practise (Shackleton, 2005). The contemporary data Shackleton (2005) obtained were compared to a study from 1993 in which no marula stems had been harvested, suggesting a breakdown in the customary laws protecting marula from being chopped with the progression of time. These findings highlight the importance of including local traditional leaders as well as the community in savanna management approaches, combined with awareness campaigns around resource utilisation.

Another SCD study that has been widely referenced is that by Lykke (1998). This study examined SCDs in relation to human impact (in particular fires) in the Delta du Saloum National Park non-conservation biosphere region in Senegal (West Africa). The authors found that human impacts affect savanna systems faster than natural vegetation changes. This finding was attributed to the continuous and widespread nature of the stress placed on the landscape as a result of compounded vegetation clearing and resource degradation. Land cover changes resulted in flat to positive SCD slopes as a result of declining densities, specifically in the smaller size classes, caused by local community harvesting (Lykke, 1998). In addition to these data, local community knowledge was considered with regard to vegetation changes and declining species. The combination of structured interviews and SCD analysis allowed for a more comprehensive assessment of vegetation changes in a disturbed savanna. Local knowledge was used to confirm findings from the SCD analysis, thereby lending further credibility to the results. Overall, it was found that more common species had negative SCD slopes (good recruitment) and thus more rigorous regeneration than less used and appreciated species (Lykke, 1998). Interestingly, *S.birrea* subsp*. birrea* is considered a less used and therefore less appreciated species in the Senegal context, although communities did mention noticing a decline in the species. An overall conclusion from the study was that the transition from valuable large-trunked trees, to a combination of shrubs and treelets in the region was concerning (Lykke, 1998).

A study specifically linking marula and land-use types in Bushbuckridge compared the SCD of marula trees in homesteads, fields and rangelands (Shackleton et al., 2003). The resultant findings were large fluctuations in frequencies in each size class over time, suggesting highly episodic regeneration (Shackleton et al., 2003). In addition, high densities of marula in homestead plots were also confirmed, with a third of those interviewed having planted marula and half the interviewees saying they nurtured any seedlings found in their yards (Shackleton et al., 2003). Furthermore, higher numbers of large adults were found in communal rangelands compared to protected areas, suggesting these trees may have been planted and then left behind when communities resettled elsewhere. Mean fruit size was also larger in villages, confirming a level of domestication (Shackleton et al., 2003). In terms of the SCDs, higher frequencies were found at 11 cm circumference but very low frequencies at 23 cm, frequencies declined between 78 - 148 cm, then peaked but declined again after 220 cm circumference (Emanuel et al., 2005). Fruit yield also varied, which is expected based on the fluctuations in recruitment, but with 99% seedling mortality in the first year (Emanuel et al., 2005).

3.1.2 Marula population densities, damage and demographics linked to land-use practices

Human utilisation of key natural resources, such as marula, often result in the opposing outcomes of either conserving or degrading the resource to varying degrees across a particular

landscape (Shackleton, 2000). The extent of these conflicting outcomes depends on localised socio-economic factors, such as the overall ecological, cultural and financial capital inherent in a particular resource (Deutsch, 2003; Raymond et al. 2009). In the case of marula, the cultural capital of the tree usually adds to the conservation of the species, whereas the financial capital of the fruit and its associated products leads to overharvesting and therefore depletion of the resource. In addition, resource utilisation varies across the landscapes and is usually specific to the management and land-use practices as defined by different land-use zones (Mugido & Shackleton, 2017). Depending on the particular land-use zone, the inherent resource practices either amplify the conservation or degradation of the species, which are further influenced by the status of the resource (ecological or social capital) across that particular land-use type (Ostrom, 2009).

While humans affect savanna landscapes through various practices, with land-use activities resulting in large-scale impacts, it is necessary to consider that socio-economic factors do not always result in direct or immediate vegetation changes. Instead, socio-economic factors influence human behaviour, which in turn lead to specific land-use choices and thus alterations in vegetation across the landscape (Twine, 2005). Essentially, changes are not always immediately obvious, with social drivers often needing to be considered retrospectively in order to understand the current changes being witnessed (Scholes, 2013; Sunderland, 2017). The lag time for vegetation change due to socio-economic factors, such as overharvesting, can be between 10-20 years for visible impacts to occur (Fisher et al., 2012). It is for this reason that understanding changes in density are of critical importance to gauge macro trends in population shifts. As various species respond differently to harvesting impacts, population density is often promoted as a useful measure for gauging the effects of harvesting on Non-Timber Forest Product (NTFP) species, particularly those species that are heavily utilised (Ruwanza & Shackleton, 2015). Marula trees are an example of a heavily utilised NTFP natural resource, making marula density a key metric for gauging the impacts of harvesting practices across various different land-use types. As a natural resource, marula is embedded in a socio-economic web of use and reliance patterns. Marula demography is therefore a useful ecological indicator of population variability across land-use types as it helps to illustrate where marula is being overharvested and thus degraded, as well as where it is being nurtured and thus conserved. Furthermore, different land-use types are the result of specific behavioural patterns based on access, availability and attribution of value towards the specific resource. In this case, these drivers relate to the marula tree and the variety of natural resources the tree provides, including fruit, bark and wood (Shackleton & Shackleton, 2005). Exploring human harvesting impacts on a NTFP such as marula, requires understanding resource utilisation demands across the various land-use contexts where it is utilised. In short, this means interrogating where marula trees are abundant, where there is paucity and what practices at the land-use level are causing these landscape level shifts. In this chapter, marula demography is the environmental indicator used to interrogate the nexus between access, availability and attribution of value across locations, land-use and settlement types in order to uncover which resource practices have the greatest impact on marula populations.

Land-use types can be used as different 'treatments' in order to test the impacts of different resource behaviour patterns, with variations in marula densities resulting across the landscape. Examining landscape differences in density along the continuum of land-use practice, provide insights into the behavioural patterns and decision-making trajectories that resulted in the development of each component of the landscape. Certain practices tend to alter the landscape

faster, or more severely, than others. Throughout the Kruger to Canyons Biosphere (K2C), the activities that have resulted in large-scale savanna land-cover change include clearing land for residential plots (homestead yards) and for arable land (fields). These land-use types are classified as converted or human modified landscapes due to the extent of alteration of the savanna ecosystem (Crews & Young, 2013). In addition, fuelwood harvesting is a relatively destructive resource activity, which takes place in the less modified landscapes of the communal rangelands, which more closely resemble conservation area savanna ecosystems (Matsika et al., 2012). Fruit harvesting alone is not considered to have large-scale land-cover impacts on marula populations at present. This is based on the marula fruit yield modelling previously conducted in the region (Emanuel et al., 2005). Emanuel et al. (2005) concluded that only 8% of the fruit crop needs to be left unharvested for the current population profile to not be impacted. However, overharvesting in the form of fruit collection is considered to have implications for germination as well as the density of juveniles in the short-term and hence the long term viability of the populations. The authors commented that more intensive marula resource use practices, such as fuelwood or bark harvesting which can directly lead to tree mortality, require further investigation (Emanuel et al., 2005). It is for this reason that fuelwood harvesting (rangelands) and the removal of trees due to settlement expansion (yards) or clearing arable land (fields) are the main focus of this particular chapter.

Within non-converted rangelands, overharvesting for fuelwood can lead to bush thinning, which has the affect of decreasing density, with any replacements through regeneration thus usually being in the smaller stem size classes (Mograbi et al., 2015). Furthermore, coppicing (re-sprouting) in the smaller size classes when larger trees are cut, combined with on going bush encroachment caused by livestock overgrazing, lead to increased sub-canopy biomass (Mograbi et al., 2015). Where more numerous smaller stems replace larger individuals, this misleadingly gives the impression of recovery and sufficient tree densities, but fails to tell a complete story in terms of actual resource extraction (Higgins et al., 1999, Chidumayo et al., 2002; Coetzer-Hanack et al., 2016). Land-use practices help to highlight conservation and stewardship approaches and in particular whether marula is being sustainably utilised across these different land-use types.

3.1.3 Impact of fuelwood harvesting on marula densities and size-class distributions

Natural resources are utilised for a range of household needs, from income generating resources, to a variety of home use requirements. Regardless of the direct or indirect value of the resource, natural resource use is a key form of subsistence and supplementary income, with fuelwood being attributed a high direct annual use value (Kirkland et al., 2007). Previously, it was considered taboo to cut marula trees, which combined with the pervasive influence of local traditional authorities who employed 'tree police' to enforce the prevention on cutting, limited chopping of marula for fuelwood occurred (Kirkland et al., 2007). However, with the erosion of customary authority and laws, combined with increased human population densities and the resultant resource pressures created by more people living on the same available land, the cutting of marula has been steadily increasing (Kirkland et al., 2007). This is exacerbated by the high cost of electricity, in particular for poorer households (Madubansi & Shackleton, 2007). With reduced alternative options for fuelwood in overharvested rangeland landscapes, marula trees (including live marula trees) are now increasingly being targeted for fuelwood purposes, making it increasingly important to understand if this includes male as well as female trees (as the fruit producers) (Madubansi & Shackleton, 2007; Matsika et al., 2012; Mograbi et al., 2015). Numerous studies have shown that community members will opt to cut trees that are perceived

to recover quickly and are therefore deemed to be sustainable to utilise (Shackleton, 2000; Neke et al., 2006). This has implications for sustainable harvesting in areas where resources are under pressure in terms of supply and demand.

Neke et al. (2006) show how harvesters tend to target species that are good at coppicing, such as marula, or with relatively large re-sprout shoots. In addition to this, cut height also impacts species regrowth; with re-sprout originating from the stem instead of the root crown resulting in taller stumps (Shackleton, 2000; Neke et al., 2006). In reality, selective or considered harvesting is the ideal. However, with limited time and resources, people will likely cut wherever tree is easiest and most accessible, sometimes removing the whole plant with regards to smaller individuals (Ticktin, 2004). In addition, tree species closer to homestead plots are more likely targets, unless they are specifically revered or protected, as the distance to carry the wood is thus reduced. Obiri et al. (2002) confirmed that harvesting of woody species usually takes place within a 5km radius from residential areas. While previously enjoying a protected status, marula trees may not have been targeted when there were numerous other species to utilise for fuelwood (Madubansi & Shackleton, 2007). However, as the status of these common property resources (CPR) have continued to decline with increased harvesting pressure, marula trees within a 5km radius of villages are more likely to be utilised for fuelwood. Of the ten tree species surveyed by Kaschula et al. (2005), respondents rated only marula and the weeping bush willow (*Combretum collinum)* as unambiguously having the best coppicing capacity of all the species utilised for fuelwood. Over time, cutting of live trees for wood leads to lower densities in the larger size classes and an increase in the smaller size classes, with the same result applying to the height classes (Twine, 2005). In addition, repeated utilisation of coppicing adults results in these trees effectively being trapped as functional juveniles, unable to produce seeds, leading to decreases in seedling density with proximity to settlements (Twine, 2005). Matsika et al. (2012) confirm that fuelwood harvesting, driven not only by residential expansion, but also by clearing for agriculture, leads to decreased wood availability and declining densities. This results in more homogenous landscapes dominated by species suited to disturbance, but also mainly in the smaller size classes (Ticktin, 2004).

The development of fuelwood markets within these rural savanna landscapes is significant in that previously, tree density gradients generally aligned with walking distance, meaning that tree population densities would increase with distance from villages. With the onset of fuelwood markets based on increasing demand, vehicles are used to collect wood and so harvesting occurs more uniformly across the landscape, eroding these density gradients around villages. Shackleton et al. (2005) found with marula specifically, that density did not increase with distance from villages. Considering that harvesting usually occurs within a 5 km radius from homesteads (Obiri et al. 2002), the disappearance of density gradients in heavily utilised environments is usually a clear indication of overharvesting of the resource. However, the fact that density did not decrease with proximity to villages, could also be due to the successful protection of adult trees by cultural norms and laws close to the villages. Therefore, it is not possible to ascertain if no gradient in density implies overutilisation without time-series data showing decreases in density over time. Regardless, outsider harvesting is considered a growing problem linked to fuelwood markets, with people from outside a community heavily utilising local resources, which suggest degradation of the resource (Shackleton, 2000; Twine et al., 2003). Most concerning is that Mograbi et al. (2015) found that the collection of dead wood only met 7% of current fuelwood demand. In short, live wood harvesting is driving the major

degradation of semi-arid ecosystems, particularly the lowveld communal savannas, the focus of this study (Madubansi & Shackleton, 2007; Matsika et al., 2013). Importantly, Matsika et al. (2012) conclude that woodland degradation is highly dependant on the specific social context of each village, further substantiating the need for localised social data to contextualise ecological findings. This finding highlights how decisions at the household level, from the perspective of managing resources in yards, fields and rangelands, can have significant impacts at the landscape level (Shackleton et al., 2008; Sunderland, 2017).

Considering the demographic changes that occur as a result of fuelwood harvesting, there are limited data on the prolonged effect of continued harvesting and coppicing cycles on keystone trees such as the marula. Demographic changes include decreased overall densities, alterations in size-class distributions and scarcity of reproductive adults coupled with lower seedling densities. Added to this is the dioecious nature of the tree, meaning these impacts could be amplified based on selective cutting of male trees for fuelwood, which distort the balance between the male to female ratios necessary for promoting pollination (Ticktin, 2004). In 2000, Shackleton et al. (2005:283) began work on a complete inventory of marula as a NTFP in Bushbuckridge and five years later concluded: "there appears to be an adequate density of fruit-bearing trees, and fruit production per tree, to support both domestic demand and the growing commercial demand in the region." However, the authors acknowledged that marula densities had been declining over the previous decade and that all indices suggested further degradation of the resource. Comparing current density differences between land-use types, as well as density changes to the resource over a fifteen-year period, are crucial for understanding whether the balance between resource demand and supply indicates sustainability.

3.1.4 Human versus elephant impact on marula densities, damage and mortality

In non-conservation areas, human induced overharvesting of fruit and fuelwood pose a direct threat to marula trees, while in conservation areas, elephants (in conjunction with fire) are the main perpetrators of tree damage (Moncrieff et al., 2008; Midgley et al., 2010; Cook et al., 2017; Mograbi et al., 2017). A fence line comparison enables examination of the contrasting impacts of these change agents (humans and elephants), when it comes to marula populations. Gaugris & van Rooyen (2010) found that human utilisation, followed by herbivory, had the most distinctive as well as rapid impact on vegetation structure while Wessels et al. (2013) found that the impact of human induced fuelwood extraction accounted for a far greater reduction in biomass than elephants and fire combined. This has important implications for understanding resource stability in terms of the macro marula population within these conservation and non-conservation spaces (rangelands). Mograbi et al. (2017) compared humans and elephants as the main drivers of treefall, concluding that human treefall patterns are more concentrated, relating specifically to wood harvesting and settlement expansion around villages. It is for this reason that these two resource utilisation practices have been identified in this chapter as having a key impact on marula and are specifically explored in terms of human impacts on marula density in yards, fields and rangelands.

Helm et al. (2009) found in KNP that the highest levels of marula mortality were in the 5-8 m height class, confirming earlier findings by Jacobs & Biggs (2002). Similar findings were recorded by Cook et al. (2017) in the Jejane Private Nature Reserve, with the highest annual mortality rates as well as elephant impact scores being recorded for the 5-8 m height class. In addition to this, there was minimal recruitment into the seedling class, which indicated that the population was not sustaining itself under the increased elephant population densities and

changes in the KNP fire policy (Helm, 2009). However, large-scale large tree senescent linked mortality observed in the region may be attributable to an episodic recruitment event that took place in the late 1800s (Shannon et al., 2008; Helm et al., 2009). Episodic recruitment has been examined as a feature of mortality, which is linked to a massive decline in herbivores in the region in the 19th century due to a rinderpest outbreak, leading to an imbalance in the herbivore to woody species ratio, with the equilibrium shifting in favour of woody species (Shannon, 2008). However, the role of senescence in mortality of large trees such as marula is poorly understood. There are estimates of old marula trees reaching up to 200 years in age, however, there are no inventories indicating what percentage of the population may reach this age or if this only applies to a few individuals (Hall et al., 2002; Chorwa & Akinnifesi, 2008). Helm et al. (2009) estimated trees in KNP might actually be in excess of 300 years of age, indicating marula trees likely live far longer than previously expected.

In non-conservation areas, human resource use in terms of wood harvesting practices is the main activity responsible for marula population declines (Madubansi & Shackleton, 2007). In addition, bark stripping by humans for medicinal purposes has a similar impact to elephants, which leaves marula trees vulnerable to fire (Helm, 2011). Understanding current trends in terms of harvesting impacts on marula in non-conservation areas of South Africa is crucial to ascertain marula population sustainability. The main threat to marula is from anthropogenic thinning combined with high drought mortality in large trees, which are also potentially the most prolific seed sources (Nghitoolwa et al., 2003). Chirwa & Akinnifesi (2008) confirm exceptionally high yields resulting from larger, older individuals, making unnatural mortality in large trees a key area of concern for the species. Despite it's bulky main roots, which allow marula to store water and therefore thrive under conditions of 500-600 mm Mean Annual Rainfall (MAR), marula trees and specifically older trees, do succumb to drought conditions (Nghitoolwa et al., 2003).

As with elephants, humans tend to select a similar size class (5-8 m) in terms of harvesting for materials such as poles, due to the diameter of the stem making them suitable for fences or as construction timber (Shackleton, 2000). Shackleton (1993b) found that communities utilising the tree for a range of purposes most regularly harvest trees in the 11-25 cm size class. This was echoed in a study conducted by Obiri et al. (2002), which found that trees in the size classes 10-20 cm were selected regardless of species. In addition, humans have a similar effect to elephant browsing by encouraging the re-sprouting of savanna species, such as marula, through continual harvesting (Mograbi et al., 2017). The overall impact of elephant and human utilisation is that as their densities increase, marula density decreases. It is for this reason that elephant damage was chosen as a key indicator to compare and contrast the two main vectors, or drivers of damage in conservation and non-conservation areas, being human and elephant interactions with marula.

Considering the range of impacts of human resource and land-use practices on marula demography, it is of critical importance to interrogate how spatial differences in marula size-class distributions, density, damage and mortality vary across locations, settlements and land-use types. In addition, while these variations across the landscape provide insights into the current status of the resource, understanding if resource utilisation patterns are sustainable requires comparing current density data with previous findings for the same location and land-use types, in order to gauge patterns in density changes. Finally, within larger complex socio-ecological systems such as the K2C biosphere, understanding determinants of demography at greater spatial scales from the perspective of the main change agents of marula density, on both

sides of the conservation and non-conservation fence line, is critical for gauging long-term sustainability of the resource. This chapter assesses differences in marula demography across different land-uses and settlement types in two study areas (Phalaborwa and Bushbuckridge) in the central lowveld of South Africa.

This chapter therefore has the following objectives:

a) To assess the spatial differences in the current overall density and size-class distributions (SCDs) of marula tree populations across:
   I. Two locations: Phalaborwa & Bushbuckridge
   II. Three land-use types: Yards, fields & rangelands
   III. Two settlement types: Rural & peri-urban

b) To assess the levels of adult mortality and regeneration:

   Explore what visible damage/impact/mortality is observed within the sampled populations and how this changes by land-use and settlement type.

c) To conduct a high-level comparison based on published studies:
   I. To compare changes in marula density (overall, male, female and juvenile as per Shackleton et al. 2002) over 15 years in Bushbuckridge (temporal changes).
   II. To ascertain how marula density (overall, adult and juvenile as per Helm, 2011) in non-conservation areas compares with conservation areas with the purposes of understanding the impacts of human vs. elephants as ecological change agents in the Kruger to Canyons biosphere region.

3.2 Methods

3.2.1 Overall density data analysis

The density data from 30 homestead yards, 20 fields and 5 rangeland transects for each of the eight villages were compared across land-use (yards, fields and rangelands) and settlement types (peri-urban and rural). For each location (Phalaborwa and Bushbuckridge), this resulted in 120 yards, 80 fields and 20 rangeland transects being surveyed. Despite the smaller number of rangeland cases when compared to the other two land-use categories, a larger area was surveyed in each transect, making it statistically robust to compare all three land-use types using a Kruskal-Wallis Test.

Density was calculated as the total number of trees in each land-use unit (individual yards, fields or rangeland transects) divided by the hectare area of that unit in order to obtain trees/ha. These calculations were based on individual trees as per Helm's (2011) methodology, the preferable approach for species where respouting is a disturbance response which results in multi-stemmed trees. Descriptive statistics and frequency analysis was undertaken for each land-use type separately and are provided in Appendix 10.1. The data were tested for normality using the Kolmogorov-Smirnov test, recommended for samples larger than 50 cases (yards and fields) and Shapiro-Wilks for samples less than 50 cases (rangelands) (Pallant, 2007). The data were also tested for skewness and kurtosis. Using a 5% level of significance, it was found that the data was not normally distributed in yards and fields, suggesting a skewed distribution, resulting in the mean being far higher than the median in many cases. The median has therefore

been included along with the mean in the results section in order to understand the ranking provided by the non-parametric tests performed in each case. Non-parametric tests were used to assess the data due to the assumption of normality being violated. However, the mean±SE is most often used when assessing biological data, as is the case with Shackleton (2002) and Helm (2011) whose methodologies have been closely followed in this study. Hence, while the medians are provided with the statistical outputs to explain the patterns and trends, the mean±SE are also included for comparative purposes with these previous studies. Finally, mean densities are usually the more suitable metric to discuss biological patterns in the data, as the median value can sometimes provide a zero value. An example is where at least half the cases do not have a tree of a specific demographic category represented; the median density value for that category would be zero. It is for this reason that the mean density patterns are used in the discussion to highlight patterns or trends in the data. For all statistical tests, a significance level of 5% ($p<0.05$) was used.

Comparisons for overall density were made using the Kruskal-Wallis Test, the non-parametric alternative to a one-way between-groups analysis of variance. Comparisons were made between land-use and settlement types, split by location, to compare changes in Phalaborwa and Bushbuckridge respectively, and split by land-use and settlement types to compare changes between locations. The Kruskal-Wallis Test was selected as it allows for the comparison of medians of the same continuous variable for three or more groups (Pallant, 2007). The Kruskal-Wallis Test converts the scores of the continuous variables to ranks and then compares if the differences in ranks is significant between the groups (Pallant, 2007).

In order to ascertain which land-use types were statistically different from each other, Mann-Whitney U-Tests (the non-parametric alternative to the t-test for independent samples) were performed between pairs of groups (yard vs. field/ yard vs. rangelands/ field vs. rangeland) comparing the difference in median ranks. In order to control for Type 1 errors, a Bonferroni adjustment/correction was applied to the alpha value (0.05), which is divided by the number of tests to be performed (which was three), in order to determine a revised alpha level for the purposes of determining significance (Pallant, 2007). The Bonferroni adjustment was applied as follows: smallest p-value of each variable tested against a significance level of $0.05 / 3 = 0.0167$, the second smallest p-value tested against a significance level of $0.05 / 2 = 0.025$ and the largest p-value tested against a significance level of $0.05 / 1 = 0.05$.

The Mann-Whitney U-Test was also used for all other comparisons between two groups (as opposed to three or more as per the Kruskal-Wallis test). In the dataset, these comparisons were between i) land-use types (split by the two locations – rangelands excluded to confirm groups could be compared considering difference in group sizes), ii) location (two locations split by land-use type) and iii) settlement type (two settlement types split by location and land-use type). Due to the smaller size of the rangeland category, the Mann-Whitney U-Test was used to compare yard and field data separately with rangelands excluded. This was done to determine if there were any significant differences that were not picked up in the comparison between all three groups as a result of the group size differences. The two comparisons yielded similar results, suggesting that the differences were large enough to be significant when all three groups were compared. The Mann-Whitney U-Test compares the equality of medians instead of means and as with the Kruskal-Wallis Test, it converts the scores of the continuous variables to ranks and then compares if the difference in ranks is significant between the groups (Pallant,

2007). In addition to this, the effect size for any significant values were calculated manually using the methodology detailed by Pallant (2007) where the effect size (r) equals the z value (z) divided by the square root (√) of the number (n) of cases: ($r = z / \sqrt{n}$). The Cohen (1988) criteria of 0.1 = small effect, 0.3= medium effect and 0.5 = large effect were applied to the results. It is advisable in the ecological and biological sciences to report the effect size as this lends a greater degree of confidence to reported findings (Nakagawa & Cuthill, 2007).

3.2.2 Size-class distributions (SCD) & slope analyses

In order to understand if marula populations have a stable structure and are regenerating, it is useful to look at size-class distributions (SCDs), with an inverse 'J-shaped' curve usually being indicative of a healthy population in re-seeding species, although not as much for resprouting populations. In addition to this, the slope angle (positive, negative or natural) provides insight into recruitment trends, with steeper slopes indicating stronger recruitment. However, as indicated by authors such as Condit et al. (1998), Lykke (1998) and Obiri et al. (2002), a SCD provides a static profile of a population at a specific time, which requires demographic information to make extrapolations about possible future population trends.

To ascertain size-class distributions, basal stem diameter size classes were delimited as follows: <0.5, 0.5-2, 2-5, 5-9, 9-14, 14-20, 20-30, 30-40, 40-50, 50-60, 60-70, >70 cm as per the exact categories used in the methodology followed by Helm (2011). Individuals below 0.5 cm were not considered to be established members of the population, being the germinants from the current season. Seedlings from 0.5-2 cm were considered to be newly established members of the population. Stems of 2-5 cm belonged to established seedlings, although these are still considered susceptible to fire and herbivore damage in rangelands and run the risk of being actively removed from yards and fields. The classes 5-9 cm and 9-14 cm were saplings that, depending on their heights, may or may not have escaped the browse and (very occasional) fire-trap in rangelands. A basal stem diameter of 14 cm was considered the threshold for juveniles becoming established as reproductive adults producing fruit (Shackleton et al. 2005; Helm, 2011). The size classes of 14-20 cm, 20-30 cm and 30-40cm divided the adult population into small to medium adults, with those over 43 cm in the 50-60 cm size class being large adults (Shackleton et al., 2002). The size classes of 60-70cm and over 70 cm were very large adults. Large and very large adults are the greatest fruit producers in the population (Nghitoolwa et al., 2003). Marula trees were classified into the corresponding size class categories based on their basal stem diameter at 30 cm above ground level (Helm, 2011). To avoid overlap between size class categories, individuals up to the specified size class were placed into the lower category. Individuals that were 0.1 cm over the lower size class were placed into the higher size class category. For example, a 2 cm individual would fall into the 0.5-2 cm category, whereas a 2.1 cm individual would fall into the 2-5 cm class. These size classes were also chosen to include more individuals with increasing size, as advised by Condit et al. (1998). Size class distributions were compared using a Two-Sample Kolmogorov-Smirnov Test to compare the frequencies in the distributions. The test statistics reported in the analysis are the Kolmogorov-Smirnov Z value as well as the significance level ($p<0.05$).

In addition, the methodology followed by Helm (2011), which incorporated the methodologies of Condit et al. (1998), Lykke (1998) and Obiri et al. (2000) in relation to SCD diameter slopes was followed. SCD diameter slopes are considered to be a good indicator of population structure at a specific point in time (Condit et al., 1998; Lykke, 1998; Obiri et al., 2000). The slope angle is obtained by running a least squares linear regression using the corrected abundance per size

class (ln(Ni+1)) as the dependent variable and the size class midpoint (ln(Ni)) as the independent variable. The frequencies are transformed by taking the natural logarithm (ln) of the frequencies because the frequency data are usually non-linear, so the data must be transformed to make it linear. The average number of individuals (Ni) in each size class was transformed by ln(Ni + 1) to account for any classes containing zero individuals (Obiri et al., 2002). The slope intercept form of the linear equation is given for each comparison: y=mx+b. In the equation, x and y are the axis variables, while m and b give the slope of the line and y-intercept. The slope can therefore be described as positive or negative, with the higher the absolute value, the steeper the slope and the lower the absolute value, the more gradual the slope. The regression co-efficient (slope) is therefore the measure of strength of the relationship. In addition to the linear equation, which is provided each time, the R^2 value is also given (values between 0 and 1). The R^2 value indicates the amount of variance in the dependent variable that is accounted for, or explained, by the independent variable (Pallant, 2007). This means that the R^2 value is essentially a goodness-of-fit value of the equation trend line to the data. Values closer to 1 indicate a close to 100% fit, suggesting that the regression model explains most of the variability of the response data around its mean. An R^2 of 1 would mean that every data point is exactly on the line, in other words the equation perfectly predicts the y value with x. Values <0.3 are interpreted as weak for the purposes of this study, while values between $0.3 \leq 0.6$ are considered a moderate fit, with values from >0.6 classified recognised as a strong fit.

The methodology of Everard et al. (1995) was used to access slope angle, as incorporated by Helm (2011), which include three categories of slopes. Negative slopes are usually indicative of on-going recruitment, characterised by more individuals in smaller size classes and fewer in the larger classes. Positive slopes are indicative of reduced or little recent recruitment, although episodic recruitment in the past could also result in a positive slope, combined with accelerated growth across the intermediate classes. Thirdly, flat slopes indicate an equal number of individuals across the size classes, which can either be the result of reduced recruitment or alternatively a relatively high number of large plants, potentially as a result of previous episodic recruitment events. In addition to this, the steepness of the slope is a key indicator of the trend being described, with steeper negative slopes indicating better recruitment than gradual slopes.

3.2.3 Mortality, tree (stem and branch) damage and bark removal analyses

Cross-tabulations for mortality, damage and bark removal were performed on the data comparing differences by location, land-use and settlement type. Mortality ratios (dead:alive) were compared for the population, as well as tree damage and bark damage by location, land-use and settlement type. Tree damage (breaking or cutting of stems and branches) was divided into four categories: primary damage (tree trunk), secondary damage (first degree branches coming off the main trunk), tertiary damage (second degree branches coming off the first degree branches) and no damage. In addition, bark removal (harvesting) was also dealt with as communities remove the bark in order to make traditional medicines. Bark removal was classified on a scale from freshly removed to complete recovery from any visible bark removal. The six categories of bark removal for statistical analysis were: 1) fresh - bark removed, 2) fresh – bark regrowth 20%, 3) recovering - bark regrowth 50%, 4) recovering - bark regrowth 80%, 5) old - bark regrowth 100% and 6) none removed.

Cross-tabulations were performed using Chi-Square Tests ($p<0.05$) with Fisher's Exact Test and a Phi Effect Size for tables in a 2 by 2 cross tabulation and Pearson's Chi-Square with a Cramer's

V Effect Size for larger than 2 by 2 cross tabulations. The Phi effect size is a correlation coefficient ranging from 0 to 1, with higher values denoting a stronger association between variables (Pallant, 2007). The Cohen (1988) criteria of 0.1=small effect, 0.3=medium effect and 0.5=large effect were then applied to the results.

The Chi-Square Test compares the observed frequencies or proportions of cases that occur in each of the categories, with the values expected if there was no association between the two variables being measured (Pallant, 2007). With a 2 by 2 table, SPSS provides the Yates Correction for Continuity, which is designed to compensate for an overestimation of the Chi-Square value, which can also be provided in the results analysis. With Chi-Square tests it is important to check that the assumption for 'minimum expected cell frequency' has not been violated. In order to not violate the assumption, at least 80% of cells need to have a frequency of 5 or more, otherwise it is not possible to provide a significance value for the cross-tabulation.

Mortality (dead:alive) tree ratios were calculated by dividing dead/alive so the ratio is *X* dead for every 1 alive tree. For example, 20 dead to 50 alive trees = 20/50 = 0.4 so the ratio is 0.4 dead trees per 1 alive tree, meaning the dead:alive ratio is 0.4:1. The *X* values obtained each time are rounded off to the nearest whole number to allow for ease of comparison between different ratio values. Mortality ratios are important for understanding how extensively marula trees are being chopped or removed, by showing where the highest mortalities are occurring in terms of land-use and settlement type. It is for this reason that trees that had appeared to die from natural causes (no evidence of human interference), were not included in this sample. There were only five trees across all fields and rangelands where cause of death could not be verified. In homestead yards, the owner clarified cause of death. For the purposes of this study, dead trees constituted all trees that had been chopped, ring barked, pushed over or dug up by humans and died as a result of these actions. Trees that had been chopped but not died, and instead had produced coppice shoots, were classified as alive. In addition to this, damage ratios are also included in this section, as marula trees are able to withstand a certain degree of damage before succumbing to mortality. Combined mortality and damage ratios thus provide a more holistic view on the overall welfare of the population.

3.2.4 Temporal and conservation land-use comparisons

In order to compare the current marula mean densities with findings published by Shackleton (2002), the village level data for Bushbuckridge, divided by land-use, were compared. Shackleton (2002) used the methodology of stems/ha, whereas Helm (2011) used trees/ha to account for multi-stemmed trees as a disturbance response. While stems/ha and trees/ha are thus not the same methodology for the purposes of some density categories being compared, overall trends can still be observed. Furthermore, being cognisant of the different methodologies when observing trends, it is possible to assume that any reductions in density between years can be considered more severe due to the elimination of multi-stem individuals in the 2017/2018 data, whereas increases can be considered to be conservative, once again as only individual trees were counted and not multiple stems. The village level data for the four Bushbuckridge villages was analysed using the non-parametric Kruskal-Wallis Test. In addition, post-hoc tests to assess density category differences between the four villages were performed using the Bonferroni Adjustment/Correction, which tested the p-values against a more stringent significance level, which involve dividing the alpha significance level of 0.05 by the number of groups (four villages): 0.05/4 = 0.0125. The Mann-Whitney U-Test and Wilcoxon Signed Rank Test were then used to compare the four density categories (overall, juvenile, male and female)

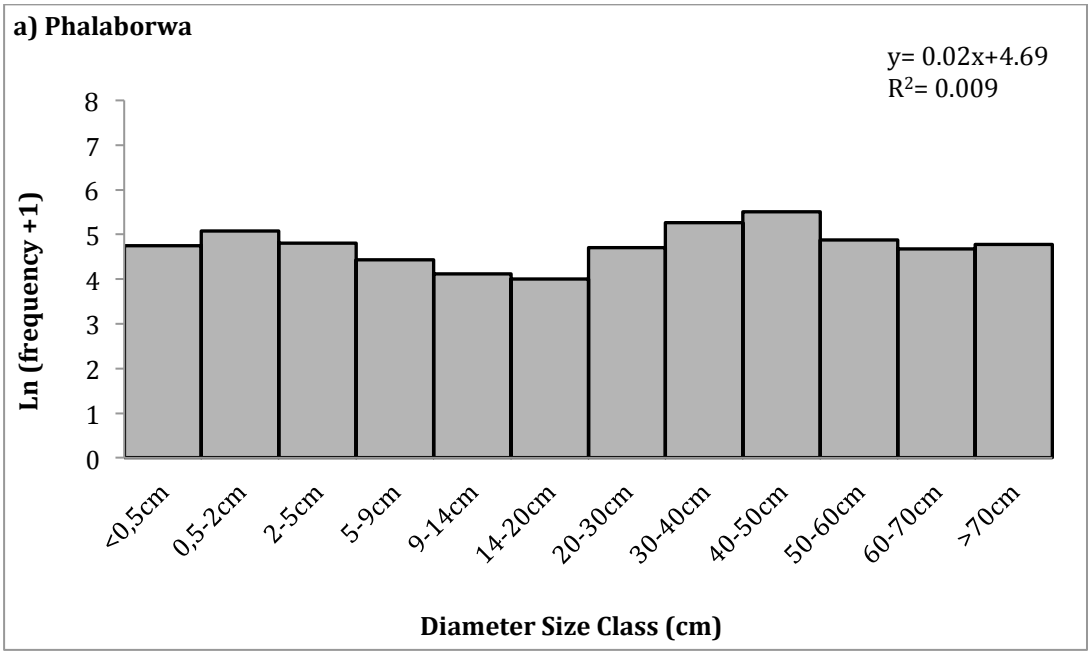
between the different pairs of village, split by land-use each time, in order to ascertain where there were significant differences. As the raw data from Shackleton was not available, the four villages were not compared statistically, but rather trends in the mean±SE were compared visually and discussed in terms of any differences between years.

In order to compare the current non-conservation marula mean densities with findings published by Helm (2011) in conservation areas, the trees/ha densities for overall, adult and juvenile densities in the Bushbuckridge rangelands were compared. In order to enable accurate comparisons, only those sites located on the same vegetation type of Granite Lowveld SVI 3 (Mucina, Rutherford & Powrie, 2005) and more specifically, as Mixed Bushwillow woodlands (Venter, 1990) in Helm's (2011) study, were compared visually. This was done to note differences between different land-use sites in conservation and non-conservation (rangelands) areas.

3.3 Results

3.3.1 Size-class distribution profiles by location (Phalaborwa and Bushbuckridge)

The SCD profiles for Phalaborwa (n=1493) and Bushbuckridge (n=4338) were significantly different ($z=13.47$, $p<0.001$). Running a regression analysis for the Phalaborwa data provided the slope angle as well as steepness of the slope, which rendered the following linear equation: $y=0.02x+4.69$ with an R^2 value of 0.009. This meant that Phalaborwa has a positive, but very gradual slope and the R^2 value indicates that the equation explains almost none of the data distribution. The regression analysis of the SCD profile for Bushbuckridge provided the following equation: with an R^2 value of 0.779. Bushbuckridge's SCD therefore has a steeply negative slope and the R^2 value indicates that the equation accounts for 78% of the variability. In addition to this, the SCD profile for Bushbuckridge indicated an inverse 'J-shaped' curve, whereas the profile for Phalaborwa had most individuals in the 30-40 cm and 40-50 cm size classes as shown in Figure 3.1.



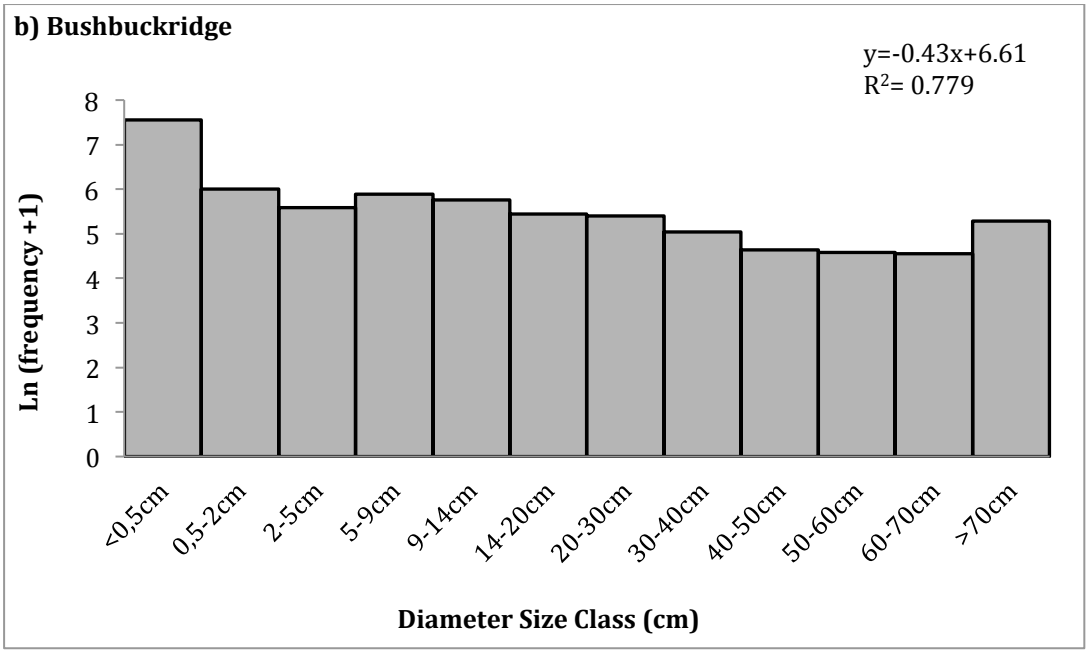


Figure 3.1: Marula size-class distribution profiles for a) Phalaborwa and b) Bushbuckridge

3.3.2 Spatial comparisons by land-use (yards, fields & rangelands)

3.3.2.1 Size-class distribution profiles across land-uses

Differences across the land-use types in Phalaborwa (yards (n=284), fields (n=542), rangelands (n=667)) and Bushbuckridge (yards (n=2639), fields (n=476), rangelands (n=1223)) were explored. SCD profiles for yards and fields, yards and rangelands, and fields and rangelands were compared.

The SCD profiles for yards and fields were significantly different in both Phalaborwa ($z=2.864$, $p<0.001$) and Bushbuckridge ($z=14.912$, $p<0.001$). In Phalaborwa, yards displayed similar frequencies in the seedling, sapling and large adult size classes but a decline in the intermediate sizes, in particular 9-14 cm and 14-20 cm classes. Fields in Phalaborwa displayed a generally flatter distribution in comparison, although there was also a decrease in the 9-14 cm and 14-20 cm size classes. In Bushbuckridge, yards and fields displayed almost reverse distributions with yards displaying an inverse 'J' shaped population whereas fields had the least individuals in the smallest size classes and the most in the largest classes.

Comparing yards and rangelands, the SCD profiles were also significantly different in Phalaborwa ($z=3.227$, $p<0.001$) and Bushbuckridge ($z=22.612$, $p<0.001$). Rangelands in Phalaborwa and Bushbuckridge both had far fewer individuals in the two smallest size classes compared to yards. Finally, the SCD profiles for fields and rangelands were also significantly different for Phalaborwa ($z=7.497$, $p=0.001$) and Bushbuckridge ($z=4.589$, $p=0.001$). Fields in both locations displayed flatter distributions whereas in Phalaborwa, the profile peaked in the larger size classes in rangelands while in Bushbuckridge, the highest frequencies were in the intermediate size classes.

The regression analysis for the SCD profile for yards in Phalaborwa provided the equation: $y=-0.01x+3.13$, demonstrating that the slope was negative but gradual with the equation accounting for very little of the variability ($R^2=0.002$). The regression analysis for yards in Bushbuckridge resulted in the equation: $y=-0.69x+5.98$, revealing that the slope was both negative and steep, with 78% of the variability explained by the equation ($R^2=0.777$).

Regression analyses for fields resulted in a marginally steep, negative slope in Phalaborwa ($y=-0.21x+4.20$), with moderate goodness-of-fit of the equation trend line to the data ($R^2=0.334$). Bushbuckridge fields ($y=0.12x+3.33$) had a gradual, positive slope with a weak goodness-of-fit measure ($R^2=0.232$).

Finally, the regression analysis for rangelands provided a steep, positive slope ($y=0.52x+2.33$) in Phalaborwa and a gradual, positive slope ($y=0.15x+3.90$) for Bushbuckridge rangelands. The R^2 values indicated that the equation predicted 74% of the variability for Phalaborwa ($R^2=0.741$), but hardly any of the variability for Bushbuckridge ($R^2=0.071$).

Comparing SCD frequencies for yards ($z=9.672$, $p<0.001$), fields ($z=4.778$, $p<0.001$) and rangelands ($z=9.974$, $p<0.001$) between Phalaborwa and Bushbuckridge, the SCDs for all three land-use types differ significantly between the two locations (Figure 3.2).

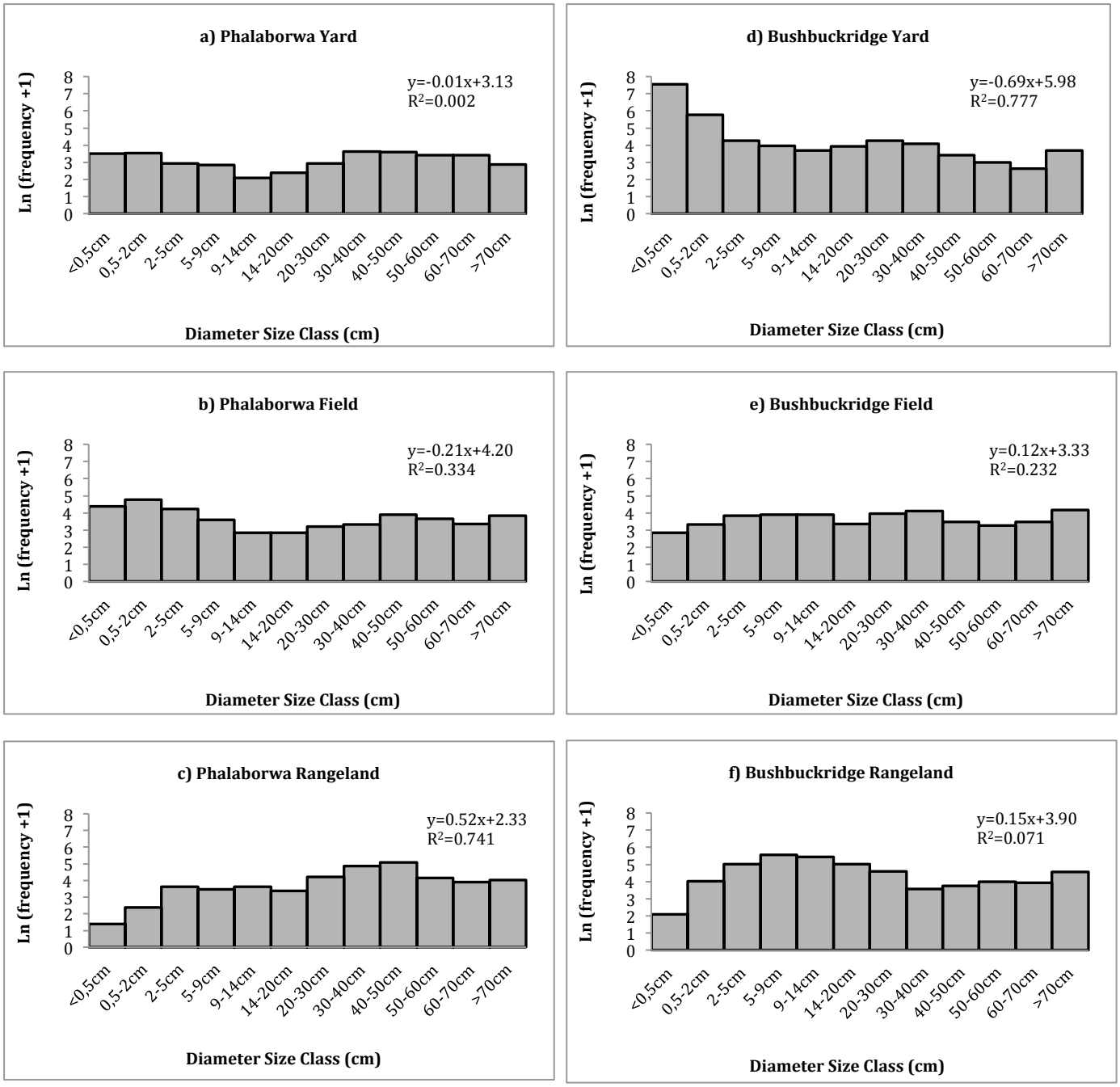


Figure 3.2: Comparison of marula SCDs for yards, fields and rangelands in (a-c) Phalaborwa (n=1493) and (d-f) Bushbuckridge (n=4338)

3.3.2.2 Overall density per land-use category in Phalaborwa and Bushbuckridge

Overall marula tree density in Phalaborwa (n=220) and Bushbuckridge (n=220) were compared by land-use type (yards (n=120); fields (n=80) and rangelands (n=20)) to ascertain significant differences. This comparison indicated that overall densities were not significantly different across Phalaborwa land-use types, whereas overall density differed significantly across Bushbuckridge (Table 3.1). In Bushbuckridge, overall density was highest in rangelands.

Table 3:1: Results of the Kruskal-Wallis test comparing overall density between yards (n=120), fields (n=80) and rangelands (n=20) within Phalaborwa and Bushbuckridge. Significant differences for the density categories between land-use types are indicated in bold.

Location	Demographic Category	Kruskal-Wallis Test Statistic	Degrees of Freedom (df)	Significance Level (p<0.05)
Phalaborwa	Overall	0.44	2	0.802
Bushbuckridge	**Overall**	**14.56**	**2**	**0.001**

In Bushbuckridge, overall median density was significantly and substantially higher in rangelands than in fields, but not in yards (Table 3.2). Overall density in yards was intermediate, significant and higher than in fields.

Table 3:2: Comparison of median and mean overall density (trees/ha) by land-use type (yards (n=120), fields (n=80) & rangelands (n=20)) in Phalaborwa and Bushbuckridge, with the significant results (<0.05) from the Kruskal-Wallis test indicated in bold - medians not sharing a common superscript letter are significantly different.

	Demographic Category	Yard (Y)		Field (F)		Rangeland (R)	
		Median	Mean±SE	Median	Mean±SE	Median	Mean±SE
Phalaborwa (n=220)	Overall	8.09	13.9±1.9	4.60	11.4±2.0	5.70	6.6±0.8
Bushbuckridge (n=220)	**Overall**	**8.96** [ac]	**25.7±4.1**	**5.47** [b]	**7.4±0.7**	**12.40** [c]	**13.4±1.5**

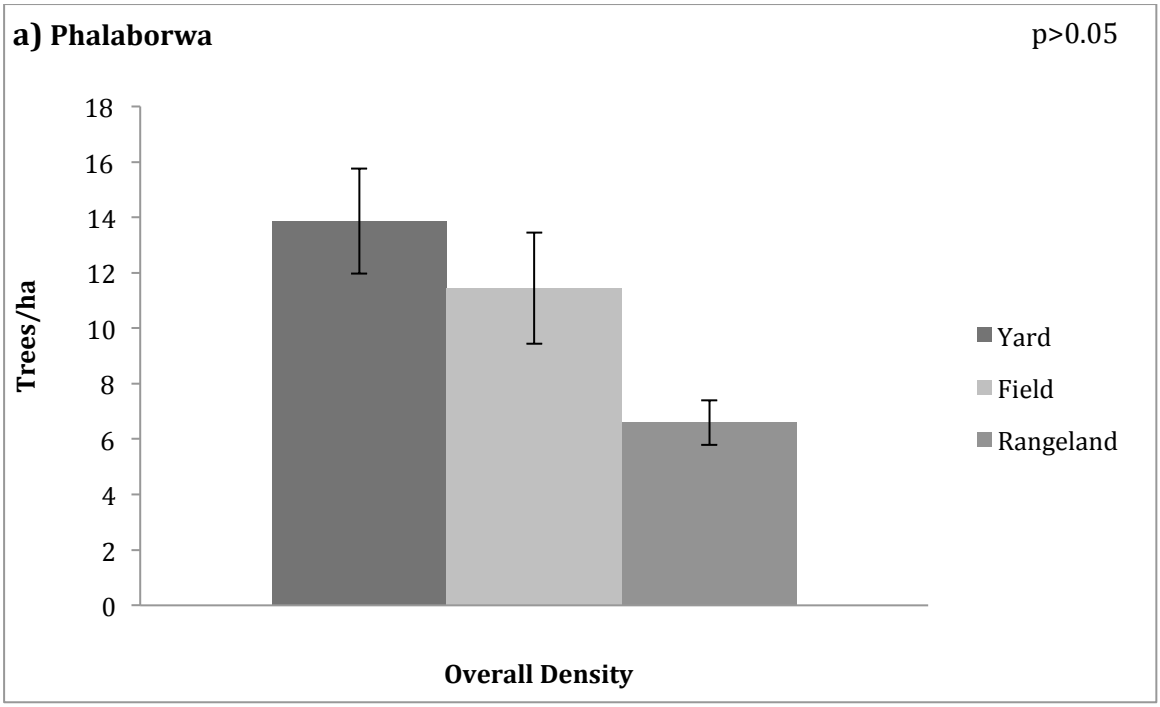
[abc] **Different superscript letters denote where overall density is significantly (p<0.05) different between yards vs. fields, fields vs. rangelands and yards vs. rangelands. Median density values for land-use types that share a common superscript letter are not significantly different (ie. overall density in yards vs. rangelands in Bushbuckridge)**

Comparing overall density values within only the significantly (p<0.05) different land-uses, the main differences were compared between yards vs. fields, fields vs. rangelands and yards vs. rangelands (Table 3.3). The statistics from the Mann-Whitney test are provided in Table 3.3. Differences in mean density between land-use types are shown in Figure 3.3.

Table 3:3: Results of the Mann-Whitney test comparing yards vs. fields (n=200), fields vs. rangelands (n=100) and yards vs. rangelands (n=140) in Phalaborwa and Bushbuckridge, with only the significantly different findings included (which were only in Bushbuckridge).

Location	Land use comparison	Demographic Category	Mann-Whitney U	Z-Value	Significance p<0.05	Effect Size (r)
Bushbuckridge	**Y vs F (n=200)**	Overall	6852	-2.97	0.003	0.2
	F vs R (n=100)	Overall	350	-3.88	0.001	0.4

* Y vs F: Yards vs Field **F vs R: Field vs Rangeland



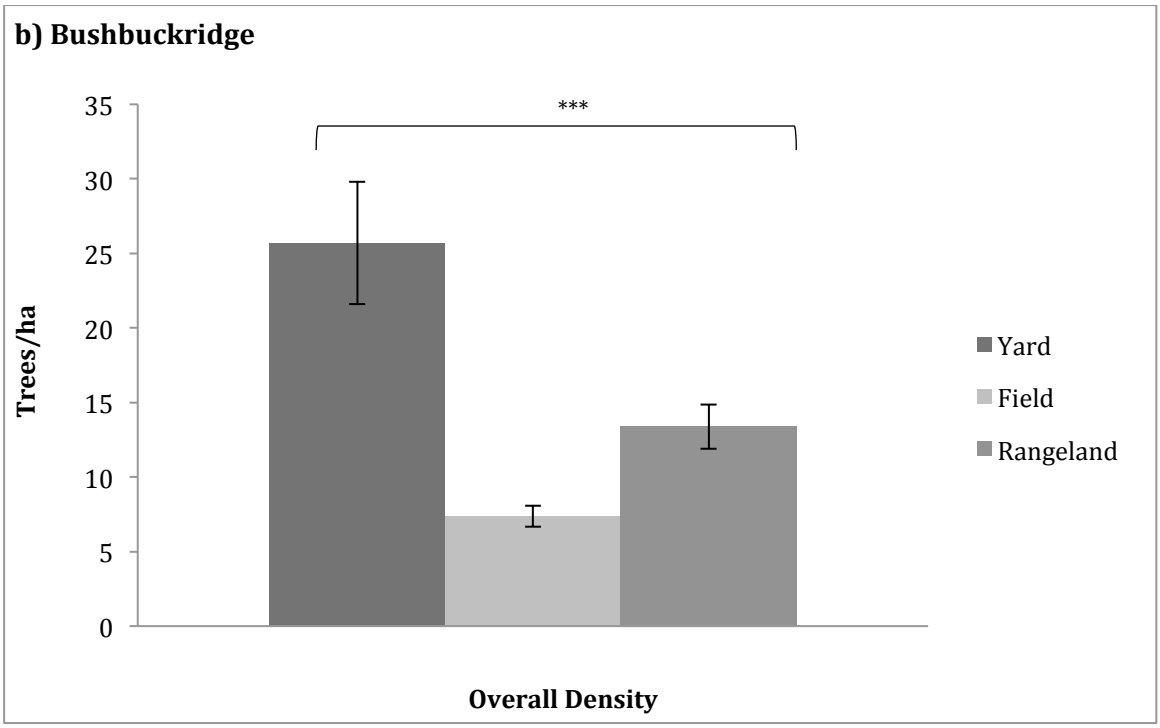


Figure 3.3: Mean density (trees/ha) ±SE comparisons for a) Phalaborwa (n =220) and b) Bushbuckridge (n=220) by land-use type (yard, fields and rangelands) using the Kruskal-Wallis test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

3.3.2.3 Overall density per land-use category between Phalaborwa and Bushbuckridge

Comparing overall densities between Phalaborwa and Bushbuckridge, divided into the three land-use types, there were no significant differences in either yards (n=240) or fields (n=160).

Overall densities differed significantly between Phalaborwa and Bushbuckridge rangelands (n=40) (U=65, -3.652, p<0.001, r= 0.6) with overall density in Bushbuckridge rangelands being more than twice that in Phalaborwa (Table 3.4). Differences in mean density by land-use type between Phalaborwa and Bushbuckridge are shown in Figure 3.4.

Table 3:4 : Comparison of overall density by land-use type (yards, fields & rangelands) between Phalaborwa (n=220) and Bushbuckridge (n=220) with significant results (Mann-Whitney test) indicated in bold (Medians).

Land-use Type	Phalaborwa	Bushbuckridge
Yard (Y)	8.09	8.96
Field (F)	4.60	5.47
Rangeland (R)	**5.70**	**12.40**

***A zero median value means that at least half of the densities were zero for that specific category. For example, at least half the yards in Phalaborwa did not have male trees and so the median density value for that category was zero.**

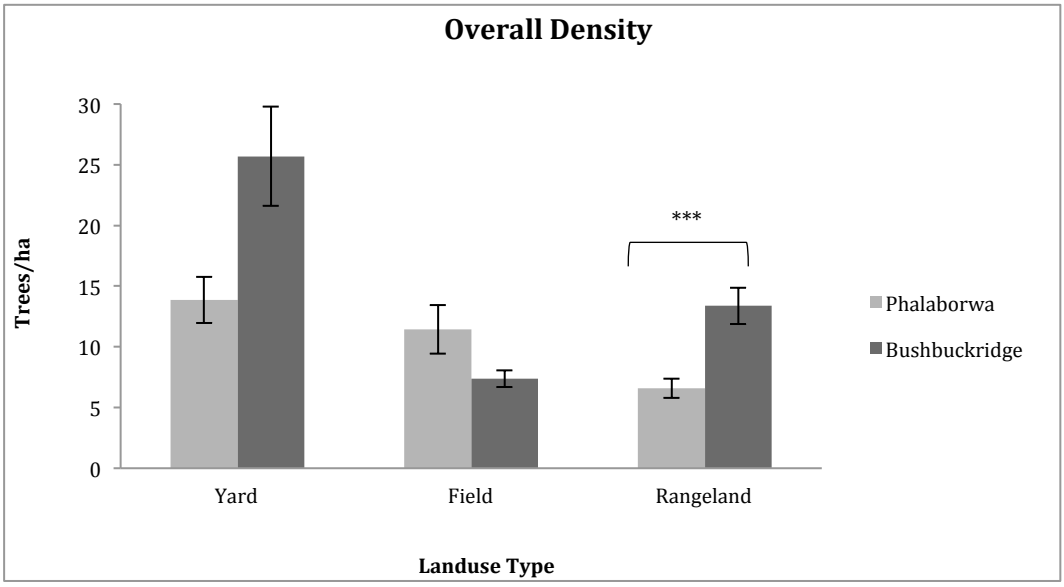


Figure 3.4: Comparison of overall marula mean density (trees/ha) ±SE by land-use type (yards, fields & rangelands) between Phalaborwa (n=220) and Bushbuckridge (n=220), using the Mann-Whitney test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

3.3.3 Spatial comparison by settlement type (rural and peri-urban)

3.3.3.1 Size-class distribution profiles across settlements

Comparing the SCD frequencies for the peri-urban (n=936) and rural (n=557) contexts in Phalaborwa, the differences were significant (z=4.878, p=0.001), with the same finding for peri-urban (n=2382) and rural (n=1956) SCD profiles in Bushbuckridge (z=3.034, p<0.001). In addition, comparing the SCD frequencies for the peri-urban contexts between the two locations

of Phalaborwa and Bushbuckridge, the peri-urban differences were significant (z=9.404, p<0.001), as were the rural differences in distributions (z=10.503, p<0.001).

The regression analysis for rural Phalaborwa provides the slope y=+0.21x+3.16, signifying a gradual, positive slope with only 35% of the variability accounted for by the equation (R^2=0.354). The regression for the peri-urban SCD in Phalaborwa provided a different slope (y=-0.10x+4.51) to the rural context being gradual but negative, with the equation accounting for even less of the variability at only 10% (R^2=0.105). The regression analysis for rural Bushbuckridge provided the opposite slope to rural Phalaborwa (y=-0.37x+5.71), demonstrating a negative as well as steeper slope, with a strong R^2 value of 0.663. Finally, the regression for the peri-urban SCD in Bushbuckridge was also negative, y=-0.48x+6.07, denoting a steep slope with 80% of the variability accounted for by the equation (R^2=0.804). The SCD profiles for rural and peri-urban settlements in Phalaborwa and Bushbuckridge are provided in Figure 3.5.

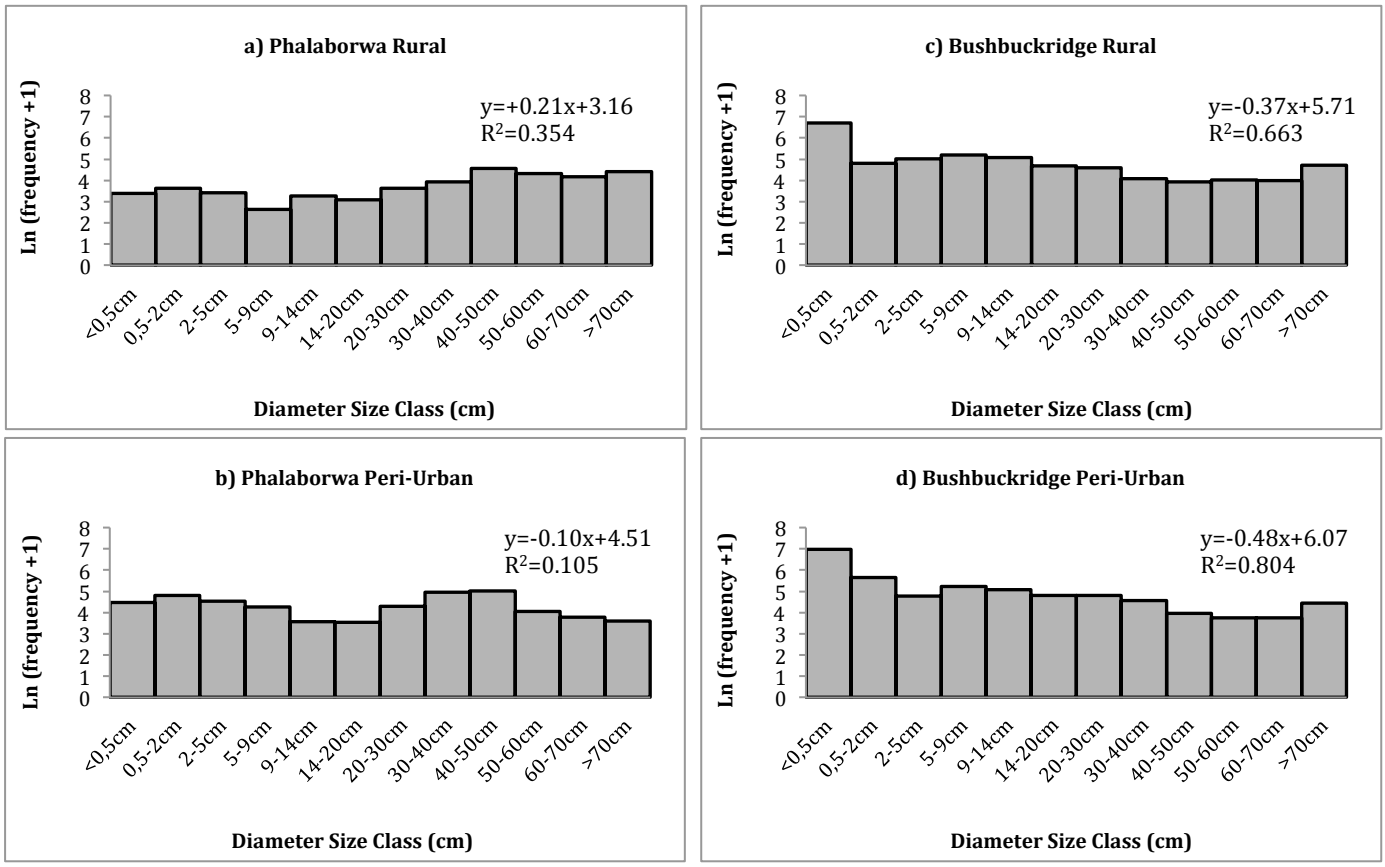


Figure 3.5: Comparison of marula SCDs for rural and peri-urban settlements in (a-b) Phalaborwa (n=1493) and (c-d) Bushbuckridge (n=4338)

3.3.3.2 Density per settlement and land-use category in Phalaborwa and Bushbuckridge

Comparing rural and peri-urban yards (n=120) in Phalaborwa, overall density differed between settlement types (U=1404, z=-2.105, p<0.05, r=0.2). Overall yard density in the rural setting was almost 1.5 times higher than peri-urban yards.

Rural and peri-urban fields (n=80) in Phalaborwa also differed significantly in terms of overall density (U=187, z=-5.899, p<0.001, r=0.7), being almost six times higher in peri-urban fields.

Comparing rangelands (n=20) between the two settlement types in Phalaborwa, overall (U=15, z=-2.649, p<0.01, r=0.6) density differed significantly. Overall density was almost twice as high in peri-urban rangelands. Across all three land-use types, overall density was higher in the peri-urban context. In Bushbuckridge yards, fields and rangelands, overall density did not differ significantly by settlement type (Table 3.5).

Table 3:5: Comparison of overall density by land-use (yards, field & rangelands) and settlement (rural & peri-urban) type within Phalaborwa (n=220) and Bushbuckridge (n=220), with significant differences indicated by the Mann-Whitney test highlighted in bold (Medians)

	Land-use Type	Peri-Urban	Rural
Phalaborwa	**Yard (Y)**	**10.09**	**6.53**
	Field (F)	**12.82**	**2.18**
	Rangeland (R)	**7.96**	**4.40**
Bushbuckridge	Yard (Y)	9.18	8.78
	Field (F)	5.99	5.33
	Rangeland (R)	11.90	14.39

Comparing the three land-use types in each location by settlement type, the main trend is that densities were higher in the peri-urban context in Phalaborwa, as shown by Figure 3.6. In Bushbuckridge, this difference is not as marked, with peri-urban and rural contexts displaying more similar densities across the land-use types (Figure 3.7).

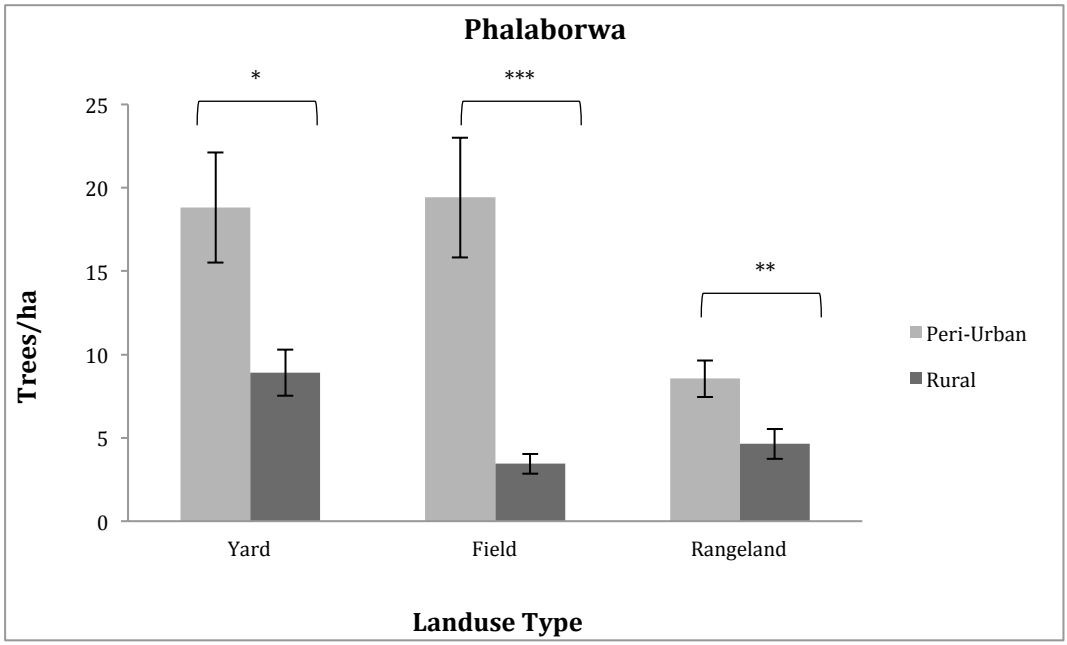


Figure 3.6: Comparison of peri-urban and rural overall mean marula density (trees/ha) ±SE by land-use type (yards, fields and rangelands) in Phalaborwa (n=220) using the Mann-Whitney test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

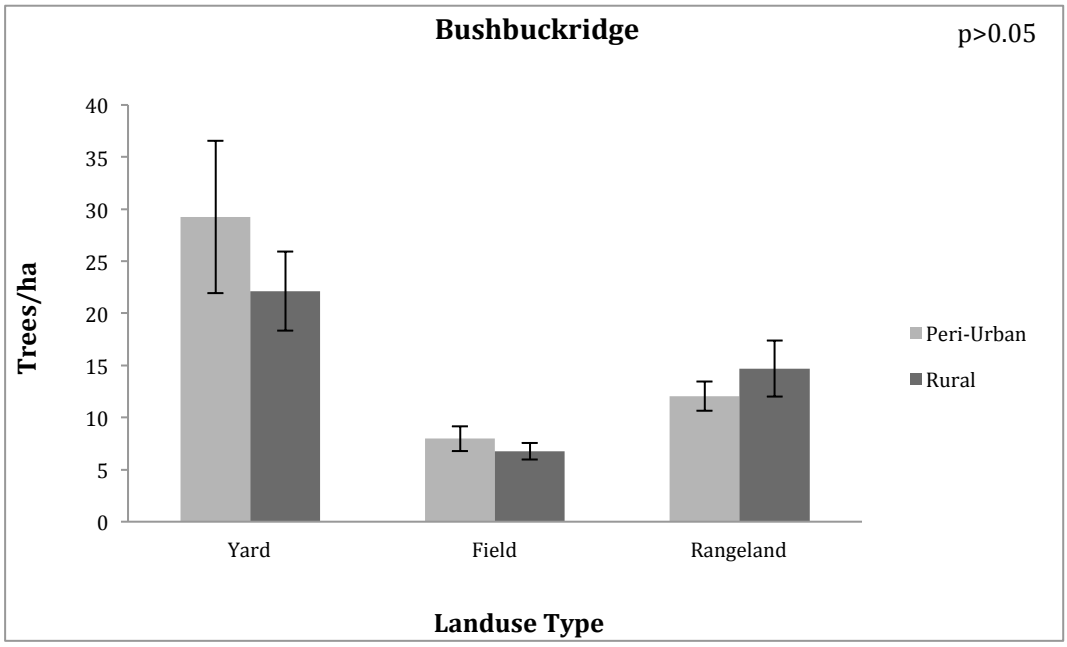


Figure 3.7: Comparison of peri-urban and rural overall mean marula density (trees/ha) ±SE by land-use type in Bushbuckridge (n=220) using the Mann-Whitney test

3.3.4 Marula mortality ratios

3.3.4.1 Marula mortality between locations

In Bushbuckridge (n=4338), the dead:alive ratio was 0.01:1 trees, this meant only 1.3% of the trees were dead. In Phalaborwa (n=1493) the ratio of dead:alive individuals in the population was 0.08:1 trees, meaning 7.3% of the population comprised dead trees. The difference between locations was significant, but small (x^2 (1, n=5831)=143.72, p<0.001, phi=0.158).

If juvenile individuals are excluded, the dead:alive ratio for adults only in Bushbuckridge (n=1023) increased from 0.01:1 (1.3%) to 0.04:1 (3.6% of the population). In Phalaborwa (n=944), which contained a much lower juvenile density than Bushbuckridge, mortality decreased from 0.08:1 (7.3%) to 0.02:1 trees, meaning 2.9% of the population were dead adult trees. In terms of adult populations, the mortality ratios for Bushbuckridge and Phalaborwa were similar (Figure 3.8).

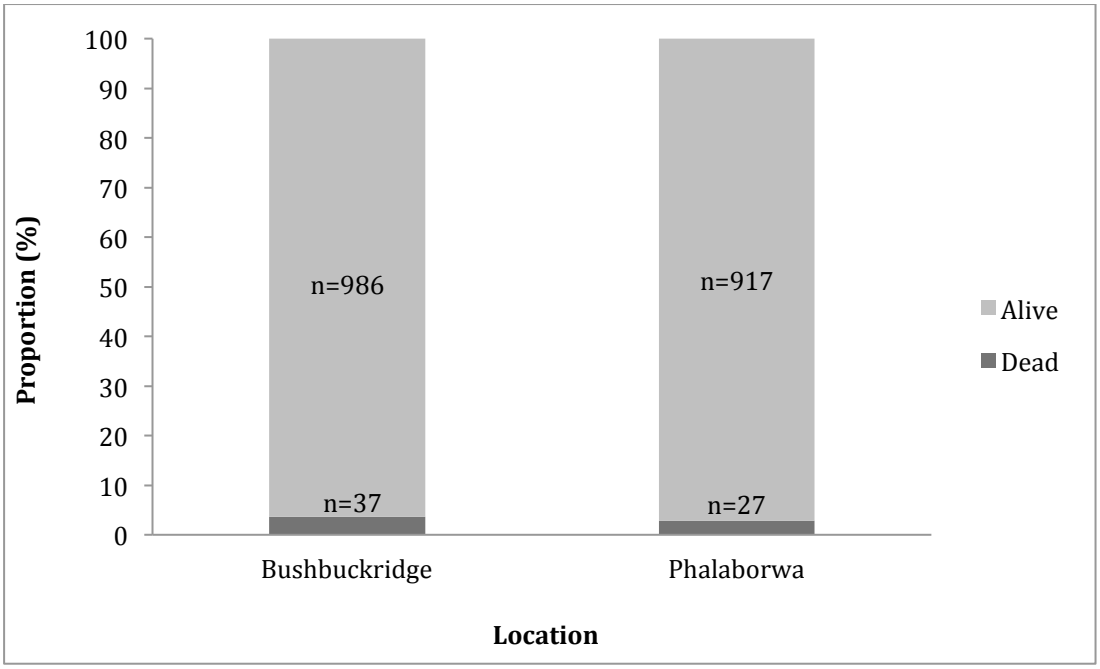


Figure 3.8: Comparison of mortality relative frequencies for adult trees in Bushbuckridge (n=1023) and Phalaborwa (n=944).

3.3.4.2 Marula mortality across land-uses

Comparing the three land-use types in Bushbuckridge and Phalaborwa separately, the mortality ratios were only significantly different, albeit small, in the latter location (x^2 (2, n=1493)= 108.98, p<0.001, Cramer's V=0.270). Phalaborwa yard (n=284) mortality ratio was 0.03:1 (2.5%) trees. In Phalaborwa fields (n=542), proportionally more dead trees were found, resulting in a ratio of 0.2:1 (16.6%) trees. Conversely, rangelands (n=667) had the least dead trees, with a mortality ratio of 0.02:1 (1.8%). In Bushbuckridge yards (n=2639) and fields (n=476), there were relatively few dead trees, rendering ratios of 0.01:1 (1.5%) trees and 0.02:1 (1.8%) trees respectively. Bushbuckridge rangelands (n=1223) displayed the lowest mortality, with a ratio of just 0.009:1 (0.9%) trees.

Looking only at the adult population in each land-use, in Bushbuckridge with an exceptionally large juvenile population, the yard (n=250) mortality ratio for the adult population alone increased from 0.01:1 (1.5%) to 0.08:1 (7.6%) dead trees. In Bushbuckridge fields (n=280), the mortality ratio increased from 0.02:1 (1.8%) to 0.03:1 (2.9%) trees when focussed only on adult mortality, while in rangelands (n=493) the ratio of dead to alive individuals increased from 0.009:1 (0.9%) to 0.02:1 (2%) trees. There were 19 dead juveniles in Bushbuckridge with 17 in yards and only one each in fields and rangelands. In Phalaborwa yards (n=176), the ratio of dead:alive increased from 0.03:1 (2.5%) to 0.04:1 (4%) when examining adult mortality, while in fields (n=219) the ratio decreased from 0.2:1 (16.6%) to 0.04:1 (3.7%) trees. In yards, all dead individuals were adults while in fields, the only dead individuals were juveniles. In rangelands (n=549), the ratio of 0.02:1 (1.8%) remained the same with the juvenile population removed, as none of the dead individuals were juveniles. Mortality ratios for adult trees across the different land-use types for Bushbuckridge and Phalaborwa are shown in Figure 3.9.

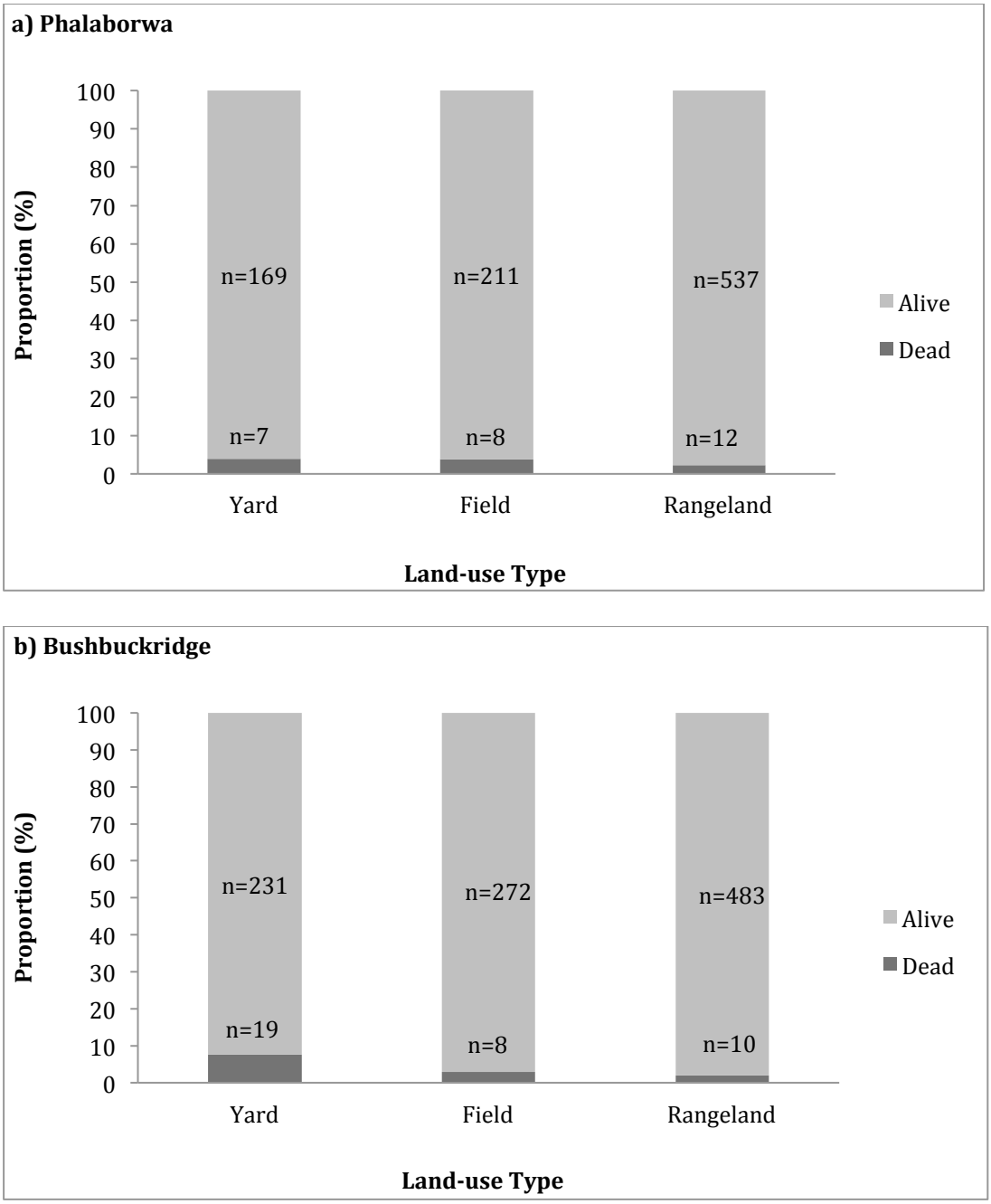


Figure 3.9: Comparison of adult mortality relative frequencies by land-use type for a) Phalaborwa (n=944) and b) Bushbuckridge (n=1023)

Yard and rangeland mortality ratios between Bushbuckridge and Phalaborwa did not differ significantly. The difference in mortality ratios between Bushbuckridge and Phalaborwa fields was significant, but small (x^2 (1, n=1018)=60.84, p<0.001, phi=0.248).

3.3.4.3 Marula mortality across settlement types

The difference in mortality between peri-urban and rural yards was not significant in either Bushbuckridge or Phalaborwa. However, in Phalaborwa fields, there was a significant and large difference between mortality ratios between peri-urban and rural fields (x^2 (1, n=542)=217.43, p<0.001, phi=-0.639). Peri-urban fields (n=372) in Phalaborwa had 0.005:1 (0.5%) dead

individuals while in rural fields (n=170), dead trees slightly outnumbered living individuals with a ratio of 1.07:1, which was 51.8% of the population. However, this was confined to only one of the two rural villages and would appear to be an anomaly. There was no significant difference in field mortality ratios between settlement types in Bushbuckridge. Finally, peri-urban and rural rangelands in both Phalaborwa and Bushbuckridge displayed no significantly different mortality ratios.

Comparing peri-urban yards, fields and rangelands between Bushbuckridge and Phalaborwa, only yards showed a significant difference in the dead:alive ratio. The difference was significant, but small (x^2 (1, n=1737)=6.62, p<0.05, phi=-0.71). Peri-urban yards in Phalaborwa (n=153) displayed a higher mortality ratio of 0.04:1 (3.9%) than Bushbuckridge (n=1584), with a mortality ratio of 0.01:1 (1%).

In the rural context, the ratio between dead and alive trees were only significantly different in fields, indicating a large difference (x^2 (1, n=402)=129.714, p=0.001, phi=-0.574). Rural fields in Phalaborwa (n=170) were dominated by dead individuals, resulting in a ratio of 1.07:1 (51.8%); while in Bushbuckridge the ratio was only 0.03:1 (2.9%) dead individuals.

3.3.5 Marula tree damage

3.3.5.1 Stem/branch damage between locations

In both Bushbuckridge (n=4338) and Phalaborwa (n=1493), primary damage (stem cutting) was the most common form of damage seen on trees, followed by secondary (cut branches emanating from stem) and then tertiary damage (cut branches emanating from secondary branches).

For the overall population in Bushbuckridge, 267 trees (6.15%) displayed damage (Figure 3.10) and 4071 (93.85%) showed no damage. In Phalaborwa, 143 trees (9.57%) indicated damage (Figure 3.10) with 1350 (90.42%) showing no damage. The differences in damage categories between Bushbuckridge and Phalaborwa was significant, but small (x^2 (3, n=5831)=34.13, p<0.001, Cramer's V=0.077).

Looking only at the adult population in Phalaborwa, 12.9% (n=122) of individuals were damaged, whereas in Bushbuckridge, 18.7% (n=192) of adult trees displayed damage.

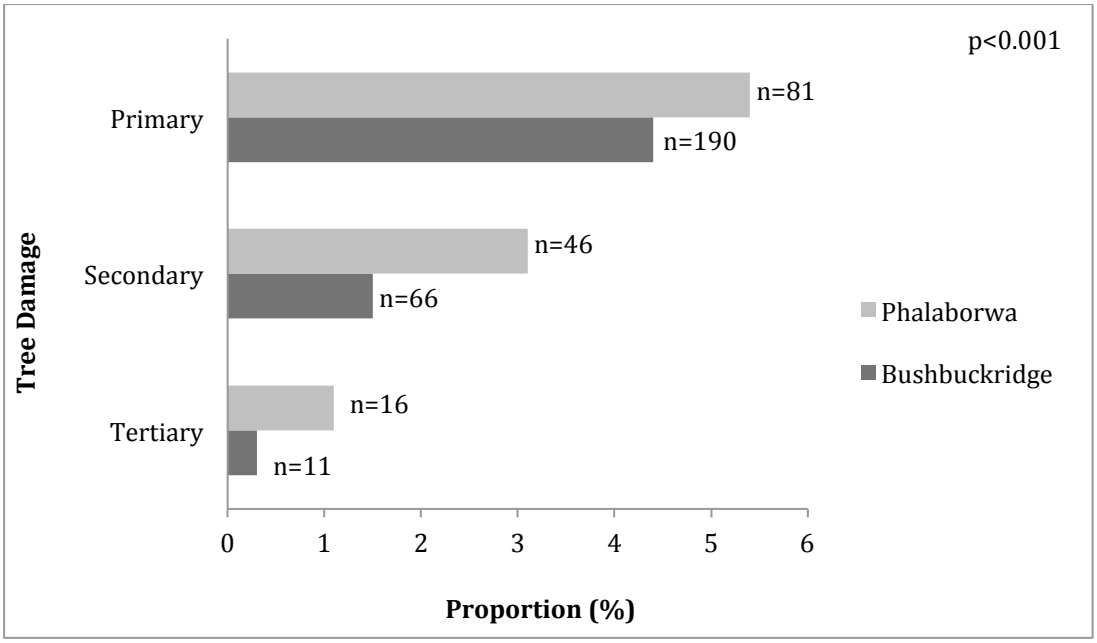


Figure 3.10: Proportion (%) of overall marula trees with stem/branch damage in Phalaborwa (n=1493) and Bushbuckridge (n=4338)

3.3.5.2 Stem/branch damage across land-uses

In both locations, primary damage was the highest category of damage across yards, fields and rangelands. In Phalaborwa and Bushbuckridge, yards displayed the highest number of trees with primary damage. Trees in fields had the second highest levels of primary damage and rangelands in both locations displayed the least primary damage (Figure 3.11).

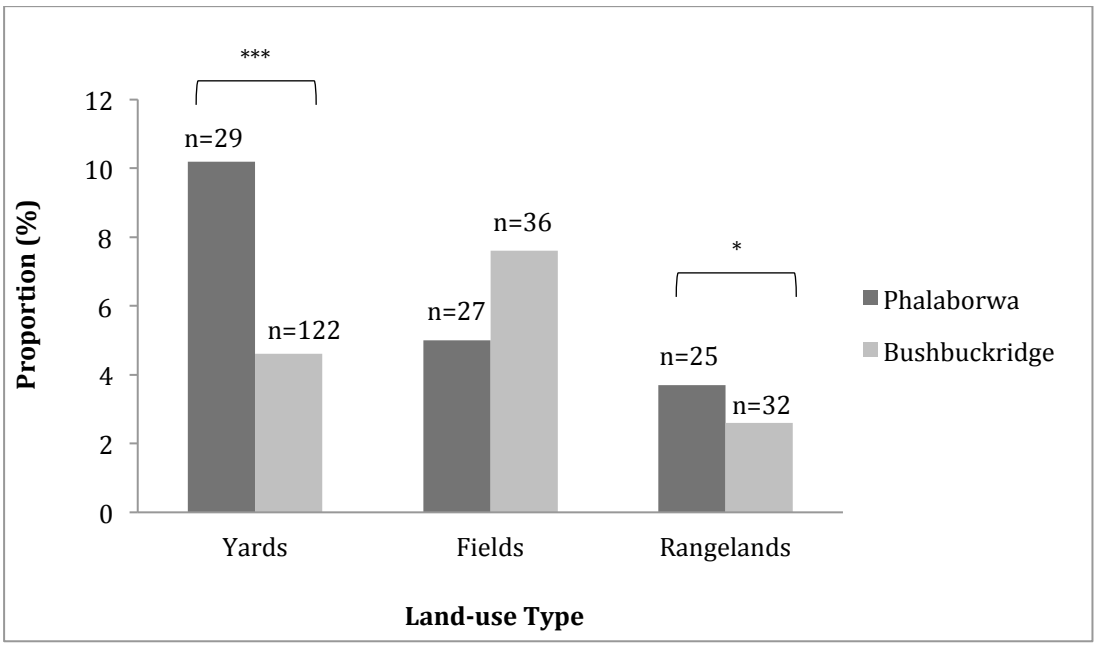


Figure 3.11: Proportion (%) of overall marula primary damage (stem) by land-use type between Phalaborwa (n=1493) and Bushbuckridge (n=4338). (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

Differences between categories across all three land-use types were significant. In Phalaborwa (x^2 (6, n=1493)=81.77, p<0.001, Cramer's V=0.165) and Bushbuckridge (x^2 (6, n=4338)=31.43, p=0.001, Cramer's V=0.060), there was a small difference. Differences were significant and small between yards in Phalaborwa and Bushbuckridge (x^2 (3, n=2923)=143.95, p<0.001, Cramer's V=0.222) and between rangelands in the same locations (x^2 (3, n=1890)=9.66, p<0.05, Cramer's V=0.071). Damage to trees in fields was similar between locations.

In terms of the adult population only, this amounted to 9.2% (n=26) in yards in Phalaborwa and 3% (n=78) in Bushbuckridge. In fields, 3.5% (n=19) of adults in Phalaborwa and 5% (n=24) in Bushbuckridge displayed damage. In Phalaborwa, 2.4% (n=16) of adult trees in rangelands had damage whereas 1.5% (n=18) of Bushbuckridge adult trees showed signs of damage.

3.3.5.3 Stem/branch damage across settlement types

It was not possible to assess the significance of differences in tree damage across settlement type due to assumptions of the Chi-Square test being violated, significance is therefore not indicated.

However, primary damage was higher in peri-urban as opposed to rural yards, fields as well as rangelands in Phalaborwa. The same was true for fields in Bushbuckridge. However, in yards and rangelands in this location, the rural context displayed higher levels of tree damage than their peri-urban counterparts. Comparing yards, fields and rangelands in the same settlement type (rural or peri-urban) between Phalaborwa and Bushbuckridge also failed to reveal any significant differences due to the violation of the minimal cell requirement for the chi-square test.

3.3.5.4 Bark damage between locations

In both Phalaborwa and Bushbuckridge, freshly removed bark was the least prevalent category with 'old – bark regrowth 100%' as the most prevalent (Table 3.6). In terms of the adult population alone, 30.5% (n=288) of the trees in Phalaborwa and 17.5% (n=179) in Bushbuckridge showed evidence of completely recovered bark damage. As more than 20% of the cells had an expected count less than 5, the assumptions of the Chi-Square test were not met. Significance is therefore not indicated.

Table 3:6: Proportion (%) of marula trees in Phalaborwa (n=1493) and Bushbuckridge (n=4338) with recent, recovered or no bark damage present

	Recently Damaged	Bark Regrowth (100%)	No Damage
Phalaborwa	0.6% (n=9)	20.6% (n=308)	78.1% (n=1166)
Bushbuckridge	0.04% (n=2)	5.9% (n=255)	93.8% (n=4071)

3.3.5.5 Bark damage across land-uses

In Phalaborwa and Bushbuckridge the categories of 'old' and 'no' damage add up to almost 100% each time, indicating the other categories of damage contribute very little towards the total, suggesting a lack of recent damage (Table 3.7). As more than 20% of the cells had an expected count less than 5, the assumptions of the Chi-Square test were not met. Significance is therefore not indicated.

Table 3:7: Proportion (%) of marula trees with recent, recovered or no bark damage across different land-use types (yards, fields & rangelands) in Phalaborwa (n=1493) and Bushbuckridge (n=4338)

	Land-Use Type	Bark Regrowth (100%)	No Damage
Phalaborwa			
	Yards	22.2% (n=63)	77.8% (n=221)
	Fields	1.8% (n=10)	95.6% (n=518)
	Rangelands	35.2% (n=235)	64% (n=427)
Bushbuckridge			
	Yards	6% (n=159)	93.7% (n=2474)
	Fields	9.2% (n=44)	90.3% (n=430)
	Rangelands	4.3% (n=52)	95.4% (n=1167)

3.3.5.6 Bark damage across settlements

Differences in Phalaborwa peri-urban and rural yards were not significant (x^2 (1, n=284)=1,71, p=0.155), but of interest are the categories of 'old- bark regrown 100%' and 'none removed'. In peri-urban yards, 25.5% (n=39) of trees had bark that had regrown 100% compared to 18.3% (n=24) of trees in rural yards. In addition to this, 74.5% (n=111) of trees had no bark removed in peri-urban yards, with 81.7% (n=107) of rural yard trees displaying no bark removal. In Bushbuckridge, no significant differences or differences of any interest were found. Due to the Chi-Square test assumptions being violated for the other land-use types in both locations, no significance values were available. However, the 'old- bark regrown 100%' category was higher in peri-urban yards in Phalaborwa but rural yards in Bushbuckridge.

3.3.5.7 Stem/branch damage and bark damage by gender

Gender and damage were compared to ascertain if trees of either gender sustain higher amounts of damage than the other. Due to violation of the Chi-Square test assumptions, it was not possible to test significant differences in tree damage and gender across the different land-use types or by settlement. However, the number of male trees with damage in yards, fields and rangelands was higher than their female counterparts, in both Phalaborwa and Bushbuckridge.

In Phalaborwa yards, the proportion of male and female trees with bark removed differed, although not significantly (x^2 (1, n=176)=2.21, p=0.133), the low p-value indicates this relationship could be of interest (Figure 3.12). The significance of differences within damage categories was not assessed due to violation of the Chi-Square test assumptions. In Bushbuckridge, no significant differences, or differences of any interest were found.

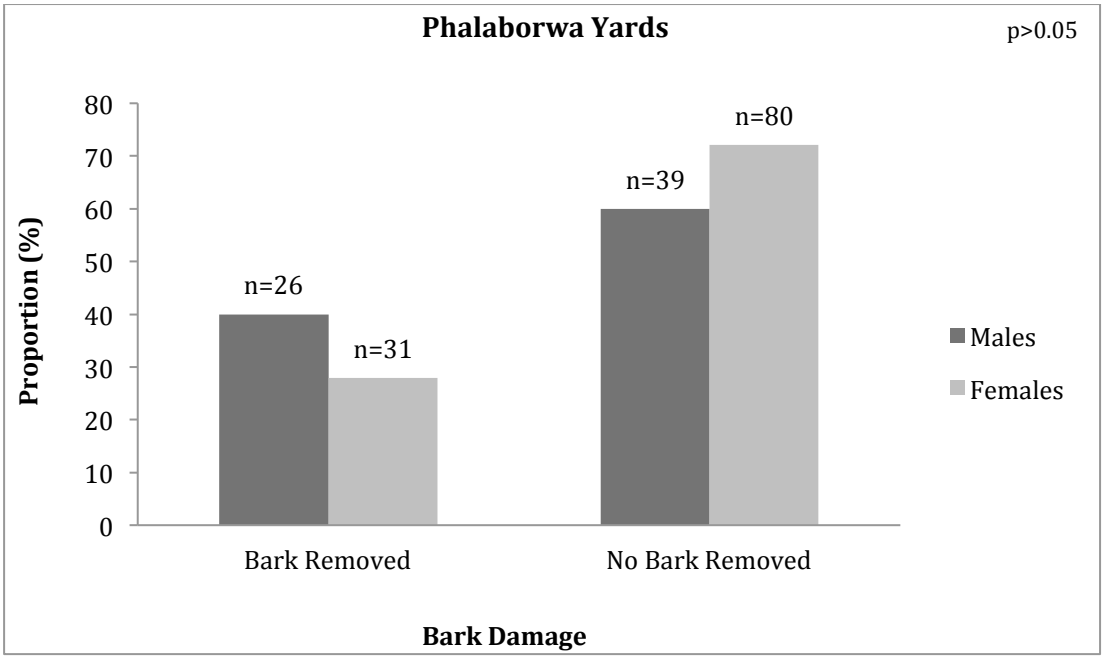


Figure 3.12: Proportion (%) of Phalaborwa yards (n=176) displaying bark removal by gender (male and female)

3.3.6 Changes in tree densities over time in the Bushbuckridge area

3.3.6.1 Temporal comparison by land-use: Bushbuckridge

Comparing marula trees in yards, fields and rangelands across the four Bushbuckridge villages of Allandale, Edinburgh, Hokwe and Rolle A, Table 3.8 highlights the differences in terms of overall and female density (Means±SE), as well as percentages of large adults and females. The 2002 density data were calculated as stems/ha, whereas the 2017 methodology followed the trees/ha calculations of Helm (2011) to account for multi-stemmed trees as a disturbance response. However, since less than 10% of the 2017 data were multi-stem individuals, the differences in results had the stems/ha methodology been utilised is very slight.

The most striking temporal change in Bushbuckridge is that overall marula densities in yards and rangelands displayed reverse trends over time (Table 3.8). In 2002, marula density in yards was 10.8±1.3 (Mean±SE), which increased to 25.7±4.1 in 2017. In rangelands, marula density was 61.3±4.5 (Means±SE) in 2002, which declined to 13.4±1.5 in 2017. Another notable trend is that the percentage of adults that are female declined in yards from 58.1% ±4.3 (Means±SE) in 2002 to 40.0% ±3.7 in 2017. However, female density remained unchanged over time in all land-use types. In fields, a substantial decline in the percentage of large adults (>43 cm) occurred from 73.9±2.9 (Means±SE) in 2002 to 36.6±4.5 in 2017.

Table 3:8: Density of *S. birrea* under different land-uses 15 years apart (Mean±SE). Densities measured as stems/ha for 2002 and trees/ha for 2017.

	Yards* (2002)	Yards (2017)	Fields* (2002)	Fields (2017)	Rangelands* (2002)	Rangelands (2017)
Density(Trees/ stems per ha)	10.8±1.3	**25.7±4.1**	5.7±0.5	7.4±0.7	61.3±4.5	**13.4±1.5**
% Large adults (>43cm)	72.7±3.6	**29.6±3.5**	73.9±2.9	**36.6±4.5**	14.2±2.1	**41.1±4.9**
% Adults that were female	58.1±4.3	**40.0±3.7**	42.3±3.0	40.7±3.9	34.1±3.6	37.9±3.0
Female density (Trees/stems per ha)	4.5±0.7	5.2±0.7	2.0±0.2	2.0±0.2	2.3±0.3	2.1±0.3

*After Shackleton (2002:5): table adapted to include 2017 data (green numbers denote increases and red numbers denote decreases in density between 2002 and 2017)

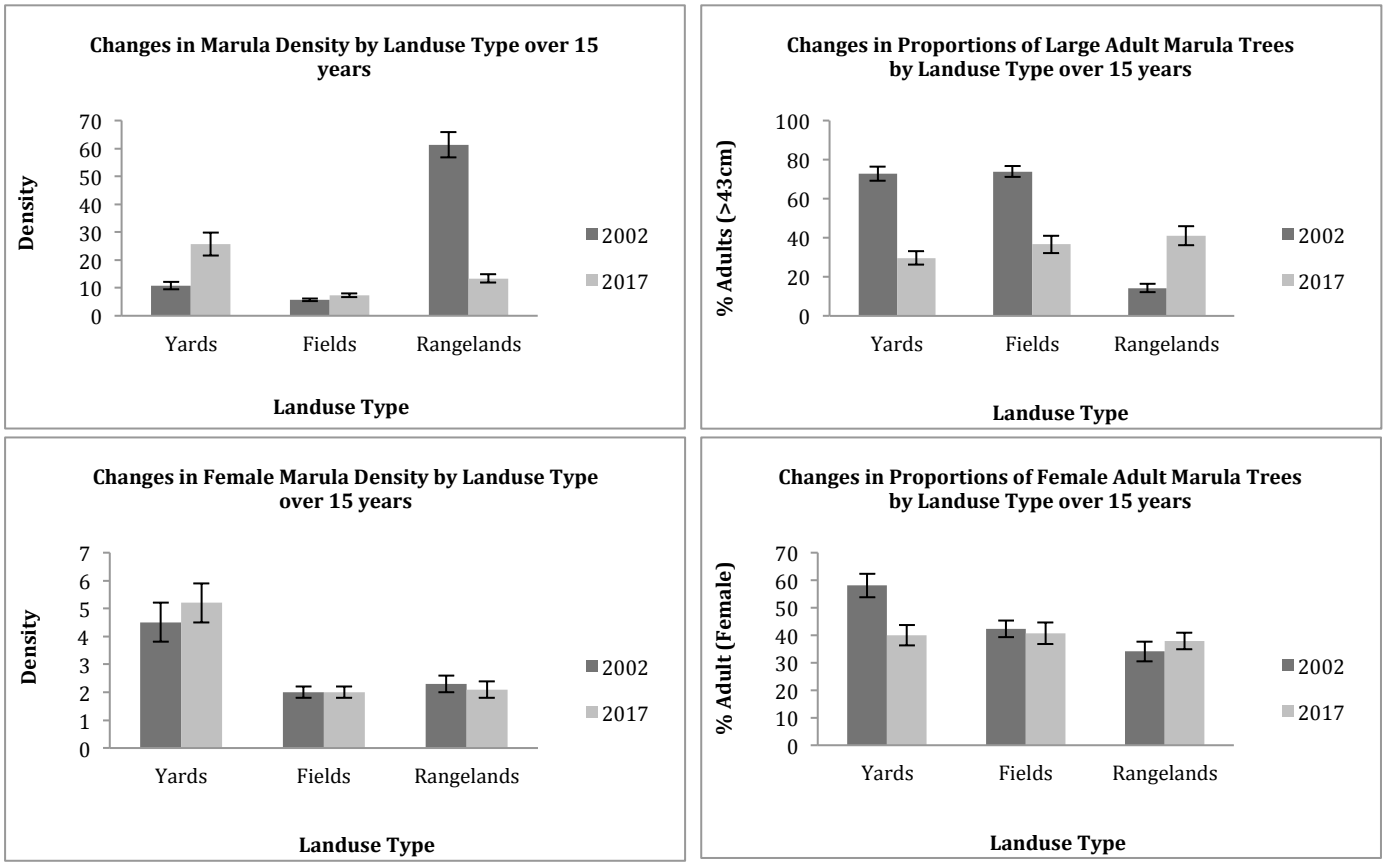


Figure 3.13: Graphical comparisons of changes in marula densities and proportions over 15 years by land-use type (yards, fields and rangelands) in Bushbuckridge

Conversely, the proportion of large adults in rangelands increased from 14.2±2.1 (Mean±SE) in 2002 to 41.1±4.9 in 2017. However, this is a proportion of a much smaller overall density and so compared to 2002, the actual number of large trees decreased by 2017 (Figure 3.13).

3.3.6.2 Temporal comparison by village: Bushbuckridge

Densities across demographic categories in the four Bushbuckridge villages of Allandale (n=50), Edinburgh (n=50), Hokwe (n=50) and Rolle A (n=50) were calculated for three land-use types, and compared with findings from Shackleton (2002). Statistical differences between villages are shown in Table 3.9. It was not possible to statistically compare rangelands as there were too few replicates when disaggregated to produce statistically robust findings.

Table 3:9: Statistical significance level, Kruskal-Wallis Test Statistic and degrees of freedom (df) for overall, adult, juvenile, male and female density categories in Bushbuckridge yards (n=120) and fields (n=80) for the four villages of Allandale, Edinburgh, Hokwe and Rolle A. Significant results (<0.05) from the Kruskal-Wallis test are indicated in bold.

Location Bushbuckridge	Density Category	Kruskal-Wallis Test Statistic	Degrees of Freedom (df)	Significance Level (<0.05)
Yards	**Overall**	4.64	3	0.200
	Adult	3.87	3	0.276
	Juvenile	**8.71**	**3**	**0.033**
	Male	3.21	3	0.360
	Female	4.91	3	0.179
Fields	**Overall**	**10.53**	**3**	**0.015**
	Adult	**15.57**	**3**	**0.001**
	Juvenile	3.34	3	0.342
	Male	**11.42**	**3**	**0.010**
	Female	6.81	3	0.078

Densities of the four demographic categories (overall, juvenile, male and female) presented in Shackleton's (2002) research appear in Table 3.10, with the same categories from the repeat surveys in 2017 displayed in Table 3.11. Visually comparing results from Table 3.10 with those from Table 3.11, the biggest change was that juvenile numbers in yards had increased in Allandale (7.3±3.1 to 8.1±4.2), Edinburgh (6.0±1.7 to 15.1±3.9), Hokwe (3.2±1.4 to 10.2±3.3) and Rolle A (3.0±1.1 to 33.4±13.1) since 2002. This has likely resulted in the increases in overall yard densities across the villages.

The opposite trend has occurred in rangelands, with juvenile numbers decreasing in Allandale (46.9±0.9 to 7.6±3.5), Edinburgh (47.8±11.9 to 10.7±2.0), Hokwe (70.1±15.8 to 7.4±1.4) and Rolle A (57.2±13.3 to 6.2±1.3) since 2002. This has likely resulted in the overall decrease in density in rangelands over time. Male and female densities have remained relatively constant compared to overall and juvenile densities in both yards and rangelands (Figure 3.14).

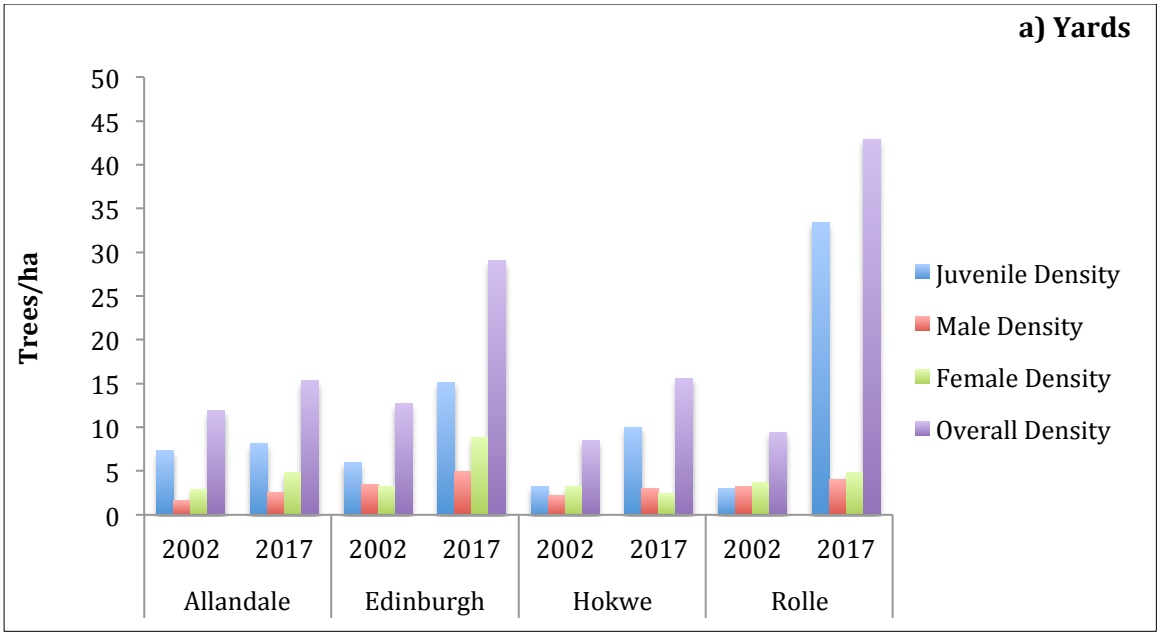
Table 3:10: Density of S. birrea within & around four villages (Mean±SE)~2002(after Shackleton et al.,2002:6)

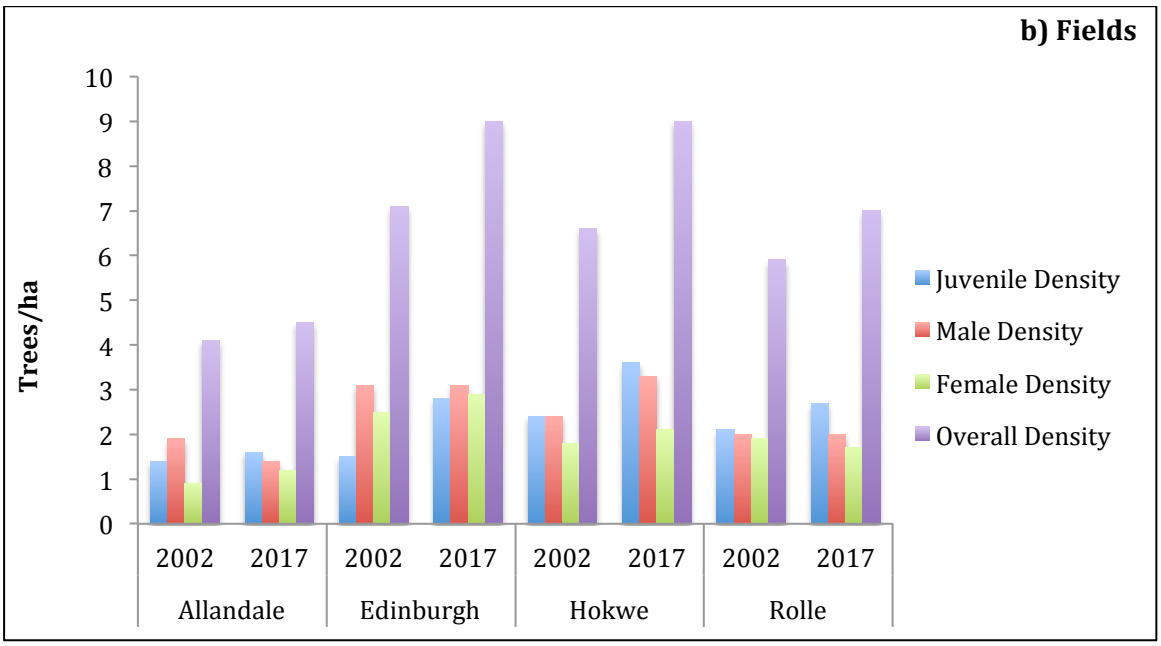
Land-use	Density Category	Allandale	Edinburgh	Hokwe	Rolle A	Significance
Yards	Juvenile Density	7.3±3.1	6.0±1.7	3.2±1.4	3.0±1.1	F=1.03
	Male Density	1.6±0.6	3.5±0.8	2.2±0.7	3.2±1.3	F=1.04
	Female Density	2.9±0.9	3.2±0.9	3.2±1.0	3.7±1.5	F=0.08
	Overall Density	11.9±4.0	12.7±2.2	8.5±1.8	9.4±1.8	F=0.57
Fields	Juvenile Density	1.4±0.4	1.5±0.7	2.4±0.8	2.1±0.8	F=0.42
	Male Density	1.9±0.4	3.1±0.7	2.4±0.3	2.0±0.4	F=1.35
	Female Density	0.9±0.3	2.5±0.4	1.8±0.3	1.9±0.5	*F=3.28
	Overall Density	4.1±0.8	7.1±1.3	6.6±0.9	5.9±1.1	F=1.50
Rangelands	Juvenile Density	46.9±9	47.8±11.9	70.1±15.8	57.2±13.3	F=0.76
	Male Density	3.3±0.6	5.6±0.9	3.1±0.7	3.4±1.2	F=2.14
	Female Density	2.0±0.6	3.8±0.7	1.6±0.5	1.9±0.8	F=1.50
	Overall Density	52.2±9.4	56.7±11.6	74.7±16.1	62.5±14.4	F=0.59

Table 3:11: Density of *S. birrea* within & around four villages (Mean±SE) ~2017

Land-use	Density	Allandale	Edinburgh	Hokwe	Rolle A	Significance
Yards	Juvenile Density	8.1±4.2	15.1±3.9	10.2±3.3	33.4±13.1	**p=0.033**
	Male Density	2.5±0.9	5.0±1.3	3.0±0.7	4.0±0.9	p=0.360
	Female Density	4.8±0.9	8.8±2.1	2.4±0.5	4.8±1.2	p=0.179
	Overall Density	15.3±4.6	29.0±5.9	15.6±3.6	42.9±13.8	p= 0.200
Fields	Juvenile Density	1.6±0.7	2.8±0.9	3.6±1.1	2.7±0.7	p=0.342
	Male Density	1.4±0.4	3.1±0.6	3.3±0.6	2.0±0.8	**p=0.010**
	Female Density	1.2±0.4	2.9±0.5	2.1±0.5	1.7±0.5	p=0.078
	Overall Density	4.5±0.8	9.0±1.3	9.0±1.3	7.0±2.0	**p=0.015**
Rangelands	Juvenile Density	7.6±3.5	10.7±2.0	7.4±1.4	6.2±1.3	-
	Male Density	3.7±1.4	2.4±0.2	4.3±0.6	2.3±0.4	-
	Female Density	2.6±0.6	2.0±0.4	2.6±0.5	1.0±0.3	-
	Overall Density	14.0±5.4	15.3±1.9	14.5±1.7	9.6±1.5	-

*significantly different at p<0.05


a) Yards
Trees/ha
50
45
40
35
30
25
20
15
10
5
0
2002
2017
2002
2017
2002
2017
2002
2017
Allandale
Edinburgh
Hokwe
Rolle
Juvenile Density
Male Density
Female Density
Overall Density


b) Fields
Trees/ha
10
9
8
7
6
5
4
3
2
1
0
2002
2017
2002
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Allandale
Edinburgh
Hokwe
Rolle
Juvenile Density
Male Density
Female Density
Overall Density

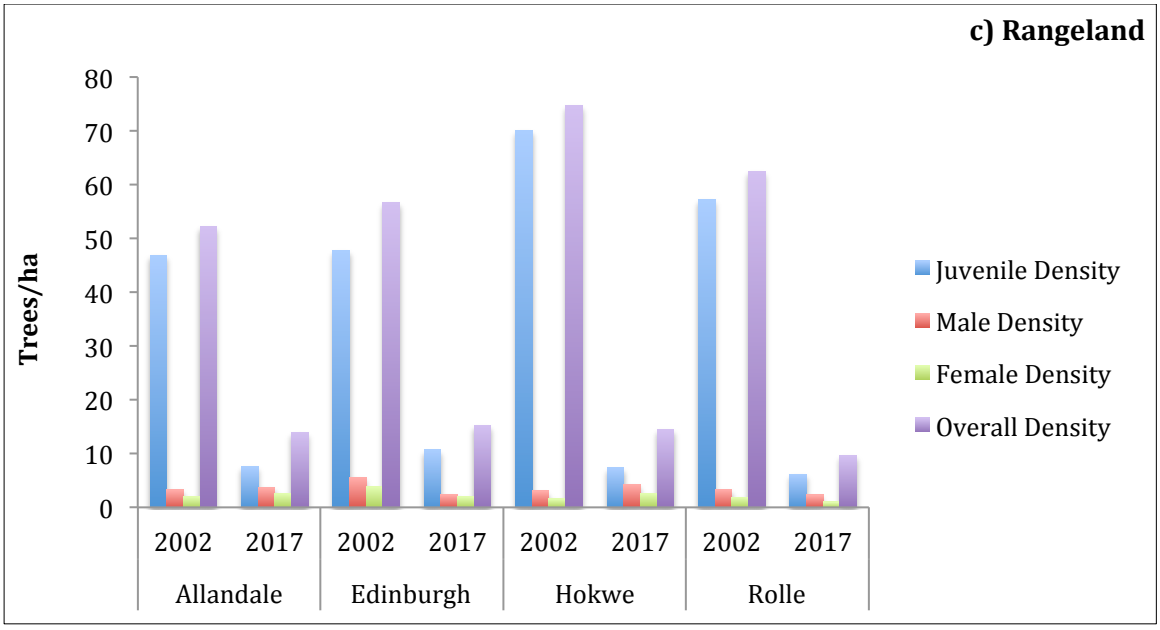


Figure 3.14: Comparison of the changes in juvenile, male, female & overall mean density for marula trees across a) Yards, b) Fields and c) Rangelands in the villages of Allandale, Edinburgh, Hokwe and Rolle in Bushbuckridge between 2002 and 2017

Yard female density increased across all villages, except for Hokwe, which decreased from 3.2±1.0 (Mean±SE) in 2002 to 2.4±05 in 2017 (Figure 3.14). The largest increase in adult female density is Edinburgh, from 3.2±09 in 2002 to 8.8±2.1 in 2017 (Figure 3.14). Adult male density in yards also increased across all four villages from 2002 to 2017, although increases were not as prominent as with female density.

In fields, overall density also increased across all four villages from 2002-2017. Similarly, juvenile density and female density increased in three of the four villages, with the exception being Rolle A, where both juvenile and female density decreased. The direction and magnitude of change in male density varied with village although it mainly increased, or remained constant with time, as was the case in Edinburgh (3.1±0.7 in 2002 and 3.1±0.6 in 2017) and Rolle A (2.0±0.4 in 2002 and 2.0±0.8 in 2017) as shown in Figure 3.14.

Overall density for rangelands across all four villages declined between 2002 and 2017, which is likely as a result of the large decline in juveniles across the village rangelands during this period. Male and female density increased in Allandale and Hokwe rangelands, but decreased in Edinburgh and Rolle A.

3.3.7 Density of *S. birrea* in conservation vs. non-conservation areas

3.3.7.1 Spatial comparison: elephants vs. humans as change agents

In non-conservation areas, rangeland is the land-use type that has been altered least by humans and therefore is most similar ecologically to the original savanna landscape. It is therefore possible by comparing Helm's sites on the same soil type to get an idea of the difference in marula densities in a conservation area and non-conservation area (the communal rangelands) to gauge and compare the impacts of elephants and humans as change agents respectively.

The 2017 data for the Bushbuckridge rangelands showed that overall marula densities are lower than the 2011 data for either KNP or the Private Reserves (Table 3.12). Adult marula densities in Bushbuckridge rangelands are higher than KNP but lower than the Private reserves, with the former conservation area experiencing greater overall elephant impact. Juvenile densities are highest in KNP, being approximately three times higher than the Bushbuckridge rangelands and the Private Reserves.

Table 3:12: Mean marula tree densities (trees/ha) under conservation vs. non-conservation land-uses

Density Category*	Bushbuckridge	KNP	Private Reserves
Overall Density	12	19	17
Adult Density	5	2	12
Juvenile Density	7	17	5

*Note: Density means are provided to the nearest whole number and std. error of mean are not available for conservation area data therefore numbers are only meant to serve as indications of different population densities

3.4 Discussion

Demographic changes across different land-use types highlights how variations in land-use practices impact marula as a key natural resource, and thus the sustainability of the socio-ecological system as a whole. The ecological indicators of SCDs, density, damage and mortality help to gauge inconsistencies in marula demographics across the landscape. Five key insights emerged from the demographic data, the first being being the negative impacts of harvesting on multi-use resources, such as marula, with overharvesting leading to diminished densities and flat or positive SCD slopes over time. The second key insight was the creation of density gradients by land-use type, with the highest overall mean densities usually in yards, followed by rangelands and the lowest in fields. The exception was Phalaborwa, where overall mean density was lowest in rangelands, with overall mortality peaking in fields. Completely cultivated fields are considered to be the most modified land-use type as all the marula trees are usually removed in order to plant arable crops. In partially cultivated and uncultivated fields as well as homestead yards, trees are often left for various reasons, including providing shade (Gouwakkinnou et al., 2011).

The third key insight was that while mortality and damage was lowest in rangelands, the socio-ecological data suggests this is potentially artificial. Whether dying of natural causes or being chopped, marula trees are usually removed in their entirety for fuelwood in rangelands. This results in diminished evidence of both mortality and damage in the rangeland context. This was supported by the higher stem and branch damage in the more human modified land-uses of Phalaborwa yards and Bushbuckridge fields. Anthropogenic drivers of stem and branch damage in yards have to do with clearing space and concerns that large trees will damage building structures. In fields, stem or branch cutting is also to optimise space and prevent shading of crops. The fourth insight was that despite male trees indicating greater levels of damage across all three land-use types, which indicates a degree of protection for female trees, in Phalaborwa the female trees in yards displayed more evidence of bark removal. This last finding is due to the specific medical properties linked to the female tree. These finding confirm that land-use choices impact the various demographic categories across the marula population differently and that various ecological indicators compared in tangent with socio-ecological trends, allow for a more holistic analysis of population structures in anthropogenic landscapes. Lastly, overall density has decreased since the prior study by Shackleton et al. (2002), with noticeable decreases in rangeland densities but increases in yards from 2002 to 2017. In addition, overall density was found to be lower in non-conservation areas (rangelands), compared to the conservation areas surveyed by Helm (2011), suggesting human resource use and specifically overharvesting for fuelwood, may be the possible cause. However, conservation areas have also experienced loses in marula density, as shown by Helm (2011), and in more recent years by Cook et al. (2017), so this is an on-going process. However, the large decreases in rangeland density as well as lower overall density compared to conservation areas suggests that overharvesting in rangelands could have detrimental long-term impacts on marula populations in non-conversation areas.

3.4.1 Varying impacts of land-uses on marula population structures in non-conservation areas

Marula trees in Phalaborwa and Bushbuckridge displayed very different population structures in terms of juvenile abundances and the proportion of large adults, which all contribute to the disparity in SCDs between locations. Overall, populations in Phalaborwa displayed positive SCD slopes, indicative of weak recruitment with an adult-dominated population, as well as an

abundance of adults in both yards and rangelands. On the contrary, Bushbuckridge had negative SCD slopes, with a juvenile-dominated population, as well as abundant juveniles in yards and rangelands. In both instances, marula populations in fields were the exception.

The harvesting of multi-use tree species, such as marula, result in a variety of impacts on the population. These impacts range from reduced recruitment, when too much fruit is removed from the system, to missing or diminished numbers in various size classes, which are specifically favoured for fuelwood (Shackleton, 2003). Oribi et al. (2002) confirm that harvesting of woody species usually takes place within 5 km from the homestead, with the 20-30 cm size classes being most utilised. In addition, Shackleton (1993b) confirmed tree size and distance from the homestead as the two most important factors shaping harvesting practices. It is therefore unsurprising that across Phalaborwa, the 9-14 cm and 14-20 cm class categories were generally lower than the other size classes, possibly indicating intensive tree felling. However, the opposite pattern was apparent in Bushbuckridge rangelands, with more numerous individuals in the 9-14 cm and 14-20 cm size classes. Numerous individuals in the smaller size classes can also be indicative of overharvesting for fuelwood which results in resprouting, as detailed by Chidumayo (2002). Chidumayo & Gumbo (2010) confirm land cover degradation results in increased density in the smaller size classes, in systems experiencing on-going overharvesting of woodland resources. In addition to this, larger scale land cover changes in these complex socio-ecological systems, such as clearing for agricultural purposes in fields, or to build new houses in villages, leads to an overall decline in the species. Over time, these patterns create flat or positive SCD slopes, which are indicative of long-term population instability. While overharvesting negatively impacts resources at the land-use level, land cover changes across the different land-use types cause changes on a larger scale. It is therefore necessary to explore resource use at a landscape level based on patterns of resource use across these different land-use types. The flat to positive SCDs created by land cover changes are due to declining species numbers across the various size classes, which Lykke (1998) attributes to the continual and widespread stress placed on savanna vegetation by human land-clearing. In addition, the wide spread degradation of savanna ecosystems is attributed to fuelwood overharvesting (Madubansi & Shackleton, 2007; Matsika et al., 2012). However, more common species (such as marula in the South African context) are likely to have negative slopes compared to less known and appreciated species which are more likely to be overharvested, such as subsp. *birrea* in Senegal (West Africa) (Lykke, 1998).

Across the different land-use types, SCDs were significantly different in Phalaborwa and Bushbuckridge when comparing yards vs. fields, yards vs. rangelands and fields vs. rangelands. The SCDs for the different land-use types were also significantly different between locations, suggesting not only different recruitment but also possibly old tree senescence across land-use type within each location. Despite displaying a negative slope overall, both fields and rangelands within Bushbuckridge indicated positive gradual slopes, suggesting weak recruitment and low levels of regeneration across these two land-use types. Only yards had a negative SCD slope, with the high numbers of juveniles contributing to the steepness of the slope. In contrast, Phalaborwa showed a positive slope overall, yet both yards and fields displayed negative slopes, with the slightly steeper slope in fields suggesting stronger regeneration in this land-use type. Rangelands on the other hand displayed a steeply positive slope, suggesting very low levels of recruitment and weak regeneration, with harvesting practices in rangelands possibly responsible for negatively impacting recruitment.

Adult populations were not dissimilar between locations in terms of relative adult tree abundance (Chapter 5). The relative abundance of large adults (>43 cm) between the two locations was also similar, despite constituting a smaller percentage of the overall population in Bushbuckridge, due to the higher juvenile numbers present (Chapter 5). The differences in adult and juvenile abundance between locations were the main contributing factors resulting in the size class distributions for the two areas being significantly different, with the high juvenile (seedling) numbers in Bushbuckridge yards leading to the inverse 'J-shaped' curve. In addition to an abundance of juveniles, there were no missing or severely limited size classes in Bushbuckridge, indicating the stable structure inherent of a typical inverse J-shaped population profile. Phalaborwa on the other hand had a positive, gradual slope, showing a lack of recruitment with higher numbers of individuals in the 30-40 cm and 40-50 cm stem diameter classes, possibly suggesting a large recruitment event in the past.

At the land-use level, the significant difference between yards, fields and rangelands in Phalaborwa resulted from adult-dominated populations in yards and rangelands, but a juvenile-dominated population in fields (Chapter 5). It is important to note that relatively fewer juveniles, as is the case in yards and rangelands, does not always signal a declining population. O'Connor & Goodall (2017) confirm that the lack of an inverse 'J curve' is not cause for concern in conserved populations in Venetia-Limpopo Reserve, due to pulsed regeneration in marula. This is especially true for species with an intermediate growth rate such as marula, provided they experience sufficient germination and survival rates (Helm, 2011; Cook et al., 2017). In addition, tree stewardship practices established in yards (Chapter 7) suggest higher survival rates than in conservation areas.

Comparing the SCDs for settlement types, the peri-urban and rural profiles were significantly different both in Phalaborwa and Bushbuckridge, as well as between these locations when comparing the same settlement type. In Phalaborwa, the rural SCD indicated weak recruitment, whereas the peri-urban profile showed stronger recruitment in the peri-urban context. This is surprising considering the limited land availability in the peri-urban context with these villages being located only 12 km from the town of Phalaborwa, whereas the rural villages are more than 50 km away, which allows for larger yards, fields and more space for communal rangelands. Larger yards and fields are likely to allow for increased germination, as the additional space means fallen fruit and seedlings are less likely to be perceived as taking up precious yard space. Paumgarten et al. (2005) confirm the significant investment rural communities place in their home gardens, which are also carefully curated to support livelihood sustenance.

In Bushbuckridge, the rural as well as peri-urban SCD profiles suggested strong recruitment and regeneration. This similarity is not surprising considering that the four Bushbuckridge villages are located in close proximity to the town of Thulamahashe, with juvenile densities being high due to prolific germination in yards across these villages (Chapter 5). In Bushbuckridge, both peri-urban and rural fields had adult-dominated populations (Chapter 5). The higher levels of field utilisation in Bushbuckridge, compounded by the removal of seedlings within this context for farming practices, mean this outcome is unsurprising. Regeneration in recently fallow fields, compared to fields that are currently cultivated was confirmed for shea trees (*Vitellaria paradoxa*) in Uganda (West Africa) (Byakagaba et al. 2011). While SCD profiles are invaluable in understanding population structure, demographic data such as density allows for a more

detailed understanding of how harvesting practices impact the resource under different land-use scenarios. The overharvesting of resources, such as marula fruit, wood and bark, can result in negative implications for males and females as well as the different size classes across the population. It is therefore crucial to understand how different human resource practices shape the marula landscape.

3.4.2 Marula density gradients across human modified landscapes

The extensive impacts of human alteration of land cover vegetation, as described by Matsika et al. (2012) and Mograbi et al. (2017) for human modified savannas, is most evident in the removal of trees in fields (space for crops) and overharvesting (chopping) of marula trees in rangelands. The comparatively lower levels of tree removal in yards, creates a land-use density gradient across these landscapes. Overall mean density was highest in yards, followed by rangelands and lowest in fields in Bushbuckridge, whereas in Phalaborwa, fields displayed the second highest mean density after yards. Interestingly, Shackleton et al. (2003) made a similar finding regarding female tree density being highest in yards, with field and rangelands having lower densities. While the particular human behaviour patterns pertaining to each of these land-use types usually forge specific distinctions, localised factors can result in variations. In Phalaborwa, overall densities were higher in fields compared to rangelands, possibly due to the protection of juveniles from herbivorous livestock in fields (due to fences) and increased fuelwood harvesting in rangelands reducing adult numbers (Madubansi & Shackleton, 2007). However, the trend of lower mean densities in fields in Bushbuckridge was confirmed by Shackleton et al. (2003) almost fifteen years prior for the same four villages, with agricultural fields displaying the lowest densities at the time. As the most modified land-use type, it is unsurprising that cultivation causes declines in density, with adult marula trees removed to make space for crops, and juveniles (seedlings) being ploughed out. A similar situation pertaining to marula, was described by Gouwakkinou et al. (2011) for subsp. *birrea* in agroforestry plots in Benin (West Africa), where adult trees and in particular specific large adults trees were left but saplings were absent, suggesting seedlings are removed. These density gradients, as a result of socio-economic impacts on the vegetation, can have a lag time of a decade or two, according to Twine (2005), making comparisons to Shackleton (2002) even more pertinent when interpreting the current findings within the context of previous studies. The negative impacts of fuelwood harvesting in rangelands in the greater Bushbuckridge area are described by Twine (2005), as well as Madubansi & Shackleton (2007), detailing how the result is the degradation of these savanna landscapes. In contrast, adult male mean density in Bushbuckridge yards increased across all four villages from 2002 to 2017, although increases were not as prominent as with female density. These findings would suggest that either the cultural or economic value of marula, or perhaps a combination of the two, is resulting in increased adult tree densities in yards. This would confirm a form of cultural conservation is taking place in homesteads.

Due to the economic value of marula, in particular the cultural capital of the female marula tree, which translates into a higher contribution to social capital, it makes sense that communities would prioritise protecting marula trees in their yards in both locations. Trees in yards can be protected from fruit theft, as opposed to fields where trees cannot be closely guarded. Fruit collectors who do not have a yard tree may therefore be forced to harvest from the rangelands if the trees in their fields have already had the ripe fruit harvested by other collectors. With the increased sales of fruit and beer over the past two decades, people are less willing to share their

fruit, with some even placing locks on field gates to prevent theft (Chapter 6). Shackleton et al. (2002) made a similar finding for marula nearly 15 years prior, suggesting that the current value nexus of marula is not a new phenomenon. Space in yards (and even fields) is often at a premium, so while yards often contain numerous marula trees of varying sizes, most yards are not large enough to support numerous large adults. This is why marula trees are not 'cultivated' domestically in yards, which would otherwise result in higher densities of large marula trees across these land-use types. Yard and field fences are what Berkes (2007) refers to as the exclusion and subtraction problem in relation to communities and commons, with fences as a prime example of exclusion, by limiting access to resources. Harvesting of live trees in rangelands is a key example of the subtraction problem, with the sum of the whole (system) being reduced by the removal of the parts (trees). This can also be described using Ostrom's (2009) SES terminology, as the declining resource units or marula densities, within the wider resource system of the savanna ecosystem. Exclusion in yards and fields causes greater subtraction of the common property resource in rangelands, thereby exacerbating the land-use gradient from yard to rangeland.

Higher human densities in Bushbuckridge are linked to higher levels of resource utilisation, specifically for fuelwood, making overharvesting a likely reality in rangelands (Matsika et al., 2012). Chidumayo (2002) highlights how increased densities occur as a result of vegetation clearing or chopping in communal rangelands. This is because overharvesting for fuelwood paradoxically leads to higher overall tree densities in terms of stems (ramets), although these are in the smaller size classes due to coppicing. This is potentially one of the reasons why rangeland mean tree density is higher than in fields in Bushbuckridge. Furthermore, trees hinder cultivation in fields unless they are located around the edges, so people are only likely to leave trees in fields if they are either highly valuable or culturally protected (such as fruiting female marula trees) or alternatively, if they are too large to remove. In addition, trees are more likely to be removed in their entirety in fields, to prevent them re-sprouting, whereas rangeland trees will be cut but then usually allowed to re-sprout as a form of regeneration (Neke et al, 2006). However, higher densities due to coppicing can give the erroneous impression of sustainable regeneration, which is confirmed by Matsika et al. (2012) in relation to the impact of fuelwood harvesting practices. The size-class distributions for rangelands in Bushbuckridge suggest that on-going intensive harvesting could lead to this outcome, with higher numbers in the intermediate size classes suggesting regeneration (Chapter 5).

Considering harvesting responses vary by species, this highlights the value of using density as a metric for gauging changes across the landscape (Ruwanza & Shackleton, 2015). Marula has a strong coppicing ability, which is confirmed by Kaschula et al. (2005), who found marula to have the reputation as the best coppicing species out of ten tree species surveyed. In addition to human utilisation having a re-sprouting effect on savanna species like marula through continual harvesting, this practice has the additional implication of encouraging further utilisation of the species, which appears more abundant as a result (Mograbi et al., 2017). One of the main reasons for this overutilisation is the erroneous perception that the tree is 'recovering' and is thus being sustainably utilised (Chidumayo, 2002). In fact, the more successful a species is at coppicing and re-sprouting the more likely it is to be targeted, which Neke et al. (2006) explain thus creates a vicious positive feedback loop of overutilisation. Harvesting becomes unsustainable at a tree level, if the rate of harvesting of coppice shoots depletes root resources before they can be replenished by photosynthesis, such that the tree eventually dies. Harvesting

is unsustainable at a population level if the majority of adult trees are felled and the re-sprouts are continually re-harvested, such that none manage to reach sexual maturity again. Over time, this can create a system shift whereby these trees essentially become trapped as functional juveniles, unable to produce seeds, further leading to decreases in seedling recruitment (Twine, 2005). While marula branches are often cut due to necessity, whole trees are not necessarily always felled. This is because marula wood is not considered desirable for cooking, as it is a soft wood that creates smoke. However, overharvesting of more desirable species leads to what Ticktin (2004) refers to as homogenous landscapes, with species like marula often remaining as part of a limited number of large tree species across the landscape. As a consequence of there being fewer large trees, marula is increasingly being targeted for fuelwood, specifically due to its reputation as a strong coppice species. Furthermore, as a large tree in the savanna landscape, marula is thus also a target for 'outsider' harvesting for fuelwood markets (Twine et al., 2003).

In Phalaborwa, overall density was higher in the peri-urban context, reinforcing the divide between settlement types. The distinction between settlement types is likely the result of two resource utilisation factors. The first is the higher reliance on natural resources in the rural context, particularly the marula fruit and wood. The second factor is water related, with no piped water in the rural context meaning that stewardship practices, such as watering juvenile plants, are less likely to occur. Paumgarten et al. (2005) highlight how water is a severely limiting factor in the Bushbuckridge context, yet where available, stewardship practices such as watering juveniles is more likely to occur. In Bushbuckridge, the population difference between the rural and peri-urban villages was not as pronounced, which is reflected in the lack of clear patterns across marula densities between the two settlement contexts. This was confirmed at the village level in Bushbuckridge, with the two peri-urban villages, which are part of the 'urban' sprawl of Thulamahashe and would thus be expected to be very similar, not displaying any significant differences.

Shifts within the socio-ecological system, based on the cultural and economic value of marula over time, reinforce the land-use density gradients from yards to rangelands. The result is generally higher adult (specifically female) densities in yards compared to fields and rangelands, where densities are lower due to trees being more openly accessible. In both contexts, adult densities were considerably lower in fields, compared to yards and rangelands, with the same pattern for large adults in Phalaborwa. This is perhaps to be expected, with cultivated fields in particular representing the most modified, or human altered, of the three land-use types. It is therefore useful to interrogate how different demographic categories within the marula population, such as male, female, adult and juvenile densities, are specifically affected by land-use activities.

3.4.3 How resource practices impact marula in terms of stem, branch and bark damage

Considering that male trees are not only felled but experience greater damage in both locations, it is important to consider the impact of tree and bark damage on marula trees, which includes any resultant mortality. Gadd (2002) highlighted how marula trees can tolerate up to 50% ring barking and 100% branch breakage before succumbing to mortality. With human induced damage likely to be less than that of elephants, it would be assumed that marula trees may display higher damage but lower mortality ratios. Mortality ratios are therefore important for understanding how extensively marula trees are being impacted by destructive land-use practices. These practices include land clearing for space in yards and fields or for fuelwood in rangelands, where whole trees are either cut or removed. Tracing where the highest mortalities

are occurring in terms of land-use and settlement type provides an indication of where marula trees are most at risk, as well as where marula is being conserved.

The mortality ratios indicate that Phalaborwa has higher marula mortality compared to Bushbuckridge. However, with the removal of juveniles from the overall population, Phalaborwa showed only a marginally more favourable dead to alive ratio. This would support findings of higher levels of resource pressure and thus overutilisation of adult marula trees in the Bushbuckridge context due to higher human densities and limited land availability. Turning to tree damage, Phalaborwa had a lower percentage of adult trees with primary damage. With greater pressure for fuelwood in the Bushbuckridge context due to higher human densities, chopping of branches for wood is likely to be more prevalent than in Phalaborwa. Nonetheless, bark harvesting was higher in Phalaborwa. This would confirms higher levels of usage of the bark for medicinal and other purposes in the Phalaborwa context, which is supported by a higher number of respondents indicating use of the bark for medicinal purposes in Phalaborwa compared to Bushbuckridge (Chapter 7). Shackleton et al. (2002) highlight how marula bark is widely used for medicinal purposes, which would make yard trees a more likely target as the 'medicine' is on hand, as opposed to needing to harvest from trees which are further away, which may prove difficult for an individual in poor health, or a family member taking care of an ill relative.

In the Kruger National Park, Gadd (2002) found that wild marula trees could survive up to 100% branch breakage before succumbing to mortality. In conservation areas, Hemborg & Bond (2007) noted that female trees use early fruit abscission, the dropping of unripe fruit on the ground, to protect trees from excessive 'browsing' damage. However, this ecological trait unfortunately appears only to protect marula trees from elephants, as humans wanting green fruit for beer will cut branches regardless. In terms of damage ratios, in both Phalaborwa and Bushbuckridge, yard trees displayed the greatest primary damage with rangeland trees displaying the least, which is a potentially surprising result, as the chopping of trees for fuelwood would assumedly leave a more obvious impact. However, removal of whole trees (primary damage) as opposed to only cut branches (secondary or tertiary damage) may be indicative of fuelwood market harvesting. Harvesting for fuelwood markets means that whole trees are removed, as opposed to household harvesting, which would usually involve simply chopping a few branches. The higher levels of primary damage in yards can be better understood in the context of the social drivers explored in Chapter 6 & 7, with respondents indicating that marula trees are generally considered to be of concern near buildings, due to branches and roots causing structural damage. This specifically applies to larger marula trees, which are feared may do damage to existing buildings, either through roots destroying foundations, or branches falling onto the house. It is for these reasons that whole trees, as well as branches, are repetitively cut in yards.

Due to higher rainfall in Bushbuckridge, field utilisation for agriculture is likely higher than in Phalaborwa, resulting in more tree damage and removals in order to maximise field space. Regrown bark damage was lowest in fields at both locations, indicating that field trees are not harvested for bark as much as yard and rangeland trees. Yard trees are an obvious source of bark if households are preparing medicine for a family member due to ease of access, while rangeland trees are a likely target while people are harvesting fruit. Field trees may therefore be overlooked as a source of bark supply given the suitability of the other two land-use contexts. Male trees displayed higher levels of damage across the three-land-use types at both locations

when compared to their female counterparts. This finding suggests a degree of care or concern for female trees, which are protected from receiving the same degree of damage. However, in Phalaborwa yards, female trees showed a greater degree of bark removal than males, possibly because the bark of female trees is specifically utilised for certain medicinal as well as cultural practices, such as fertility rites. This is as a result of the female tree being considered to have potent medicinal powers. In addition, due to the regenerative nature of bark, the ability for it to regrow therefore makes it a sustainable resource, especially within yards where harvesting is limited to household use only.

There were higher levels of damage across the three-land-use types in the peri-urban context in Phalaborwa, with the same finding for bark damage, suggesting a greater degree of utilisation in the peri-urban context. Greater utilisation in the peri-urban context is to be expected due to limited land availability. The combined peri-urban land-use area surveyed was 26.27 ha across yards and fields in Phalaborwa, but was three times this (91.07 ha) in the rural context. Essentially, rural yards were almost twice as large as their peri-urban counterparts and rural fields were almost four times the size. In short, yards and fields are smaller in the peri-urban context, which is to be expected with the increased land-use pressure in more urban contexts resulting in limited space and thus land availability. Interestingly, peri-urban and rural yards and fields were not too dissimilar in Bushbuckridge, which is also to be expected considering there was not a clear divide between the peri-urban and rural contexts. However, in Bushbuckridge there was higher damage in the rural context in yards and rangelands, which might also suggest a greater reliance on natural resources, such as marula, in the more rural context. These findings are therefore anticipated, with numerous studies highlighting the higher reliance on natural resources in more rural contexts (Arnold & Perez, 2001; Wynberg et al. 2002; Kaschula et al., 2005; Belcher & Schreckenberg, 2007; Sunderland et al., 2017). Shackleton et al. (2011) specifically highlights the role natural resources play as crucial safety net for poorer communities within rural contexts, which ultimately leads to higher levels of utilisation and often overutilisation of the resource.

Despite the potential depletion of the resource, mortality was low across all three land-use type with the mortality and damage data indicating marginal impacts on marula populations. However, these findings need to be understood within the wider socio-ecological context. Trees that are chopped in yards are usually completely removed to prevent regrowth or coppicing, while in rangelands, the whole tree is extracted for fuelwood markets, so there were very few examples of trees that had died and been left for long periods of time. Even the wood from trees that die of natural causes will be collected before too long, meaning that there is not considerable evidence of dead trees scattered across the rangelands. Mortality data therefore indicated that the highest numbers of dead trees were located in fields in Phalaborwa, followed by yards, and fewest in rangelands. While this might appear contradictory, in yards and fields, people are likely to remove the entire trunk, including the roots. Unlike elephant utilisation of marula in conservation areas, where pollarded trees remain visible, human utilisation often leaves very little evidence of the reality of tree mortality. The first reason this is likely to happen is to remove the entire stump, preventing the possibility of tree coppicing or roots continuing to grow, thereby causing damage to nearby buildings. This behaviour is especially likely to occur if the safety of a building is the main reason for the tree having been removed. The second reason is to remove any evidence of a marula having been chopped, either in a yard or field, due to local prohibition on chopping. Comparing yards and fields, people are more likely to make the extra

effort of removing the entire stump in a yard due to concern over tree regrowth. In fields, a part of the tree may be left as it is not as much of a concern if it were to re-sprout, considering there are no buildings nearby. This would mean that with the majority of stumps being completely removed in yards, there would be less evidence of any trees being chopped when compared to fields. This is even more likely to occur in relation to large trees in fields, as it is more difficult and less of a necessity to remove the entire stump. A similar finding in terms of tree removal was made for marula trees larger than 40 cm in stem diameter in agroforestry systems in Namibia (southern Africa) (Nghitoolwa et al., 2003). This would suggest that the true scope of tree removal in yards might not in fact be apparent, suggesting that longer-term research is far more beneficial than once-off studies for obtaining an accurate indication of mortality.

Yards presented the highest mortality ratios in Bushbuckridge, followed by fields and the least in rangelands. However, it is important to note that the majority of mortalities in Bushbuckridge yards were juveniles, with only two adult mortalities. This means that while there was more evidence of mortalities due to the juvenile count, the lack of evidence of adult mortalities supports findings in Phalaborwa. However, it is still perturbing that trees are being chopped in yards in Bushbuckridge, the land-use type where the cultural value of these trees might have been the greatest factor in favour of their conservation. As with mortality data in Phalaborwa, this result might be considered to conflict with anticipated findings, as the highest mortality would be assumed to occur in rangelands where trees are chopped for fuelwood. This is especially true, considering fuelwood consumption levels are deemed to be as high as 85-95% of households in the region (Madubansi & Shackleton, 2007). However, trees chopped for fuelwood are also likely to be removed in their entirety in rangelands, especially for fuelwood markets as this provides maximum financial return on the harvesting efforts required. It is for this reason that finding evidence of chopped trees in rangelands is also less likely, as the entire tree is once again removed, as is the case in yards. The only exception would be for very large trees where it is likely a stump would be left, but not for medium size classes which are easier to chop down and therefore are more likely to be a target for fuelwood harvesters (Nghitoolwa et al., 2003; Gouwakinnou et al., 2011).

3.4.4 Temporal changes in marula densities in Bushbuckridge over the years

In terms of the temporal comparison in Bushbuckridge, two findings are of interest. The first is the increase in mean marula densities in yards over the 15-year period (2002 to 2017), while mean densities have simultaneously declined in rangelands. The second is the decrease in the percentages of both large adults as well as female trees in the population during this time.

While stems/ha (2002) and trees/ha (2017) are not directly comparable metrics, the assumption is that there would be higher densities with stems/ha as it accounts for individuals with multiple stems whereas trees/ha counts these as one individual. The increase in density in yards is thus likely even more pronounced than what the values suggest, while the decrease in rangeland density is perhaps not as severe. However, while yard density has increased more than two fold, rangeland density has decreased by 75%. This means that simply attributing changes to the difference in methodologies resulting from comparing multi-stemmed and individual trees, cannot account for the full effect of such a decline. The declines in rangeland densities are likely attributable to a combination of two factors. The first is the increased chopping of trees for fuelwood markets (where the whole tree is removed) which leads to decreases in adult numbers. The second relates to increases in livestock (per head) as human populations increase, which are likely affecting juvenile recruitment at the other end of the

marula life stage profile through goats and cattle eating seedlings in the rangelands. Furthermore, with increasing human densities over the past 15 years, these changes are likely accelerating as resource demand and thus pressure intensifies, which Twine (2005) highlighted as cause for concern well over a decade prior. The overall result of these combined processes is likely the marked decreases in marula densities, as a common property resource, in the open access rangelands.

Interestingly, +/- 80% of yards surveyed in 2002 and 2017 contained a marula tree, with almost half of all yards surveyed in both years containing an adult female marula tree Shackleton (2002). However, the most telling figure is the percentage of trees that were large adults as well as female adults, with both these figures declining substantially over 15 years. This means that while the number of yards with marula trees has increased over time, as well as the overall density of marula trees, the percentage of these populations that are large adults as well as female trees have substantially decreased. This is based on the fact that while the density of female trees has increased marginally over time, the proportion of the population that are female has declined more noticeably. This could be explained by two, possibly concurrent, land-use practices. The first relates to people chopping large marula trees in their yards in order to build, or because they are concerned the trees will damage their houses. These practices directly reduce the density of both female as well as large adult trees in yards. The second practice relates to the increased number of juveniles in yards, possible as an indirect consequence of marula beer making, with the increased proportion of smaller/younger trees comprising a larger percentage of the overall yard tree population. This means that the remaining female (and large trees) in yards would comprise a smaller proportion of a larger population as a result of the spikes in juvenile densities. This would also suggest either more cultivation or protection of young trees, than potentially occurred in the past.

The overall increase in density in yards over time could be attributed to the 'forests' of marula seedling arising from germinating endocarps, discarded during the marula beer making process. This practice of leaving the endocarps to germinate may not have been as widespread 15 years earlier in 2002, possibly in part due to the fact that marula beer was not as widely sold, with it previously being taboo to sell marula beer. However, despite beer not being sold, it would still have been extensively brewed for domestic consumption to share with relatives, as detailed by Shackleton and Shackleton (2005). In 2005, Shackleton found that 15% of the households sold marula beer while in 2017, almost 25% of households sold marula beer (Chapter 6). The number of people selling beer in 2002 would likely have been lower as the taboo on selling beer only started to lift after 1998 (Shackleton, 2005). This trend of increased beer selling over time, and thus increased juveniles from the beer making, is confirmed by the fact that 1 in 5 (20%) of the surveyed yards in 2017 had heightened numbers of marula seedlings (<0.5 cm), suggesting these are not isolated incidents. However, the number of households brewing beer has only increased slightly in this time period, with Shackleton and Shackleton (2005) indicating that approximately 70% of households made beer in 2005, while in 2018 this went up to 75% of households. The higher number of juveniles in yards in recent times may indicate a trend towards increasing marula stewardship, with these individuals being left to recruit through in certain yards.

In addition to the proportion of fields with a marula tree increasing over time, the actual density of trees in fields has also increased. This interpretation is based on two assumptions, the first being that a 2017 trees/ha methodology should yield lower densities than stems/ha, yet there

has been an increase over time. The second assumption is that the average size of fields in Bushbuckridge has remained constant over the past 15 years. Comparing the different density classes by village from 2002 to 2017, there has been a general trend of increasing numbers of juveniles and adults across the four villages. Female density from 2002 to 2017 has remained constant, while the percentage of trees that are female has decreased slightly. As with yards, the percentage of large adults have halved from 2002 to 2017. This would suggest that either, the older trees are dying off and not being replaced by ingrowth from smaller adult size classes, or large trees are being removed to make space for planting crops. The reality is most likely a combination of both of these outcomes. A third alternative is that there are more smaller/younger trees now, with the larger/older trees simply constituting a smaller percentage of the total number of trees, although it is not possible to verify this with the data. Comparing juvenile densities in fields across the four villages, these have all increased while the other categories have remained constant. This suggests that increases in population, as indicated in yards, is likely caused by spikes in juveniles, but it is not clear how many of these individuals are removed, casting doubt as to how many actually recruit through to adulthood.

The largest decrease in density from 2002 to 2017 occurred in rangelands. Around the four villages, adult male and female densities have remained relatively unchanged from 2002 to 2017. However, the most significant change has been a massive decrease in juveniles across all four villages, resulting in an overall mean density decrease in rangelands from 61.3±4.5 in 2002 to 13.4±1.5 in 2017. Increases in livestock pressure are likely a contributing factor, but the fact that male and female densities have not changed notably may be confirmation of the strong coppicing nature of marula (Shackleton, 2001; Kaschula et al., 2005). However, stable adult densities in rangelands are not an indication of a stable population overall, as overharvesting appears to have resulted in higher densities, but in stems in the lower size classes, as observed by Chidumayo (2002).

3.4.5 Marula densities in conservation versus non-conservation areas

Comparing conservation and non-conservation (rangeland) areas is essentially a comparison of the main landscape change agents, specifically those that target marula. In conservation areas, elephants pose a threat to large marula trees while herbivores such as impala predate seedlings (Helm, 2011; Helm et al., 2011). In rangelands, humans are the main threat to adult trees with livestock such as goats predating marula seedlings. In terms of overall density, rangelands had the lowest marula densities compared to the Kruger National Park and Private Reserves. This might suggest that humans have more of a negative impact on marula populations than elephants, previously thought to be the main perpetrators of marula damage. However, looking specifically at adult marula trees, Kruger National Park displayed lower densities than rangelands, with the Private Reserves (lower elephant density than Kruger Park and only following recent introduction) having the highest densities. The reverse is true for juveniles, with the lowest densities in private reserves and highest in Kruger Park, with rangelands in the middle. Juvenile densities may actually be lower in rangelands due to the exclusion of elephants from these systems. Elephant feeding on marulas and the subsequence scatter hoarding by squirrels enhance germination. This may account for the some of the difference, with lower elephant densities in the Private Reserves, which also coincides with lower levels of recruitment. Rangelands therefore had higher adult densities but lower juvenile densities than adjacent conservation areas. This may be due to fire regimes in rangeland areas which are irregular, but if more frequent are less intense than in conservation areas (Mograbi et al., 2017).

The often larger fire intervals in conservation areas may provide enough time for marula seedlings to escape to more fire tolerant height classes (Helm, 2011). In addition, increasing herbivore pressure in rangelands could also be responsible for lower juvenile densities.

The results suggest that humans are not causing the same levels of destruction to adult trees as elephants in conservation areas at present. However, on-going overharvesting may begin to impact recruitment due to insufficient fruit being left on the ground. This would mean that in excess of 92% of the fruit is currently being harvested, which according to Emanuel et al. (2002), would result in the marula population profile being negatively impacted. In addition, overharvesting for fuelwood may create non-functional adults over-time with repeated coppicing preventing these trees from being able to produce seeds. This is especially important considering that rangelands are the least modified of the three land-use types in the human-dominated landscapes of the study sites.

Comparing fields and yards to conservation areas is likely to indicate human land-cover damage as the most impactful on marula populations over time. However, cultural practices such as beer making and tree stewardship in yards result in large numbers of juveniles in Bushbuckridge, as well as the protection of female and large adult trees of both genders. In contrast to elephants, which mainly target and therefore damage female trees for their fruit, there is evidence of higher levels of tree damage to male trees in non-conservation areas, which would suggest a degree of protection for female trees across certain anthropogenic land-use types. However, unlike elephants that remove bark from trees of either gender, female trees showed higher levels of bark removal in non-conservation areas due to cultural rites and practices around the potency of female trees for medicinal purposes (Chapter 7).

This places humans in a dual role of both causing population decline while also helping to conserve the species. Adult trees are likely to be removed if they are too close to a building, making only those yards where the tree is valued culturally or economically, a safe haven for adult marula trees. Due to the apparent abundance of the species, people will chop a marula tree in their yard as other fruiting trees are deemed to be available, and in fact considered to be more freely abundant in rangelands. Consequently, only adult trees in yards where the tree is culturally valued and respected are truly safe from being chopped. With the breakdown of customary law and cultural practices, the question remaining is whether culture alone can protect this iconic species (Chapter 7).

3.5 Conclusion

Land-use choices in communal savanna landscapes provide novel examples of species conservation, as well as exploitation. Marula mean density varied considerably between Phalaborwa and Bushbuckridge, with weak recruitment overall in Phalaborwa but negative SCDs for Bushbuckridge indicating strong recruitment. At each location, densities would be assumed to be highest in homestead yards, where trees are protected and nurtured, followed by fields which are safeguarded by fences and lowest in rangelands, where they are open access common property resources (CPR) for harvesting and fuelwood. The spatial data on marula density and SCDs indicated that population structures vary significantly across the land-use gradient in terms of the degree of anthropogenic influence, with fields as the most altered followed by yards and the least being rangelands. This creates a marula density gradient by land-use type, with the highest overall mean densities usually in yards, followed by rangelands and the lowest in fields (with completely cultivated fields as the most human modified land-use

type). The higher marula densities in yards suggests a form of cultural conservation may be taking place.

Marula conservation in many of the yards is juxtaposed against the removal of marula where trees pose a threat to buildings, or in fields where they interfere with agricultural practices, as well as in rangelands where they are chopped for fuelwood. These factors are mitigated by adult marula trees potentially left in yards where their cultural value outweighs their infrastructural threat, or in fields where their economic value surpasses that of arable land. Although beneficial to the survival of marula as a species, this creates homogenous landscapes in these contexts with marula as one of few remaining very large savanna trees left in the landscape when other species are removed (Scholes, 2009). Due to the coppicing nature of marula, combined with the practice of chopping branches for fuelwood, overharvesting of marula in rangelands is likely the most direct threat to the species. This is confirmed in the Bushbuckridge context, where higher human densities have led to increases in overall marula density in yards over the past 15 years, but overutilisation in rangelands has resulted in overall density decreases across this land-use type. Differences at the settlement level help to unpack the impacts of resource use pressures with differing land availability gradients. In Phalaborwa, where the rural and peri-urban divide is most distinct, higher densities across the marula density categories in the peri-urban context support the theory of overreliance, overutilisation and overharvesting in the rural context.

Given the harvesting of marula for fuelwood, overharvesting of marula in rangelands is likely the most direct and immediate threat to the species. Community management approaches, in association with traditional leaders, are one possible avenue for increasing awareness of the impacts that overharvesting and destructive land-use choices have on marula populations. This includes the widespread felling of adult trees in rangelands, the necessity of stewardship and care for juvenile plants in yards and fields, and the need to conserve male as well as female adults across all three land-use types, as opposed to only in yards. Long-term research, combined with inclusive management approaches could help to ensure the future sustainability of this important natural resource and iconic savanna tree species.

4. A Matter of Bias: Are Female Marula Trees Favoured by Communities in Non-Conservation Areas of the Lowveld Region?

4.1 Introduction

Rural communities across South Africa's inhabited savanna ecosystems, rely on natural resources for subsistence income and livelihood support. The social and environmental components of these systems are often integrated at a landscape level through a web of numerous and complex connections (Ostrom, 2009). It is estimated that these human-inhabited savanna ecosystems across South Africa are home to just under one third of the national population (Bennett & Barrett, 2007). In the Limpopo and Mpumalanga provinces of South Africa, the Greater Kruger Region is a key coupled human and natural system. Across the Kruger to Canyons (K2C) Biosphere Reserve, human livelihoods are central to ecosystem functioning, with daily individual human decisions substantially impacting ecosystems (McHale et al., 2013). Ndangalasia et al. (2007) highlight the importance of studies and inventories that aim to monitor harvesting of plant resources by human populations living adjacent to protected areas in sub-Saharan Africa. Importantly, how residents use and value a resource, or the whole ecosystem within which they co-exist, differ from high-level economic evaluations of ecosystem services. Shaped by decades, centuries and sometimes even millennia, human-inhabited savanna systems can therefore be understood as a "continuum of intensity of anthropic impact" (Maranz & Wiesman, 2003:1505).

Human knowledge systems in relation to environmental decision-making are comprised of multiple ways of knowing and understanding these landscapes. These knowledge systems comprise personal beliefs, cultural values and ecological knowledge and in turn shape how sustainably people interact with their surroundings (Gaoue & Ticktin, 2009; Raymond et al., 2009). Behavioural choices in relation to natural resources, such as marula (*Sclerocarya birrea* subsp. *caffra*), are important as they guide many of the decisions pertaining to harvesting of the resource. These decisions include which species to harvest and which to leave, the parts of the tree to be harvested, as well as when, where and how much to harvest each time (Shackleton, 2002; Djossa et al., 2008). In turn, these decisions impact the state of the natural resource, specifically demographics such as male and female density and gender ratios in dioecious tree species. It is therefore crucial to explore density and gender ratios across different land-use types to ascertain how resource use is impacting population structures. Due to the multi-faceted outcomes associated with the harvesting of a multi-use species such as marula, which is used for a variety of resources, nuanced resource management approaches that incorporate institutional multiplicity are required (Geldenhuys, 2004).

4.1.1 Tree gender ratios and density: How resource use choices shape these biological indicators

Since 1930, gender ratios in dioecious trees have formally been held to 'Fisher's Principle' of a 1:1 ratio of male to female individuals within a specific population (Hardy, 2002). However,

circumstances do exist where this ratio does not occur due to the underlying assumptions not holding and biased sex ratios occurring as a result (Hamilton, 1967; Hardy, 2002). Dioecism is considered more common in tropical than temperate ecosystems (Opler & Bowa, 1978). Under natural selection, a 1:1 sex ratio is stable from an evolutionary perspective; otherwise a frequency-dependent advantage to the less common of the sexes would result (Fisher, 1930). Female trees in dioecious species invest more in reproduction, as they are required to produce seeds and fruit in addition to flowers. The necessitated production of seeds, fruit and flowers in female trees can result in reduced growth, mainly as a consequence of the products of photosynthesis being diverted away from growth towards costly reproduction. This reduction in growth can be due to reduced photosynthetic rates or higher photosynthesis efficiency as an adaptive response, with mortality sometimes resulting in stressful conditions in certain species (Obeso, 1998; Wheelwright & Logan, 2004). However, responses to reproductive investment vary by species with some females being able to afford to invest up to ten times the biomass than males in reproduction. Yet, annual growth rates are usually equivalent for both sexes, indicating that females can compensate for greater reproductive investment, which is why most dioecious plants are not obviously sexually dimorphic (Queensborough et al., 2007).

Environmental conditions are influential in terms of the degree of sexual dimorphism when it does occur in a species (Boecklen & Hoffman, 1993). However, there may be inter-sex differences in terms of allocation of resources to reproduction and growth patterns or rates, which result in male-biased sex ratios in many tree species (Obeso et al., 1998; Queensborough et al., 2007). Due to the greater reproductive cost born by the female tree, it is anticipated that in stressful habitats that female individuals would suffer higher mortalities, resulting in spatial segregation of the sexes (SSS), causing greater distances between individuals of the different genders (Verdu & Garcia-Fayos, 1998; Wheelwright & Logan, 2004; Verdu, 2004). In turn, greater distances reduce the success of pollen reaching the stigmas of female flowers, decreasing the reproductive success of both genders (Verdu & Garcia-Fayos, 1998; Verdu, 2004). Dioecious varieties of the Cape Flora species-rich Fynbos vegetation in South Africa have adapted to these greater distances with higher than expected instances of wind pollination occurring (Steiner, 1988). Segregation of the sexes usually occurs as a consequence of four factors: i) reproduction costing the one sex more than the other, ii) sex choices of the individual plant/tree based on physiological or environmental conditions, iii) females at specific sites skewing the sex ratios of their progeny or iv) male and female seeds having different germination requirements (Bierzychudek & Ekhart, 1988).

While female trees allocate more energy to reproduction and defence, males tend to spend more on vegetative growth, resulting in males experiencing higher rates of herbivory (Boecklen & Hoffman, 1993; Verdu & Garcia-Fayos, 1998; Verdu, 2004). The vegetative dimorphism in the dioecious shrub, *Leucadendron xanthoconus* appears to be caused by selection for extravagant floral display in males, but not females (Bond & Maze, 1999). Verdu & Garcia-Fayos (1998) tested the preponderance of male individuals of the Mediterranean shrub *Pistacia lentiscus L.* (Anacardiaceae), which belongs to the same family as marula, finding that males were not more common in stressful or in xeric (drier) habitats. Yamashita & Abe (2002) looked at evidence of sex changes in both directions in *Bischofia javanica,* an invasive dioecious tree in the Bonin Islands, off the western pacific of Japan. While not related to marula, the authors made an interesting discovery worth considering in relation to the study species. The authors found that more male trees became female, with the largest trees remaining consistently female, likely due

to the greater biomass needed for fruit maturation, with the intermittent sizes switching genders and the smallest trees remaining male (Yamashita & Abe, 2002). The authors commented that trees in other taxa usually change genders due to resource availability (water, light and nutrients). Young populations start out male-dominated, but reach a 1:1 ratio in more mature populations, when sufficient resources have been accumulated to support the cost of fruit maturation (Yamashita & Abe, 2002). Marula has been found to display both male and female flowers on the same tree (hermaphroditism) (Hall et al., 2002; Nghitoolwa et al., 2003; Chirwa & Akinnifesi, 2008). However, while androdioecy (males and hermaphroditic individuals) is a rare reproductive system, Hall et al. (2002) and Nghitoolwa et al. (2003) have both found this in marula (subsp. *caffra*), with hermaphrodite trees showing greater drought tolerance than males. Trees classified as female in the first year of a study based on the flowers, were found later on to display male flowers, prompting Msukwa et al. (2019) to call for a more detailed investigations into this sex change behaviour. However, there are many dioecious trees, such as the semi-deciduous forest *Trichilia* species (Meliaceae) from south-eastern Brazil, that display no sex switching, a clear 1:1 sex ratio and no variation in size between the sexes, as well as no spatial segregation or clumping, yet also no fruit production without pollination (Morellato, 2001).

A close relative to marula is *Mangifera indica* (Anacardiaceae), otherwise known as the common mango fruit tree. *M. indica* is an exotic species in South Africa, indigenous to the Indian subcontinent. Shackleton et al. (2000) found that while indigenous trees such as marula used to be eaten for taste, that mango is now primarily chosen instead. The study found that 68% of community residents in Bushbuckridge chose to plant commercially valuable trees such as mango, as opposed to the 46% who planted indigenous trees like marula for the same reason. Compared to marula, which is considered almost entirely dioecious (although hermaphrodites have been observed), mango is andromonoecious, meaning that individual trees bear variable male and hermaphrodite flowers. In mango trees, the ratios of these flowers depend on the specific cultivar, climatic conditions, production the previous season and even location on the tree (Asif et al., 2002; Lora, 2018). Geetha et al. (2016) explain that mango produces hermaphrodite and staminate parts on the same inflorescence, with ratios influenced by genetic and environmental factors. Temperature is one of the most important determinates of hermaphrodite flowers in mango with warmer climates increasing fruit production, as this affects the flower sex ratio by increasing the number of hermaphrodite flowers (Fitchett et al., 2016; Geetha et al., 2016).

Gouwakinnou et al. (2011) conducted an extensive study of marula sex ratios in *Sclerocarya birrea (A. Rich) Hochst* subsp*. birrea* in Benin, West Africa. Although a different subspecies to *S. birrea* subsp*. caffra,* it provides insights with regards to the other marula subspecies. For subsp*. birrea,* the authors conclude that sex ratios are important for pollination, with human impacts shaping population ratios and local perceptions of dioeciousness being the most important factor determining which trees farmers selectively remove from fields (Gouwakinnou et al., 2011). Gouwakinnou et al. (2011) found that fewer young people (28% of those under 40 years of age) knew about sex separation. This lack of knowledge was attributed to low levels of fruit exploitation as well as commercialisation potential of the resource not being realised by the communities in the region (Gouwakinnou et al., 2009). The main value of the tree in Benin is for medicinal purposes, with no particular cultural or ritual practices associated with marula, except for the older and larger trees in communities being revered for their age and presence

(Gouwakinnou et al., 2011). Understanding the impacts of harvesting on gender ratios in the South African context is crucial to gauge if resource use choices are negatively impacting gender ratios. In addition, it is important to understand across which land-use types ratios are most or least biased, based on these human resource use choices.

Despite subsp. *birrea* not being the object of market exchange in Benin, farmers maintain these wild trees in agroforestry systems. Combined with the multi-purpose use of the tree, this suggests a degree of integration into the culture of the community regardless (Gouwakinnou et al., 2011). While subsp*. birrea* only has a use value associated with it in Benin (West Africa), in Tanzania (East Africa), *S. birrea* subsp*. caffra* was previously not harvested due to its value and status in traditional worship where it is associated with ancestral sacrifice (Luoga et al. 2000). However, subsequently subsp. *caffra* has been commercialised for timber and handcrafts (Luoga et al., 2000). As a useful tree in Benin, the authors observed that there is a higher degree of selection of subsp. *birrea* by humans with selective removal of trees most pervasive in agroforestry landscapes, which has a direct influence on adult sex ratios within these dryland contexts (Gouwakinnou et al., 2011). The authors observed the lack of African studies focusing on factors influencing male to female distances, specifically in dryland tree species such as marula (Gouwakinnou et al., 2011). As with other dioecious species, male marula investment ends at flower productions, while female marula investment in reproduction continues through seed and fruit production, with the authors anticipating finding male dominated populations. However, possibly due to the higher levels of selective removal of male individuals in agroforestry systems, the populations are not biased and displayed a random distribution of the sexes with the authors observing that unbalanced sex ratios effectively act to reduce population size (Gouwakinnou et al., 2011). Interestingly, Gouwakinnou et al. (2009) found that marula trees in protected areas demonstrated clumping but that in agroforestry systems the trees exhibited a quasi-random distribution. While random population distributions can result in constraints in pollen flow, given the close proximity of trees due to higher densities, this is only a problem where densities are low (Gouwakinnou et al., 2011). Jacobs and Biggs (2002) found that marula populations in the protected Kruger National Park also displayed highly clumped distributions. Understanding where marula trees are being chopped down (mortality) or damaged (cutting branches or bark removal) across the landscape, as well as which genders are being targeted, is important in order to gauge the stability of the overall population demographic profile.

4.1.2 Marula gender ratios and density in conservation vs. non-conservation areas of South Africa

Gender ratios and density are biological indicators of both individual tree as well as species population health. In conservation areas where elephants are present, the main source of utilisation is from elephants (*Loxodonta africana*) eating the fruit as well as the bark. In 2008, Helm (2009) resurveyed marula trees from a 2001 survey in the Kruger National Park (KNP) to gauge changes in gender ratios over eight years. Helm (2009) found that within KNP, gender ratios deviated from the 1:1 ratio, with a male to female ratio of 1.7:1. This indicates a slightly male-dominated population, likely the result of preferential utilisation of female trees by elephants (Hemborg & Bond, 2007). In an undisturbed savanna, marula populations are anticipated to display equal gender ratios and any deviation from such a ratio is thus anticipated to be due to ecological drivers (Helm, 2011). This assumption is based on the premise that there is no genetic predisposition for biased primary gender ratios (Opler & Bawa, 1978).

Hemborg & Bond (2007) examined the impacts of elephant browsing on sexual dimorphism in marula, concluding that female branches were shorter than males, as well as less ramified and carried fewer reproductive shoots. However, while browsing by large herbivores should lead to higher resistance in female branches, the authors found no difference between male and female individuals in terms of wood density and stem diameter (Hemborg & Bond, 2007). This would suggest that in marula, the sexual dimorphism is a result of the costly reproductive allocation in females, as well as sexual selection (Hemborg & Bond, 2007). The authors noted that where marula densities are lower, elephants feed exclusively on marula, leading to higher mortality and damage risk, specifically for females (Hemborg & Bond, 2007). Early fruit abscission (unripe or partly ripe fruit on the ground) may be a response in marula to create a trade-off between attracting herbivores for fruit dispersal and incurring the risk of browse injury (Hemborg & Bond, 2007). In contrast to this, Gadd (2002) found no preference for female trees, concluding that elephants are not selective between male and female marula trees in terms of bark and branch browsing, particularly in the winter months when there is no fruit. In addition, Gadd (2002) showed that marula trees tolerated up to 50% ring barking and 100% of branch breakage before succumbing to mortality, including main stem breakage with many coppicing in response.

Humans also have a direct bearing on gender ratios and density in non-conservation areas, mainly due to the value of the fruit. Slight gender biases towards females, specifically in the 71-80 cm stem diameter classes, were established in Namibian marula populations (Nghitoolwa et al., 2003). This pattern would suggest that males below 40 cm in stem diameter are possibly tolerated and retained in agroforestry systems. This is because they are not yet considered too large, in terms of either shading crops or taking up space and resources needed for arable crops (Nghitoolwa et al., 2003). However, above this size, it would seem these trees are removed if confirmed to be male. Specifically, male trees are removed in fields where they are considered to have an adverse effect on crops due to the need for more water and light, or in favour of the use of mechanical equipment (Nghitoolwa et al., 2003; Gouwakinnou et al., 2009). Interestingly, there were no gender imbalances amongst the largest trees (over 80 cm), suggesting these are either left alone at this size for shade or considered too difficult to remove after this stage. With bees and other flying insects, such as wasps, as the main pollinators of marula, the imbalance in the 71-80 cm class would become problematic for bees to pollinate effectively if the distance between genders is greater than 1500 m (Nghitoolwa et al., 2003).

Studies focussing specifically on spatial arrangements of male and female plants and the influences on pollination intensity, as well as progeny sex ratios, show that females closer to the males capture more pollen (Van Drunen & Dorken, 2012). This proximity likely affects the quality of the offspring (Stehlik et al., 2003; Van Drunen & Dorken, 2012). In addition to this, distance is usually more of a factor than male frequency in terms of negative associations between pollen loads and reproductive success in species with male and female plants (Van Drunen & Dorken, 2012). This is due to the fact that fewer males in a population are still able to sustainably pollinate females, provided the distances between these males are not too far for key pollinators to fly (Nghitoolwa et al., 2003). However, lower frequencies and hence densities of males normally result in larger distances between individuals, meaning the two are usually not mutually exclusive. This suggests that mating success is not only context dependent but also directly influenced by plant density, with the ability for a smaller number of males to pollinate a large number of females being based on a combination of high levels of activity by pollinators as

well as flower visitation bias (Van Drunen & Dorken, 2012). In addition to this, higher pollen density also results in more female-biased sex ratios in the progeny of certain plant species (Stehlik et al., 2003). Examining where male trees are removed across the landscape in the lowveld context helps to identify if marula populations are currently at risk from resource use choices. Understanding the gender ratios and density differences in marula populations in the human inhabited savanna ecosystems of the South African lowveld is therefore central to establishing if populations are indeed stable, and whether they may be affected by interrupted pollen flows, as a result of heavily skewed gender ratios.

Humans play a dual role as change agents in savanna systems, both as a profound threat as well as the custodians responsible for the conservation of a key species such as marula in human-impacted landscapes. It is therefore necessary to understand the impacts of human activity on marula gender ratios and density, in order to gauge overall resource sustainability. This chapter explores what the ecological indicators of male and female densities and gender ratios signify regarding the stability of marula populations within the lowveld region of South Africa, from the perspective of how human resource practices may be impacting the species. These ecological indicators are assessed across different land-uses and settlement types in two study areas (Phalaborwa and Bushbuckridge) in the central lowveld of South Africa.

The objectives of this chapter are as follows:

a) To determine what proportion of the population comprises fruit-bearing adults, the densities and gender ratios of male versus female trees in the population and whether this is balanced:
    I. Within and between each location, to examine how male/female ratios and densities differ between land-use type (yards, fields or rangeland)
    II. Within and between each location, to examine how male/female ratios and densities differ between settlement type (rural or peri-urban)

4.2 Methods

4.2.1 Statistical analysis for male and female densities and gender ratios

In order to understand the drivers behind male or female biased populations, gender ratios as well as differences in male and female densities were assessed. Data was collected from individual male and female marula trees across yards, fields and rangelands. The gender of trees was ascertained by the presence of fruit on the female tree during fruiting season and by the prolific presence of endocarps under certain trees out of fruting season. The individual tree data were compiled into a dataset with the tree as the individual case, resulting in 5832 cases (rows of individual tree data). The area sizes surveyed in order to gather the data in Phalaborwa consisted of yards (20.69 ha), fields (96.64 ha) and rangelands (98.57 ha). In Bushbuckridge, there were larger yards (31.37 ha), but smaller overall field sizes (69.86 ha), although similar rangeland areas (91.23 ha). Discrepancies in rangeland sizes are due to fields intersecting transects, which were removed from both the survey as well as transect area.

4.2.1.1 Gender ratio analyses

Cross-tabulations for gender were performed on the data comparing male and female adult tree ratios by location, land-use and settlement type. Cross-tabulations were performed using Chi-

Square Tests ($p<0.05$) with Fisher's Exact Test and a Phi Effect Size for tables in a 2 by 2 cross tabulation and Pearson's Chi-Square with a Cramer's V Effect Size for larger than 2 by 2 cross tabulations. The Phi effect size is a correlation coefficient ranging from 0 to 1, with higher values denoting a stronger association between variables (Pallant, 2007). The Cohen (1988) criteria of 0.1=small effect, 0.3=medium effect and 0.5=large effect were then applied to the results. For tables larger than 2 by 2, Cramer's V is used, which takes into account the degree of freedom, but requires additional manual calculations to determine which criteria to use to determine the correlation. This involves subtracting 1 from the number of categories in the row variable (R-1) and then doing the same for the column variable (C-1) and then using the smaller of the two numbers. If R-1 or C-1 is equal to 1 (two categories) then small=0.01, medium=0.30 and large=0.50. If R-1 or C-1 is equal to 2 (three categories) then small=0.07, medium=0.21 and large=0.35. If R-1 or C-1 is equal to 3 (four categories) then small=0.06, medium=0.17 and large=0.29. The effect size is provided with the results of the analyses. It is advisable in the ecological and biological sciences to report the effect size as this lends a greater degree of accuracy and confidence to reported findings (Nakagawa & Cuthill, 2007).

The Chi-Square Test compares the observed frequencies or proportions of cases that occur in each of the categories, with the values expected if there was no association between the two variables being measured (Pallant, 2007). With a 2 by 2 table, SPSS provides the Yates Correction for Continuity, which is designed to compensate for an overestimation of the Chi-Square value, which can also be provided in the results analysis. With Chi-Square tests it is important to check that the assumption for 'minimum expected cell frequency' has not been violated. In order to not violate the assumption, at least 80% of cells need to have a frequency of 5 or more, otherwise it is not possible to provide a significance value for the cross-tabulation.

Gender (male:female) ratios were calculated by dividing males/females so the ratio is *X* males per 1 female. For example: 1,000 males to 1,500 females = 1,000/1,500 = 0.66 so the male:female ratio is 0.66:1. Where the decimal value is provided separately from the ratio, a value above 1 (such as 1.04) indicates a male dominant population, whereas values below 1 (such as 0.66) indicate a female dominated population. The *X* value is rounded off to two or three decimal places, as appropriate, in order to show proximity to 1 due to Fisher's 1:1 ratio. Any variations from Fisher's (1930) 1:1 ratio in male to female individuals, resulting in either a male or female dominated population are noted and significant differences are explained. In order to trace the impacts of land-use on marula, it is important to understand if this ratio changes by location, settlement and land-use type and what factors are responsible for these changes.

4.2.1.2 Male and female density analyses

Density was calculated as the total number of trees in each land-use unit (individual yards, fields or rangeland transects) divided by the hectare area of that unit in order to obtain trees/ha. These calculations were based on individual trees as per Helm's (2011) methodology for dealing with multi-stemmed trees as a disturbance response. Using a 5% level of significance, it was found that the data was not normally distributed in yards and fields, suggesting a skewed distribution, resulting in the mean being far higher than the median in many cases. The median has therefore been included along with the mean in the results section in order to understand the ranking provided by the non-parametric tests performed in each case. A full explanation for why mean and median values are used to assess density can be found under the methodology section for Chapter 3.

Comparisons for male and female densities were made using the Kruskal-Wallis Test, the non-parametric alternative to a one-way between-groups analysis of variance. Comparisons were made between land-use and settlement types, split by location, to compare changes in Phalaborwa and Bushbuckridge respectively, and split by land-use and settlement types to compare changes between locations. The Kruskal-Wallis Test was selected as it allows for the comparison of medians of the same continuous variable for three or more groups (Pallant, 2007). For all Kruskal-Wallis Tests, a significance level of 5% ($p<0.05$) was used.

In order to ascertain which land-use types were statistically different from each other, Mann-Whitney U-Tests (the non-parametric alternative to the t-test for independent samples) were performed between pairs of groups (yard vs. field/ yard vs. rangelands/ field vs. rangeland) comparing the difference in median ranks. In order to control for Type 1 errors, a Bonferroni adjustment/correction was applied to the alpha value (0.05). A full explanation of how the Bonferroni adjustment/correction was applied can be found under the methodology section for Chapter 3.

The Mann-Whitney U-Test was also used for all other comparisons between two groups (as opposed to three or more as per the Kruskal-Wallis test). For all Mann-Whitney U-Tests, a significance level of 5% ($p<0.05$) was used to establish significance. In addition to this, the effect size for any significant values were calculated manually using the methodology detailed by Pallant (2007) where the effect size (r) equals the z value (z) divided by the square root (√) of the number (n) of cases: ($r = z / \sqrt{n}$). A full explanation of how the effect size and Mann-Whitney U-Tests were applied can be found under the methodology section for Chapter 3.

Finally, the Wilcoxon Signed Ranks Test (the non-parametric alternative to the paired t-test) was used to compare specific density categories (Pallant, 2007). The Wilcoxon signed-rank test is used to compare two matched samples to assess whether their population mean ranks differ – making it a paired difference test. This test was used to compare: male density vs. female density in order to see where they differed significantly by location, land-use and settlement type. As with Mann-Whitney, the Wilcoxon Signed Ranks avoids comparing means and instead converts scores to ranks and then compares these for significance. Once again, the effect size (r) was calculated manually using the methodology: ($r = z / \sqrt{n}$), except that n is the number of observations here. These pair-wise comparisons were split by location and land-use type.

4.3 Results

Overall, 5831 marula trees were sampled with 1493 in Phalaborwa and 4338 trees in Bushbuckridge. There were more trees in the peri-urban context with 3318 and 2513 trees in the rural context. Across the three land-use types, the majority of trees (2923) were found in homestead yards, followed by 1890 in rangelands and 1018 in fields. In Phalaborwa, of the 944 adult trees surveyed, 24 of the dead individuals could not be assigned a gender status, meaning that there were a total of 920 adult trees. In Bushbuckridge, there were 32 unknown adults out of 1023 adult trees, resulting in a total of 991 trees.

4.3.1. Marula gender between locations

Comparing ratios between Phalaborwa and Bushbuckridge, there was a slightly female-dominated population in Phalaborwa but a slightly male-dominated population in Bushbuckridge (Figure 4.1). The gender ratio was 1.15:1 male to female trees in Bushbuckridge. In Phalaborwa, the ratio was 0.88:1 trees. The difference between these male to female ratios for the two locations is small, but significant (x^2 (1, n=1911)=8.15, p<0.01, phi=-0.066).

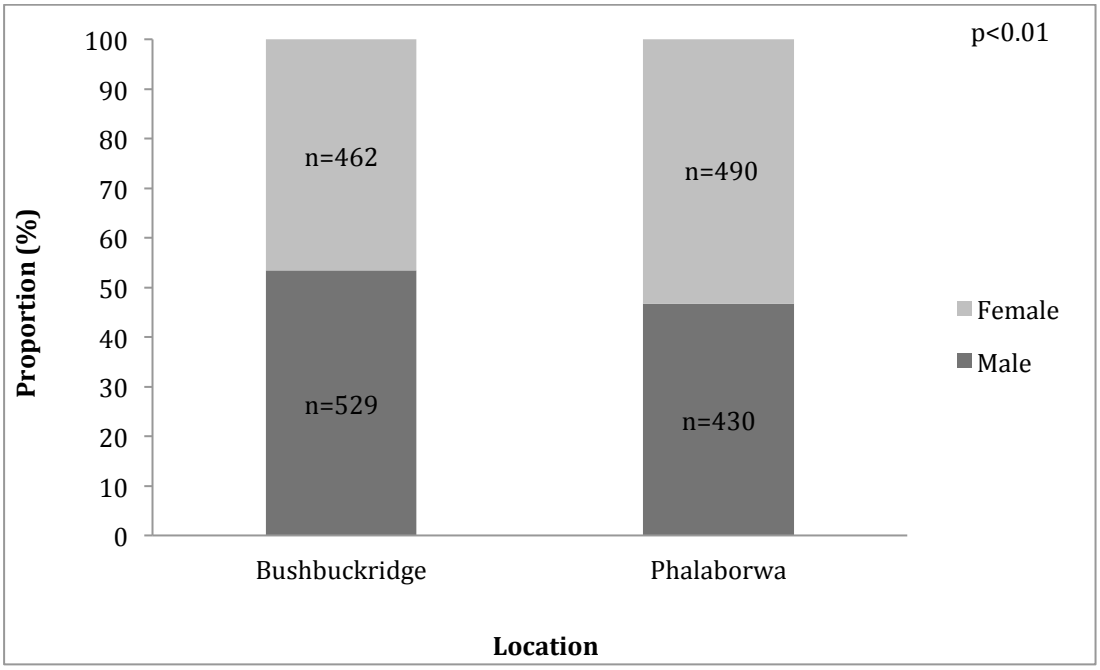


Figure 4.1: Comparison of adult marula male and female gender relative frequencies by location (Bushbuckridge (n=991) & Phalaborwa (n=920)).

4.3.2 Male and Female Density by land-use (yards, fields & rangelands)

Male and female marula tree densities in Phalaborwa (n=220) and Bushbuckridge (n=220) were compared by land-use type (yards (n=120); fields (n=80) and rangelands (n=20)) to ascertain significant differences. Male and female densities were significantly different from each other across Phalaborwa land-use types, while neither differed significantly across Bushbuckridge (Table 4.1).

Table 4:1: Results of the Kruskal-Wallis test comparing male and female density between yards (n=120), fields (n=80) and rangelands (n=20) within Phalaborwa and Bushbuckridge. Significant differences for the density categories between land-use types are indicated in bold.

Location	Demographic Category	Kruskal-Wallis Test Statistic	Degrees of Freedom (df)	Significance Level (p<0.05)
Phalaborwa	**Male**	**11.29**	**2**	**0.004**
	Female	**12.80**	**2**	**0.002**
Bushbuckridge	Male	4.79	2	0.91
	Female	3.54	2	0.170

Examining the significantly different median densities in Phalaborwa, the demographic category of female density was highest in yards while male density was highest in rangelands. The median and mean ranks produced from the Kruskal-Wallis tests are provided in Table 4.2. Median female density was significantly and substantially higher in yards than in fields, but intermediate in rangelands, differing significantly from fields, but not yards (Table 4.2). Male median density in Phalaborwa was both significant and higher in rangelands compared to both yards and fields (Table 4.2). In fields, male density was higher than yards, but was not significant. The statistics from the Mann-Whitney test are provided in Table 4.3.

Table 4:2: Comparison of male and female median and mean density (trees/ha) by land-use type (yards (n=120), fields (n=80) & rangelands (n=20)) in Phalaborwa and Bushbuckridge, with the significant results (<0.05) from the Kruskal-Wallis test indicated in bold - medians not sharing a common superscript letter are significantly different.

	Demographic Category	Yard (Y)		Field (F)		Rangeland (R)	
		Median	Mean±SE	Median	Mean±SE	Median	Mean±SE
Phalaborwa	**Male**	***0.00** [a]	**3.4±0.5**	**0.23** [ab]	**1.6±0.3**	**2.40** [c]	**2.7±0.4**
(n=220)	**Female**	**3.55** [ac]	**5.6±0.7**	**0.41** [b]	**1.5±0.3**	**2.30** [c]	**2.6±0.3**
Bushbuckridge	Male	*0.00	3.6±0.5	1.58	2.5±0.3	2.40	3.2±0.4
(n=220)	Female	2.38	5.2±0.7	1.37	2.0±0.2	1.82	2.1±0.3

***A zero median value means that at least half of the densities were zero for that specific category. For example, at least half the yards in Phalaborwa did not have male trees and so the median density value for that category is zero.**

[abc] Different superscript letters denote where overall density is significantly (p<0.05) different between yards vs. fields, fields vs. rangelands and yards vs. rangelands. Median density values for land-use types that share a common superscript letter are not significantly different (ie. overall density in yards vs. rangelands in Bushbuckridge)

Table 4:3: Results of the Mann-Whitney test comparing male and female density in yards vs. fields (n=200), fields vs. rangelands (n=100) and yards vs. rangelands (n=140), with only the significantly different demographic categories included which were all in Phalaborwa.

Location	Land use comparison	Demographic Category	Mann-Whitney U	Z-Value	Significance p<0.05	Effect Size (r)
Phalaborwa	**Y vs F* (n=200)**	**Female**	3726	-2.82	0.005	0.2
	F vs R (n=100)**	**Female**	354	-3.94	0.001	0.4
	Y vs R* (n=140)**	**Male**	802	-2.58	0.010	0.2

* Y vs F: Yards vs Field **F vs R: Field vs Rangeland ***Y vs R: Yard vs Rangeland

The main trends between land-use types, shown by the means are highlighted in Figure 4.2. Due to the skewed nature of the data, the patterns are not always the same as those reflected by the medians.

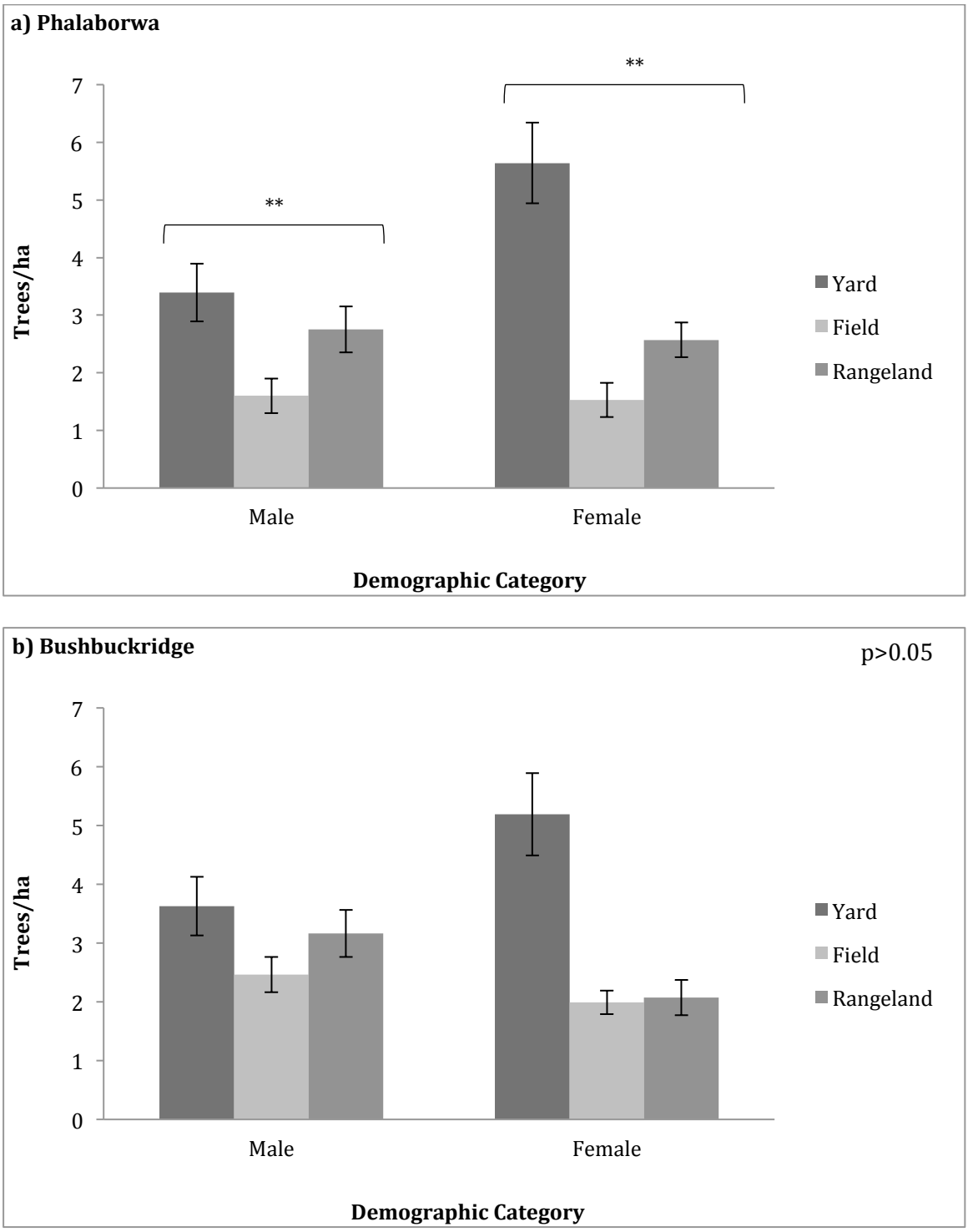


Figure 4.2: Mean male and female density ±SE (trees/ha) comparisons for a) Phalaborwa (n =220) and b) Bushbuckridge (n=220) by land-use type (yard, fields and rangelands) using the Kruskal-Wallis test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

4.3.2.1 Male:female density comparisons by land-use in Phalaborwa and Bushbuckridge

Comparing male:female density across the different land-use types using the Wilcoxon Signed Ranks Test, these differed significantly in yards in Phalaborwa (n=240), with male < females. The difference between male vs. female was small. In fields (n=160), and rangelands (n=40) neither differed significantly. In Bushbuckridge yards (n=240), male < female with the difference being small. Fields (n=160) showed no difference whereas Bushbuckridge rangelands (n=40) showed a significant and medium difference, with: male > female. The extent of these differences for both Phalaborwa and Bushbuckridge are indicated by the effect sizes in Table 4.4 with the relationship between male and female densities shown in Table 4.5.

Table 4:4: The z value, significance and effect size (Wilcoxon Signed Ranks) for male compared to female density across land-use types ((yards (n=240), fields (n=160) and rangelands (n=40)) in Phalaborwa and Bushbuckridge.

Location	Land-use	Statistic	Male:Female
Phalaborwa	**Yard**	Z value	-2.737
	(n=240)	Significance	**0.006**
		Effect Size	0.2
	Field	Z value	-0.103
	(n=160)	Significance	0.918
		Effect Size	0.008
	Rangeland	Z value	-0.403
	(n=40)	Significance	0.687
		Effect Size	0.06
Bushbuckridge	**Yards**	Z value	-2.160
	(n=240)	Significance	**0.031**
		Effect Size	0.1
	Fields	Z value	-1.172
	(n=160)	Significance	0.241
		Effect Size	0.09
	Rangeland	Z value	-2.819
		Significance	**0.005**
	(n=40)	Effect Size	0.4

Table 4:5: Summary table showing the nature of the relationship comparing male and female density across land-use types. Significant differences are highlighted in bold (M – male, F – female)

	Yards	Fields	Rangelands
Phalaborwa	**M<F**	M>F	M>F
Bushbuckridge	**M<F**	M>F	**M>F**

Despite variability in the nature of the relationships between land-use types (Table 4.6; Figure 4.3), females were denser in yards while males had higher densities in both fields and rangelands.

Table 4:6: Density comparisons of male:female showing significant differences in male and female median densities (trees/ha) split by land-use types (yards (n=240), fields (n=160), rangelands (n=40)) in Phalaborwa and Bushbuckridge, with significant results (Wilcoxon Signed Ranks) indicated in bold.

	Density Categories	Land-use Types		
		Yard (Y)	Field (F)	Rangeland (R)
Phalaborwa	Male Density	**0.00**	0.23	2.40
	Female Density	**3.55**	0.41	2.30
Bushbuckridge	Male Density	**0.00**	1.58	**2.40**
	Female Density	**2.38**	1.37	**1.82**

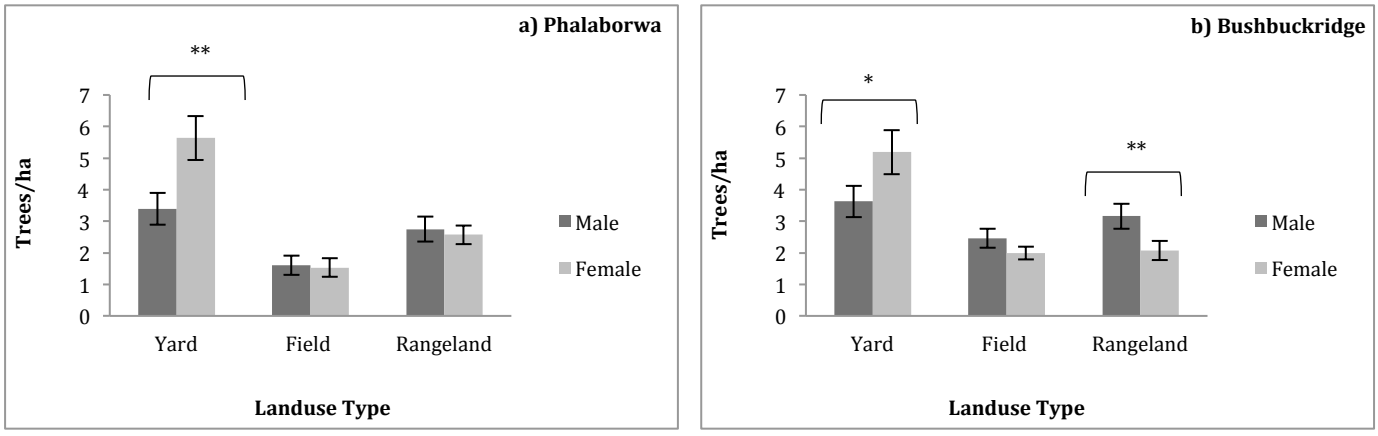


Figure 4.3: Mean density (trees/ha) ± SE for combinations of demographic categories (M v F) across land-use types in a) Phalaborwa and b) Bushbuckridge using the Wilcoxon Signed Ranks test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

4.3.2.2 Male and Female Density per land-use category between Phalaborwa and Bushbuckridge

Male and female densities between Phalaborwa and Bushbuckridge yards (n=60) did not differ significantly.

In fields (n=160), densities were significantly different between the two locations for males (U=2184, z=-3.551, p<0.001, r=0.3) and females (U=2539, z=-2.324, p=0.020, r=0.2). Male and female densities were lower in Phalaborwa fields compared to Bushbuckridge. Male and female density in Bushbuckridge fields were almost three times higher than in Phalaborwa.

Male and female densities did not differ significantly between Phalaborwa and Bushbuckridge rangelands (n=40). Differences in male and female medians (Table 4.7) and mean±SE (Figure 4.4) density by land-use are shown for each location.

Table 4:7: Comparison of male and female density by land-use type (yards, fields & rangelands) between Phalaborwa (n=220) and Bushbuckridge (n=220) with significant results (Mann-Whitney test) indicated in bold (Medians).

Land-use Type	Demographic Categories	Phalaborwa	Bushbuckridge
Yard (Y)	Male	*0.00	*0.00
	Female	3.55	2.38
Field (F)	**Male**	**0.23**	**1.58**
	Female	**0.41**	**1.37**
Rangeland (R)	Male	2.40	2.40
	Female	2.30	1.82

***A zero median value means that at least half of the densities were zero for that specific category. For example, at least half the yards in Phalaborwa did not have male trees and so the median density value for that category was zero.**

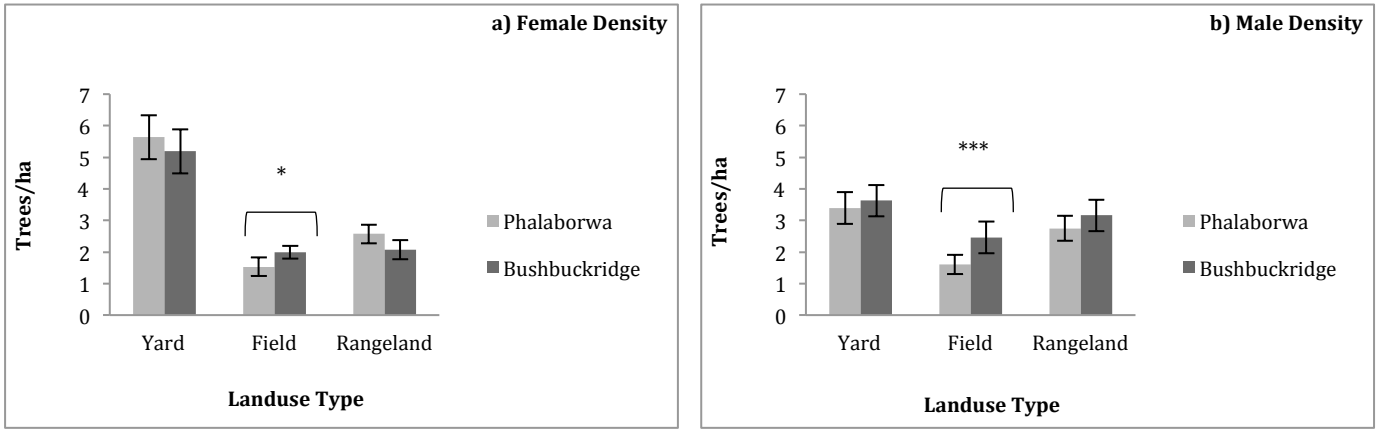


Figure 4.4: Comparison of marula mean ±SE density (trees/ha) demographic categories a) female and b) male by land-use type (yards, fields & rangelands) between Phalaborwa (n=220) and Bushbuckridge (n=220), using the Mann-Whitney test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

Examining the mean densities in Figure 4.4, it is possible to see the interesting pattern of female densities being higher in yards and rangelands in Phalaborwa, while male densities were higher across all three land-use types in Bushbuckridge.

4.3.3 Marula gender ratios across land-uses (yards, fields and rangelands)

Gender ratios differed significantly between the three land-use types of yards, fields and rangelands in both locations. In Bushbuckridge yards (n=250), the population was slightly female dominated with a ratio of 0.76:1 trees. In Bushbuckridge fields (n=265), the gender ratio was 1.05:1 trees, showing slight male dominance. Finally, rangelands (n=476) displayed a very male dominated population, with a skewed ratio of 1.49:1 trees.

In Phalaborwa yards (n=176), the gender ratio was slightly female dominated at 0.59:1 trees. In fields (n=209), the male to female ratio was 0.74:1 trees, again displaying female dominance.

Rangelands (n=535) in Phalaborwa had the most even gender ratio of 1.07:1 trees, being closest to Fisher's (1930) 1:1 ratio. The proportion of male to female individuals by land-use type is provided in Figure 4.5.

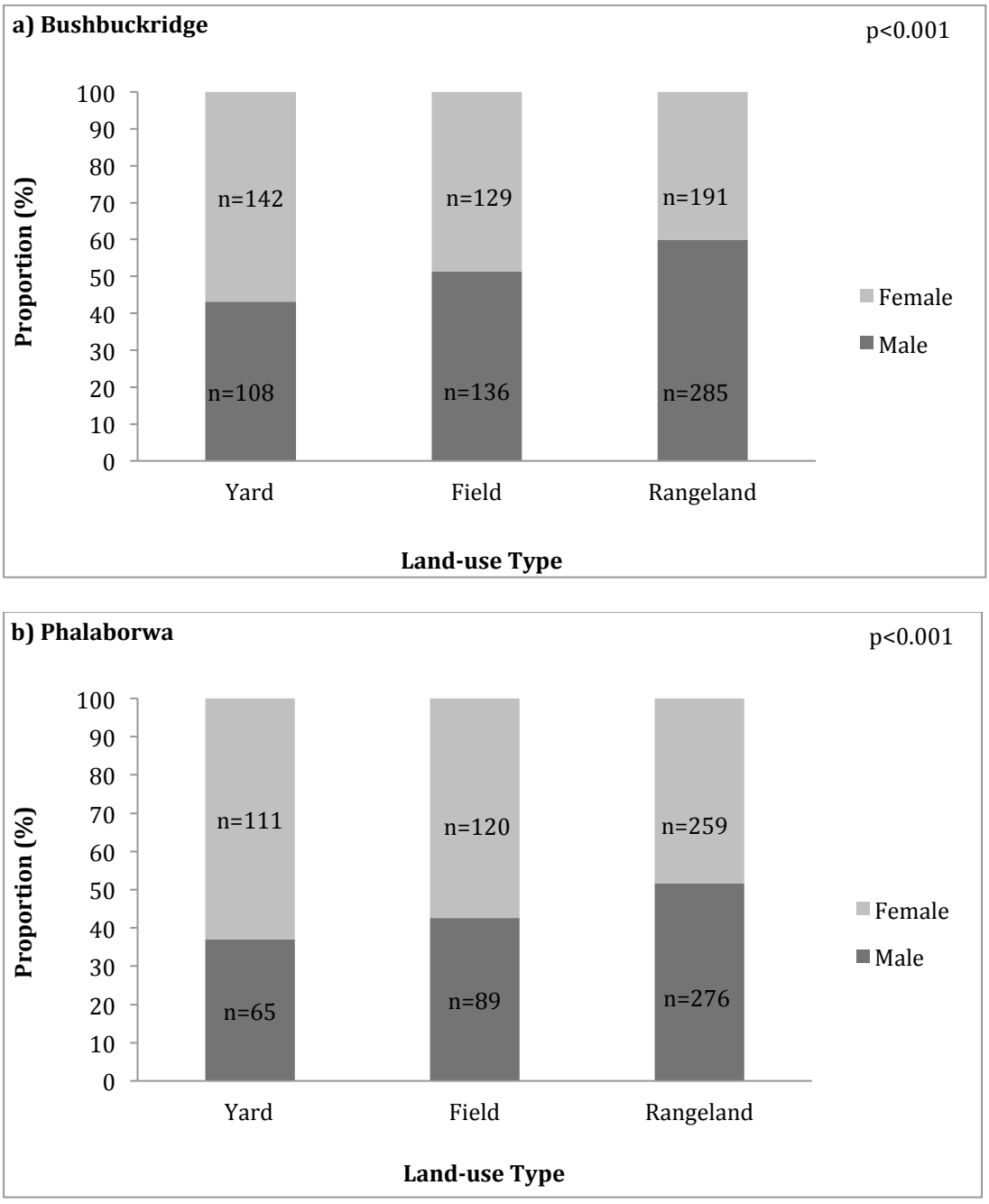


Figure 4.5: Comparison of marula male and female gender relative frequencies by land-use type (yards, fields & rangelands) for a) Bushbuckridge (n=991) & b) Phalaborwa (n=920)

The difference in gender ratios between land-use types is significant, but small, in Phalaborwa (x^2 (2, n=920)= 13.31, p<0.001, Cramer's V=0.120). Bushbuckridge demonstrated a similar outcome with a small, but significant, difference in gender ratios between land-use types as well (x^2 (2, n=991)=18.93, p<0.001, Cramer's V=0.138).

Gender ratio differences between Phalaborwa and Bushbuckridge yards were not significant (x^2 (1, n=426)=1.43, p=0.229). Likewise the difference in gender ratios between Phalaborwa and Bushbuckridge fields were also not significant (x^2 (1, n=474)=3.24, p=0.064).

However, there was a significant difference between gender ratios between Phalaborwa and Bushbuckridge rangelands (Figure 4.6), although this difference was small (x^2 (1, n=1011)=6.67, p<0.01, phi= -0.083).

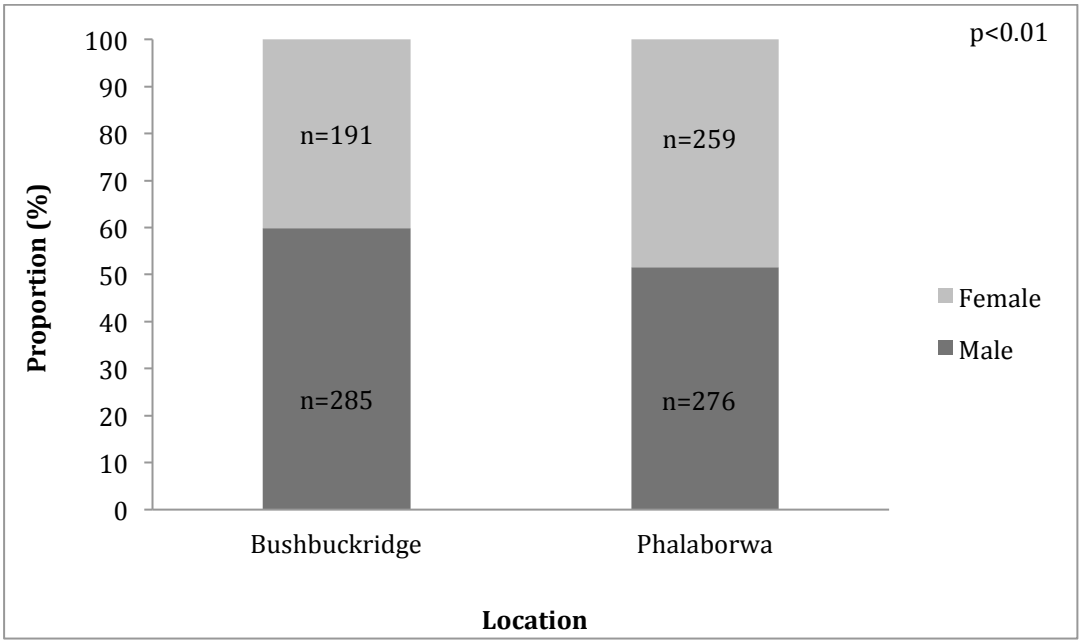


Figure 4.6: Comparison of rangeland gender relative frequencies for Bushbuckridge (n=476) and Phalaborwa (n=535)

4.3.4 Male and female marula spatial comparison by settlement type (rural and peri-urban)

4.3.4.1 Density per settlement and land-use category in Phalaborwa and Bushbuckridge

Comparing rural and peri-urban yards (n=120) and fields (n=80) in Phalaborwa, male and female densities did not differ between settlement types.

Comparing rangelands (n=20) between the two settlement types in Phalaborwa, male (U=10.5, z=-2.998, p=0.003, r=0.7) densities differed significantly, being almost three times higher in the peri-urban context.

In Bushbuckridge yards, fields and rangelands, neither male nor female density category differed significantly by settlement type (Table 4.8).

Table 4:8: Comparison of demographic categories by land-use (yards, field & rangelands) and settlement (rural & peri-urban) type within Phalaborwa (n=220) and Bushbuckridge (n=220), with significant differences indicated by the Mann-Whitney test highlighted in bold (Medians)

	Land-use Type	Demographic Categories	Peri-Urban	Rural
Phalaborwa	Yard (Y)	Male	*0.00	*0.00
		Female	5.23	2.97
	Field (F)	Male	*0.00	0.38
		Female	*0.00	0.47
	Rangeland (R)	**Male**	**3.63**	**1.70**
		Female	2.50	1.80
Bushbuckridge	Yard (Y)	Male	1.86	0.00
		Female	1.40	4.69
	Field (F)	Male	1.46	1.71
		Female	1.14	1.72
	Rangeland (R)	Male	3.00	2.19
		Female	1.50	2.12

***A zero median value means that at least half of the densities were zero for that specific category. For example, at least half the yards in Phalaborwa did not have male trees and so the median density value for that category was zero.**

Comparing the three land-use types in each location by settlement type, the main trend is that male and female densities were higher in the peri-urban context in Phalaborwa, as shown by Figure 4.7. In Bushbuckridge, this difference is not as marked, with peri-urban and rural contexts displaying more similar densities across the land-use types (Figure 4.8). However, female density was higher in the rural context, which was the opposite trend to Bushbuckridge.

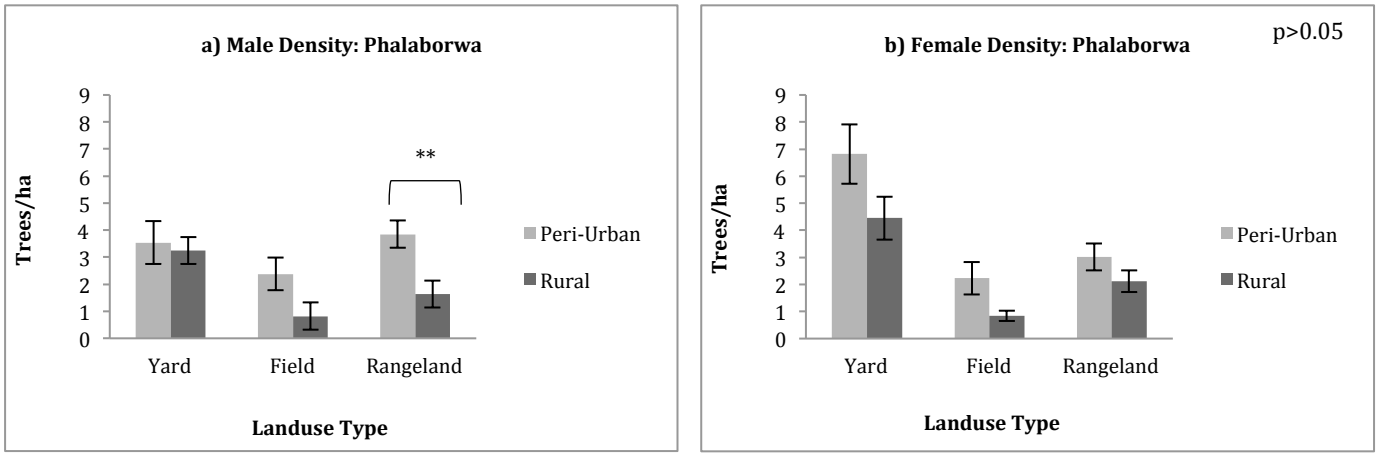


Figure 4.7: Comparison of peri-urban and rural a) male and b) female marula mean densities (trees/ha) ±SE by land-use type (yards, fields and rangelands) in Phalaborwa (n=220) using the Mann-Whitney test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

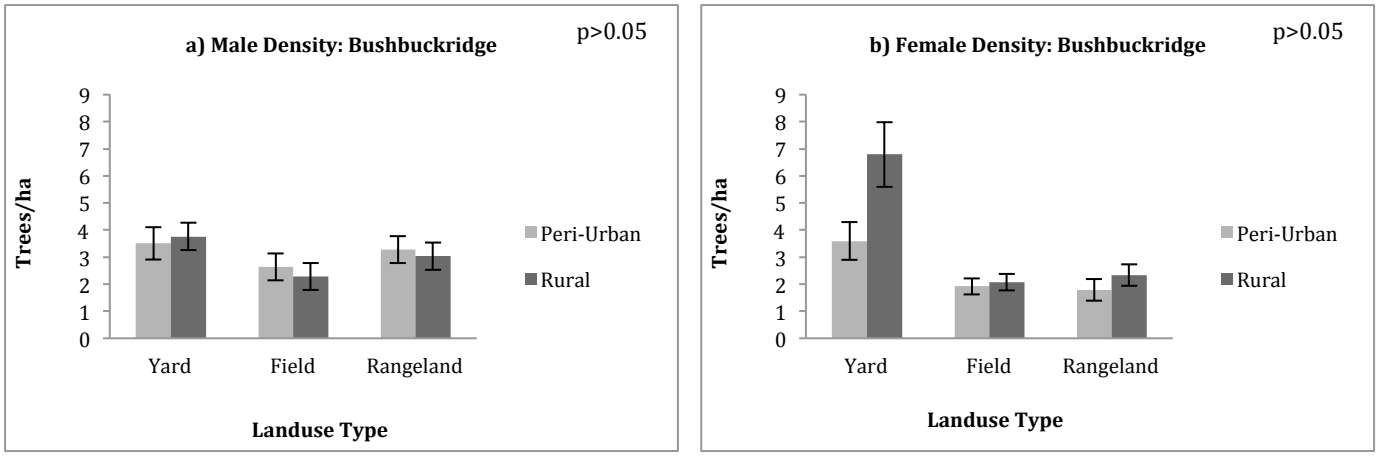


Figure 4.8: Comparison of peri-urban and rural a) male and b) female marula densities (trees/ha) ±SE by land-use type (yards, fields and rangelands) in Bushbuckridge (n=220) using the Mann-Whitney test.

4.3.4.2 Marula gender ratios across settlement types

In peri-urban yards (n=126) in Bushbuckridge, the gender ratio was 1.07:1 trees, being male-dominated but almost on par with a 1:1 ratio. Conversely, rural yards (n=124) in Bushbuckridge had a female dominated population with a gender ratio of 0.53:1 trees. In peri-urban yards in Phalaborwa (n=75), the male:female gender ratio was 0.47:1 trees. This represents a strong female bias and a large departure from Fisher's (1930) 1:1 gender ratio. Similarly, in Phalaborwa rural yards (n=101), the ratio was again skewed towards a female dominated population, being 0.68:1 trees (Figure 4.9).

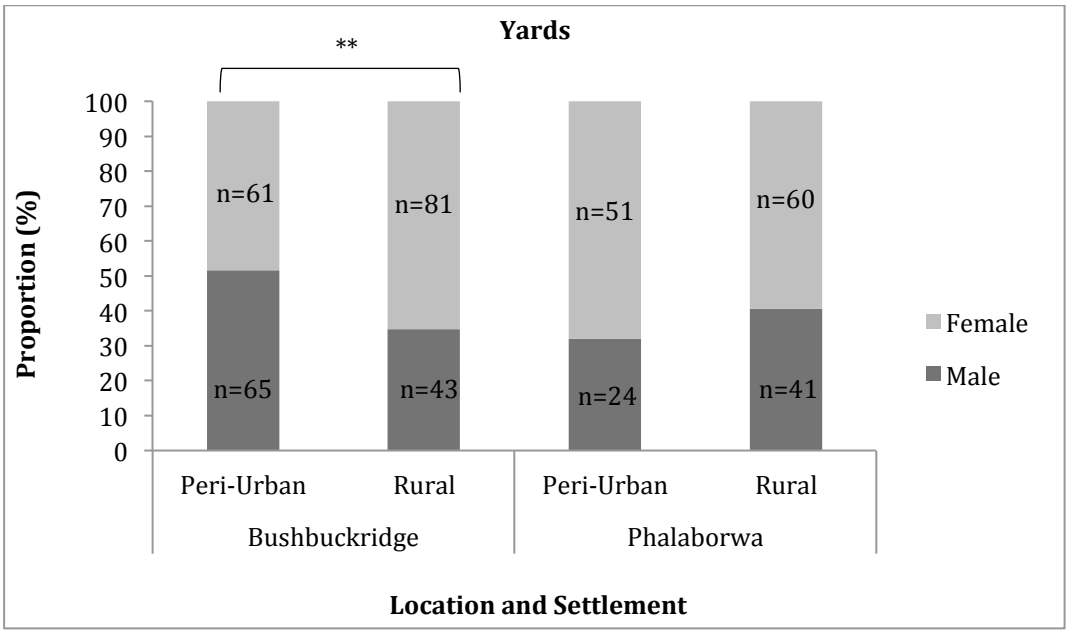


Figure 4.9: Comparison of male and female relative frequencies in yards across peri-urban and rural settlements in Bushbuckridge (n=991) and Phalaborwa (n=920)

In peri-urban fields (n=141) in Bushbuckridge, there was a gender ratio of 1.2:1, in favour of male trees, while rural (n=124) Bushbuckridge fields were female dominated, with a gender ratio of 0.91:1 trees. In peri-urban Phalaborwa fields (n=105), the gender ratio was 0.81:1 trees. Rural fields (n=104) were also female-dominated, with a gender ratio of 0.68:1 (Figure 4.10).

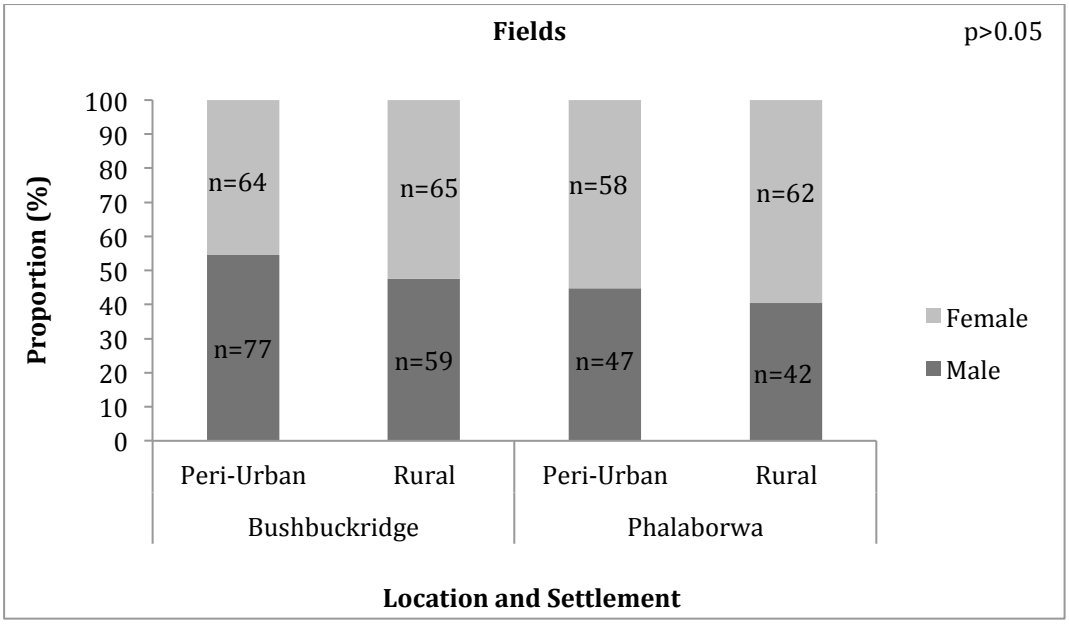


Figure 4.10: Comparison of male and female relative frequencies in fields across peri-urban and rural settlements in Bushbuckridge (n=991) and Phalaborwa (n=920)

In peri-urban Bushbuckridge rangelands (n=236), the gender ratio was 1.78:1, indicating a strongly male dominated population. In rural rangelands (n=240), the population was also male dominated, with a ratio of 1.26:1 trees. Peri-urban rangelands (n=328) in Phalaborwa indicated a male dominated population, with a ratio of 1.31:1 trees. Conversely, rural rangelands (n=207) in Phalaborwa, displayed a male:female ratio of 0.77:1 trees, indicating a female dominated population (Figure 4.11).

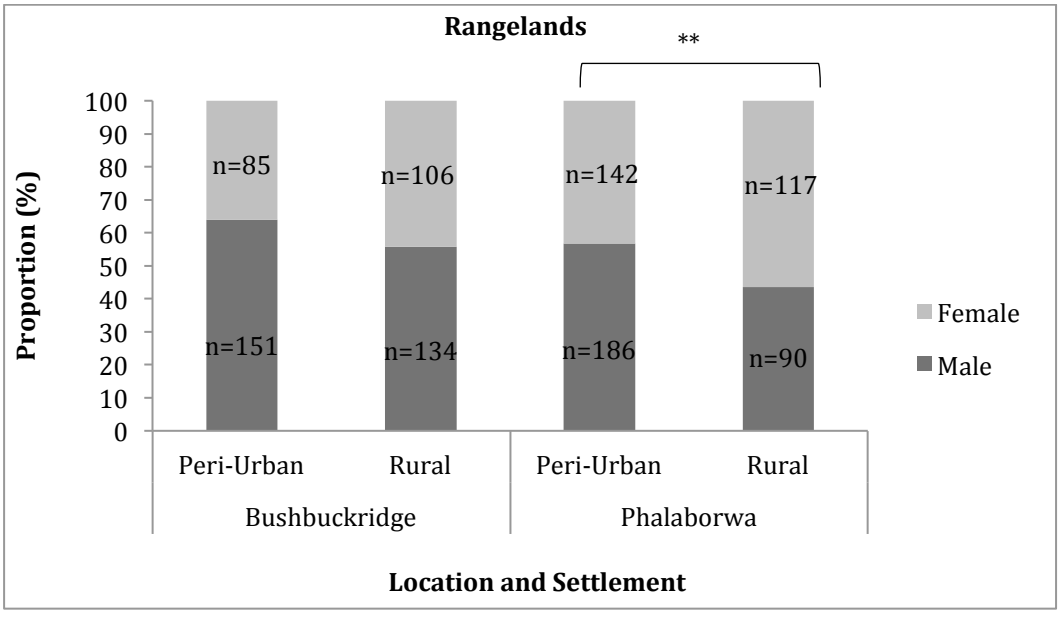


Figure 4.11: Comparison of male and female relative frequencies in rangelands across peri-urban and rural settlements in Bushbuckridge (n=991) and Phalaborwa (n=920)

In Bushbuckridge, the difference in gender ratios between peri-urban and rural yards was significant but small (x^2 (1, n=250)=6.61, p<0.01, phi=0.171). In Phalaborwa, however, the difference was not significant (x^2 (1, n=176)=1.02, p=0.271). There were no significant

differences between the gender ratios of peri-urban and rural fields in either Bushbuckridge (x^2 (1, n=265)=1.04, p=0.27) or Phalaborwa (x^2 (1, n=209)=0.25, p=0.577). However, the difference between peri-urban and rural rangelands in Phalaborwa was significant, but small (x^2 (1, n=535)=8.37, p<0.01, phi=0.129). While peri-urban and rural rangelands in Bushbuckridge were not significant (x^2 (1, n=476)=2.96, p=0.076).

Comparing peri-urban yards, fields and rangelands between Bushbuckridge and Phalaborwa, it was only yards that showed a significant, but small difference, in the male to female ratio between locations (x^2 (1, n=201)=6.539, p<0.01, phi=-0.191). In the rural context, the gender ratio between male and female trees was significantly different only in the rangelands, again being small (x^2 (1, n=447)=6.30, p=0.01, phi=-0.123).

4.4 Discussion

4.4.1 A matter of location: resource practices skew non-conservation gender ratios

While marula is utilised for cultural and economic purposes in both Phalaborwa and Bushbuckridge, differences in local resource practices play a significant role in shaping how the species is utilised. This finding contains important lessons regarding the inherent variability in localised impacts of human and natural resource interactions for other developing country contexts. Resource use practices, including the selective removal of trees is most pervasive in human modified landscapes (yards and fields), which have a direct influence on adult gender ratios in species such as marula across these land-use types (Gouwakinnou et al., 2011). This finding is not unique to marula in the South African context, with Gouwakinnou et al. (2011) making a similar discovery for subsp. *birrea* in Benin, where the selective removal of adult trees takes place in agroforestry systems. For both locations surveyed in South Africa, gender ratios were only marginally skewed with similar densities between genders, suggesting that pollination flows should not be adversely affected by the imbalance in the frequencies of male to female individuals, assuming key pollinators remain sufficiently active and the gender ratio of trees in the population does not become further biased (Van Drunen & Dorken, 2012).

Differences in gender ratios between locations were significant, with the most noteworthy distinction being the male dominated population in Bushbuckridge compared to the female dominated population in Phalaborwa. While Fisher's 1:1 ratio is anticipated in most contexts in which dioecious trees exist, slightly skewed male dominated populations often manifest due to the reproductive cost born by female individuals (Boecklen & Hoffman, 1993; Verdu & Garcia-Fayos, 1998; Verdu, 2004). Due to female trees allocating more energy to reproduction and defence, female trees in dioecious species can be compromised in stressful or arid environments, leading to higher mortality rates (Verdu & Garcia-Fayos, 1998; Verdu, 2004). In Bushbuckridge, the reproductive strain placed on the female tree could account for the slightly male dominated population overall. Phalaborwa's population is slightly female skewed, which is unexpected as Phalaborwa would be assumed to have an even more strongly male biased population given the lower rainfall levels, which place female trees under further resource stress. The resultant strain of female reproductive costs should therefore be even more pronounced in this context, so against this expectation, the finding of a female dominated population in Phalaborwa is surprising. Verdu & Garcia-Fayos (1998) tested the preponderance of male individuals of the Mediterranean shrub *Pistacia lentiscus L.* (Anacardiaceae), which belongs to the same family as marula, finding that males were not more common in stressful or xeric (drier) habitats. However, the female dominance in Phalaborwa must therefore be

attributed to other factors, such as human resource use choices. In particular, the chopping of male trees in lieu of female trees is a finding that Shackleton et al. (2003) observed in the Bushbuckridge context more than a decade prior to this study. If excessive felling of male trees occurs, this could result in concerns around pollination flows between genders.

In Phalaborwa, there appears to be a slightly higher economic and cultural value placed on female trees compared to Bushbuckridge. Findings from Chapter 6 and 7 indicate that a higher proportion of respondents in Phalaborwa sell marula produce, as well as engage in certain cultural practices, compared to Bushbuckridge. This has possibly resulted in a higher value being placed on female trees as the all important fruit producers, with male trees therefore more likely to be removed or cut for fuelwood in this context. Shackleton et al. (2003) found that only female trees with undesirable traits (such as bad tasting fruit) are usually cut or removed, which results in a form of selection or domestication taking place. The result is that when comparing land-uses, yard trees are usually identified as having the most desirable qualities, specifically in terms of factors such as fruit size and quality (Shackleton & Shackleton, 2005). While this does not mean that marula is not important culturally in Bushbuckridge, potentially the cultural value ascribed in this context is not enough to protect the species from exploitation under heightened conditions of fuelwood shortages. In contrast, the economic value in Phalaborwa is possibly enough incentive to forgo the short-term benefits of cutting for wood.

4.4.1.2 Similarities between female and male densities between locations

Considering that human alteration of savanna systems impacts both woody vegetation composition as well as structure, it is interesting to note where gender densities vary by land-use type. Female mean density in Phalaborwa yards was very similar to female mean density in Bushbuckridge yards. This speaks to the pervasive value of marula as a natural resource, which has led to uniformity in terms of its utilisation within yards, even across different geographical regions.

Male mean densities were only marginally higher in Bushbuckridge yards, compared to Phalaborwa. Male densities in both contexts were also lower than their female counterparts by a similar margin. Due to the economic value of the fruit, it is understandable that non-fruiting male trees are deemed less valuable. Despite the geographical differences, female densities were almost identical in yards across both contexts. Female trees maintain an associated higher financial capital value in Phalaborwa with the proximity of the processing plant, potentially explaining why female densities are almost the same as in Bushbuckridge, despite the lower rainfall in this location. This finding speaks to the value of the female tree, not only culturally (higher social capital) but also economically (financial capital), which has led to this particular category of marula being conserved and cared for to the extent that there are similar densities in two quite different geographical locations. This is noteworthy, especially considering that Phalaborwa is an area with lower densities across the categories due to lower water availability when compared to Bushbuckridge. The socio-economic dynamics contributing to this outcome are discussed in more detail in Chapters 6 and 7, which interrogate the economic and cultural value of marula.

Sunderland et al. (2017) highlight the intersection between human activity and the conversion of savanna systems, which is adeptly illustrated by increases in female density being linked to land-use practices in yards. The overall homestead yard area surveyed in Phalaborwa was 20.69 ha, which equates to an average yard size of 0.172 ha (120 homestead yards), or a total of 5.8

homestead yards per hectare. Across this area, there were 111 female trees, meaning there are approximately 0.93 female trees per yard. Essentially, this means there was approximately one female tree per yard in Phalaborwa. There were 65 male trees in the same area, which equates to 0.54 male trees per homestead yard, half the number of female trees for the same area. In Bushbuckridge, yard areas were larger, with 31.37 ha overall, equating to an average yard size of 0.261ha (120 homestead yards) or a total of 3.8 homestead yards per hectare. Across this area, there were 142 female trees and 108 male trees, meaning there were 1.18 female trees and 0.90 male trees per yard. This means that not only are there more female trees per yard (albeit larger yards) in Bushbuckridge compared to Phalaborwa, but that male and female tree numbers are very similar in Bushbuckridge. This may support the supposition that marula trees are valued more for their economic worth in Phalaborwa, with Chapter 6 indicating higher levels of marula produce sales occurring in Phalaborwa in comparison to Bushbuckridge. The possible outcome of this economic worth is that the fruiting female tree is protected to a greater extent in yards in Phalaborwa.

In contrast, lower produce sales and more even gender ratios in Bushbuckridge may support the supposition of a higher cultural, as opposed to economic value, in this context (Chapter 7). This result is likely as a consequence of both genders being utilised in yards for cultural ceremonies, as highlighted by Shackleton & Shackleton (2005), explaining the similarity between gender numbers. The cultural value and social importance of the tree are discussed in more detail in Chapter 7. This is in contrast to Phalaborwa where without the added economic value of the fruit, removal of male marula trees is more likely to occur before their female counterparts, with female trees only being removed where neither cultural nor economic values are prioritised. Shackleton et al. (2003) confirm that female trees are usually only felled where the fruit is considered undesirable. In both contexts, male densities are higher in fields and rangelands compared to yards. This trend suggests that while the combined economic and cultural value of female marula trees results in their preservation in yards, in rangelands the female tree may be overharvested for produce such as fruit and bark, resulting in overall numbers being adversely affected. These findings are important for two reasons, the first being that over time, extensive gender imbalances can lead to decreased pollination, which can negatively impact the species from a reproductive perspective. Secondly, the overharvesting of female trees for fruit in rangelands results in reduced fruit availability, in turn impacting seedling numbers and recruitment (Chapter 5).

4.4.2 Not in my backyard: the influence of land-use and settlement on gender ratios and density

Gender ratios across the different land-use types (yards, fields and rangelands) in Phalaborwa and Bushbuckridge differed significantly. This was not repeated in the density findings, with only yards showing a significant difference in Phalaborwa, while yards and rangelands differed significantly in Bushbuckridge. Interestingly, female density was only higher than males in yards, with male density being higher in both fields and rangelands in both locations. This pattern was echoed in the gender ratios, which were most skewed in yards, with these populations being female dominated, likely due to the preference given by community members to the female tree as the fruit producer. Shackleton et al. (2003) found that trees in yards were not only nurtured but also specifically selected for desirable traits associated with the fruit. Male trees are thus more likely to be removed from yards. In contrast, rangelands displayed male dominated populations, with compounded resource pressure and the overutilisation of the female tree for resources such as fruit and bark, possibly contributing to the biased ratios. Due

to the open access context associated with rangelands, common property multi-use tree species such as marula are likely to be heavily impacted, especially the female trees, which are utilised for multiple resources simultaneously. Gaoue & Ticktin (2007) found that in multi-use tree species, the larger size classes tend to be harvested more and in higher proportions. The impacts of these harvesting choices on size-class distributions were discussed further in Chapter 3. In addition, female marula trees are the most prolific seed source, suggesting that higher yields may result in higher levels of utilisation, ultimately impacting the longevity of the not only larger, but especially larger female marula trees (Nghitoolwa et al., 2003). The perception, due to the higher yields, is that the resource is suitably abundant, so all the available fruit under and even on the tree, can therefore be collected without causing any damage or harm to the resource. The result of this overutilisation is what Verdu & Garcia-Fayos (1998) and Wheelright & Logan (2004) refer to as spatial segregation of the sexes (SSS), where females suffer higher mortalities in stressful habitats (such as overharvesting of a communal resource), resulting in greater distances between individuals of the different genders. The concern with this segregation over time, is a reduction in pollen loads and thus reproductive success. Van Drunen & Dorken (2012) explain how this segregation impacts reproduction directly in contexts where individuals are spaced further apart than allows for successful pollination by key pollinators. The male bias in rangelands may therefore be the result of a combination of the effects of the reproductive strain carried by female trees, further exacerbated by the extent of resource harvesting practices, especially as rangeland trees are perceived to be an abundant common property resource in these open access systems.

In Phalaborwa, yards and fields were both female biased, although only yards displayed a higher mean density of females. Rangelands demonstrated a more balanced male to female ratio, although slightly male biased and with higher male densities overall. This suggests the establishment of an anthropogenic linked gender ratio gradient across the landscape, with human interference being most profound in yards and fields, the most human modified of the three land-uses. This has resulted in higher female numbers across these land-use type, but particularly yards where females are clearly favoured for fruit production. This finding was confirmed by the density data, with density gradients being noted, including the highest female densities in yards, a conclusion which was also reached by Shackleton (2002). In yards or fields, people are more likely to remove a male tree before a female tree due to the higher economic and cultural value placed on the fruit. Shackleton et al. (2003) highlight how despite traditional authority prohibitions against felling fruit trees, with the erosion of customary law, trees are increasingly being felled and in particular the male marula tree. Government extension officers actively encouraged the cutting of male trees previously, failing to understand the important role of the male tree within these ecosystems (Shackleton et al., 2003). The ecological implication of this legacy almost two decades later are the continued cutting of male trees by communities, under the misconception that they are ecologically redundant and that female trees will fruit without male trees being present in the population (Shackleton et al., 2003). In addition to the need for male trees in order to pollinate female individuals, male trees also play an important role in the provision of ecosystem services as well as providing agroforestry related benefits.

As with Phalaborwa, yards in Bushbuckridge were female dominated and with higher female densities, suggesting that at least in yards, females are being conserved due to their cultural and economic value. The dominance of females in yards, but not fields in Bushbuckridge, could

indicate a degree of cultural conservation is taking place. Duvall (2007) noted that baobab trees were more prolific in villages in West Africa where a baobab culture existed. Venter and Witkowski (2010) compared this finding to sites in the South African context where this underlying culture was deemed to be lacking. A similar situation exists regarding marula, where trees in yards are nurtured due to a marula culture. However, this culture of marula is premised on a combination of cultural and economic values in the South African context (Shackleton & Shackleton, 2005). This is based on the presumption that if the trees were conserved purely for their economic value, there would be female dominated populations in fields as well, as these trees would be considered too valuable to chop down. However, it is mainly trees in yards that are used for cultural ceremonies (Chapter 7), suggesting that female prevalence in this context alone is more likely a result of the combined economic, as well as cultural value of the tree, across this particular land-use type. Furthermore, this finding would suggest that one without the other might result in diminished instances of conservation, as have been observed elsewhere. Luoga et al. (2000) observed a similar trend with subsp. *caffra* in Tanzania (East Africa), where trees were previously revered in cultural worship and as a result, were not harvested. However, with the breakdown of customary practices, the instances of commercialisation of the tree for timber and handcrafts increased, resulting in reduced conservation of the species.

In Benin (West Africa), Gouwakinnou et al. (2011) found that human impacts are directly responsibly for shaping population gender ratios in agroforestry systems, with local perceptions of dioeciousness as the most important factor determining which trees farmers actively elect to remove from fields. However, where knowledge pertaining to marula (subsp. *birrea*) dioeciousness is lacking, trees of either gender are more likely to be removed. This lack of knowledge was directly attributed to low levels of fruit exploitation as well as communities not fully realising the commercialisation potential of resources in the region (Gouwakinnou et al., 2009). Without the necessary supply chains in place, the demand for the fruit in commercial products is lower and thus demand for the resource is lower. Furthermore, subsp. *birrea* is utilised in Benin for mainly medicinal purposes, with no particular cultural or ritual practices associated with this marula subspecies (Gouwakinnou et al., 2011). Not only is subsp. *caffra* in South Africa valued culturally, but almost the full economic potential of the female marula tree can be realised without the actual tree being felled. This combination of factors means the combined socio-economic importance of marula produces a value nexus, which results in species conservation.

Comparing yards with fields in Phalaborwa, the ratio of males to females was more skewed in yards compared to fields, with almost similar densities in fields, suggesting that male trees are tolerated less in yards. In agroforestry systems, trees smaller than 40 cm in base stem diameter are usually tolerated (Nghitoolwa et al., 2003). However, these trees are removed after this stage if found to be male, possibly before they become too large and difficult to remove after the fact. The fact that yards have the most disproportionate gender ratio as well as densities is concerning, as it confirms that male trees are targeted for felling when space is required, either to extend current buildings or in order to build new structures (Chapter 7). As the most human modified land-use type, it would be anticipated that cultivated fields, might display higher female to male ratios (Gouwakinnou et al., 2011). This is based on the assumption that a male tree would be selected before a female individual when issues such as competition for resources, or desired use of mechanical equipment become a concern (Nghitoolwa et al. 2003).

Fields in Phalaborwa were female biased, although this was only slight due to the similarities in density. Linked to low rainfall, agricultural activity is likely lower in Phalaborwa due to limited water availability, possibly indicating lower levels of field utilisation within this context and therefore fewer instances of male trees being removed in favour of agricultural pursuits. Interestingly, fields in Bushbuckridge were male dominated, in contrast to the female dominated fields in Phalaborwa. The male dominance in Bushbuckridge fields was only slight and is therefore more likely a result of the natural male biased populations that occur due to the dioecious nature of marula trees. The gender ratios were more similar in the field context, compared to rangelands where female numbers were more notably lower than males, likely suggesting human overutilisation is more of a factor in rangelands. Lower female densities in rangelands in both locations confirms this finding. In addition to female biased populations, Phalaborwa fields also had higher levels of mortality than Bushbuckridge fields, suggesting that dead trees could be male, which is particularly marked in the rural field context with an anomaly in terms of dead trees. However, fields sampled in Mbaula village may have previously been rangeland that had specifically been cleared to convert to fields, as this level of mortality was not found in any of the other seven villages surveyed. This would also account for larger field sizes in the Phalaborwa context, as these were possibly previously rangeland, which has been demarcated and fenced to form fields. When comparing land-use types between locations for mortality ratios, it is thus unsurprising that fields between locations demonstrated a significant difference.

Comparing the three land-use types in terms of gender bias between Phalaborwa and Bushbuckridge, rangeland is the land-use type that is significantly different between the two locations. In Phalaborwa rangelands, similar gender ratios would support Fisher's Principle of a 1:1 ratio, suggesting that no discretion is applied in terms of which gender is utilised for fuelwood harvesting. In contrast, Bushbuckridge displayed an extreme male bias in rangelands. The male bias in rangelands could be due to the dioecious nature of the species. However, this bias could also indicate that female trees are potentially being over-utilised. After yards, which showed the greatest differences in density, with females much higher than males, rangelands were the second most dissimilar, with males higher than females. Female trees in rangelands are utilised for a combination of fuelwood and fruit harvesting, with harvesting practices such as chopping branches to obtain wood or green fruit, possibly impacting the longevity of trees. Shackleton (2004) found that marula beer makers at the time of the study preferred green fruit, as this allowed for ideal fruit ripeness to be selected. Removing green fruit from the tree would usually entail cutting a branch or shaking a tree, actions which may ultimately affect longevity. These behaviours could be especially destructive considering that marula beer is currently widely made and sold across Bushbuckridge, suggesting this practice may be commonplace. Destructive harvesting practices negatively impact multi-use natural resources (Djossa et al., 2008), with the compounded implications of anthropogenic and environmental threats such as drought, further increasing the likelihood of mortality (Nghitoolwa et al., 2003).

Examining settlement types in Phalaborwa, both peri-urban and rural yards and fields are female dominated, whereas peri-urban yards in Bushbuckridge displayed an almost 1:1 ratio with only rural yards being female dominated. In Phalaborwa, peri-urban land-use types displayed higher female densities, while in Bushbuckridge, this trend was not apparent. In terms of Bushbuckridge fields, rural fields were female dominated but peri-urban fields were male dominated. These differences in ratios in a single location once again suggest that human

resource choices are likely responsible for the gender dominance of the populations. These findings suggest a slight bias towards female trees in rural contexts, possibly due to a combination of increased levels of cultural practices and traditions as well as higher levels of traditional authority governing these practices in the rural setting. In rangelands, all but rural Phalaborwa rangelands were male dominated, confirming once again that the dominance of female trees appears only in the more human modified contexts of yards and fields. However, female dominance in rural rangelands in Phalaborwa indicates an overwhelming prioritisation of female trees not only at this location but also in the rural context, most likely for a combination of cultural as well as economic reasons. While the extent of female biased populations in Phalaborwa might hint at cultural conservation of marula trees, the reality is that for every instance of a female tree being protected, there is a strong likelihood that a male tree is being removed from the population.

4.5 Conclusion

Gender ratios and differences in density across land-use types provide key insights into human resource utilisation choices. Homestead yard populations are female biased with higher female densities due to preference for female trees, which have heightened cultural as well as economic value in this context. While cultural conservation may take place in yards, the likely overutilisation of female trees as an open access resource and source of both fruit and bark, may be negatively impacting genders in the open rangelands, leading to male biased populations and higher male densities in this context. While male dominated populations are anticipated in dioecious species (Boecklen & Hoffman, 1993; Verdu, 2004), the additional strain of harvesting practices is likely exacerbating this bias by causing higher mortality in female individuals in rangelands. However, due to differences in resource use and practices across the different land-use types, differences in density alternate across the landscape, resulting in alternating male and female biased populations by land-use type. The result is overall similar densities and only slightly skewed populations. Due to the proximity of these difference land-use types, there is no segregation of the species at a population level, meaning pollen flows are not affected by local resource practices at present.

The key lessons from these findings are around the interconnections between human resource use and ecological impacts in non-conservation areas in terms of gender ratios and density. Future research initiatives that aim to understand the ecological impacts of marula resource utilisation will be fortified by interdisciplinary approaches that combine methodological approaches. Despite heavy utilisation of marula, the slightly skewed ratios across land-use types would suggest that the population structure is stable from the perspective of pollination, specifically based on sufficient ratios between individuals. In addition, user preferences towards the female tree for fruit and bark removal do not appear to be negatively impacting population structure at present (Chapter 3). It remains unclear based on current evidence regarding marula mortality if ratios are a cause for concern, with potentially larger scale chopping and tree removal occurring for fuelwood markets than is indicated by residual evidence (Chapter 3). While mortality ratios may not signify cause for concern, indications around current fuelwood use would suggest otherwise. Longer-term research initiatives where trees are tagged and checked over extended periods are recommended to address issues of tree removal from the population due to chopping.

5. Juvenile to Giant: The Impacts of Land-use Practices on Marula Recruitment and Population Structures in Non-Conservation Areas

5.1 Introduction

The harvesting of Non-Timber Forest Products (NTFPs), such as fruit, wood and bark from savanna tree species may have a variety of ecological consequences. The implications of overharvesting include altered rates of survival, growth and reproduction for the harvested individuals (Gaoue & Ticktin, 2007). Overharvesting tends to occur in contexts where there are high human densities, combined with limited natural resources (Shackleton et al., 2002; Shackleton et al., 2005). With accelerated biodiversity loss across the globe compounded by a changing climate, there is a growing need for large-scale NTFPs studies that directly examine how anthropogenic disturbance impacts specific tree species (Shackleton, 2001; Madubansi & Shackleton, 2007). Numerous NTFP studies have examined the socio-economic impacts of natural resource use on various user groups relying upon these resources for livelihood sustenance (Heubach et al, 2011; Pandey et al., 2016; Mugido & Shackleton, 2017). However, there are fewer studies that have focussed on these resource impacts in relation to multi-use tree species such as marula (*Sclerocarya birrea* subsp. *caffra*).

It is important to understand how different land-use impacts affect multi-use species, which are harvested for a variety of resources including fruit, bark, leaves and wood. This is necessary in order to understand how to secure future sustainability of the species, including under a variable climate (Gaoue & Ticktin, 2007; Klimas, 2007). Gaoue & Ticktin (2007) found that in multi-use tree species, the larger size classes tend to be harvested more and in higher proportions for wood, resulting in implications for the population structure, as larger individuals are a prolific seed source (Nghitoolwa et al., 2003). Shackleton (2005) found the same outcome in relation to marula fuelwood harvesting in Bushbuckridge (Mpumalanga lowveld, South Africa), with uniform harvesting in communal rangelands suggesting extensive resource pressure, even with increases in distance from villages. However, harvesting practices that impact germination and recruitment, such as fruit collection, also have key impacts on population regeneration and require greater understanding (Venter & Witkowski, 2013). While impacts on recruitment directly affect the initial life stages of species such as marula, resource practices in relation to larger individuals across different land-use types determine the population profile at the other end of the life stage spectrum. Understanding the influences and impacts of land-use practices on all life stages of a species ensure that key challenges to the overall sustainability of the species are understood, specifically in terms of resource use across different land-use types. It is for these reasons that examining the impacts of land-use practices on the densities and ratios of different life stages of the marula population, are a crucial step for determining where the population is potentially vulnerable or stable throughout the landscape.

5.1.1 Marula population structures in conservation areas

5.1.1.1 How germination and recruitment bottlenecks impact marula populations

Understanding demographic changes requires focussing on life stages of the population from recruitment and transitions through to mortality. Two of the most important drivers of woody plant dynamics in savannas are fire and herbivory, both singly, as well as their interactions (Staver et al., 2009; Midgley et al., 2010). Helm & Witkowski (2012) completed extensive work examining the impacts of various biotic and abiotic factors on population structures of marula populations in the Kruger National Park (KNP). Using the approach specified by Condit et al. (1998), Lykke (1998) and Obiri et al. (2002), Helm & Witkowski (2012) identified four population structures for marula in the KNP: the first were adult-dominated with a positive slope and very few individuals in smaller classes, indicating a lack of recruitment while the second were juvenile-dominated populations with more individuals in smaller size classes and a negative slope indicating good recruitment (Condit et al., 1998; Lykke, 1998; Obiri et al., 2002). The third group were healthy recruiting populations as indicated by an inverse 'J-shaped' curve and a flat or slightly negative slope (O'Connor & Goodall, 2017). The final group displayed missing size classes in the 5-9 cm and 14-20 cm stem diameter classes and a bi-modal distribution (Helm & Witkowski, 2012).

Helm & Witkowski (2012) explain that marula populations exhibit the inverse 'J-shaped' curve of a healthy population when elephants (*Loxodonta africana*) are not present, meaning that marula populations without disturbance maintain a stable structure. However, in the presence of elephants, combined with frequent fire and intensive herbivory, marula populations in KNP display unstable, non-recruiting SCDs (Helm & Witkowski, 2012; O'Connor & Goodall, 2017). Elephant–fire synergy also specifically demonstrates increased mortality in large trees (Moncrieff et al., 2008; Helm, 2011). O'Connor & Goodall (2017) concur that multiple states of established individuals suggest temporally varying regeneration and recruitment, based on marula populations in Venetia-Limpopo Nature Reserve, South Africa. In addition to this, missing size classes are likely attributable to a combination of elephant impact and fire suppression of juveniles, with juvenile-dominated populations being linked to elephant destruction of larger individuals. Fire and herbivory interactions are also important due to the fact that their combined impact can act as a strong limitation to recruitment, resulting in a lethal combination for woody plant recruitment and transitions between size classes (Helm et al., 2011). However, in some cases, herbivory alone, notably by elephant and impala, can be more of a limiting factor than fire (Midgley et al., 2010).

Germination of marula seeds is more likely to occur within a specific climatic envelope, with ideal temperatures ranging between 27-37 °C (Murye & Pelser, 2018). In addition to this, marula seeds do not germinate readily when dropped from the canopy, instead remaining quiescent for more than 6 months in a transient seed bank in the soil below the parent tree, until the opercula surrounding the seeds has decomposed (Helm et al. 2011). Recruitment bottlenecks can occur due to the operculum restricting germination (von Teichman et al. 1986). This dormancy ensures that the seeds only germinate under favourable conditions, such as when there is sufficient rain the following season. Marula have larger seeds, which confer great advantages in the regeneration niche, including better dormancy as well as faster growing seedlings which are better competitors. In addition, since marulas are fairly long lived, they can rely on the storage effect to survive periods of poor recruitment. In conservation areas, the factors that break dormancy include fruit removal, burial, and notably, elephant feeding.

Germination is improved through mammal consumption, which has the dual role of removing the opercula covering the seeds, allowing germination in the same season in which the seed was produced, while also aiding in the dispersal of the seeds away from the parent tree (Djossa et al., 2008; Midgley et al., 2010). Mammalian ingestion specifically speeds up germination due to acid digestion (Lewis, 1987). Marula seedlings are found to be far less dispersed in the communal rangelands of non-conservation areas, due to a lack of diverse mammal dispersal agents such as elephants and baboons. This deficit in dispersal agents can result in up to 25% of the seedlings being located beneath the parent tree in these contexts (Helm et al., 2011). Due to the clustering effect of seedlings under the parent tree in non-conservation area, these individuals are often removed in yards or fields where they are perceived to be numerous and thus taking up valuable space which could be used for other purposes (Paumgarten et al., 2005).

Recruitment can often be considered a bottleneck, because resprouting is generally considered a trade-off against recruitment (Bond and Midgley 2001). While the demography of each species is unique, given the prevalence of resprouting in species such as marula, this is a key cause of recruitment bottlenecks and affects the transition of juveniles to fire-proof or herbivore-proof size classes (Higgins et al. 2000; Midgley and Bond 2001; Bond 2008). Survival and growth at the seedling stage presents a major bottleneck in the recruitment of woody species (Sanchez-Gomez et al. 2006). This includes how marula saplings survive and out-grow this damage, mainly through height, but also barks thickness and diameter growth to a certain degree (Midgley et al., 2010). Height enables escape from the browse-trap, which would otherwise result in recruitment bottlenecks through heavy herbivory of seedlings by species such as impala, acting as a limiting factor to both recruitment and transitions into higher size classes (Staver & Bond, 2014). Escaping the so-called fire-trap requires juveniles to reach an 'escape height' of typically 2–3m in order to avoid top-kill (Higgins et al. 2000). Marula trees are resistant to fire from 7 cm stem diameter (2.75 m height), which is also the minimum diameter for reproduction (Jacobs & Biggs, 2001; Helm et al., 2011). Escaping the browse-trap or release from browsing results in increases in tree sizes (Staver & Bond, 2014). It is for these reasons that the slopes of size-class (stem diameter) distributions are considered to be a good indicator of population structure at a specific point in time (Condit et al., 1998; Lykke, 1998; Obiri et al., 2000).

Seedling regeneration in marula under various conditions may actually be continuous and not episodic, as previously thought (Jacobs & Biggs, 2002). However, fewer juveniles in a population are not always indicative of a declining population. This is because relatively fast growing larger tree species, such as marula, tend to have fewer small individuals than slower growing species (Helm, 2011). In terms of population structure, this means that while small trees make up a lower percentage of the overall population of fast growers, they still constitute the most numerous in terms of their individual size classes (Lykke, 1998). Adult-dominated populations are indicative of a prior recruitment event, followed by seedling predation, which affects on-going recruitment (Helm & Witkowski, 2012). These authors predict that high adult numbers support a lack of recent recruitment, which could lead to population decline if episodic recruitment does not occur to prevent this bottleneck at the seedling level

While size classes alone are not considered to be an adequate predictor of future population trends, combined with demographic data, it is possible to gain an in-depth understanding of current and future population dynamics (Condit et al., 1998). Higher numbers of juveniles can be a strong predictor of future size-class distributions, specifically where these juveniles have

higher survival percentages and faster growth rates, resulting in steeper SCD slopes indicative of population growth (Lykke, 1998). In relation to marula specifically, disturbance also has an impact on fruit production, with only trees with larger stem diameters producing fruit at more disturbed sites, compared to smaller individuals at less disturbed sites (Helm et al., 2011). Helm et al. (2011) found that marula has a small, persistent seed bank but that recruitment is heavily reliant on the current season's fruit crop.

Water stress is another key factor leading to seedling mortality and is considered more detrimental than burning, although water stress and fire combined result in the highest cases of mortality (Midgley et al., 2010). It is therefore important to understand the plight of seedlings and saplings within complex socio-ecological systems (SES), such as non-conservation areas of the lowveld. In order to understand the implications of population structures, it is essential to examine both recruitment as well as large tree senescence simultaneously, which together provide insights into the causes of both population regeneration as well as mortality.

5.1.1.2 Large marula trees, age and senescence impacts

The inverse 'J-shaped' structure attributed to a healthy population should not be expected of all savanna tree species, specifically those in arid or semi-arid conditions, due to pulsed regeneration, recruitment and mortality (O'Connor & Goodall, 2017). Resprouting is generally considered a trade-off against recruitment, with many species that rely on resprouting therefore displaying a non-recruiting SCD profile (Bond and Midgley 2001). Even under low fire, herbivore and harvesting pressure, the stability of woody populations is a rare outcome, particularly in environments that are characterised by large climatic variations (Shackleton, 1993a). However, herbivores and fire combined are able to kill much larger trees than either could individually (Helm, 2011). Understanding the combined impacts of these factors is key for determining long-term survival rates.

Due to the instability of woody populations in environments characterised by large climatic variations, climate is therefore a key factor in understanding population structures in savanna landscapes (Shackleton, 1993a). This pertains to both wild (conservation area and communal rangeland trees) as well as more domestic (yard and field) marula populations, in particular how lowered rainfall affects large trees. Combined with natural vegetation changes, inter-annual climate variability and disturbances are key factors in affecting and shaping sub-tropical savanna ecosystems (Zeng & Neelin, 2000). Marula (subsp. *caffra*) growth rates were assessed in plots in Malawi (south-east Africa) that received water, fertiliser and compost and compared to plots that received no additional inputs (Akinnifesi et al., 2008). Interestingly, the slowest growth rates were in plots that received all three inputs, followed by plots with irrigation but no fertiliser or compost, while the fastest growth rates were in plots that received nothing. These findings suggest that marula has adapted to infertile soil and unimodal rainfall regimes, unlike mango *(Mangifera indica)* which is also a member of the Anacardiaceae family (like marula) and which flourished with the addition of compost, fertiliser and irrigation (Akinnifesi et al., 2008). This study highlights the importance of examining intersecting edaphic, climatic and management variables when examining savanna indigenous fruit trees such as marula. Climate has a direct impact on larger and thus older trees, with trees in the semi-arid savannas of the lowveld region being at the limit of their rainfall distribution. These trees are therefore expected to experience greater mortality and less regeneration, specifically with the increased frequency and severity of droughts in the region (O'Connor & Goodall, 2017). Helm & Witkowski (2012) expressly state that natural senescence of large trees requires further investigation and

understanding. In addition, Helm (2009) found that a reproductively mature marula tree of 14 cm in stem diameter (44 cm circumference) would be approximately 59 years old, confirming that the larger trees in KNP of 80 cm diameter and above are likely in excess of ~300 years of age. The fact that marula trees have shallow but wide spreading root systems indicates that soil moisture content, and therefore the spatio-temporal nature of rainfall, affects growth potential in marula (Helm, 2011). Considering that larger marula trees may be older than previously thought, it is necessary to gauge if these individuals will be able to withstand further long-term climatic variation in the lowveld region.

Prolonged drought, which leads to the mortality of large trees, is of concern, especially as these trees are often the most prolific seed sources of their respective species (Nghitoolwa et al., 2003; Patrut et al., 2018). The issue of disappearing large tree species and senescing savanna parklands, due to a combination of anthropogenic factors and climate change, is a key issue in the Sahel region of Africa (Maranz, 2009). Savanna parkland areas are ecosystems shaped by human activity, suggesting that edible fruit tree species were likely introduced during higher rainfall periods in the region. As these trees are anthropogenically distributed, when the climate shifts, they are left stranded below their rainfall tolerance limits (Maranz, 2009). Increased densities of marula trees in the 30-50 cm size class in KNP are likely from prior human settlements located in the area, indicating the pervasive impact of human settlements on savanna landscapes (Helm & Witkowski, 2012). A widely referenced study by Shone (1979) found that the felling of large marula trees took place in the lowveld during the 1950s in order to make wooden toilet-seat covers, which may have removed numerous key, older individuals from the population at the time.

Marula trees in conservation areas that contain elephant populations are at risk of local extirpation due to high levels of utilisation of large adults, as well as failed regeneration due to seedlings being targeted by other browsers. While there may be regeneration, this usually remains supressed by fire and herbivory. In addition, both these drivers of population structure are compounded by these trees being at the limit of their rainfall distribution (Helm & Witkowski, 2012; O'Connor & Goodall, 2017). This rainfall limit could mean that any further climatic changes would have negative consequences for trees that are already over-utilised by either elephants or humans. It is therefore critical to combine understandings of the long-term implications of human impact on size-class distributions in non-conservation areas, with the impacts on germination and older individuals in the population.

5.1.2 Marula regeneration and large tree impacts in non-conservation areas

Elephants are largely responsible for shaping marula population structures in conservation areas where marula trees and elephants co-exist. In non-conservation areas it is human harvesting and land-use practices (both stewardship as well as destructive practices) that affect population structure. Large trees are often removed in agroforestry systems in order to reduce competition for light and water, as well as to make space for the use of mechanical equipment (Nghitoolwa et al., 2003). Unlike elephants, which target mainly larger trees, humans tend to utilise a range of sizes for different purposes (Helm et al., 2011).

In Benin (West Africa), the population structure for the shea tree (*Vitellaria paradoxa*), a socio-economically important tree in the region, was compared across farmed land and protected areas (Djossa et al., 2008). The farmed areas incorporated an indigenous parkland farming system where cultivation occurred around preserved trees, similar to the agroforestry systems

in which marula trees grow in South African fields (Shackleton, 2002; Djossa et al., 2008). The authors found that farming activities increased recruitment and that adult trees were conserved, resulting in the tallest and largest trees being located in farmed lands (Djossa et al. 2008). In a separate study by Byakagaba et al. (2011), shea populations were compared across different field types, using density and SCD to describe population structures. Findings indicated that population structure and regeneration were influenced by land management regimes, with more stable populations and higher regeneration in recently fallow fields, compared to old fallow fields or current fields (Byakagaba et al., 2011). Saplings were also negatively affected by farming activities, with Gouwakinnou et al. (2009) finding saplings to be almost entirely absent from agroforestry systems in Benin. This lack of recruits is likely to affect the viability of the population long-term, especially in relation to the mature adults of longer lived species (200-300 years) such as marula trees, meaning that the recruitment gap is not immediately obvious (Djossa et al., 2008). As with marula seedlings in anthropogenic landscapes, the majority of shea tree seedlings were located underneath adult parent trees (Shackleton, 2002; Djossa et al., 2008). This lack of dispersal is often analysed in terms of the Janzen-Connell model, whereby seedlings under parent trees are considered to be at risk from predators and pathogens of the parent tree (Djossa et al., 2008). However, in relation to marula, this is reduced to a large degree by collection and thus dispersal by human agents in anthropogenic landscapes. This means the Janzen-Connell model applies to a lesser extent where either the main adult pathogens do not affect juveniles, or where the seeds (fruit) are collected, extracted and discarded when produce is made from the fruit. This is due to these practices allowing the seeds to germinate where they have been dispersed (Djossa et al., 2008).

Human resource use choices and population structure impacts were also the focus of a study examining the regeneration of *S.birrea* subsp*. birrea* across different land-use types in Benin (West Africa). This study found that the population structure differed significantly by land-use type (Gouwakinnou et al., 2009). Adult densities were higher in conservation as opposed to agroforestry areas, although seed germination was favoured within the latter. In addition to this, the largest adults were located in agroforestry systems but saplings were absent (Gouwakinnou et al., 2009). The authors attributed bulk germination events within agroforestry systems to the greater levels of fruit production, with excess fruit falling to the ground and being buried during farming activities. However, to reduce competition, farmers remove seedlings, leading to a gap in seedling to adult transition in the population (Gouwakinnou et al., 2009). In addition to this, farmers also tend to ring-bark or fell large adult trees as the shade is considered a hindrance to crop development. The number of large individuals in the population (over 100 cm in stem diameter) is therefore indicative of an advanced or aging population with few recruits to replace these individuals (Gouwakinnou et al., 2009).

In the Limpopo province of South Africa, Venter and Witkowski (2011) made similar population structure findings in relation to baobabs (*Adansonia digitata*) by linking fruit yield to different harvesting scenarios. The overall finding was that villages and fields had the highest tree densities and highest fruit volumes. These authors compared density, SCDs and population trends between land-use types, discovering that baobab populations did not display the inverse 'J-shaped' distribution of a healthy population. However, this might not be applicable to larger long-lived species, which can sustain their population levels despite low or episodic recruitment (Venter & Witkowski, 2010). Further, a J-shape may not necessarily be expected in arid and semi-arid enviroments. While recruitment did not appear to be limited by seed production,

infrequent rainfall was the major limiting factor, combined with livestock predation of those seedlings that do manage to establish in this context (Venter & Witkowski, 2013). In addition, adult baobabs do not recruit as successfully in these villages. This is the opposite of baobab populations in villages in West Africa, where the fruit is highly utilised and people therefore actively protect seedlings (Duvall, 2007). In addition to protecting seedlings, the Manika-speaking people of West Africa directly disperse the baobab seeds around their villages by collecting large quantities of the fruit and then discarding the seeds, where they are then able to germinate (Duvall, 2007). The authors of the South African study noted that this practice of actively protecting seedlings was based on a 'baobab culture' (Venter & Witkowski, 2010). The conclusion from the South African context was that despite displaying a flat SCD slope, which is indicative of trees that grow rapidly in the small size classes and have high overall survival, the population is likely healthy as it can sustain low or episodic recruitment (Venter & Witkowski, 2010). However, the impact of climate change on baobabs can be devastating, with severe drought likely causing the loss of larger individuals and preventing the establishment of seedlings (Patrut et al., 2018). A key finding pertaining to baobabs is that the rainfall from the previous season likely has a large impact on fruit production (Venter & Witkowski, 2013). With climate models predicting that the natural distribution area for baobabs is likely to get drier and hotter, compounded by increasing livestock pressure, recruitment bottlenecks are likely to only worsen with climate change (Venter & Witkowski, 2013).

Shackleton (2002) came to a similar conclusion regarding recruitment and rainfall for marula in Bushbuckridge, indicating that fruiting is possibly connected to soil moisture, which is based on the previous rainy season. This creates a two-year marula cycle; with rainfall from one year impacting the following season's fruiting. While marula densities are usually also higher in anthropogenic landscapes, with fruit production positively linked to the size of the tree, growth and fruit production rates were found to be low in marula in the study context (Shackleton, 2002). However, as with the baobab culture of West Africa, households in Bushbuckridge tend to not only plant marula seedlings or stem cuttings in their yards or fields, they also allow the seeds to germinate under adult trees. Farmers in both Bushbuckridge (South Africa) and the North Central Region of Namibia, actually tend to select marula trees based on fruit mass, suggesting a level of domestication, with greater tree densities in fields than communal rangelands (Leakey et al., 2005). Furthermore, the selection by communities of trees with high-quality marula fruit in yards can therefore be classified as a form of domestication (Thiong'o et al., 2002).

While agroforestry is practised in Bushbuckridge with many large trees being preserved in fields, it was confirmed that homestead trees had the highest yields (Emanuel et al., 2005). Felling female trees and bark removal were considered the biggest risks to marula populations (Emanuel et al., 2005). Fruit harvesting was considered less of a concern, provided enough fruit is left under the trees to allow for recruitment. The authors advised that 92% of the fruit could be removed without impacting the current population profile (Emanuel et al., 2005). High and Shackleton (2000) compared the use of wild versus domesticated resources across communal rangelands, fields and yards in Bushbuckridge. The finding was that wild plants only provided 31% of the income value in yards, compared to the 69% fulfilled by domesticated varieties, which included fruit trees. The only exception was for marula, which at the time had not been supplanted by domestic varieties. However, mango provided a higher average income across the households surveyed, with 82.3% of households choosing to grow mango, compared to the

40.3% growing marula (High & Shackleton, 2000). These findings indicate that while marula population regeneration and long-term sustainability is susceptible to impacts at the land-use level, populations appeared stable at the time previous studies were conducted in the lowveld context. It is therefore of crucial importance to update these inventories, as the status of marula populations have likely shifted as a combined result of climate, changing land-use patterns, growing human populations and cultural change. When combined, these factors make it necessary to understand anthropogenic impacts on various marula life stages as well as the population's regeneration capacity. Furthermore, in a rapidly changing socio-ecological context, it is important to ascertain to what extent the populations have changed or stayed the same, which might have important implications for long-term sustainability. This chapter assesses anthropogenic impacts on various life stages of the marula population and recruitment across different land-uses in two study areas (Phalaborwa and Bushbuckridge) in the central lowveld of South Africa.

The objectives of this chapter are as follows:

a) To compare the current densities of saplings, adults and large adults across the three land-use types of yards, fields and rangelands as well as by settlement type and how these compare between Phalaborwa and Bushbuckridge.

b) To assess how the overall adult to juvenile and adult to large adult ratios compare between Phalaborwa and Bushbuckridge.

c) To ascertain the current population ratios of adults to juveniles and adults to large adults (>43 cm) across the three land-use types of yards, fields and rangelands.

d) Within and between each location, to explore how successful recruitment is and what demographic changes indicate about current resource utilisation by land-use (yards, fields or rangeland) and settlement (rural & peri-urban) type.

5.2 Methods

5.2.1 Maturity (juvenile, adult and large adult) ratio analyses

Demographic data on adult to juvenile ratios, as well as the proportion of the population consisting of large adults, are indicated in the results. This distinction is based on the division between fruit bearing (adult) and non-fruit bearing (juvenile) individuals with large adults as the greatest fruit producers (Nghitoolwa et al., 2003). This information helps to clarify if marula populations in specific locations, land-use and settlement types are actively recruiting as well as what proportion of the population are aging adults in comparison to overall adult populations. This is important to understand in terms of long-term population regeneration. Following Shackleton et al. (2002) and Helm (2011), any stems >14 cm in basal diameter 30 cm above ground height were considered reproductively mature adults, while stems ≤14 cm were classified as juveniles. Individuals were considered to be large adults where stem diameter exceeded 43 cm (Shackleton et al., 2002). Saplings were all juveniles from 0.5 – 14 cm and seedlings were $\leq$0.5 cm in basal stem diameter.

In order to assess maturity ratios, adult:juvenile as well as the proportion of the overall population that were adults:large adults were compared. Cross-tabulations for maturity (adult:juvenile) as well as for adult:large adult ratios were performed on all the tree data, comparing these ratios by location, land-use and settlement type. Cross-tabulations ($p<0.05$) were performed using Chi-Square Tests for independence with Fisher's Exact Test (including Yates Continuity Correction and Phi Effect Size for tables in a 2 by 2 cross tabulation) and a Pearson's Chi-Square with Cramer's V Effect Size for larger than 2 by 2 cross tabulations. The Cohen (1988) criteria of 0.1=small effect, 0.3=medium effect and 0.5=large effect was then applied to the results. For tables larger than 2 by 2, Cramer's V is used, which takes into account the degree of freedom, but requires additional manual calculations to determine which criteria to use to determine the correlation. This involves subtracting 1 from the number of categories in the row variable (R-1) and then doing the same for the column variable (C-1) and then using the smaller of the two numbers. If R-1 or C-1 is equal to 1 (two categories) then small=0.01, medium=0.30 and large=0.50. If R-1 or C-1 is equal to 2 (three categories) then small=0.07, medium=0.21 and large=0.35. If R-1 or C-1 is equal to 3 (four categories) then small=0.06, medium=0.17 and large=0.29. The effect size is provided with the results in the analyses.

5.2.2 Maturity proportions for the four life stages (seedlings, saplings, adults, large adults)

It is important to note that while seedlings ($\leq$0.5 cm) in conservation areas are usually regarded as not being viable ecologically due to factors such as herbivory and water stress, under certain non-conservation land-use conditions, these individuals may be able to survive due to anthropogenic factors such as watering and fences. These factors result in some of these individuals establishing and recruiting through to adulthood in contexts where the likelihood would otherwise be low. It is for these reasons that seedlings ($\leq$0.5 cm stem diameter) have been included in the maturity comparisons. The first step is to assess the proportions of the population comprising each maturity stage, with the key split being whether an individual is fruit bearing (adult) or non-fruit bearing (juvenile). This distinction has been based on the fruiting status of an individual informing the natural capital and therefore decision making regarding the resource. The second step is to split juveniles into seedlings and saplings and adults into intermediate adults and large adults. These two ends of the continuum (seedlings and large adults) are critical life history stages in terms of recruitment bottlenecks and seed (fruit) productivity. This was done in order to show how each segment contributes to the overall population.

5.2.3 Demographic categories of sapling, adult and large adult densities

Density was calculated as the total number of trees in each land-use unit (individual yards, fields or rangeland transects) divided by the hectare area of that unit in order to obtain trees/ha. Abundant numbers of seedlings in the smallest size class were found in yards where the beer is made and seeds discarded. These seedlings, equal or below 0.5 cm, were removed from the density data set for the purposes of density calculations. This was done to ensure these seedlings did not provide an inaccurate reflection of the current population status, based on trees per hectare calculations, as this category has very different recruitment and survivorship compared to the rest of the size classes due to human removal before establishment.

Comparisons for saplings, adult and large adult densities were made using the Kruskal-Wallis Test, the non-parametric alternative to a one-way between-groups analysis of variance. Comparisons were made between land-use and settlement types, split by location, to compare changes in Phalaborwa and Bushbuckridge respectively, and split by land-use and settlement

types to compare changes between locations. The Kruskal-Wallis Test was selected as it allows for the comparison of medians of the same continuous variable for three or more groups (Pallant, 2007). For all Kruskal-Wallis Tests, a significance level of 5% ($p<0.05$) was used.

In order to ascertain which land-use types were statistically different from each other, Mann-Whitney U-Tests (the non-parametric alternative to the t-test for independent samples) were performed between pairs of groups (yard vs. field/ yard vs. rangelands/ field vs. rangeland) comparing the difference in median ranks. In order to control for Type 1 errors, a Bonferroni adjustment/correction was applied to the alpha value (0.05). A full explanation of how the Bonferroni adjustment/correction was applied can be found under the methodology section for Chapter 3.

The Mann-Whitney U-Test was also used for all other comparisons between two groups (as opposed to three or more as per the Kruskal-Wallis test). For all Mann-Whitney U-Tests, a significance level of 5% ($p<0.05$) was used to establish significance. In addition to this, the effect size for any significant values were calculated manually using the methodology detailed by Pallant (2007) where the effect size (r) equals the z value (z) divided by the square root (√) of the number (n) of cases: ($r = z / \sqrt{n}$). A full explanation of how the effect size and Mann-Whitney U-Tests were applied can be found under the methodology section for Chapter 3.

Finally, the Wilcoxon Signed Ranks Test (the non-parametric alternative to the repeated measures t-test) was used to compare: adult density (>14 cm) vs. sapling density (<14 cm) and adult density (>14 cm) vs. large adult (>43 cm) density.These categories were compared in order to see where they differed significantly by location, land-use and settlement type.

5.3 Results

5.3.1 Marula population structure by location (Phalaborwa and Bushbuckridge)

5.3.1.1 Maturity by location

Comparing Phalaborwa and Bushbuckridge, Phalaborwa had 63.2% (n=944) adults and 36.8% (n=549) juveniles out of a total of 1493 individuals. In Bushbuckridge, the juvenile population was extensive with 76.4% (n=3315) of the population surveyed being juveniles and 23.6% (n=1023) adults. The difference in adult and juvenile numbers between locations was significant and medium (x^2 (1, n=5831)=779.23, $p<0.001$, phi=0.366). This significance is likely as a result of the differences in juvenile numbers, with a higher relative abundance of juveniles in Bushbuckridge, as adult numbers were similar between Phalaborwa (n=944) and Bushbuckridge (n=1023).

In terms of overall juveniles (n=3315) in Bushbuckridge, 57.4% (n=1902) were $\leq$0.5 cm seedlings while 42.6% (n=1413) were saplings, ranging from 0.5 cm to 14 cm in size. In Phalaborwa (n=549), there were more saplings than seedlings, with only 21% (n=115) of juveniles being seedlings and 79% (n=434) saplings. The relative proportion of the population comprising juveniles (seedlings and saplings), compared to the overall adult populations (>14 cm basal diameter), is provided in Figure 5.1.

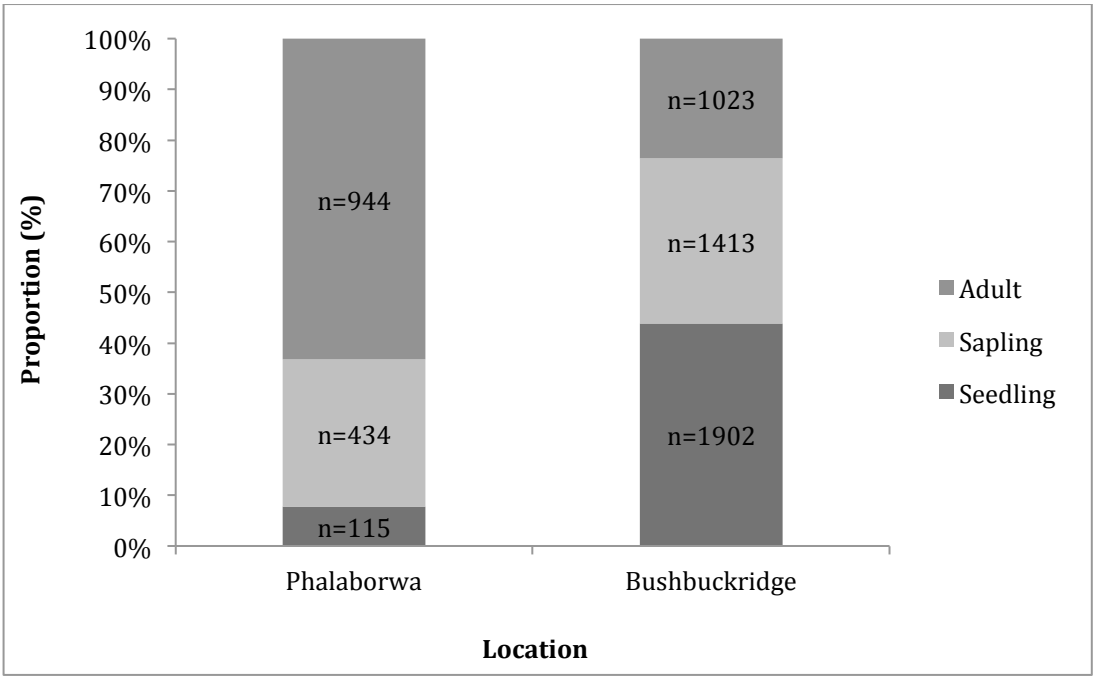


Figure 5.1: Proportion (%) of the population comprising seedlings (≤0.5 cm), saplings (0.5≤14 cm) and all adult individuals (>14 cm) in Phalaborwa (n=1493) and Bushbuckridge (n=4338)

5.3.1.2 Large tree contributions by location

In Phalaborwa, n=539 (36.1%) of the population were classified as large adult trees. In Bushbuckridge, due to the high numbers of juveniles in the overall population, while 457 individuals were classified as large adults, this only constituted 10.5% of the overall population. The difference in the number of large trees between locations was significant but small (x^2 (1, n=5831)=510.82, p<0.001, phi=-0.297).

The contribution of large adults (>43 cm basal stem diameter), intermediate adults (14≤43 cm basal stem diameter) and saplings (0.5≤14 cm basal stem diameter), are compared as relative proportions of the overall population in Figure 5.2.

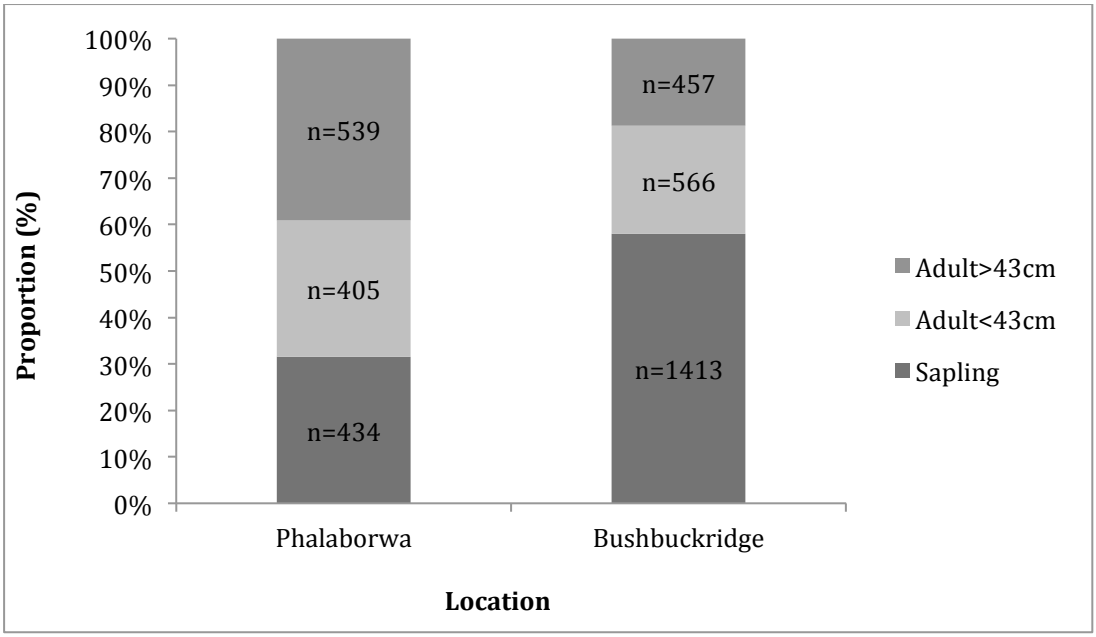


Figure 5.2: Proportion (%) of the marula population comprising saplings (0.5≤14cm stem diameter), intermediate adults (14≤43 cm diameter) and large adult (>43 cm diameter) individuals in Phalaborwa (n=1493) and Bushbuckridge (n=4338)

5.3.2 Marula population structure across land-uses (yards, fields and rangelands)

5.3.2.1 Maturity across land-uses

In Phalaborwa yards there were 62% (n=176) adults and 38% (n=108) juveniles. In fields, adults accounted for 40.4% (n=219) of the population and juveniles 59.6% (n=323), while in rangelands adults comprised 82.3% (n=549) and juveniles 17.7% (n=118). Land-use types in Bushbuckridge showed very different maturity ratios with only 9.5% (n=250) adults and 90.5% (n=2389) juveniles in yards. In contrast, fields displayed 58.8% (n=280) adults and 41.2% (n=196) juveniles; rangelands had 40.3% (n=493) adults and 59.7% (n=730) juveniles. The number of adults relative to juveniles was significant and moderate between land-use types in both Phalaborwa (x^2 (2, n=1493)=226.06, p<0.001, Cramer's V=0.389) and Bushbuckridge (x^2 (2, n=4338)=809.47, p<0.001, Cramer's V=0.432).

These differences were most apparent in the higher proportion of adults in rangelands (and to a lesser degree in yards) in Phalaborwa and the very high contribution of seedlings in yards and rangelands in Bushbuckridge. The number of juveniles (seedlings: ≤0.5 cm basal stem diameter) and saplings: 0.5≤14 cm basal diameter) compared to overall adults (>14 cm basal stem diameter) are provided as a relative proportion of the overall population in Phalaborwa and Bushbuckridge (Figure 5.3).

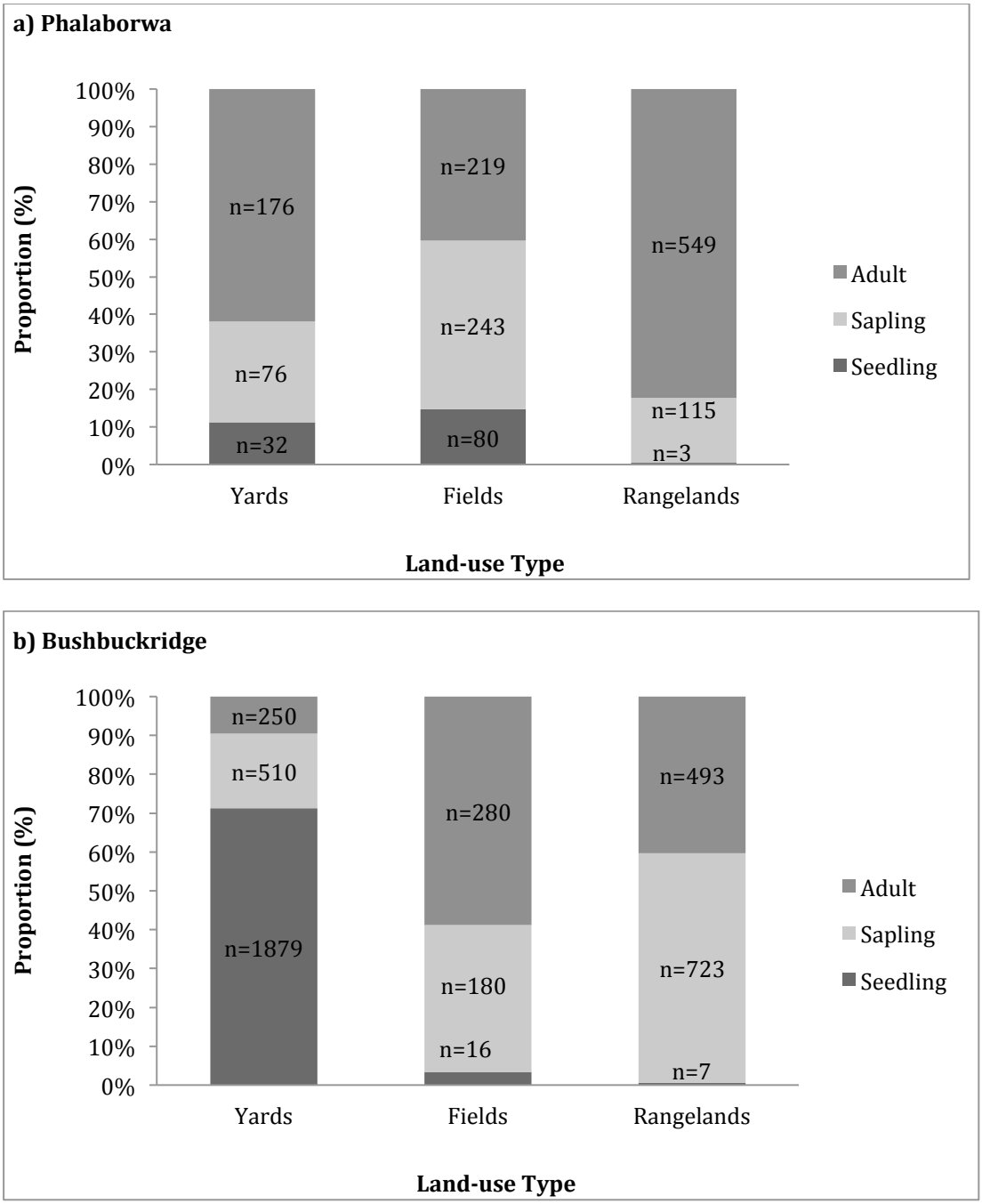


Figure 5.3: Comparison of the proportions of juveniles (≤14 cm) [segmented into seedlings (≤0.5 cm) and saplings (0.5≤14 cm)] as well as overall adult marula trees (>14 cm) marula trees across land-use types in a) Phalaborwa (yards (n=284), fields (n=542) & rangelands (n=667)) and b) Bushbuckridge (yards (n=2639), fields (n=476) & rangelands (n=1223))

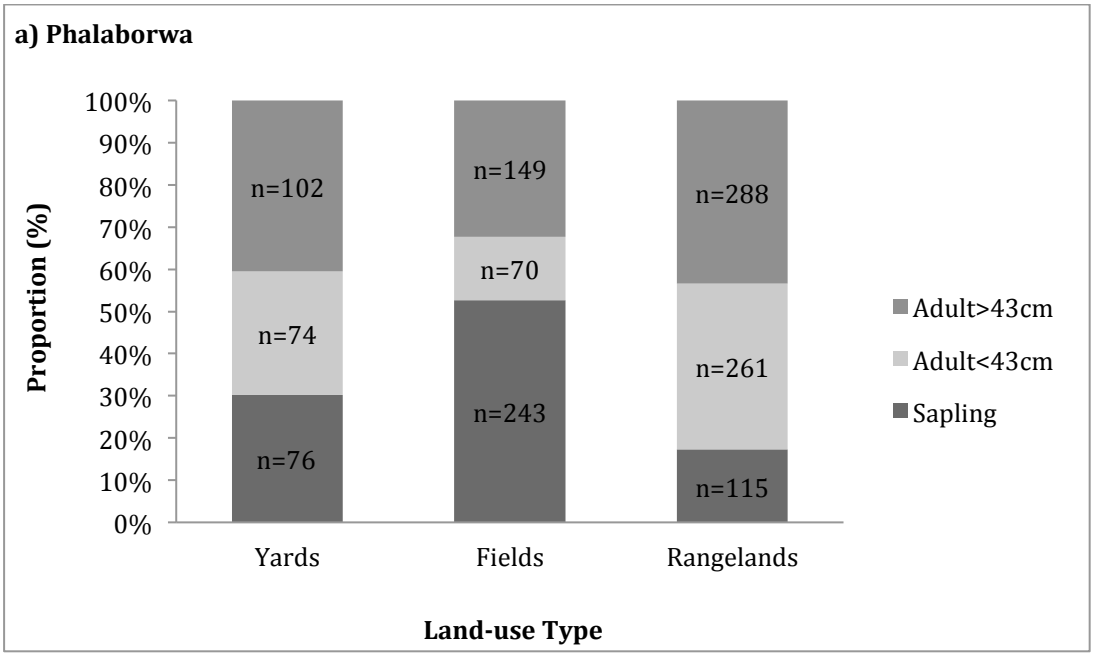
Comparing differences in maturity for yards, fields and rangelands between Phalaborwa and Bushbuckridge, the differences were significant with a medium to large difference between yards (x^2 (1, n=2923)=563.41, p<0.001, phi=0.441) and rangelands (x^2 (1, n=1890)=306.06, p<0.001, phi=0.404) but only a small difference between fields (x^2 (1, n=1018)=33.67, p<0.001, phi=-0.184). Yard and rangeland differences were likely due to the heightened juvenile numbers in these land-uses in Bushbuckridge, with fields in Phalaborwa displaying a higher relative abundance of juveniles compared to Bushbuckridge.

5.3.2.2 Large tree contributions across land-uses

In Phalaborwa, large trees were found in greatest relative abundance in rangelands (43.2%, n=288), followed by fields (27.5%, n=149) and then yards (35.9%, n=102). In Bushbuckridge, rangelands (18.3%, n=224) again had the most large trees across the different land-use types, followed by fields (29.2%, n=139) and then yards with only 3.6% (n=94).

In Phalaborwa, the difference in the number of trees >43 cm in stem diameter compared to those ≤43 cm diameter across the land-use types was significant but small (x^2 (2, n=1493)=31.91, p<0.001, Cramer's V=0.146), while in Bushbuckridge there was a medium difference (x^2 (2, n=4338)=390.68, p<0.001, Cramer's V=0.300).

The relative proportion of intermediate (14≤43 cm basal stem diameter) as well as large adults (>43 cm) as part of the overall population, with seedlings (≤0.5 cm basal diameter) excluded, but saplings (0.5≤14 cm basal diameter) included, are shown in Phalaborwa and Bushbuckridge (Figure 5.4).



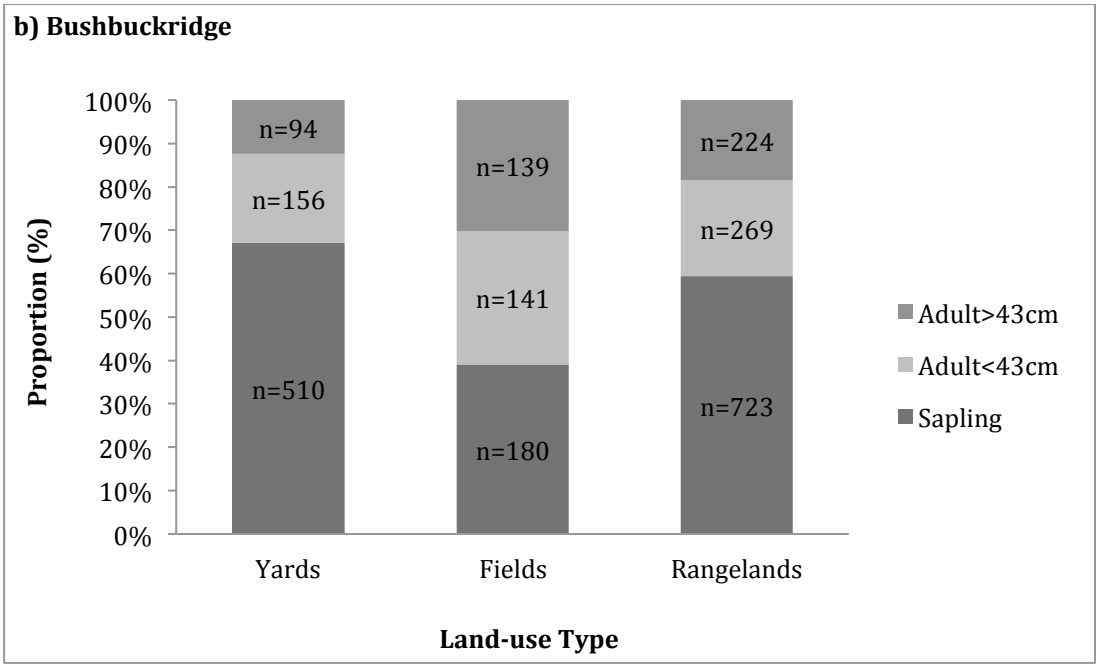


Figure 5.4: Comparison of proportions of juveniles (saplings: 0.5≤14 cm), intermediate adults (14≤43 cm) and large adult (>43 cm) marula trees across land-use types in a) Phalaborwa (yards (n=252), fields (n=462) & rangelands (n=664)) and b) Bushbuckridge (yards (n=760), fields (n=460) & rangelands (n=1216))

Comparing large adult trees across yards, fields and rangelands between Phalaborwa and Bushbuckridge, the differences were significant and medium between yards, with a higher relative abundance of large adults in Phalaborwa yards (x^2 (1, n=2923)=423.88, p<0.001, phi=-0.383). Differences were once again significant, but small to medium, between rangelands, with a similar relative abundance of large adults between locations (x^2 (1, n=1890)=133.83, p<0.001, phi=-0.267). Fields are not significantly different in terms of the proportion of large adults between Phalaborwa and Bushbuckridge.

5.3.2.3 Density per land-use category in Phalaborwa and Bushbuckridge

Sapling, adult and large adult marula tree density in Phalaborwa (n=220) and Bushbuckridge (n=220) were compared by land-use type (yards (n=120); fields (n=80) and rangelands (n=20)) to ascertain significant differences. This comparison indicated that sapling and adult densities differed significantly across Phalaborwa land-use types, whereas only sapling density differed significantly across Bushbuckridge land-use types (Table 5.1).

Table 5:1: Results of the Kruskal-Wallis test comparing sapling, adult and large adult densities between yards (n=120), fields (n=80) and rangelands (n=20) within Phalaborwa and Bushbuckridge. Significant differences for the density categories between land-use types are indicated in bold.

Location	Demographic Category	Kruskal-Wallis Test Statistic	Degrees of Freedom (df)	Significance Level (p<0.05)
Phalaborwa	**Sapling**	**28.59**	**2**	**0.001**
	Adult	**13.54**	**2**	**0.001**
	Large Adult	5.79	2	0.555
Bushbuckridge	**Sapling**	**17.01**	**2**	**0.001**
	Adult	3.57	2	0.168
	Large Adult	2.91	2	0.233

Examining only the significantly different median densities in Phalaborwa, adult density was highest in yards, while saplings were highest in fields. In Bushbuckridge, sapling density was highest in rangelands. The median and mean ranks produced from the Kruskal-Wallis tests are provided in Table 5.2.

Table 5:2: Comparison of median and mean density (trees/ha) for sapling, adult and large adult densities by land-use type (yards (n=120), fields (n=80) & rangelands (n=20)) in Phalaborwa and Bushbuckridge, with the significant results (<0.05) from the Kruskal-Wallis test indicated in bold - medians not sharing a common superscript letter are significantly different.

	Demographic Category	Yard (Y)		Field (F)		Rangeland (R)	
		Median	Mean±SE	Median	Mean±SE	Median	Mean±SE
Phalaborwa	**Sapling**	***0.00**[a]	**4.9±1.4**	**2.11**[b]	**8.1±1.8**	**0.34**[bc]	**1.1±0.5**
(n=220)	**Adult**	**7.47**[ac]	**9.0±1.0**	**1.91**[b]	**3.4±0.5**	**4.90**[c]	**5.4±0.7**
	Large Adults	2.97	4.9±0.6	0.95	2.0±0.3	2.10	2.6±0.3
Bushbuckridge	**Sapling**	**2.97**[ac]	**16.7±3.7**	**0.81**[b]	**2.7±0.4**	**7.80**[c]	**8.0±1.1**
(n=220)	Adult	5.37	8.9±1.0	3.63	4.7±0.5	4.79	5.4±0.6
	Large Adults	*0.00	3.1±0.4	0.58	2.1±0.3	1.83	2.0±0.3

***A zero median value means that at least half of the densities were zero for that specific category. For example, at least half the yards in Phalaborwa did not have male trees and so the median density value for that category is zero.**

[abc] Different superscript letters denote where overall density is significantly (p<0.05) different between yards vs. fields, fields vs. rangelands and yards vs. rangelands. Median density values for land-use types that share a common superscript letter are not significantly different (ie. overall density in yards vs. rangelands in Bushbuckridge)

The main trends between land-use types as shown by the means are highlighted in Figure 5.5. Due to the skewed nature of the data, the patterns are not always the same as those reflected by the medians.

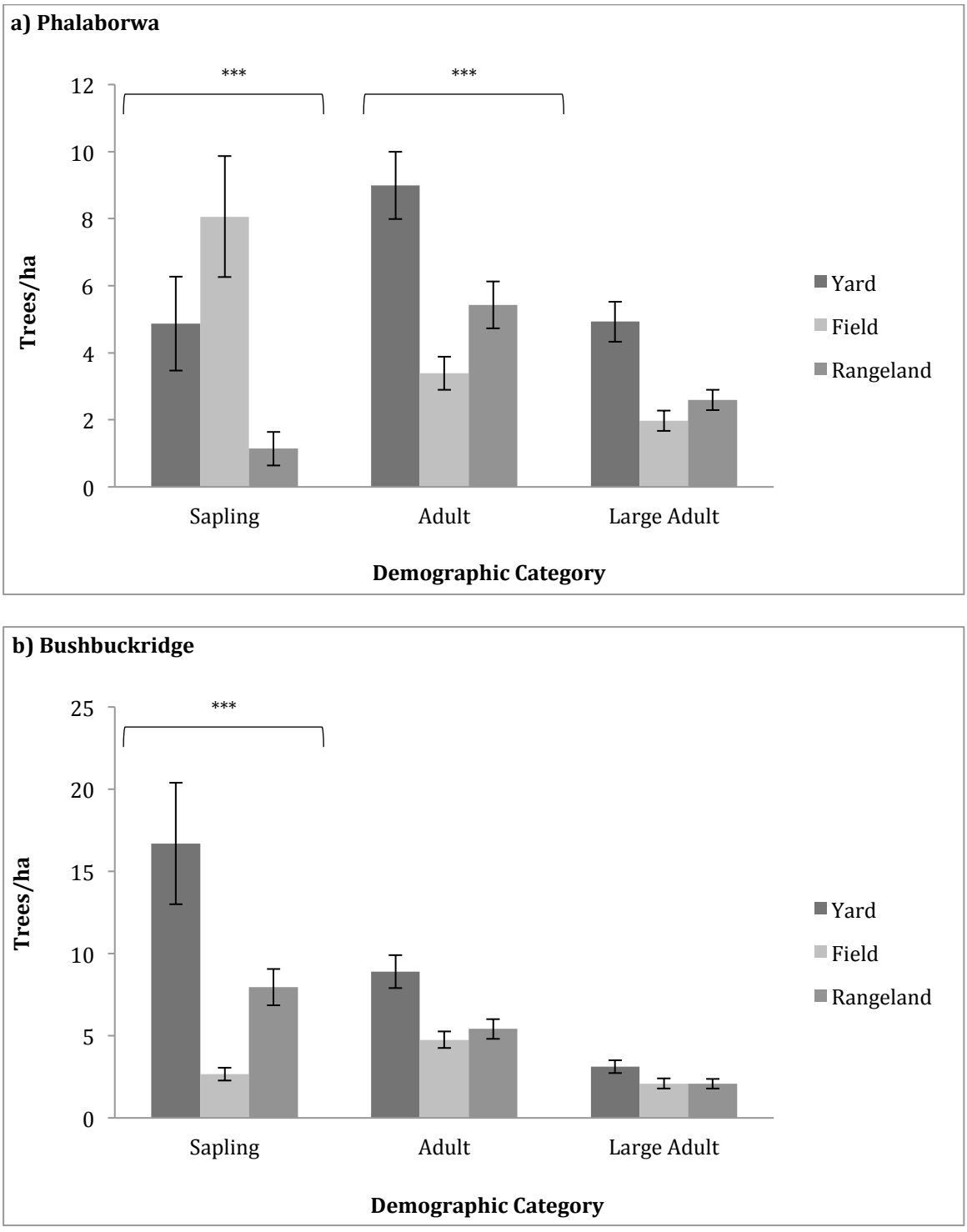


Figure 5.5: Mean (trees/ha) ±SE density comparisons for sapling, adult and large adult demographic cateogries in a) Phalaborwa (n =220) and b) Bushbuckridge (n=220) by land-use type (yard, fields and rangelands) using the Kruskal-Wallis test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

Comparing density values within only the significant ($p<0.05$) demographic categories for the different land uses, the Mann-Whitney test (Table 5.3) helped to ascertain where the main differences are between yards vs. fields, fields vs. rangelands and yards vs. rangelands, as shown in Table 5.3.

In Phalaborwa, median density of adults was significantly and substantially higher in yards than in fields, whereas sapling density was substantially higher in fields than yards (Table 5.3). Adult density in rangelands was substantially higher and differed significantly from fields, but not yards. Median sapling density in Phalaborwa fields was both significant and higher in fields compared to yards, and higher but not significant compared to rangelands (Table 5.3). However, sapling density in rangelands was both significant and higher than in yards.

In Bushbuckridge, sapling median density was substantially higher in rangelands than both yards and fields, but only significantly so compared to fields (Table 5.3). Yard sapling density was intermediate, significant and higher than in fields. The statistics from the Mann-Whitney test are provided in Table 5.3.

Table 5:3: Results of the Mann-Whitney test comparing yards vs. fields (n=200), fields vs. rangelands (n=100) and yards vs. rangelands (n=140) in Phalaborwa and Bushbuckridge, with only the significantly different demographic categories included.

Location	Land use comparison	Demographic Category	Mann-Whitney U	Z-Value	Significance p<0.05	Effect Size (r)
Phalaborwa	**Y vs F*** **(n=200)**	**Sapling**	2991	-5.11	0.001	0.4
		Adult	3559	-3.14	0.002	0.2
	F vs R** **(n=100)**	**Adult**	392	-3.53	0.001	0.4
	Y vs R*** **(n=140)**	**Sapling**	802	-2.95	0.003	0.2
Bushbuckridge	**Y vs F** **(n=200)**	**Sapling**	3911	-2.32	0.020	0.2
	F vs R **(n=100)**	**Sapling**	263	-4.73	0.001	0.5

* Y vs F: Yards vs Field **F vs R: Field vs Rangeland ***Y vs R: Yard vs Rangeland

5.3.2.4 Demographic combination comparisons by land-use in Phalaborwa and Bushbuckridge

Comparing the densities of the demographic categories (adult vs. sapling and adult vs. large adult) across the different land-use types using the Wilcoxon Signed Ranks Test, both combinations were significantly different in yards in Phalaborwa (n=240): adult > sapling and adult > large adult. There was a medium (intermediate) difference between both pairs. In fields (n=160), only adult > large adult densities differed significantly, displaying a medium difference

between densities as indicated by the effect size. In rangelands (n=40), adult > sapling and adult > large adult differed significantly, both showing a large difference in densities relative to one another.

In Bushbuckridge yards (n=240): adult > large adult, showing a medium difference. In fields (n=160) both adult > sapling and adult > large adult densities differed significantly, displaying a medium difference between adults and sapling, but a large difference between adults and large adults. Bushbuckridge rangelands (n=40) showed significant differences between both combinations: adult < sapling and adult >large adult. The first displayed a medium difference while the difference between adults and large adults was large. The extent of the differences between combinations for both Phalaborwa and Bushbuckridge are indicated by the effect sizes, provided in Table 5.4.

Table 5:4: The z value, significance and effect size (Wilcoxon Signed Ranks) for the density values of demographic category combinations across land-use types (yards (n=240), fields (n=160) and rangelands (n=40)) in Phalaborwa and Bushbuckridge.

Location	Land-use	Statistic	Adult:Sapling	Adult:Large Adult
Phalaborwa	**Yard**	Z value	-4.902	-5.232
	(n=240)	Significance	**0.001**	**0.001**
		Effect Size	0.3	0.3
	Field	Z value	-1.432	-4.782
	(n=160)	Significance	0.152	**0.001**
		Effect Size	0.1	0.4
	Rangeland	Z value	-3.698	-3.922
	(n=40)	Significance	**0.001**	**0.001**
		Effect Size	0.6	0.6
Bushbuckridge	**Yards**	Z value	-0.785	-6.955
	(n=240)	Significance	0.433	**0.001**
		Effect Size	0.05	0.4
	Fields	Z value	-3.833	-6.624
	(n=160)	Significance	**0.001**	**0.001**
		Effect Size	0.3	0.5
	Rangeland	Z value	-2.315	-3.921
	(n=40)	Significance	**0.05**	**0.001**
		Effect Size	0.4	0.6

While there is considerable variability between land-use types (Table 5.5; Figure 5.6), a consistent relationship across locations was that adults occurred in higher densities than large adults, irrespective of location or land-use. A summary of maturity relationships is provided in Table 5.6.

Table 5:5: Density comparisons of sapling, adult and large adult combinations, showing significant differences in median densities (trees/ha) split by land-use types (yards (n=240), fields (n=160), rangelands (n=40)) in Phalaborwa and Bushbuckridge, with significant results (Wilcoxon Signed Ranks) indicated in bold.

	Density Categories	Land-use Types		
		Yard (Y)	Field (F)	Rangeland (R)
Phalaborwa	Adult	**7.47**	1.91	**4.90**
	Sapling	**0.00**	2.11	**0.34**
	Adult	**7.47**	**1.91**	**4.90**
	Large Adult	**2.97**	**0.95**	**2.10**
Bushbuckridge	Adult	5.37	**3.63**	**4.79**
	Sapling	2.97	**0.81**	**7.80**
	Adult	**5.37**	**3.63**	**4.79**
	Large Adult	**0.00**	**0.58**	**1.83**

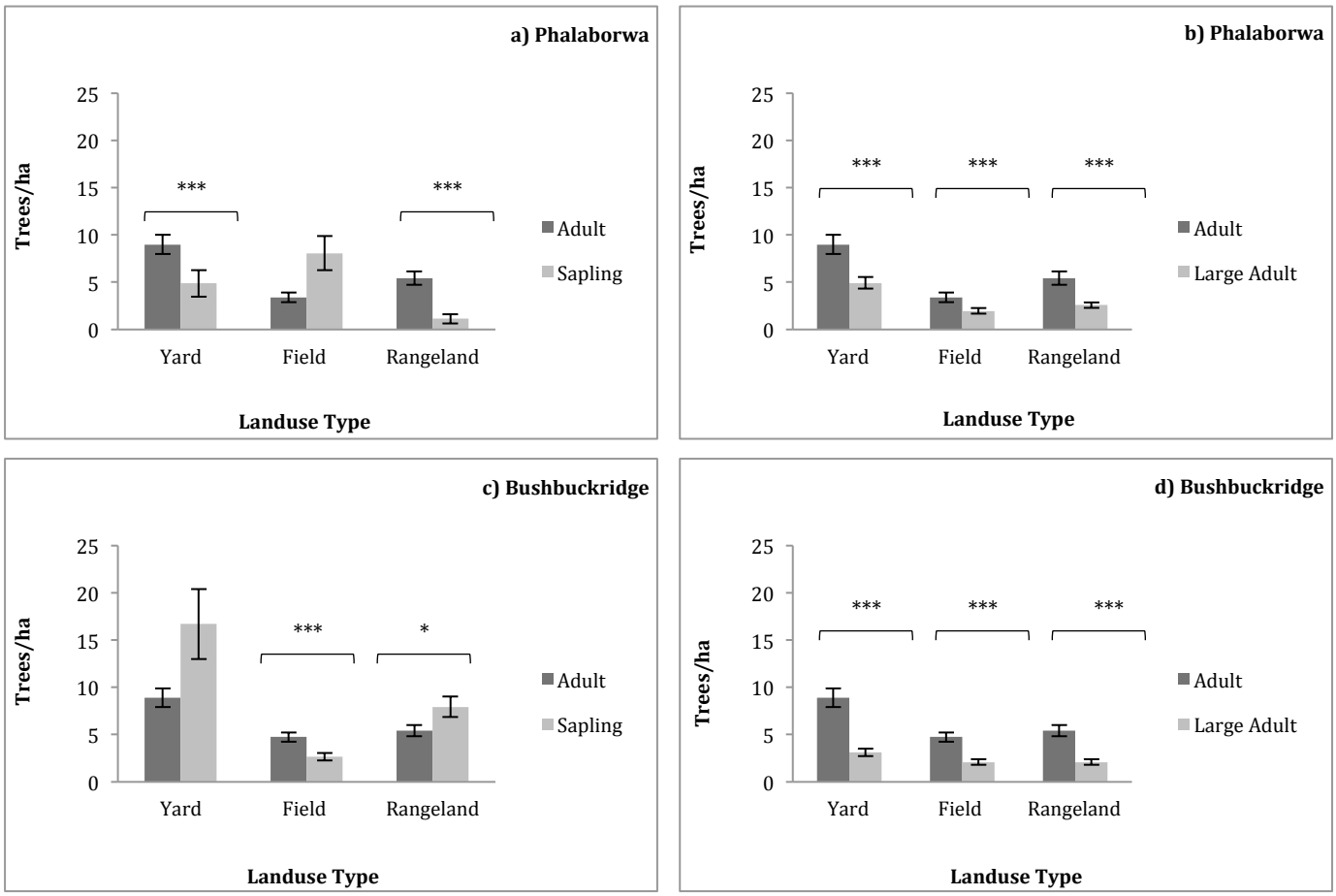


Figure 5.6: Mean density (trees/ha) ± SE for combinations of sapling, adult and large adult categories across land-use types in Phalaborwa (a-b) and Bushbuckridge (c-d) using the Wilcoxon Signed Ranks test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

Table 5:6: Summary table showing the nature of the relationship between demographic category pairs across land-use types. Significant differences are highlighted in bold (A – adult, S – sapling, LA – large adult)

	Yards	Fields	Rangelands
Phalaborwa	A>S	A<S	**A>S**
	A>LA	**A>LA**	**A>LA**
Bushbuckridge	A>S	**A>S**	**A<S**
	A>LA	**A>LA**	**A>LA**

5.3.2.5 Density per land-use category between Phalaborwa and Bushbuckridge

Comparing the densities for the three demographics categories between Phalaborwa and Bushbuckridge, divided into the three land-use types, in yards (n=240) only saplings differed significantly (U=4851, z=-4.977, p<0.001, r=0.3). Using the median to compare density patterns, sapling densities were almost three times higher in Bushbuckridge yards than in Phalaborwa.

In fields (n=160), densities were significantly different between the two locations for adults (U=2223, z=-3.341, p<0.001, r=0.3) and saplings (U=2590, z=-2.148, p<0.05, r=0.2). Overall adult densities were lower in Phalaborwa fields compared to Bushbuckridge. Adult density in Bushbuckridge fields was almost twice that in Phalaborwa. However, sapling density was more than twice as high in Phalaborwa fields compared to Bushbuckridge. Fields were the land-use type indicating the most variability across the density categories between locations.

Densities differed significantly between Phalaborwa and Bushbuckridge rangelands (n=40) for sapling density (U=24, z=-4.770, p<0.001, r=0.8). Sapling density in Bushbuckridge rangelands was almost eight times higher than those in Phalaborwa (Table 5.7).

Table 5:7: Comparison of demographic categories by land-use type (yards, fields & rangelands) between Phalaborwa (n=220) and Bushbuckridge (n=220) with significant results (Mann-Whitney test) indicated in bold (Medians).

Land-use Type	Demographic Categories	Phalaborwa	Bushbuckridge
Yard (Y)	**Saplings**	***0.00**	**2.97**
	Adult Density	7.47	5.37
	Large Adult≥43cm Density	2.97	*0.00
Field (F)	**Saplings**	**2.11**	**0.81**
	Adult Density	**1.91**	**3.63**
	Large Adult≥43cm Density	0.95	0.58
Rangeland (R)	**Saplings**	**0.34**	**7.80**
	Adult Density	4.90	4.79
	Large Adult≥43cm Density	2.10	1.83

***A zero median value means that at least half of the densities were zero for that specific category. For example, at least half the yards in Phalaborwa did not have male trees and so the median density value for that category was zero.**

Examining the mean densities in Figure 5.7, it is possible to see that while sapling densities differed between Phalaborwa and Bushbuckridge, adult densities were very similar in both

yards and rangelands with only fields differing between locations. Large adult densities, however, showed a trend of being lower in Bushbuckridge compared to Phalaborwa (except for fields where there was some variability). This is an interesting trend considering Bushbuckridge generally had higher densities across the different land-use types, except for fields, which once again displayed variability.

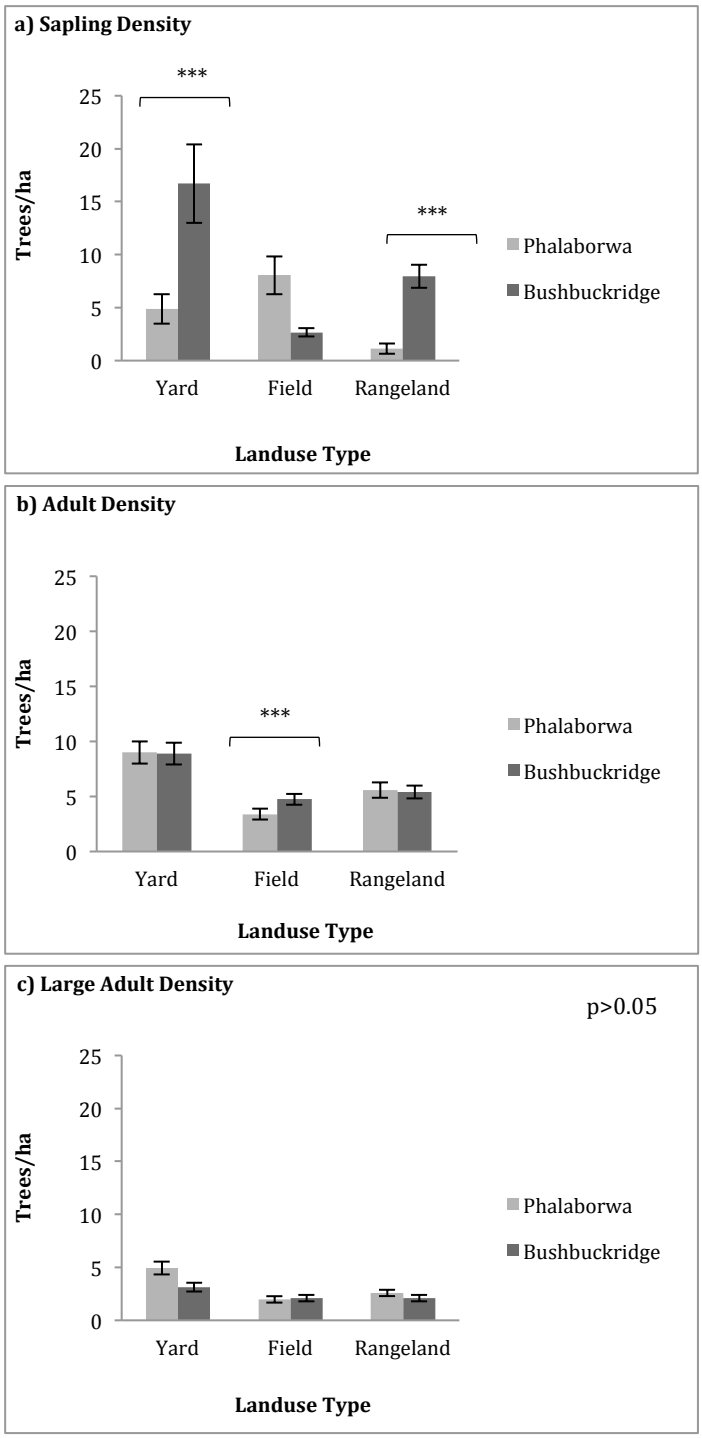


Figure 5.7: Comparison of marula mean density (trees/ha) ±SE demographic categories a) sapling, b) adult and c) large adult by land-use type (yards, fields & rangelands) between Phalaborwa (n=220) and Bushbuckridge (n=220), using the Mann-Whitney test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

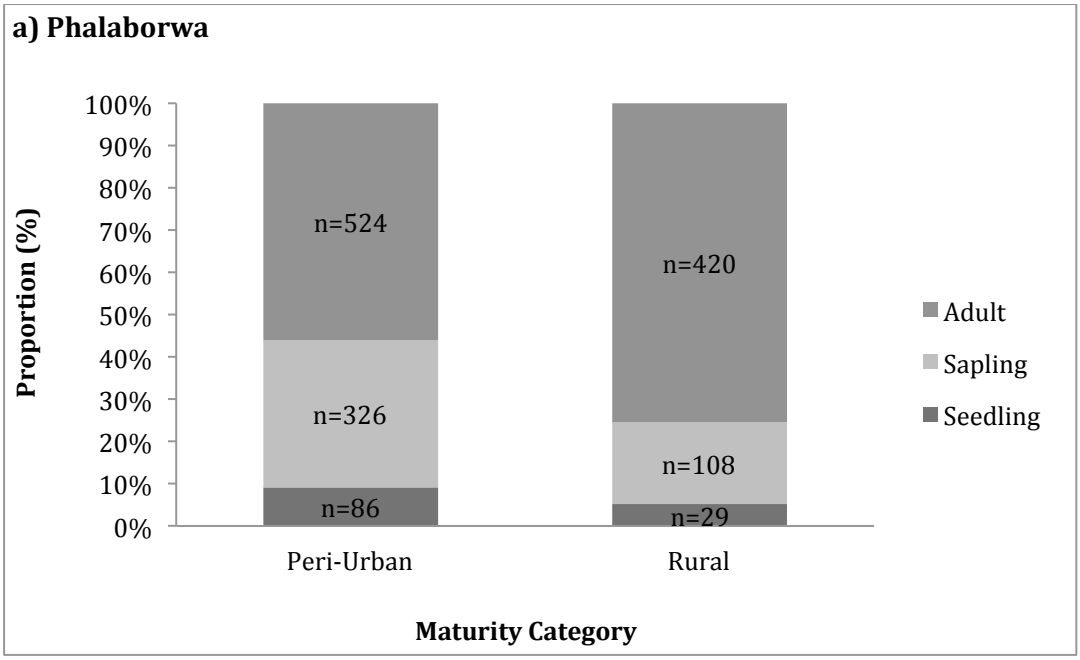
5.3.3 Marula population structures across different settlements (rural and peri-urban)

5.3.3.1 Maturity across settlements

Comparing tree maturity in yards between different settlement types, differences in the relative abundance of adults and juveniles were significant and slight in Phalaborwa (x^2 (1, n=284)=22.44, p<0.001, phi=-0.288) and in Bushbuckridge (x^2 (1, n=2639)=10.22, p<0.001, phi=-0.064). In Phalaborwa, adult and juvenile relative abundance was similar in peri-urban yards but adult relative abundance was three times higher than juveniles in rural yards. In Bushbuckridge, juveniles comprised the largest maturity class within the population in both peri-urban (92%, n=1458) and rural yards (88.2%, n=931). Comparing tree maturity in peri-urban and rural fields, only Phalaborwa (x^2 (1, n=542)=59.28, p<0.001, phi=-0.335) showed a significant difference between adult and juvenile relative abundance across the two settlement types, with the difference being moderate, despite juveniles being almost three times higher than adults in peri-urban fields and only half as numerous as adults in rural fields. Comparing rangelands between settlement types, only Bushbuckridge (x^2 (1, n=1223)=5.58, p<0.05, phi=0.069) showed a significant, but slight, difference between the relative abundance of adults and juveniles. Juvenile numbers were higher than adults across both settlements types, comprising 56% (n=310) of the population in peri-urban rangelands and 62.8% (n=420) in rural rangelands.

Comparing tree maturity ratios in peri-urban yards between Phalaborwa and Bushbuckridge, the difference was significant and moderate (x^2 (1, n=1737)=225.94, p<0.001, phi=0.364), most likely the consequence of the large number of juveniles in Bushbuckridge (92%, n=1458) compared to Phalaborwa (51%, n=78). Similarly, differences in maturity ratios between peri-urban fields (x^2 (1, n=616)=59.78, p<0.001, phi=-0.315) and rangelands (x^2 (1, n=965)=146.14, p<0.001, phi=0.391) between the two locations were significant and moderate. These differences were likely as a result of the large number of juveniles in peri-urban fields in Phalaborwa (70.7%; n=263) and the higher proportion of juveniles in Bushbuckridge rangelands (56%, n=310). Comparing maturity ratios for the land-use types in the rural context between Phalaborwa and Bushbuckridge, only yards and rangelands were significantly different, with a large difference between rural yards (x^2 (1, n=1186)=319.46, p<0.001, phi=0.522) and a moderate difference between rural rangelands (x^2 (1, n=925)=144.38, p<0.001, phi=0.397). Rural yards in Bushbuckridge (88.2%, n=931) had far higher juvenile numbers than Phalaborwa (22.9%, n=30). This pattern was repeated for rural rangelands in Bushbuckridge (62.8%, n=420) when compared to Phalaborwa (18.4%, n=47).

The relative proportion of juveniles, disaggregated into seedlings ($\leq$0.5 cm basal stem diameter) and saplings (0.5$\leq$14 cm basal diameter), compared to overall adult individuals (>14 cm basal stem diameter) are provided for Phalaborwa and Bushbuckridge (Figure 5.8).



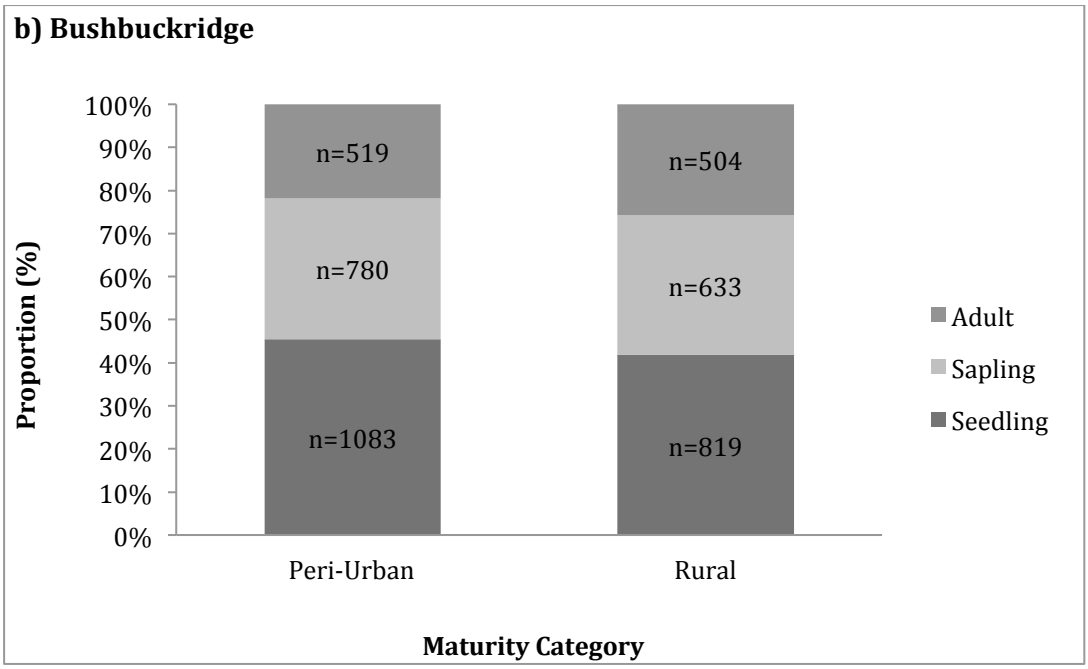


Figure 5.8: Comparison of proportions of juveniles (seedlings (≤0.5 cm) & saplings (0.5≤14 cm)) and overall adult (>14 cm) marula trees across settlement types in a) Phalaborwa (peri-urban (n= 936) & rural (n=557)) and b) Bushbuckridge (peri-urban (n= 2382) and rural (n=1956))

5.3.3.2 Large tree contributions across settlements

The proportions of large adult trees (>43 cm stem diameter) as a proportion of the population differed significantly from trees below the 43 cm threshold when comparing peri-urban and rural yards in both Phalaborwa (x^2 (1, n=284)=14.70, p<0.001, phi=0.235), as well as Bushbuckridge (x^2 (1, n=2639)=7.68, p<0.01, phi=0.056). Peri-urban yards in Phalaborwa had fewer large individuals (25.5%, n=39) compared to rural yards (48.1%, n=63). In

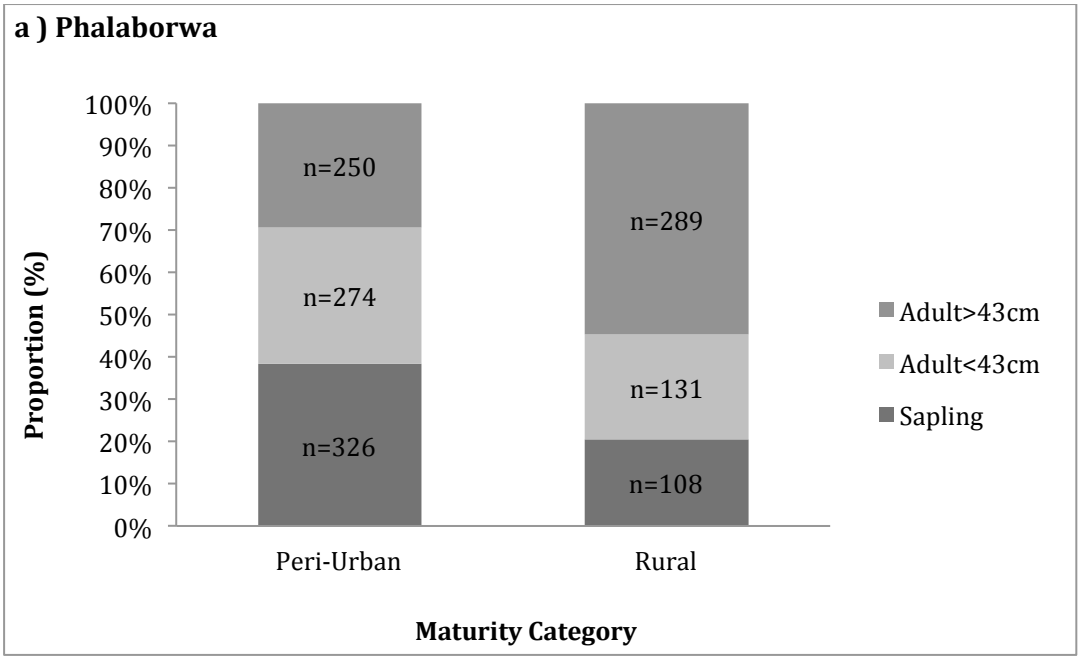
Bushbuckridge, a similar pattern occurred, with slightly higher large adult numbers in peri-urban yards (2.7%, n=43) compared to 4.8% (n=51) in rural yards.

Fields in Phalaborwa (x^2 (1, n=524)=75.00, p<0.001, phi=-0.376) showed a significant and moderate difference in the proportion of trees falling above and below the 43 cm threshold between settlement types. In rural fields, 52.4% (n=89) adults were large, compared to 16.1% (n=60) in peri-urban fields. The difference was significant but slight between peri-urban and rural fields in Bushbuckridge (x^2 (1, n=476)=31.33, p<0.001, phi=0.261). Rural fields had a higher number of large adults (41.4%, n=96), compared to 17.6% (n=43) in the rural context. Comparing peri-urban and rural rangelands, the difference was also significant and slight in both Phalaborwa (x^2 (1, n=667)=17.42, p<0.001, phi=-0.165) and Bushbuckridge (x^2 (1, n=1223)=4.98, p<0.05, phi=-0.066). Large adults were higher in peri-urban rangelands in Bushbuckridge (21.1%, n=117) as well as in Phalaborwa (36.7%, n=151).

Comparing large adult trees across peri-urban yards between Phalaborwa and Bushbuckridge, the difference was significant and moderate (x^2 (1, n=1737)=155.88, p<0.001, phi=-0.304), most likely as a result of the large number of trees below the 43 cm threshold in Bushbuckridge (97.3%, n=1541) compared to Phalaborwa (74.5%, n=114). There were no significant differences comparing peri-urban fields between locations. However, peri-urban rangelands in Phalaborwa had a far higher number of trees above the threshold (36.7%, n=151) compared to 21.1% (n=117) in Bushbuckridge, resulting in a significant but slight difference (x^2 (1, n=965)=27.93, p<0.001, phi=-0.172).

Comparing the land-use types between Phalaborwa and Bushbuckridge in the rural context, yards (x^2 (1, n=1186)=246.02, p<0.001, phi=-0.460), fields (x^2 (1, n=402)=4.32, p=0.033, phi=-0.109) and rangelands (x^2 (1, n=925)=132.30, p<0.001, phi=-0.381) were all significantly different between Phalaborwa and Bushbuckridge. Differences in yards were moderate to large, with a slight difference between rural fields, and a moderate difference between rural rangelands. Rural yard differences were most likely due to the much lower number of large adult trees relative to the overall population in Bushbuckridge (4.8%, n=51) compared to Phalaborwa (48.1%, n=63). In rural fields, the difference was only slight, as large adult numbers were similar in rural Phalaborwa (52.4%, n=89) and Bushbuckridge (41.4%, n=96) fields. Rural rangelands once again showed a moderate difference between locations, as a result of much higher numbers of individual trees falling below the 43 cm threshold in Bushbuckridge (84%, n=562) compared to Phalaborwa (46.5%, n=119).

The proportion of large adults in the overall population with seedlings ($\leq$0.5 cm) excluded, but saplings (0.5<14 cm) included, which are considered to have successfully recruited, are shown for Phalaborwa and Bushbuckridge (Figure 5.9)



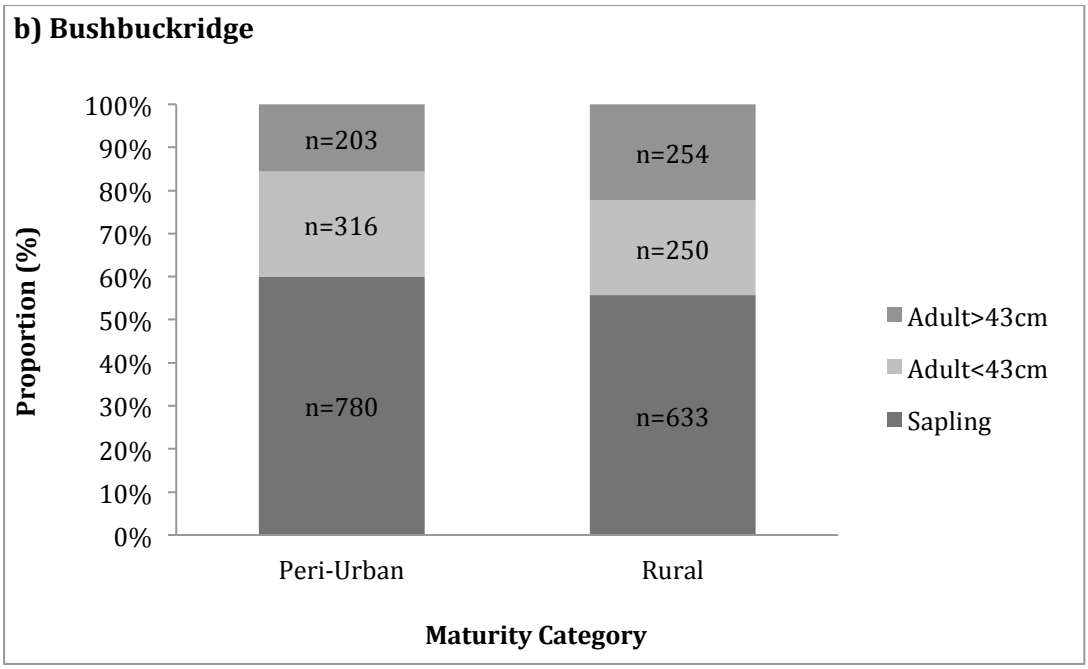


Figure 5.9: Comparison of proportions of juvenile (sapling: 0.5≤14 cm), adult (14≤43 cm) and large adult (>43 cm) marula trees across settlement types in a) Phalaborwa (peri-urban (n= 850) and rural (n=528)) and b) Bushbuckridge (peri-urban (n= 1299) and rural (n=1137))

5.3.3.3 Density per settlement and land-use category in Phalaborwa and Bushbuckridge

Comparing rural and peri-urban yards (n=120) in Phalaborwa, densities differed between settlement types for saplings ($U=1477$, $z=-2.319$, $p<0.05$, $r=0.2$), although densities were similar across yards.

Rural and peri-urban fields (n=80) in Phalaborwa also differed significantly in terms of sapling ($U=234$, $z=-5.567$, $p<0.001$, $r=0.6$) densities. In peri-urban fields, sapling densities were more than eight times higher than in rural fields.

Comparing rangelands (n=20) between the two settlement types in Phalaborwa, adult (U=17, z=-2.496, p<0.05, r=0.6) densities differed significantly, being almost twice as high in peri-urban rangelands. Across all three land-use types, significantly different densities were higher in the peri-urban context.

In Bushbuckridge yards and rangelands, none of the density categories differed significantly by settlement type. However, in fields (n=80), large adult densities were significantly different between peri-urban and rural villages (U=446.00, z=-3.588, p<0.001, r=0.4), with large tree densities being three times higher in the rural context (Table 5.8).

Table 5:8: Comparison of demographic categories by land-use (yards, field & rangelands) and settlement (rural & peri-urban) type within Phalaborwa (n=220) and Bushbuckridge (n=220), with significant differences indicated by the Mann-Whitney test highlighted in bold (Medians)

	Land-use Type	Demographic Categories	Peri-Urban	Rural
Phalaborwa	Yard (Y)	**Saplings**	***0.00**	***0.00**
		Adult Density	8.56	5.99
		Large Adult≥43cm Density	*0.00	3.78
	Field (F)	**Saplings**	**8.41**	***0.00**
		Adult Density	2.66	1.56
		Large Adult≥43cm Density	0.02	1.37
	Rangeland (R)	Saplings	0.60	0.10
		Adult Density	**6.35**	**3.60**
		Large Adult≥43cm Density	2.83	1.90
Bushbuckridge	Yard (Y)	Saplings	2.97	3.35
		Adult Density	5.09	6.22
		Large Adult≥43cm Density	*0.00	*0.00
	Field (F)	Saplings	1.28	*0.00
		Adult Density	3.79	3.53
		Large Adult≥43cm Density	***0.00**	**2.63**
	Rangeland (R)	Saplings	7.20	10.61
		Adult Density	4.11	4.99
		Large Adult≥43cm Density	1.55	2.18

***A zero median value means that at least half of the densities were zero for that specific category. For example, at least half the yards in Phalaborwa did not have male trees and so the median density value for that category was zero.**

Comparing the three land-use types in each location by settlement type, the main trend was that densities were higher in the peri-urban context in Phalaborwa, as shown by Figure 5.10. In Bushbuckridge, this difference is not as marked, with peri-urban and rural contexts displaying more similar densities across the land-use types (Figure 5.10).

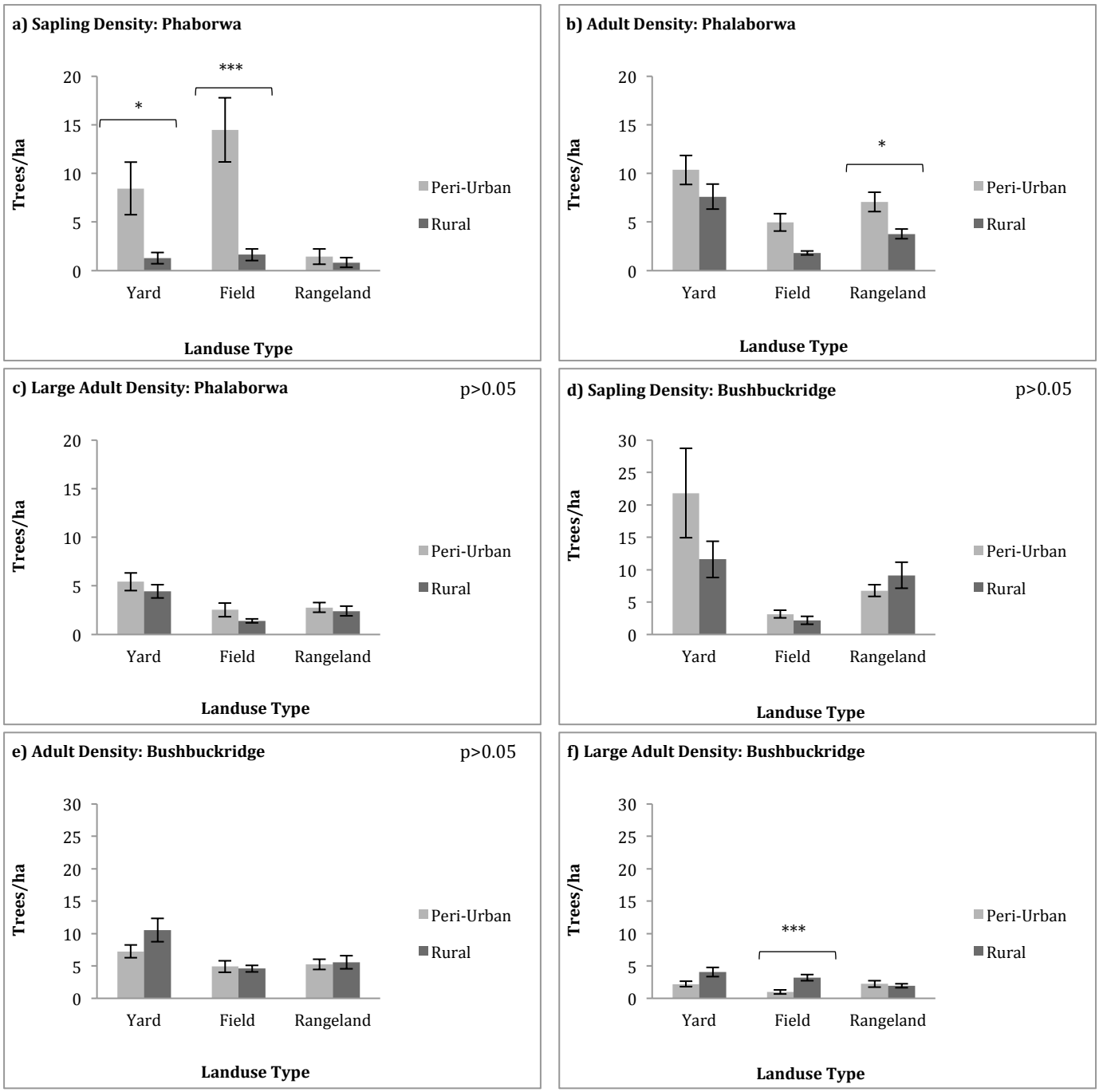


Figure 5.10: Comparison of peri-urban and rural marula mean densities (trees/ha) ±SE by land-use type (yards, fields and rangelands) for juvenile, adult and large adults in (a-c) Phalaborwa (n=220) and (d-f) Bushbuckridge (n=220) using the Mann-Whitney test. (Symbols denote significant differences: *p<0.05; **p<0.01; ***p<0.001)

5.4 Discussion

5.4.1 Marula population structures differ across non-conservation areas

Repeated patterns of particular land-use and resource practices across the landscape combine to influence marula population structures in both Phalaborwa and Bushbuckridge. This finding illustrates how localised practices can impact a resource, such as marula, at the population level. The implications of the resource practices, specific to particular land-use and settlement types, revealed four key outcomes. The first outcome is that multi-use tree species such as marula, are particularly susceptible to different resource use practices across land-uses and settlements, resulting in a range of positive and negative implications for the overall population structure. The second outcome pertains to juveniles, especially the smaller seedling classes, being able to effectively establish in anthropogenic landscapes to a far larger degree than in formally protected areas. This is due to the removal of the usual limiting factors causing recruitment bottlenecks. For example, heightened juvenile numbers occurred in yards in Bushbuckridge and fields in Phalaborwa. Third, was the higher mean density of large adults in yards compared to both fields and rangelands. However, there are worrying implications of land-use practices on larger individuals, with the specific removal of these trees creating cause for concern. Finally, the fourth outcome explores how climate change is likely to impact marula population structures, in terms of both recruitment as well as accelerating large tree senescence. These four key findings are important in uncovering the narrative around how land-use and resource utilisation impact marula population structures. Essentially, these findings draw attention to the extent of the removal of adult marula trees (including larger individuals) from fields and rangelands for planting and fuelwood extraction purposes respectively, but suggest that the species is afforded some degree of protection in yards, particularly the female tree (Chapter 4).

5.4.1.1 Resource practices impact the life stages of marula as a multi-use tree species

Differences in marula population composition across the different land-use types are a direct result of different utilisation practices, which occur as a consequence of human behaviour patterns. It is therefore necessary to understand marula population structure not just in terms of the wider location, but also more specifically across different land-use types. The Bushbuckridge marula population displayed significant differences between land-use types, but was inverse to Phalaborwa, with juvenile-dominated populations in yards and rangelands and an adult-dominated population in fields. This highlights the importance of understanding land-use practices within a specific local context, with higher field utilisation in Bushbuckridge resulting in lower levels of juvenile establishment. Differences occur as a direct result of resource utilisation, for example in yards trees may be retained for shade, which is contrasted with fields where they are often removed to prevent the shading of crops. The removal of large marula trees in fields was demonstrated in agroforestry systems in Namibia (southern Africa), highlighting the widespread and pervasive nature of human-resource interactions for a species such as marula by (Nghitoolwa et al., 2003). Human impacts are not only widespread, but have landscape level implications over relatively short time periods. Lykke (1998) confirmed how humans impact savanna systems faster than natural vegetation change, with overharvesting and land clearing resulting in decreasing densities and flat SCD slopes. Rangelands differed from yards and fields, with trees in the intermediate adult sizes being targeted for fuelwood, whereas trees of this size are tolerated in yards, both as a source of fruit and site of cultural practices. Cultural practices include ceremonies such as communicating with the ancestral spirits at a marula tree, which Shackleton & Shackleton (2005) highlighted as an important ritual for the

communities of the Bushbuckridge region. The inherent differences in terms of how humans interact with marula according to land-use type, highlight the varying impacts of behaviour patterns, which in turn have a profound effects on overall population stability.

Understanding how resource use practices affect different demographic categories across the population is particularly important for a multi-use tree species, such as marula, which is harvested for its fruit, wood and bark (Gaoue & Ticktin, 2009). While Gaoue & Ticktin (2009) found that larger trees are usually harvested in multi-use species, Shackleton (1993b) established that the 11-25 cm stem diameter size classes were the most utilised amongst a variety of tree species. In addition, size and distance from village were confirmed as being more important selection factors than species (Shackleton, 1993b). This result was consistent with overharvesting of individuals in the 9-14 cm and 14-20 cm size classes across all land-use types in Phalaborwa, as well as fields in Bushbuckridge. Declining numbers in these size classes, mainly for construction timber or fuelwood, require key attention in tree species that appear more abundant. Due to the trait of marula being a strongly coppicing individual, the re-sprout stems make the species appear more abundant (Kaschula et al., 2005). However, as noted by Chidumayo (2002), this misconception may in fact be due to negative human behaviour such as chopping and clearing practices in anthropogenic landscapes, creating a positive feedback loop of overutilisation. The higher levels of harvesting that marula thus experiences are often a direct result of the perception that the trees will easily regenerate. Over time, these misconceptions can lead to long-term population structure damage if not carefully managed (Obiri, 2002).

Across Bushbuckridge, the classes with the least individuals were between 40-70 cm stem diameter, with an increase in numbers of individuals greater than 70 cm in stem diameter. This correlates with earlier SCD profiling for the species by Emanuel et al. (2005), who found at the time that marula numbers declined in the intermediate size classes, with an increase in large adults, then a decline in very large adults. The higher tree numbers in the large adult size classes in 2005 could be responsible for the increased number of trees now over 70 cm in the current dataset. The human legacy of the domestication of wild tree species, which are planted in settlements and then left behind when communities move, is a long established concept (Thiong'o et al., 2002). Human practices play a key role in shaping species distribution across the landscape, as demonstrated by authors such as Shackleton et al. (2003) and Maranz (2009), who attribute human settlements to the presence of the largest trees in rangelands (South Africa) and savanna parklands (Sahel region). Even in conservation areas, some of the larger trees in KNP may be the remnants of human settlements (Helm & Witkowski, 2012), although many of the largest individuals in the region chopped down to make toilet seat covers in the 1950s (Shone, 1979). This dual quality of anthropogenic settlements as both a source of resource stewardship as well as the cause of species degradation, sometimes simultaneously to varying degrees across the landscape, highlights the pervasive implications of human land-use practices on savanna systems (Mograbi et al., 2015).

5.4.1.2 Increased juvenile recruitment and establishment in anthropogenic landscapes

In conservation areas, ecological drivers such as drought, heightened herbivory and intense and frequent fires severely impact seedlings and saplings survival rates, resulting in far lower numbers in the smaller juvenile classes (Helm, 2011). In Bushbuckridge, the negative, steep SCD profile is indicative of a strongly recruiting population (Chapter 3). Abundant juveniles tend to

occur in yards where marula beer is made, or fields that have been cultivated, indicating a strong link between human land-use activities and marula density.

Unlike juveniles in conservation areas, juveniles in yards do not experience fire and thus do not get caught in the fire-trap, which is the ecological mechanism usually responsible for causing recruitment bottlenecks (Helm et al., 2011). Prolific juveniles in yards also experience reduced herbivory (due to the presence of fences), thereby preventing the vast majority getting caught in the browse-trap. Seed predation is also reduced in yards as rodents, usually the main perpetrators, are less common in these more urbanised contexts. In addition, with increased water availability in yards reducing possible water stress, a further contributor to recruitment bottlenecks. The majority of seedlings in Bushbuckridge were typically between 0.3–0.5 cm in basal stem diameter, suggesting they had survived for at least one season. This finding indicates that given the opportunity to establish, these seedlings may recruit through to adulthood. Therefore, unless intentionally removed, these individuals will likely make a contribution to the overall population structure. Gouwakinnou et al. (2009) found similar examples of mass seed germination of subsp. *birrea* in agroforestry systems in Benin (West Africa), resulting in large numbers in the seedling classes. This finding supports the idea that seeds and seedlings in anthropogenic landscapes may experience different ecological impacts compared to those in conservation areas.

In Bushbuckridge, yard sapling mean densities were significantly higher than in fields and rangelands combined. This difference is attributed to behaviours around beer making and leaving discarded kernels (endocarps) in the yards (Chapter 6 & 7). This is a prime example of the financial capital of the resource (beer making) contributing to a higher natural capital (marula densities). This anthropogenic practice acts as a replacement activity for mammalian dispersal, which includes breaking dormancy through digestion. The manual removal of the operculum would therefore occur where the endocarps are crushed, either intentionally to extract the nuts or unintentionally in the extraction process during beer making. While beer making is also important culturally in Phalaborwa, one reason for the lower sapling densities in this context could be lower levels of beer production, with more households selling their fruit to the Distell processing plant. Due to the smallest, mostly ephemeral size class being removed from the analysis, the remaining seedlings and saplings encountered likely represent individual specimens with a higher likelihood of being retained as part of the overall population. This imparts some notion of population stability, as the sapling density exceeds that of the larger maturity classes, conforming to the theoretical inverse J-shaped size class distribution of stable populations (Chapter 3). Low sapling densities in Bushbuckridge fields may be due to a lack of fences, which increases the threat of herbivory by livestock resulting in a recruitment bottleneck. This is exacerbated by the fact that any fruit left under adult female trees in fields is usually collected for beer making, leading to increased dispersal, but reduced recruitment in fields. The negative impacts of the commercialisation of natural resources, including reduced recruitment of juveniles, are described by authors such as Djossa et al. (2008). This is specifically relevant in relation to various NTFP and the resulting reduced conservation of overharvested species.

The fact that not only juveniles in the smallest size classes, but those below the browse and fire-trap height in yards, are protected from the three main ecological drivers of recruitment bottlenecks (water stress, herbivory and fire) allows for the conservation impact to be directly connected with the human stewardship practices resulting in these outcomes. However, where

humans actively remove the seedlings, this would be the anthropogenic surrogate for herbivory in conserved areas. These practices are watering juveniles, fences preventing livestock browsing and a complete lack of fire due to residential plots not being burnt. Duvall (2007) reported a similar finding in terms of tree stewardship for baobabs (*Adansonia digitata* L.) in West Africa. The baobab fruit is highly utilised and prized in these West African communities, resulting in people being responsible for the dispersal of the seeds by discarding them around the villages, where they germinate and recruit through to adulthood. This ability to recruit through to adulthood is as a direct consequence of baobab juveniles being actively conserved in the villages of these Manika-speaking communities, where seedlings are actively protected from livestock herbivory (Duvall, 2007). This finding is contrasted with baobabs in South Africa which do not recruit as well in villages, even when compared to open plains, due to the lack of a robust 'baobab culture' in these communities (Venter & Witkowski, 2010). Interestingly, increased instances of recruitment were found in the Limpopo National Park (Mozambique), a conservation area that contains human settlements (Edkins et al., 2007). The connection made by Duvall (2007) between human cultural behaviours and positive resource impacts is similar to marula in the South African context. In particular, in areas such as Phalaborwa and Bushbuckridge where a 'marula culture' has led to seeds germinating most prolifically around villages, and particularly across yards in Bushbuckridge and fields in Phalaborwa.

Sapling mean densities were highest in fields in Phalaborwa compared to the other two land-use types, likely due to the conditions of cultivation (turned soil and reduced vegetation cover) allowing seeds to germinate. A combination of lower rainfall, combined with high temperatures in Phalaborwa, may mean seeds are not able to germinate as easily due to the compacted, hard, dry crust at the top of the soil profile (Helm, 2011). Helm (2011) details how this creates a barrier to recruitment, thereby affecting the seed bank in the soil. However, other factors such as fire, herbivory and competition with grasses are likely to also impact successful recruitment in rangelands, but to a lesser degree in fields. This is because large herbivores are often excluded by fences, fields are usually not burnt and cultivated fields do not have extensive grass cover. In non-conservation areas, cultivation helps to break dormancy through burial. Cultivation breaks the hard soil layer, enabling seeds to be buried in the soil and thereby germinate. Due to the fruit dropping directly below the parent tree, cultivation of fields enables germination, with periods of leaving fields fallow resulting in an opportunity for these individuals to then establish as part of the population. These results are similar to findings by Byakagaba et al. (2011) in Uganda (West Africa), which indicated that regeneration in shea trees, a tree similar to marula in terms of its socio-economic profile, were highest in recently fallow fields and lowest in fields that were currently cultivated.

Marula have larger seeds and therefore an advantage in the regeneration niche in terms of better dormancy as well as faster growing seedlings which increases their competitive advantage. However, while seeds are able to germinate, factors such as water stress result in very few seedlings actually surviving into their second year, meaning that ecological factors outside of human activity are the main cause of seedling loss from the smallest classes. However, where seedlings are able establish past their second year, due to water availability and the protection afforded by field fences from livestock predation, it is still unlikely that they will recruit through to adulthood in most cultivated fields. This is because while cultivation enables germination, established seedlings are then subsequently removed by ploughing in cultivated fields. Issues such as seed predation are also higher in the field context. It is for these

reasons that seedlings smaller than 0.5 cm in basal stem diameter were removed from the density dataset, with the underlying assumption that seedlings larger than this had successfully recruited. Although this is no guarantee of survival, with saplings also often dug up and removed from cultivated fields, especially before they are able to establish and therefore become too big, or too difficult, to remove. However, where fences are lacking, the presence of livestock may result in bottlenecks due to herbivory in fields, however this does enable mammalian dispersal with ingestion breaking dormancy, thereby allowing seeds to germinate elsewhere.

Sapling mean densities were higher than adults in rangelands in Bushbuckridge, which is to be expected in a typical stable population. In a typical stable population, the size class frequency will represent an inverse 'J', with most individuals in the smaller size classes and the fewest in the largest size classes. In contrast, a very interesting finding in Phalaborwa is the opposite pattern in this context, with adult densities being higher than saplings. This finding could be linked to fruit harvesting in the Phalaborwa context, with the existence of the Distell processing plant in this location until 2019, possibly leading to more intensive fruit harvesting. Intensive fruit harvesting can result in decreased seedling recruitment due to less available fruit on the ground for germination (Djossa et al., 2008). It is likely this trend did not affect the current adult population in Phalaborwa, as they very likely recruited through to adulthood before the processing plant came to exist. The contrast between the population structures in the rangelands of these two contexts highlights the varying impacts of human resource harvesting and utilisation patterns on natural resources. In particular, the population structures suggest negative practices such as continued overharvesting, possibly causing a decline in the status of this common property resource (CPR) in Phalaborwa rangelands.

While recruitment bottlenecks are unique to different savanna woody plant species (Chidumayo, 2013), recruitment bottlenecks severly limit juvenile numbers in conservation areas. Recruitment is supressed in conservation areas due to marula individuals in the 0.5-2 cm size class being affected by fire, whereas browser pressure impacts individuals in the $\leq$0.5 cm size class specifically (Helm et al., 2009). Cook et al. (2017) found only two marula seedlings in a marula focussed study in Jejane Private Nature Reserve, which was attributed to to factors such as seed predation, seedling herbivory and saplings caught in the firetrap. Helm (2011) found marula seedlings (<0.5 cm) at eleven of the nineteen sites in the Kruger National Park; with these individuals even dominating the SCD profile at one site. However, this site was an animal exclosure (fenced area preventing larger mammal interactions with plant species), which due to the presence of a boundary fence, provides similar conditions to yards and fields in terms of protection from herbivores. The 0.5 cm to 2 cm size (sapling) classes were dominant in seven of Helm's (2009) KNP sites, indicating that these individuals had managed to establish past the first year. However, there was a far greater abundance of juveniles in the yard context in Bushbuckridge and field context in Phalaborwa. This confirms that across these non-conservation landscapes, particularly where anthropogenic stewardship influences are most apparent, seedlings in the smallest size classes may experience quite different conditions to their conservation counterparts. The unique conditions offered by non-conservation land-use types enable the smallest seedling classes to recruit successfully at potentially a far greater scale.

Table 5:9: Summary of the various factors contributing to recruitment bottlenecks

Landuse	Germination Barriers	Seed Predation	Seed Dispersal	Water Limitations	Fire	Herbivory
Yard	Endocarps*	Low	Anthropogenic	Low	None	Negligible
Field	Mixed**	Medium	Mixed	Medium	None	Intermittent
Rangeland	Water	High	Mammalian	High	Limited	Regular

* An in tact operculum can be a limiting factor as there is no mammalian dispersal in yards and ingestion by mammals speeds up removal of the operculum

** Cultivated fields may have higher water access and with cattle and goats acting as dispersal agents

This has been confirmed in other contexts, with high harvest populations of the multi-use tree species, *Khaya senegalensis* (Meliaceae) in Benin (West Africa), displaying significantly lower densities of seedlings and saplings compared to low harvest populations (Gaoue & Ticktin, 2007). The reduced number of saplings in fields in Phalaborwa and Bushbuckridge is echoed in the shea tree literature (Djossa et al., 2008) as well as for *S.birrea* subsp. *birrea* (Gouwakinnou et al., 2009). Similarities between all three studies include juveniles being located under the adult tree and large individuals preserved in agroforestry systems, but with saplings forming a missing size class, as seedlings are removed during farming activities. In Benin (West Africa), the mechanism of bulk germination of marula (subsp. *birrea*) is responsible for numerous seedlings in agroforestry systems where large marula trees are maintained in agricultural fields (Gouwakinnou et al. 2009). Due to the greater levels of fruit production, the excess fruit falls to the ground and is buried during ploughing or tilling activities. In Phalaborwa, fields displayed a juvenile-dominated population (59.6%), suggesting a similar mechanism is responsible. However, in contrast to subsp. *caffra* in Phalaborwa, Gouwakinnou et al. (2009) found that saplings and adults from 5-20 cm were almost entirely absent. In Phalaborwa, saplings were found to be abundant, but as with subsp. *birrea,* individuals in the 9-14 cm and 14-20 cm size classes were the most diminished of all the size classes in fields.

While marula trees at undisturbed sites in conservation areas have been shown to display a stable structure, marula trees at disturbed sites only produce fruit at larger stem diameters when compared to those at undisturbed sites (Helm & Witkowski, 2012). The result is less available fruit overall due to fruit production being delayed until trees are larger before they begin producing (Helm, 2011). In non-conservation areas, disturbance caused by human activities, such as bark harvesting for medicine and branch harvesting for fuelwood could be creating a similar effect, which is then compounded by the overharvesting of fallen fruit on the ground. Anthropogenic behaviour such as the overharvesting of fruit, impact recruitment directly, due to a lack of available fruit left under the parent trees (Djossa et al., 2008). Juveniles in rangelands are not dispersed as widely as those in conservation areas, where large mammals distribute the seeds in their dung, with as many as 25% of juvenile trees in rangelands growing below the parent tree (Helm et al., 2011). In this study, all seedlings in the smallest size classes measured were found below an adult parent tree. Where all the fruit is removed under the marula tree, diminished recruitment follows due to the seed bank for the current season being based on the fruit crop from the previous season (Helm, 2009). Emanuel et al. (2005) indicated that as much as 92% of marula fruit could be harvested before the population is unduly affected. The adult-dominated populations in Phalaborwa, in both yards as well as rangelands, possibly confirm this finding of diminished recruitment. The possibility is that the economic driver, shaped by the financial capital of the fruit, may have resulted in less than the required 8% of fruit being left on the ground, thereby reducing germination potential. Despite the high number

of juveniles in yards in Bushbuckridge, there was low regeneration across fields, which were adult-dominated. It will take time to ascertain if the yard individuals are able to recruit through to adulthood and therefore contribute positively to the overall population structure in Bushbuckridge. In order to obtain this information, long-term comparative studies are required, illustrating the importance of these type of studies for species conservation. If the overwhelming majority of the juveniles (seedlings) do not reach adulthood then this would suggest that in reality, regeneration in Bushbuckridge is weak and potentially of concern in terms of long-term population stability.

5.4.1.3 Bring back the giants: land-use impacts on larger marula trees

The seminal research by Helm (2011) on the age of marula trees in the Kruger National Park, found that individuals greater than 80 cm in basal stem diameter are likely in excess of 334 years of age. This means that a tree of 14 cm in stem diameter is approximately 59 years old. This study located 117 large adult trees in Phalaborwa and 196 large trees in Bushbuckridge greater than 70 cm (with the largest tree measuring 125 cm in basal diameter). These findings would suggest that marula trees in non-conservation areas may potentially be even older than those in conservation areas.

Human alteration and modification of savanna systems, is evident across the landscape but is perhaps most evident in the erosion of density gradients in rangelands around settlements, observed by Shackleton (2005). Specifically, the decline of larger individuals within the population is concerning, which is due to human land-use activities. Chidumayo (2002) identifies land clearing and tree chopping practices as the most direct causes of larger tree removal. In the lowveld context, while larger adults are removed to build or extend houses in yards, it would seem that the greatest risk to these trees are in arable fields, where they are removed for planting purposes, as well as in rangelands where they are utilised for fuelwood. The long-term damage to savanna systems of growing fuelwood demand was raised by Shackleton et al. (2003) and echoed by Matsika et al. (2012), with rampant usage creating on-going cause for concern. This would support the premise that at present only 7% of current fuelwood demand is being met by the collection of dead wood in the greater Bushbuckridge region (Mograbi et al., 2015). Therefore, the high levels of harvesting of not only dead marula trees, but also live marula trees within this context, indicate the extent of the fuelwood crisis (Madubansi & Shackleton, 2007).

Large adult tree numbers were higher in the rural context, possibly as a result of space for larger trees, combined with increased instances of traditional practices, which likely lead to the preservation of larger individuals. The lower levels of larger adults in the peri-urban context may confirm the erosion of customary law, with the value of the older and larger trees being eroded along with cultural practices.The lower proportion of large adults in yards, especially in Bushbuckridge, is an unexpected and concerning finding considering the cultural value placed on marula. It was assumed that the biggest and therefore oldest trees would be protected in people's yards given their use for various cultural practices, or otherwise as the land shrines of individual families (Shackleton et al., 2002). Numerous studies have even suggested that larger individuals in yards, including marula, are an indication of domestication, with fruit or seedlings from larger, more prolific fruiting individuals previously having been selected and planted (High & Shackleton, 2000; Shackleton et al., 2003; Emanuel et al., 2005). However, there appears to be pervasive removal of larger individuals in yards is due to the underlying roots and overhanging branches posing a substantial risk to buildings (Chapter 7). This perspective, as well as the

reality of the biological characteristics of the tree, may be negatively affecting the number of larger individuals as a proportion of the overall population across this land-use type. Large tree numbers may also be declining in yards due to a decisive lack of planting, with respondents indicating these trees are being replaced by domesticated fruit tree species such as mango (*Mangifera indica*). Mango is often the preferential choice as it provides the dual economic value of being eaten by household members, thereby saving on purchased produce, as well as being sold for direct income (Paumgarten, 2005). Respondents indicated that given the option, mango is the favoured choice in terms of an edible fruit when compared to marula (Chapter 6). Two decades prior to this study, High & Shackleton (2000) already found that mango provided a higher average income across the households surveyed, with 82.3% of households choosing to grow mango, compared to the 40.3% growing marula.

The variability in large tree numbers in fields is likely due to differences in field cultivation histories between locations. Fields are likely more regularly cultivated in Bushbuckridge due to higher rainfall, resulting in larger individuals being left around the periphery over time, as trees in the middle of fields are removed to make space for crops. Once trees reach a certain size, usually 40 cm to 80 cm stem diameter, they are usually left alone as they are too large to remove easily (Nghitoolwa et al., 2003). Djossa et al. (2008) confirmed that the highest proportions of the largest trees were located in farmed land in Benin. In contrast, in fields that are irregularly cultivated, when a field is suddenly utilised after a period of time, any larger trees that are in the way will be removed. This means that in newly acquired fields, there are likely to be higher mortality levels, as space is cleared for arable purposes. In the current study, the largest tree measured was located in a Phalaborwa field, despite the highest proportion of large trees being in rangelands (43.4%) in this context. In Bushbuckridge, the largest tree measured was in a yard, but the highest proportions of large trees were located in fields (30.2%). This would confirm Gouwakinnou et al. (2009) findings that larger individuals are left in agroforestry systems, but that smaller adults are removed to make space for crops.

Interestingly, Nghitoolwa et al. (2003) observed the opposite finding for subsp. *caffra* in Namibia (southern Africa), where trees $\leq$40 cm were found to be tolerated in agroforestry systems. The authors postulate this allowance may be an attempt to ascertain if these trees will bare fruit, but above this size the trees are removed in order to allow more light and water for crops, as well as to favour use of mechanical equipment (Nghitoolwa et al., 2003). However, the authors confirmed that the largest trees appear to remain uncut, as is the case in the South African context. In addition, Nghitoolwa et al. (2003) confirm that the combined influences of anthropogenic thinning, increasing fire intensity and drought mortality are impacting large trees which are the most prolific seed sources, causing negative implications in terms of population regeneration. Considering these findings, it is perhaps unsurprising that the largest individuals are to be found in rangelands in Phalaborwa, with rural rangelands comprising the majority of large adults (53.5%). Shackleton et al. (2003) extrapolate that the higher numbers of very large adults in communal rangelands may be attributable to trees that were originally planted in homesteads and then abandoned when communities relocated.

5.4.1.4 Potential impacts of a changing climate on marula population structures

The impacts highlighted above are likely to be compounded by climate change, with increasing number of drought years exacerbating the current anthropogenic pressures on savanna systems (Engelbrecht & Engelbrecht, 2016). Current key pressure factors on these human occupied savanna systems include high human population density, which Khalid et al. (2013) confirm

contributes to soil erosion, elevated livestock numbers, increased rainfall run-off and loss of grass and canopy cover due to poor land-use management. However, on-going severe droughts may in fact reduce livestock numbers which could also negatively impact recruitment through diminished mammalian dispersal. Over time, these stressors are likely to impact the longevity of marula populations so that older trees may appear to be 'disappearing' from the population, as observed in Chapter 7. In addition, with fuelwood reliance as high as 90-95% of households (Madubansi & Shackleton, 2007), the growing issue of fuelwood markets and 'outsider' harvesting (Twine et al., 2003) is increasingly of concern. This is of particular concern in Bushbuckridge where fuelwood use remains as high as 92.2% (Ragie et al., 2020). This study therefore confirms that the consequence of these combined factors is that marula is increasingly a target for chopping, as one of the larger tree species in the savanna landscape. It is this exact nexus of factors that have led authors, such as Madubansi & Shackleton (2007) and Matsika et al. (2012), to attribute not only woodland, but also overall savanna degradation in the Bushbuckridge region, to fuelwood drivers as a destructive land-use activity. Over time, these changes create what Shackleton et al. (2008) refer to as a land-use impact landscape, a key example of which is the accelerated decline in the largest trees as fuelwood harvesting intensifies. This is a prime example of a shift in the socio-ecological system occurring at difference scales, in this case the temporal scales of increasing climate change highlighted globally, compounded by the social variables of land-use practices and resource harvesting demonstrated locally.

Marula seedling regeneration is usually considered to be continuous (Jacobs and Biggs, 2002), with the current seed bank based on the previous season's fruit crop (Helm et al., 2011). It is important to explore the impact of temperature and rainfall on both seedlings, as well as larger and thus older adult individuals as prolific seed sources (Nghitoolwa et al., 2003). Venter & Witkowski (2013) stress the impact of rainfall, on both recruitment, as well as large tree senescence in baobabs. These findings are particularly applicable to marula, with the persistent seed bank characteristic of marula being reliant on the quantity of fruit from the previous season, which is rainfall dependent (Helm et al., 2011). Shackleton (2002) explains how fruit production is based on the soil moisture from the previous season's rainfall, linking fruit production and persistent seed banks in two-yearly regenerative cycles. This means that not only rainfall variability, but also extended drought years, could have a devastating long-term impact on marula regeneration and thus population structure.

Germination is climate dependent and likely to be negatively impacted by increasing temperatures, with marula's climatic envelope for germination being 27-37°C (Murye & Pelser, 2018). It is yet to be confirmed if marula responds in a similar manner to mango (*Mangifera indica*), with increasing temperatures resulting in increased fruit production (Fitchett et al., 2016). Reduced regeneration has been explored in baobabs, as well as large baobab mortality being linked to climate change (Patrut et al., 2018). This finding of increased adult mortality has been confirmed for marula, specifically in terms of rainfall variability (O'Connor & Goodall, 2017). It is therefore unsurprising that the hotter and drier Phalaborwa had positive SCD slopes overall, indicating weak regeneration. These positive slopes are possibly the result of both seedlings, as well as the larger individuals as the source of seeds, being negatively impacted by hotter and drier conditions. Shackleton's (2002) work linking fruit production with soil moisture content from the previous season further reinforces that climate change, and specifically rainfall variability, impact marula viability on both ends of the life spectrum. The

climatic envelope of species, such as marula, are a key cause for concern under accelerated climate change with both rainfall and temperature patterns shifting. While Akinnifesi et al. (2008) confirm that marula is adapted to infertile soils and unimodal rainfall; extended drought conditions will result in large tree mortality (O'Connor & Goodall, 2017). The long-term results are possibly senescing savanna parklands as a consequence of permanent shifts in climatic zones, such as in the Sahel region (Maranz, 2009).

The higher human densities in Bushbuckridge, result in encroachment into available rangeland for conversion into residential plots and arable fields. Rangeland conversion usually results in vegetation clearing, which in turn causes a rapid decrease in density. With increasing rainfall variability linked to climate change, in a season with good rainfall, larger trees in newly converted fields are also more likely to be removed with immediate effect to make space for crops. Furthermore, any available fields are more likely to be utilised, which results in any new recruits, in the form of marula seedlings, being removed when the soil is tilled for planting. The higher rainfall levels in Bushbuckridge also likely correspond to higher levels of agricultural activity, with water being a limiting factor in crop production. Bushbuckridge had a higher number of fields observed to be currently cultivated, with a population that was dominated by adults (58%), thereby confirming the removal of juveniles in this context. Higher field utilisation correlating with lower juvenile numbers was confirmed for both subsp. *birrea* in Benin (Gouwakinnou et al., 2009), as well as for the shea tree in Uganda (Byakagaba et al., 2011). Cultivated fields displayed the lowest levels of regeneration due to the removal of seedlings and saplings. However, field usage is not always concurrent from one season to the next, which often means that cultivation (tilling the soil) and then leaving a field fallow for a season or two may actually encourage recruitment, by allowing seeds to establish as well as survive past the first few precarious seasons. However, the ability for seeds to be sown when field soil is tilled is a land-use practice that is likely to decrease with climate change. This is due to increasing temperatures and decreasing rainfall, making it impossible to harvest crops in areas already severely water restrained.

5.5 Conclusion

Marula population structures in non-conservation areas of Phalaborwa and Bushbuckridge indicate that populations are currently stable. The data indicated a stable population, which displayed a range of demographic classes across all land-use types. In addition, populations displayed healthy proportions of mature trees and significant numbers of juveniles in the sapling size classes. Although only Bushbuckridge yards displayed high numbers of new recruitments, this does not necessarily mean the population is not stable. Marula trees are typically longer living trees, meaning that even where recruitment levels are lower (such as in Phalaborwa) this has not resulted in any missing or severely diminished size classes. However, of more concern is the possibility that reduced recruitment is a more recent phenomenon, and that will take time to reflect in the larger size classes. This outcome stresses the need for long-term monitoring studies to record these changes in population structure. Reduced recruitment could be as a result of a reduction in stewardship practices linked to declining customary practices, as well as climate variability impacting germination (Shackleton, 2002; Helm, 2011). Based on the current recruitment levels, specifically with larger numbers of seedlings being sustained across yards within Bushbuckridge, current population levels are likely to be maintained.

Data suggest that recruitment and specifically seedling establishment is being enabled in yards due to discarded kernels from making marula beer (Chapter 6), and in fields where cultivation activities such as turning the soil enables germination. The majority of seedlings are at the upper end of the seedling spectrum, in terms of stem diameter, suggesting that they have not been removed for at least one season. Given the opportunity to establish and recruit beyond the early bottleneck stages, these individuals have the potential to contribute meaningfully to the adult population. While large individuals are more numerous than anticipated, the lower number of large individuals in yards is cause for concern, with this land-use type typically being where cultural conservation is most likely to occur. Large individuals also showed a decline in the rangelands in Bushbuckridge. In addition, overharvesting of intermediate adult trees is apparent across all land-use types in Phalaborwa, as well as fields in Bushbuckridge. This is likely driven by increased resource pressure due to growing human populations. While overall population structures appear stable, overharvesting of specific classes could result in not just missing classes over time, but also longer-term damage to the stability of the population as a whole. In addition, the compounded effects of a changing climate with longer, more intense droughts could have severe impacts on a species already at edge of range provenance.

More information is required to understand the compounded factors that trigger reduced recruitment in marula in non-conservation areas, as well as the impact of prolonged drought on older trees. Climate change and specifically rainfall variability (O'Connor & Goodall, 2017), is likely to negatively affect both future recruitment as well as older tree senescence, thereby compromising overall population stability at both ends of the life spectrum. The low seedling numbers in Phalaborwa yards and low large adults in Bushbuckridge yards already provide evidence of potential future instability if not addressed. These findings suggest an important disconnect between tree stewardship and population structure, which is likely to be exacerbated by increasing climate variability. Current knowledge on population structures in non-conservation areas can help to inform resource management decisions, while simultaneously serving as a valuable baseline for future population studies. In villages, where marula populations are currently nurtured due to the marula culture built around this resource, engaging traditional authorities and understanding cultural practices should be incorporated into future studies.

6. To Sell or Not to Sell: Livelihood Strategies Governing Resource Use within the Complex Socio-Ecological System of the Informal Marula Bioeconomy

6.1 Introduction

The human inhabited semi-arid savanna ecosystems of South Africa are prime examples of complex socio-ecological systems (SES) (Paumgarten, 2005; Kirkland et al., 2007). Across these savanna systems, patterns of resource use are maintained by transactional decisions based on reliance of key resources such as marula (*Sclerocarya birrea* subsp. *caffra*). Within the socio-ecological system of the marula bioeconomy, complex patterns of resource use and dependence have developed, governed largely by the economic value of the resource. Understanding the economic role marula plays in livelihood sustenance across savanna ecosystems is important for establishing the overall resource utilisation landscape. Households in these mainly rural communities have highly diversified livelihood strategies, which incorporate formal and informal employment where possible, but with significant reliance on natural resources from the savanna ecosystem and heavy subsidisation by state grants for child support and pensioners (King & Peralvo, 2010). Within these savanna ecosystems, marula trees (*Sclerocarya birrea* subsp. *caffra*) provide key natural resources which are utilised for both livelihood support and sustenance, but increasingly are being over utilised due to land-use pressures and resource limitations (Shackleton, 2005; Matsika, 2012). Interrogating this interplay, specifically the degree of dependence between resource users and the resource, helps to uncover inherent winners and losers. This is necessary to determine how livelihoods are sustained based on this important non-timber forest product (NTFP). These lessons can then be applied to other contexts where human-resource reliance, based on a key NTFPs, operate to sustain livelihoods.

6.1.1 Human utilised savannas as complex socio-ecological systems

Savannas provide a range of natural resources due to their composition as complex tree-grass ecosystems (Mograbi, 2015). Across the Kruger to Canyons (K2C) Biosphere Region of the South African lowveld, natural resource reliance is a key component of livelihood strategies. Rural communities living in these areas utilise natural resources for a variety of reasons. The utilisation of these resources include as a fuelwood source and a range of domestic products, such as wild foods, thatching grass and poles for both fences and construction (Kirkland et al., 2007). Importantly, NTFP items provide a vital source of income and cash savings for the poorest households (Shackleton et al., 2002). This is not only applicable to the poorest households relying on essential resources for food and income, but also the slightly wealthier households, able to utilise a wider range of natural resources (Twine et al., 2003; Makhado et al., 2009). Households that rely heavily on natural resources are often vulnerable to any shocks to the system, such as recurring drought. This is amplified where the system is unable to recover in the short-term (Shackleton & Shackleton, 2004; Walker et al., 2004; Poppy et al., 2014). While rural communities apply various livelihood strategies for daily survival, most incorporate natural resources, highlighting the interconnectedness of communities and their immediate environment (Shackleton & Shackleton, 2002; de Sherbinin, 2008; Paumgarten et al., 2011).

Livelihood strategies result in two-way interactions based on the reciprocal use of the resource and the resultant impact of the utilisation on the immediate environment (Belcher & Vantomme, 2003; Kaschula, 2005). Harvesting is a disturbance activity that has ecological implications for the resource and landscape as a whole (Mograbi, 2015). Harvesting behaviours are the first level at which a natural resource is disturbed. In relation to marula, this pertains to fruit harvesting impacts, as well as the chopping of branches and the felling of whole trees for fuelwood purposes. The second level of disturbance is at a landscape level and relates to the large-scale removal of the resource altogether. This removal includes chopping marula trees to make space in homesteads (yards) to build houses, in fields to plant crops or in rangelands, where they are felled for fuelwood markets.

The negative implications of resource overutilisation are not a new phenomenon, with people playing an influential role in altering both landscapes and land cover for centuries. The impact of indigenous people, on both woody species distribution and composition in savanna ecosystems, is probably much greater than previously thought (Maranz & Wiesman, 2003). Specifically, communities take resources with them when they move. This not only alters the landscape but the historical range of a species can therefore be linked to human migration. Humans and marula have had a long history of use and dependence in southern Africa, dating back millennia. There is archaeological evidence to suggest human ancestors, as far back as 10 000 BC - 9000 BC, consumed marula fruit (Palmer & Pitman, 1972; Shone, 1979; Chirwa & Akinnifesi, 2008). Furthermore, Stone Age marula kernels were found in cave excavations in Zimbabwe (Hutchings et al., 1996). Marula endocarps have also been found in all layers of cave excavations, including unbroken marula kernels at Mapungubwe Hill, on the banks of the Limpopo River. This provides further evidence of extensive marula use and consumption over the past 1000 years (Palmer & Pitman, 1972; Scott, 2005). Human consumption and use of marula based on it's cultural and economic value has created a continuum of trees from wild to 'domesticated', with evidence of selection of trees with bigger fruits in human dominated environments (Shackleton et al., 2002). Furthermore, human resource choices have created what Maranz & Weisman (2003) refer to as indigenous parkland, essentially a landscape of random but well-spaced trees. These landscapes have resulted from indigenous 'farming' practices, in which major economic species such as marula are maintained and protected, while others are removed or neglected. In turn, human resource choices affect biological traits such as gender ratios through resource selection. Overutilization can ultimately result in stem, branch or bark damage and even tree mortality.

6.1.2 Exploring marula resource use within a changing socio-ecological savanna landscape

Humans alter savanna landscapes in non-conservation areas through land-use practices, which are based on specific behavioural choices based on land tenure. Land tenure in this context pertains to the nature of the relationship that individuals or groups of people hold, in relation to land and land-based resources, as well as any local customary rules that define the ways in which access to land is allocated, transferred, used or managed. The legacy of the former Apartheid Regime is that the "Homelands" were traditionally located on poor agricultural land, with limited yields as well as restricted land availability. This has in turn resulted in ever increasing pressure on the already heavily utilised land, which needs to be made available for on-going housing and agricultural expansion (Mograbi et al., 2015; Coetzer-Hanack et al., 2016). Across the rangeland areas of the lowveld, settlements are usually under traditional authority land tenure. Under the governance of local traditional authorities, communal landscapes were

historically demarcated into residential land, arable fields and communal rangelands. Across these different land-use types, specific resource behaviours and choices governed resource use. The eight villages analysed in this study are a prime example of an eco-social landscape, where ecological and social variables intersect to shape resource utilisation. Each land-use type is shaped by specific behavioural patterns based on access, availability and attribution of value to the resource. The institutional issue of control means that while open access rangelands are accessible, marula is depleted faster due to compounded resource pressure. Over time, this has resulted in limited availability of other fuelwood options (Matsika et al., 2012). Alternatively, marula trees in yards are not accessible to all in the community, with many of these trees being maintained and even planted due to the economic and cultural value attributed to marula. This is specifically true of the female marula tree, which is valued both economically as well as culturally (Shackleton & Shackleton, 2005).

Landscape ecology promotes the supposition that any given social system is inextricably linked to its specific ambient ecological surrounding. Combined, these systems are able to self-organise as well as co-evolve to form one unified landscape (Kaschula, 2005; Ostrom, 2009; McGinnis & Ostrom, 2014). Social and economic dimensions are therefore an integral part of the global ecological order, which is impacted as much by biophysical as socio-cultural factors (Polasky, 2008). While ecological drivers of change across savanna systems are reasonably well understood, socio-economic drivers of change remain less so (Liu et al., 2007; Schluter et al., 2014). In addition, while there has been a plethora of work done on how the environment responds to human changes, fewer studies exist entailing how humans react to environmental change at the local level (Redman, 2004). This is particularly important when considering the crucial livelihood support role that natural resources, such as marula, provide for local communities. As climate change impacts continue to affect important natural resources upon which human societies rely, understanding how economic drivers influence resource use is a key knowledge challenge. In addition, understanding how resource availability impacts rural communities, is a key component of ensuring these contexts remain sustainable. Specifically, the uncertainty surrounding human response behaviours to local environmental change remains poorly understood (Schluter et al., 2012; Melnykovych, 2018). Gaps exist in current understandings of how resource use patterns impact natural landscapes and in turn how declining resources impact livelihood strategies in different contexts (Twine et al., 2005). To truly interrogate these co-evolving systems, requires embedding marula use within its specific socio-economic context to uncover the reliance patterns of the marula resource users. In addition, it is necessary to examine the resilience of the resource users to any shocks to the system (Shackleton et al., 2011).

The economic value of a natural resource can thus be used as an indicator to gauge potential harvesting intensity, with higher value commodities experiencing higher levels of utilisation (Gaoue & Ticktin, 2009). More extensive indicators are required to monitor biodiversity and in particular eco-system services, in order to develop common monitoring schemes combined with longer-term observations (Feld et al., 2009). In particular, savanna rangelands are continually under resource utilisation pressure from the combined influences of land-use intensification, settlement expansion and climate change (Scheiter et al., 2019). This study aims to build on previous research investigating the potential consequences of the two-way interactions inherent in socio-ecological systems. In particular, a key focal area is how local economic value can impact biodiversity conservation. Specifically, the role of marula as a natural resource in

sustaining local livelihoods is interrogated as well as how utilisation of the resource differs across the landscape. Sustainability of a resource is ultimately based on the interlinking contextual social, ecological and economic factors (Binder et al., 2013; Steele et al., 2015). This begs the question - how to promote biodiversity conservation and resource utilisation simultaneously?

6.1.3 Marula populations as a feature of land-use and resource choices

Wild foods and fuelwood are considered the most important forest products that rural communities rely upon, not just for current consumption, but also as pathways out of poverty (Vedeld et al., 2007). This is demonstrated in people's homesteads, with huge investment by the rural poor in their gardens, including planting fruit trees such as marula (Paumgarten, 2005). In semi-arid, agro-ecological regions, such as the human inhabited savanna landscapes of South Africa, the highest densities of trees in yards are maintained for edible fruit. Despite endemic drought, erratic rainfall and low quality soil, the trend is towards high-value exotics being favoured over indigenous trees (Paumgarten, 2005). Marula is the exception to this rule, as an indigenous variety with a higher economic worth (Shackleton & Shackleton, 2005). While factors such as water availability limit stewardship practices, cues to care (Nassauer, 1995) are behaviours people demonstrate to show pride in their yards. These activities express care and pride in the natural resource, such as sweeping around a large tree. These practices may be amplified where the resource has a higher economic value to the household. Even the poorest households will still invest time and resources in planting, watering and caring for trees (McHale et al., 2013). This often leads to enhanced species richness, as opposed to the common narrative of environmental degradation and resource depletion (Hardin, 1968). Natural resources in coupled human and natural systems therefore need to be understood holistically (Reyers et al., 2012). This means the characteristics of a natural resource such as marula, include its contractual agency, which needs to be incorporated into conservation planning and management approaches (Thiel et al., 2012). To do this requires delving into the economic contribution of natural resources to local livelihoods. Firstly, to interrogate how the financial capital of the resource shapes the utilisation context, but also to aid in species conservation.

Marula is a key example of a NTFP natural resource at the centre of a complex web of social and ecological linkages. This is premised on its prominence as a keystone species from an ecological, social and economic perspective (Shackleton et al., 2000; Shackleton, 2004; Sunderland et al., 2004, Shackleton et al., 2007; Wynberg et al., 2002). Marula is utilised as a key natural resource, as well as being culturally revered by many of the Tsonga, Sepedi and Venda communities of the lowveld region of South Africa (Wynberg et al., 2003). Marula forms a key aspect of livelihood sustenance for many rural households. This is mainly due to the economic value of the fruit, which is the prized ingredient in two alcoholic beverages with quite diverse backgrounds (Shackleton, 2002; Shackleton et al., 2002; Wynberg et al., 2007). Marula fruit is fermented locally and made into a culturally significant beer, which was previously taboo to sell, but has been sold informally in more recent times (Shackleton, 2001; Shackleton & Shackleton, 2005). The use of marula products to replace household groceries, such as jam or juice, also offer an alternative to purchased goods for the poorest, who often cannot afford the cash expense (Kirkland et al., 2007). In addition, products such as marula jam and nuts are often sold locally within the communities for additional subsistence income (Shackleton et al., 2001). Marula fruit is therefore heavily harvested in the lowveld for a variety of reasons. Marula fruit is also sold formally to Distell, the makers of the internationally purchased liqueur, Amarula Cream

(Shackleton et al., 2001; Shackleton et al., 2003). This means that marula trees are not only an important aspect of the geographical landscape; they form an integral part of the economic and cultural landscapes (Kaschula et al., 2005; Giannecchini et al., 2007). Combined, these create a unified eco-social landscape (Kaschula et al., 2005).

Utilisation of a natural resource for the purposes of development is only said to be sustainable if "the sum of the capitals (financial, social and natural) does not decrease as a result of the action" (Scholes, 2009:114). To understand if the marula eco-social landscape is sustainable requires not only quantitative data regarding the natural resource, but also qualitative data about its specific uses (Polasky, 2008; Shackleton& Pandey, 2014; Pandey, 2016). In particular, understanding the key characteristics of the resource users is necessary to gauge the nature of contractual agency within the system (Thiel et al., 2012).

In conjunction with empirical data regarding a natural resource like marula, qualitative concepts of meaning and value, based on the financial capital of the resource, can help provide a deeper understanding of the eco-social landscape (McHale et al., 2013). The lowveld marula bioeconomy catchment is therefore one such context, where the "ecological questions are infused with a discursive understanding of the construction of ecological knowledge and the power and pressures behind choices and decisions regarding people's cultural and physical environment" (Kaschula et al., 2005: 412). Resource use patterns are not only informed by human-resource interactions, but also intergenerational human interactions, specifically in terms of cultural perceptions differing between generations (Møller et al, 2002; Bohman et al., 2009). Inherent in this approach are the thresholds and feedback loops that drive system change (Biggs et al., 2015). Socio-spatial changes therefore require linking ecosystem changes with the social behaviours that drive these shifts (Arnold & Perez, 2001; Scheiter et al., 2019). In a complex socio-ecological system, this can be done by noting not only the differences, but also the similarities between the resource units in the resource system (Ostrom, 2009). Differences in the resource units (marula) across the resource system (the savanna ecosystem) help to uncover the underlying resource use patterns that have shaped the resultant resource system. Central to this approach is weighing the impacts of the economic value of the resources against the resilience of the system (Stokols, 2013).

6.1.4 The economic contribution of non-timber forest products such as marula

Shackleton et al. (2007) classify the uses of natural resources for economic purposes into three distinct classes: 1) a source of basic needs such as nutrition, 2) cash savings on purchased resources and 3) a safety-net in times of shock. Often product reliance begins as a safety net but then evolves into a livelihood income strategy. Livelihood income strategies can either be subsistence or supplementary (Belcher & Ruiz-Perez, 2005). A subsistence strategy provides most of the household's livelihood, whereas a supplementary strategy is a secondary livelihood source, supplementing the main source of income. Where either strategy is successful, the next level of poverty alleviation is the actual reduction of overall poverty. This means the resource user is able to improve household circumstances through the commercial value of the natural resource (Belcher, 2005). Usually, a household utilising NTFPs for supplementary income will rely on these resources for less than 50% of their total household income (Ruiz-Perez et al., 2004). Due to marula's seasonality, reliance on marula would usually be regarded as supplementary, considering it is not available for the remainder of the year. When natural resources such as marula are sustainably used and managed, they can help to form the basis of

ecological integrity within complex socio-ecological systems (Kirkland et al., 2007). As a source of natural capital, together with social, human and economic capital, these resources can contribute towards the integrity of socio-ecological systems that are adaptive and thus resilient (Deutsch, 2003; Rolfe, 2006; de Sherbinin, 2008; Stokols, 2013). As such, natural capital resources increase economic capital. But even more critical for the poorest, they act as a safety-net in times of shock, such as the death of a breadwinner or endemic drought (Belcher, 2005; Paumgarten, 2005; de Sherbinin, 2008; Shackleton et al., 2007). This is particularly relevant for households in low rainfall and thus low productivity agro-ecological zones (Mugido & Shackleton, 2017). Examples of these low productivity zones, include those settlements based in semi-arid savanna ecosystems, which are the focus area of this study (Shackleton et al., 2008).

A large oversight in development policy historically, are the enormous cash savings that natural resources such as marula provide, not just for poor households but also for Government (Shackleton & Pandey, 2014). Shackleton (2004) highlights that while agricultural extension services exist for arable crops and animal husbandry, no such multi-level and sectorial approach exists for NTFPs like marula. This is despite the reality of how critical NTFPs are for meeting the everyday basic needs of the poor. Shackleton & Shackleton (2004) highlight the high financial subsidies (several billions of Rands annually) that would be required from Government to furnish the same needs that natural resources freely provide for rural communities. The current social grant system in South Africa provides a vital safety-net for the poorest households by providing financial subsidies. These are specifically for vulnerable socio-economic groups such as children, the elderly and the disabled (Neves et al., 2009; van der Berg et al., 2010). In particular, the grants for children and pensioners have ensured that the poorest households affected by the HIV/Aids pandemic, especially in rural South Africa, have been able to put food on the table despite adults of working age either being severely ill or otherwise deceased (Booysen, 2004). Household compositions in rural South African often involve extreme examples of intergenerational dependency, such as the elderly taking care of young children, young children caring for their elderly family members or child-headed households (Madhavan & Schatz, 2007). While providing fundamental support, the small size of these grants, coupled with high unemployment levels are barely sufficient to keep most households above the poverty line (van der Berg, 2002; Altman et al., 2009). This results in widespread household food insecurity. It is for these reasons that gaining food or income from a free resource, other than the opportunity cost involved in harvesting, allows poor households to invest what little cash they do have available into other fundamental items (Shackleton & Shackleton, 2004).

According to the Poverty and Environmental Network, rural households derive as much as 25% of their income from natural resources (Sunderland, 2017). In addition, women play a central role in income generating activities associated with land-use practices (Dovie et al., 2005; Shackleton et al., 2011). The greater majority of those involved in woodland resource extraction are female. This amount is even higher for the many households relying on marula for income in the lowveld, with the majority of those collecting and utilising the fruit being women (Shackleton & Shackleton, 2005). Due to the complex nature of rural poverty, households are often vulnerable to a range of shocks, with limited contextual data regarding the actual depth and breadth of NTFPs use as an actual safety-net (Paumgarten, 2005). Shackleton and Shackleton (2002) focussed on the important subsistence value of marula as NTFPs, highlighting natural goods as a key component of resilience building. Product reliance often starts out as a

safety-net in times of emergency, but evolve into viable livelihood options (Shackleton & Shackleton, 2002).

In order for a natural resource to provide sufficient livelihood support, the nexus of quantity, quality and access must be simultaneously met (Milgroom et al., 2014). However, commercialisation of a resource is not always the panacea it is proposed to be financially. Due to the complexity and length of supply chains, commercialisation of NTFP often has little direct cash benefit for the primary producers (Pandey, 2016). Marula is a case in point, with the actual fruit collectors and custodians of the trees receiving a marginal amount in terms of financial compensation. This is particularly true in relation to the economies of scale generated by commercial enterprises utilising the fruit for various products. Commercial off-takers of marula fruit are able to offer relatively low prices as compensation for fruit collection due to the abundance of the fruit, which means the market is easily saturated at present. As a result of these large-scale industries, the resultant intensive marula fruit gathering can have genetic impacts on the species. This includes a type of reverse selective planting, whereby most of the fruit is collected from individuals with traits like larger fruit size, leading to fewer of these trees being able to recruit successfully over-time (Arnold & Perez, 2001; Shaanker et al., 2004). However, this is mitigated to a certain degree by households selectively planting trees with larger fruit size, resulting in 'domesticated' varieties of the species, which are specifically prized for their biological traits.

The opposite end of the commercialisation spectrum is that as a valuable resource continues to deplete, domesticated or synthetic alternatives are often sought as replacements. This leaves local communities worse off than they were to begin with due to the removal of the vital safety-net created by the initial reliance on the resource (Arnold & Perez, 2001, Belcher & Schreckenberg, 2007). Once again, marula is a prime example with the potential commercial cultivation of marula placing countless households at severe risk of crucial income loss, should this ever materialise at scale (Wynberg et al., 2003). Even where a resource is abundant, it can lead to poverty alleviation deficits. Oversupply of a resource can leave many poorer communities entangled in a poverty trap when the resource starts to lose value. This requires greater levels of harvesting and human capital input in order to harvest ever-increasing amounts to meet income needs (Belcher & Schreckenberg, 2007). There is also the very real risk of any adequate financial gains not going to the intended beneficiaries. Instead these gains often flow to the large corporations with the capital to generate and sustain the necessary supply chains (Belcher & Schreckenberg, 2007). However, there are some examples where it has worked relatively well, such as in relation to the baobab trade in South Africa (Venter & Witkowski, 2013b).

In response, more nuanced management approaches to resource utilisation are required, including studies to accurately understand the actual harvesting and management practices applied by local people (Ticktin, 2004; Ndangalasi et al., 2007). In addition to a wider variety of management approaches being required, intra-community socio-economic differences are also seldom taken into account. This pertains to variations in response strategies to different shocks, as well as individual experiences of the stress factors placed on these resources (Paumgarten & Shackleton, 2009; Paumgarten & Shackleton, 2011). The use of marula by communities therefore exists in a complex setting of resource governance, which requires both greater contextual as well as differentiated interrogations.

With the potential to reduce poverty while building resilient livelihoods, increased data on marula resource use, the amounts required and frequencies of harvesting deemed necessary to support subsistence livelihoods are required. While studies addressing these issues have been implemented previously, there has not been an updated inventory of marula resource reliance for over a decade. This is important because marula continues to be used as a key livelihood support strategy and is likely to be impacted by any environmental shocks, such as temperature and rainfall shifts caused by climate change (Helm, 2011; Mograbi et al., 2015). Quantifying the economic value of marula to communities, while simultaneously understanding different livelihood strategies, helps to create a profile of marula's role in livelihood support. In addition, this crucial information can be used to understand what future scenarios, where marula is impacted by climate change, might mean for communities whose resilience is closely connected to this resource.

Understanding the extent of community reliance on a NTFP such as marula, particularly as a natural resource that is widely utilised across the savanna landscape, is therefore a key knowledge challenge. To understand this reliance requires localised investigation of the five socio-economic factors that influence the extent of dependence on NTFPs. These five factors are: location of the resource, household wealth status, gender, education and seasonality (Timko et al., 2010). To uncover this information, firstly issues of access and land tenure in relation to marula need to be explored, in addition to understanding the demographic profiles of the households utilising marula resources and thirdly, the overall contribution of marula to household incomes. These three knowledge areas are interrogated in this chapter in order to understand the potential resilience of the marula informal bioeconomy. This is important in order to address the long-term impacts of marula dependency, particularly in the context of a changing climate. The climate for the lowveld region of South Africa is projected to become both drier and hotter, leading to even greater local vulnerability if not appropriately addressed (Engelbrecht et al., 2013; MacKellar, 2014; Malherbe et al., 2014; Engelbrecht & Engelbrecht, 2016). Considering both the direct, as well as indirect economic contribution of marula to some of the poorest households, understanding the reliance patterns on marula is a crucial step in understanding current supply and demand. In particular, the extent of resource reliance can be used to gauge the potential impacts of any shocks to the system. These include impacts caused by a changing climate, for the communities living on the lowveld savanna ecosystems. Finally, these lessons provide insights for similar contexts of human-resource reliance.

The objectives of this chapter are as follows:

a) To understand marula access and availability in Phalaborwa & Bushbuckridge, specifically:

    a. To explore how factors such as land tenure and access impact marula fruit collection practices.
    b. To interrogate how collection practices differ across land-use types.

b) To interrogate how economic drivers shape marula resource utilisation strategies across the landscape:
    a. To explore how economic drivers vary by land-use types (yards, fields and rangelands).

c) To explore the economic value of marula within the informal marula bioeconomy (household use and sale of marula produce):
    a. To understand household demographics and the socio-economic profiles of marula resource users.
    b. To interrogate what resource utilisation strategies households apply in order to sustain their livelihoods.
    c. To quantify the importance of income from marula produce sales in terms of livelihood sustenance.

d) To gauge changes in the marula bioeconomy over time:
    a. To compare the current extent of marula resource reliance to research by Shackleton & Shackleton (2005).

6.2 Methodology

Semi-structured interviews were conducted with individuals in 240 households, divided equally between the eight Bushbuckridge (n=120) and Phalaborwa (n=120) villages. Unfortunately, it was not possible to gain a completely random sample of respondents as each household indicated which member would be interviewed, based on the person collecting marula. As this is determined by cultural norms, this resulted in a skewed sample in terms of gender, with more females being interviewed, although a range of ages were accomodated. However, where tested statistically, the data was checked for skewness. All interviews were conducted with the assistance of an interpreter over a 6-month period from January to June 2018. The questionnaire was specifically divided into eight sections, with the purpose of obtaining the categories of data necessary to answer the specific research questions. The eight sections of the survey were: 1) socio-demographic data, 2) marula fruit collection data, 3) marula tree use data, 4) economic value of marula data, 5) cultural value of marula data, 6) marula access and land tenure issues data, 7) marula management and stewardship data and 8) resource availability and climate change perceptions data. Those sections of the questionnaire (10. Appendix: 10.2 Research Instrument) covered in this chapter include the household socio-economic characteristics; uses of marula; sales and income; access and land tenure issues and resource availability. In addition, qualitative information was captured during interviews in order to complement the quantitative data. Interviews were conducted with only one member of each household, however, on numerous occasions other household members wanted to provide information. Wherever possible, additional members from a few households were grouped together to create informal focus groups. These informal focus groups were specifically used to qualify certain information, and to provide a greater degree of insight into the more complex issues provided by respondents.

6.2.1 Analyses of marula resource use and economic contributions to households

Cross-tabulations for marula resource use and economic contributions to household income were performed in SPSS on the data using Chi-Square Tests ($p<0.05$) with Fisher's Exact Test and a Phi Effect Size for tables in a 2 by 2 cross-tabulation and Pearson's Chi-Square, with a Cramer's V Effect Size, for larger than 2 by 2 cross-tabulations. Analyses were performed on all questionnaire responses excluding 2 by 2 binary cross-tabulations such as Yes/No responses by Location (Phalaborwa/Bushbuckridge).

With a 2 by 2 table, SPSS provides the Yates Correction for Continuity, designed to compensate for an overestimation of the Chi-Square value, which was provided with the statistical outputs for the Chi-Square value. With Chi-Square tests it is important to check that the assumption for 'minimum expected cell frequency' has not been violated. In order to not violate the assumption, at least 80% of cells need to have a frequency of 5 or more, otherwise it is not possible to provide a significance value for the cross-tabulation.

6.2.2 Logistic regression analysis for marula fruit collection

A logistic regression was used in SPSS to test a model predicting binary outcomes based on a mix of nine categorical and continuous independent variables. The categorical dependent variable being tested was the binary response (Yes/No) to the collection of marula fruit. The independent variables tested were: location, gender, age, yard marula, field access, household income, employment and most accessible land-use types (fields & rangelands). Due to the smaller number of cases associated with distance to fields and rangelands, these were not included in the model. An important assumption to consider with a logistic regression is the sample size, this is particularly problematic where you either have a larger number of predictors and a smaller sample size or categorical predictors with limited cases. It is for these reasons that certain data categories could not be included in the model as independent variables. The independent variables included in the model were tested for collinearity, with high tolerance values indicating low correlations between variables.

The predictor variables were tested for 'goodness of fit' with the Omnibus Tests of Model Coefficients providing a highly significant value, indicating the model is a better bit than the original estimate provided by SPSS. The Hosmer-Lemeshow Goodness of Fit test was not significant, indicating that the model is worthwhile. The Cox and Snell R Square as well as Nagelkerke R Square were both calculated in order to indicate the range of variability explained by the chosen set of variables. The Classification Table for the model indicated that it correctly classified 70.4% of the cases, an increase from the original output of 67.9%, which indicates a strong model. Finally, the Variables in the Equation Table were included with the results, which provide information about the importance or contribution of each of the predictor variables. The significance value indicates which of the predictors provides a significant contribution. Two of the most important statistics include the B values (probability of a case falling into a specific category - with a positive or negative result indicating the direction of the relationship) and the Odds Ratio: "the change in odds of being in one of the categories of outcomes when the value of a predictor changes by one unit" (Pallant, 2007: 176). Finally, each variable in the model has an odds ratio, which is a 95% confidence interval with a lower and upper value.

6.2.3 Multiple regression analysis for total marula income

A standard multiple regression analysis was used to analyse the continuous dependent variable of total marula income in relation to six independent variables: location, gender, field access, sell fruit, sell beer and sell nuts. A multiple regression is able to ascertain how well a set of variables is able to predict a particular outcome. The ten independent variables initially included in the analysis were: location, gender, age, yard marula, field access, sell fruit, sell beer, sell nuts, household income and employment. Preliminary analyses were performed to ensure there were no violations of the assumptions in terms of sample size, normality, outliers linearity, multicollinearity and homoscedacity. The cases that were outliers were removed from the model, using the chi-square values, which were calculated based on the number of independent variables and degrees of freedom. The R Square, Degrees of Freedom, Residual, F statistic and

significance values for the model were all reported. These statistics indicated that the model explained a high percentage of the variance in the dependent variable. When evaluating each of the independent variables, the Beta value under the Standard Coefficients was provided with the largest Beta values making the strongest unique contribution to explaining the dependent variable (Pallant, 2007). Finally, the significance value indicates if this variable is making a statistically significant unique contribution to the prediction of the dependent variable.

6.2.4 Descriptive social insights for marula's economic value

A thematic analysis methodology was applied to the social data in order to ensure a robust approach to identifying, analysing, organising, describing and reporting themes found within the social data set (Braun & Clarke, 2006; Nowell et al., 2017). Thematic analysis is a useful methodology for examining the perspectives of different research respondents, highlighting similarities and differences and thereby generating insights by noting key trends in the outcomes (King, 2004; Nowell et al., 2017). Due to the large nature of the data set, this allowed for a structured and methodical approach for identifying key trends in the data, allowing the main themes to emerge with reduced interpreter bias. However, a key disadvantage of thematic analysis is its flexibility, which can lead to inconsistencies and a lack of coherence when uncovering themes derived from the data (Holloway & Todres, 2003). This can be mitigated by assuming a clear epistemological position that underpins the study's empirical claims (Holloway & Todres, 2003). In this case, the social data was used to verify ecological findings and vice versa. In other words, a repeated statement made by respondents could be verified by ascertaining if the ecological findings supported this claim. In order to meet the requirements of credibility, transferability and dependability, data was captured into spreadsheets and coded by category and then aggregated by research question in order to allow patterns to emerge by village and settlement type (rural and peri-urban). These were then further aggregated at the location level (Bushbuckridge and Phalaborwa) for the purposes of discussing high-level socio-economic trends in this chapter.

The first step involved coding the descriptive data for thematic responses. Coding simplifies the data and enables specific characteristics of the data to emerge (Morse & Richards, 2002). During coding, important sections of text are identified, labelled and indexed according to how they relate to a theme or issue in the data (King, 2004; Nowell et al., 2017). The themes were predominantly generated inductively from the raw data but in certain cases, these were generated deductively from theory and prior research (particularly the previous studies by Shackleton et al. (2002-2005) in Bushbuckridge. The themes were reviewed and refined before being finalised. The second step involved overlying the quantitative outputs (including those that were statistically analysed) with the descriptive responses, cross referencing key findings with recurring descriptive themes. Finally, the key themes emerging from the anecdotal data were independently crosschecked with the statistical outcomes from the ecological data to confirm if the anecdotal evidence supported the significant quantitative outputs. The write-up of thematic findings should endeavour to be a coherent, logical, non-repetitive and interesting account of the data within and across themes (Braun & Clarke, 2006; Nowell et al., 2017). Direct quotations from respondents should be included to enhance the illustration and interpretation of specific points as well as to demonstrate the prevalence of the key themes (King, 2004). When writing up the findings, referring to the literature is advisable to confirm the research findings (Tuckett, 2005).

In order to illustrate patterns in the quantitative responses that were not analysed statistically,

certain data are provided as the proportion of respondents. While certain questions had a simple numerical answer, such as the number of people living in a household, other answers were provided as ranges. An example being the profiling of household incomes, where individuals were not comfortable disclosing exact household income amounts. Therefore, income ranges were given and respondents selected the range applicable to their particular household. In most cases, the proportion was calculated based on the overall sample in each location, which were the 120 households surveyed. In certain cases, the value was calculated as a proportion of a different total, for example the number of respondents who make marula beer, calculated as a percentage of only those respondents that actually collect the fruit. In these examples, proportions are a percentage of 'user' households and are rounded to the nearest first decimal place, or otherwise whole number in the temporal comparison section. Where the proportion is calculated as a percentage of a different total, the sample size is given in the text. Calculations of averages, such as the average household size (including members of all ages), are computed based on the mean±SE of the data. In other examples, where range answers were given, the median of that range is used to then assess the average based on the number of applicable cases each time. The gross income value that the different marula products provide to individual households was obtained by multiplying the amount of produce sold in a month by the established local informal economy price. These amounts were then multiplied by three months to calculate the value per marula season, which is generally accepted as running from January to April (three months) each year.

After applying a quantitative approach to the ecological data in previous chapters, a mainly qualitative approach has been applied to the social data in this chapter in order to highlight how different, yet complimentary, research methodologies can assist in providing a more comprehensive understanding of resource utilisation within complex socio-ecological systems. This means the intention and focus of this chapter is specifically around understanding the complex socio-ecological system of the lowveld marula bioeconomy using a semi-qualitative approach. This is done firstly to uncover the bioeconomy narrative as told by the resource users, as well as to explore the outcomes through a socio-economic lens. Personal accounts and quotations from respondents have therefore also been included to further illustrate key points in the narrative.

6.3 Results

6.3.1 Demographic profiles of respondents

The demographic profiles of respondents interviewed for the social surveys are provided in Figure 6.1, with the highest number of respondents falling in the 25-34 year age category. Furthermore, more females volunteered to be interviewed (approximately two thirds of respondents), likely due to the primary role woman play in the marula bioeconomy.

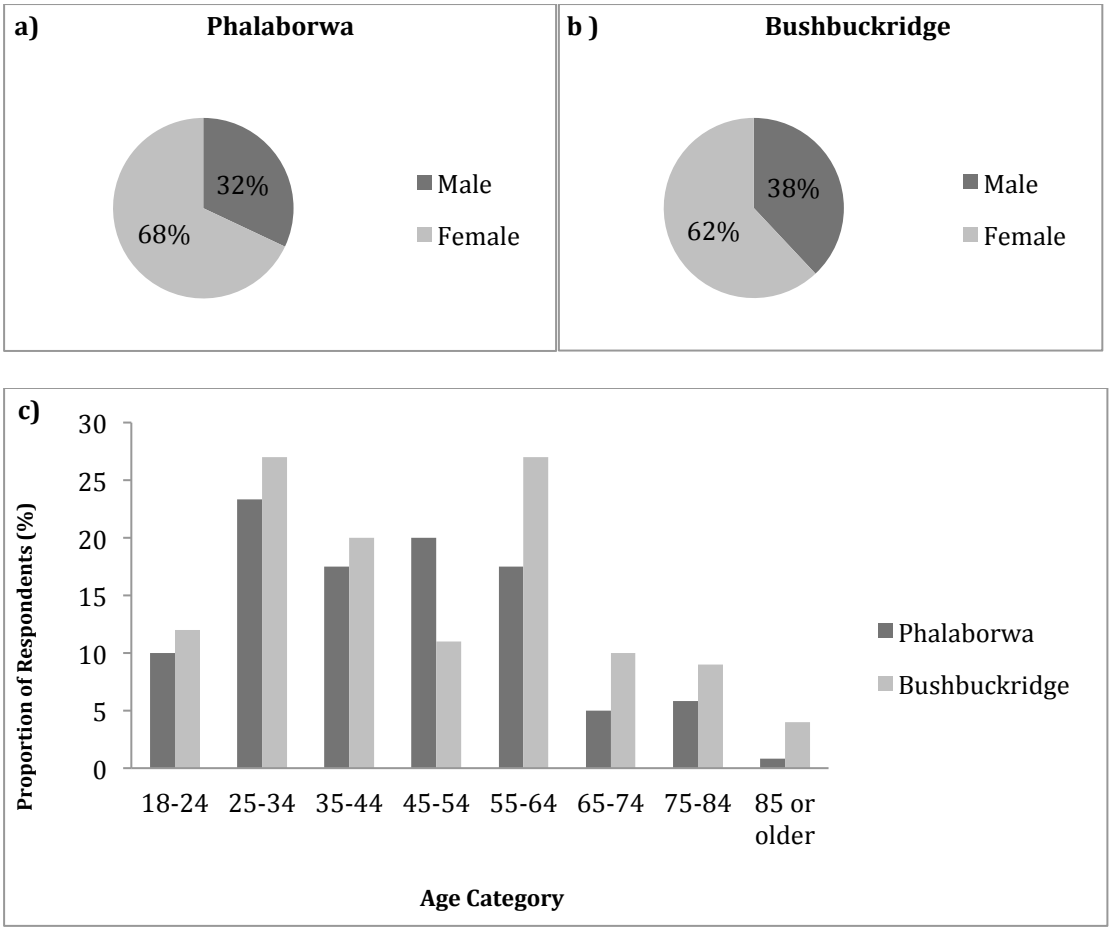


Figure 6.1: Demographic profiles of respondents in a) Phalaborwa (n=120) and b) Bushbuckridge (n=120) including c) age categories

6.3.2 Land access, tenure and marula fruit collection practices

Marula trees are pervasive in yards in both locations, with 83.3% (n=100) of the surveyed yards in Bushbuckridge (n=120) containing marula trees, divided exactly between rural and peri-urban settlement types. In Phalaborwa (n=120), the proportions of rural (n=60) and peri-urban (n=60) yards containing marula trees were also similar: 75% (n=45) and 71.6% (n=43) respectively. Overall, 73.3% (n=86) of yards in Phalaborwa contained a tree, or multiple trees.

When asked about field access (in order to grow and/or collect produce such as marula fruit), only 30% (n=36) of Bushbuckridge respondents confirmed field access compared to 49.2% (n=59) of Phalaborwa respondents. For those community members with field access in Phalaborwa (n=59), 74.6% (n=44) of their fields contained a marula tree, which constituted 37% access in terms of the overall sample (n=120). In Bushbuckridge (n=36), 77.8% (n=28) of accessible fields contained a marula tree, which constituted 23% (n=120) of the overall respondents (Figure 6.2).

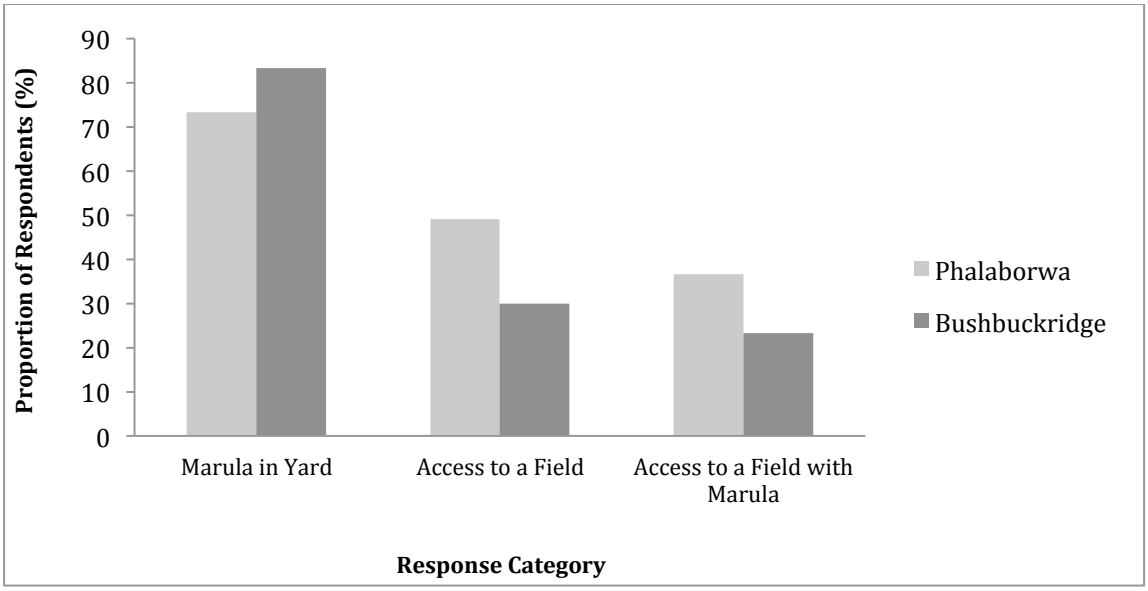


Figure 6.2: Marula prevalence across yards in Phalaborwa (n=88) and Bushbuckridge (n=100), as well as field access in Phalaborwa (n=59) and Bushbuckridge (n=36)

Respondents with access to a field in Bushbuckridge (n=36) were asked about the time taken to reach their field (by walking). The largest response category (41.7%, n=15) selected was a 5-10 minute walk. In comparison, the two largest response categories in Phalaborwa (n=59) were 26-30 minutes (30.5%, n=18) and 51-60 minutes (27.1%, n=16). Comparing the time taken to walk to fields (0-30 minutes) compared to those with a walk longer than 30 minutes, the difference between the two locations was significant (x^2 (1, n=95)= 7.17, $p<0.01$, phi =0.297). This difference is likely due to the 80.6% (n=29) of people in Bushbuckridge (n= 36) with a shorter than 30 minute walk, compared to 50.8% (n=30) in Phalaborwa (n=59). The full range of times taken for respondents to walk to the nearest accessible field are shown in Figure 6.3.

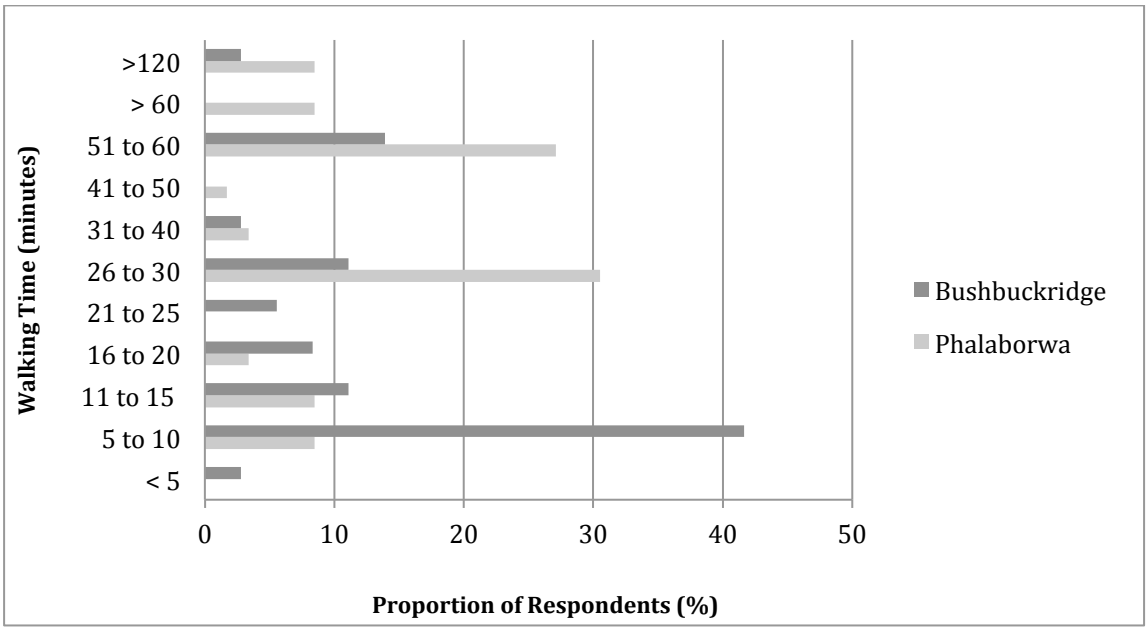


Figure 6.3: Time (minutes) taken by respondents who own, or have access to a field, to walk from the homestead to their nearest field in Phalaborwa (n=59) and Bushbuckridge (n=36)

When asked how they came to own their field/s, just over a third (35.3%, n=12) of respondents in Bushbuckridge (n=36) explained they assumed an abandoned field. In Phalaborwa (n=59), the largest segment of respondents (40.7%, n=24) indicated that they were given a field by the Induna (Headman).

Comparing the main categories of ownership (use abandoned field, inherited from family, given by Induna or other) the differences between the two locations were significant (x^2 (3, n=94)= 8.37, $p<0.05$, Cramer's V=0.298). This was likely due to the differences in field acquisition practices between locations, with the majority in Bushbuckridge using an abandoned field, while the majority in Phalaborwa obtained their field from the Induna. The rest of the field acquisition categories are provided in Figure 6.4.

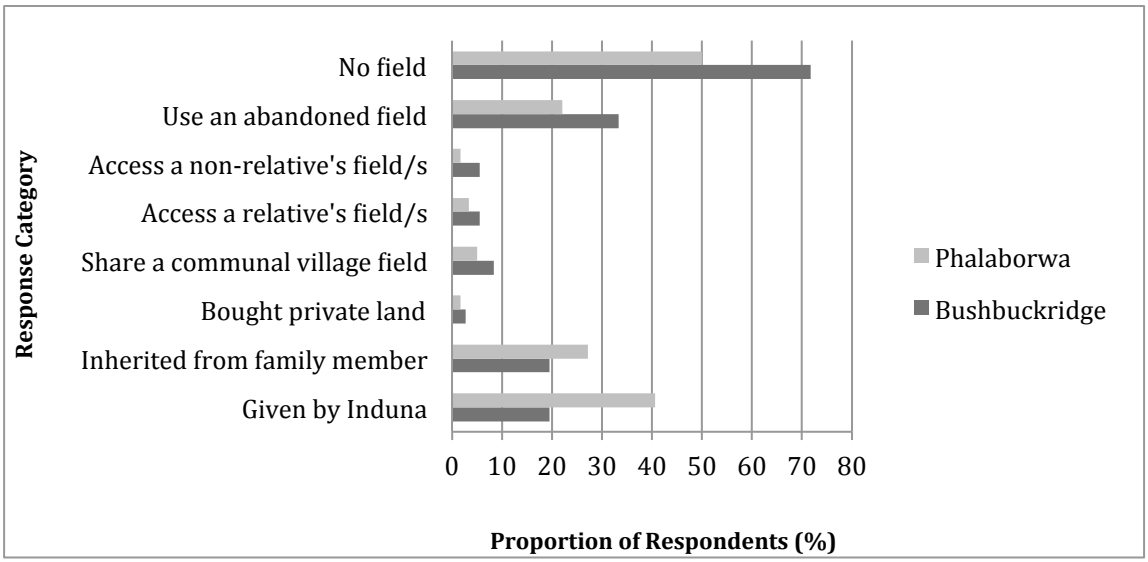


Figure 6.4: Field acquisition categories in Phalaborwa (n=59) and Bushbuckridge (n=36), including no field access in both locations (n=120)

The third land-use type where community members can access marula trees are in the communal rangelands surrounding their respective villages. Typically, accessing rangeland areas closest to respondent's homesteads took collectors 26-30 or 51-60 minutes to walk to in both locations (Figure 6.5). In Bushbuckridge, rangelands were less than 30 minutes away for 50% (n=28) of those collecting there compared to 48.7%(n=38) in Phalabborwa. Categorising the walk to the rangelands as short (0-30 minutes), intermediate (31-60 minutes) or long (more than 60 minutes), the differences between Phalaborwa and Bushbuckridge were not significant (x^2 (2, n=134)= 2.84, p=0.241). This finding indicates similarities in walking distance between locations.

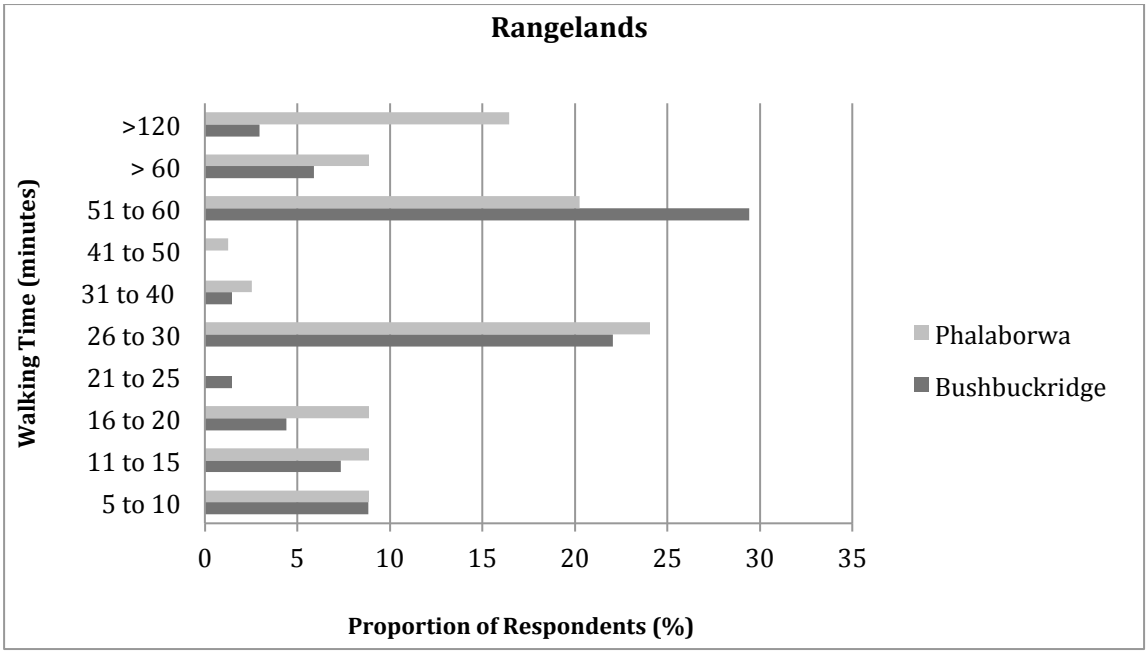


Figure 6.5: Time (minutes) taken for fruit collectors to reach communal rangelands in Phalaborwa (n=78) and Bushbuckridge (n=56) from their homesteads

Those community members who indicated collecting marula fruit in the past season were asked where they go to collect marula fruit in Bushbuckridge (n=68). The clear majority of respondents (83.8%, n=57) specified the communal rangelands. Similarly, in Phalaborwa (n=93), 84.9% (n=79) indicated rangelands (Figure 6.6).

An elderly woman in Rolle A (Bushbuckridge) remembers: *"We didn't need to go to the bushes (rangeland) back then to collect as there were so many marula trees around the village, now this is no longer the case."* In both locations, respondents selected yards as the next most popular choices after rangelands in terms of locations for collecting marula fruit.

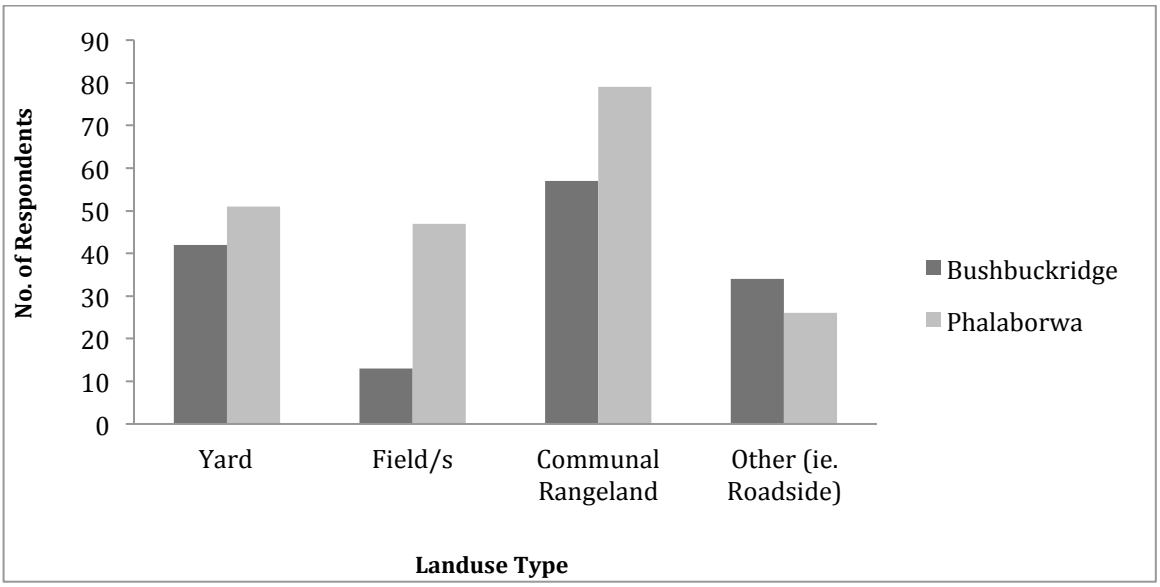


Figure 6.6: Marula fruit collection activities by land-use type in Phalaborwa (n=93) and Bushbuckridge (n=68)

Respondents identified as marula fruit collectors, were asked where they collect the most fruit in terms of actual fruit volumes. Three quarters (70.5%, n=48) of respondents in Bushbuckridge (n=68) specified the communal rangelands. Phalaborwa (n=93) respondents also indicated collecting the greatest volumes in rangelands (61.3%, n=57). Comparing the land-use types where respondents collect the most fruit between Phalaborwa and Bushbuckridge, including those who do not collect but used to collect, the differences were significant (x^2 (4, n=240)= 14.66, $p<0.01$, Cramer's V=0.247). After rangelands, fields were identified as the next land-use type where the greatest volumes are collected in Phalaborwa, compared to yards in Bushbuckridge.

When asked to justify their preference for rangelands as the most popular land-use type for plentiful fruit collection, respondents indicated that the primary reason is due to the numerous trees at the 'bushes'. However, respondents qualified this answer by explaining that the numbers of trees have been decreasing, mainly due to people chopping these trees for firewood. In turn, this requiring fruit collectors to walk further distances to gather the same amount of fruit as previously possible. Many respondents described this phenomenon as *"the distances between trees has increased,"* an indication possibly of fewer trees in the population overall.

In terms of ease of access to land in order to collect marula fruit, the majority of those collecting in both locations felt that it is still relatively easy to access places where marula trees grow. This was confirmed by 70% (n=84) in Phalaborwa and 77.5% (n=93) in Bushbuckridge. Rangelands were given as the most accessible land-use type by 74.2% (n=89) of respondents in Phalaborwa and 71.7% (n=86) in Bushbuckridge. Comparing field, rangeland and roadside access between Phalaborwa and Bushbuckridge, the differences were significant (x^2 (2, n=240)= 7.45, $p<0.05$, Cramer's V=0.176). Despite similarities in rangeland access between locations, followed by roadside and then fields, the differences in preference between roadside and fields were greater in Bushbuckridge and far more similar in Phalaborwa. Considering these results, it is important to note the lengthy times and therefore distances, required to reach the rangelands in order to collect this fruit. Respondents further suggested that it could take three to four times as long to return with the actual fruit collected. Furthermore, the majority of those confirming they collect fruit regularly in order to sell, specified that they use a 50 kg or 80 kg maize meal sack/bag, which is incredibly heavy and cumbersome to carry once full. In Bushbuckridge (n=34), 94.1% (n=32) of respondents indicated they use these bags; in Phalaborwa (n=49) 89.8% (n=44) confirmed this choice.

Female collectors in the informal focus groups indicated that they are able to carry one half-filled 80 kg bag per trip, which weighs approximately ~40 kg and can be carried on the collector's head. Usually the 80 kg bag is not filled to the top, so the estimated weight provided by respondents for a 'full' bag for sale is around 70 kg.

In terms of the main difficulties that collector's of marula fruit experience, 86.8% (n=59) gave difficulty in carrying the fruit as the main restriction to collecting in Bushbuckridge (n=68), with long distances to walk and physical safety concerns also featuring prominently. A young woman from Rolle A (Bushbuckridge) described her concerns around physical safety as follows: *"You can go to the bush to collect by yourself, but you will not come back."* Considering the extent of these issues, 36.7% of respondents in Bushbuckridge still indicated that there was no difficulty in collecting fruit.

This problem is not unique to Bushbuckridge, with a young woman from Lulekani (Phalaborwa) explaining: *"Women are attacked collecting marula fruit – it happens every few seasons that someone is raped."* In Phalaborwa (n=93), 39.8% (n=37) of fruit collector's gave difficulty in carrying fruit as the main constraint to collecting, followed by physical safety concerns and long distances to walk as other major concerns.

Comparing the main categories of collection obstacles (difficulty carrying fruit, physical safety issues, long walking distances or no difficulty) the differences were not significant (x^2 (4, n=230)= 6.77, p=0.149), indicating similarities in the difficulties experienced between locations. Respondents were asked to select as many answers as are applicable to their situation, meaning the numbers in Figure 6.7 do not necessarily add up to 100%.

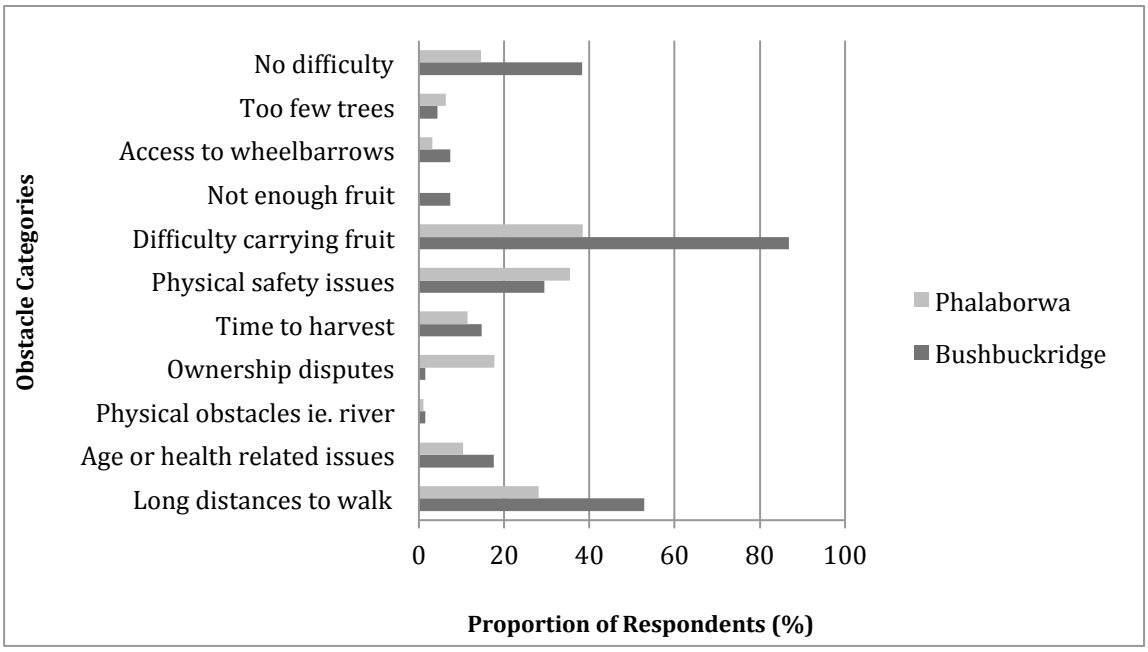


Figure 6.7: Obstacles to marula fruit collection in Phalaborwa (n=93) and Bushbuckridge (n=68)

6.3.3 Marula resource choices and strategies across different land-uses

6.3.3.1 Variables impacting marula collection

A logistic regression was performed to assess the impact of a number of factors on a respondent's likelihood to collect marula fruit in both Phalaborwa and Bushbuckridge. The collinearity statistics indicated that the tolerance values were high (greater than .1), indicating low correlations between independent variables in the model. The full model containing the nine remaining predictors was statistically significant (x^2 (9, n=240)= 35.669, p<0.001), indicating that the model was able to distinguish between factors that increase the likelihood of marula collection and those that do not. The Hosmer-Lemeshow Goodness of Fit test had a significance level of p>0.05 indicating that the model is worthwhile (x^2 (8, n=240)= 9.22, p=0.324). The model as a whole explained between 13.8% (Cox and Snell R Square) and 19.3% (Nagelkerke R squared) of the variance in marula collection likelihood and correctly classified 70.4% of cases, an increase from the original output of 67.9%, which indicates a strong model.

As shown in Table 6.1, three of the independent variables made a unique, statistically significant contribution to the model (location, field access and employment). The strongest predictor of

marula collection was location (p<0.001), recording an odds ratio of 3.20. This indicated that respondents in Phalaborwa were over 3 times more likely to collect marula fruit than those in Bushbuckridge. The odds ratio of 2.14 for field access (p<0.05), indicated that respondents with a field were twice as likely to collect marula fruit than those without field access. Finally, employment recorded an odds ratio of 0.43 (p<0.05), indicating that those who are employed are less than half as likely to collect marula fruit compared to those who are unemployed.

Table 6:1: Statistical Outputs from the Regression Analysis Predicting the Likelihood of Marula Fruit Collection

	B	**S.E.**	**Wald**	**Df**	**p**	**Odds Ratio**	**95% C.I. lower**	**95% C.I. upper**
Location	1.16	0.34	12.01	1	**0.001**	**3.20**	1.66	6.18
Gender	0.36	0.35	1.05	1	0.305	1.43	0.72	2.83
Age	0.11	0.17	0.42	1	0.520	1.11	0.81	1.54
Yard Marula	0.66	0.36	3.38	1	0.066	1.93	0.96	3.88
Field Access	0.76	0.34	4.93	1	**0.026**	**2.14**	1.09	4.19
Household Income	0.04	0.31	0.02	1	0.895	1.04	0.56	1.93
Employed	-0.84	0.34	6.25	1	**0.012**	**0.43**	0.22	0.83
Fields Accessible	0.30	0.71	0.18	1	0.669	1.35	0.34	5.41
Rangelands Accessible	0.47	0.37	1.60	1	0.206	1.6	0.77	3.31

6.3.3.2 Resource use choices and strategies in yards

While it is prohibited by Traditional Authorities (as well as the National Forest Act, 84 of 1998) to chop down a marula tree anywhere in the surveyed communities, 60% (n=72) of households in Bushbuckridge (n=120) reported removing a tree due to the threat posed to buildings. Only 31.7% (n=38) of respondents admitted to the same in Phalaborwa (n=120), as shown in Figure 6.8. Comparing those who confirmed damaging a marula tree (including cutting branches, cutting it down but allowing regrowth or ring-barking/cutting it down completely) with those that denied ever damaging a marula, the differences between locations were significant (x^2 (1, n=240)= 18.28, p<0.001, phi=0.284). A higher proportion of households in Bushbuckridge reported damaging a marula tree in their yard. In Edinburgh (Bushbuckridge), an elderly man was surprised when asked if he is allowed to chop the marula tree in his yard stating: *"Cutting trees is only prohibited outside your yard but not within, that is your business."* In Selwane

(Phalaborwa), a middle-aged woman explained the actual reality of cutting a marula tree: *"You cannot cut marula trees in or outside your yard. If the tree is in your yard and you need to cut it down then you must get a permit at R150/tree from Tribal [The Traditional Authority]."*

The cutting of larger marula trees in yards leads to reductions in adult marula densities (Chapter 3), while the discarding of kernels from marula beer making leads to spikes in recruitment and increases in marula density in the smallest size class ($\leq$0.5 cm). In Lulekani (Phalaborwa), a young woman explained: *"You just throw the nuts to the ground after making beer and new trees grow from them."* In Bushbuckridge (n=120), only 19.2% (n=23) of households stated that they have actively planted a marula tree and even fewer in Phalaborwa (n=120, Figure 6.8), with only 10.8% (n=13) concurring. The reasons provided by the majority of respondents to explain why marula trees are not planted in greater numbers relates to the perception that these trees occur naturally. When explored in more detail, it was overwhelmingly stated that marula trees are *"natural"* or *"God's trees"* and therefore do not need to be planted or watered. In Rolle A (Bushbuckridge), a middle-aged man justified this view: *"Culture teaches people that marula trees grow without planting or water. That is their way."* Further, when asked why marula trees are not planted in greater numbers intentionally, a young woman in Edinburgh (Bushbuckridge) replied: *"There is no need to plant marula. We have more trees now than before because people make beer and then throw the seeds away, so new trees have grown-up everywhere."* Superfluous seedlings in yards are usually removed not long after they become visible, which is usually after a season, due to the perception that they make the yard appear messy and unkempt. This reality means that in smaller yards where space is at a premium, fruit and kernels are unlikely to be left to germinate.

Fruit trees, including exotic varieties, are specifically selected and planted in yards, with 93.3% (n=112) of households in Bushbuckridge and 68.3% (n=82) of Phalaborwa households having planted fruit trees other than marula. In Bushbuckridge, 86.7% (n=104) of households had specifically planted a mango tree, with 61.7% (n=74) stating they prefer mango to marula. In Phalaborwa, 58.3% (n=70) had planted a mango tree with only 46.7% (n=56) preferring mango to marula.

Despite the economic value of the female tree, when asked about planting trees that have been selected based on specific qualities or traits, none of the respondents had explicitly selected their trees in Bushbuckridge. In Phalaborwa, only one household had specially planted a branch from a female tree. Tree ownership practices in yards are highlighted in Figure 6.8, respondents could provide more than one answer, meaning that proportions amount to more than 100%.

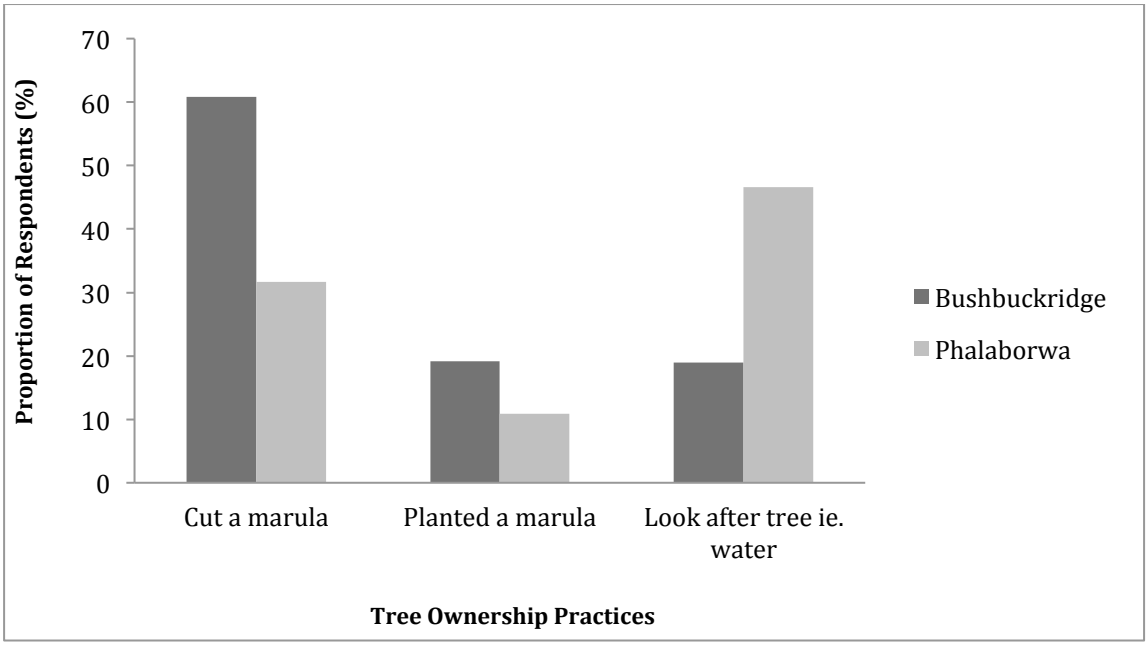


Figure 6.8: Tree ownership practices (positive and negative), for those with a marula in their yard in Phalaborwa (n=88) and Bushbuckridge (n=100)

To many respondents, the idea of interfering with the tree seemed unnatural, except for watering the occasional juvenile that had specifically been left in the hopes of harvesting fruit. In Mbaula (Phalaborwa), where water is a scarce commodity, a woman in her forties laughed at the concept of watering her marula trees, saying: *"Why must I worry about these trees? These are God's trees. He must worry about them."* In Bushbuckridge (n=100), 85% (n=85) of households with marula trees answered that they do *"nothing"* to care for their trees, while in Phalaborwa (n=88), 88.6% (n=78) of respondents do nothing at all to care for their trees. However, some respondents take steps to care for their tree, with 47.7% (n=42) of respondents in Phalaborwa (n=88) concurring, which includes activities such as either watering, cleaning away weeds or placing protective bricks around the base. Comparing the number of respondents who have either planted a marula tree or take care of their tree, in contrast to those who have done neither, the differences between locations were not significant (x^2 (1, n=240)= 0.69, p=0.407). This finding confirms a similar pattern of minimal tree stewardship between locations. The majority of those watering (n=17) trees in Phalaborwa are in peri-urban (76.5%, n=13) villages (Benfarm and Lulekani), where water is piped, compared to only 23.5% (n=4) in the rural context (Selwane and Mbaula) where water is not piped and is thus considered scarce. In Bushbuckridge (n=100), only 19% (n= 19) confirmed they do anything to take care of their tree.

6.3.3.3 Resource use choices and strategies in fields

Female trees are often left in fields in order to obtain fruit, but non-bearing male trees are generally removed where they are deemed to be taking up desirable arable land. In addition, seedlings are ploughed out each season in order to plant food crops. In reality, many large marula trees are cut in fields: *"Either for wood or to make fences for fields,"* according to an elderly man from Benfarm (Phalaborwa). In Bushbuckridge (n=120), 8.3% (n=10) of respondents admitted they have chopped down a field marula tree, compared to only 5% (n=6) in Phalaborwa (n=120, Figure 6.9).

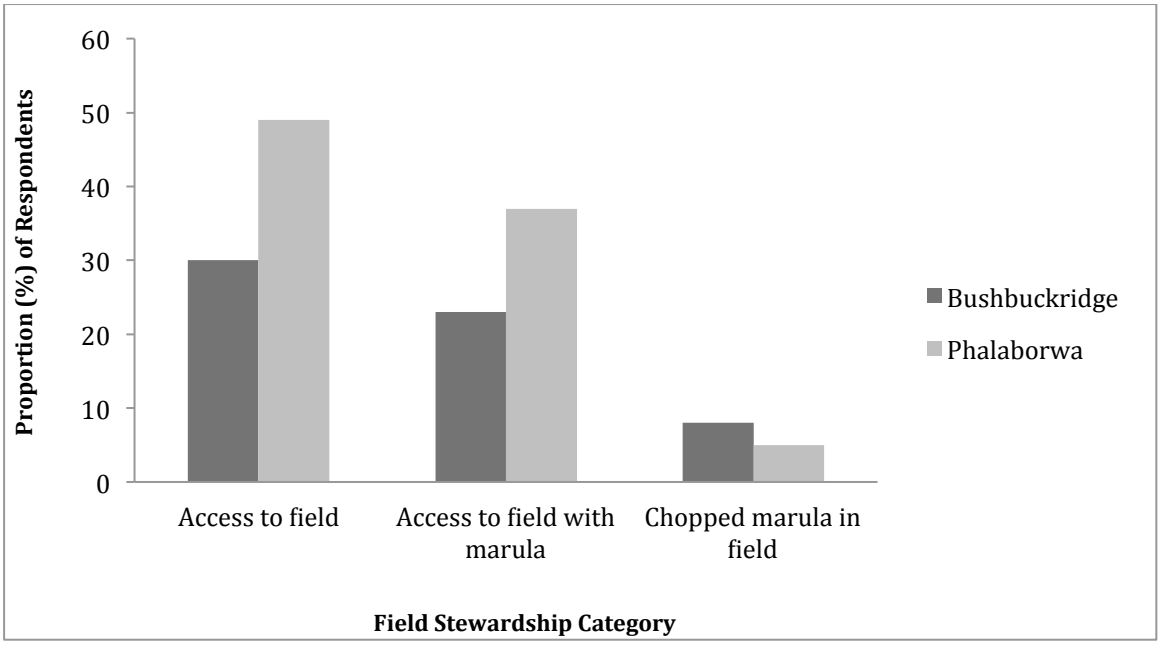


Figure 6.9: Field access in Phalaborwa (n=120) and Bushbuckridge (n=120) as well as marula ownership practices in fields in Phalaborwa (n=44) and Bushbuckridge (n=28)

Comparing those respondents who have chopped a marula in a field with those that denied ever doing so, the differences between locations were not significant (x^2 (1, n=240)= 0.60, p=0.439). Due to the prohibition on cutting live marula trees, it is unlikely respondents would admit to chopping trees in fields, as confirmed in both locations. However, respondents explained that where space is at a premium, larger trees are removed to clear space for crops or in order to turn the plough. In addition, removing juveniles is not seen as harmful to marula populations, because they are so numerous. A young man from Selwane (Phalaborwa) described how: *"When people plough, they remove all the little ones, they are just there for decoration for a season or two."* Adult marula trees are not normally used for cultural purposes within fields and are thus more likely to be removed if they do not serve an economic purpose. An elderly woman from Edinburgh (Bushbuckridge) described how: *"There are a lot of fields these days with no marula trees. We never had that in the past."* Fields are usually open rangeland areas that have been fenced, which means that over time, the marula trees inside the fenced area are removed for wood or to make space for arable land. A young man from Lulekani (Phalaborwa) summed up this transition as follows: *"There are not enough marulas now because people go to the fields and come back with wheelbarrows full of marula wood. Or trucks go to the bushes (rangelands) and come back full of marula logs."*

6.3.3.4 Resource use choices and strategies in rangelands

In rangelands, marula trees are utilised entirely for economic reasons. These economic drivers include for fuelwood, fruit for beer (which is most often sold) and fruit for sale, mainly to the Distell factory trucks. Certain respondents indicated that they collect fruit from the rangelands in order to make beer for cultural reasons but usually due to the time, effort and larger quantities characteristic of collecting from the rangelands, these excursions most often support the sale of beer. A young woman from Benfarm (Phalaborwa) noted: *"Since the trucks started collecting fruit, people are only picking to make money now."* A family in Lulekani (Phalaborwa) observed: *"People cut down the trees or cut the branches to get the fruit – even if it is not ripe. They are desperate to fill their bags before the truck arrives."* Other respondents explained: *"The*

truck is not reliable and will go to the village that pays the highest price, which means the fruit goes rotten when they do not arrive as previously indicated." This actively encourages people to pick unripe fruit, which will not spoil and gives them an opportunity to sell if the truck does eventually come to their village. In terms of marula's economic value in rangeland landscapes as fuelwood, wood is intended for personal cooking or heating, but also to be sold in fuelwood markets. In Benfarm (Phalaborwa), a peri-urban village where rangeland space is at a premium due to urban expansion, a few ladies at an informal focus group agreed: *"People are now forced to use this tree for firewood. They are even chopping the live trees."*

When asked if they use marula for firewood, 56.6% (n=68) of Bushbuckridge (n=120) households confirmed that they use the wood, with 50% (n=60) of Phalaborwa (n=120) households admitting they also use the wood (Figure 6.10). In Edinburgh (Bushbuckridge), a middle-aged woman explained: *"People only cut dead trees in the past. Now they cut the living ones as well."* When divided according to rural or peri-urban households, 56.6% (n=34) of rural Bushbuckridge households and 55% (n=33) of peri-urban households use marula wood. In Phalaborwa, 53.3% (n=32) of rural households and 46.6% (n=28) of peri-urban households use marula wood. In Edinburgh (Bushbuckridge), a young woman in her twenties explained: *"A lot of vans come from the bushes [rangelands] with wood these days."*

When asked if there are any consequences for chopping a live marula tree, 77.5% (n=93) of Bushbuckridge (n=120) households specified there are, with 70.8% (n=85) of Phalaborwa (n=120) households confirming there are consequences (Figure 6.10). When asked what the consequences are for chopping a live marula tree, respondents stated that you would get arrested, taken to the tribal authority and forced to pay a fine. Comparing those that agree there are consequences for chopping a live marula tree with those who felt there are no consequences, the differences between locations were not significant (x^2 (1, n=240)= 1.07, p=0.302). This confirms similar local customary practices around chopping live marula trees, with the system of being arrested and paying a fine being applied in both locations.

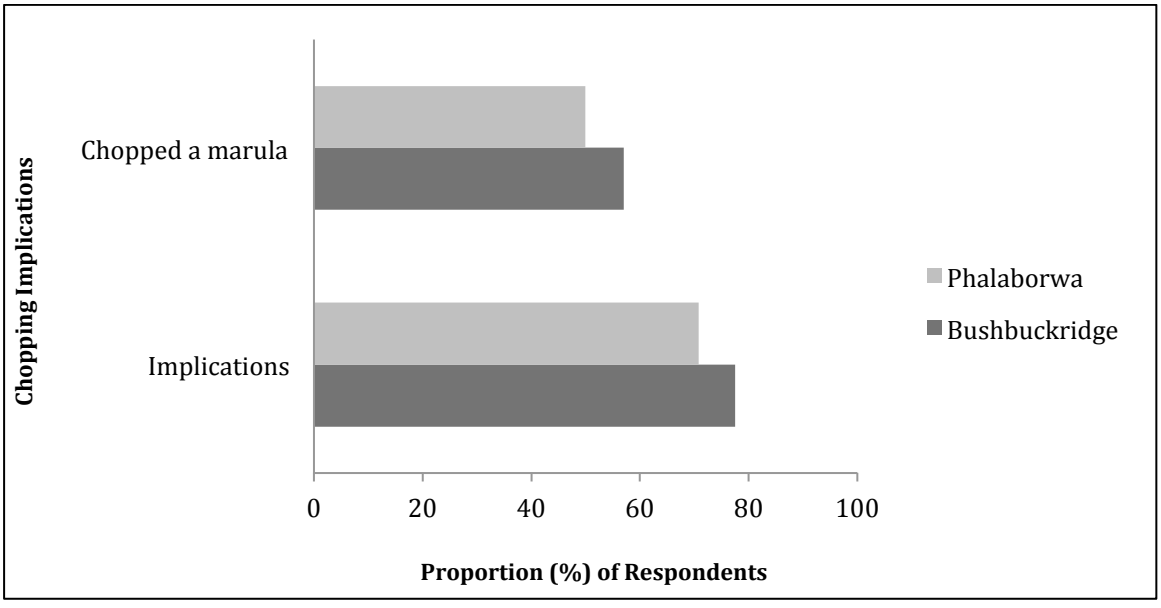


Figure 6.10: Proportion (%) of respondents who have chopped a live marula tree for fuelwood despite being aware of the consequences in Phalaborwa (n=120) and Bushbuckridge (n=120)

Splitting the answers regarding chopping live trees according to settlement type, with tribal authority assumed to be more pervasive in the rural context, 81.6% (n=49) of rural households (n=60) indicated there are consequences for chopping a live marula compared to 68.3% (n=41) of peri-urban households (n=60) in Bushbuckridge. In Phalaborwa, 80% (n=48) of rural households (n=60) confirmed there are consequences, with 63.3% (n=38) of peri-urban (n=60) households agreeing.

However, chopping marula is usually done out of necessity, an elderly woman from Lulekani (Phalaborwa) explains: *"Electricity is too expensive, even if people have access they still chop marula for cooking purposes."* Many respondents also refer to the cultural preference of cooking with wood, either because this has always been the way, or because it makes the food taste better.

6.3.4 Economic value and livelihood contribution of marula to households

Household income in Phalaborwa and Bushbuckridge is derived from a combination of informal economic activities, reliance on social grants and formal employment. In Bushbuckridge (n=120), only 28.3% (n=34) of households have a member employed whereas in Phalaborwa (n=120), 30% (n=36) of households have someone formally employed.

Households generate direct income from the sale of marula fruit, or products made from the fruit, which include beer, nuts and jam. In addition, household use of these products also allows the household to save what is often critically important cash income, which would otherwise be spent on obtaining these products commercially. The majority of marula fruit collectors are women in both locations, with 74% (n=50) women and 26% (n=18) men in Bushbuckridge (n=68) and 86% (n=80) female and 14% (n=13) male collectors in Phalaborwa (n=93).

Households display a range of marula resource utilisation strategies, from choosing to only use the resource at home, to only selling marula resources with no home utilisation involved, as well as a combination of both approaches. In Bushbuckridge (n=120), the largest category of respondents indicated that their households (47.5%, n=57) utilise marula for home use only, followed by 33.3% (n=40) who use marula resources at home as well as selling produce. In Phalaborwa (n=120), the majority of households incorporate a combined approach (70%, n=84) with 15% (n=18) using marula for home use only. Comparing the range of marula utilisation strategies between locations, the differences were significant due to the preference for home use in Bushbuckridge but a combined home use and selling approach preferred in Phalaborwa (x^2 (3, n=240)= 36.5, p<0.001, Cramer's V=0.390). The range of strategies households utilise are provided in Figure 6.11.

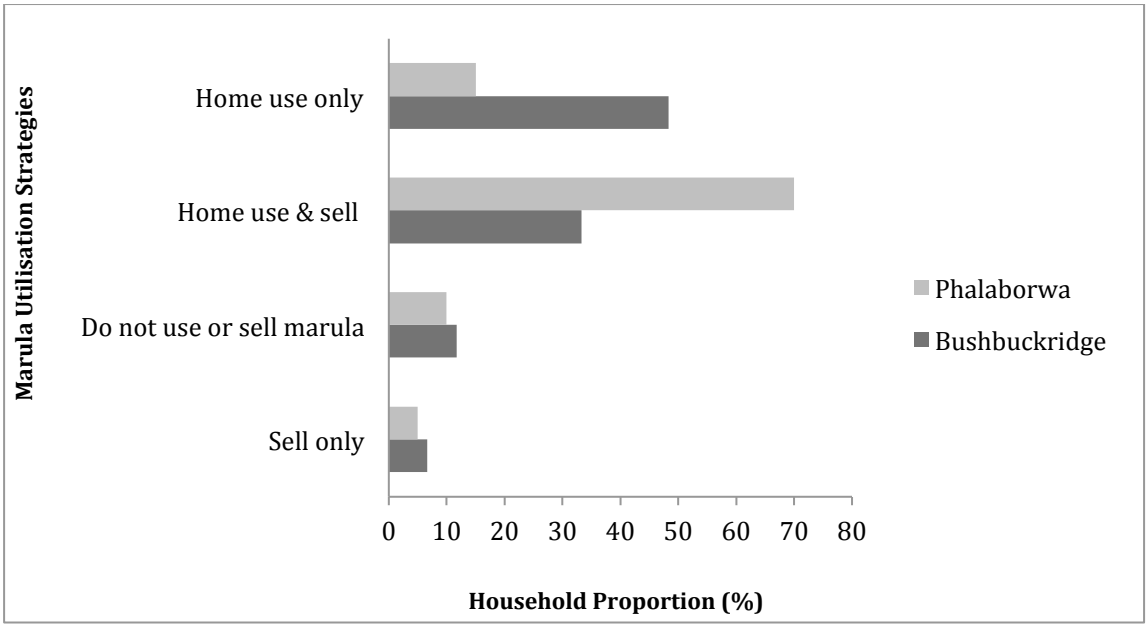


Figure 6.11:Comparison of marula utilisation strategies in Phalaborwa (n=120) and Bushbuckridge (n=120)

A standard multiple regression model was used to assess the factors that contribute to total household marula income for marula season (dependent variable) in Phalaborwa and Bushbuckridge. The model was significant ($p<0.01$) and explained explained 63.5% of the variance in total marula income with $R^2=0.635$. The ANOVA showed that this result was significant F (6, 223)= 64.68, $p<0.001$. Three independent variables were statistically significant: selling fruit, beer or nuts. Based on their beta values, selling beer made the greatest contribution to total marula income, (beta= 0.475, $p<0.001$), followed by selling fruit (beta= 0.421, $p<0.001$) and lastly selling nuts (beta= 0.115, $p<0.05$).

Profiling household incomes, the majority of households in Bushbuckridge (75%, n=90) and Phalaborwa (85.8%, n=103) earn R2,999 ($190) or less, as shown in Figure 6.12. Based on the median for each income range category and the number of households per income bracket, the average (mean±SE) monthly household income in Bushbuckridge (n=120) is R2,360±R113 ($150) and R1,844±R102 ($118) in Phalaborwa (n=120).

This is not a high income per person considering the average (mean±SE) household size in Bushbuckridge is 5.5±0.3 and 6.1±04 people in Phalaborwa. This means household income equates to approximately R429 ($27) per person/month in Bushbuckridge and slightly lower at around R302 ($19) per person/month in Phalaborwa.

The income per person is for all members of the household, rather than a measure of average income per adult. This is intended to portray the income the family has available in order to sustain their livelihoods, so while children are not income earners, they are income users.

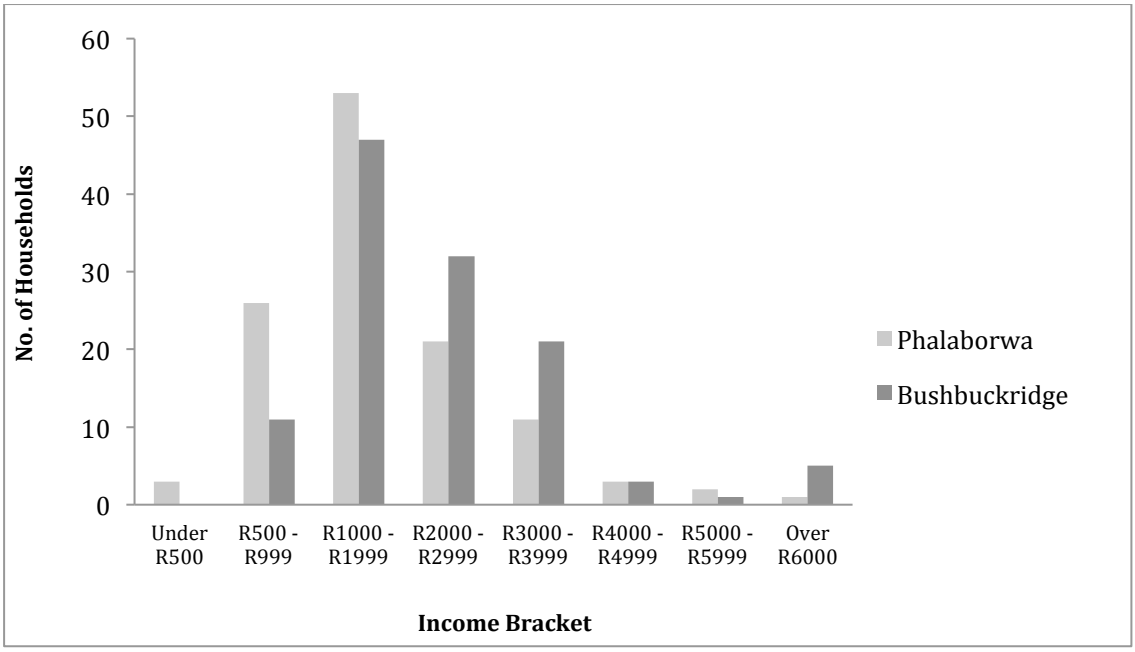


Figure 6.12: Average Monthly Household Income in Phalaborwa (n=120) and Bushbuckridge (n=120)

Dividing household income into a lower (less than R2000/month) and higher (more than R2000/month) income bracket between locations, the differences in income were significant (x^2 (1, n=240)= 6.8, p<0.01, phi= 0.177). This difference was due to the majority of households in Bushbuckridge (n=62; 51.7%) earning below R2000/month whereas the majority in Phalaborwa (n=79; 65.8%) earned more than R2000/month.

Overall, 85% (n=102) of households in Bushbuckridge (n=120) and 89.2% (n=107) in Phalaborwa (n=120) indicated that they harvest parts of the tree (such as fruit, wood and bark) for home use. Amongst these, the majority specified that the fruit harvested was used to make beer (88.2%, n=90) in Bushbuckridge (n=102) and 91.6% (n=98) in Phalaborwa (n=107). The top three resource uses being beer making, eating of nuts and adding to food dishes in Phalaborwa, with fuelwood in Bushbuckridge being the third highest utilisation category (Figure 6.13).

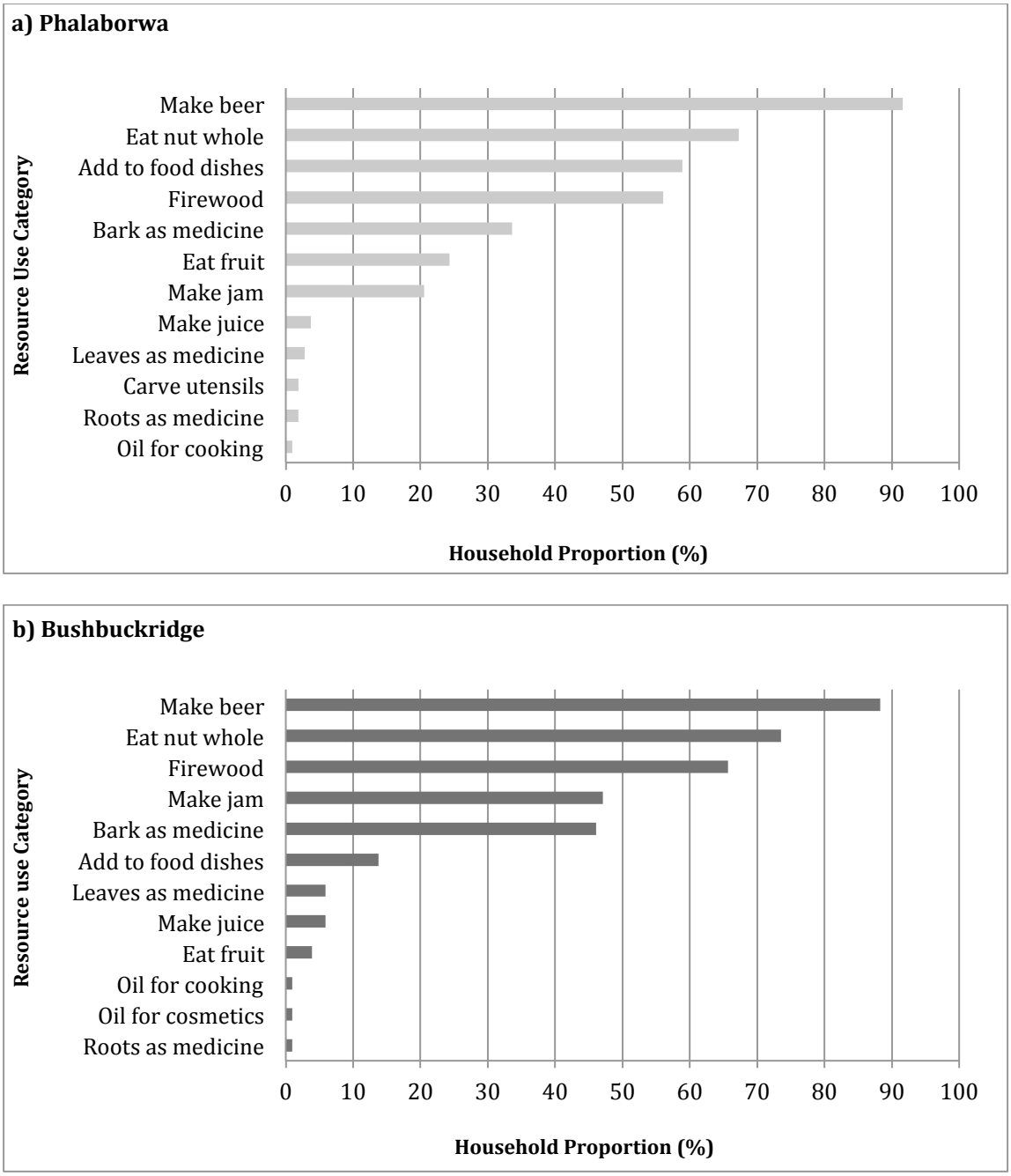


Figure 6.13: Household marula use in Phalaborwa (n=107) and Bushbuckridge (n=102)

In terms of harvesting marula tree resources (fruit, wood, bark) to sell, a clear majority in Phalaborwa (n=120) exhibit this behaviour (69.2%, n=83) compared to only 35% (n=42) in Bushbuckridge (n=120). When asked about increased resource harvesting as a result of resource demands, respondents indicated that they have observed more people chopping marula trees over the past decade. In Bushbuckridge (n=120), 52.5% (n=63) of respondents confirm they have observed increased chopping, with 58.3% (n=70) in Phalaborwa (n=120) stating the same. Comparing the observations of increased cutting or no increase in cutting over the past decade between the two locations, the differences were not significant (x^2 (1, n=240)= 0.61, p=0.436). This finding indicates similar trends between locations in terms of increased observations of cutting of marula trees. In addition, respondents were asked if they have observed more people collecting marula fruit over the past decade. In Bushbuckridge (n=120),

55.8% (n=67) disagree while in Phalaborwa (n=120), 81.7% (n=98) agree they have noticed an increase in marula fruit collection. This difference in opinion between the two locations was significant, with a large majority in Phalaborwa observing increased collection of marula fruit, compared to the majority in Bushbuckridge who have observed the opposite (x^2 (1, n=240)= 34.57, p<0.001, phi=-0.388)

In Bushbuckridge (n=68), the highest numbers of respondents currently collect marula resources to sell, indicating that they sell the fruit (50%, n=34). The second most popular sale item was marula beer (39.7%, n=27), with the third being marula nuts (35.3%, n=24). In Phalaborwa (n=93), a different pattern emerged, with the highest number of respondents indicating they sell the beer 76.3%, n=71), followed by the fruit (52.7%, n=49) and thirdly the nuts (39.8%, n=37). The patterns for the sale of marula related products in each location are provided in Figure 6.14.

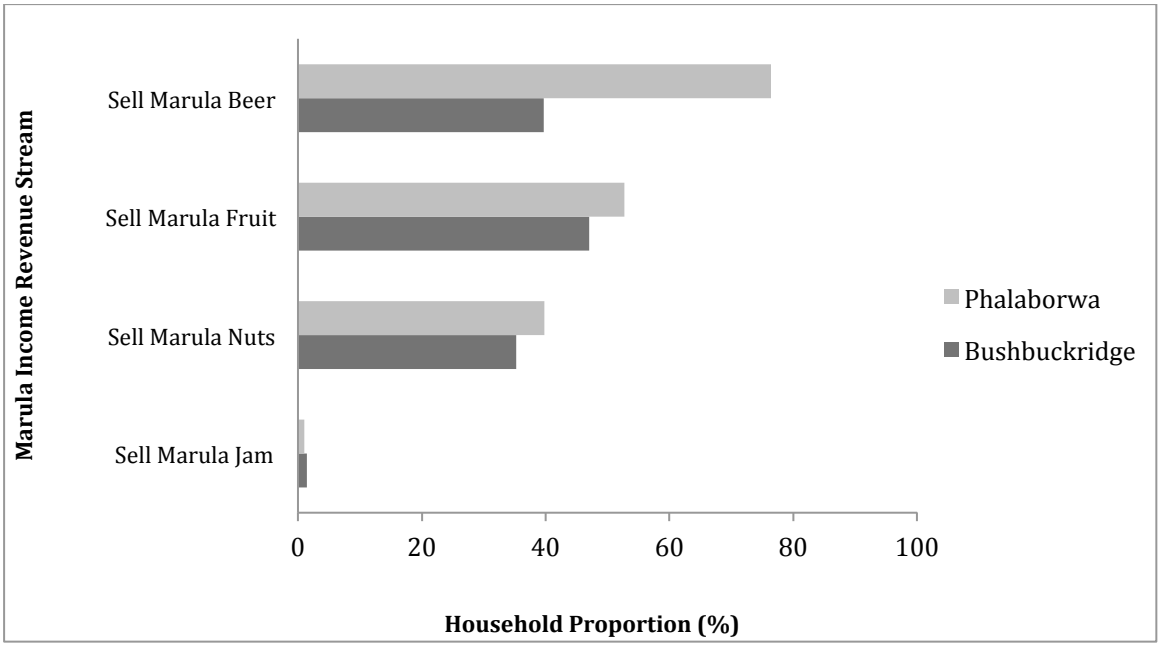


Figure 6.14: Sale of marula related products by households currently collecting the fruit in Phalaborwa (n=93) and Bushbuckridge (n=68)

In both locations, 100% of the fruit sold is destined for the formal marula industries, the majority being sold to the Distell trucks for the production of Amarula Cream liqueur. Respondents indicated that there are other trucks that also collect the fruit or nut kernels, although these come far less often during marula season and respondents were not sure to what company or organisation those trucks are affiliated. When asked about the price per bag, the standard price from Distell was given as R38 per bag at the time, but respondents indicated a range of prices from R15 to R45 per bag. In Bushbuckridge (n=31), 67.7% (n=21) make less than R1000/month from marula fruit sales whereas in Phalaborwa (n=48), 60.4% (n=29) make more than R1000/month. This difference in income generation from marula fruit sales was significant (x^2 (1, n=79)= 4.90, p<0.05, phi=0.275).

The main difficulties given regarding the sale of marula fruit were the issue of getting the fruit to market, too many sellers, the price being too low and not enough customers. When comparing these categories, due to the 'minimum expected cell frequency' being violated, it is not possible

to get a conclusive significant result (x^2 (3, n=68)= 9.35, p=0.025, Cramer's V=0.371). The main difficulties with selling marula fruit are shown in Figure 6.15.

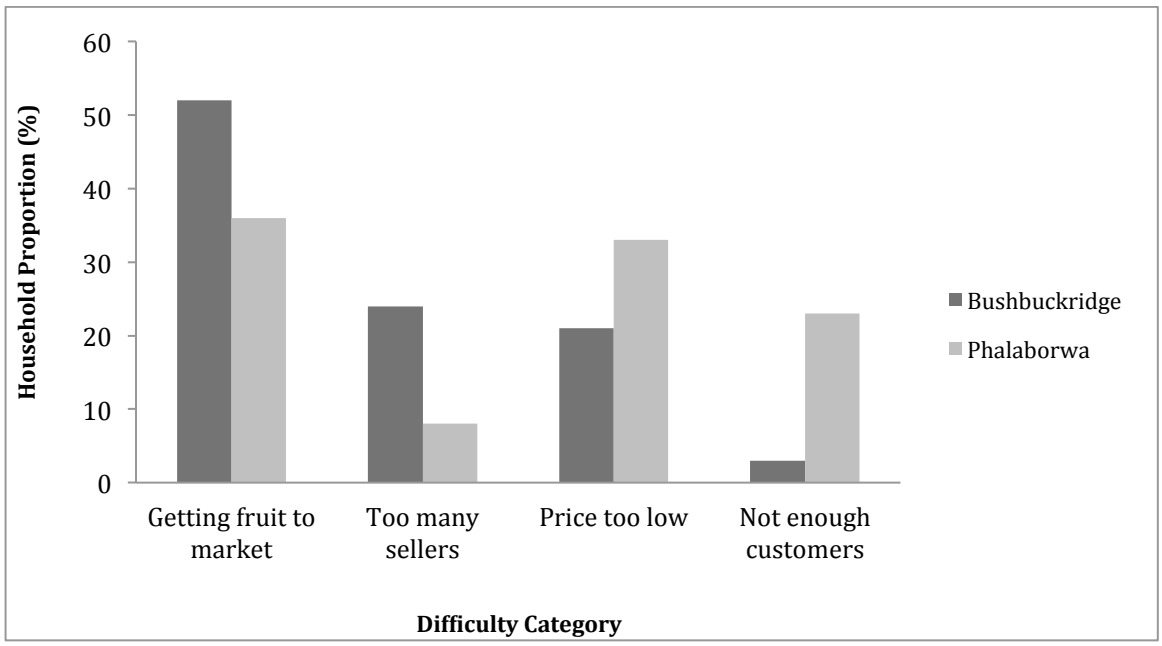


Figure 6.15: Difficulties encountered in relation to selling marula fruit in Phalaborwa (n=39) and Bushbuckridge (n=29)

In contrast to marula fruit, which is sold entirely to the formal industry, in both locations 100% of marula beer is made for sale to members of the community. Marula beer is either sold at markets or to customers who came to the seller's house in order to purchase marula beer specifically. The beer is sold in either 750 ml (R5-R10), 1L (R10-R15) or 2L (R15-20) bottles which have set prices regardless of the location. The price brackets are to accommodate the two types of beer made from marula fruit, which are commonly produced by sellers. Marula beer is brewed in two ways to make a strong or a weaker brew. The stronger version has a higher alcoholic and lower water content as it is left for longer to ferment and is more expensive than the weaker version. In both Bushbuckridge (n=27) and Phalaborwa (n=71), the majority of beer sellers make less than R1000/month. Overall, 57.7% (n=41) of Phalaborwa beer sellers and 51.9% (n=14) of Bushbuckridge sellers made under R1000/month, which was not a significant difference (x^2 (1, n=98)= 0.90, p=0.653). Certain trees are considered to have better fruit for brewing beer, with the brewers knowing which trees to use depending on the type of beer, as well as occasion that it is being brewed for specifically. Fruit containing a higher water content is considered the best for beer making with the hotter, drier weather being blamed for poor quality fruit and thus beer.

The main difficulties associated with the sale of marula beer in Bushbuckridge (n=24) were given as too many sellers (37.5%, n=9) and not enough customers (29.2%, n=7). In Phalaborwa (n=62), the marula beer sellers echoed these two categories, with 25.8% (n=16) quoting too many sellers and a further 27.4% (n=17) indicating there are not enough customers. Comparing the main categories (too many sellers and not enough customers) with those experiencing no difficulty with selling the fruit, the differences between the two locations were not significant due to similarities in difficulties, or a lack thereof, experienced by beer sellers between locations (x^2 (2, n=86)= 1.56, p=0.459).

Income from marula product sales is generated through three main income streams in both locations: the sale of fruit, beer and nuts. The average household income from these three revenue streams during marula season is provided in Figure 6.16.

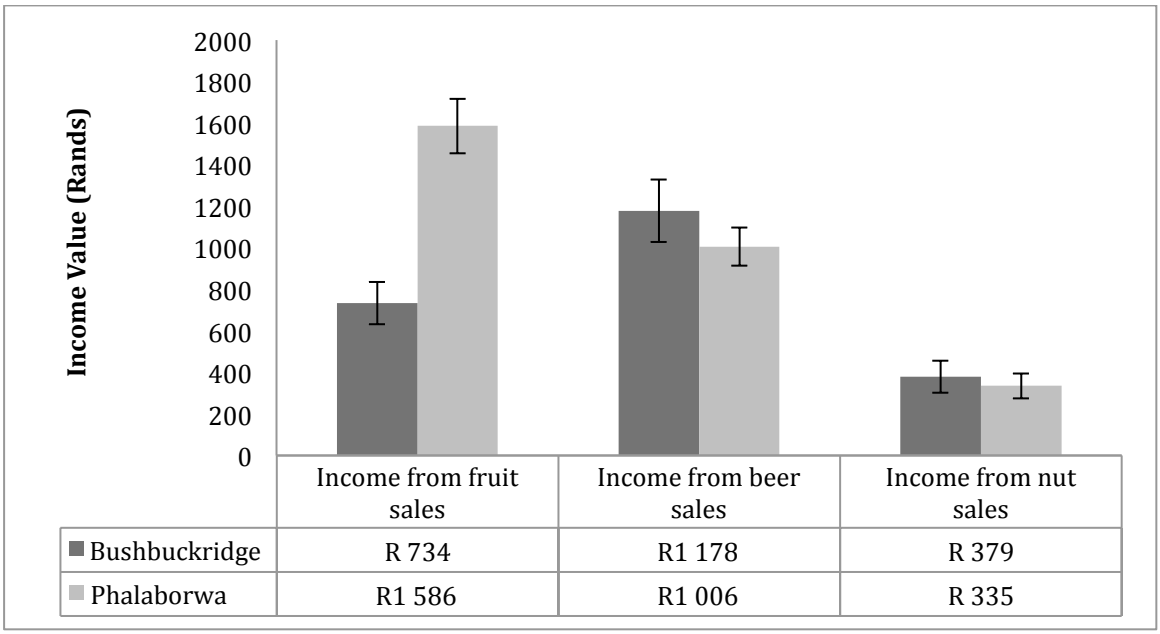
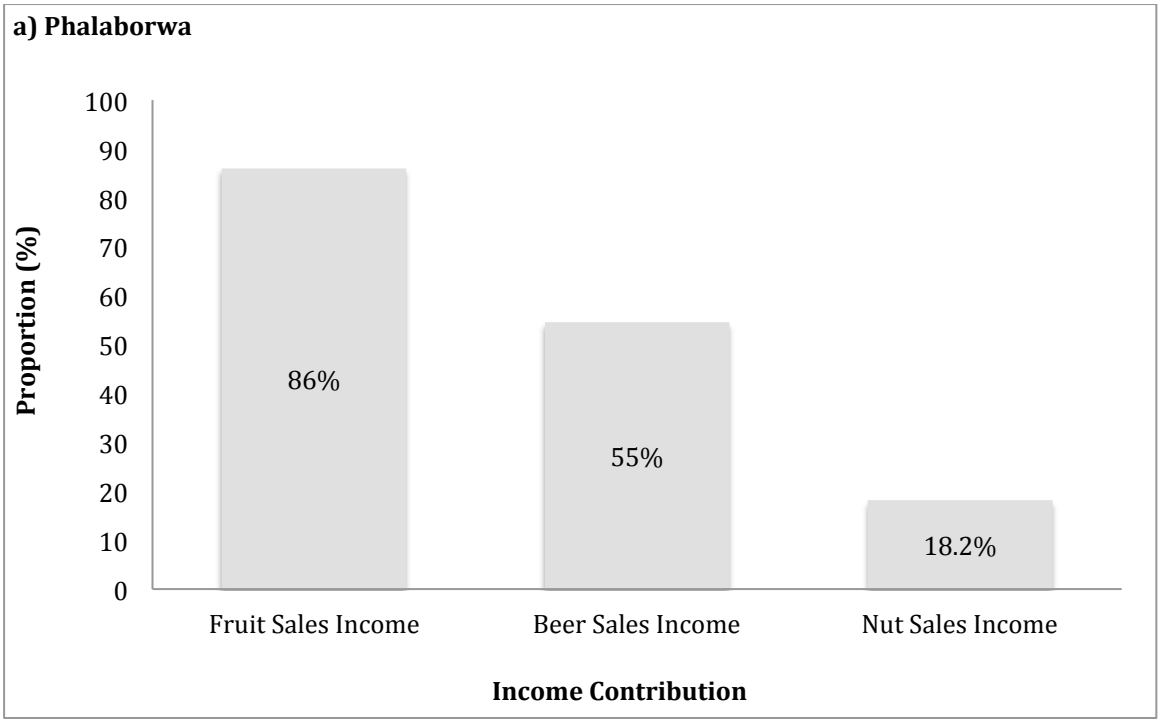


Figure 6.16: Average (mean±SE) monthly household income of those selling marula produce in Phalaborwa (fruit (n=49), beer (n=71) and nuts (n=36)) and Bushbuckridge (fruit (n=34), beer (n=27) and nuts (n=24))

The average monthly household income derived from the sale of fruit, beer and nuts were calculated as a proportion of the average (mean±SE) monthly household income in Bushbuckridge (R2360±R113) and Phalaborwa (R1844±R102). This was used to calculate the relative contribution of each income stream as a proportion of the overall household earnings. This information makes it possible to ascertain the extent of the contribution of each income stream to overall household earnings and thus the importance of this income in sustaining livelihoods in each location. In Bushbuckridge, marula beer sales (49.9%) made the largest contribution to household earnings, while in Phalaborwa, marula fruit sales (86%) were the largest contributor (Figure 6.17).



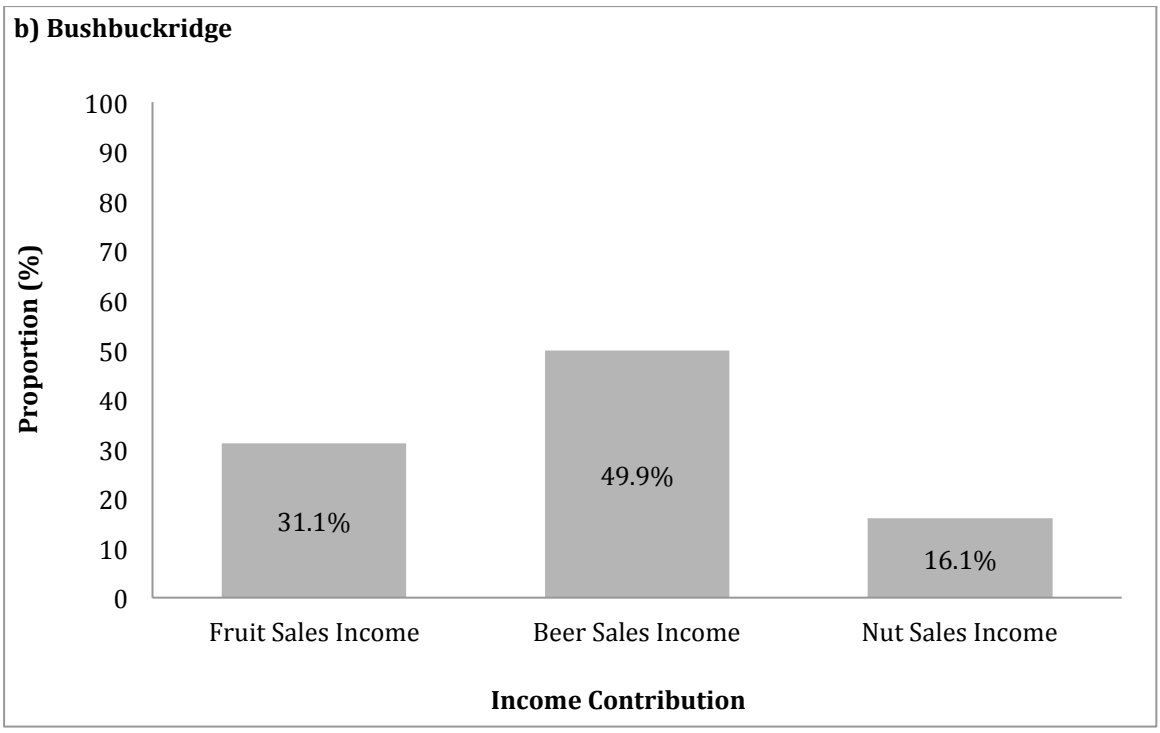


Figure 6.17: Relative contribution (%) of average fruit, beer and nut sales to average monthly household income in Phalaborwa (n=120) and Bushbuckridge (n=120)

In both locations, the monthly income generated from marula nut sales contributed the least to monthly income. The majority of nut sellers in Bushbuckridge (n=22) made less than R1000/month (n=20; 90.9%), which was similar to Phalaborwa (n=38) where 84.2% (n=32) made under R1000/month. This difference was not significant (x^2 (1, n=60)= 0.12, p=0.698).

6.3.5 Temporal changes in economic value and practices pertaining to marula in Bushbuckridge

Comparing the economic value of marula in 2018 with a previous study by Shackleton & Shackleton (2005) allowed for changes over an almost 15 year period to be assessed. Comparisons were made between those using marula for home use in 2005 compared to 2018, as well as the proportion of respondents selling marula fruit or products and the approximate household income generated from marula sales. In terms of the changes in percentage of households using marula for home use, the differing proportions of respondents are provided in Table 6.2.

Table 6:2: Comparison of the proportion of respondents utilising marula or marula products for home use in 2005 (n=146) from ~Shackleton & Shackleton (2005) and 2018 (n=120) in Bushbuckridge

Marula Use/Product	2005	2018
Fruit		
Beer	91%	75%
Eat Fruit	94%	3%
Jam	46%	40%
Juice	13%	5%
Kernels		
Eat nut	88%	63%
Add to dishes	61%	12%
Oil (cooking)	0.7%	1%
Oil (cosmetics)	1%	0%
Wood		
Firewood	94%	56%
Carving	5%	0%
Utensils	10%	0%
Medicine		
Bark	39%	39%
Leaves	4%	5%
Roots	8%	1%

There were three main categories of marula resources that were utilised for income generation in 2005, which were repeated in the 2018 results. The three income generating streams pertaining to marula are the sale of fruit, beer and nuts. The comparison between marula resource sales between 2005 and 2018 are given in Table 6.3.

Table 6:3: Proportion of respondents selling marula fruit or products in 2005 (n=146, from ~Shackleton & Shackleton, 2005) and 2018 (n=120) in Bushbuckridge

% Respondents	2005	2018
Selling Fruit	90%	28%
Selling Beer	15%	23%
Selling Nuts	54%	20%

Lastly, the comparison between the earnings generated from marula fruit and product sales per season in 2005 compared to 2018 are shown in Table 6.4. The Rand values from 2005 were adjusted by the year-on-year Inflation Rate increases, as issued by the South African Reserve Bank from 2005-2017, which provides the 2018 present day equivalent of the original income values.

Table 6:4: Comparison of per household income generated by selling marula products in 2005 (n=146, from ~Shackleton & Shackleton, 2005) and 2018 (n=120) as well as the 2018 inflation rate adjusted income data from 2005. The income range is shown each time.

Marula Income	2005 Previous Study	2018 Inflation Adjusted Data (2005)	2018 Current Study
Fruit	R38 - R335	R76.28 – R672.45	R684 – R2052
Beer	R500 – R1000	R1003.66 - R2007.32	R1178 – R3534
Nuts	R119 – R325	R238.87 – R652.38	R396 – R1118

6.4 Discussion

Exploring the extent of marula resource reliance amongst the rural communities of the lowveld savanna ecosystems highlights three important findings about local livelihoods and resilience. The first finding pertains to land tenure and specifically the negative impact of insecure land tenure on the conservation of this NTFP. Insecure land tenure has been identified by numerous authors as not only contributing to declines in resource stewardship, but also the overall resource base, due to overharvesting practices pertaining to open access resources (Berkes, 2003; Shackleton et al., 2003; Emanuel et al., 2005; Bisong and Andrew-Essein 2010; Paumgarten et al., 2011). The next lesson relates to local differentiation in terms of economic drivers and how these shape marula utilisation choices across the landscape. It is this local heterogeneity that has led authors such as Berkes (2007) and Khalid et al. (2013) to stress the importance of understanding the pluralistic and multi-level nature of community-based

resource use and reliance. Finally, the third finding uncovers the complex contributions of a NTFP resource, such as marula, to livelihood sustenance in a socio-ecological system (Liu et al., 2007). Social and economic dimensions are an integral part of the ecological order, which is impacted as much by biophysical as socio-cultural factors (Polasky, 2008). The large contribution of marula related income to household earnings illustrates the crucial role marula plays in sustaining livelihoods. This outcome suggests a high degree of reliance on this important NTFP, making communities vulnerable to any shocks to the system.

6.4.1 Walking a mile in the shoes of a marula fruit collector: land access and tenure

The extent of dependence on NTFPs is generally determined by five socio-economic factors. These five socio-economic factors are location of the resource, household wealth status, gender, education and seasonality (Timko et al., 2010). Marula resource reliance provides interesting insights into how rural communities integrate NTFPs into livelihood strategies, with all five socio-economic categories influencing resource collection strategies. This is due to collection strategies being influenced by the location of marula across different land-use types, with mainly poor, female collectors with limited formal education using this seasonal resource as a key form of supplementary income to reduce household poverty. It is usually the poorest households in particular who rely heavily on NTFPs for food and vital cash income (Makhado et al., 2009; Paumgarten & Shackleton, 2009). In addition, poor households are more likely to experience insecure land tenure for agricultural production, making collected resources all the more central to subsistence income strategies (McElwee, 2008). This raises the importance of understanding NTFP reliance in relation to land tenure. Individual community members are more likely to conserve a resource, or natural area, over which they have livelihood autonomy. Essentially, concern for the environment is usually connected to 'stewardship assets.' These are assets over which people exercise some degree of access and tenure and from which they derive extrinsic benefits in terms of natural, cultural or financial capital (Berkes, 2003;Deutsch et al., 2003; Berkes, 2007, Bennett et al., 2018).

Access to marula trees varied across the landscape based on three determinants of access and land tenure. The first was whether individuals belonged to households in possession of a marula tree in their yards. The second pertained to access or ownership of a field (or fields) containing marula trees, while the third related to the respondent's physically ability to collect marula fruit from trees in the surrounding communal rangelands. While a large percentage of the population sampled in South Africa had access to a marula tree in their personal yard in both Bushbuckridge (83.3%) and Phalaborwa (73.3%), far fewer had access to a field. Just under a third of respondents in Bushbuckridge and half of the respondents in Phalaborwa indicated access to a field. Despite lower levels of access, the numbers of fields containing marula trees were very high regardless. These findings confirm reasonably high levels of access across private land-use types, due to the pervasive presence of marula trees in both yard and field land-use types across the bioeconomy landscape. As a result, those with field access are therefore twice as likely to collect marula fruit when compared to those without access.

Despite field access being higher in Phalaborwa, the reality is that it is far more labour-intensive. This is due to over half of those community members with access to a field needing to walk on average 30-60 minutes to reach these fields. In contrast, the majority of collectors in Bushbuckridge only needed to walk for 5-10 minutes. Distance and quantities collected are usually directly proportional, with longer distances to collecting locations usually reducing the level of utilisation of NTFPs (Shumsky et al., 2014). However, in juxtaposition to the longer

walking distances, land tenure appeared more secure in Phalaborwa. This is due to the majority of field owners having directly acquired their field from the Induna (Headman). This denotes a clear transfer of ownership and thus a sense that the field is a stewardship asset (Deutsch et al., 2003). As a result, just under half of those collecting in Phalaborwa chose to utilise fields as a regular aspect of their collection strategy. However, the longer walking times are likely to diminish resource utilisation to a certain degree (Shumsky et al., 2014). This means that in reality, despite the more secure land tenure, the barrier of physical distance reduces field access in Phalaborwa.

In comparison, the majority of those with access to a field in Bushbuckridge indicated that they assumed use of an abandoned field. These fields technically belong to the Induna (Headman) and can therefore be taken away at any time. Lack of secure land tenure, pertaining to Bushbuckridge fields, means that these trees are less likely to be actively protected, as there is a reduced sense of ownership (Berkes, 2003). Authors such as Weiss et al. (2019) highlight how concepts of resource ownership inform pro-environmental attitudes and behaviours, which in turn are influenced by underlying socio-economic characteristics. Essentially, this means that for the wider community, the lack of secure land tenure essentially redefines these fields as open-access land-use types. As a result, a sense of personal stewardship is likely lacking. In turn, this can lead to overharvesting and a decline in the resource base over time (Bisong & Andrew-Essein, 2010). The fear that the field may be taken away at any time could also result in unsustainable harvesting practices occurring, as the temporary owner may attempt to obtain the maximum amount of resources while the tentative tenure remains in tact. Land tenure regimes in Nigeria were compared with patterns of resource use across various land-use types, with the authors highlighting the decline in common-property resources (CRPs) in communally owned areas, as opposed to private land (Bisong & Andrew-Essein, 2010). Berkes (2007) confirms how resource conservation increases with the degree of control and ownership. Sustainable harvesting practices are not only connected to land tenure security, but also wider socio-economic issues. These issues include access to social capital, environmental attitudes and alternative livelihood development strategies or opportunities (Bremer et al., 2013). Combining all these factors in the Bushbuckridge context, including lack of secure land tenure, this means no guarantee of on-going field access and increased uncertainty of supply. It is therefore unsurprising that fruit collection from fields is not considered a central component of marula utilisation strategies for the majority of collecting households in Bushbuckridge.

Despite the high numbers of households with access to marula trees in their own yards in both locations, rangelands were given as the preferred location for fruit collection. The majority of respondents specified rangelands as a preferred location as it allows for higher absolute volumes to be collected. This preference is despite the long walking distances required to reach these rangelands. In Bushbuckridge, only 12.5% of respondents specified that it took more than 60 minutes to reach their specific collection site, whereas in Phalaborwa the distances were slightly longer, with 23.1% of taking more than 60 minutes to walk one-way to collect the fruit. The fact that distance is not a deterrent, would support the notion of a higher degree of dependency on marula as a supplementary source of income in these locations. This finding would suggest that laborious harvesting practices are acts of necessity, rather than choice, likely due to diminished resilience. Communities usually utilise a variety of resources to generate subsistence income and sustain livelihoods (Twine et al., 2003). This would suggest that a more labour and time intensive resource, such as marula, may not be the popular choice. However,

the perseverance and time commitments of marula collectors despite long walking distances, is likely due to marula being a hardy species in an otherwise semi-arid area of reduced agricultural productivity (Akinnifesi et al., 2008). Reliance on natural resources usually increases in low productivity areas, as it is harder for communities to grow their own food crops (Mugido & Shackleton, 2017). In addition, the income generated from natural resource sales are fundamental for purchasing necessary food items that cannot otherwise be grown.

In addition to the physical distances that must be covered on foot in order to collect marula fruit, an equally important consideration is the return trip carrying the collected fruit. Respondents struggled to quantify an estimated return time with a bag of marula fruit. However, indications suggested it could take anywhere from three to four times as long to walk the return distance carrying the fruit. Where distances are exceptionally long, respondents clarified that they sometimes spend a few consecutive days, walking up to 10-15 km back and forth, in order to achieve this end. Authors such as Obiri et al. (2002) confirm that resource harvesting usually takes place within a 5 km radius of homes as this is the distance most people can walk carrying produce. Shackleton (1993b) made a similar finding in relation to fuelwood choices in Bushbuckridge. Once again, this dedication to marula highlights the high levels of dependency on this resource for crucial cash income. Furthermore, this dependency is despite the seasonality of the fruit, which means it is only available for a quarter of the year. These factors combine to further reduce the resilience of fruit collectors, who are usually women and have multiple time stressors placed on them in terms of supporting their families through unpaid labour (Shackleton et al., 2011). The time invested is a gamble if the fruit is not sold to the factory trucks, with the majority of respondents indicating that these trucks are not reliable. This means that the time invested in collecting fruit may ultimately be wasted. This financial loss comes at the expense of diminished time and resources to engage in the other supplementary income activities necessary to meet daily livelihood requirements.

While many fruit collectors have the option of using wheelbarrows to reduce the load, the majority of those collecting explained that it is too difficult to push wheelbarrows through the 'bush.' Instead, they choose to carry the fruit on their heads. Households with slightly higher income levels are able to rent donkey carts when large fruit volumes are collected (Twine et al., 1993b). This option is not available to poorer households who desperately need the additional income generated by larger fruit volumes. However, this cost is especially prohibitive for respondents who rent a donkey cart when they have in excess of 20 bags of fruit, but then the truck from the factory does not arrive on time and all the fruit goes rotten. Consequently, the greatest difficulty experienced by those respondents collecting fruit in both Phalaborwa and Bushbuckridge was the issue of transporting all the collected fruit. This is particularly frustrating for collectors as rangelands are specifically utilised in order to maximise fruit collection. Especially, as larger volumes can be gathered in rangelands, compared to limited yard and field trees. The physical barrier of distance once again reinforces pre-existing vulnerabilities in communities, reducing the resilience of poorer households in meeting their livelihood quotas (McElwee, 2008).

Compounding the issue of longer distances to the rangelands in Phalaborwa, physical safety concerns featured more prominently than in Bushbuckridge. Respondents here suggested that it is not safe to go to the 'bushes' to collect. This is likely due to the more remote locations of the available rangelands, making them unsafe for female collectors. This acts as a further barrier to livelihood security based on gender (Shackleton et al., 2011). In addition to the assistance

provided in carrying the collected fruit, female respondents noted that they choose to collect in pairs for physical safety reasons. The prominence of physical safety as a concern that was raised, illustrates the dominance of female fruit collectors, with the vast majority of collectors at both locations being women. While it is common for women to be the primary collectors of NTFPs in rural areas (Dovie et al. 2005), these additional safety concerns reduce the adaptive resilience of women (and girls) while further compromising their livelihoods security. Underlying socio-economic imbalances, such as the lower literacy rates historically born by women and girls (Dovie et al., 2005), further exacerbate systemic cycles of entrenched poverty and the high local unemployment rates (Twine, 2005). Despite the mentioned difficulties, the majority of respondents in Phalaborwa (70%) and Bushbuckridge (77.5%) still felt that it is relatively easy to access marula fruit due to the numerous trees in the rangelands. The higher number of respondents in Bushbuckridge is likely linked to the slightly improved proximity of rangelands to villages at this location.

While numerous respondents indicated they would prefer numerous large marula trees in their yard, in most instances this is impossible due to limited space. In order for a natural resource to provide livelihood sustenance, the nexus of quantity, quality and access must be simultaneously addressed (Milgroom et al., 2014). The fact that marula can meet these requirements might explain why long distances to the rangelands are endured, carrying heavy bags in order to collect enough fruit to sustain a living from sufficient fruit volumes. As a result of the demands of quality and quantity, trees with these properties are usually favoured in yards, as a form of domestication of the species (Shackleton et al., 2002). However, while larger marula trees provide more fruit in general (Nghitoolwa et al., 2003; Akinnifesi et al. 2008), it is worrying to note that the lowest relative abundance of large trees were located in yards in Bushbuckridge (Chapter 5). This may be due to the fact that even yards that contain a couple of large marula trees are unlikely be able to support a larger family without members having to collect additional fruit elsewhere. In turn, this lowers the economic status of yard trees as the main source of fruit.

Numerous respondents suggested that as a result of climate change, trees are either producing less fruit or phenological changes are causing early fruit drop. This can sometimes be up to a month or more in advance, leading to further difficulties in respondents reaching their required fruit quotas. While marula beer makers can change their collection strategies to accommodate the earlier fruit drop, those selling the fruit to companies like Distell explained that at the time, the main collection months were still from January to March. This means that the early season fruit is often not purchased which results in lost earnings. In turn, this has prompted more intense harvesting as well as competition around the sale of the remaining fruit during the prescribed marula season. Chirwa et al. (2008) highlight how commercialisation often results in overexploitation of NTFPs in rural areas, with participatory natural resource management approaches required to ensure commercialisation benefits flow to the economically marginalised. As the impacts of climate change worsen, with projections for Limpopo indicating hotter and drier conditions (MacKellar et al., 2014; Malherbe et al., 2014; Engelbrecht & Engelbrecht, 2016), the vulnerability of fruit sellers is likely to increase. This is unless effective participatory management approaches are implemented to compensate for implications such as a shorter marula season and thus severely reduced income.

Traditions pertaining to marula have generally meant that practices concerning fruit collection have continued in order for marula beer to be made for cultural ceremonies. This is despite

respondents acknowledging that marula is considered hard work. However, time will tell if the on-going transition from a 'culture' of marula to an economy of marula will continue to extract the current levels of dedication only while there are no viable alternatives. It is therefore important to consider what this means for the conservation of the species as a whole. This is especially true considering that environmental concern is comprised of a combination of both environmental and social considerations combined (Hunter et al., 2010).

6.4.2 How economic drivers influence marula resource use across different land-use types

6.4.2.1 Economic drivers in yards

The first economic driver influencing marula resource practices in yards relates to residential land-use choices. At a landscape level, marula trees are impacted by land clearing for settlement expansion. Marula trees are also chopped near existing houses to make space for building extensions. These behaviour patterns relate to people's concerns that large trees will damage new or existing houses, due to the extensive branch and root systems of marula trees. In addition, larger trees take up space in smaller yards. In Bushbuckridge, 60.8% of respondents confirmed removing a large marula due to these reasons, with half the number in Phalaborwa (31.6%) echoing this response. Considering the economic cost of buildings being damaged in this socio-economic context, it is an understandable response, even if not always necessary. However, occasionally there is no cause for concern as a tree is not located near a building and yet these too are quite often removed. An elderly woman in Allandale (Bushbuckridge) explained the sentiment towards large trees in yards as follows: "*The younger generation chop big trees so that their new houses can be seen. The older generation left the trees as protection from big winds and storms*." Inter-generational differences are common, especially in households where family members fulfil the roles of teacher and apprentice in passing on the communal ways of life (Madhavan & Schatz, 2007). It is important to remember that another intergenerational difference is that houses in the past were mainly smaller huts, which meant they not only took up less space in yards, but the thatch roofs would have been easier to repair than the tile or corrugated iron roofs of today. Bohman et al. (2009) refer to this as tradition in transition, where the revaluing of traditions can be seen as a response to social and economic change. In relation to marula, this tension between the generations is also largely premised on perceptions around the value of marula beer. The older generation are accustomed to utilising marula for traditional beer, which was never sold. This has resulted in tensions developing towards the younger generation, who are largely perceived to be proponents of selling their culture for economic benefit (Chapter 7). The cutting of marula trees in yards by the younger generation is therefore interpreted as another act of ignorance carried out by the culturally indigent.

The second economic driver shaping marula practices in yards pertains to the economic value of the female tree as the provider of fruit. This results in female, as well as juvenile trees, being protected in yards (Chapter 3). Female trees are specifically protected as the source of fruit while less often, seeds and saplings (from truncheons) are intentionally planted, with the idea of harvesting fruit from the adult female tree one day. However, this behaviour pattern is very rare. This deficit in active planting practices is likely due to a lack of necessity, with marula endocarps germinating very easily when discarded in yards from marula beer making (Chapter 5). In semi-arid, agro-ecological regions, such as the human inhabited savanna landscapes of South Africa, the highest densities of trees in yards are maintained for edible fruit (Paumgarten et al., 2005). The economic value of the female tree is therefore the largest contributing factor to

female trees being prioritised in yards (Paumgarten et al., 2005). This is not a recent trend, with Shackleton et al. (2003) finding 15 years prior to this study that it is usually the male marula tree that is felled. Even the poorest households will invest time and available resources into planting and maintaining fruit trees (Kirkland et al., 2007). Baobab recruits in Mali (West Africa) villages occur as a consequence of stewardship practices directed towards juveniles, which are maintained due to the economic value of the fruit (Duvall, 2007). The economic value of fruit trees in the South African context has generally resulted in a trend towards high-value exotics, such as mango, being favoured over indigenous trees (Shackleton et al., 2010). However, marula is the exception, as an indigenous variety with a higher economic value due to the fruit.

6.4.2.2 Economic drivers in fields

In fields, the main economic driver for tree removal concerns food production, specifically the need to grow crops (including cash crops) as well as fuelwood demand. In comparison to yards, land-use choices in fields are far more diverse. This is due to the varying uses of fields from full cultivation, through to no cultivation at the other end of the spectrum. Many fields are a mix and therefore qualified as partly cultivated. In addition, some fields were previously cultivated but had been left fallow. The impacts of land-use intensification in Mali (West Africa) were found to include deteriorated parklands, due to the harvesting of economically valued NTFPs (Dhillion and Gustad, 2004). In particular, the negative impacts of harvesting baobab NTFPs across different land-use types, such as cropland and fallow fields, were explored. The finding was that damage was ultimately higher in croplands (Dhillion and Gustad, 2004). Distinctions in land-use types are equally important in relation to marula, including the impact of field types and in particular of cultivated fields. This is due to resource practices such as the removal of all marula trees in fully cultivated fields, unless there is space around the periphery where they will not shade crops (Gouwakinnou et al., 2009). However, usually the largest and thus oldest trees will be left, probably due to the difficulty involved in removing them, in addition to the quantities of fruit large female trees can provide. A similar finding was made in agroforestry systems in Benin (West Africa), with the largest and oldest trees being located in farmed lands (Djossa et al., 2008). In cultivated fields, seedlings are usually ploughed out before they are able to establish, in order to plant arable crops. This means that recruitment beyond the seedling stage is more successful in partly cultivated or abandoned fallow fields. Turning the soil for crop production promotes germination, which can be beneficial if those germinants are able to recruit through to the sapling stage. This finding was confirmed by Byakagaba et al. (2011), who found recently fallow fields allow for regeneration in shea tree populations in Uganda (East Africa).

However, a clear disconnect exists between acknowledgement of the formal protection of the species on the one hand and adherence to these regulations on the other. The majority of respondents agreed that marula trees are protected from being chopped in fields (and rangelands), which are perceived as communal resources. In addition, these respondents indicated that there are economic consequences for chopping live marula trees, such as being arrested and paying a fine. However, this knowledge does not translate into avoidance behaviours, with trees being chopped regardless. Kirkland et al. (2007) found that despite being aware of regulations to prohibit the chopping of live trees, that communities in the Bushbuckridge region are forced to chop out of economic necessity. It is possible that the perception is likely very different from the reality, with more rampant chopping taking place than is indicated by respondents. This is due to economic drivers such as demand for fuelwood sales (Matsika et al., 2012). When asked if they would chop a marula tree in a field, very few

respondents in both Bushbuckridge and Phalaborwa were willing to admit to this act. Far fewer of those who have access to fields admitted to chopping marula trees in Phalaborwa. Tree chopping in fields was much higher in Bushbuckridge, where land tenure is not secure. This outcome is likely the result of increased land-use pressure and the consequently higher demand for fuelwood (Madubansi & Shackleton, 2007). Kirkland et al. (2007:7) highlight growing resource scarcity in the Bushbuckridge region and in particular fuelwood shortages, resulting in the perception that the "bush is no more" due to the rampant chopping of live marula trees. Scheiter et al. (2019) take this a step further by connecting economic and vegetation change models, illustrating how economic drivers decrease vegetation cover, with settlement expansion and the removal of trees for agricultural purposes as prime examples.

6.4.2.3 Economic drivers in rangelands

In rangelands, there are two main economic drivers shaping resource practices across this land-use type. The first economic driver pertains to the use of fuelwood, whether for household use, or for sale in fuelwood markets (Matsika et al., 2012). This results in the resource being harvested in higher quantities. Fuelwood gathered for home use is also considered an income saving strategy, as households do not need to rely on paid electricity. In addition, these households so not need to purchase wood if they are physically able to collect it themselves. In rangelands, trees are chopped indiscriminately, with no obvious prioritisation or avoidance of female trees (Chapter 4). The indiscriminate use of trees for fuelwood in Bushbuckridge is confirmed by Shackleton (1993b). Distance and tree size are the most important selection criteria for harvesting (Obiri et al. 2002), meaning that any female trees in the desired size classes within proximity of villages will be felled. This undermines the argument that the higher the commercial value of a NTFP, the more likely it is to be conserved in reality (Arnold & Perez, 2001, Belcher & Schreckenberg, 2007).

Fuelwood harvesting as an economic driver is underpinned by two social findings, the first is that over half of the respondents utilise marula for fuelwood. This is despite it being unlawful, and even an undesirable wood for cooking, as it is soft and smokes easily (den Adel, 2002). The second social finding is that due to the per capita quantities of fuelwood required, it is likely that respondents utilise rangeland trees as a source of fuelwood. Monthly per capita quantities of fuelwood required per household are in the region of 44.9 kg (Madubansi & Shackleton, 2007). Trees targeted for fuelwood are unlikely to be yard trees as these occur in limited abundance and would soon be depleted. This means households would need to utilise rangeland trees in order to meet on-going demand. Numerous respondents used the opportunity of being asked about fuelwood use to speak about rampant chopping of marula trees in rangelands. This included the excessive use of marula for fuelwood, under the guise of it being something they have observed, knowing it is prohibited to chop live trees themselves. Understanding the underlying drivers of resource exploitation can assist in developing sustainable co-management practices that ensure future sustainability.

The fact that marula fuelwood usage is relatively high in both locations, especially for a protected tree (Twine, 2005), raises concerns for the species in the rangeland landscape. Twine et al. (2003b) indicate how the breakdown of traditional management of communal resources is exemplified in the budget cuts to chiefs. Local chiefs were previously able to hire 'tree police' in order to enforce the prohibition on the cutting of live trees. While dead wood is preferential to live trees, resource scarcity means that live trees are now being utilised. This finding is supported by the fact that deadwood only meets 7% of current fuelwood demand in the

Bushbuckridge region (Mograbi et al., 2015). The lines around resource ownership often blur in yards and fields, with respondents suggesting that these trees belong to the individual landowner and can thus be utilised as the owner chooses. However, even in rangelands where there is no dispute as to the communal ownership of the resources, rampant chopping of live trees still takes place (Matsika et al., 2012). This is despite respondents indicating that rangelands are governed by the Induna (Headman), with individual claims to the trees therefore being invalid. In addition, any harm inflicted on the communal rangeland trees is seen as damage inflicted on a shared resource, as well as against the wider community, due to the economic value of the tree. Community members therefore have no individual right to destroy common property resources, as these behaviours impacts other member's livelihoods (Twine, 2005). The fact that a protected tree, as well as an economically (and culturally) important species, is widely chopped suggests a clear disregard for Traditional Authority. This includes a wider erosion of customary practices in general, which is symptomatic of traditional authorities not being able to adequately enforce the rules around chopping live trees (Twine et al., 2003b). Even in the more rural villages where Traditional Authorities retain some legitimacy, it is likely that live trees are cut as necessitated by extreme resource use pressure (Kirkland et al., 2007). Due to increased resource demands, respondents agreed that more people are chopping marula trees now compared to just a decade ago, which most respondents felt raised cause for concern.

The second economic driver of marula harvesting in rangelands is the commercial use and sale of the fruit. In Phalaborwa, the majority of respondents indicated that more people are collecting the fruit now compared to a decade ago. In Bushbuckridge, the opposite was found, with the majority disagreeing that fruit collecting has increased. The perception in Bushbuckridge that fewer people are collecting fruit presently may be linked to the more prevalent marula beer culture in Bushbuckridge (Chapter 7). Previously, almost everyone would have collected fruit to make marula beer to share. However, the majority of those collecting presently do so in order to sell the fruit or beer, which means fewer collectors overall.

Respondents indicated that the rangelands were where they collected the most often, as well as the most abundant fruit. However, even this seemingly abundant resource appears to drive competition between collectors. Respondents specified that they not only needed to wake up very early (before 4am) to collect sufficient quantities, but that very large volumes are required to sustain a living. Marula fruit is collected in larger quantities per tree in the rangelands, as collectors will usually gather all available fruit under the tree in order to avoid having to walk further to harvest from additional trees. In contrast, land tenure in yards and to a lesser degree fields, means respondents can gather as much fruit as they need at a time due to exclusive access to the fallen fruit at a later stage. In rangelands, collected fruit does not belong to the collector and anything that cannot be carried in one journey is therefore open to theft, meaning dependence on rangeland trees is accompanied by a certain amount of livelihood insecurity. This practice requires collectors to hide most of the collected fruit to be gathered at a later stage, adding to the additional efforts of transporting it home. Once again, this confirms the on-going struggles of sustaining a livelihood through this natural resource. It is therefore unsurprising that those involved in formal employment are only half as likely to collect marula fruit as those who are unemployed. Considering the strenuous nature of this work, compounded by the physical safety risks of collecting the fruit, it is necessary to quantify if the end result of all this labour is some degree of livelihood stability. This is based on the economic contribution of marula to overall household income.

6.4.3 The economic value of marula livelihood strategies to households

6.4.3.1 The economic value of marula to households

Understanding the extent to which marula, as a natural resource, makes a key financial contribution to subsistence livelihoods, involves analysing the economic value generated by the resource. Earnings can be divided into an income savings stream and an income-generating stream. The first is the direct income generated from the sale of either the fruit, or the products made from the fruit, of which marula beer is the largest contributor. The second income stream is the indirect cost savings, which are generated by the use of marula products in the home. These create cash savings as marula products (such as jam or wood) can be substituted for bought items, thereby saving the household money.

Overall household remunerations in both Phalaborwa and Bushbuckridge are comprised of a combination of earnings. These are generated from very limited formal employment opportunities and numerous informal economy income generating activities. Formal employment in both locations is very low at 28.3% of households in Bushbuckridge and 35% in Phalaborwa. However, in this study, a household was considered to be directly involved in formal employment as long as one member of the household was currently working at the time the research was conducted. Considering the larger household sizes, with an average of 5.5 people in Bushbuckridge and 6.1 people in Phalaborwa, the actual levels of unemployment based on individual members instead of overall households would be considerably higher. Informal activities include strategies such as selling marula and other products, which are usually homemade, as well as informal employment. However, the majority of household earnings come directly from social or child grants, or a combination of both. Households with at least one or more older persons generally had a higher overall household income. This is due to these households receiving the monthly pension of R1600 (households interviewed before 1 April 2018) and R1690 (households interviewed after 1 April 2018). This cash injection into the household helps to pay for critical food items each month. Households with an elderly person and children have even slightly higher overall income. However, the additional income of only R380 (households interviewed before 1 April 2018) and R400 (households interviewed after 1 April 2018) per child ostensibly does not go very far in terms of covering the additional associated expenses. All households interviewed admitted that the child grant is clearly very little additional income, but that households where the parents do not have access to child grants at all are by far the worse off in terms of monthly income. The poorest households are those with no access to grants, who rely entirely on the subsistence income generated through informal economic activities. Some households depend heavily on the income generated during marula season; trying to maintain a living the rest of the year based on minimal cash savings from the first three months of the year.

The average household incomes in Bushbuckridge (~R317 per person/month) and Phalaborwa (~R303 per person/month) mean that communities in both locations are living below the poverty line for South Africa. These numbers are far below the StatsSA (2018) poverty lines at the time the study was conducted, with the food poverty line being R547 per person/month and the lower bound poverty line being R785 per person/month. In comparison to the World Bank (2015) global poverty line of $1.90/day, this equates to $0.71/day (R10.57) in Bushbuckridge and $0.70/day (R10.45) in Phalaborwa, taken at the exchange rate at the time the research was conducted. This means that the majority of households in both locations are also living well below the global poverty line.

6.4.3.2 Household livelihood sustenance strategies

As with other natural resources in most rural contexts, NTFPs are utilised in order to mitigate poverty, either as a livelihood strategy or as a safety net in times of emergency (Belcher, 2005; Rolfe, 2006). In order to survive within a context of high local unemployment and extreme poverty, households generally apply three livelihood sustenance strategies to generate and sustain earnings in relation to marula. The first strategy falls under the category of income savings, the second would be classified as income generating, while the third is a combination of the two. The main difference between the first two utilisation strategies is that some households opt to keep all the fruit for household use exclusively (income savings), while others choose to employ a combination. Those employing a combined approach prefer to sell some of the fruit and produce made from the fruit (income generating), while opting to keep the rest for home use. The third option involves selling all the fruit and produce for maximum income generation benefit. Many households oscillate between the three approaches based on necessity. The household's surveyed in this study battled to quantify indirect monthly savings based on marula usage, but most households provided estimates ranging from R50 – R200 per month. As a general rule, households applying a combined approach, tended on average to keep between a third and a quarter of the fruit collected for household use, while opting to sell the rest. Marula beer was the most commonly produced product for home use in both Bushbuckridge (88.2%) and Phalaborwa (91.6%). This allows households a large savings on the purchasing of commercial beer products, which would otherwise be considered too expensive. In households where this is a consideration, the cost savings provided by marula beer ranged from R100 – R500, based on the cost of commercially sold beer products and the number of household members partaking of the marula beverage. In order to reduce the cost of commercial beer purchases outside of marula season, many households bury marula beer filled bottles underground. These can purportedly be safely consumed up to six months later.

The consumption of whole marula nuts was the second highest home use category in both locations, indicating that consumed nuts save on purchased varieties. Despite the preference for nuts as a consumable, the actual consumption of the marula flesh does not seem as popular. Marula fruit has the potential to make a reasonable contribution to local diets due to its high Vitamin C content (Shackleton & Shackleton, 2005). However, the actual consumption of the whole fruit was seldom mentioned. This may be in part due to a growing preference for non-indigenous fruit varieties, such as mango. Respondents clearly indicated a preference for mango as an edible fruit over marula. A major difference between locations is the use of ground marula nuts as an additive to food dishes in Phalaborwa, being the third most utilised home product. The use of marula bark as a source of medicine, confirmed by 46% of households in Bushbuckridge and 34% in Phalaborwa, also saves critical household income on medicine purchases. Medicine is usually a high cost item, making marula *muti* (medicine) even more crucial for poorer households. This is especially true considering the range of ailments the bark is purported to treat, from stomach issues such as diarrhoea to skin irritations.

The number of respondents selling the fruit, beer and nuts were higher in Phalaborwa across all three categories compared to Bushbuckridge. In Bushbuckridge, only one quarter of the households who currently collect the fruit, indicated that they sell the marula beer, while in Phalaborwa it was more than double that number with a similar pattern repeated in the fruit sale data. This suggests a possibly higher commercial, and thus economic value, attributed to marula in the Phalaborwa context. The higher revenues generated from fruit sales in this

context, which were more than double those generated from fruit sales in Bushbuckridge, suggest that marula fruit sales make a larger contribution to poverty reduction in this location. In Phalaborwa, fruit sales made the highest contributed to monthly household income, while beer sales contributed to just over half. In Bushbuckridge, the opposite pattern occurred with beer sales making the larger monthly household income contribution, while fruit sales contributed a smaller proportion. These figures suggest that marula beer, as well as fruit sales in Bushbuckridge, fall into the category of supplementary income. Supplementary income, as defined by Ruiz Perez et al. (2004), is additional income that usually contributes below 50% of overall household earnings. Marula fruit sales in Phalaborwa were the clear exception. A similar finding was made in terms of high contributions of NTFPs to household income (79%) in Sundarban Biosphere Reserve (India), although this was from a range of natural resources and not just one source, as is the case with marula (Singh et al., 2010).

Marula NTFPs are unique in that they tend to contribute to a larger proportion of household earnings. This contribution is higher than many other NTFPs in other parts of Africa, despite formally constituting supplementary income. In Benin, NTFPs contribute around 39% of local household income, with poorer households being more dependent on NTFP income (Heubach et al., 2011). In Cameroon, NTFPs contribute half this amount (15%), according to a study by Ambrose-Oji (2003). This finding applied to mainly wealthier households, with poorer migrant communities only relying on natural resources for 6% of their overall income. In Zambia, NTFPs provide 34% of household incomes, although once again, wealthier households earned up to ten times more income from NTFPs than poorer households (Mulenga et al., 2011). In Sudan, supplementary NTFP income from fruiting tree species ranged from 26% all the way up to 51% (Adam et al., 2013). In Ethiopia, NTFP contributed to almost half (47%) of household income (Melaku et al., 2014). In the South African context, Paumgarten & Shackleton (2009) confirm that while wealthier households tend to purchase more NTFPs, poorer households sold far higher quantities. Considering the low socio-economic status of the majority of the households in this study, the higher sales of marula NTFP would corroborate Paumgarten & Shackleton's (2009) findings. Contemplating the high levels of reliance on marula for monthly income during marula season, a key point of concern is how poorer households make up this deficit in the months outside of a marula season. This would indicate that poorer households are heavily reliant on any cash savings from marula as a safety-net out of marula season (Shackleton et al., 2004). The heightened dependence of these households makes them exceptionally vulnerable to any shocks to the system. These include phenological changes as a result of climate change, which limit the window for fruit sales, thereby reducing critical income. Due to the limited three month duration of the marula season, the sale of marula products as a livelihood supplementary strategy are unlikely to ever achieve poverty alleviation (Belcher & Ruiz-Perez, 2005). However, the vital income, which is both saved as well as generated during marula season, is certainly able to reduce poverty levels. In particular, this applies to slightly wealthier households, which are able to sell larger volumes of either the fruit or beer (Twine et al., 2003; Makhado et al., 2009).

At the time of this study, the possibility of selling directly to the factory in Phalaborwa likely increased the demand for fruit, resulting in the harvesting of marula fruit in larger quantities, with more respondents selling fruit here. Respondents in Phalaborwa indicated being able to sell the fruit directly to the processing plant at a higher rate than that paid by the trucks, which come to the various villages from the processing facility to collect the fruit in both Phalaborwa

and Bushbuckridge. It was suggested by a few of the respondents that some truck drivers take a portion of the payment for the fruit in exchange for making unscheduled purchases from certain villages. Respondents indicated that as a result, selling directly to the trucks was not without complication, as the trucks reportedly did not always stick to the scheduled collection dates, meaning that often large volumes of collected fruit go rotten, and thus much needed income is lost. The latter may be a deterrent for fruit sellers in Bushbuckridge, who do not have the option of taking the fruit directly to the processing plant.

The likelihood of respondents collecting marula fruit was found to be three times higher in Phalaborwa compared to Bushbuckridge. There is a clear relationship between the presence of the factory collection truck and people collecting the fruit. Numerous older respondents in Phalaborwa stated that the prolific collection for money has led to unsustainable practices. This was explained at an informal focus group in Mbaula (rural Phalaborwa) as follows: *"People are so desperate to make money that they will chop branches from the tree to fill up their bags."* The fact that the fruit is thus green is seen as an added benefit as it does not go rotten if the collection trucks do not come on time.

While this study ended before the closure of the Phalaborwa factory, it is likely this closure will have direct socio-economic impacts on the household selling fruit in this context. The likelihood is that households will continue to sell fruit to the factory trucks, as is the case in Bushbuckridge. However, the perceived unreliability of the trucks is possibly the reason for lower levels of fruit sales in the Bushbuckridge context. This means that those households in Phalaborwa who were able to rely on sales directly to the factory for a larger segment of their household income will have to diversify their supplementary income strategies. Assuming these households can diversify, then the impacts will be largely mitigated. However, if they are not able to adapt quickly, then this could leaves these households exposed to any further shocks to the system, such as drought conditions (Paumgarten & Shackleton, 2011).

In addition to the lower levels of fruit sales in Bushbuckridge, the lower levels of marula beer sales may be partly explained by a higher cultural value attributed to the beer (Chapter 7). Marula beer was previously revered culturally, meaning that it was prohibited to sell the beer until after 1998 (Shackleton, 2004). Over the past two decades, the cultural value associated with the beer has begun to erode, resulting in an increase in the volumes of sellers. However, those still following traditional ways disagree with beer selling. While the number of fruit and beer sellers were similar in Bushbuckridge, the former was much higher than the latter in Phalaborwa. A preference for beer sales confirms the numerous difficulties associated with selling the fruit in both contexts. These detracting factors make beer selling the more obvious choice, even with the relative proximity of the Distell factory in Phalaborwa. This diversification into combined beer and fruit sales in Phalaborwa may mean these households are more resilient to the closure of the factory. The numbers of sellers are likely more equal in Bushbuckridge due to the number of beer sellers being curbed by cultural taboo and fewer fruit sellers, due to the inherent difficulties. In addition to unreliable factory trucks, sellers indicate the double jeopardy of first transporting fruit home and then on to various collection points. In comparison, marula beer is hard to make initially but once made it is easier to transport in 25L buckets to market. This journey can be made by taxi, with many customers coming directly to the seller's house. Interestingly, the sale of marula beer was found to make the largest contribution to household income, likely due to the higher sales price per unit of beer. Those selling marula beer in both locations quoted the high number of competitive marula beer sellers as the main difficulty in

attempting to earn a sustainable income. However, if a seller gets a reputation for making good quality marula beer, numerous customers will make a point of buying from them directly.

6.4.3.3 Temporal changes in the marula bioeconomy in Bushbuckridge

Overall household patterns showed a decrease in the use of marula for beer, fruit, juice and nuts between 2005 and 2018. Only the use of jam in households in both periods has remained constant. The most marked decrease has been in the eating of whole marula fruit, which diminished from 94% in 2005 to only 3% in 2018. However, Shackleton and Shackleton (2005) mention how many woman indicated they would taste the fruit as they collect, which likely contributed to the high overall amount of fruit consumed. If tasting had been included under the consumption of fruit in the 2018 sample, then the percentage would be considerably higher. This is due to all of those respondents collecting fruit for beer making, indicating that they sample the fruit as they collect. This is based on the taste of the fruit, which determines the quality of the beer, which in turn dictates the number of customers. If beer makers' pattern of tasting the fruit is included in the 2018 dataset, then consumption of marula would increase to 75% (n=90) in Bushbuckridge and 82% (n=98) in Phalaborwa. However, an important simultaneous trend that has occurred over this timeframe is a preference for non-indigenous fruits, in terms of both taste, but also economic value. In particular, mango has become very popular, even replacing marula in certain yards, as the fruit can be both eaten as well as sold. In addition, respondents indicated that mango is easier than marula in terms of labour inputs, as it can just be picked and then sold at the side of the road. Shackleton (2000) found that indigenous fruits were still popular amongst 72% of respondents twenty years ago, with 55% of respondents indicating taste as the main reason. When asked about a preference between mango and marula in 2018, 62% of respondents in Bushbuckridge and 47% in Phalaborwa indicated a preference for mango. The higher sales of marula in Phalaborwa may be the reason that marula is still the more popular choice in this context. This is likely due to the proximity of the factory, making direct sales plausible. With the closure of the factory, it is likely that fruit sales may decrease in Phalaborwa, possible aligning with those in Bushbuckridge, which is located far from the factory. In Bushbuckridge, the majority who selected mango indicated that this was due to the dual role mango plays as both a food source and potential income stream. In Rolle (Bushbuckridge), a young man explained: *"Marula is a snack but mango is a meal."* In addition, the higher rainfall in Bushbuckridge allows exotic fruit trees, such as mango, to survive (Akinnifesi et al., 2008).

There is a preference for planting exotic fruit trees in yards in Limpopo Province, with water limiting the planting of fruit trees, even in the Bushbuckridge region (Paumgarten et al., 2005). Twenty years prior to this study, High & Shackleton (2000) found that marula was the indigenous exception at the time, not having been supplanted by domestic varieties. However, mango provided a higher average income across the households surveyed, with 82.3% of households choosing to grow mango, compared to 40.3% growing marula (High & Shackleton, 2000). A decade later, Shackleton (2010) found that as a general trend, indigenous trees such as marula used to be eaten for taste, but that primarily mango was chosen instead. In spite of this finding, the proportion of those choosing to plant commercially valuable trees, such as mango, had decreased from 82.3% (2000) to 68% (2010) of community residents (High & Shackleton, 2000; Shackleton, 2010). Interestingly, marula managed to maintain its market share over the decade, with planting increasing from 40.3% in 2000 to 46% in 2010 (High & Shackleton, 2000; Shackleton, 2010). While very few respondents indicated planting marula in 2018, the fact that

83% of yards in Bushbuckridge contained a marula tree, would suggest that marula maintains its tentative socio-economic prominence at present. It will be interesting to see what happens over the next decade considering the fact that 86.7% of households indicated they had specifically planted a mango tree, with 61.7% stating they actually prefer mango to marula in Bushbuckridge.

A second noteworthy temporal pattern was the decrease in the usage of marula wood for firewood over this period, from 94% of respondents in 2005 to 56% in 2018. This may speak in part to increased electrification during this period. However, most households are not able to afford electricity costs over and above the free household quota (Madubansi & Shackleton, 2007; Matsika et al., 2012). This makes it a surprising finding that fuelwood demand has decreased, while land-use and resource pressures have increased over this time. However, this finding is supported by studies examining fuelwood consumption. In 2003, fuelwood consumption of households in Mametja (Limpopo Province), was estimated at ~4000 kg per household annually (Twine et al., 2003). A decade later in 2013, Matsika et al. (2013) assessed fuelwood consumption in Bushbuckridge, concluding that consumption was ~3000 kg annually per household. This would suggest a decrease of ~1000 kg per household over a decade, which would support the decrease in fuelwood use in Bushbuckridge from 2005 to 2018.

Marula as an ethno-medicine has largely remained unchanged since 2005, with only the use of the roots decreasing. The use of the bark as medicine has remained constant at 39% of community residents, which is likely due to the widely regarded effectiveness of marula in treating stomach ailments. In addition, this provides much needed cost savings in terms of purchased medicines. In terms of the trends around the sale of marula and marula related products, the number of respondents selling marula fruit dropped by around a third from 2005 to 2018, with the sale of nuts having decreased by approximately half the proportion of respondents. The use of nuts as an additive in food dishes also declined, possibly a symptom of cultural attrition, with fewer households eating the traditional dishes to which marula would have been added in the past. Only the sale of beer has increased during this time. With the erosion of customary law, the increased sale of marula beer is perhaps an expected consequence. Especially considering the inherent difficulties in collecting large fruit quantities and an already saturated market deterring fruit sellers. While selling the fruit involves only the labour to collect and carry, the strenuous nature of this work makes the R38 per 80 kg bag tough manual labour, for little financial benefit. Marula beer involves labour in terms of the fruit collection and additional time preparing the actual beer. However, the beer is sold for 750ml (R5-R10), 1L (R10-R15) or 2L (R15-20) per bottle, with an 80 kg bag required to make a 25L bucket of beer. This means the return on time invested is far higher for the beer, with a maximum profit of R250 per 80 kg bag (25L bucket) when selling beer, compared to the R38 per 80 kg bag for the fruit on its own. It is likely that the higher return on investment for marula beer has resulted in the increased sales over time.

Respondents specifically noted the hard work involved in extracting the nuts from the kernel, possibly leading to the decrease in the number of nut sellers over time, based on the minimal financial returns on the time invested in making up a packet of marula nuts. Respondents indicated it would take at least a day to prepare a cup of nuts, which sells for R10, or two days for a bottle of nuts, which sells for R20. The sale of marula wood carvings and utensils was not mentioned at all by respondents, possibly due to a decline in the traditional uses of marula utensils. A prime example is the marula spoon previously used to serve beer in cultural

ceremonies, which is likely less in demand now. In addition, the selling of marula wood carvings are most likely viewed as taboo due to the prohibitions on cutting live marula trees, which would be required for most carvings. Finally, despite the decreases in the proportions of fruit and nut sellers, the average household income ranges generated from the sale of marula products have increased, as would be expected over time. However, these amounts are both insufficient as well as uncertain, as there is no guarantee of income each season. This means that at present, marula earnings are unable to seriously contribute to any material reductions in terms of the high levels of poverty endemic in the region.

6.5 Conclusion

While marula products are not able to provide large-scale poverty alleviation in the Bushbuckridge and Phalaborwa areas, this important NTFP enables poor households to meet a range of livelihood needs nonetheless. Marula use strategies allow communities to sustain livelihoods by both generating cash incomes (income generating stream) as well as providing a substitute for other household items (income savings stream), which would otherwise require cash expenditure. Households therefore apply three supplementary livelihood strategies, either retaining all produce for home use or alternatively, opting to sell all marula related produce for maximum profits. The third strategy entails a combination of both based on necessity and need. Marula produce, particularly the fruit sales in Phalaborwa as well as the beer sales in both locations contributed towards more than half the household monthly income for the duration of the season. This income is therefore crucial in providing livelihood sustenance, especially for the poorest households. This means these households are vulnerable to any shocks to the systems, such as drought or phenological changes affecting potential fruit sales. Accurately understanding the actual harvesting and management practices applied by local communities is therefore important for addressing long-term sustainability (Ticktin, 2004; Ndangalasi et al., 2007).

The marula bioeconomy is stratified across the three dominant land-use types within these non-conservation savanna areas. Economic drivers specifically impact resource harvesting and utilisation choices. The economic drivers dictating resource patterns in yards, relate to settlement expansion. Scheiter et al. (2019) identify settlement expansion as placing the greatest pressure on rangeland sustainability, combined with land-use intensification and climate change. The main economic drivers shaping marula resource practices in fields pertain to crop production and thus food security, with large marula trees and seedlings removed to make space for arable land. In rangelands, marula is utilised entirely for it's economic capital, in particular the fruit and wood, which are used at the household level but also sold commercially. Local governance issues, such as land tenure and access, as well as declines in traditional governance, negatively impact the amplification of livelihood benefits that marula would otherwise provide. Insecure land tenure linked to field ownership and therefore uncertain access, has led to lower levels of resource stewardship in Bushbuckridge fields, compared to Phalaborwa. In addition, the erosion of customary law practices and Traditional Authority in both locations has resulted in high levels of firewood usage in rangelands, despite the reported financial consequences attached to such actions.

While the household usage, as well as sale of marula products, has declined over the past 15 years, the cash injection from the marula products sold (specifically the fruit, beer and nuts) provides much needed cash income for very poor households. Many households attempt to save

marula income to use as a safety-net outside of marula season. However, large quantities of marula fruit are required to generate small pockets of income, whether through fruit or beer sales. Income from fruit sales was easier to generate in Phalaborwa, due to the proximity of the factory. The closure of the factory is likely to result in decreased fruit sales as these can only be made to the trucks going forward, which are considered unreliable. Therefore, without the extenuating circumstances created by the reliability of direct factory sales, households may find themselves struggling to adjust in order to generate sufficient supplementary income.

The burden of acquiring large fruit volumes to sustain livelihoods is further compounded by long walking distances to gather fruit. The small financial returns and large time investments needed to sustain livelihoods make marula an economic strategy of extreme necessity and not one of choice. Considering these factors, it is perhaps not surprising that marula use and thus overall economic value is potentially on the decline over the past two decades. The dual cultural and economic value of marula requires on-going research to focus on the complete socio-economic value this resource provides. Crucially, it will be necessary to explore opportunities to scale up the current economic benefits of a resource that is receiving growing international attention commercially (Wynberg et al., 2003; Emanuel et al., 2005). While the resource appears plentiful and there is no apparent competition between commercial and local enterprises at present, it is not clear if the socio-economic footprint of the marula bioeconomy is sustainable. Bolstering the local marula bioeconomy would require large-scale reciprocal community and commercial relationships, in order to increase overall socio-economic benefits.

7. Like Sands Through the Hourglass: The Shifting Cultural Value of Marula as a Non-Timber Forest Product

7.1 Introduction

The marula tree (*Sclerocarya birrea* subsp. *caffra*) is valued culturally for the fruit, which is used to make marula beer, the cornerstone of a variety of cultural rituals and rites. In addition, the tree is also culturally significant, as the site for certain cultural practices. The beer and tree are utilised together by local communities in sacred cultural ceremonies, which involve communicating with the ancestors (Shackleton, 2004; Shackleton & Shackleton, 2005). Unlike certain economic and even ecological benefits produced by ecosystem services, which can sometimes be replaced, the cultural values of an ecosystem or landscape are irreplaceable (Plieninger et al., 2013). This is because cultural ecosystem services develop over long time periods, as a result of complex and dynamic relationships between humans and ecosystems within a given landscape (Plieninger et al., 2013). Complex socio-ecological systems (SES) are therefore interacting stores of natural, cultural and economic capital. System shifts within these complex SES caused by humans, such as marula deforestation as a resource use choice, are informed by the local environmental knowledge of the communities living on the land. In turn, these local resource use choices result in ecosystem consequences, such as a reduction of the resource base. It is at this intersection point, between the on-going economic and ecological transactions of communities and a natural resource that cultural values intervene to determine the nature of the contract (DeFries, 2007). Marula has a high cultural capital, which may inform when and why it is transformed into other capital stores. An example is the economic value of the fruit or wood, producing cash income and savings (economic capitals), derived from the beer and fuelwood. The socio-symbolic aspects of a SES, such as the cultural value attributed to a natural resource such as marula, determine the ontological transactions. These transactions build resilience into the system, where the decrease of a particular capital is mitigated by the mobilisation of other capitals. In other words, the social or human capital the resource provides, such as the sharing of marula beer, is deemed a more valuable capital store than the economic value derived from chopping the tree for firewood.

The non-financial benefits of resource transactions, in relation to marula, include the direct improvement of overall quality of life for community members (Shackleton, 2008). This includes understanding how the additional capitals associated with the resource, such as the embedded social and human capital, reduce the vulnerability of the poorer members of the community. Shackleton & Shackleton (2005) give the example of gifting marula beer during marula season when resources are high, which reinforce or strengthen certain social relations. These transactions allow poorer members of the community to call upon a neighbour for a favour in return later in the year, when resources are generally running low. Marula beer is an example of a key cultural resource that creates connections beyond purely economic transactions (Shackleton, 2004). In fact, the cultural value of marula beer was so carefully guarded that it was prohibited to sell the beer before 1998 (Shackleton, 2004). As the cultural value associated with the beer has begun to erode, the volumes of sellers have increased over the past two decades. Women making the beer would know the best trees with the most favourable fruit for beer

making, often preferring green fruit so they can choose the level of ripeness (Shackleton, 2004). Importantly, Shackleton (2004) identifies the biggest threat to fruit availability as the demand for marula fuelwood. Behaviour choices across different temporal and spatial scales are therefore continually evolving, mutually adaptive transactions, between a resource and the resource users (DeFries, 2004).

There is an on-going paradigm shift regarding human-nature transactions, which are being redefined as 'win-lose' scenarios within multi-zone conservation planning approaches. These approaches accept that some biodiversity losses need to occur in order to secure certain high-level conservation wins (DeFries, 2004; Reyers et al., 2012). Win-lose scenarios can be understood as 'small loss, big gain' transactions, which are often exogenous and high-level in origin. Sometimes these transactions are the result of local, endogenous feedback mechanisms (DeFries, 2004, Reyers et al., 2012). A key example of a local, endogenous feedback mechanism is spatially predominant resource depletion, interspersed with patches of conservation efforts across the landscape, due to the inherent cultural value of a particular species. An example of this is marula being conserved in people's yards (Chapter 3). The end result of these socio-economic processes of value attribution, are communities maintaining a resource that meets a variety of capitals, across a specific landscape. Ultimately, for these scenarios to work requires a set of compromises in terms of species conservation and community livelihood sustenance (Lambin, 2009). Essentially, this requires a move away from binary terms of conserved or not conserved within these multi-functional landscapes. This includes interrogating the consequences of the actions displayed by stakeholders involved in conserving a particular species (Reyers et al., 2012). In particular, communities utilising marula trees are a prime example of both custodians, as well as perpetrators of resource degradation. The result is a landscape of both conserved and not conserved spaces. Furthermore, this approach recognises the contributions of different land-use zones, such as rangelands, to species conservation. While biodiversity conservation levels may be lower than in formal conservation areas, this approach includes the inherent characteristics of the natural resource in conservation planning, ensuring these conservation opportunities are not lost (Thiel et al., 2012). This is important within the South African context, with as much as 80% of plant and invertebrates occurring under grazing management regimes. In addition, the country has shown a 19±7% decline in species diversity from its pre-colonial state three centuries prior (Biggs et al., 2006).

7.1.1. Cultural landscape of marula as shaped by traditional environmental knowledge

A transactional understanding of human-nature interactions places cultural values as the cornerstone of developing place-based solutions. In particular, finding local solutions in response to environmental degradation in order to ensure robust socio-ecological systems. Landscapes and the natural resources contained therein are valued in multiple ways by the people most closely associated with them (Stephenson, 2007). The cultural values associated with a natural resource are therefore socially accepted constructs, which develop and change over time (Stephenson, 2007). Cultural landscapes are not only subjective and experiential, but cognitive meaning incorporates past experiences of communities as a whole, which inform present value associations. These past or embedded values are important in understanding how socially constructed values shift over time. Humans are thus both active participants in evolving the landscape, as well as static receivers of information from these changing landscapes (Raymond et al., 2009). Traditional Environmental Knowledge (TEK) systems view people as an integrated part of the natural world, as opposed to having domain over nature (Pierotti &

Wildcat, 2000). Ethnoecological approaches exploring TEK aim to understand how and why, in open access resource systems, people utilise their environment in specific ways (Gaoue & Ticktin, 2009).

Key to ethnoecological approaches of exploring resource use are transfers of specialist knowledge from one generation to the next. This includes the youth, as not only knowledge custodians but also direct participants in resource activities (Luoga et al., 2000). Normally, ethnobotanical knowledge is held by the older members of a community and is transferred orally, highlighting the need for urgency in capturing this information before it is lost along with the older generation. Local communities will have a broad knowledge base pertaining to the characteristics of the complex SES within their locality (Godgil et al., 1993). The unique characteristics of this knowledge base are inextricably tied to the belief systems and thus cultural traditions of that specific community. Observations and thus concerns around key changes in the system are transmitted from generation to generation with knowledge custodians usually expressing "logically informed environmental concerns" (Hunter et al., 2010: 9). Science-based societies have been criticised for oversimplifying SES, with the adverse implications of on-going environmental degradation and ultimately resource exhaustion as a direct result (Godgil et al., 1993: 151). TEK and scientific observation need not be maintained as mutually exclusive methodologies. This is because the result of combining these two forms of knowledge acquisition, specifically in relation to environmental change impacts, is ultimately the reduction of uncertainty (Huntington et al., 2004). Furthermore, TEK and scientific paradigms do not need to be kept distinct either, as is common practice (Berkes, 2007; Shackleton et al., 2011).

It is for these reasons that a methodology that combines social and natural science approaches has been applied in this study, in order to address comprehensive resource use and sustainability issues simultaneously. Kaschula et al. (2005) encourage using local indigenous knowledge to gauge the extent of symbolic and cultural values attached to a specific natural resource. Often cultural fragmentation can be used as a mirror to view environmental degradation, as communities make sense of environmental changes experienced through socially constructed lenses. Combining TEK with scientific perspectives provides a more encompassing approach that includes humans and culture in the overall analysis. The advantages of this approach are verifiable outcomes, obtained through careful comparisons of TEK observations with those produced from scientific analysis. Specifically, understanding how people view their impact on a resource helps to explain why certain resources are over-utilised while others are conserved (Gaoue &Ticktin, 2009). Sadly, many local level conservation practices are intricately linked to culture and as cultural beliefs are eroded, those practices are lost.

7.1.2 Environmental concern and resource stewardship

Environmental concern is based on a combination of contextual cultural and physical factors, with location or proximity to nature and natural resources positively influencing conservation attitudes (Hunter et al., 2010). Human values shape the extent of engagement in environmental issues, with people displaying communitarian worldviews being more likely to change negative behaviours, compared to those with more individualistic worldviews (Corner et al., 2014). Local environmental stewardship is usually enabled by intrinsic motivations such as values and beliefs, as well as extrinsic rewards such as economic, social or physical benefits (Bennett et al., 2018). In contexts where livelihood autonomy is promoted and social and human capital are

high, positive social change and pro-environmental behaviours are more likely. In contrast, where livelihood autonomy is undermined and social and human capital are depleted, negative environmental impacts usually follow (Bennett et al., 2018). In contexts where local communities rely on a natural resource, such as marula, for a variety of livelihood as well as cultural services, concern for the environment is often expressed as a combination of environmental and social issues (Hunter et al., 2010). However, it is important to remember that ecological responsibility cannot simply be understood by exploring human-nature linkages. Instead, it requires a deeper exploration of the underlying life cultures that inform those interactions (Mukherjee, 2016).

Research investigating care for the environment has generally indicated that younger, liberal and more educated people tend to show greater concern for the environment. Further, women generally show greater levels of environmental concern and thus pro-environmental behaviour than men (Dietz, 2002; Hunter et al., 2010; Weiss, 2019). However, other key factors highlighted in the literature are physical proximity to environmental assets and specific cultural values pertaining to that resource (Raymond et al., 2009; Hunter et al., 2010). Cultural capital literature stresses landscape connections between people and their environment. This literature highlights how spatial proximity increases concern, but that cultural values maintain it (DeFries, 2007). According to social-ecological principles, understanding SES as a store of capitals means that while resources can be transformed from one capital to another, they are not interchangeable. This means capital stores cannot be depleted, or the system becomes unsustainable (Scholes, 2009; Stokols, 2013). Interestingly, environmental stewardship is shaped as much by economic and political factors as it is by cultural ones (Ostrom, 2009).

Resource scarcity and environmental degradation are often linked to economic livelihoods, making it difficult for community members to separate these issues (Hunter et al., 2010). However, in a complex SES, economic consequences are not always the most valued outcome of quantification attempts, such as Payment for Ecosystem Services (PES) (Thompson & Freiss, 2019). Often the socio-cultural value of a resource may be as important, if not more important, than the direct economic value to the local users (Grillos, 2017). Bremer et al. (2013) explain how full participation in PES are inextricably linked to a larger array of concerns including land tenure security, access to social capital, the cultural value associated with the resource, environmental attitudes and the availability of alternative livelihood strategies. Biotic indicators used to monitor ecosystem services and in particular biodiversity, need to be coupled with social contributions at a variety of scales (Feld et al., 2009). This is exemplified in the Millennium Ecosystem Assessment (2001), which classifies ecosystem services into different categories including provisioning, regulating and cultural services. Cultural services include non-material benefits derived from nature, such as spiritual enrichment. While indicators exist to assess the ecosystem or its biodiversity, there are no proper systems in place to assess the actual ecosystem services (Feld et al., 2009).

Community-based conservation has been touted as crucial for sustainability as well as being a key approach for improving positive attitudes towards conservation. This is based on the understanding that knowledge frames attitudes, which in turn inform beliefs, with beliefs translating into behavioural intent, which ultimately underlie actions (du Toit, 2002; Berkes, 2003; Lepp, 2016). In this regard, there has been much improvement in attitudes but less success in encouraging conservation behaviours. The root causes of many environmental problems have been attributed to the on-going trend of people being distanced from their

environment, with the most obvious solutions being based on the placement of humans back into ecosystems (Berkes, 2003). However, the complexity of realigning people with nature is vast, with academic interrogation of these solutions requiring varied sources of ecological knowledge. In this regard, biodiversity conservation needs to be recognised as much as a social process as an ecological one (Lepp, 2016).

The attitudes of communities on the Kruger National Park (KNP) border were examined in relation to perceptions towards the park, to understand what informed local attitudes (Anthony, 2007). Key findings included negative attitudes being linked to damage causing animals such as elephants, which break out of the park and cause destruction to communal farmland. However, 72.9% of the 240 households interviewed across 38 communities had never actually been into the park (Anthony, 2007). Protected areas have historically excluded local communities, which is detrimental for conservation initiatives. The negative consequences of this exclusion include exacerbating issues such as wildlife poaching and resource exploitation. Efforts have been made to increase inclusion through initiatives such as the Kruger National Park's People and Conservation Programme. Environmental Education programmes focussed on Kruger Park specifically have included an additional 70 000 people per annum through day programmes with 5000 Kids in Kruger per year (Swemmer et al. 2017). Furthermore, the park directly employs approximately 4500 people, with the conservation areas surrounding Kruger employing an additional 7880 individuals (Swemmer et al. 2017). However, recent literature argues that with the increased threat of poaching, the 'fortress conservation' paradigm is not only still in existence in relation to Kruger National Park, but is being reinforced (Buscher, 2016). Authors such as Macharia et al. (2010), Anderson (2016) and Bennett et al. (2017) highlight the importance of community-based conservation, in addition to the development of a more inter-disciplinary conservation science. This incorporates nuanced understandings of social-ecological interactions in response to exclusionary conservation approaches. Importantly, communities are not a static, isolated group but instead change through time, as do the ecosystems of which they are a part. Together, these make up complex socio-ecological systems requiring a pluralistic cross-cultural conservation ethic (Berkes, 2003).

7.1.3 Perceptions and attitudes: How cultural values inform climate change concern

7.1.3.1 Behavioural responses to potential climate impacts on marula populations

The South African Long Term Adaptation Scenarios (LTAS), as well as the international Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5, 2013), both confirm warming, as well as increased variability in rainfall for South Africa. Mean annual temperatures in South Africa have increased by at least "1.5 times the observed global average of 0.65°C over the past five decades and extreme rainfall events have increased in frequency" (Ziervogel et al., 2014). Climate change models project both hotter, as well as drier conditions, for the whole northern region of South Africa over the coming decades (Tshiala et al., 2011; MacKellar, 2014; van Wilgen et al., 2015; Engelbrecht & Engelbrecht, 2016).

From the perspective of marula trees in semi-arid savanna systems, which are at the limit of their rainfall distribution, precipitation is a key environmental indicator (O'Connor & Goodall, 2017). Marula trees already at their edge of range provenance are likely to be severely affected by any further decreases in rainfall (Maranz; 2009). This means climate variability is likely to have negative implications for marula as a keystone cultural, economic and ecological species. In turn, this will adversely impact not only local livelihood sustenance but also the social systems

and immaterial benefits derived from marula (Shackleton & Shackleton, 2005). Research findings by Akinnifesi et al. (2008) suggest that marula has adapted to infertile soil and unimodal rainfall regimes, which makes them a hardy species. However, with increases in the frequency of severe drought years set to increase in coming decades (Engelbrecht & Engelbrecht, 2016), it is not clear how marula trees will respond to excessive heat and lack of rainfall for extended periods of time. Patrut et al. (2018) found that extended drought was responsible for increased mortality in many of the largest baobab (*Adansonia digitata* L.) trees across Africa. With the largest and thus oldest marula trees as the most prolific fruiters (Nghitoolwa et al., 2003), heightened fruit yields sustained by these trees are likely the foundation of the marula bioeconomy (Nyoka et al., 2014; Mkwezalamba et al., 2015). Increased mortality of large marula trees would therefore be cause for concern in terms of long-term sustainability planning. In addition, temperature changes are likely to result in phenological shifts (Shackleton, 1999; Msukwa et al., 2019). These shifts could further reduce resilience, resulting in increased vulnerability in terms of the social structures (and cultural systems) relying on this resource.

Considering the heightened dependence of rural, developing country communities on NTFP for livelihood sustenance, numerous authors have explored how these communities perceive climate change impacts. In addition, a key focal area is the range of adaptive strategies implemented in response to climatic changes (Balama et al., 2010, Pramova et al., 2012; Rahman & Alam 2016; Dey et al., 2018). NTFPs are fundamental in boosting not only adaptive capacity, but also social and financial capital (Balama et al., 2016). Adaptive strategies are usually based on local social, ecological and economic processes. This highlights the need to understand not only the actual climate impacts, but also how communities perceive these impacts, as this determines the nature of the response strategies (Bele et al., 2013). Forest dependent communities face a variety of challenges linked to changes in temperature and rainfall in Bangladesh (Rahman & Alam, 2016). As a result, the multiple adaptation strategies developed as a response are based on local knowledge of the resource. Perceptions of climate change are a key theme in the literature. Communities in Cameroon who rely on NTFPs were found to already be exposed to climate change conditions, with temperature and rainfall as the main perceived disturbances (Bele et al., 2013). In Tanzania, Balama et al. (2013) measured farmer's perceptions of climate change, as well as how they responded to these adverse conditions. The result was that rainfall and temperature are the key factors influencing local adaptation strategies. Dey et al. (2018) developed metrics to measure perceptions of climate change phenomenon, resulting in high perception scores pertaining to climatic changes but low livelihood impact perception scores. This meant that in terms of the knowledge-adaptation index utilised in the study, the actual responses to climate change were considered moderate (Dey et al., 2018). In communities utilising NTFPs in Tanzania, Msalilwa et al. (2013) corroborated locally perceived changes in rainfall and temperature with available climate data for the region. The findings were that perceived increases in temperature and extensive fluctuations in rainfall were in line with climate records for the region. In South African, negative impacts of recurring drought conditions on small-holder farmers in Limpopo were examined by Mpandeli et al. (2015) using South Africa Weather Service Data (SAWS) from 1921-2013. The devastation to crops and livestock meant local farmers are acutely aware of extremely variable rainfall. Communities usually develop multiple adaptive strategies in tandem, although these are usually specific to affected resources. A common strategy amongst

NTFP users is to diversify the range of resources utilised (Balama et al., 2013; Bele et al., 2013 Rahman & Alam, 2016)

Qualitative studies focused on local community perceptions regarding climate change in Limpopo have been undertaken by Rankoana (2016) and Chikosi et al. (2019), concluding that perceptions of climate change are largely centred on temperature and rainfall variability. Furthermore, understanding rural community knowledge of climate change is considered to be of utmost importance as it shapes critical adaptation strategies (Chikosi et al., 2019). Those living closest to the land often feel climatic variations most directly, specifically changes in rainfall and temperature. In response, local communities are often the first to not only observe environmental changes, including variations in climate, but also to adjust their behaviour patterns in response to these changes. Local adaptation measures are normally only taken by those who actually perceive climatic changes to be occurring. These perceptions in turn hinge on direct experience (Maddison, 2007). African farmers in particular, have become adept at detecting climatic changes, with experience leading to more precise claims of temperature and precipitation changes (Maddison, 2007). While temperature changes are a good indicator of changing environmental conditions, precipitation is often of even greater importance, due to the direct impact it sanctions on human livelihoods (Rankoana, 2018). The strongest evidence to support claims of climatic changes are consistent reports across specific regions of the same type of observable changes occurring (Maddison, 2007; Reser et al., 2014).

Experience and beliefs affect, and are affected by each other. This means that while observable climate impacts may lead to experiential verification, the degree of certainty of prior belief is what fundamentally shapes perceptions of actual impact (Reser et al., 2014). However, it is fundamental to understand cultural and social contexts, as these are highly influential in framing how climate change risks are perceived (Ballantyne, 2016; Weber, 2016). Essentially, the relationship between "memory and history, past and present" creates a discourse on social-environmental problems, which are firmly grounded in lived experience (Anderson, 2016: 18). Implicit in this is interrogating how meaning is created, in particular tension between the rural past and present. This is specifically relevant in relation to cultural and historical aspects of climate change, with narratives around issues such as drought being a cultural construct (Anderson, 2016). In this vein, narratives regarding place as a concept, are able to construct social identity with "life stories as cultural artefacts" (Anderson, 2016: 19). Oral histories are one such way to understand landscape and climate change, where the lived concept of place is expressed through a cultural lens of environmental change (Riley & Harvey, 2007). Climatic changes are therefore perceived through the lens of any pre-existing cultural worldviews that individuals or communities possess (Wolf & Moser, 2011). Cultural values that result in enhanced interactions and understandings of nature often provide local communities with strong cues regarding seasonal shifts or changes in phenology (Reser et al., 2014; Shi et al., 2015). However, causal knowledge significantly increases concern, provided it does not conflict with underlying cultural values (Shi et al., 2015). Due to the fact that perceptions are created through pre-existing worldviews, these perceptions may be formed by a few dramatic climate related events, as opposed to actual incremental changes over time (Muita et al., 2016). Sociologists have argued against current models of expert only knowledge generation in relation to understanding environmental threats. Instead, experts promote local ways of knowing that help to broaden current understandings of risk. In addition, sociologists claim that researchers need to learn to interrogate environmental issues by unpacking cultural systems within which

meaning is embedded (Anderson, 2016). Academic authors reiterating this sentiment indicate how dominant scientific discourse often blames the rural poor for environmental degradation, a key example being resource exploitation under the guise of the 'Tragedy of the Commons' (Hardin, 1968; Eriksen et al., 2011). In many cases these narrow interpretations need to be expanded to include social justice and environmental integrity in adaptation processes. This will begin to address the underlying social, cultural, political and ethical dimensions. Regardless, there is clear evidence that psychological responses to environmental change, including climate change impacts, range from acceptance and certainty to distress and disbelief. In turn, these affect response behaviours in relation to perceived or direct experiences (Reser et al., 2014).

There are limited studies exploring community level observations in terms of shifts in climate, including how communities perceive their own vulnerability. There is also limited understanding in terms of what adaptation practices result as a consequence of these perceptions (Rankoana, 2018). Perceptions of climate change are based on what communities observe in their local environment, with community elders often having long-term memories of both observed as well as experienced environmental changes (Rankoana, 2018). Human memory is strongly influenced by recent impactful events, such as drought or floods, meaning that personal narrative taken in isolation can be an unreliable witness. An example is the opinion often held by researchers is that farmers' memories can be 'faulty'. Farmers can accurately recall events of the previous five years or significant weather changes over time. However, a few bad years in terms of rainfall can lead to an overly pessimistic outlook, which may not always be supported by the climate data for a specific region (Moyo et al., 2012).

Human and meteorological information can be combined to verify noticed changes, with humans being quick to notice any localised changes. This is specifically relevant not only where there is a close association between human livelihoods and nature, but also because social aspects such as culture, spirituality and social systems are frequently connected to local environments (Rankoana, 2018). Indigenous farmers often associate their observations with other social changes occurring concurrently within their community, highlighting the need to understand social and ecological data in conjunction (Boillat & Berkes, 2013). In this regard, it is especially useful for scientists to understand that contradictions occur when local knowledge is explored outside of a specific cultural context. In addition, local perceptions of temperature and precipitation changes are sometimes able to capture more localised contexts than meteorological data alone (Bomuhangi et al., 2016). Local knowledge can in fact be used as a place-based tool to ground-truth climate models with fine-grained knowledge of biophysical systems, helping to enhance understandings of the impacts of climate change at local scales (Reyes-Garcia et al., 2016). These interactions are particularly valuable as they are based on long histories of interactions between biophysical and social systems (Reyes-Garcia et al., 2016).

7.1.3.2 Community perceptions about marula conservation

There are two key studies, which have directly examined people's attitudes to conservation and marula trees, specifically in the Ha-Mashau, Ha-Mashamba and Matiyene communities in Limpopo Province, South Africa (Sinthumule & Mashau, 2019; Sinthumule & Mzamani, 2019). In addition, these studies have explored the strategies people employ to protect marula trees in communal rangelands. The authors in these studies specifically sought to understand if marula trees were being conserved and what attitudes or perceptions were leading to these behaviours in the local context. Attitudes indicated that marula trees are both important as well as protected. This was confirmed by 90% (n=135) of those interviewed, indicating that they had

neither harvested nor cut branches of marula trees in Ha-Mashau and Ha-Mashamba villages (Sinthumule & Mashau, 2019). In Matiyene, 92% (n=295) of respondents said marula was an important tree and 87% (n=261) indicated that they do not chop the tree for fuelwood (Sinthumule & Mzamani, 2019). In addition to this, 84% (n=126) of respondents felt that marula should be protected, with a further 76% (n=117) indicating that it was their personal duty to protect marula. Finally, 75.5% (n=113) said that it was taboo to cut a marula tree (Sinthumule & Mashau, 2019). While respondents in Ha-Mashau and Ha-Mashamba indicated that they did not plant or cultivate marula and that it seeded naturally, respondents in Matiyene (n=69) specified that they had actively planted marula (Sinthumule & Mashau, 2019; Sinthumule & Mzamani, 2019). However, both sets of authors did note that marula was not commercialised in this region of Limpopo, unlike other parts of Limpopo. Marula in the context of this study was therefore more valued for it's social capital, strengthening social bonds rather than the economic value generated from being sold (Sinthumule & Mashau, 2019).

Sixty percent of the older generation in Matiyene indicated that they believed the tradition of marula continues to play a role in the protection and conservation of marula (Sinthumule & Mzamani, 2019). Marula beer is often described as "social glue" due to the social capital generated by the gifting, sharing and sense of community created by ceremonies associated with this beverage (Nwonwu, 2007:252). Previously, communities were described as selecting and nurturing high-yield individuals in their yards and fields but in recent times, the economic value of the fruit has resulted in fewer households allowing others to harvest from their personal trees (Nwonwu, 2007). In addition to this, marula trees were not previously used for fuelwood, unless deemed to be dead, with it being taboo to harvest directly from marula trees or to cut branches when harvesting (Shackleton & Shackleton, 2005). Despite local Traditional Authorities no longer enforcing cultural regulations, minimal impacts on marula populations in parts of Limpopo are attributed to the local cultural value of marula. Protection of the species, resulting as a direct consequence of this value attribution, is firmly based on the services marula is perceived to provide to local people (Sinthumule & Mashau, 2019). The fact that marula trees are conserved outside of formal conservation areas at a regional landscape level reinforces the importance of integrating indigenous knowledge with scientific findings (Sinthumule & Mzamani, 2019). However, it should be stated that the studies mentioned in relation to the cultural conservation of marula in Limpopo, do not provide accompanying ecological data on marula population structures or density to validate social data findings regarding marula conservation (Sinthumule & Mashau, 2019; Sinthumule & Mzamani, 2019).

Community attitudes to conservation are key ingredients in ensuring successful resource utilisation, specifically in the lowveld region of South Africa where the granite lowveld vegetation type is classified as threatened due to both cultivation and settlements (Mucina & Rutherford, 2006; Munyati & Sinthumule, 2014). This is echoed by Munyati & Sinthumule (2014), who found that indigenous forests at Vondo (Limpopo) were conserved through community rules and regulations. In contrast, despite land reform programmes providing access to more land, as well as rural electrification to reduce deforestation, the woodlands around Xanthia in Bushbuckridge were degraded due to an inability to enforce communal rules (Munyati & Sinthumule, 2014).

Considering the important role cultural values play in conserving key NTFPs such as marula, understanding how this resource is valued across the landscape is critical. Understanding not only how cultural value is ascribed, but also how it is maintained (or lost over time) are key

focal areas. As the basis of the marula bioeconomy, understanding potential climate impacts on marula is of crucial importance. This requires not only interrogating the potential impacts of climate on the resource, but fundamentally how resource users perceive these changes. Furthermore, are resource users able, and willing, to adapt their utilisation strategies to conserve this important cultural capital. Understanding the impacts as well as implications of climate change in tandem, help to uncover the resilience of the marula SES. A key component of this work is to acknowledge local TEK, as well as resource knowledge in general, to appreciate how local understandings of climate variability are interpreted and understood. An important outcome is to determine if resource users are concerned about how marula, as a key cultural (and economic) asset, may be affected by climate change. In addition, it is necessary to ascertain whether this knowledge, combined with awareness and beliefs are likely to change negative environmental behaviours such as tree chopping. Combining local TEK, cultural values and potential concern (or lack thereof) about marula as an important NTFP resource helps to generate a holistic understanding of resilience within the system, as well as the possible risks to the future sustainability of marula.

The objectives of this chapter are as follows:

a) To explore how local traditional environmental knowledge (TEK) about marula as a resource informs cultural values, including how value is attributed to marula:
    a. To explore how value attribution has changed over time in Bushbuckridge by exploring specific cultural practices, as well as how it differs spatially between Bushbuckridge and Phalaborwa.
    b. To interrogate to what extent choices over marula resource use & extraction are informed by cultural beliefs and practices.
    c. To understand who the custodians of marula knowledge are within the communities.

b) To understand if the cultural capital of a key NTFP, such as marula, leads to conservation practices based on value attribution. Specifically:
    a. To uncover if the cultural value of marula leads to conservation and concern regarding the resource.
    b. To understand what cultural values look like in reality from the perspective of tree stewardship and resource use practices.

c) To interrogate the perceived impacts of climate change on marula from the perspective of the community members:
    a. To gauge perceived changes in terms of rainfall and temperature patterns.
    b. To gauge perceived impacts of climate variability on marula population structures as well as fruit yields.
    c. To explore human behavior change (adaptive strategies) in response to perceived climatic changes, specifically temperature and rainfall patterns.

7.2 Methodology

In order to obtain insights into the cultural value attributed to marula as a natural resource, semi-structured interviews were conducted with individuals from 240 households, across four

villages in Bushbuckridge (n=120) and a further four villages in Phalaborwa (n=120). In order to qualify certain information, informal focus groups were held in each village to provide a greater degree of insight into the more complex issues highlighted by respondents. Interviews were conducted in the local vernacular with the assistance of an interpreter, from January to June 2018. The sections of the questionnaire (10. Appendix: 10.2 Research Instrument) that were utilised in this chapter are: household socio-economic characteristics; marula management and stewardship; cultural value of marula and resource availability and climate change. In order to provide contextual detail, anecdotal information such as quotations, were captured in order to illustrate key points in the narrative.

7.2.1 Analyses of data on marula cultural practices, stewardship and resource perceptions

Cross-tabulations for data on marula's cultural contribution and conservation practices relating to the resource base were performed in SPSS using Chi-Square Tests ($p<0.05$). Fisher's Exact Test with a Phi Effect Size was used for analyses in a 2 by 2 cross-tabulation and Pearson's Chi-Square, with a Cramer's V Effect Size, for larger than 2 by 2 cross-tabulations. Analyses were performed on all questionnaire responses excluding 2 by 2 binary cross-tabulations such as Yes/No responses by Location (Phalaborwa/Bushbuckridge). With a 2 by 2 table, SPSS provides the Yates Correction for Continuity, designed to compensate for an overestimation of the Chi-Square value, which was provided with the statistical outputs for the Chi-Square value. Where the assumption for 'minimum expected cell frequency' had been violated, it was not possible to provide a significance value for those cross-tabulations.

In most cases, proportions provided in the results section were calculated based on the overall sample (n=120) in each location. In certain cases, the proportion was calculated from a different total, for example the number of respondents falling within a specific age category, which is a subset of the overall sample. Where proportions were calculated from a different total, the sample size is given in the text and in corresponding tables or figures.

7.2.2 Logistic regression analyses for fuelwood use, yard marula damage & changes in marula's importance over time

In order to gauge marula's value attribution as a culturally important resource and whether this value translates into stewardship practices, three logistic regressions were run in SPSS to test models that predicted outcomes based on a mix of different categorical and continuous independent variables. The first model explored the variables contributing to marula fuelwood use with the categorical dependent variable being the binary response (Yes/No) to the use of marula wood. The intention was to guage what aspects (if any) of marula's value nexus may contribute to its conservation. In order to ascertain what variables impact fuelwood use (dependent variable), the independent variables of location, gender, age, household income, marula's value attribution (importance), practicing *kuphahla,* accessible land-use types (field/rangeland), previous damage to yard marula, implications for damaging marula trees and concern relating to current marula populations were all assessed. The variable marula value attribution (the reasons respondents think marula is important) were recoded into three categories: resources, financial support and cultural value. The concern categories were recoded into: decreasing fruit, decreasing trees, too few females and difficulty finding fruit.

The second model analysed the variables contributing to cutting/damaging a marula tree in yards (the land-use type where trees are used in cultural practices) with the categorical dependent variable being the binary response (Yes/No) to damaging a yard marula. In order to

ascertain what variables impact damaging a yard marula (dependent variable), the independent variables of location, gender, age, yard marula, fruit collection, collecting in yards, marula value attribution (importance), practicing *kuphahla*, implications for damaging marula trees, concern over marula populations and whether respondents sell the fruit or beer were all assessed. The variable 'marula value attribution' was recoded into three categories: resources, financial support and cultural value. The 'concern' categories were recoded into: decreasing fruit, decreasing trees, too few females and difficulty finding fruit.

The third model explored what variables are likely to contribute to a respondent suggesting that the value of marula has decreased over time to understand what factors may be causing this shift. In this model, the dependent variable was the binary response (Yes/No) to marula's value having decreased. In order to ascertain what variables may contribute towards a perceived decrease in marula's importance (dependent variable), the independent variables of location, gender, age, yard marula, field access, fruit collection, fuelwood use, medicinal use, practicing *kuphahla* and whether the respondent sells the fruit or beer were all assessed.

The independent variables for all three models were tested for collinearity, with high tolerance values indicating low correlations between variables. These predictor variables were then tested for 'goodness of fit' with the Omnibus Tests of Model Coefficients providing a highly significant value, indicating the models are a better bit than the original estimates provided by SPSS each time. The Hosmer-Lemeshow Goodness of Fit test was not significant each time, indicating that the models are worthwhile. The Cox and Snell R Square as well as Nagelkerke R Square were calculated in order to indicate the range of variability explained by the chosen set of variables. The Classification Table for the model indicates the number of cases correctly classified, which showed increases from the original outputs each time, indicating strong models. Finally, the Variables in the Equation Table were included with the results, which provide information about the importance or contribution of each of the predictor variables. The significance value indicates which of the predictors provides a significant contribution. Finally, for each odds ratio, a 95% confidence interval with a lower and upper value are provided.

7.2.3 Descriptive social insights on marula's cultural value

To explore the social aspects of marula culture and tradition, a mainly qualitative approach has been followed in this chapter. This approach has also been selected in order to highlight how different methodologies can assist in providing a complete picture of resource utilisation within complex SES. This means the focus of this chapter, is to understand the cultural aspects of the lowveld marula bioeconomy, using a qualitative approach and socio-cultural lens.

A thematic analysis methodology was applied to the social data in order to ensure a robust approach to identifying, analysing, organising, describing and reporting themes found within the social data set (Braun & Clarke, 2006; Nowell et al., 2017). Thematic analysis is a useful methodology for examining the perspectives of different research respondents, highlighting similarities and differences and thereby generating insights by noting key trends in the outcomes (King, 2004; Nowell et al., 2017). A clear epistemological position was applied to ensure this approach underpinned the study's empirical claims (Holloway & Todres, 2003). This was done by using the social data to verify ecological findings and vice versa. In other words, a repeated statement made by respondents could be verified by ascertaining if the ecological findings supported this claim. In order to meet the requirements of credibility, transferability

and dependability, data was captured into spreadsheets and coded by category and then aggregated by research question in order to allow patterns to emerge by village and settlement type (rural and peri-urban). These were then further aggregated at the location level (Bushbuckridge and Phalaborwa) for the purposes of discussing high-level cultural trends in this chapter. During coding, important sections of text were identified, labelled and indexed according to how they relate to a theme or issue in the data (King, 2004; Nowell et al., 2017). The quantitative outputs (including those that were statistically analysed) were then overlayed with the descriptive responses, cross-referencing key findings with recurring descriptive themes. Finally, the key themes emerging from the anecdotal data were independently crosschecked with the statistical outcomes from the ecological data to confirm if the anecdotal evidence supported the significant quantitative outputs. A full explanation of the thematic analysis approach applied to this study is contained in the methodology for Chapter 6.

In terms of age categories provided by respondents, those respondents 18-24 years were classified as youth, with the categories 25-34 years as well as 35-44 years classified as young adults. Those respondents in the 45-54 years as well as 55-64 years were considered middle-aged with 65-74 years and 75-84 years classified as elderly. Individuals over 85 years of age were considered very elderly.

To gauge changes in marula abundance, as well as temperature and rainfall changes, over the past ~20 years as well as ~50 years, respondents were asked a series of time sensitive questions based on their age category. Questions relating to shorter (~20 years) and longer (~50 year) time periods were used for three reasons:

i. Confirming perceived changes over different time periods is a way to verify findings as shorter term changes may not always be as obvious, while over longer time periods clear trends may emerge;
ii. Providing different memory triggers also enables a time-line to emerge of when noticeable changes may have first occurred;
iii. Individual memory can be faulty but testing changes perceived by a younger and older audience over different time periods creates a collective memory of verifiable data.

Respondents between the ages of 30 to 50 years were asked a series of questions which required them to think back to extensive floods that happened in 2000 (as a mental trigger) and answer whether they thought marula population numbers have changed since around that time (~20 years prior to the interview). The options in terms of changes in marula population numbers were: more, less or the same number of trees. Respondents over 50 years of age were asked to think back to when they were approximately 20 years of age (as the mental trigger), giving a window of change over an approximately 40-60 year period (~50 years), depending on the age of the respondent.

In addition, respondents were asked whether they had noticed any changes in rainfall and temperature in the area over the same timeframes of ~20 years and ~50 years. In terms of temperature and rainfall, respondents could select if these factors had: increased, decreased or stayed the same. The purpose of these data was to gauge local perceptions towards climatic changes using a qualitative methodology and was not intended as a climate change study using localised observations to corroborate climate records. In Bushbuckridge, 19 respondents were younger than 30 years of age; meaning 101 respondents answered these three questions, with

65 respondents less than 50 years of age, leaving 55 respondents. In Phalaborwa, 24 respondents were under the age of 30 years, leaving 96 respondents, with 72 respondents under the age of 50 years, leaving 48 respondents.

In terms of the cultural ceremonies explored in detail in this chapter, these have been selected based on the research conducted by Shackleton & Shackleton (2005), who provided data on the proportion of respondents practicing three main cultural ceremonies: *kuphahla* (communicating with the ancestors)*, xikuha* (gifting beer to the Headman) and *xirhwalo* (celebrations involving marula beer). While other cultural ceremonies, such as *ubukhanyi* (first fruits ceremony), were mentioned by community members during the course of the interviews, these were not included in the research instrument at the time of the study and are therefore examined in less detail.

7.3 Results

7.3.1 Demographic profiles of respondents

The majority of respondents interviewed were female, with these individuals coming forward most often when an interview with a household member on the topic of marula was requested. This is likely due to the central role women play in the marula bioeconomy. Overall, 61.6% (n=74) of respondents were female in Bushbuckridge (n=120) and 68.3% (n=82) in Phalaborwa (n=120). Interviews were conducted with respondents of various ages, who were asked about various cultural practices pertaining to marula (Figure 7.1). This made it possible to ascertain if the cultural knowledge associated with marula is only held by the older generation, or if younger members of the community are also marula knowledge custodians.

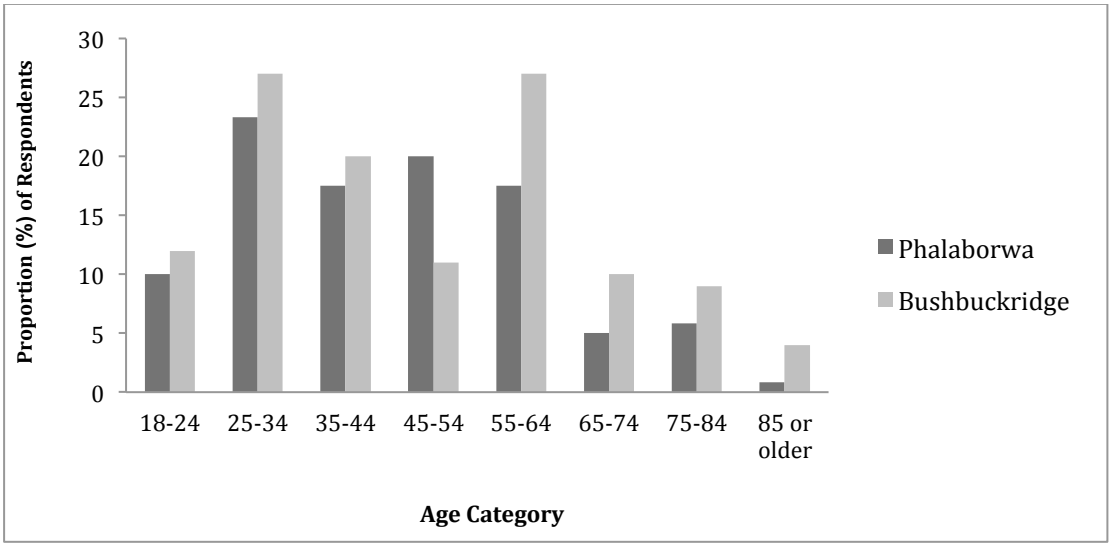


Figure 7.1: Age profile of survey respondents in Phalaborwa (n=120) and Bushbuckridge (n=120)

7.3.2 Cultural practices and local knowledge about marula

7.3.2.1 Marula's importance as a cultural resource

When asked if marula, locally known as *inkanyi* in Tsonga or *morula* in SePedi, is an important tree culturally, 100% of respondents in Phalaborwa (n=120) and Bushbuckridge (n=120) indicated that marula is indeed important.

An elderly man from Edinburgh (Bushbuckridge) illustrated the importance of the marula tree as follows: *"Marula is the house of our ancestors."* A man in his sixties from Benfarm (Phalaborwa) explained the cultural importance of marula as follows: *"These trees are part of our culture. You are not allowed to cut them down."*

When prompted to provide a reason for their answer, 35% (n=42) of respondents in Phalaborwa (n=120) gave resources as the main reason followed by financial or monetary value (32.5%, n=39) with only 20% (n=24), giving custom/tradition as their reason. In Bushbuckridge, the primary reason was resources (41.7%, n=50), followed by customs/tradition (24.2%, n=29) and financial support third (17.5%, n=21) (Figure 7.2). Comparing the main reasons provided for why marula is important (tradition, resources, financial support or other) between locations, the differences were not significant (x^2 (3, n=240)= 7.28, p=0.063). This finding is due to the similarity in responses given, confirming the pervasive nature of marula's importance across different contexts.

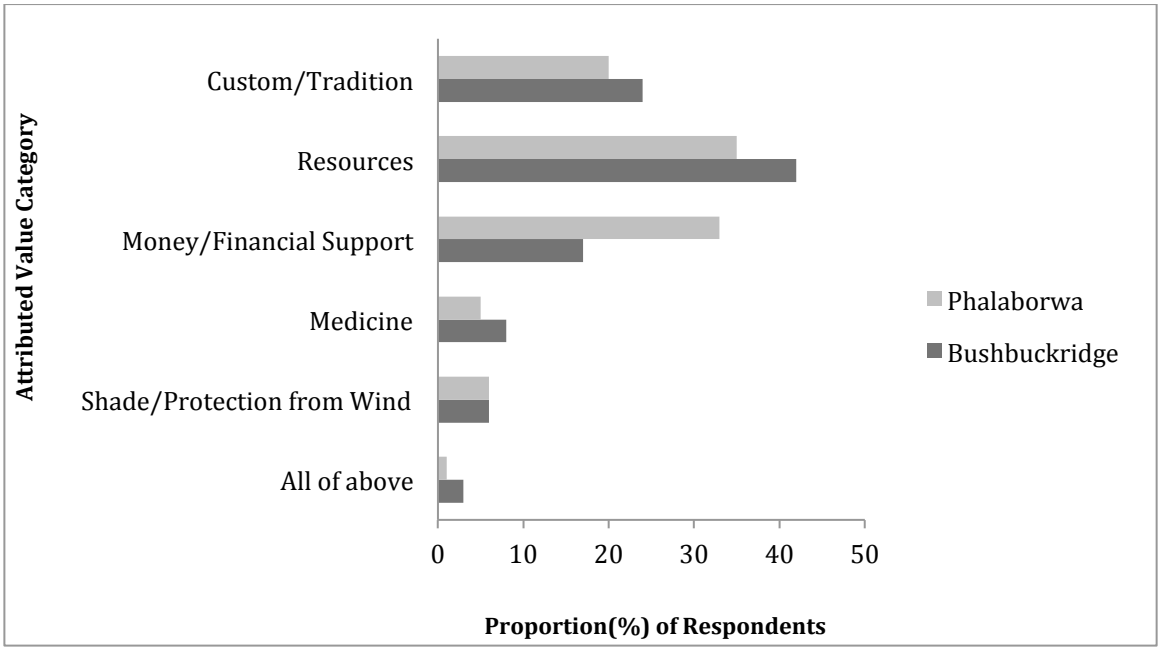


Figure 7.2: Marula value attribution by respondents in Phalaborwa (n=120) and Bushbuckridge (n=120)

In order to understand what factors may contribute to marula being perceived as less important, a logistic regression was performed to assess what variables are likely to result in the opinion that marula's importance has decreased over time in Phalaborwa and Bushbuckridge. The collinearity statistics indicated that the tolerance values were high (greater than 0.1), confirming low correlations between independent variables in the model. The model containing the eleven predictors was statistically significant (x^2 (11, n=240)= 30.435, p=0.001). The Hosmer-Lemeshow Goodness of Fit test had a significance level of p>0.05 indicating that the model is worthwhile (x^2 (8, n=240)= 5.61, p=0.690). The model as a whole explained between

11.9% (Cox and Snell R Square) and 15.9% (Nagelkerke R squared) of the variance in the likelihood of variables contributing to the opinion that marula's importance has decreased. The model correctly classified 65.4% of cases, an increase from the original estimate of 50%, which indicates a strong model.

As shown in Table 7.1, two of the independent variables made a unique, statistically significant contribution to the model: gender and sell beer. The strongest predictor of whether a respondent is likely to be of the opinion that marula's importance has decreased is if they sell the beer ($p<0.05$), recording an odds ratio of 2.06. This indicated that respondent's who sell marula beer are twice as likely to be of the opinion that marula's importance has decreased than those who do not sell marula beer. The odds ratio of 2.03 for gender ($p<0.05$), indicated that twice as many men compared to women felt marula's importance had decreased.

Table 7:1: Statistical outputs from the regression analysis of factors contributing to the opinion that marula's importance has decreased

	B	**S.E.**	**Wald**	**Df**	**p**	**Odds Ratio**	**95% C.I. lower**	**95% C.I. upper**
Location	-0.178	0.311	0.329	1	0.566	0.837	0.455	1.538
Gender	0.709	0.353	4.044	1	**0.044**	**2.032**	1.018	4.057
Age	0.248	0.158	2.481	1	0.115	1.282	0.941	1.746
Yard Marula	0.358	0.339	1.117	1	0.291	1.430	0.736	2.778
Field Access	-0.587	0.302	3.772	1	0.052	0.556	0.308	1.005
Collect Fruit	-0.524	0.331	2.505	1	0.114	0.592	0.310	1.133
Use Marula Wood	0.288	0.306	0.886	1	0.347	1.334	0.732	2.432
Use for Medicine	0.331	0.320	1.066	1	0.302	1.392	0.743	2.607
Practice *Kuphahla*	0.148	0.324	0.209	1	0.647	1.159	0.615	2.186
Sell Fruit	-0.520	0.318	2.672	1	0.102	0.594	0.319	1.109
Sell Beer	0.725	0.345	4.417	1	**0.036**	**2.064**	1.050	4.057

Despite the fact that cultural practices govern marula use in these communities, many of the older members felt that there is an erosion of culture and that the youth do not value or appreciate the tree as it was in the past. A very elderly woman from Allandale (Bushbuckridge) explains: *"The younger generation use the tree for fruit and beer to sell. The older generation used to use the tree for protection from the wind and beer to share."* A middle-aged woman from

Mbaula (Phalaborwa) shared a similar view about the youth saying: *"The younger generation only value the tree for economic reasons these days."* When asked if the importance of marula has changed over time, 57.5% (n=69) of respondents in Bushbuckridge (n=120) felt it had decreased. In Phalaborwa (n=120), a slight majority 53.3% (n=64) felt that the value of marula had remained the same (Figure 7.3). This difference in opinion, with the majority in Bushbuckridge stating marula's importance had decreased, compared to Phalaborwa where the majority felt it had remained the same, was significant (x^2 (2, n=240)= 8.41, p<0.05, Cramer's V=0.187).

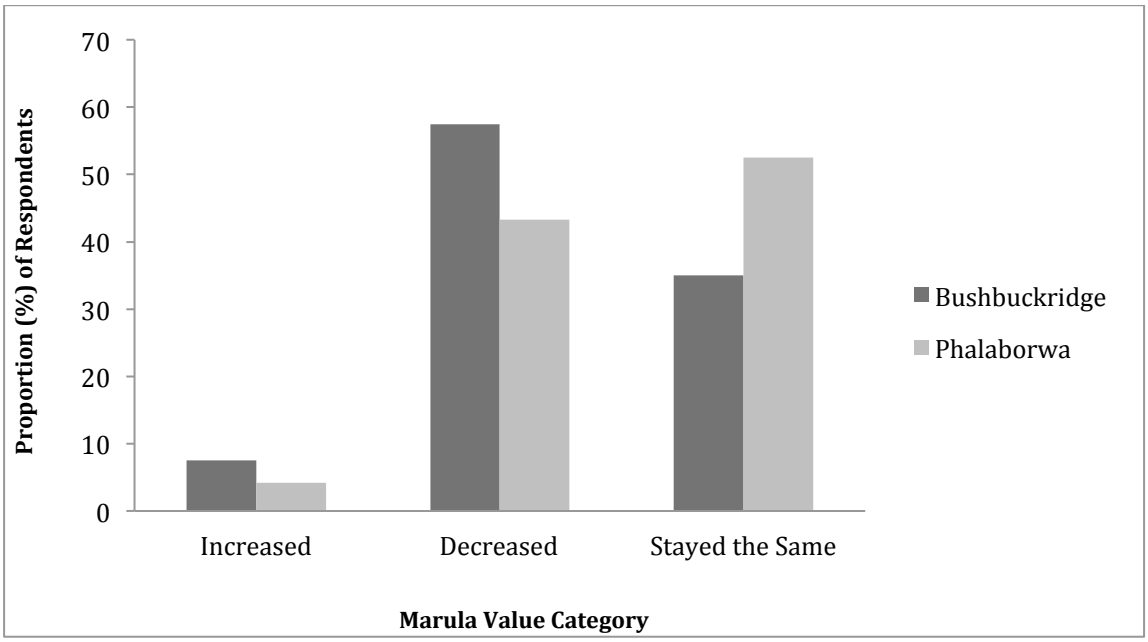


Figure 7.3: Proportion (%) of respondents in Phalaborwa (n=120) and Bushbuckridge (n=120) who felt the value of marula had increased, decreased or stayed the same over time

Some members of the community felt that there is a complete disconnect between generations, which was expressed during informal focus groups in both Phalaborwa as well as Bushbuckridge. When asked if they were aware of the differences between male and female marula trees, 85% (n=102) of Bushbuckridge respondents and 85.8% (n=103) of Phalaborwa respondents indicated in the positive. This suggests that very few individuals lack cultural knowledge about the tree. However, of those in the minority were mainly 35 years of age or younger, confirming that when it comes to cultural ignorance, it is more the youth and young adults who are lacking this knowledge. This disconnect was expressed by an elderly man from Allandale (Bushbuckridge), stating: *"There is no link from the older generation to the younger generation anymore. We have done away with our culture."*

7.3.2.2 Cultural practices focussing on marula beer

When asked what they do with the marula fruit, 75% (n=90) of respondents in Bushbuckridge (n=120) indicated that they made marula beer, but only 22.5% (n=27) reported selling the beer that they brewed. In Phalaborwa (n=120), 81.7% (n=98) said they made beer, with 59.2% (n=71) of those also selling the product (Figure 7.4). When asked about the selling of marula beer, an elderly woman from Mbaula (Phalaborwa) explained: *"Marula beer is for culture, these days people sell their culture."*

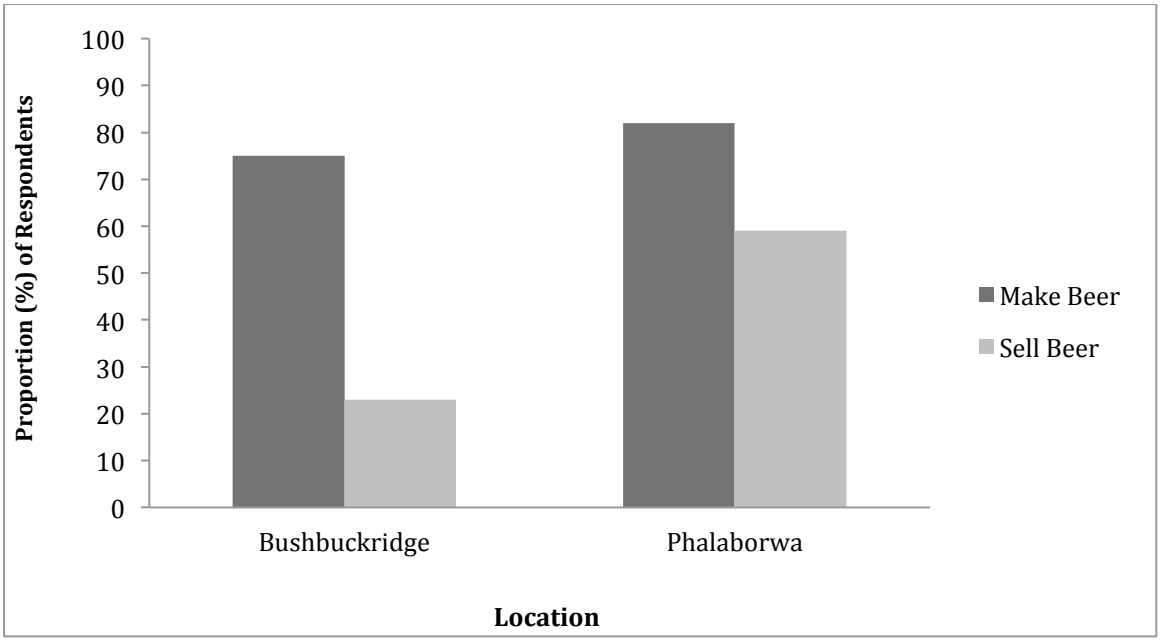


Figure 7.4: Comparison of the proportion (%) of respondents in Bushbuckridge and Phalaborwa who make beer (n=90; n=98) compared to those selling the beer (n=27; n=71)

Apart from the fruit, which is used to make marula beer, the tree is also utilised in its entirety for cultural ceremonies. Respondents were asked whether they, or anyone they know, participate in three widely practiced cultural ceremonies: *xikuha*, *kuphahla* or *xirhwalo*. As an adult tree, both female and male individuals are considered to be the "house of the ancestors" according to respondents. Adult trees are used for *kuphahla*, a cultural practice that involves communicating with the ancestors at the tree. In Phalaborwa (n=120), 45.8% (n=55) of respondents practice *kuphahla,* while 41.6% (n=50) confirmed they practice this tradition in Bushbuckridge (n=120) (Figure 7.5). This is usually done at a tree that is significant to the family, for example in the family's yard, although trees in fields or rangelands can be used if they are deemed important. However, focus group attendees confirmed that the latter is not commonly practised. Usually, larger and presumably older trees are more revered and therefore used for cultural practices, although this is not always the case. Further, marula is culturally revered because of the beer and it's role in communicating with the ancestors. Marula beer is made from the fruit of the female tree and is considered a potent brew, not just for communicating with the ancestors, but also as a medicine. Some respondents indicated that if there is no suitable marula tree available, properly prepared marula beer can be used to communicate with the ancestors, although some of the older members of the community disagreed with this sentiment. As part of the *kuphahla* ceremony, the person wishing to communicate with the ancestors will sip the marula beer and then spit it out at the base of the specific marula tree, which is to be used for *kuphahla*. This cleansing of the mouth readies the speaker to begin communicating with the ancestors. A middle-aged man from Selwane (Phalaborwa) explained the role of the marula beer as follows: *"Marula beer is the medium we use to communicate with the ancestors."*

Marula beer and the marula tree also form part of a key ritual, sometimes referred to as the first fruits ceremony (*ubukhanyi* after the Tsonga name for the tree), which takes place at the beginning of marula fruiting season. The ceremony involves asking the ancestors for their blessing on the beer. It is believed that drinking marula beer before the ancestors have properly

blessed it will make you seriously ill. It is for this reason that almost all marula beer makers, who produce the beer for home consumption, will practice this ceremony. This ceremony differs from *kuphahla* in that the specific purpose is to ask for the ancestors blessing on the beer, as opposed to asking for general guidance or intervention from the ancestors in daily troubles. As part of the opening ritual, the beer is widely shared and drunk by members of the community, with many explaining how this is a happy time for everyone involved. In addition, yard trees that are able to produce very fine tasting fruit for beer, are considered to be blessed by the ancestors. An old woman in Hoke (Bushbuckridge) would not allow her tree to be measured, or even touched, for fear it would pollute the tree or offend the ancestors, thereby removing their blessing.

Another cultural ceremony, known as *xikuha*, takes place at the beginning of marula season, and is the offering of marula beer to the local Induna (Headman). Every household in the village is expected to offer a 5 kg bucket of beer to the Induna at the start of the season. Once all the beer has been gathered and a ritual tasting has taken place, the beer is then shared amongst the community. However, with the increased sale of the fruit and now also the beer (Chapter 6), many households indicated this practice is no longer followed, as there is not enough beer to go around anymore. Respondents explained that this practice used to be compulsory, but that the Induna (Headman) no longer commands the necessary authority to insist it takes place every year. In addition, many respondents indicated this practice has not taken place for many years now. *Xikuha* is an important ceremony, not only in maintaining the position of the Headman but it "reinforces one of their primary functions as custodian of cultural and traditional matters" (Shackleton & Shackleton, 2005: 17). When asked if they perform *xikuha*, 40.8% (n=49) of respondents in Phalaborwa (n=120) indicated that they have gifted beer to the Induna, with 55.8% (n=67) of Bushbuckridge (n=120) respondents having done the same (Figure 7.5). A young woman in her thirties from Lulekani (Phalaborwa) explained why *xikuha* no longer takes place regularly: *"Since this business of selling marula fruit began, we no longer do xikuha as there is not enough fruit now. People are into the business of marula, not the business of culture."*

In addition, marula beer is also a key aspect of weddings and funerals. One woman explained: *"Marula is there when we are born and it is there when we die."* When a couple get married, the family of the bride will make marula beer for the whole bridal party and take it to the family home of the groom along with other gifts. This festivity is known as *xirhwalo* and although usually associated with weddings, can take place to celebrate any major occasion. When asked if they have performed *xirhwalo*, 57.5% (n=69) of respondents in Phalaborwa have performed this ritual at some point in their life, with 53.3% (n=64) in Bushbuckridge (n=120) having done the same (Figure 7.5). A branch of the marula tree is sometimes used to gather the spirit of the departed by sweeping around the body and this is then taken back to the family homestead and planted. This tree is then thought to house that person's spirit and will be considered a very sacred tree. One old woman from Edinburgh (Bushbuckridge), who had lost her husband and both her sons, planted marula trees at the head of their graves. She found it a daily struggle to live on her own in the family homestead due to her advanced age, but when asked why she did not go to live with a relative she answered: *"How can I leave this place? My husband and my sons are here [indicating the marula trees planted atop each grave]. How can I leave them?"*

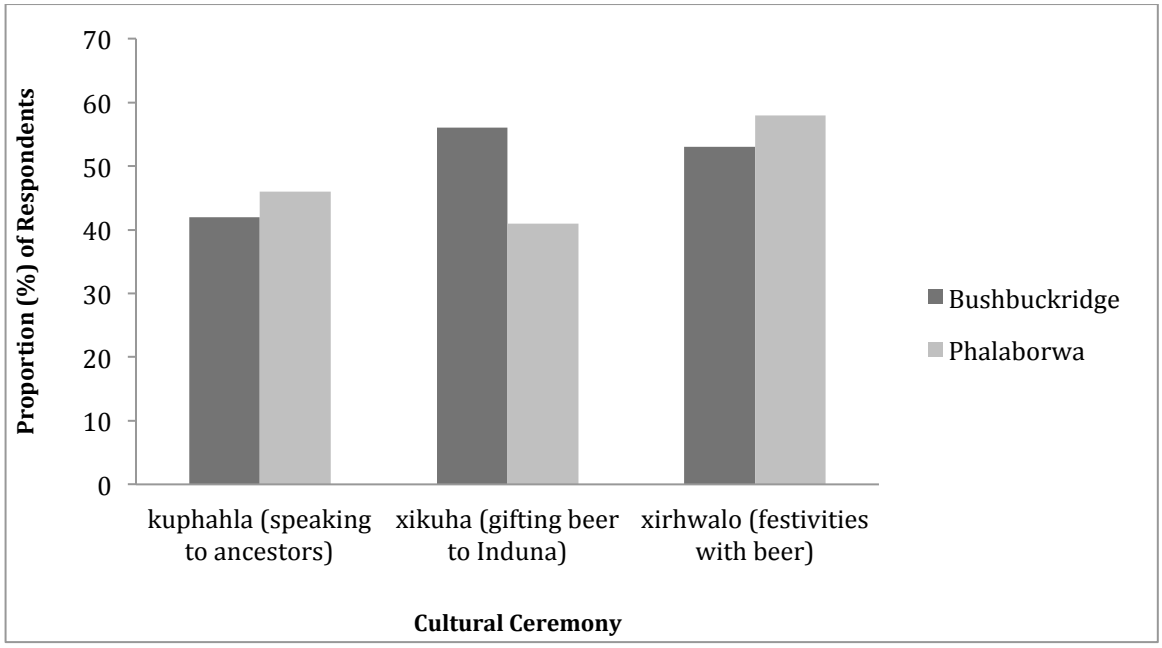


Figure 7.5: Proportion of respondents (%) who participate in the cultural ceremonies of *kuphahla, xikuha* and *xirhwalo* in Phalaborwa (n=120) and Bushbuckridge (n=120)

7.3.2.3 Marula as a medicinal resource

Marula as a natural resource is used for numerous medicinal purposes, including the beer. When drunk at its most potent, is believed to be a cleansing laxative that flushes out the intestinal tract, thereby healing any stomach disorders. More popular amongst men, this takes the form of self-medicating by drinking the more potent beer for stomach troubles. A middle-aged man from Hokwe (Bushbuckridge) explained the following about the beer: *"Marula beer is a type of medicine – it cleans your stomach and insides out."*

When asked if marula is used for medicinal purposes, 32.5% (n=39) of Phalaborwa respondents confirmed they use the bark, leaves or roots of the tree for different medicinal remedies, with 42.5% (n=51) of respondents in Bushbuckridge using marula as medicine. Comparing those who use the bark, leaves or roots for medicinal purposes compared to those that do not, the differences between locations was not significant (x^2 (1, n=240)= 2.15, p=0.142). This confirms similar practices around using marula for traditional purposes between locations. Bark or leaves from a female tree are sometimes used in remedies to treat infertility in women, as well as facilitating the gender of an unborn child in pregnancy, due to cultural beliefs around the potency of the female tree. The largest categories of respondents in Phalaborwa (30%, n=36) and Bushbuckridge (39.2%, n=47) claim to use bark from the tree to cure stomach ailments, specifically boiling the bark in water for diarrhoea or worms in children (Figure 7.6).

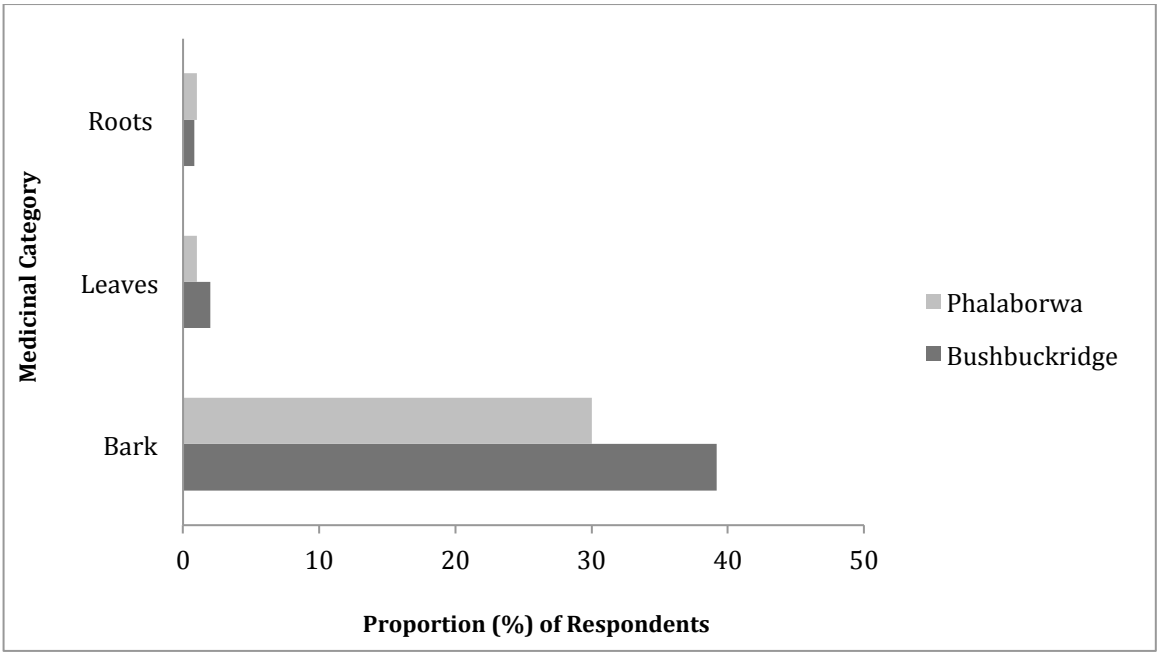


Figure 7.6: Proportion (%) of respondents who utilise the roots, leaves or bark from the marula tree for medicinal purposes in Phalaborwa (n=120) and Bushbuckridge (n=120)

7.3.2.4 Temporal changes in marula's cultural value in Bushbuckridge

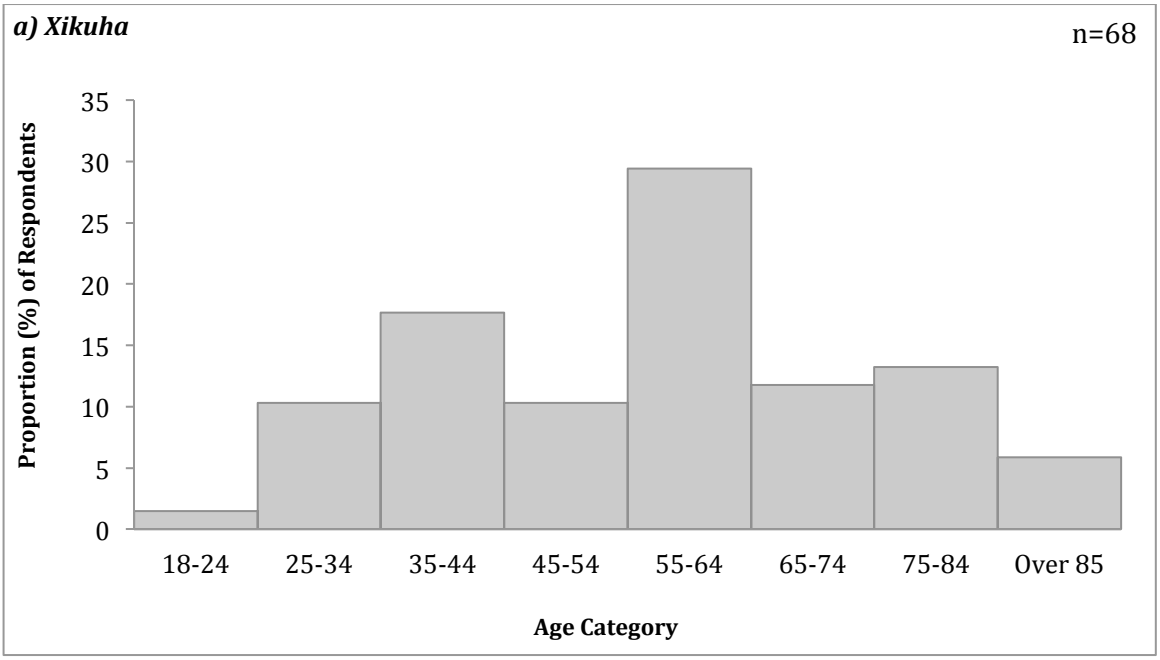
Shackleton and Shackleton (2005) asked 142 respondents in Allandale, Edinburgh, Hokwe and Rolle A (Bushbuckridge) whether they, or anyone they knew, had practiced *xikuha*, *kuphahla* or *xirhwalo*. In 2018 the same questions were posed to respondents (n=120) as part of the current study. Across the Bushbuckridge villages, the participation in different cultural ceremonies has decreased over time, with the exception being *kuphahla* (Table 7.2). The overall percentage of households practicing, or knowing others who practice traditional ceremonies, declined from 84% in 2005 to 65.8% of respondents in 2018. Across all the villages (except Rolle A which showed a 0.7% increase), the percentage of those households practicing *xikuha* has also declined, with the overall percentage decreasing from 64% in 2005 to 56.7% in 2018 (Table 7.2). However, the percentage of those practicing *kuphahla* has increased across all the villages (except Rolle A which showed a decrease), with the overall percentage increasing from 32% in 2005 to 41.7% in 2018.

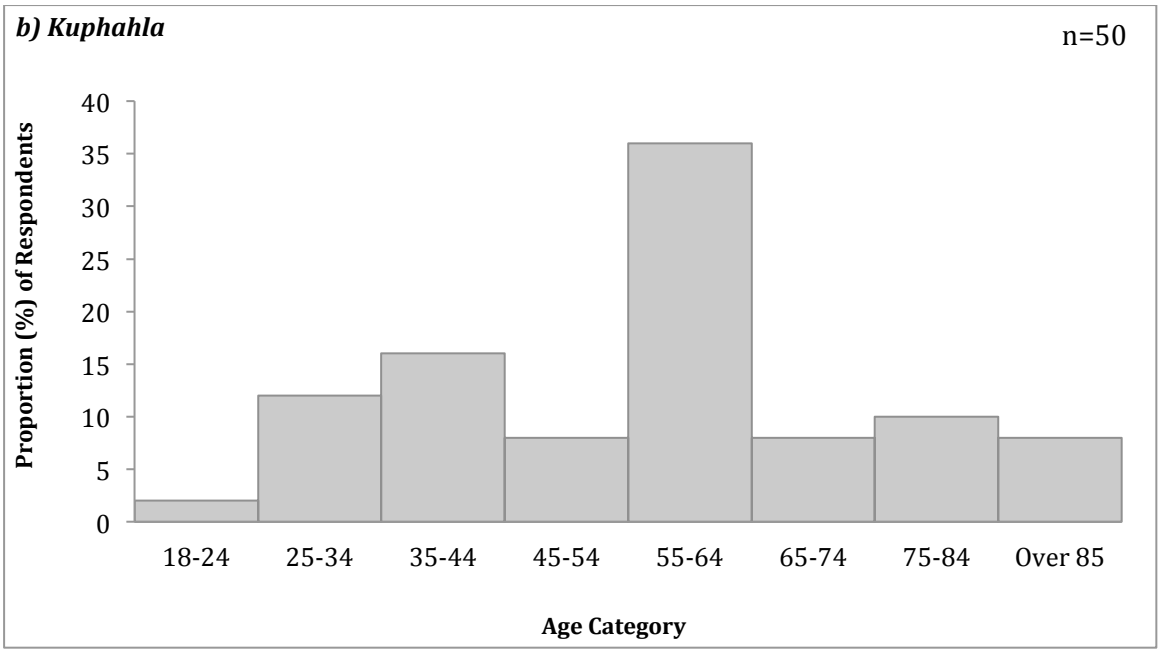
Shackleton and Shackleton (2005) indicated that many respondents strongly expressed that they themselves do not practice *kuphahla,* but know others that do, possibly due to the practice being seen as 'unchristian'. In 2018, only 20% of respondents indicated that they do not personally practice kuphahla, as they are Christian and the church forbids this practice. Finally, the percentages of those practicing *xirhwalo* has also decreased across all four villages, with the overall percentage declining from 82% in 2005 to 54.1% of respondents in 2018 (Table 7.2). Overall, the percentages of those practicing *xirhwalo* declined the most (27.9%), followed by *xikuha* (7.3%). In contrast, *kuphahla* increased by 9.7% across the four villages. Table 7.2 shows the responses from 2005, contrasted with the current responses.

Table 7:2: Prevalence of marula use in traditional ceremonies with red denoting decreases and green indicating increases over time (~Shackleton & Shackleton, 2005: 17)

	Allandale		Edinburgh		Hokwe		Rolle A		All	
	2005	2018	2005	2018	2005	2018	2005	2018	2005	2018
% of households practicing or knowing others that practice	80	**70**	92	**57**	81	**67**	83	**70**	84	**66**
Xikuha **(presenting beer to the Headman) (% of households)**	66	**60**	78	**53**	58	**57**	56	**57**	64	**57**
Kuphahla **(an offering of beer to the ancestors) (% of households)**	37	**57**	36	**43**	28	**33**	36	**33**	32	**42**
Xirhwalo **(festivities where beer is shared) (% of households)**	81	**67**	81	**53**	82	**43**	79	**53**	82	**54**

To understand if cultural practices are stratified by age, which would indicate cultural values differ between generations, the number of respondents participating in each practice were compared across the age categories. The age category with the highest number of participants across all three cultural practices, were participants 55-64 years of age, followed by those 35-44 years of age. The third highest number of participants practicing *kuphahla* and *xirhwalo* were 25-34 years, while there were more participants aged 75-84 years practicing *xikuha.* The differences in age between those practicing *xikuha* (x^2 (3, n=120)= 29.29, p<0.001, Cramer's V=0.494), *kuphahla* (x^2 (3, n=120)= 16.38, p<0.001, Cramer's V=0.369) and *xirhwalo* (x^2 (3, n=120)= 19.94, p<0.001, Cramer's V=0.408) were all significant. This finding confirms that cultural practices are indeed stratified by age, with those who are middle aged upholding these traditions. The numbers of respondents in each age category participating in the three cultural practices are shown in Figure 7.7.


a) Xikuha
n=68
Proportion (%) of Respondents
35
30
25
20
15
10
5
0
18-24
25-34
35-44
45-54
55-64
65-74
75-84
Over 85
Age Category


b) Kuphahla
n=50
Proportion (%) of Respondents
40
35
30
25
20
15
10
5
0
18-24
25-34
35-44
45-54
55-64
65-74
75-84
Over 85
Age Category

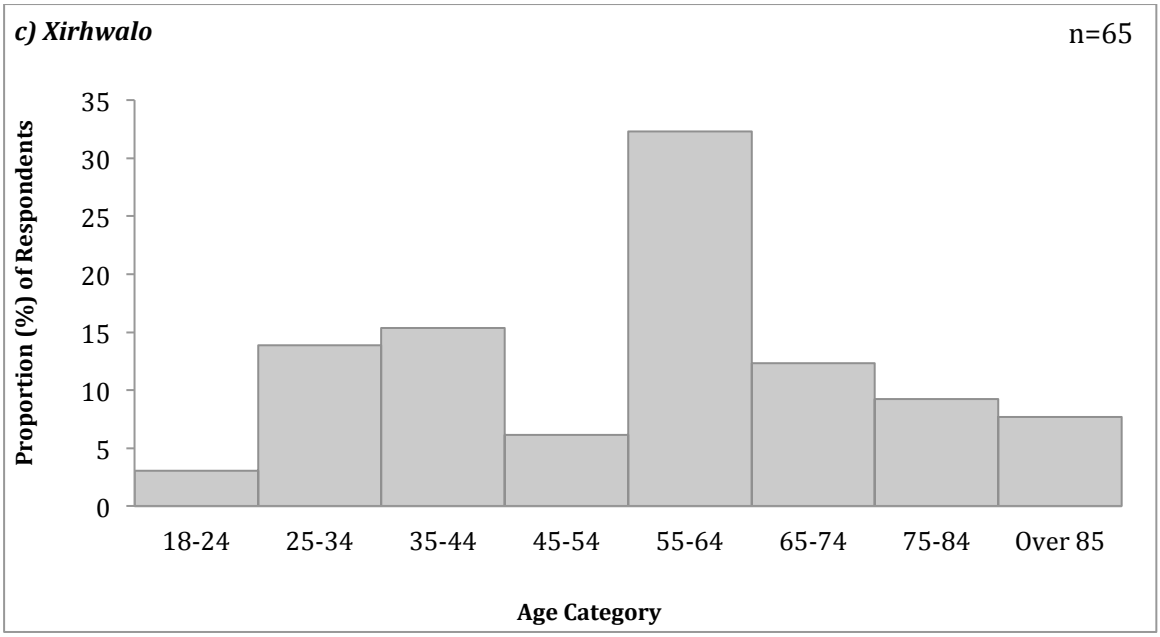


Figure 7.7: Proportion of respondent's practicing a) *xikuha* (n=68), b) *kuphahla* (n=50) and c) *xirhwalo* (n=65) by age category in Bushbuckridge

7.3.3 Marula conservation and tree stewardship

Considering the prevalence of cultural associations and attachments to marula, the pressing issue is whether this translates into conservation practices. In other words, are adult marula trees exempt from cutting as a consequence of their inherent cultural value? When asked if they have ever damaged a marula tree in their yard, 60% (n=72) of respondents from Bushbuckridge (n=120) admitted they had done so while only 31.7% (n=38) admitted to the same in Phalaborwa (n=120). In response to being asked about the type of damage they have caused, the majority (n=25) in Phalaborwa and Bushbuckridge (n=45) explained that this involved cutting down the tree (or ring-barking it) intentionally and leaving the tree to die. Comparing those who confirmed damaging a marula tree with those that denied ever damaging a marula, the differences between locations were significant (x^2 (1, n=240)= 18.28, p<0.001, phi=0.284). This difference is attributed to the higher number of households in Bushbuckridge who reported damaging a marula tree in their yard. Across both locations, age did not impact whether respondents were more or less likely to damage or cut down a marula tree. In Phalaborwa, due to the 'minimum expected cell frequency' being violated, it was not possible to get a conclusive result (x^2 (3, n=120)= 2.35, p=0.503). In Bushbuckridge, the generational differences in terms of respondents admitting to damaging a yard marula were not significant (x^2 (3, n=120)= 1.89, p=0.596). However, while differences between the age groups from 18 – 74 years of age were not significant, a common pattern was that the smallest number of respondents having damaged or cut a yard marula were over 75 years of age in both locations. The numbers of respondents, who have damaged a marula as well as the type of damage, are provided in Figure 7.8. Respondents could indicate more than one damage category, if necessary.

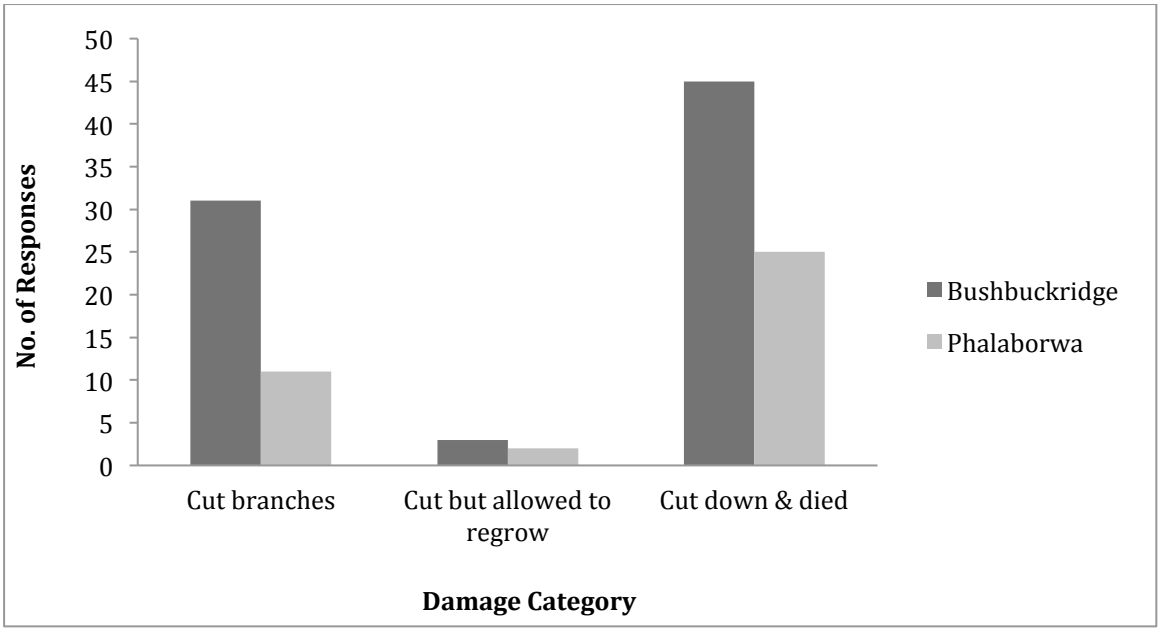


Figure 7.8: Damage inflicted on marula trees in yards in Phalaborwa (n=120) and Bushbuckridge (n=120)

Considering the important nexus between cultural practices, yard marula trees and stewardship, a logistic regression was performed to assess the impact of a number of factors on a respondent's likelihood to damage/cut down a marula in their yard in Phalaborwa and Bushbuckridge. The collinearity statistics indicated low correlations between the independent variables in the model. The model containing the seventeen predictors was statistically significant (x^2 (17, n=240)= 48.609, p<0.001), indicating that the model was able to distinguish between factors that increase the likelihood of damaging a yard marula compared to those that decrease the likelihood. The Hosmer-Lemeshow Goodness of Fit test had a significance level of p>0.05 indicating that the model is worthwhile (x^2 (8, n=240)= 6.37, p=0.606). The model as a whole explained between 20.7% (Cox and Snell R Square) and 27.7% (Nagelkerke R squared) of the variance in the likelihood of damaging a yard marula and correctly classified 68.6% of cases, an increase from the original estimate of 56.2%, indicating a strong model.

As shown in Table 7.3, two of the independent variables were statistically significant: location and yard marula. The strongest predictor of damaging a yard marula were households with a marula tree in the yard (p<0.001), recording an odds ratio of 6.40. This indicated that those households with a marula in the yard were more than six times more likely to damage tree/s than those without a marula in their yard. The odds ratio of 0.30 for location (p<0.01) indicated that respondents in Phalaborwa were only a third as likely to damage a yard marula tree, compared to those in Bushbuckridge.

Table 7:3: Statistical outputs from the regression analysis predicting the likelihood of respondents damaging a yard marula

	B	S.E.	Wald	Df	p	Odds Ratio	95% C.I. lower	95% C.I. upper
Location	-1.194	0.378	9.956	1	**0.002**	**0.303**	0.144	0.636
Gender	-0.295	0.425	0.482	1	0.488	0.745	0.324	1.712
Age	0.030	0.176	0.029	1	0.865	1.030	0.730	1.454
Yard Marula	1.856	0.507	13.417	1	**0.000**	**6.397**	2.370	17.266
Collect Fruit	-0.369	0.409	0.817	1	0.366	**0.**691	0.310	1.540
Collect in Yard	0.004	0.366	0.000	1	0.990	1.004	0.490	2.058
Resources	-0.196	0.431	0.206	1	0.650	**0.**822	0.354	1.913
Financial Support	-0.066	0.467	0.020	1	0.888	0.936	0.375	2.340
Culture	-0.064	0.521	0.015	1	0.902	0.938	0.338	2.606
Practice *Kuphahla*	0.269	0.352	0.584	1	0.445	1.309	0.656	2.611
Damage Implications	0.259	0.394	0.431	1	0.511	1.295	0.598	2.806
Decreasing Fruit	0.508	0.479	1.127	1	0.289	1.662	0.650	4.248
Decreasing Trees	-0.001	0.409	0.000	1	0.999	0.999	0.449	2.226
Too Few Females	1.068	0.627	2.901	1	0.089	2.909	0.851	9.943
Difficulty Finding Fruit	1.058	0.617	2.937	1	0.087	2.880	0.859	9.658
Sell Fruit	-0.533	0.340	2.457	1	0.117	0.587	0.301	1.143
Sell Beer	-0.163	0.398	0.168	1	0.682	0.849	0.389	1.853

In Phalaborwa, the majority of field owners (40.7%, n=24) confirmed that the Induna gave them their field, while only 17.6% (n=6) reported that this is how they acquired their field in Bushbuckridge. Comparing the main categories of ownership (use abandoned field, inherited from family, given by Induna or other) the differences between the two locations were significant (x^2 (3, n=94)= 8.37, p<0.05, Cramer's V=0.298), likely due to the differences in field acquisition practices between locations. The Induna usually gives fields to community members and as such the trees are seen as belonging to either the Induna or the wider community, meaning individuals do not have the right to cut these trees. Only 10% (n=6) of those with access to (or ownership) of a field in Phalaborwa (n=59) admitted to cutting a marula tree in their field. In Bushbuckridge (n=36), 27.7% (n=10) of respondents with field access (or ownership) admitted to cutting a marula tree. The differences between those admitting to have chopped a field marula tree compared to those that had not were not significant (x^2 (1, n=240)= 0.60, p=0.439). This finding confirms the Traditional Authority prohibition on chopping live marula trees, making it unlikely that respondents would openly admit to chopping marula trees in fields.

When asked if they believe marula trees are protected from being chopped, 63.3% (n=76) confirmed they thought this to be the case in Phalaborwa (n=120), with 70.8% (n=85) indicating that the associated consequences was being taken to the Tribal Authority and being forced to pay a fine. In Bushbuckridge (n=120), 73.3% (n=88) said marula trees are protected within their communities, 77.5% (n=93) agreed that there are consequences associated with tree cutting (Figure 7.9). Comparing those that agree there are consequences for chopping a live marula tree with those who felt there are no consequences, the differences between locations were not significant (x^2 (1, n=240)= 1.07, p=0.302). This confirms similar local customary practices around chopping live marula trees, with the system of being arrested and paying a fine being applied in both locations.

Despite over 60% of people acknowledging not only the protected status of the tree, but also consequences thereof, in Bushbuckridge (n=120) over half the respondents (56.6%, n=68) still use marula for fuelwood. Fifty percent (n=60) of respondents in Phalaborwa do the same.

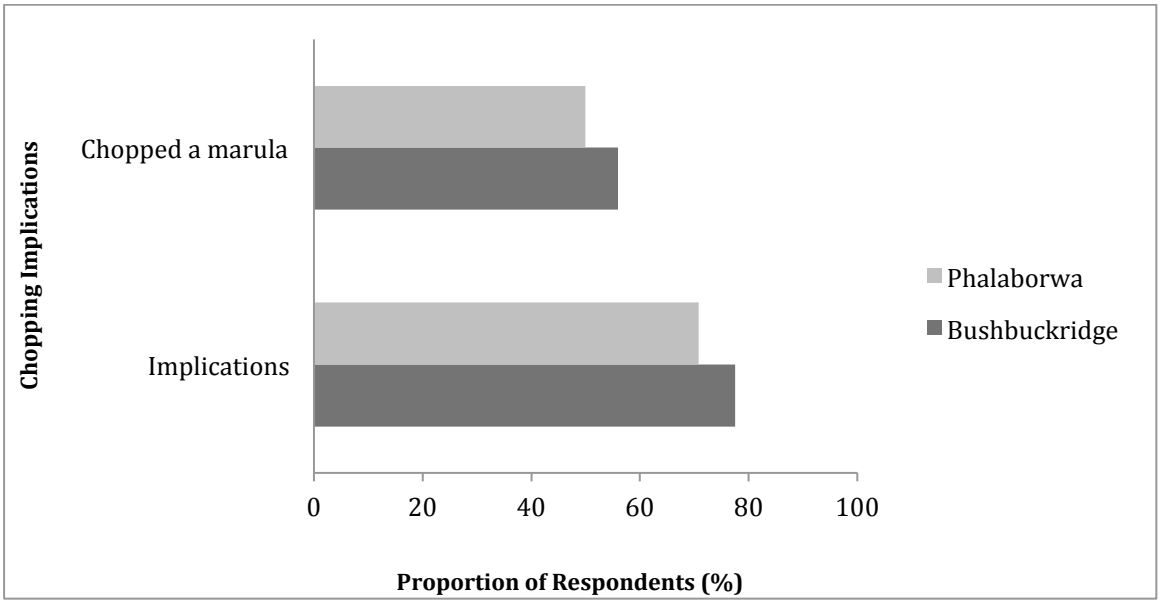


Figure 7.9: Fuelwood use and consequences in Phalaborwa (n=120) and Bushbuckridge (n=120)

Considering the important role of marula as a natural resource, excessive fuelwood use creates cause for concern as it depletes the resource base if harvesting is unsustainable. A logistic regression was performed to assess the impact of a number of factors on a respondent's likelihood to use marula for fuelwood in both Phalaborwa and Bushbuckridge. The collinearity statistics indicated low correlations between independent variables in the model. The full model containing the final sixteen predictors was statistically significant (x^2 (16, n=240)= 40.377, p=0.001), indicating that the model was able to distinguish between factors that confirm the likelihood of using marula wood compared to those that do not predict fuelwood use. The Hosmer-Lemeshow Goodness of Fit test had a significance level of p>0.05 indicating that the model is worthwhile (x^2 (8, n=240)= 3.38, p=0.908). The model as a whole explained between 15.5% (Cox and Snell R Square) and 20.7% (Nagelkerke R squared) of the variance of the likelihood of using marula wood and correctly classified 64.6% of cases, an increase from the original estimate of 53.3%, which indicates a strong model.

As shown in Table 7.4, the strongest predictor of marula fuelwood use was gender (p<0.01), recording an odds ratio of 2.68. This indicated that female respondents were nearly three times more likely to use marula wood than male respondents. The odds ratio of 0.23 for difficulty finding fruit (p<0.05) indicated that respondents who were concerned about insufficient marula fruit supplies were one fifth as likely to use marula wood, compared to those who were not concerned. While not significant, the p values for household income and practicing *kuphahla* indicate that these independent variables are of interest. Those who are unemployed or do not practice *kuphahla* are almost twice as likely to use marula wood compared to those who are either employed or practice *kuphahla* as a key cultural ceremony.

Table 7:4: Statistical Outputs from the Regression Analysis Model Predicting the Likelihood of Marula Fuelwood Use

	B	**S.E.**	**Wald**	**Df**	**p**	**Odds Ratio**	**95% C.I. lower**	**95% C.I. upper**
Location	-0.098	0.321	0.093	1	0.760	0.907	0.483	1.701
Gender	0.987	0.361	7.493	1	**0.006**	**2.684**	1.324	5.443
Age	0.147	0.164	0.806	1	0.369	1.159	0.840	1.598
Household Income	0.545	0.294	3.438	1	**0.064**	**1.724**	0.969	3.067
Resources	-0.209	0.381	0.300	1	0.584	0.811	0.384	1.713
Financial	-0.217	0.424	0.262	1	0.609	0.805	0.350	1.848
Cultural	0.439	0.506	0.751	1	0.386	1.550	0.575	4.181
Practice *kuphahla*	0.573	0.319	3.226	1	**0.072**	**1.774**	0.949	3.316

Fields Accessible	0.139	0.620	0.050	1	0.823	1.149	0.341	3.874
Rangelands Accessible	0.326	0.391	0.697	1	0.404	1.386	0.644	2.983
Yard Damage	0.212	0.305	0.483	1	0.487	1.236	0.680	2.248
Damage Implications	0.432	0.349	1.532	1	0.216	1.540	0.777	3.050
Decreasing Fruit	0.600	0.458	1.721	1	0.190	1.823	0.743	4.470
Decreasing Trees	0.093	0.358	0.067	1	0.795	1.097	0.544	2.211
Too Few Females	-0.445	0.543	0.671	1	0.413	0.641	0.221	1.859
Difficulty Finding Fruit	-1.472	0.612	5.787	1	**0.016**	**0.230**	0.069	0.761

Respondents indicated that they have observed increased chopping of marula trees over the past decade. In Bushbuckridge (n=120), 52.5% (n=63) of respondents confirmed they have observed increased chopping, with 58.3% (n=70) in Phalaborwa (n=120) stating the same. A middle-aged woman from Mbaula (Phalaborwa) summed up the perceived problem with chopping marula trees as follows: *"There are fewer trees now – most of them have been cut down for profit."* Comparing the observations of increased cutting or no increase in cutting over the past decade between the two locations, the differences were not significant (x^2 (1, n=240)= 0.61, p=0.436). This finding indicates similar trends between locations in terms of increased observations of cutting of marula trees.

Finally, respondents were asked if they have observed more people collecting marula fruit over the past decade. In Bushbuckridge (n=120), 55.8% (n=67) disagreed, while in Phalaborwa (n=120), 81.7% (n=98) agreed they had noticed an increase in marula fruit collection. This difference in opinion between the two locations was significant, with a large majority in Phalaborwa observing increased collecting of marula fruit, compared to the majority in Bushbuckridge who have observed the opposite (x^2 (1, n=240)= 34.57, p<0.001, phi=-0.388).

Changes in the observed number of people picking fruit, or chopping trees, are provided in Figure 7.10.

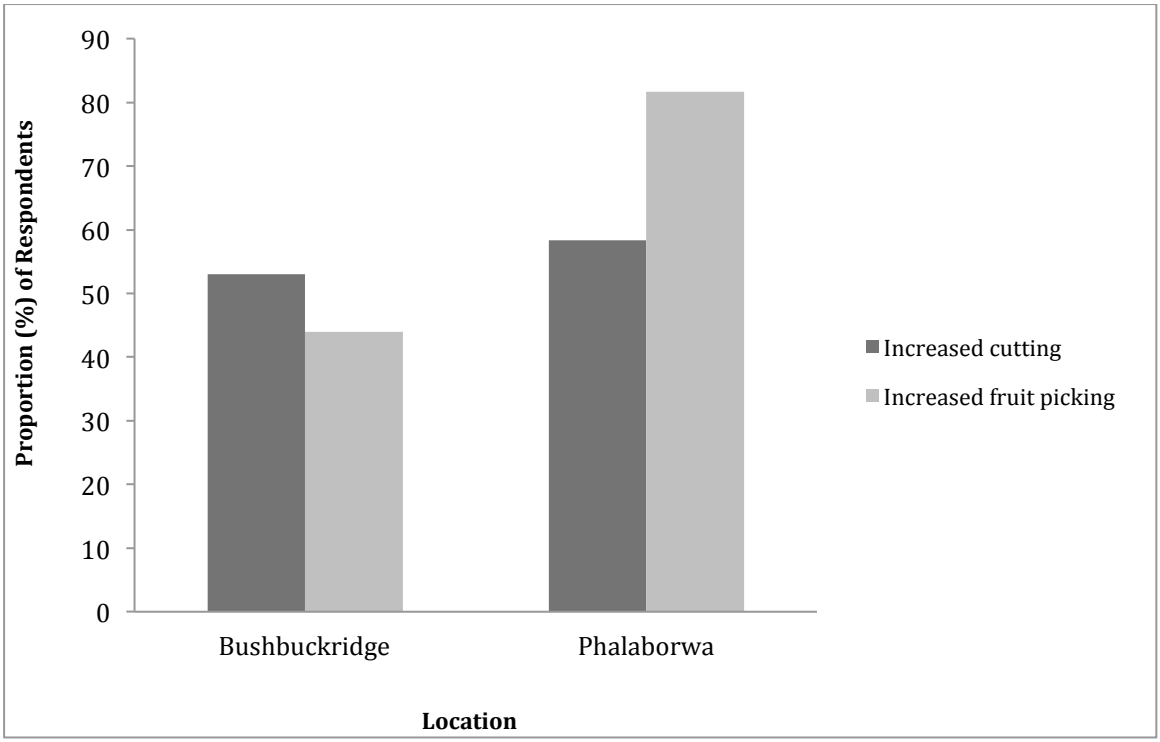


Figure 7.10: Proportion of Respondents in Phalaborwa (n=120) and Bushbuckridge (n=120) who have noticed an increased in marula tree cutting and fruit picking over ~10 years

7.3.4 Perceived impacts of climate change on marula population structure & fruit production

Overall, 64.4% (n=65) of respondents in Bushbuckridge (n=101) felt that marula numbers have declined since the year 2000, with 66.6% (n=64) of Phalaborwa (n=96) respondents being in agreement.

The similar patterns in perceived changes in marula populations between locations meant the differences were not significant (x^2 (3, n=240)= 6.48, p=0.091). In addition, the number of respondents who felt marula numbers have either increased, or stayed the same, is provided in Figure 7.11.

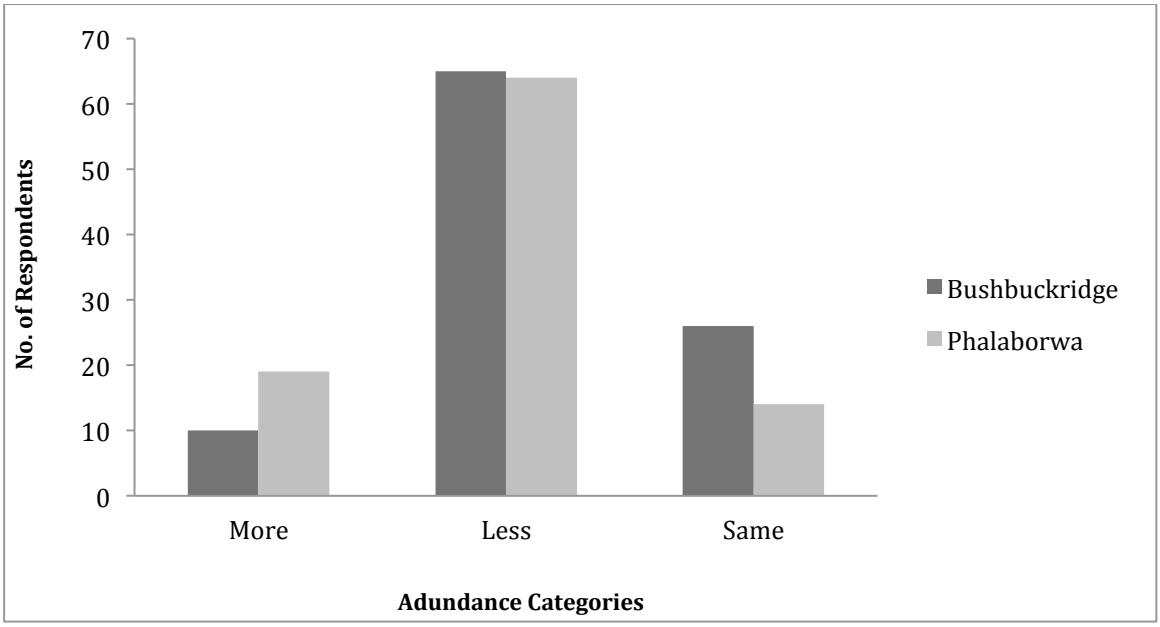
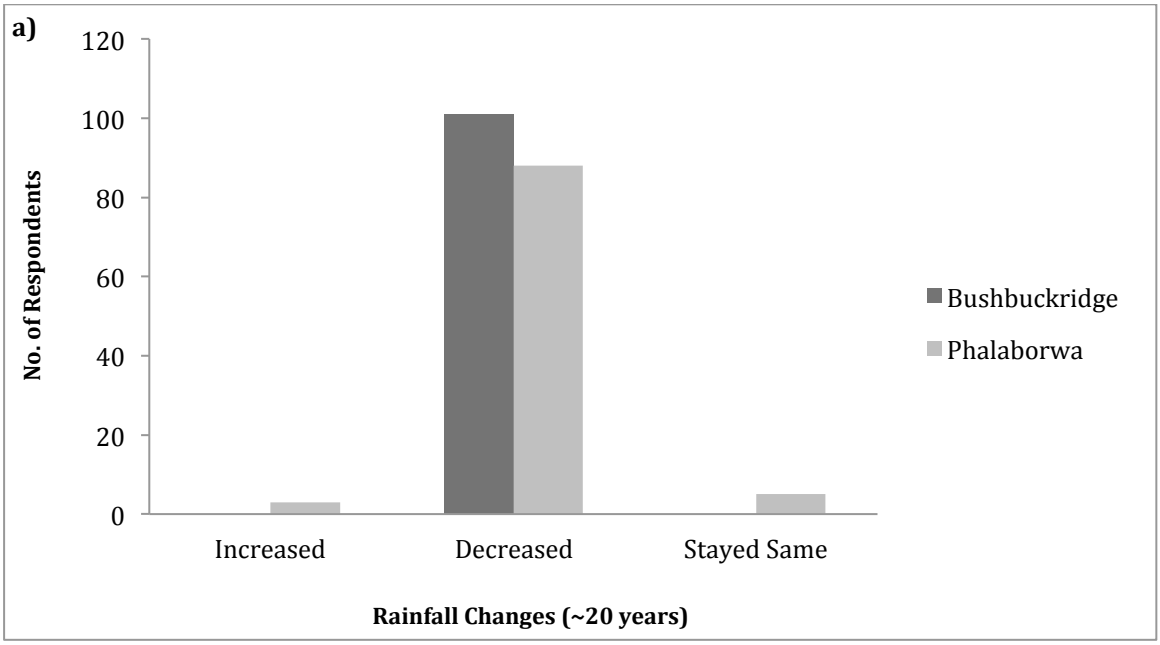


Figure 7.11: Marula population change over approximately 20 years, as perceived by Phalaborwa (n=96) and Bushbuckridge (n=101) residents aged 30-50

In terms of observed changes in the local weather patterns, in Bushbuckridge, 100% (n=101) of respondents stated that rainfall has decreased over the past ~20 years, with a further 90% (n=91) specifying that temperatures have increased over the same period. In Phalaborwa (n=96), 91.7% (n=88) agreed that rainfall has decreased over this period, with 81.3% (n=78) stating that temperatures have also increased. Perceived changes in rainfall and temperature are given in Figure 7.12.



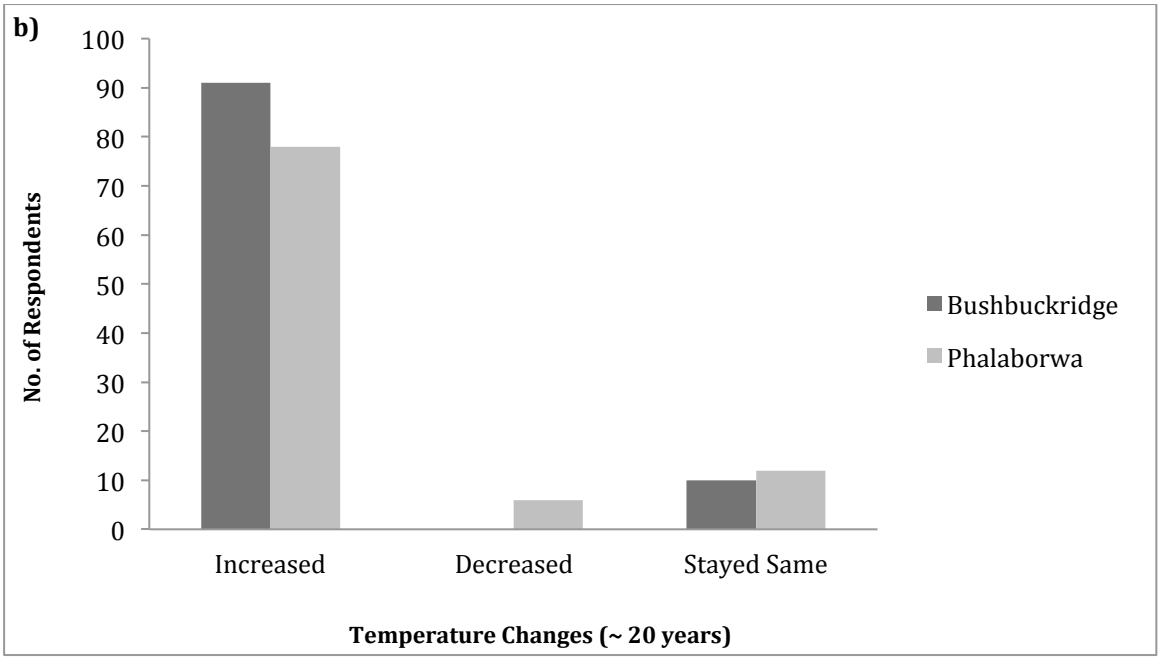


Figure 7.12: Perceived a) rainfall and b) temperature change over approximately 20 years, as observed by respondents ages 30-50 years in Bushbuckridge (n=101) and Phalaborwa (n=96)

The rainfall and temperature data for the 10 years prior to this study show general patterns over recent years. The temperature and rainfall data highlight the drought years and extreme temperatures, specifically from 2014 – 2016, the three years directly preceding this study. Weather patterns for Bushbuckridge from 2009-2020 are shown in Figure 7.13, and for Phalaborwa in Figure 7.14.

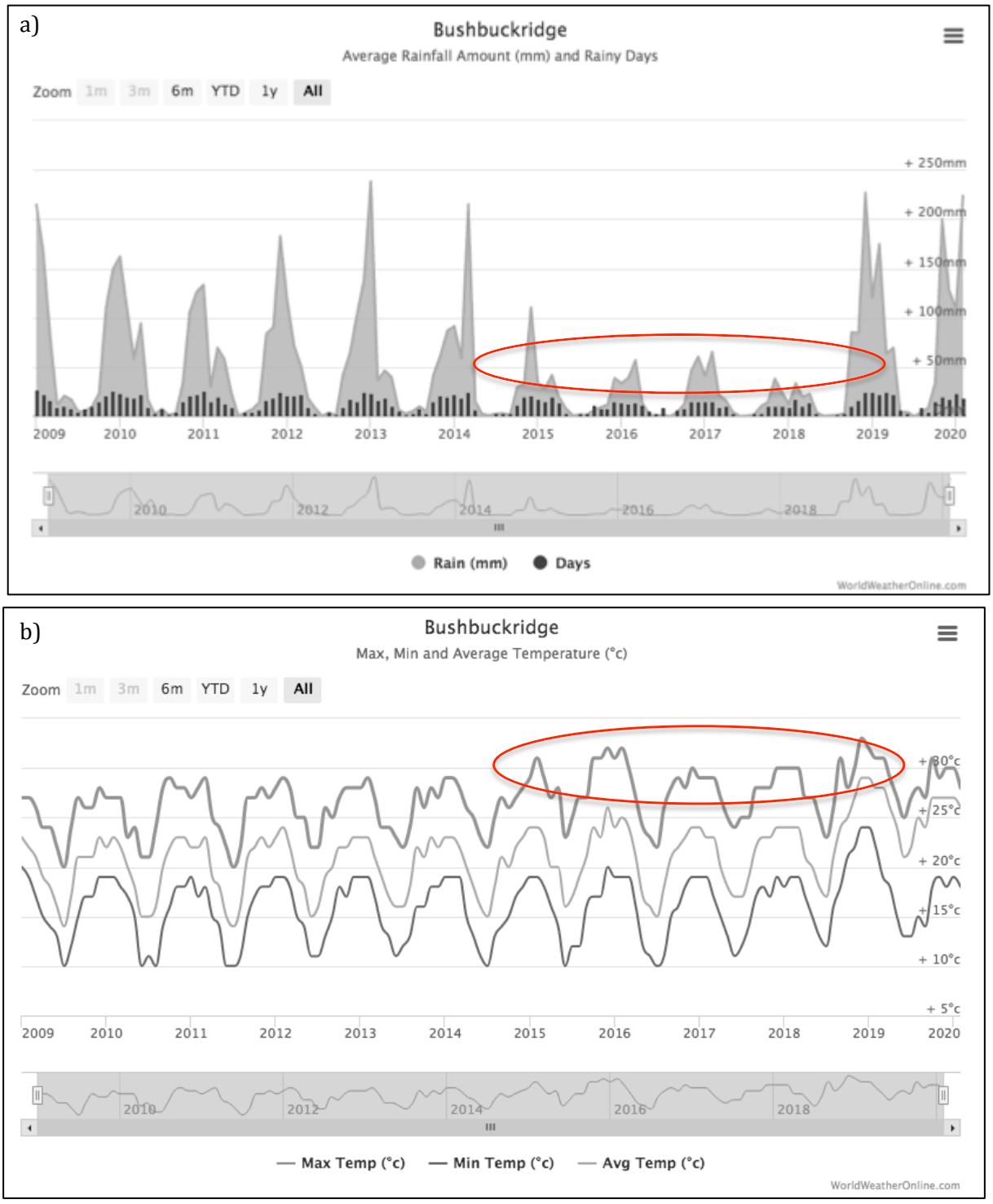


Figure 7.13: a) Rainfall and b) temperature patterns for Bushbuckridge from 2009-2020, indicating the low rainfall and high temperature years from 2015-2018 (source: WorldWeatherOnline)

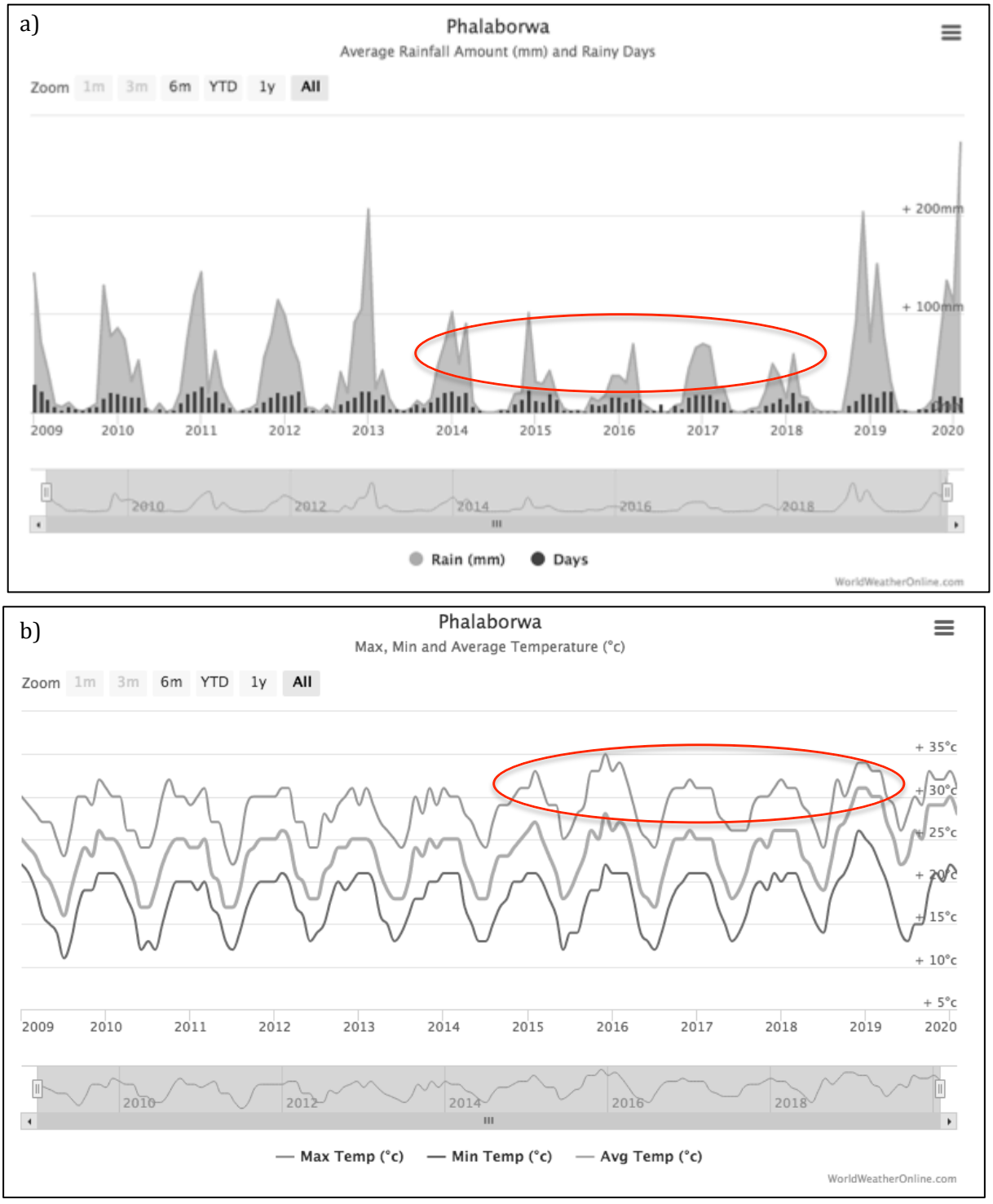


Figure 7.14: a) Rainfall and b) temperature patterns for Phalaborwa from 2009-2020, indicating the low rainfall and high temperature years from 2015-2018 (source: WorldWeatherOnline)

In order to gauge marula population changes as well as climatic variation over a longer time period, respondents who were 50 years of age and older were asked a more extensive list of questions. Overall, 76.4% (n=42) of respondents in Bushbuckridge (n=55) felt that marula numbers have declined since they were a young adult, with 75% (n=36) in Phalaborwa (n=48) agreeing. In addition, the proportions of respondents who felt marula numbers have either increased, or stayed the same, are provided in Figure 7.15.

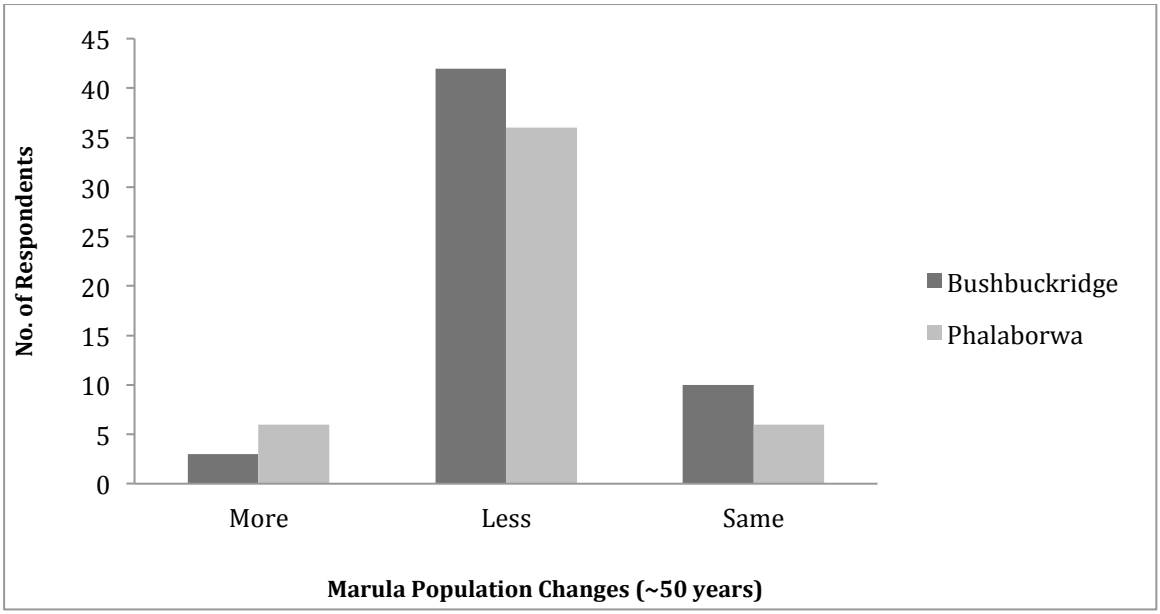


Figure 7.15: Number of respondents ages ≥50 years in Phalaborwa (n=48) and Bushbuckridge (n=55) whose perception is that marula population numbers have either increased, decreased or stayed the same over approximately 50 years

Decreasing tree numbers, as well as the relationship between marula and local climate, were explained by an elderly woman from Edinburgh (Bushbuckridge) as follows: *"The big trees are dying from a lack of rain and the small trees are unable to grow big due to the lack of rain."* In addition to declining overall marula numbers, 69.1% (n=38) of respondents in Bushbuckridge (n=55) stated that female marula numbers specifically have declined over the past ~50 years. Seventy-five per cent (n=36) of respondents in Phalaborwa (n=48) shared this sentiment (Figure 7.16).

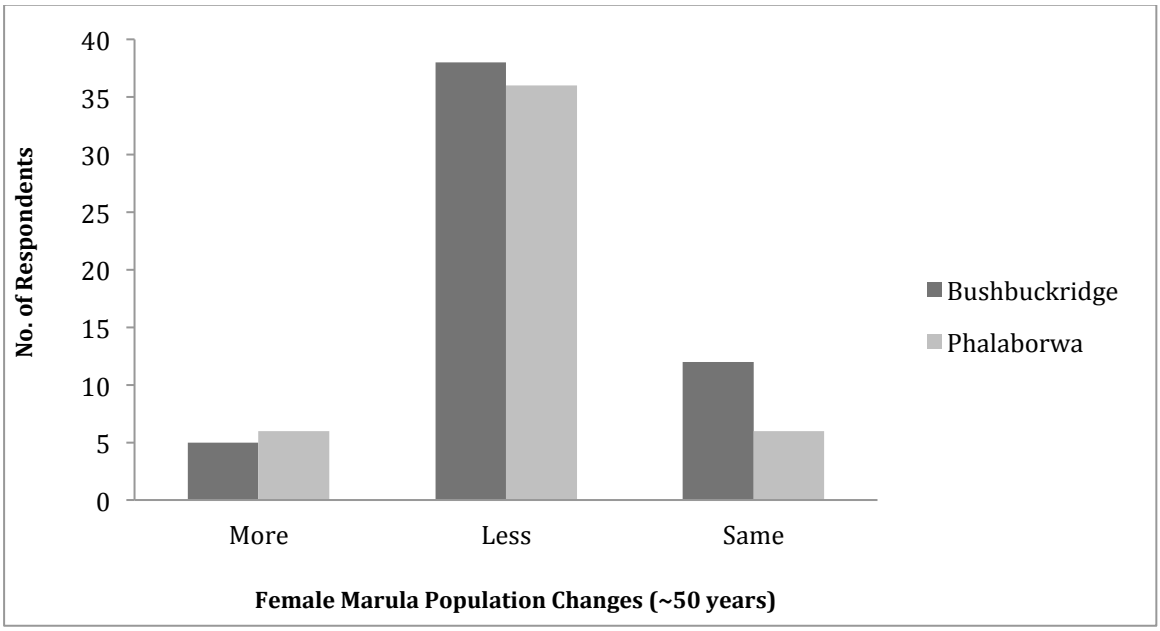


Figure 7.16: Number of respondents ages ≥50 years in Phalaborwa (n=48) and Bushbuckridge (n=55) whose perception is that female marula population numbers have either increased, decreased or stayed the same over approximately 50 years

Respondents in Bushbuckridge (n=55) were mixed in their perceptions of change in juvenile density; with increases (34.5%, n=19), decreases (32.7%, n=18) and unchanged (32.7%, n=18) abundances all being indicated. However, in Phalaborwa, the majority (72.9%, n=35) of surveyed individuals felt that juvenile numbers have simply declined over the past 5 decades (Figure 7.17).

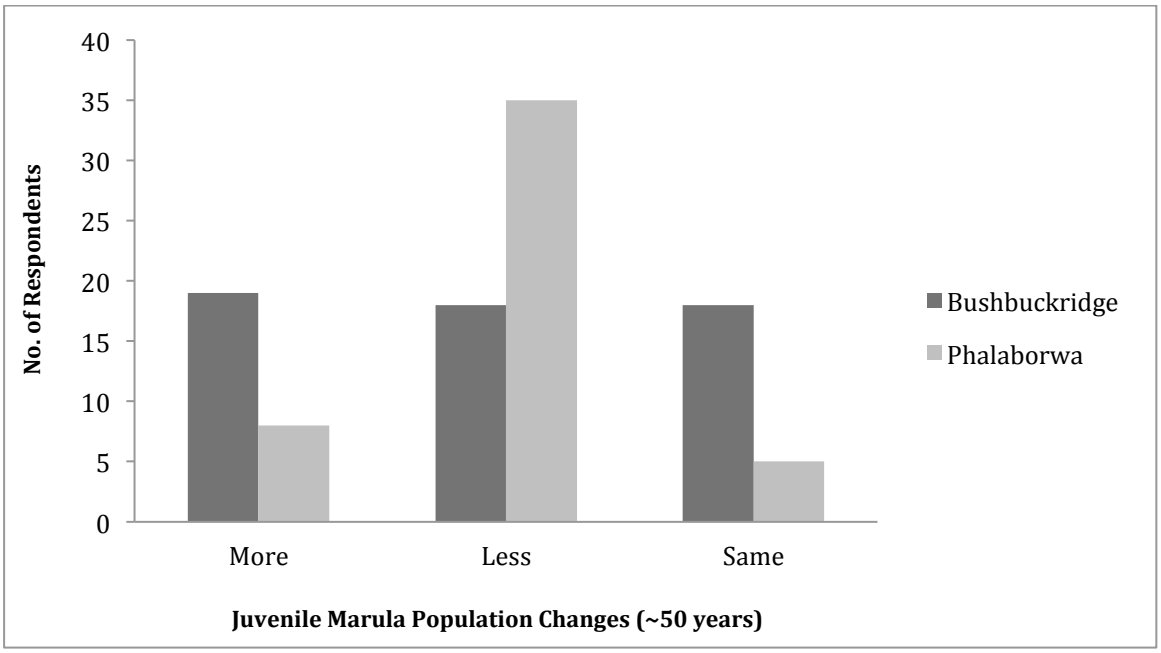
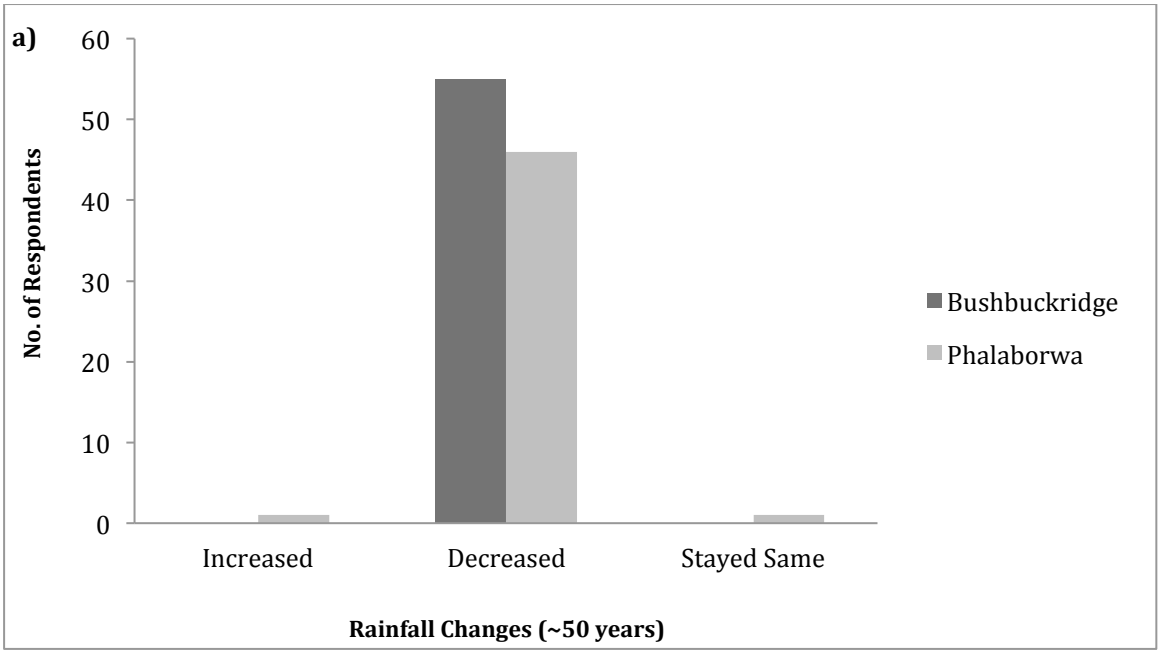


Figure 7.17: Number of respondents ages ≥50 years in Phalaborwa (n=48) and Bushbuckridge (n=55) whose perception is that juvenile marula population numbers have either increased, decreased or stayed the same over approximately 50 years

In Bushbuckridge, 100% (n=55) of respondents indicated that rainfall has decreased since they were young, with a further 76.4% (n=42) saying that temperatures have increased since that time (Figure 7.18). In Phalaborwa (n=48), there was a similar sentiment with 95.8% (n=46) and 89.6% (n=43) of respondents stating decreased rainfall and increased temperatures, respectively (Figure 7.18).



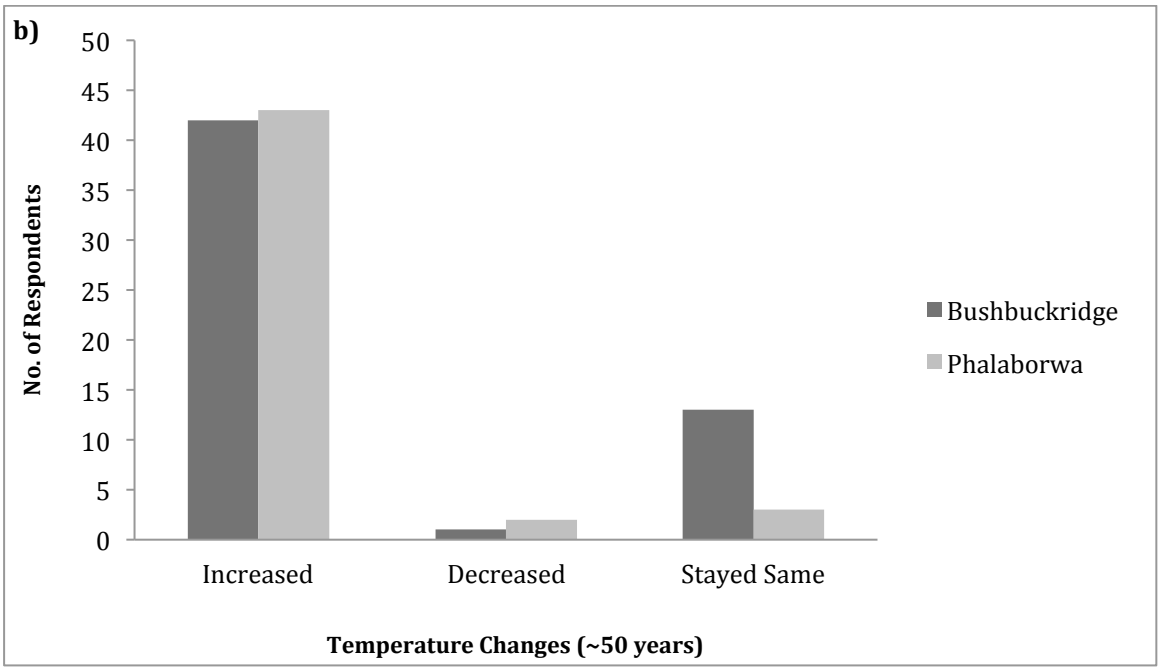


Figure 7.18: Number of respondents ages ≥50 years in Phalaborwa (n=48) and Bushbuckridge (n=55) who perceive that a) rainfall and b) temperature in the area has either increased, decreased or stayed the same over approximately 50 years

Respondents of all ages were asked to discuss the implications of any long-term weather changes in focus groups. One elderly woman from Hokwe (Bushbuckridge) bemoaned the current lack of rain stating: *"When the rain comes now it is like poison. Nothing grows anymore."* The severity of storms, often combined with strong winds, were mentioned by respondents in separate informal focus groups in Phalaborwa and Bushbuckridge. A middle-aged man from Mbaula (Phalaborwa), provided an example of these types of storms: *"The rain doesn't come these days but when it does it is not the kind of rain that gives food. It is the kind of rain that destroys everything."* In other words, the rain may not come but when it does, the severity of the storm damages food crops, increasing food insecurity. Respondents in the informal focus groups

also felt that in addition to rainfall and temperature, that heavy winds are also affecting the trees, with an elderly woman from Selwane (Phalaborwa) explaining: *"It is very windy these days so fruit is dropping earlier now when it is not yet ripe."* Respondents indicated that fruit drop could be up to a month early in some instances.

In addition to rainfall seemingly affecting fruit production, it also affects fruit quality for beer making purposes, with multiple respondents stating that 2018 had been a bad year for marula beer due to a lack of rain. An elderly woman from Benfarm (Phalaborwa), who has made marula beer most of her life, explained the problem as follows: *"The fruit is dry this year due to lack of rain – it is bad quality fruit for making beer."* This problem is not unique to Phalaborwa, with multiple respondents in Bushbuckridge saying that the fruit is now "shivunde" which means bad, mainly as a result of a lack of water. An elderly woman from Hokwe (Bushbuckridge), who has also been a marula beer maker since she was a young woman, states the following: *"The fruit then had a lot of water - the fruit these days is bad quality as it has too little water from no rain."* The problem with '"shivunde" fruit is that customers insist on tasting the beer before buying and if it tastes bad then the sellers lose customers.

Also in the context of the informal focus groups, respondents indicated that changes in climate have possibly led to phenological shifts. Respondents explained how the marula season has shifted since they were younger, sometimes starting up to a month earlier in December and then ending earlier, in February instead of March. These changes in phenology, are described by a middle-aged man from Allandale (Bushbuckridge): *"The fruit starts quickly and then ends quickly. You have to be quick or you miss the season nowadays."* In order to gauge how environmental changes may have impacted marula populations over this longer time period, specifically in terms of fruit production, respondents were asked if they felt the amount of available fruit has changed. In Bushbuckridge, 74.5% (n=41) felt that the amount of available fruit has decreased, with 75% (n=36) in Phalaborwa also stating that fruit volumes have declined over the past ~50 years (Figure 7.19).

An elderly woman from Mbaula (Phalaborwa) described the impact of decreasing fruit availability: *"There was too little fruit this year, we know this due to the marula beer season ending early, due to lack of fruit. Not all the trees that usually have fruit did this year."* In order to gauge more recent environmental changes as well as allow respondents of all ages to answer, the same questions regarding fruit production were put to all respondents, but the time frame was limited to the preceding five seasons. In Bushbuckridge, 71.7% (n=86) of respondents felt that there is less fruit currently compared to just five years ago; 62.5% (n=75) of respondents in Phalaborwa (n=120) felt the same (Figure 7.19). Comparing perceived changes in the volume of marula fruit over the past 5 years, the similarities in opinion between locations meant that the differences were not significant (x^2 (2, n=240)= 3.67, p=0.160).



Figure 7.19: Proportion (%) of respondents who felt fruit volumes have declined over ~50 in Phalaborwa (n=48) and Bushbuckridge (n=55) as well as more recently over a ~5 year period (n=120)

A young man from Lulekani (Phalaborwa) attributed declining fruit production directly to climate change stating: "*The trees are producing less fruit due to climate change.*" Respondents were then asked if they were concerned about the status of marula trees in their community as well as what concerns them most. In Bushbuckridge (n=120), 76.6% (n=92) of respondents indicated they are concerned about marula, with 34.2% (n=41) of respondents listing decreasing tree numbers as their primary worry. A further 25.8% (n=31) quoted decreasing fruit drop as their concern. In Phalaborwa (n=120), only half (52.5%, n=63) the respondents showed concern regarding marula trees. Decreasing number of trees (27.5%, n=33) was quoted as the main concern, followed by decreasing fruit drop, too few females and difficulty finding fruit (8.3%, n=10) which were all equally shared concerns. The differences in concern between location where significant (x^2 (4, n=240)= 21.52, p<0.001, Cramer's V=0.299). The main concerns provided by respondents in relation to marula tree populations are provided in Figure 7.20.

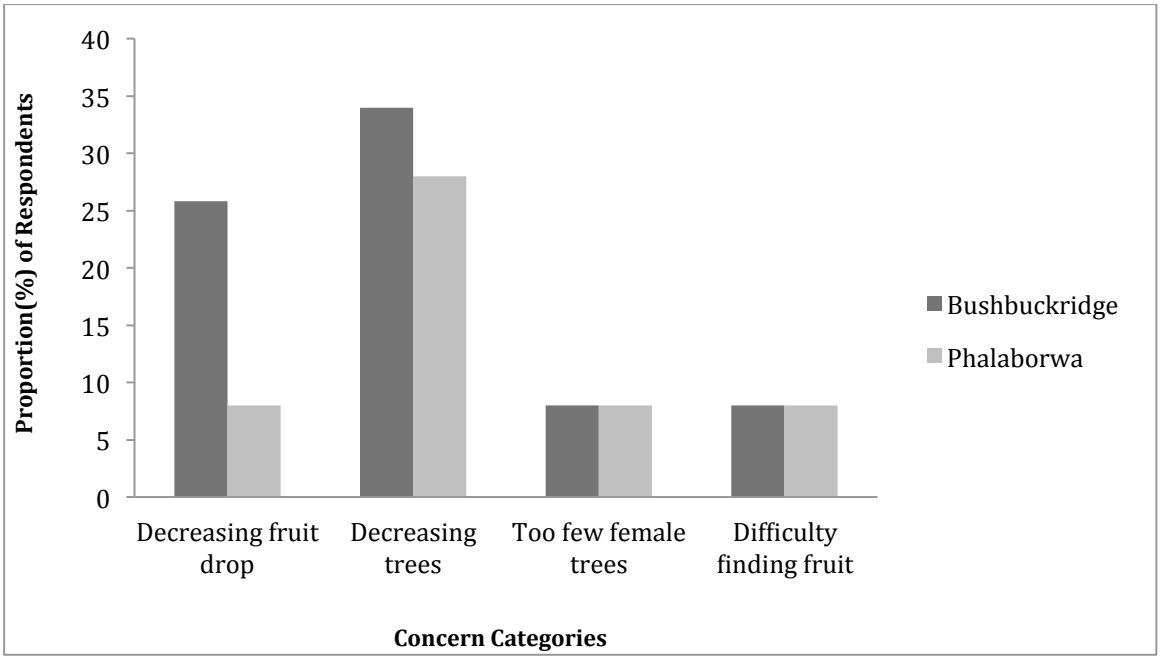


Figure 7.20: Comparison of the main concerns provided by respondents in Phalaborwa (n=120) and Bushbuckridge (n=120) regarding marula trees in and around their villages

Numerous respondents indicated that the main problems affecting marula are not a lack of rain, but a continuous lack of rain, for many consecutive years in a row. An elderly woman from Allandale (Bushbuckridge) described how in her experience: *"Marula trees can survive 2-3 years of harsh drought but after that they start dying."* A middle-aged woman from Selwane (Phalaborwa) defined this problem in practice: *"You need to walk further distances between trees, as well as collect from more trees, to reach your quota due to less fruit being available."* Other respondents felt concerned about the future impacts of reduced rainfall on the marula tree, with an elderly man from Rolle (Bushbuckridge) stating: *"The trees are starting to die due to lack of rain. Future generations will not know this tree."*

7.4 Discussion

The cultural ecosystem services provided by NTFPs, such as marula, are divided into both tangible as well as intangible functions. Together, these enhance the customary practices, traditions, livelihoods and well-being of social groups (Lake et al. 2018). The cultural landscape of marula provides interesting insights into how cultural value is attributed to a non-timber forest product. In addition, it is possible to analyse what value attribution might mean, in terms of resource use implications for important NTFPs in a variety of locations. The cultural ecosystem services that flow from NTFPs are produced through social-ecological systems with spatial, temporal, and social dimensions. These operate at various scales from the individual plant through to the community level (Lake et al., 2018). Traditional environmental knowledge (TEK) transactions usually position *Homo sapiens* as a component of ecosystems, as opposed to having dominion over the natural system (Pierotti & Wildcat, 2000). Godgil et al. (1993) explain how indigenous communities usually possess broad knowledge and behavioural responses based on innate knowledge of the complex socio-ecological systems in their locality. This has led authors such as Gaoue & Ticktin (2009) to stress how social drivers of resource use are key to conservation biology. Furthermore, many conservation practices are directly linked to culture, reinforcing the importance of understanding local worldviews (Voggesser et al., 2013).

However, because culture is fluid rather than static, it means that culture changes all the time in both subtle and tangible ways. Furthermore, humans express or communicate their cultural systems in a variety of ways, making it difficult to ring-fence a particular set of cultural practices or define cultural dynamics other than at a fixed point in time. Traditional knowledge systems help to define some of the key tenets of a particular culture at a given point in time. Specifically, TEK is important for understanding indigenous worldviews, which are informed by the cultural landscape within which important natural resources such as marula are embedded. Huntington et al. (2004) advocate the importance of holistic scientific perspectives that include humans and culture. This includes the advantages of combining TEK and scientific observation to understand phenomenon such as climate change. Marula customary practices, the resultant resource use choices and the concern and stewardship practices resulting from local cultural worldviews provide three key findings, applicable to other contexts where important NTFPs are embedded within cultural systems. The first finding pertains to the importance of understanding different TEK systems, as well as how cultural beliefs and practices are both informed by, as well as inform TEK. The second finding is connected to the first, building on a body of theory showing how cultural beliefs informs environmental concern (or lack thereof), which in turn impacts the resource base through resource use choices. Finally, the third finding pertains to how perceptions around natural phenomenon, such as climate change, are informed by both TEK as well as cultural beliefs. These perceptions result in shifts in resource use choices in response to the perceived impacts.

7.4.1 TEK and marula: the diminishing ecocultural knowledge informing cultural identity

Marula is indisputably valued and appreciated culturally in both Phalaborwa and Bushbuckridge, with 100% of respondents stating that the tree is culturally important. Numerous respondents, specifically in the Phalaborwa context where higher percentages of beer and fruit are sold (Chapter 6), offered economic answers to questions regarding marula's cultural value. This was confirmed in Chapter 6 where respondents in Phalaborwa were found to be more than three times as likely to collect marula fruit. Those participating in cultural practices involving the beer would still collect the fruit but it would likely not elicit the same number of collectors or volumes of fruit. An economic response to a cultural question is symptomatic of communities embedded in a complex socio-cultural system. However, the reasons for this value attribution diverged between locations. While respondents in both locations based marula's importance on the resources the tree provides, respondents in Phalaborwa focussed more on the monetary (economic) value of marula, while in Bushbuckridge, the traditional (cultural) aspects were also a priority. Marula beer making is an example of a practice where the commodity (the beer) is equally important culturally and economically. This makes it difficult to separate the cultural and economic values when ascertaining prominence (Wynberg et al., 2002). This is due to the use values (input into commercial production and ecosystem services) and non-use values (cultural significance) being interlinked (Berkes, 2007). It is for this reason that it is not always possible to separate the underlying value of the various components of the system from one another (Khalid et al., 2013). Authors such as Berkes (2007) and Khalid et al. (2013) stress the importance of understanding the pluralistic and multi-level nature of community-based conservation, as informed by local traditional knowledge and identity. The economic value of a commodity may not always be the basis for which it is most highly valued. Factors such as capacity building and long-term ecological benefits often rank higher than monetary value alone (Bremer et al., 2013; Grillos, 2017). The divergent approaches regarding the use of marula beer in these two locations

illustrates how the application of cultural identity differs based on local cultural values. Importantly, these values also shift and change as cultural norms are revised and new beliefs and practices are integrated. Cultural values can be understood as socially accepted ways of assigning value (Stephenson, 2007). The fact that the majority of respondents making marula beer in Bushbuckridge elect to keep the beer they make for home use (which includes cultural uses), indicates that the intangible social capital of marula is ascribed a higher value in this context. In Phalaborwa, while cultural practices are still well entrenched, the majority opt to sell (economic) the beer they produce. This suggests that tangible ecosystem services retain a higher value attribution in this context. Interestingly, those that sell the beer were found to be twice as likely to be of the opinion that marula's cultural value has decreased. This finding tends to confirm the claim by respondents that those selling the beer are selling their culture – suggesting that marula's value is intricately attached to it's cultural prominence and that as this has eroded, so has it's value attribution.

Regardless of the intention behind marula beer production, marula trees are undoubtedly integrated into community life. A prime illustration of this point is the fact that the clear majority of respondents, regardless of age or gender, are aware of certain key features of the trees. Specifically, the vast majority know about the dioecious nature of marula. This enforces the pervasive nature of local TEK in this context, with respondents across the demographic profile possessing this marula specific knowledge. Interestingly, of the respondents who were unaware of the difference, the majority were between the ages of 18-34 years in both locations. This suggests that it is the younger generation who are less knowledgeable in both locations. The older members of society usually hold ethnobotanical knowledge, emphasising the need for it to be captured before it is lost (Luoga et al., 2000; Gaoue & Ticktin, 2009; Sinthumule & Mzamani, 2019). However, specialist knowledge is often transferred between generations, especially when the youth are involved in resource activities (Gaoue & Ticktin, 2009). Marula beer making, whether for economic or cultural reasons, is a prime example of a resource activity where the knowledge around this practice is passed on to younger generations. However, despite the heightened levels of use and awareness around the tree, older respondents felt that the value of the tree and its associated importance in the cultural life of the community is declining. While respondents appear to attach a higher economic value to marula in Phalaborwa, the relative number of respondents practicing *kuphahla* are also higher here than in Bushbuckridge. However, *xikuha* is practised more in Bushbuckridge. This creates an interesting value association pattern, as both *kuphahla* and *xirhwalo* are practices that participants choose to do in their personal capacity. However, *xikuha* is a communal activity, performed by the whole village every year. So while there may be higher levels of personal commitment to cultural traditions in Phalaborwa, community practices and specifically those involving the beer, are more strictly observed in Bushbuckridge.

Over the thirteen-year period from 2005 to 2018, two of the three cultural traditions reviewed have shown a decline, in terms of the number of practitioners in Bushbuckridge. Only *kuphahla* has increased over this time period. This is an interesting outcome considering that *kuphahla* incorporates both the tree and the beer. The other two cultural traditions, *xikuha* and *xirhwalo,* are based entirely on the marula beer. In Mbaula (Phalaborwa), at an informal focus group, the older members of the group bemoaned the decline in cultural practices involving the beer, stating: *"In the past the whole community collected and then drank marula beer together to celebrate special occasions. Now that time has passed."* Exploring marula from the perspective of

its social capital value, cultural ceremonies such as *xikuha* and *xirhwalo* are much more than simply opportunities for beer to be shared. These ceremonies are in fact key modes of building social capital, not only between members of the community, but also in terms of reinforcing hierarchy in relation to the role of the Induna (Shackleton, 2004; Shackleton & Shackleton, 2005). Shackleton & Shackleton (2005) explain how gifting beer to the Induna (Headman) at the start of the marula season (*xikuha*) is a type of voting system, with high volumes indicating not only implicit support but also absolute approval. Since the role of the Induna as the legitimate source of authority has begun to erode (Findlay & Twine, 2018), this practice has started to break down. This is supported by the decrease from 2005 to 2018 in those practicing *xikuha*. In addition, respondents directly indicated that with the increased sale of fruit and beer that the community has actively chosen to refrain from this practice. Instead, community members choose to sell the beer rather than give it away. In Bushbuckridge, the dire need to sustain a livelihood from marula beer may account for many of those refusing to practice *xikuha* at present. However, it would appear that the majority of those respondents no longer taking part have chosen to do so due to a combination of not only diminished fruit volumes, meaning income generating activities are prioritised, but also the diminished authority of the Induna. Kirkland et al. (2007) corroborate how cultural erosion is linked to declining institutional authority in communal areas. This would suggest that the issue is one of combined economic necessity and cultural attrition. Many of the older members of both communities lament this cultural decline in lieu of profit. An elderly man from Allandale (Bushbuckridge) summed this sentiment up best by explaining: "*The youth today are throwing away their culture to fill up their pockets."*

The cultural practice showing the biggest decline since 2005, in terms of practitioners is *xirhwalo*, the gifting and sharing of beer amongst the community. Where *xikuha* seeks to reinforce the role of the Induna, *xirhwalo* operates to create and maintain key social bonds amongst families and members of the community. The practice of gifting beer is an incredibly important social/human capital store for the poorest and most vulnerable members of the community (Shackleton, 2004). By gifting beer, which is made from freely available fruit and the maker's own labour, these members are able to build social bonds and establish favours during marula season. These favours can then be claimed out of season when necessary resources are running low. The diverse cultural dimensions of NTFPs, such as communal harvesting and sharing of resources, result in important social capital building (Lake et al., 2018). Cocks and Wiersum (2014) link the biodiversity conservation of a variety of NTFPs to the cultural practices of the amaXhosa tribe in South Africa, highlighting how cultural appreciation and communal practices lead to species conservation. Of concern, is that as these beliefs erode, so too do the conservation practices based purely on the cultural appreciation of the species. A similar finding was made for the tree species *Khaya senegalensis (Meliaceae)*, in Benin, with local TEK informing cultural practices (Gaoue & Ticktin, 2009). This in turn resulted in the sustainable harvesting of the tree. The authors observed how many of the local conservation practices are directly linked to the cultural value of the tree. With the erosion of local culture due to Christianity, these practices are being lost (Gaoue & Ticktin, 2009). Once again, this highlights the issue of culture's fluidity and how shifting cultural practices may result in previous practices to be lost or discontinued, including those with conservation centred outcomes, which is to the detriment of the species around which the practices are based. A similar situation pertains to marula in terms of the practitioners of *kuphahla*, with those observing Christianity stating they no longer participate in traditional cultural practices due to

their religion. Where previously, maintaining key social bonds and hierarchical structures may have been as important as the economic value of selling marula fruit or beer, these practices have now largely fallen away. As these practices erode, so too do the conservation practices based purely on the cultural appreciation of the species. Two elderly ladies in an informal focus group in Allandale (Bushbuckridge) clarified the situation: *"People have made marula their business, and forgotten that culture used to be their business."*

The fact that *kuphahla* is the only practice to have increased during the past thirteen years, would potentially suggest that trees in yards might be conserved to a certain degree for this purpose alone. This is because in addition to the beer, a marula tree must usually be used to perform this ceremony (Shackleton & Shackleton, 2005). The female-biased populations (Chapter 4) in both Phalaborwa and Bushbuckridge yards may further support this theory. While either tree can be used to perform *kuphahla*, female trees are afforded twice the cultural protection, as they can be used to communicate with the ancestors, as well as providing the fruit for making beer, a key component of the cultural practice. A woman in her forties from Mbaula (Phalaborwa) highlighted the importance of the beer: *"This beer is like data [mobile phone data], we use it to communicate with the ancestors."* In addition, female trees are afforded a third layer of protection, due to the numerous economic benefits of the fruit. This makes male trees the more obvious choice for removal when residential expansion occurs, meaning they are afforded less protection (Chapter 4). Interestingly, instances of practicing *kuphahla* were higher in Phalaborwa, coupled with higher instances of fruit sales in this context (Chapter 6), which coincide with the finding that respondents in Phalaborwa are only a third as likely to damage or chop down a marula tree in their yard when compared to Bushbuckridge. In the Bushbuckridge context, there were a higher number of respondents who have both cut trees, ring barked or damaged trees in yards, despite the higher levels of cultural association with marula in this context. This would suggest that in Bushbuckridge, in spite of the cultural value, there is reduced stewardship. In contrast, the increased economic activity around marula in Phalaborwa (Chapter 6) leads to increased stewardship. However, the reality in Bushbuckridge is very possibly also a consequence of the positive feedback loop resulting from heightened resource pressure. This suggests the combined economic and cultural capital of the fruit hold more weight than the cultural capital of the tree alone, making the combined cultural and economic value of the tree the strongest determinant of it's protection. The removal of male trees was highlighted by a woman in Hokwe (Bushbuckridge) as follows: *"People do not chop trees in their yards – they only chop male trees to build houses."* This insight would suggest that for some, the male tree is actively excluded from what is considered to be a valuable marula. However, in a household where a male tree is used for communicating with the ancestors, it is likely to only be chopped if the roots are perceived to pose a risk to the building's foundations. While male trees are key for pollination, this is not always understood and so non-fruiting trees are deemed less valuable both culturally and economically. In this case, a lack of TEK regarding the imperative for male trees for pollination is directly contributing to the degradation of the species.

Lack of local TEK, leading to species degradation, was highlighted by Gouwakinnou et al. (2009) in Benin (West Africa), where only 28% of respondents knew about the distinction between male and female marula trees. This is in comparison to 85.4% of respondents in South Africa (n=240) who knew the difference. The authors attribute this limited TEK to the low levels of fruit utilisation in Benin, leading to limitations in knowledge (Gouwakinnou et al., 2009). In addition, subsp. *birrea* is also not culturally valued in Benin (Gouwakinnou et al., 2011). This has

resulted in higher levels of removal in agroforestry systems, with those individuals not utilising the tree seeming to lack the necessary knowledge about the differences in gender out of season. In the context of this current study, where subsp. *caffra* is highly utilised for the fruit, as well as being culturally valued, almost three times the number of respondents were aware of gender differences. Many respondents stated that they know which particular trees in fields and rangelands are female, regardless of whether they are currently bearing fruit or not. This knowledge reduces the likelihood of a female tree being accidently removed out of fruiting season.

When asked about the key differences between male and female trees, respondents gave different explanations for observed changes in marula populations. A middle-aged woman from Benfarm (Phalaborwa), provided the following explanation for population changes: *"There are more fruit trees (female trees) now – they have changed from male to female."* Numerous respondents explained the decrease in tree numbers as male trees becoming female. While androdioecy (a combination of male and hermaphrodite flower-bearing trees) does occur within marula populations, it has not been confirmed if marula trees switch genders. Gender switching does occur with some other androdioecious species (Nghitoolwa et al., 2003). However, Msukwa et al. (2019) observed apparent changes from female to male trees in marula populations in Malawi, highlighting the need for further investigations into sex change behaviour. The apparent change that respondents identify could be an indication of more males being removed from the overall population. Additionally, this could be an example of what Yamashita & Abe (2002) explain as the mature population displaying more females over time due to increased resource availability, such as improved water and nutrient access. Either way, this is a prime example of how utilising scientific, as well as local traditional environmental knowledge in tandem, can generate more robust findings. Huntington et al. (2004) compared various local TEK gathering approaches with conventional scientific methodologies to contrast differences in proposed findings. The long-term observations of community elders in specific hunting grounds in the Artic region of North America were contrasted with real-time field based observations of animal populations over time and space. The conclusion was that TEK, in addition to scientific perspectives, can provide more holistic perspectives as well as robust results than either methodology alone. Indigenous knowledge and conventional scientific observations can be made compatible by acknowledging that any contradictions can be solved be ensuring the knowledge is not taken out of the cultural context from which it emanates (Boillat & Berkes, 2013). In all likelihood, the observation of male trees becoming female likely highlights how people make sense of the fact that female 'fruiting' trees appear more abundant. This is not necessarily due to an increase in female trees per se but likely as a result of the decline in male trees, making female trees relatively more abundant.

The decline in male trees was attributed by many older respondents to the loss of culture, with the economic value of the female trees ensuring their conservation. There is a general sentiment amongst the older generation that the youth are ignorant to the cultural practices surrounding marula and only use it to make money. Notably, there appears to be some tension between those who value the tree for economic reasons and those who see it purely as a cultural asset. An elderly woman in Howke (Bushbuckridge) explains angrily: *"This beer is for culture, our culture is not for sale."* In Lulekani (Phalaborwa), an elderly man reminisced sadly: *"We used to pick marula to drink beer, now everyone is picking for money."* The older generation regret the perceived conversion of marula from a cultural asset to an economic commodity. This means the

youth in both locations are blamed for the erosion of local culture and declining cultural practices and associated knowledge. However, it appears that increased engagement with the tree continues regardless and could ultimately lead to higher levels of conservation. While there were no clear patterns of younger respondents being more likely to damage or chop down a marula tree in their yard, in both locations, the oldest respondent group had the least number of respondents who had damaged or cut a marula. This would suggest that either cultural attrition has been taking place for much longer than anticipated, or alternatively, the younger generations are involved in conservation practices to a greater degree than suggested by the older generation. In many households, as the older generation are gradually no longer able to collect and process the fruit, the baton has been passed on to the youth who have stepped up to learn the ways of marula. This has resulted in the transfer of not only knowledge, but also key cultural practices. Unfortunately, while this may result in the transfer of knowledge between generations, sustainable resource use only occurs as the combined result of intersecting beliefs, social values and ecological knowledge (Wolf & Moser, 2011). This means that while certain cultural practices around marula may continue, as well as the maintenance of certain valued trees in yards and fields, this does not necessarily ensure that marula conservation will continue into a new generation.

7.4.2 Resource concern: the reality of cultural conservation

Biodiversity conservation can be connected with the positive interactions that occur between communities and culturally valuable species, or whole venerated ecosystems (Cocks & Weirsum, 2014). A prime example is that of medicinal plants utilised by the amaXhosa communities in the Eastern Cape (South Africa), which leads to conservation based on the range of cultural uses attributed to these plant species (Cocks & Weirsum, 2014). The personal use of marula resources for medicinal purposes reinforces the cultural significance of the tree, with the treatment of ailments elevating the cultural capital of this resource. This additional capital possibly adds a further layer of protection from being removed or chopped down. Cultural values leading to marula conservation are not unique to South Africa, with subsp. *caffra* in Tanzania also being revered culturally in ancestral worship. This resulted in harvesting being previously prohibited (Luoga et al., 2000). However, as in the South African context, with the erosion of these cultural beliefs, the tree has begun to be harvested for both timber and handcrafts. As a culturally valuable species, marula trees can be argued to experience a degree of cultural conservation as a result of the reverence ascribed to them. This is specifically true in yards, where trees are utilised for a variety of cultural practices. The inherent cultural facets of natural resources, often lead to restorative ecological processes, including stewardship practices (Senos et al., 2006). As a result, respondents identified the biggest threat to marula trees across the three land-use types as the clearing of trees for settlement expansion. The future of trees not yet contained in yards hang in the balance, based on the unique mix of cultural and economic values held by the households who own the land on which these trees stand. With an ever-increasing human population, multiple respondents identified the plight of trees currently located on land still to be cleared for housing as being most at risk, specifically pertaining to the observed trend of declining marula numbers.

The majority of respondents indicated that they have witnessed increased levels of tree chopping across the land-use types over the past decade. In Bushbuckridge, 51.7% of respondents had witnessed increased levels of tree chopping, with 58.3% of Phalaborwa respondents indicating the same. Kirkland et al. (2007) looked at fuelwood shortages in

Bushbuckridge, with 80% of respondents confirming that diminished tree numbers were due to the cutting of live trees, while 17% indicated that residents chop live marula trees. The heightened levels of marula tree cutting in Phalaborwa were in turn met with higher levels of concern regarding marula trees in this context. Furthermore, respondents who were concerned about the difficulty of finding fruit due to insufficient fruit volumes were only one fifth as likely to use marula for fuelwood compared to those who did not share this same concern. In Phalaborwa, a quarter of respondents were concerned about the decreasing number of trees, compared with only a fifth of respondents in Bushbuckridge identifying decreasing trees as a cause for concern. Respondents in both locations confirmed declining fruit quantities over the previous five years. Interestingly, concern over declining fruit yield is expressed both in economic and cultural terms. Younger and middle-aged respondents generally expressed concern over how families would be supported, if crucial earnings are lost, along with declining marula fruit volumes. Older respondents expressed concern over the younger generation not being able to experience marula and its role as a cultural keystone species in the community in future. This reinforces what Reser et al. (2014) describe as experience and belief affecting and being affected by one another. In other words, the declining fruit quantities are not the primary concern of the older generation, who are no longer focussed on marula as a source of livelihood sustenance. These respondents are therefore more concerned by the decline in the customs and traditions that they have witnessed over the course of their lifetime. In contrast to this, the younger and middle-aged respondents are still largely the main breadwinners and therefore directly involved in the economies of scale pertaining to marula (Chapter 6). This makes respondents in this age category acutely aware of any changes in fruit abundance. While the limited number of concerned residents in both locations may seem counterintuitive, Mukherjee (2016) explains how ecological responsibility must not simply be confined to interrogating human-nature linkages. Understanding ecological responsibility therefore requires exploring the underlying contemporary capitalism (economic drivers) in addition to the life cultures (cultural drivers) that inform these interactions (Mukherjee, 2016). Underlying belief systems are therefore the key connection between environmental knowledge and pro-environmental behaviours. Rankoana (2018) confirmed how rural communities are quick to notice local environmental changes as their livelihoods, culture and social systems are all inextricably connected to the local environment.

In terms of cultural conservation, due to large female and male trees being respected culturally, they are more likely to be left in yards for cultural ceremonies. However, any cultural protection afforded to marula trees in either location do not extend to trees in fields and rangelands, as these are generally not used for cultural practices. This is an important component of cultural conservation, as it highlights the central role of space and place in the attribution of cultural value to certain components of the landscape (Lynn et al., 2013). Lynn et al. (2013) highlight the multi-faceted relationship that communities usually have with particular places and spaces. Landscapes contribute directly to cultural identity, with cultural values being based on constructs of both time and place (Stephenson, 2007). Given the lower cultural value of marula trees in fields, it is interesting to note the high proportion of fields with marula trees, 81% in Bushbuckridge and 86% in Phalaborwa. Despite over 80% of fields in both locations containing trees, numerous respondents voiced concern at the perceived number of fields without marula trees. Concern was also raised over the more abundant chopping practices taking place across this land-use type. Yet, very few respondents openly admitted to chopping a marula tree in a field themselves. This is likely as a direct result of it being unlawful to do so without a permit

from the Traditional Authority. This is an example of what Moser & Wolf (2011) refer to as the knowledge and awareness of personal impacts not being sufficient for action. This issue highlights the need for participatory management approaches for common property resource such as marula, in order to ensure sustainable practices are followed.

In fields, the economic value of the fruit is likely the main driver of conservation practices, although custodianship may be linked to Traditional Governance to a certain degree. While marula is a formally protected tree, many respondents identify trees in yards as being under the owner's jurisdiction, but field trees as belonging to the Induna. In Phalaborwa specifically, a higher number of fields were given to the owners directly by the Induna, which correlated with lower levels of tree cutting. This confirms that stewardship practices increase with secure land tenure (Bisong & Andrew-Essein, 2010). However, the fact that field trees are perceived as belonging to the Induna means the increased stewardship could also be classified as an indirect form of cultural conservation. This is due to the customary prohibition on chopping marula being adhered to in this context. Furthermore, this indigenous form of agroforestry, with mixed cropping and trees enhances biodiversity conservation. This is a prime example of species conservation occurring under a broader definition of cultural appropriation, which Cocks et al. (2014) advocate be included under the umbrella definition of biodiversity conservation linked to cultural value. Marula conservation in fields in Phalaborwa is therefore a prime example of combined intrinsic and extrinsic motivations (Bennett et al., 2018). Cultural beliefs and values are the intrinsic driver, with the external benefits of mixed cropping, including maximum crop and fruit yields, being the extrinsic motivation.

Despite the solid premise for marula conservation based on the cultural value of the species, this does not appear to be the complete reality of species conservation across the landscape. In reality, it would appear that tree stewardship practices increase with economic value and decrease with cultural value. In addition, this trend tends to confirm the hypothesis that the higher the commercial value of a NTFP, the more likely it is to be conserved (Arnold & Perez, 2001; Belcher & Schreckenberg, 2007). This is in contrast to Sinthumule and Mzamani's (2019) finding that the protection and conservation of marula trees in northern Limpopo are directly linked to the tradition and culture of marula. The authors note that in the villages where marula is protected, the tree is still more highly valued for its social, as opposed to financial role. In addition, marula trees in these villages have not yet been commercialised to the same degree as is in other parts of Limpopo, such as Phalaborwa (Sinthumule & Mashau, 2019).

Resource pressure, to a larger degree in Bushbuckridge, has resulted in a positive feedback loop with a higher social capital but a lower natural capital resulting in instability. This imbalance is due to a lack of other necessary capitals (such as financial) in the Bushbuckridge context. This has resulted in the overall system becoming unsustainable (Scholes, 2009). The result of higher reliance on natural resources, combined with higher human densities in Bushbuckridge, is likely responsible for reduced marula conservation practices. This is despite the combination of a stronger Traditional Authority and higher cultural associations with marula. While in theory the Traditional Authority's prohibition on chopping marula extends to those trees in rangelands, the reality appears to be very different. While previously being quite successful at regulating the use of common property resources, the authority of traditional leaders have been continually eroding, since the onset of democracy in South Africa after 1994. Importantly, traditional leaders were previously given a budget to hire crucial 'tree police' who could enforce local rules pertaining to tree chopping and harvesting (Kirkland et al., 2007). The depletion of fuelwood in

communal lands, despite the traditional law of only being allowed to cut dead wood is no longer feasible due to resource pressure. This has resulted in the extensive chopping of live trees illegally (Matsika et al., 2013; Findlay & Twine, 2018). In addition, marula trees in rangelands are the likely source of firewood as one of the remaining large, abundant trees in the landscape (Kirkland et al., 2007). The reality of marula depletion is therefore the unfortunate by-product of the daily necessity of resource pressures and limited availability of other fuelwood options (Madubansi & Shackleton, 2007; Mograbi et al., 2015). The key issue is whether the pockets of species conservation, mainly in yards, due to the combined cultural and economic value attributed to marula, are enough to counteract the daily realities of open access fuelwood harvesting in rangelands (Chapter 5).

7.4.3 Climate change impacts on marula: perceptions and behaviour change regarding fewer 'good' trees

When it comes to culturally significant species, communities are not only concerned about the impacts of climate change on the actual NTFP in terms of diminished livelihoods, but also the implications for important cultural relationships with the resource (Voggesser et al., 2013). Local perceptions of climate change impacts are informed by a range of structural, social and cultural factors (Weber, 2016). Cultural values that enhance interactions and understandings of nature can result in a heightened awareness of seasonal shifts or changes in phenology (Reser et al., 2014; Shi et al., 2015). While causal knowledge is likely to increase concern, this is provided it does not threaten cultural values. Wolf & Moser (2011) take this a step further by detailing how knowledge and even personal impact are not sufficient for action. While adaption behaviours are only likely to be taken by those who directly experiences climate change (Maddison, 2007), the greater the threat and closer the proximity to the impacts, the more likely behaviour change is to result (Hunter et al., 2010).

Studies exploring community perceptions about localised climatic changes, particularly from the perspective of vulnerability and adaptation practices are important (Rankoana, 2018). Specifically, these studies are necessary for understanding how changes are perceived as well as responses to these changes. Recent changes in rainfall and temperature will directly impact how communities perceive changes in weather (Moyo et al. 2012; Muita et al., 2016). It is for this reason that the rainfall and temperature data from the 10 years prior to this study were included, in order to understand general trends over recent years. The temperature and rainfall data from 2009-2020 highlighted the drought years and extreme temperatures in the three years (2014 – 2016) preceding this study (Archer et al., 2017; Siderius et al., 2018). This likely had a strong influence on the answers respondents provided, including the consensus around increasing temperatures and decreasing rainfall. While heightened cultural capital may result in examples of increased conservation in certain contexts, perceived or real threats to the resource base as a result of climate change, are key drivers of behaviour change (Reser et al., 2014). Therefore, understanding how communities perceive changes in both marula population structures, as well as the environmental or climatic factors influencing these changes, helps to uncover what informs behaviour change. Considering the large-scale collection of marula fruit across the resource landscape of the lowveld region, it is interesting to connect the social data around climate and environmental change with the ecological findings. Rankoana (2018) confirms how local indigenous communities often notice climatic changes, which are then confirmed by meteorological data. This is due to local livelihoods as well as cultural systems being closely entwined with the natural world. Changes in temperature and precipitation in

particular are crucial because of the direct link to livelihood sustenance. From the perspective of marula trees in semi-arid savanna systems, which are at the limit of their rainfall distribution, precipitation is a key environmental indicator (O'Connor & Goodall, 2017). Trees already at the edge of range provenance are likely to be severely affected by any further decreases in rainfall (Maranz; 2009). This vulnerability is compounded by harvesting pressure, especially the combination of bark, wood and fruit harvesting in a multi-use species such as marula (Gaoue & Ticktin, 2009).

When asked if they thought marula numbers have declined since 2000, the majority of respondents in both locations agreed that there are fewer trees now compared to ~20 years ago. Marula densities in rangelands around Bushbuckridge have indeed declined by 21.9% when compared to the 2005 study by Shackleton (2005). Considering rangelands are where the majority of fruit collecting takes place, the social data corroborate this ecological finding. The majority of older respondents in Bushbuckridge indicated that not only have marula tree numbers declined since they were younger, but also the number of female trees. However, there was divided opinion between locations regarding changes in juvenile numbers. This might be expected, considering the high juvenile numbers in yards across Bushbuckridge, giving the impression of abundant juveniles in this context. In contrast, the far lower juvenile numbers in Phalaborwa, confirm notions of scarcity. In Phalaborwa, there were strong perceived declines for all marula categories, with over 70% of respondents indicating decreases in the overall population, female trees and juveniles. Further, fruit volumes were also perceived to be in decline. This perception was strongest over the ~50-year timeframe, although the majority of respondents confirmed declining volumes over the previous five years as well. Those respondents indicating that fruit quantities have not declined attribute this to the specific chopping of only male trees for fuelwood. This finding is supported by the skewed gender ratios, with female biased populations occurring numerous times across the different land-use types (Chapter 4).

In addition to perceived decreases in marula numbers, the majority of respondents in Bushbuckridge (90%) and Phalaborwa (81.3%) indicated that temperatures have increased over the past ~20 years. Increasing temperatures over this period, for the Limpopo region of South Africa, have been indicated by numerous climate models (Tshiala et al, 2011; MacKellar, 2014; van Wilgen et al., 2015; Engelbrecht & Engelbrecht, 2016). Reser et al. (2014) highlight how the strongest evidence to support climatic changes, as noted by local respondents, is the consistency of reports of a similar nature across a particular region. Older respondents all reported the same climatic changes of higher temperatures and lower rainfall over the longer time period as well (~50 years). Tshiala et al. (2011) confirm temperature increases of 0.12°C per decade from 1950-1999 for this region. This data corroborates respondents findings of temperature increases in both Bushbuckridge (76.4%) and Phalaborwa (89.6%) over the past ~50 years or more. Temperature increases from 1980-2014 across South Africa have also been confirmed (Jury, 2017).

Fewer respondents in Bushbuckridge indicated that temperatures had increased, while more respondents in Phalaborwa confirmed temperature increases. This could be due to generally hotter and drier conditions in Phalaborwa, which have impacted respondent's perceptions about climatic conditions. Moyo et al. (2012) emphasise how recent bad years can affect how communities interpret weather severity. The 2014-2015 as well as 2015-2016 summer rainfall years were recorded as two of the driest consecutive seasons in Phalaborwa, possibly since

record keeping began in 1954 (Swemmer, 2016). In Tanzania, Msalilwa et al. (2013) compared locally perceived changes in rainfall and temperature, finding that these were in line with the local climate records for the region. African farmers are particularly adept at detecting climate change, with the strongest evidence of this accuracy being the consistent stories of change across the region (Maddison, 2007).

In Bushbuckridge, there was unanimous agreement regarding rainfall decline over the past ~20 (100%) as well as ~50 years (100%). In Phalaborwa, the majority agreed that over ~20 (91.7%) and ~50 year (95.8%) periods that rainfall has been steadily decreasing. The majority consensus around changing rainfall patterns lends credibility to the accuracy of the community's collective memory. Climatologists confirm localised changes in rainfall patterns, with generalised trends emphasising drier (in addition to hotter) conditions for parts of Limpopo, a region where endemic drought is only likely to worsen (MacKellar et al., 2014; Malherbe et al, 2014; Engelbrecht & Engelbrecht, 2016). An important rainfall trend observed by respondents is the occasional phenomenon of far more intense storms, when it does rain, which cause damage to both crops and property. This supports regional climatic projections, which indicate more intense storms for the north-eastern parts of South Africa (Engelbrecht et al., 2013).

When asked about the experiential aspects of rainfall levels decreasing and temperatures increasing, the majority of answers contained explanations regarding drought devastating arable food and vital cash crops. In addition, the direct result of lower rainfall and higher temperatures for many people was a decline in harvestable resources. A middle-aged woman from Lulekani (Phalaborwa) detailed her concerns thus: *"In the past, there would be the odd year where there was no rain. This was known as a 'hungry year.' Now, it has been a 'hungry year' for almost 4 years. The people are starving."* This lack of rain is a cause for huge concern as the marula tree is a source of livelihood sustenance for many people. A young woman from Rolle (Bushbuckridge) expressed her apprehension, in terms of livelihood loss, as follows: *"Families do not work around here, they rely on the tree for their whole income. How will they support their families if the rain stops and there is not enough fruit?"* These concerns stem from changes in climate causing tree numbers and fruit quantities to decline, or at best creating 'bad' quality fruit for making beer.

Living directly off the land, specifically for respondents such as farmers, can lead to pessimistic attitudes in terms of weather changes (Moyo et al., 2012). In particular, recent changes over previous years, or big weather events, have the greatest impact on how respondents interpret local climatic changes. However, where households can no longer grow arable crops, the cause for concern is extremely valid. For many, the loss of livelihoods through declining marula fruit quantities are often connected to feelings of cultural erosion. The climate change impacts that most concerned respondents in relation to marula trees, were often explained as issues of cultural deterioration. This was specifically prevalent in the more peri-urban villages. Also known as cultural fragmentation, this can be viewed as a mirror to reflect environmental degradation (Kaschula et al., 2005). Rankoana (2016:677) confirms how climate change is often explained "in terms of a cessation of cultural activities as well as livelihood patterns." In the Limpopo context, this cessation incorporated the brewing of traditional beer as well as the first-fruits ceremony (Rankoana, 2016). This finding is based on the fact that communities often make sense of experienced environmental changes through socially constructed lenses (Kaschula et al., 2005; Riley & Harvey, 2007). For example, a decline in an environmental

variable such as rainfall can lead to declining numbers in large marula trees, which are unable to withstand numerous drought years (O'Connor & Goodall, 2017). While respondents attribute declining tree numbers to drought, these decreases are also interpreted symbolically as owing to the decline of local culture. Respondents will therefore explain in parallel how the ancestors are being neglected, meaning they no longer send the rain, which is needed by the larger trees to survive. Marula trees in communities are an essential part of the cultural landscape, with numerous respondents comparing these trees to people. This is not surprising considering how closely connected social and environmental issues are in these localities (Riley & Harvey, 2007). Many of the elders interviewed in this study compared the bigger, and thus older, marula trees to their own generation, saying that like their generation these trees are dying off (or being chopped down) and soon will be no more. And because the youth are blamed for the degradation of culture, they are also fingered as the ones responsible for removing the large marula trees. As one old woman from Selwane (rural Phalaborwa) explained: *"If you have money then you chop the tree to build your house, but if you have knowledge then you will build your house around it."*

An elderly woman from Mbaula (Phalaborwa) made sense of the variability in tree numbers as follows: *"Marula trees are like people, they are born and they die, but they are always around."* Oral histories are one such way to understand these changes, where the lived concept of place is expressed through the cultural lens of environmental change (Riley & Harvey, 2007). In this sense, the culture of marula can be understood as a form of social identity. Respondents relate the life and death of the tree as a result of drought, to social cycles of cultural decline and loss of meaning, particularly as a result of cultural erosion. For example, what Anderson (2016:23) refers to as "weathering loss" is a social construct, built around the enduring hardship and resilience required to deal with a changing climate by those living directly off the land. This causal knowledge is likely to increase environmental concern, provided it does not conflict with cultural values (Wolf & Moser, 2011). The almost total agreement that rainfall had decreased across both locations in recent decades, with the clear majority agreeing that temperatures have also increased concurrently, lends credence to the work of authors who promote combining social and ecological (or climatic) data in order to improve overall data accuracy (Boillat & Berkes, 2013; Bomuhangi et al., 2016; Reyes-Garcia et al., 2016; Rankoana, 2018).

A theme that came up repeatedly in the social data is a specific form of concern for marula trees, in particular the 'good' marula trees. These are usually older, larger trees that are known for being prolific fruiters. Chirwa and Akinnifesi (2008) confirm that larger, and thus older trees are usually the more important seed sources. It is usually older trees that provide the most fruit, with these larger individuals traditionally being located in yards (Chapter 5). While the mean densities of large adults were higher in yards in Phalaborwa and Bushbuckridge, the proportion of the population that were large adults were higher in rangelands (Chapter 5). In addition, older trees are more susceptible to sustained drought conditions (O'Connor & Goodall, 2017). Authors such as Patrut et al. (2018) have linked drought conditions with mortality in the largest baobabs across Africa. With possible declines in the numbers of these prolific fruiters in marula populations due to either drought, human removal or both, it is perhaps unsurprising that many members of the community have asked: *"Where have all the 'good' trees gone?"* However, this question is multi-faceted because this also refers to perceptions around declining tree or fruit numbers in rangelands, where the majority of the fruit is collected. These perceptions are further compounded by previously productive trees producing less fruit, as well as phenology

changes causing fruit production outside of the usual marula season. With both these impacts likely being as a consequence of climate change. In addition to this, the water content of the fruit is a key factor in terms of qualifying what is a 'good' as opposed to a 'bad' tree for making marula beer. Slightly higher water content is considered the ideal for making marula beer. The three years preceding this study from 2014 - 2016, were classified as average to below average annual rainfall for the region (Archer et al., 2017; Siderius et al., 2018). With continued observable decreases in rainfall over recent years, many respondents felt that climate change and specifically poor rainfall, were responsible for the disappearance of the 'good' trees.

Over the past ~50 years, the majority of respondents in each location also indicated a perceived decline in both marula tree numbers, as well as marula fruit quantities. Venter & Witkowski (2013) highlight rainfall as a key impediment to baobab recruitment. While there have not been any definitive studies confirming similar patterns in marula trees recently, local communities in both Phalaborwa and Bushbuckridge indicate that the lack of rain is responsible. In terms of the impacts on larger trees, respondents observed noticeable changes, giving a two-fold explanation as the basis for large tree disappearance. The first relates to visual queues pertaining to the overall appearance of marula trees. Trees perceived to be impacted by drought are described as being 'dry', a concept that relates to the brittle nature of the wood, which supposedly burns faster than the marula wood from a tree that is not 'dry.' In addition, 'dry' trees are also considered to be generally unhealthy, with yellow leaves and bad tasting fruit that lacks sufficient water content. In extreme cases, 'dry' trees produce far less fruit, or none at all. These trees are often cut down in yards, as they are a risk to buildings, as they purportedly fall over easily causing damage. When asked if these trees are actually dead when they fall, respondents took care to explain that many of the trees are still alive. However, these trees are considered to be 'unhealthy' which results in various insect infestations. These infestations cause the trees to ultimately die, or fall over due to the brittle nature of the wood. den Adel (2002) confirms that marula is considered a soft wood which is likely the reason it decays easily, with respondents indicating it is not ideal for making items such as wooden utensils.

The second mechanism for explaining large tree disappearance is one of experiential reinforcement. This is based on respondent's ability to navigate across the landscape to the best fruiting trees, season after season. Respondents can identify exactly where key fruiting individuals are in relation to any point on the landscape and if they provide more or less fruit than 'normal' during a particular season. Respondents claim that in recent years, they have returned to the rangelands the following marula season only to find that some of these key fruiting trees have vanished completely from the landscape. Respondents then need to locate new collecting grounds with 'good' fruiting trees, a collection strategy that is reported to be increasingly difficult as overall numbers continue to decline. In reality, some of the 'good' trees probably become less desirable first in terms of their fruit turning 'bad', once it becomes too dry and therefore unsuitable for beer making. When asked if these key trees are not perhaps being chopped down, respondents indicated that people know where the best fruiting trees are located and would not chop them for firewood. Respondents suggested that marula trees can tolerate a few bad dry seasons but after that they simply get drier and drier until they eventually fall over and are collected for firewood, leaving no trace of their existence in the landscape. Forest communities in Tanzania (East Africa) altered their resource reliance strategies in response to increases in temperature and rainfall variability directly impacting the resource base of key NTFPs (Msalilwa et al., 2013). The sentiment of marula trees dying due to drought is

summed up by a very elderly woman from Mbaula (Phalaborwa), who explained how in her experience: *"The drought is killing these trees, they survive for a few years but after that they just start dying."*

When asked about fruit availability, many community members answered as though the current season encompasses two years. Respondents would refer to a marula season occurring two years prior as being the 'previous' marula season. This response makes sense in light of Shackleton's (2002) finding that rainfall from one season, affects the fruit production of the following season. Fruiting in marula is linked to soil moisture content, which in turn is linked to the previous rainy season (Shackleton, 2002; Helm, 2009). Combining ecological data with social explanations helps to uncover this local understanding of the concept of what constitutes a 'current' season, with many people considering marula seasons to run in two yearly cycles. Due to many respondents understanding seasons as pairs, when asked if they are currently collecting fruit, the answer was given in the affirmative, even if they only previously collected the year prior to that. When asked about fruit availability over the past five years however, the consensus in Bushbuckridge (71.7%), and Phalaborwa (62.5%) was overwhelmingly that fruit yields have declined.

It is interesting to therefore note whether the described perceptions around a changing climate and the potential impacts on marula translate into behaviour change practices. In Bushbuckridge 75.8% of respondents said they were worried about the current status of marula populations, but only 51.6% of respondents in Phalaborwa indicated the same concerns. These levels of concern may be directly linked to perceptions around fruit availability. Decreasing fruit drop was identified as the greatest cause for concern in both Bushbuckridge and Phalaborwa, followed by declining tree numbers. It is worth noting that decreasing fruit drop should garner greater levels of anguish, as it links concern for marula directly to the cultural and financial ecosystem services that the tree provides, through the provision of fruit (Bennett et al., 2018). In response to these environmental concerns, many respondents mentioned measures to adapt to the current changes in marula population structures. The main approaches employed by respondents at present are to adapt current collection strategies to incorporate new collecting grounds in their village rangeland, expand collecting ranges to cover a larger area, or to utilise the rangeland of a neighbouring village. Planting trees was generally not mentioned as a possible adaptation strategy. This is potentially due to the longer time-frames required to obtain the benefit of additional fruit. However, a few respondents indicated that if the drought continued they would need to start watering their yard trees. Maddison (2007) highlights how climate change perceptions are likely to change when the direct impacts are more severe and thereby warrant intervention, meaning a sudden decrease in fruit availability is likely to raise greater levels of concern.

7.5 Conclusion

Marula is undeniably recognised as a culturally significant tree by local communities in Phalaborwa and Bushbuckridge, centred within a complex web of social and human capital transactions. Occurrences of marula conservation, based purely on cultural value alone, are difficult to delineate, with cultural and economic values often existing in parallel to create pockets of conservation practices. In particular, the higher cultural capital attributed to the female tree as the bearer of the highly valued fruit, creates instances of species conservation. This is reinforced by cultural practices in yards, which work to amplify the value of marula

across this land-use type. Traditional families protect adult trees in yards as the 'house of the ancestors', although residential land clearing has diminished the number of large trees across this land-use type in recent years. This is profound in light of Sinthumule & Mzamani's (2019) finding that the protection and conservation of marula trees in northern Limpopo are directly linked to the tradition and culture of marula. In Bushbuckridge and Phalaborwa, the on-going erosion of culture and the breakdown of customary law, in addition to traditional authorities no longer actively policing the chopping of marula, have resulted in commercial interests largely replacing the cultural value previously attached to marula. Participatory management approaches that include local traditional authorities in governance hierarchies are both a viable and necessary solution to reduce unsustainable resource practices. Respondents identified increasing temperatures and decreasing rainfall over approximately 20 and 50-year timeframes as negatively impacting marula populations. These climate changes are linked to declining tree numbers, fruit yields and loss of larger key fruiting individuals. While responses to these concerns included adaptation of fruit collection strategies; tree stewardship practices such as decreased cutting or increased planting, did not feature prominently. However, local environmental knowledge around aspects of marula, such as gender differences was high. Yet, this did not always translate into sustainable resource choices, with male trees often removed from the population. Awareness and outreach campaigns, especially in schools that teach the key role of male trees for pollination purposes may help to ensure knowledge leads to conservation. However, considering the role of beliefs in informing action, local cultural practices need to be nurtured and supported in tandem with education. Unless these issues are addressed, the erosion of culture combined with increased resource harvesting pressures, are likely to cause on-going biodiversity losses (Luoga et al, 2000). Without understanding the pluralistic and multi-level nature of community-based conservation, approaches that do not address local heterogeneity will fail (Berkes, 2007; Khalid et al., 2013).

At present, marula can best be described as a species caught between values. As the cultural value of the species appears to generally be on the decline; the economic value of the species is on the rise. Local community programmes that encourage the mutual sharing and learning of practices that build social capital should thus be strongly encouraged by local authorities. Considering the importance of integrating indigenous knowledge with scientific findings, in order to understand conservation requirements, these results speak to the importance of a pluralistic, cross-cultural conservation ethic if marula is to remain a sustainable natural resource (Berkes, 2003). This is perhaps the best example of the variable consequences of cultural conservation, highlighting that while cultural values may be eroding, certain traditions may in fact be growing. While it might seem obvious to try and separate the cultural and economic values of marula, it is perhaps the nuanced combination of these values that are ultimately leading to pockets of marula conservation. Research methodologies that combine the ecological and climatic data with local perceptions around environmental changes, such as this study, are valuable in understanding contexts that exhibit complex resource use practices and reliance patterns. Additionally, approaches that incorporate nuanced understandings of cultural practices in a modernising society, may be best suited to identify future opportunities for up scaling the benefits of these practices. However, any proposed solutions need to be cognisant of the fact that culture is fluid and so practices that may either be beneficial or detrimental to marula are likely to be continually evolving and shifting as cultural practices change. This is not just relevant for marula conservation, but is pertinent for the wider socio-economic benefits of communities utilising keystone cultural, economic and ecological species.

8. Synthesis: Importance of Linking Ecological and Social Data to Comprehensively Explain Resource Use in Complex Socio-Ecological Systems

8.1 Introduction

Biodiversity losses from biophysical changes to the natural environment are accelerating; brought about by anthropogenic factors including land cover change and intensive resource harvesting (Mograbi et al., 2015). Mitigating these losses requires understanding the current status of natural resources across various socio-ecological systems. This is the crucial first step in ensuring long-term resource sustainability (Partelow & Winkler, 2016). The second step involves understanding the underlying socio-economic drivers of change. Biodiversity losses at the landscape level, caused by land cover changes in vegetation, are most apparent in human modified environments. This results in spatial differentiation, due to selective and therefore uneven removal of species across these landscapes. Over time, this causes loss of biodiversity within ecosystems, specifically in landscapes heavily utilised by humans. Changes to woody vegetation usually occur on two levels, with resource removal at the landscape level resulting in large-scale alteration of the resource base, while resource harvesting has a direct impact on individual species, which are targeted for specific resources. Resource harvesting can therefore impact negatively on local species populations, which collectively aggregate up to changes in resource availability and the structure and composition of ecological communities. In severe cases, these cause depletion of the resource overall.

At the resource level, resource harvesting and utilisation practices usually impact tree-based resources and vegetation negatively, specifically multi-use natural resources Multi-use tree species are utilised for a variety of natural resources including fruit, bark, wood, leaves and roots. Overharvesting impacts overall population structures, resulting in mortality and declining woody vegetation cover, as a result of increased damage, skewed gender ratios, diminished recruitment and missing size classes (Shackleton et al., 2002; Shackleton et al., 2003; Shackleton & Shackleton, 2005; Twine, 2005; Emanuel et al., 2005; Wynburg & Laird, 2007). The above two steps lead to the crucial third step, which is to understand interactions between the social and ecological components in order to gauge overall changes to the socio-ecological system. Essentially, the key question is how are ecological systems changing in response to human activity and in turn, how do human change agents react and adapt to shifting resource availability? It is exactly the complexity of these two-way interactions that led Farina (2000) to refer to socio-ecological systems as cultural landscapes. Cultural landscapes are defined as: "geographic areas in which the relationships between human activities and the environment have created ecological, socio-economic and cultural patterns and feedback mechanisms" (Farina, 2000:313).

Human-inhabited savannas are examples of key socio-ecological systems across the lowveld region in South Africa. The combined social and ecological components of these systems make them a perfect example of a cultural landscape. Understanding how users in this context value a

key natural resource, such as marula, is necessary to gauge its complete value nexus. In addition, perceptions of how essential, scarce and depletable the resource is are crucial parameters for assessing the ecological findings (O'Connor, 1993). Utilising social and ecological data in tandem to verify findings on both sides of the ontological fence, allows for reduced uncertainty. This provides a higher degree of confidence that proposed solutions are viable in securing sustainability of the system as a whole. In this study, the first step was to understand the marula resource status, and the second to uncover the socio-economic drivers affecting marula populations across land-use types. The final step was to identify linkages between the social and ecological components, to assess and understand the overall stability of the marula bioeconomy catchment.

8.1.1 Marula resource use in socio-ecological systems

Marula is an example of an iconic species that is ecologically important, economically valuable and culturally significant. Exploring the marula bioeconomy as a complex socio-ecological system requires moving beyond identifying social and ecological variables within the resource system. This ensures the examination of the boundary, or eco-social interface, where social and ecological variables intersect (McGinnis & Ostrom, 2014). To do this involves comparing ecological indicators, being aspects of the marula population, with variables shaping these outcomes across the embedded socio-economic context. The social variables here pertain to human choices around marula resource use and practices.

In this study the eco-social interfaces, where ecological and social variables connect, are the harvesting practices and resource use choices across the land-use types of yards, fields and rangelands. These points of intersection are important according to complexity theory, as this is the site of the adaptive innovation and self-organisation that drives shifts within the system (Schneider & Somers, 2006; Uhl-Bien et al., 2007). The points of eco-social intersection become apparent after layering the social data (responses from 240 individual household interviews and informal focus group discussions, Chapters 6-7) with the ecological surveys (population data for 5832 marula trees, Chapters 3-5). Finally, here in chapter 8, the social data is used to contextualise and explain the ecological indicators, highlighting the insights gained from combining quantitative and qualitative data in order to understand the complete socio-ecological system. The social data expands the ecological findings by providing place-based contextual narrative to explain why changes are likely to be occurring. This is based on the human and cultural practices transforming the landscape. In addition, the social data also allows for informed interpretation of the resource demographics, to fully understand how land-use practices and resource use choices impact the marula population.

Various socio-spatial changes in marula population demographics were explored in this study, by linking different land and resource use choices, with the social factors shaping these changes. Socio-spatial perspectives assume that space operates as both a product, and a producer, of changes in the natural environment. Marula demographics were analysed across eight surveyed villages, divided equally between Bushbuckridge and Phalaborwa, in the lowveld region of South Africa. The major spatial differences between these two locations are variations in soil, topography and climate, with Bushbuckridge being on the wetter end of the rainfall gradient. Culturally the communities also differ, with Bushbuckridge being predominantly Shangaan (Tsonga), while Phalaborwa has Tsonga and Pedi communities. In Bushbuckridge, almost one quarter of the population derive from a former-Mozambican refugee community (Shackleton, 2000; Mograbi et al., 2015). Likewise, Phalaborwa also hosts a former-Mozambican refugee

community. Phalaborwa has a clear rural and peri-urban distinction between villages, while higher population densities and limited communal land availability in Bushbuckridge make this distinction less apparent. In both locations, land availability is at a premium, exacerbated by on-going residential expansion into the already limited rangeland. It is important to note that there are multiple points of intersection between the ecological and social variables in complex socio-ecological contexts. In this study, the most profound changes became apparent when examining the impacts of the economic and cultural values ascribed to marula at a land-use and settlement level. Specifically, this study uncovered the degree to which marula demographics are influenced and shaped by the economic, and cultural values, of the communities utilising this resource.

The current status of the marula resource was determined by exploring population structure, determined by examining six key ecological indicators: population density, size class distributions, mortality, maturity ratios, damage, and gender ratios (Figure 8.1). The resource is embedded in a complex socio-ecological context, in which numerous household economics (income savings and income generating activities) and cultural drivers (cultural practices and immaterial benefits such as social capital) impact the resource (Figure 8.1). The two-way interactions between socio-economic and ecological elements of the system mean that the marula bioeconomy is both adaptive and co-evolving. Essentially, the status of the resource base is impacted by the socio-economic context and in turn, the socio-economic context is continually impacting and shaping the resource base. Over time, the nature of these interactions determines the sustainability of the marula bioeconomy catchment.

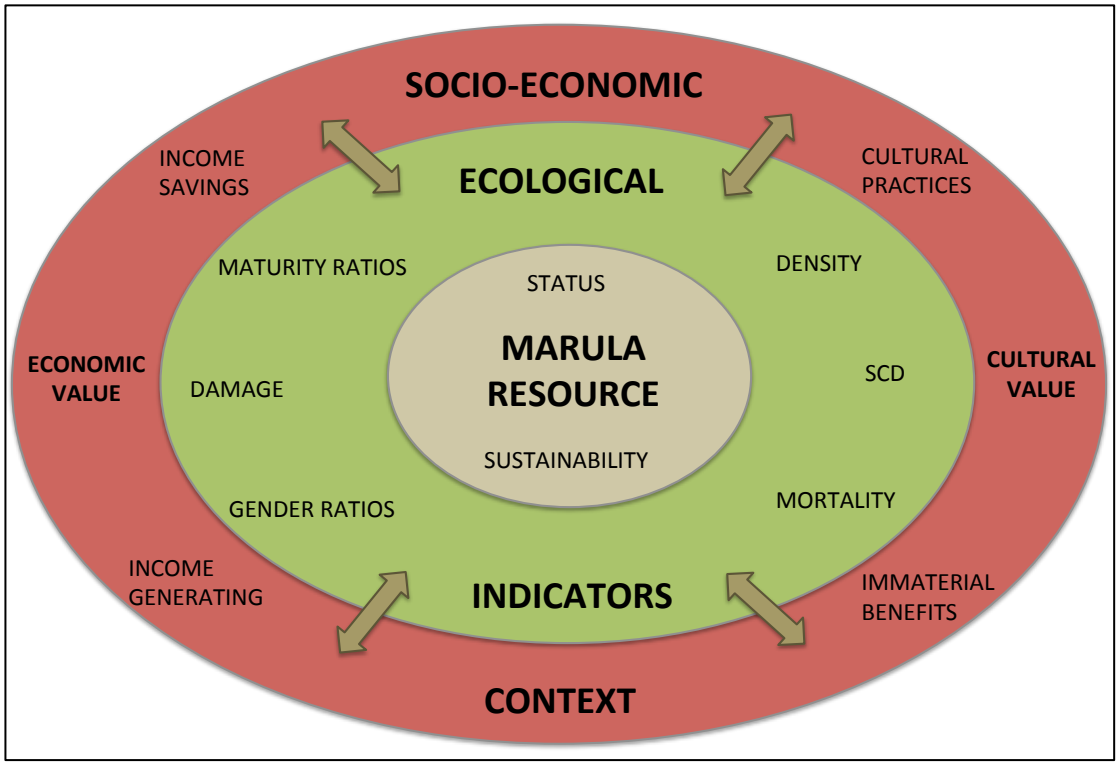


Figure 8.1: Summary diagram of the marula bioeconomy, showing the ecological indicators used to determine the current status of the resource, embedded in a socio-economic context. The sum total of the two-way interactions between the socio-economic context and the resource determine resource sustainability. (SCD=Size-Class Distribution)

The six ecological indicators were compared across three land-use types (yards, fields and rangelands) in the non-conservation savannas of Phalaborwa and Bushbuckridge. Across the three different land-use types, different human behaviour patterns and choices have resulted in different marula demographics, driven by a range of social and economic factors. Harvesting behaviours represent the first level at which marula, as a natural resource, experiences human disturbance. This relates to fruit harvesting impacts (collection of ripe fruit under the female tree) as well as the chopping of branches (either for fire wood or to obtain the green fruit to sell). The second level of human disturbance to the species is at a landscape level and relates to the large-scale removal of the natural resource from the system altogether. This is either as a result of chopping marula trees to make space in yards to build houses, in fields to plant crops or in rangelands where trees are felled for fuelwood and specifically fuelwood markets.

Across yards, fields and rangelands the ecological indicators verify if the natural capital status of the marula resource is robust, and thus the resource use sustainable. The social variables are the behaviours or choices around marula use and value, which either compromise, or alternatively strengthen the overall sustainability of the resource. This relates to both the social capital, or cultural significance attached to the resource, as well as the financial capital, which is the subsistence income derived from the resource (Deutsch et al., 2003; Rolfe, 2006). It is possible to trace the extent of shifts within the system by observing transfers between the different stores of capital, based on marula as a key resource. Marula contributes to various forms of livelihood capital. The first is financial capital: income from marula fruit, nut and beer sales, as well as entrepreneurial skills. The second is social capital: sharing of marula beer and the local ethic of reciprocity, cultural rites and rituals, reinforcement of local institutions and legitimisation of leaders. Third there is human capital: health (medicine), nutrition and food security. Lastly is natural capital: tree stewardship practices including planting, watering, retaining trees as well as a selection of favourable genotypes/forms of domestication.

Understanding the magnitude of changes within the system can best be assessed by exploring the cultural and financial capital stores of marula, as well as how these stores are depleted or regenerated. High economic worth can lead to either active conservation (such as on private land with strong and secure tenure rights) or alternatively, to over-exploitation in poorly governed common property areas and open-access systems. In other words, the extent to which marula is conserved, or not conserved, is a measure of various aspects of marula's cultural significance and economic worth. In addition, it is important to remain conscious of how these values compete with the everyday realities of space requirements for building or planting, as well as the daily pressures of fuelwood harvesting needs. Essentially, are the inherent social, financial and human capital stores of marula sufficient to increase the natural capital of this species, resulting in its overall conservation?

Applying an SESF approach to marula bioeconomy catchment, the resource system is the savanna, the resource units are the marula trees, the governance system are the local traditional authorities, and the resource users are the communities and companies who are off-takers of the resource. While interesting to note differences regarding the resource units (marula) within the resource system (savanna) at the two marula-dependant locations (Phalaborwa and Bushbuckridge), it is rather the similarities that speak to the pervasive and enduring characteristics of marula, regardless of context. Exploring the SES of the lowveld marula bioeconomy catchment has produced some unexpected findings regarding the sustainability of marula as a key natural resource. The results provide insights into the behaviour patterns

behind resource depletion, as well as how ecological traits lead to social misconceptions, which in turn drive behaviours that are unsustainable.

While these insights and lessons have been generated in the context of the marula bioeconomy catchment, the lessons provided are widely applicable. Specifically, the marula bioeconomy can be used as a blueprint for certain other rural contexts in developing countries, where NTFP resource use and reliance sustain millions of the poorest in the population. This bioeconomy model will be especially useful where the NTFP resource provides a key source of supplementary income as well as being valued culturally. With accelerated global change and climate impacts, it is necessary now more than ever, to interrogate drivers of sustainable resource use for a variety of developing country contexts (Biggs et al., 2015; Sunderland et al., 2017). This necessity is based on the fact that NTFP form the basis of numerous socio-economic systems (Arnold & Perez, 2001), thereby helping to maintain livelihoods and driving sustainable development agendas (Shackleton et al., 2007; Dovie, 2009; Heubach et al., 2011; Shackleton et al., 2011; Shackleton et al. 2011). In the face of climate change and on-going resource degradation as a result of human utilisation patterns, understanding natural resource use, reliance and resilience has never been more relevant, or more pressing (Berkes, 2003). In addition, it is important to note that the key findings from the marula bioeconomy are relevant lessons for other context in which key NTFP resources forms the basis of a crucial socio-ecological system (Berkes, 2007; Khalid et al., 2013).

NTFP usage and biodiversity conservation require nuanced management approaches to both harvesting and resource utilisation, which need to be based on the actual harvesting and management practices applied by local communities (Ticktin, 2004; Ndangalasi et al., 2007). The fact that marula is not just economically valuable but is also culturally significant, means that lessons from the lowveld context can be applied wherever a natural resource sustains both livelihoods and communal structures. As a multi-use resource, which not only contributes to local human resilience, there are also important lessons to be learned from marula's growing status as a commercially viable product in long and complex supply chains (Marshall et al., 2003; Sunderland et al., 2004; Shackleton et al., 2005; Shackleton et al., 2007; Dovie, 2009; Shackleton et al., 2011). In particular, this study has explored what shifts in the economic and cultural spheres mean for marula in terms of long-term sustainability. Finally, this chapter examines how these lessons can be applied in other contexts to develop robust systems in an increasingly uncertain world.

8.2 Linking Social Narratives with Ecological Indicators: How Land-Use and Resource Practices Influence and are Influenced by Marula Populations

Applying Ostrom's (2009) SESF to the marula bioeconomy catchment, it is interesting to note the patterns uncovered by linking the ecological indicators with the socio-economic factors driving ecological changes. The social drivers identified as having the greatest impact on marula population demographics are human land-use practices, followed by resource choices. This means that the ecological and social variables intersect at the eco-social interface of land-use practices and resource choices, within the cultural landscape of marula utilisation. Across yards, fields and rangelands, specific land-use patterns alter these landscapes, which in turn drive changes in marula population demographics. The marula resource use practices identified in this study are informed by the economic and cultural value of the marula resource across the various land-use types. As natural resource bases are degrading internationally, it is becoming increasingly more critical to understand resource management at the local level (Polasky, 2008;

Mooney et al., 2009). Central to the SES research agenda are analytical contributions that drive transformative change processes (Partelow & Winkler, 2016). This research was intended to respond to requests by authors such as Kaschula et al. (2005), to combine hard-system scientific approaches with soft-system methodologies for tackling human complexity in ecosystems.

Applying a SES framework to marula, it is possible to see that the resource units, the individual marula trees, appear to be declining within the resource system of non-conservation savanna landscapes. This is due to overutilisation by the resource users (the community members), combined with weak traditional governance structures. Strong traditional governance structures are required to rectify misconceptions around the sustainability of marula (Chapter 7). Kirkland et al. (2007) confirm the negative consequences on NTFP resources, such as marula, of diminishing traditional authority and customary law. Marula is a NTFP resource embedded in a context of both complex challenges as well as drivers of resource degradation. This complex web of engagement with the marula resource base is driven by factors such as cultural attrition (with its associated shifts in value systems), poverty and resultant resource reliance, land shortages, tenure (in)security, the contested role of hereditary chiefs in a modern democracy and the degree of agency of citizens in a young democracy. Cultural attrition is a process that occurs over time, as traditional values are slowly lost, along with an aging older generation. Cultural attrition is further exacerbated by the extreme poverty of the marula- reliant communities in Phalaborwa and Bushbuckridge, with the economic value of the resource taking precedent in the struggle to sustain livelihoods. Cultural and economic drivers are further influenced by local land-use factors, such as land shortage and insecure land tenure. Land shortage increase resource pressure due to a larger strain being placed on the available resources, while insecure land tenure is usually accompanied by diminished resource stewardship, due to a lack of custodianship over the land and resources contained therein. While the cultural taboos surrounding the chopping live trees, and specifically marula as a protected tree (National Forestry Act, 84 of 1998) work to conserve the resource base, these are enforced by a system of hereditary chiefs whose power base is declining. Contestation over the demarcation of governance roles between local Government structures and chieftainships has resulted in a dilution of local power, meaning that customary law regulations are not enforced (Findlay & Twine, 2018). Further, the agency of voters in a young democracy means that the once supreme rule of local chiefs are being challenged by the concept of individual rights, which include common property access and rights to communal resources. All of these challenges and drivers both exacerbate, and are exacerbated by, the perceptions of local resource users, some of which result in misconceptions towards the resource base.

Marula trees were identified by survey respondents as being most at risk from settlement expansion and overharvesting. The large-scale removal of rangeland trees for fuelwood markets can be particularly damaging to the resource base (Madubansi & Shackleton, 2007, Matsika et al., 2012). Across all three land-use types, the main drivers of these changes are economic in nature (Chapter 6). These economic drivers manifest in the building or extending of houses in yards, planting crops in fields or energy (fuelwood) requirements in rangelands. However, these drivers are underpinned by various perceptions (key human value judgements) and sometimes misconceptions about the resource. An example are the varying perceptions towards male trees, which are often considered to be less socio-economically important (value judgement) than the female tree as they do not yield fruit. In addition, the importance of the male trees for reproduction are not always clearly understood, resulting in the misconception that these trees

can be felled (Chapter 4; Shackleton et al., 2003). There are four ecological traits of marula that have lead to specific perceptions towards the tree, with certain misconceptions resulting in negative resource practices.

The first social perception is that marula roots pose a threat to building foundations, while the branches of larger individuals are considered a risk to building roofs (Chapter 3). While roots and branches close to buildings do indeed pose a risk, which confirms this perception, this concern is taken to an extreme in many instances with large trees being removed even before a new building is erected. This is where the perception becomes a misconception, as large trees not located anywhere near a building are unlikely to cause any damage. The second perception is that male trees are 'barren', with the accompanying misconception being that these trees are unnecessary, other than as a possible source of fuelwood (Chapter 4). This means male trees are selectively ring barked, or felled and uprooted in yards and fields, to make space for buildings or crops and felled for fuelwood in rangelands. These behaviours are based on the value judgement that these trees have little economic value (Shackleton et al., 2003). The third perception is that due to juveniles germinating easily in yards and fields, these individuals are considered superfluous (Chapter 5). While juvenile numbers are indeed numerous, the misconception is that it is therefore not harmful to the overall population to remove these in large quantities. As a consequence, large numbers of juveniles are removed under the erroneous assumption that such an action will not impact the wider population. The fourth perception by communities is that trees in rangelands are being sustainably harvested (Chapter 6), yet due mainly to their strong coppice trait, this is often a misconception which results in unsustainable harvesting (Kaschula et al., 2005; Chidumayo, 2002; Neke et al., 2006).

The main ecological findings in Phalaborwa and Bushbuckridge, in relation to marula density gradients, the SCD slopes, gender dominance across land-types, maturity prominence by land-use types as well as trends in mortality and damage are displayed in Figure 8.2.

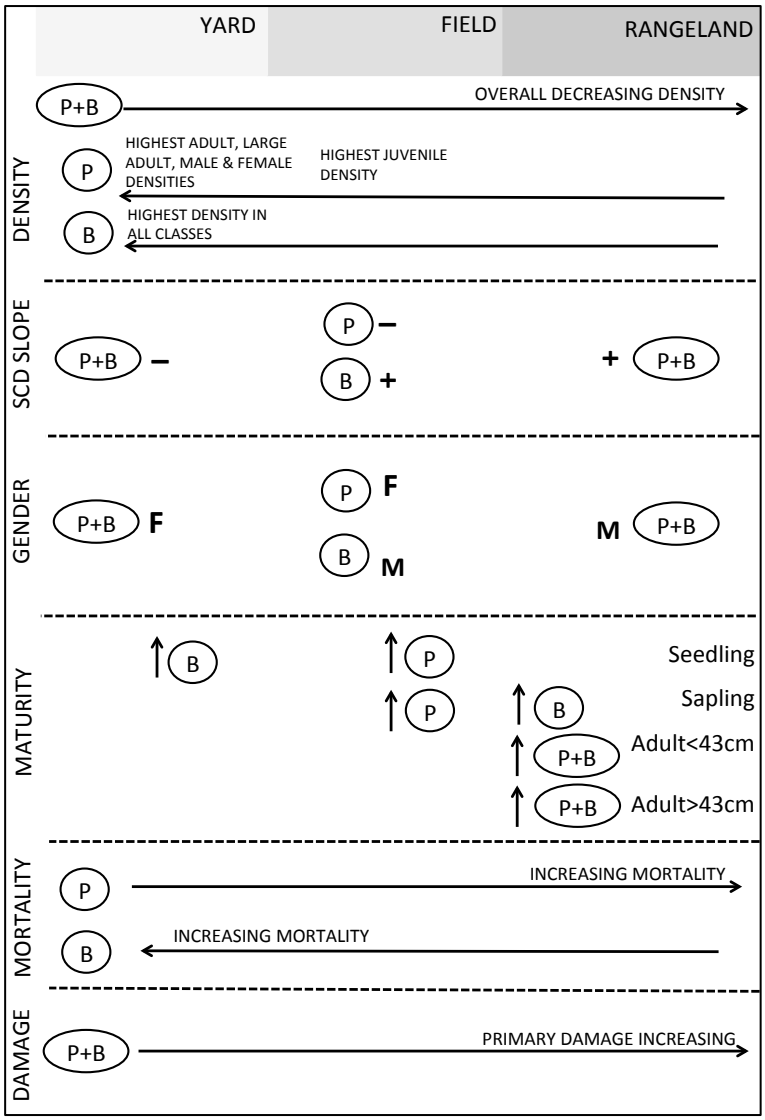


Figure 8.2: Infographic detailing the main findings in relation to marula density gradients, SCD slopes, gender dominance, maturity prominence as well as mortality and damage patterns by land-use types (Location: Phalaborwa= (P) and Bushbuckridge = (B); Gender: Male = (M) and Female= (F); SCD: Positive Slope = (+) and Negative Slope = (-); ↑= Location + Land-use where maturity class highest; ←→ = Increasing/Decreasing trend)

In terms of mean density, overall density was highest in yards in both locations and decreased through fields and rangelands (Chapter 3). In contrast, adult, large adult, female and male densities were all highest in yards in Phalaborwa with juveniles highest in fields (Chapter 4 and 5). In Bushbuckridge, all the density classes were highest in yards (Chapter 3). SCD slopes were negative in yards for both locations, suggesting strong recruitment but positive in rangelands, indicating the opposite. In addition, Bushbuckridge also had a positive slope in fields, while in Phalaborwa fields displayed a negative slope (Chapter 3). Yards displayed female-dominated populations in both locations, while rangelands were male dominated (Chapter 4). Bushbuckridge also had male biased fields, whereas fields were female biased in Phalaborwa (Chapter 4). In both locations, adult and large adult populations were highest in rangelands, saplings were also highest in rangelands in Bushbuckridge (Chapter 5). Saplings and seedlings were highest in fields in Phalaborwa, with yards containing the highest number of seedlings in Bushbuckridge (Chapter 5). Mortality increased across the land-use types from yards to

rangelands in Phalaborwa, while the opposite trend occurred in Bushbuckridge with mortality increasing from rangelands to yards (Chapter 3). In both locations, primary damage increased along the human-impact gradient from yards to rangelands (Chapter 3).

8.2.1 Linking land-use practices with temporal changes in marula density

Human change agents account for the major structural and functional changes to vegetation in modified landscapes (Mograbi et al., 2017). This finding is demonstrated by the intensive clearing of marula for settlement expansion (Matsika et al., 2012). Gaugris & van Rooyen (2010) found that human utilisation had the most distinctive, as well as the most rapid, impact on vegetation structure. Understanding land-use practices are important for any socio-ecological resource where geo-spatial considerations impact the resource base. Geo-spatial considerations are the consequence of changing impacts across the landscape, meaning differences in each location, land-use or settlement type affect the resource differently. Using the marula demographic category of density as the ecological indicator being compared across different land-uses, from yards to rangelands over a 15-year time frame, revealed a few key findings.

The first finding is the presence of land-use density gradients as defined by Shackleton et al. (2005). Marula densities across six demographic categories (overall, adult, large adult, juvenile, male and female) were generally higher in yards, decreasing across rangelands and lowest in fields, with intermittent variability at the local contextual level (Chapters 3 - 5). This is not a recent phenomenon, with Shackleton et al. (2003) finding the overall pattern of lower mean densities in fields almost fifteen years prior, for the same four villages in Bushbuckridge. This illustrates the value of studies where patterns in population structures can be examined over longer time periods, allowing for changes to be compared and contrasted. Shackleton et al. (2005) found that with marula specifically, overall density did not increase with distance from villages. The social data can be used to interrogate why this might be the case, providing the additional perspective of the human change agents utilising the resource. This offers insights into the main contributing factors towards the removal of marula at the disaggregated land-use level. Specifically, social data highlight where marula trees are most at risk across the landscape, based on the social factors contributing to their removal. The social factors explored in detail were the drivers leading to removals of large trees in yards for building purposes, for ploughing/planting in arable fields and large-scale felling for fuelwood in rangelands. By understanding the drivers underlying the human choices that negatively impact marula across these different land-use types, it is possible to find resource management solutions to reduce this vulnerability.

A second key finding was that tree densities in rangelands have decreased significantly over the past 15 years, compared to the study by Shackleton (2002) in the same four Bushbuckridge villages. While certain demographic categories of marula density are higher in rangelands at present, this is not necessarily an indication of a healthy population. This is because the increased densities are stems in the smaller size classes, likely as a result of overharvesting (Chidumayo, 2002; Matsika et al., 2012). In addition to this, percentages of female and large adult trees have also declined across all three land-use types, indicating a fundamental erosion of the resource base (Chapter 3). It is concerning that this depletion applies to what are considered valuable natural assets, from both a cultural as well as economic perspective. These valuable assets being female trees and large adults, as the source of fruit and the most prolific fruiters (Chirwa & Akinnifesi, 2008). A third finding is that adult densities in rangelands are almost identical between Phalaborwa and Bushbuckridge. This speaks to similar land-use

practices, including likely overutilisation in the case of adult marula trees in rangelands, regardless of geographic context (Chapter 5). With both the cultural and financial capital of the tree lacking in rangelands, male and female trees are utilised equally, suggesting that the economic necessity of fuelwood is a powerful overarching factor (Chapter 4). This driver is likely causing overall depletion of the resource, albeit in a uniform manner, with both genders being chopped indiscriminately.

In contrast, a fourth finding is that yard densities in Bushbuckridge have increased substantially since the Shackleton (2002) study. However, the very high densities of juveniles in the current study were usually located in two specific land-use contexts. The first was in yards where beer is made and the endocarps discarded. The second was in fields where juveniles are not ploughed out, or predated by livestock due to the presence of fences (Chapter 5). The low survival rates of the smallest size class of seedlings (<0.5cm) meant these were removed from the density dataset, in order to ascertain if the remaining seedling and sapling classes are likely to recruit through to adulthood. Without the social data to explain the anomaly in the ecological data, the 'forests' of marula seedlings in yards could be mistakenly interpreted as evidence of a strongly recruiting population (Chapter 5; Chapter 6).

8.2.2 Linking cultural practices with gender ratios and differences in male and female density

Exploring the ecological indicators of gender ratios, as well as differences in male and female density, the eco-social interface is the intersection between cultural practices and resource value (Chapter 4). Complexity theory suggests that the system is likely to self-organise based on the issues of access, availability and attribution of value (Partelow, 2016). The aim of this research was to highlight which demographic categories within the marula population are most at risk, where trees are most vulnerable to exploitation, as well as the underlying drivers causing unsustainable practices. For example, male trees are most vulnerable in yards due to either, or both, settlement expansion and low economic value. In contrast, female trees are most at risk in rangelands due to economic exploitation. Generating similar localised outcomes for NTFPs in a variety of rural contexts is an important knowledge challenge that needs to be addressed for numerous other key NTFPs across the developing world. This is especially true considering that environmental concern is comprised of a combination of both environmental and social considerations (Hunter et al., 2010).

Due to the cultural value of marula under customary law (Kirkland et al., 2007), the value base of the resource was almost entirely premised on its social capital in the past (Shackleton, 2004). However, with the erosion of customary law, the economic value of the resource is increasing, while its cultural value appears to be in decline. This attribution of value means that over time, access and availability of the resource are likely to be impacted (Berkes, 2007). The economic value of the fruit creates a dual tension. Economic drivers can lead to overutilisation and thus degradation of the resource in the pursuit of profit (Hardin, 1968; Belcher et al., 2005). Cultural values on the other hand can result in conservation of the species, where the marula tree is safeguarded as an asset in yards and sometimes even fields (Chapter 7). At present, the cultural value of marula appears sufficiently pervasive to influence the current resource trajectory through cultural practices at the land-use level.

A strong driver of gender ratios, as well as differences in male and female density, is the cultural value attributed to adult marula trees in yards. Female trees are valued for their fruit, which is used to make the beer utilised in cultural practices. In addition, both male and female trees are

used as the site where *kuphahla* (communicating with the ancestors) is performed (Chapter 7). These cultural practices influence key decisions around retaining (including planting) as well as removing trees from yards. Understanding marula gender ratios and densities within these human modified savanna systems goes hand-in-hand with an interrogation of the cultural narrative shaping these ecological outcomes. Species conservation through cultural appreciation is well documented in the literature and is one type of anecdote to Hardin's (1968) 'tragedy of the commons' diagnosis.

Biodiversity conservation has been linked to a variety of NTFPs, based on the local cultural practices of the communities. Cocks and Wiersum (2014) link the cultural practices of the amaXhosa tribe in South Africa to medicinal plant species, highlighting how cultural appreciation and communal practices lead to species conservation. In Benin, Gaoue & Ticktin (2009) confirm a similar finding for the African mahogany (*Khaya senegalensis)* tree species, with local indigenous knowledge and cultural practices leading to sustainable tree harvesting. Tensions between traditional and western ways of life have resulted in certain cultural practices being discontinued. Of concern, is the fact that as these beliefs erode, so too do the conservation practices based on the cultural appreciation of the species. In relation to the African mahogany, the authors noted the erosion of local culture due to Christianity (Gaoue & Ticktin, 2009). This was echoed in this marula study, with certain survey respondents stating they no longer participate in traditional cultural practices, such as *kuphahla,* due to their religion. These lessons apply to numerous rural contexts globally. In particular, where the diverse cultural dimensions of NTFPs, such as communal harvesting and sharing of resources, result in important social capital building (Lake et al., 2018). Yet unfortunately, many of these key natural resources are in decline due to overharvesting and commercialisation (Arnold & Perez, 2001). Mbiba et al. (2018) stress how social capital is secondary to natural capital in terms of reducing the vulnerability of NTFP dependent households.

Combining the ecological indicator of tree gender, with the cultural value attributed to female trees, the eco-social outcome is an increase in female densities and female-dominated populations where marula is culturally valued (Chapter 4). This confirms the reality of cultural value attribution. However, this eco-social outcome highlights a very pertinent knowledge deficit. Specifically, the fact that the necessity of more balanced gender ratios across the landscape for pollination is neither understood, nor considered, when decisions around the removal of male trees is concerned. This lack of traditional environmental knowledge (TEK) is contributing directly to the degradation of the species. The potential consequences of limited TEK were examined by Gouwakinnou et al. (2011) for marula (subsp. *birrea)* in Benin (West Africa). Limited marula TEK in Benin was attributed to the combination of low levels of fruit utilisation (economic), in addition to a lack of overall cultural value in relation to subsp. *birrea* in Benin (Gouwakinnou et al., 2009). Due to the limited knowledge of gender differences in Benin, very little discretion was applied when removing a marula tree. The application of this cultural lens to the South Africa context, where female trees are favoured, has resulted in the female-dominated populations in yards. This gender bias is likely as a consequence of the male counterparts being removed.

Segregation of the species occurs in yards due to female marula trees being afforded a higher degree of protection than their male counterparts. Male trees are therefore preferentially removed, with the result being a higher ratio of female to male trees in yards. This results in not only higher female densities and skewed gender ratios in yards (Chapter 4), but also more

opportunities for seedlings to germinate (Chapter 5), which creates a positive feedback loop between female and juvenile densities across yards. Even in yards where marula beer is not made, due to the higher likelihood of the presence of a female parent tree, any dropped fruit that is not collected or swept away, has the potential to germinate (Chapter 5). This attribution of value has created a type of conservation continuum, with yards in both Phalaborwa as well as Bushbuckridge displaying female dominated populations, mixed dominance in fields and male dominance in rangelands. This suggests a gradient from yards to rangelands, with yards and fields as the most human-modified environments and rangelands as the least. Considering that many dioecious populations are normally slightly male biased (Obeso, 1998; Wheelwright & Logan, 2004), the strong female dominance in yards is clearly a result of human cultural and economic practices across these landscapes. While this may not be ideal, studies have shown that a small number of male trees are able to pollinate a larger number of female trees, provided activity by key pollinators is sufficiently high (Van Drunen & Dorken, 2012). With bees and other flying insects such as wasps as the main pollinators of marula, the imbalance in gender ratios is only problematic for bees to pollinate effectively if the distance between genders is greater than 1500 m (Nghitoolwa et al., 2003). These findings highlight the first eco-social intersection point of cultural conservation, concerning how the cultural value of marula leads to the protection of the species. However, protection does not apply to the whole population and across the land-use types where it does apply, the outcomes are variable.

The fact that yards had the most disproportionate gender ratios is potentially concerning, as it actually undermines the cultural conservation hypothesis (Chapter 7). This is based on the fact that male trees in yards are also utilised for cultural practices such as *kuphahla*. In theory, this means the male tree should be conserved alongside the female tree. However, the lack of fruit on male trees either means the cultural value of the beer is more highly regarded, or the economic value of the fruit precedes both. This finding is also supported by the social data finding that the cultural value of marula has decreased over time (Chapter 7). As a result, male trees are deemed not to be as valuable and therefore are afforded a lower level of protection in yards as a direct result (Chapter 4). The older generation blame the removal of male trees on a decline in culture, which is attributed to the ignorance of the younger generation. This was highlighted by a middle-aged woman in Benfarm (Phalaborwa): *"Younger people cut these trees to build houses or to stop the tree cracking their house. The young population is growing rapidly and building houses everywhere."* Considering how tightly embedded marula is within the culture of the community, understanding the implications of cultural attrition is a key aspect of marula conservation. In addition, these lessons can act as a warning for all contexts where communal practices regarding resource use are shifting, highlighting the importance of protecting cultural practices. This finding increases the imperative to understand what social drivers increase pro-environmental behaviours as well as concern for natural resources (DeFries, 2007; Hunter et al., 2010).

While marula is utilised the most in yards for cultural purposes, trees that are seen as a risk to buildings will be removed regardless of household levels of cultural appreciation. The one exception to this may be if trees are deemed to be sacred, such as those planted on graves (Chapter 7). This appreciation manifests in the landscape design of each yard. Essentially, whether people maintain or remove trees depends on whether they are viewed as an asset or burden (Nassauer, 1995; McHale et al., 2013). Trees that are valued culturally are seen as an asset, as well as providing shade or being aesthetically appealing (Paumgarten et al., 2005).

Respondents indicate sweeping around valued trees, removing grass and watering juveniles (Chapter 7). In yards where the tree is neither valued culturally, nor for the economic value of the fruit, the tree is seen as creating a mess and removing the fruit and juveniles are considered a chore (Chapter 7). Regardless of local variability, the eco-social outcome was the same across Phalaborwa and Bushbuckridge, with female-dominated populations in yards. The female-dominated population in yards confirms the pervasive nature of marula resource utilisation. Specifically, the similarities in population structure across two rather different geographical locations. These findings highlight how the socio-economic impacts of humans on savanna systems are a less well understood aspect of savanna ecology. With increasing human encroachment on natural areas, human impacts on savanna ecosystems require increasing attention (Fisher, 2012). Central to answering this knowledge challenge was unpacking the inherent dual tensions between traditional culture and modernity, as well as the youth and the elderly, in rural savanna socio-ecological contexts. Bohman et al. (2009:446) refer to this as "tradition in transition", where the revaluing of traditions can be seen as a response to social and economic change. Understanding the extent of this nuanced dynamic in relation to the cultural value ascribed to marula, makes it possible to identify cultural leadership and traditional knowledge approaches as crucial aspects of proposed solutions.

While the cultural value of the tree may not always result in its conservation, the economic value of the tree may partly achieve this result. The economic value of the fruit is an equally important driver in terms of gender ratios and male to female densities across land-use types. The financial value attached to female trees, reinforces the female-dominated populations in yards. However, this is not repeated in fields and rangelands with male-dominated populations in these land-use types. Male dominance in rangelands could also indicate that spatial segregation of the sexes is occurring here. This is possibly due to female trees suffering higher mortalities in stressful habitats, such as overharvesting of a communal resource (Bierzychudek & Ekhart, 1988). The overutilisation of the female trees may be causing the skewed ratios in rangelands, as opposed to it simply being as a result of the dioecious nature of the tree. This is supported in the social data, as explained by a family in Lulekani (Phalaborwa): *"People cut down the [female] trees or cut branches to get the fruit – even if it is not ripe. They are so desperate to fill up their bags quickly."* In addition, fruit sellers and beer makers often prefer the green marula fruit. This is because the green fruit does not go rotten if the truck from the factory does not arrive on schedule and the ripeness of the fruit can be selected for beer making (Chapter 6).

In both Phalaborwa and Bushbuckridge, the proportion of households making marula beer for household consumption was higher than those selling the beer for income generating purposes (Chapter 6). Furthermore, there was a higher percentage of beer and fruit sellers in Phalaborwa compared to Bushbuckridge. When asked why marula is an important tree, the majority of respondents in Phalaborwa attributed the value of marula to financial reasons (Chapter 6). In Bushbuckridge, sale rates were substantially lower than production levels, suggesting the beer is still made predominantly for personal and traditional reasons. In addition to this, the cultural value of the beer was given as the main reason for the trees local importance in Bushbuckridge (Chapter 7).

In Phalaborwa, higher levels of fruit and beer sales suggest that the economic value of the tree likely outweighs the cultural value in this context. In contrast, there was evidence of more traditional uses of the marula beer occurring in Bushbuckridge (Chapter 6; Chapter 7). Interestingly, the increased economic activity around marula in Phalaborwa has been

accompanied by an increase in certain cultural activities. These activities are possibly responsible for the lower mortality levels observed here. This is the second eco-social intersection of cultural conservation, which is the indivisibility of cultural and economic capital in driving stewardship. This not only confirms that cultural and economic values are indivisible from one another (Berkes, 2003; Khalid et al., 2013), but also that they are not mutually exclusive. This is due to an increase in one possibly leading to an increase in the other. This is perhaps not surprising considering that the preoccupation with the female tree translates into fewer removals, as well as encourages utilisation for other purposes. For example, a family who protect their tree for cultural reasons, may then decide to start selling the fruit. Ultimately, even when the cultural practices subside, the tree is still preserved for it's economic value in yards. Furthermore, the higher levels of economic value attribution translate into increased stewardship levels in Phalaborwa, with fewer instances of tree cutting than in the Bushbuckridge context (Chapter 7). Stewardship in yards, as well as fields, highlights the key role of secure land tenure in increasing pro-environmental behaviours. In Phalaborwa, field tenure was more secure, with the resultant higher instances of stewardship corroborating the link between stewardship and ownership of an environmental asset (Berkes, 2003; Shackleton et al., 2003; Emanuel et al., 2005; Bisong & Andrew-Essein, 2010; Paumgarten et al., 2011).

Economic and cultural drivers are responsible for the creation of the marula density gradient, resulting in the higher female and male densities in yards, compared to fields and rangelands (Chapter 4). In addition to the economic value of marula creating the density land-use gradient, the cultural value of the resource has reinforced this spatial and temporal shift of the system. This is as a direct result of the inherent social capital of the tree combined with taboos around tree chopping, as enforced by local customary law and chiefs (Chapter 7). Over time, densities have increased in people's yards and decreased in fields and rangelands. This conversion of the landscape is not unique to South Africa, with Sunderland et al. (2017) illustrating how transitions along the forest to field continuum occur in other parts of the world, including Zambia, Burkina Faso, Cameroon, Ethiopia, Indonesia and Bangladesh. This continuum in the marula bioeconomy landscape has resulted in higher densities, specifically of female trees in yards, where communal access is limited, attribution of value is high and availability is consistent. This finding speaks to the opportunity of on-going conservation of the species due to its cultural value (Chapter 7; Voggesser et al., 2013). A key finding as a result of the cultural capital of the female tree, is that female densities are almost identical in yards in both Bushbuckridge and Phalaborwa (Chapter 4). This is despite numerous geographical differences between the locations. The consistency in female densities between locations, despite all the contextual differences, speaks to the fact that certain values pertaining to marula are more pervasive than contextual differences. These include the economic value of the fruit (Chapter 6), followed by the cultural value of the beer made from the fruit (Chapter 7). Male densities were generally lower than female densities across land-use and settlement types. This finding was supported by the social data, illustrating the misconception that male marula trees are unimportant both economically and ecologically (Chapter 6). Numerous respondents explained: *"People do not chop marula trees, only the male tree."* As a result, male trees are generally more of a target, due to the combination of the lower cultural and financial capital of these trees, including by live fuelwood harvesters in rangelands (Twine et al., 2003).

These outcomes highlight the importance of linking social (cultural and economic) drivers with ecological findings. These outcomes are valuable for understanding what drives NTFP species

conservation in a variety of rural, developing country contexts. The combination of financial and cultural capital surplus substantiates why female densities are almost the same in yards in both locations, despite differences in overall density. More than any other finding, this result speaks to the enormous value attributed to the female tree, which allows for one particular category of marula to be conserved and cared for to the extent that similar densities are able to occur in two quite different locations. This is noteworthy, especially considering that Phalaborwa experienced lower densities across all the other categories, due to lower levels of water availability overall when compared to Bushbuckridge (Chapters 3 - 5).

However, cultural valuable attribution without economic value may not be sufficient to lead to species conservation (Chapter 7). Both capitals need to be present simultaneously in order for conservation of the tree to be assured. This is perhaps best illustrated in fields and rangeland land-use practices. In fields and rangelands, the cultural value of the tree is not always recognised by all of the various user groups. This means different species are often removed from fields to plant crops (Byakagaba et al., 2011), or are targeted for fuelwood in rangelands (Matsika et al., 2012). This finding is applicable to any important NTFP distributed across different land-use types, such as cropland and communal rangelands. Over time, the system could reach a threshold, such as the serious degradation of the resource, which may result in a change of behaviour. This behaviour change may drive the system to shift spatially again as fewer trees are chopped. How well the overall system is able to recover over time depends on the resilience of the coupled human-natural system (Liu et al., 2007). Based on the diminished traditional authority in lowveld communities (Kirkland et al., 2007; Twine & Findlay, 2018), the governance aspect of the socio-ecological system is compromised. It is therefore not clear if the current trajectory would be altered timeously, while the resource base is still sufficiently stable and plentiful (Chapter 5).

Considering that the three biggest threats to marula are land clearing for residential plots and arable fields and large-scale felling of trees in rangelands for fuelwood, underlying socio-economic factors need to be urgently addressed if marula populations are to be sustained in the long-term. This is due to the deeper socio-economic factors centred around poverty and resource reliance driving the marula utilisation agenda. These drivers are exacerbated by land shortages resulting in smaller yards, the felling of whole adults trees in the context of fuelwood shortages and poverty resulting in fuelwood use, as electricity is too expensive. Furthermore, any attempt to regulate the chopping of live trees is undermined by the diminished role and thus regulation of communal lands by traditional authorities (Findlay & Twine, 2018).

8.2.3 Linking resource practices with marula maturity densities, ratios and size classes

Understanding population structure requires an understanding of the life history of the tree from juvenile to large adult (Condit et al., 1998). In particular, exploring those factors that drive regeneration and juvenile recruitment at one end of the marula population life cycle, and mortality and tree senescence at the other end. For the ecological indicators of size class as well as maturity ratios and densities, the eco-social interface where changes to the system are most apparent are marula resource utilisation practices. Populations of multi-use tree species, such as marula, are at risk from the overharvesting of natural resources due to the range of natural products harvested from each tree (Geldenhuys, 2004). Multi-use NTFP species are usually utilised by local communities for their fruit, wood and bark (Gaoue & Ticktin, 2009). This multi-use profile increases the likelihood of population instability in the long-term as a variety of size classes are utilised for a variety of resources (Shackleton, 2002; Wynberg et al., 2002;

Shackleton & Shackleton, 2005). In addition to this, marula trees in the communities included in this study are vulnerable to climatic changes as they are at the limit of their rainfall distribution in the semi-arid savanna socio-ecological systems of South Africa (O'Connor & Goodall, 2017).

Prominent SCD methodologies, such as the widely replicated approach utilised by Lykke (1998), combine SCD data with local knowledge in order to gain a more comprehensive study of a disturbed savanna. Phalaborwa displayed an adult-dominated population compared to Bushbuckridge's juvenile-dominated population (Chapter 5). In addition to this, in Phalaborwa a larger portion of the population constituted large adults, with stem diameters 43 cm and greater. However, fewer juveniles do not always signal a declining population, especially for relatively fast growing larger tree species such as marula, provided they experience high survival rates (Helm, 2011; O'Connor & Goodall, 2017). Survival rates are an important consideration as the social data indicated that seedling marula trees in yards and fields are usually removed after a season or two, either to clear the yard or to make space for food crops (Chapter 5). Therefore the large juvenile population in Bushbuckridge does not necessarily constitute a stable population, as represented by the inverse 'J-shaped' curve, since there is failed recruitment into the larger size classes.

In Bushbuckridge, the recruiting population is the result of high juvenile numbers in yards, particularly where beer is made and kernels are discarded. The SCD profiles for Phalaborwa indicated weak recruitment across land-use types, likely caused by lower rainfall and therefore available water (Chapter 3). At the other end of the size class spectrum, survey responses indicated that large individuals are removed for economic reasons in yards, where they are considered to pose a risk to buildings, especially if the household has no use for the fruit. In fields, large marula trees are removed when shade is thought to hinder crop growth, particularly where the arable crops are considered the more valuable resource. However, the largest trees are often left as they are too large to remove, usually around the perimeter of fields where they do not affect crops. Djossa et al. (2002) confirmed that the largest (between 40 cm to 80 cm diameter) shea trees (*Vitellaria paradoxa)* are left in agroforestry systems in Benin, likely due to the difficulty in removing them. The findings in the South African context point to the value of having aggregated, as well as complimentary, social and ecological data. Specifically, where co-evolving trends can be analysed in tandem, in relation to different land-use types. In addition, the reliability of the combined methodologies and data validate authors such as Huntington et al. (2004), who promote combining TEK and scientific observation. This is especially true in relation to environmental change impacts, which ultimately reduce the inherent uncertainty in the research outcomes (Bomuhangi et al., 2016; Reyes-Garcia, 2016).

The SCDS for marula in yards and fields in Phalaborwa had negative slopes with only rangelands indicating a severely unstable, non-recruiting population with a positive slope (Chapter 3). In Bushbuckridge, yards also displayed negative slopes, indicating strong recruitment. In contrast, both fields and rangelands showed positive slopes, suggesting diminished recruitment. This is a key eco-social intercept, with the ecological outcomes being shaped by a combination of the underlying resource use practices (social) and environmental factors (ecological). Reduced recruitment in rangelands is likely the result of a combination of factors including intermittent fire, livestock predation and rainfall interactions (Helm, 2011). In addition to these factors, the overharvesting of marula fruit for commercial purposes is a key contributor. This is due to the reduced fruit availability under the parent tree for germination (Djossa et al., 2008). In terms of large adult abundance, this was lowest in yards in Bushbuckridge, where stewardship would be

considered to be more prominent, and highest in rangelands where trees are open access and thus assumed to be more at risk from harvesting pressure. However, due to yards being a more human modified land-use type, it is perhaps unsurprising that abundance would be higher in rangelands, where there are less disturbed natural populations. In addition, density indicated that large adult densities were in fact higher in yards, indicating that in terms of absolute abundance, the numbers are higher in yards (Chapter 5). These findings highlight the importance of understanding the underlying socio-economic uses that shape the ecological data, with space shortages in yards contributing to the reduced absolute abundance of large adults in yards. Furthermore, despite the assured economic returns of marula trees in yards, resource collection practices indicated that respondents obtain the majority of the fruit for financial purposes from the rangelands (Chapter 6). This is due to the more numerous rangeland trees effectively supplying the large fruit quantities required for livelihood purposes.

Large marula trees were quoted by resource users as being cut extensively in yards in order to clear land to build new houses, extend existing buildings or whenever the root systems or branches of large trees were purported to pose a risk to pre-existing buildings (Chapter 6). The ecological traits of marula having an extensive root system and large canopy are the ecological drivers in these situations. When combined with the economic driver of building or extending an existing house, the eco-social interface is the decline in adult marula densities, specifically very large adults (Chapter 5). In both Phalaborwa and Bushbuckridge, 100% of respondents gave the threat of large marula trees to buildings as their reason for chopping a marula in their yard (Chapter 7). Numerous older respondents hinted that their generation would leave a large marula tree in their yard in the past as it afforded protection from wind and shade from the sun. In contrast, the younger generation were described as being more concerned with larger trees hiding their house from view (Chapter 7). This would suggest that there is also an element of personal status driving the removal of large trees in yards, meaning that the widespread perception that they will cause damage to buildings may not be as pervasive currently.

However, it is worth remembering that when the older generation were establishing their homesteads that most people still lived mainly in traditional huts, which did not have foundations, and had a small footprint in the yard compared to a modern house. In addition, a thatch roof is both easier and cheaper to repair than a damaged corrugated iron, or tiled roof, on a modern house. The smaller surface area of a hut roof compared to a multi-roomed house meant that a hut also had a much lower probability of an overhanging branch falling on it. So, there is collinearity between age of respondent, type of house they are likely to have built when they built their first house, and their concern about adult trees posing a threat to their house. Considering the cost of a new roof within the economic context of these communities, the concern around building damage is very understandable (Chapter 6). Understanding the perceptions of local communities, as well as how this shapes concern for natural resources, is highlighted by Hunter et al. (2010) as being central to resource conservation.

At the land-use level, Phalaborwa displayed adult-dominated populations in yards and rangelands, with juvenile dominated populations in fields. Bushbuckridge displayed the opposite pattern, with juvenile dominated yards and rangelands, and adult dominated fields (Chapter 5). Juvenile dominated yards (Bushbuckridge) and fields (Phalaborwa) raise an interesting eco-social consequence. Marula seeds are able to easily germinate in certain yards and fields where conditions are ideal, such as tilled soil, increased water availability and a fence for protection from livestock herbivory. Fences around both these land-use types reduce

herbivory, especially by livestock. In addition, a complete lack of fire regimes and grey water (from washing clothes) increases the chances of seedling surviving in yards. These high survival rates for seedlings are unprecedented in conservation areas, where herbivory and fire are present (Cook et al., 2017), with the exception of herbivore exclosures (Helm, 2011). The higher numbers of juveniles across these land-use types have led to a perception that they are numerous everywhere and that removing them is therefore not damaging to the wider population. As a result, the reality is that the majority of juveniles are unlikely to recruit through to adulthood. Likewise, Duvall (2007) confirmed that the success of baobab (*Adansonia digitata* L.) recruits in Mali (West Africa) was based on stewardship practices in communities where the tree is economically and culturally valued.

The ability for juveniles to grow from kernels thrown into yards is the ecological trait that drives these densities (Chapter 5). The economic driver is the desire to make money from marula beer, hence the discarded kernels (Chapter 6). However, due to their prolific numbers in yards, seedlings are perceived as numerous. Therefore, there is little concern in removing them to keep the yard tidy, or to make space for planting other trees or crops in fields. Respondents indicated that large seedling populations are often removed annually or biennially, but that this is based on the individual yard or field owner's preference (Chapter 6). This means the majority do not recruit through to adulthood. In contrast, the overharvesting of fruit in rangelands likely leads to reduced germination, possibly resulting from a lack of available fruit on the ground (Djossa et al., 2008). This is relevant when considering the comparison of elephant impacts in conservation areas with humans as landscape change agents in non-conservation areas (Mograbi et al., 2017). Overall and juvenile densities were lower in rangelands compared to sites in the Kruger National Park on the same soil and vegetation type. This suggests that recruitment dynamics in communal contexts are being adversely affected, which is of concern if the future sustainability of marula is to be ensured (Chapter 3).

Land-use practices in fields result in a range of positive and negative consequences for large marula densities. Respondents indicated that land is cleared for arable crops, with large trees seen as competition for resources (Gouwakinnou et al., 2011). However, fields that are ploughed but then not planted, or planted and then left fallow, provide opportunities for marula to not only geminate but also recruit through to adulthood if left unaltered (Chapter 5). Across Africa, similar findings are reported for the shea tree in Uganda (Byakagaba et al., 2011), the baobab tree in Mali (Duvall, 2007) and for marula (subsp. *birrea*) in Benin (Gouwakinnou et al., 2009). Due to adult trees (in particular large adult trees) in fields not being used for cultural ceremonies as prolifically as in yards, the protection afforded to culturally valued trees applies far less in the former (Chapter 7). However, the economic value of the female tree may offer a degree of protection, as many respondents specified leaving female trees in fields as these can be harvested for fruit. Nghitoolwa et al. (2003) reported a similar finding for marula trees in Namibia (Southern Africa), with the largest and oldest trees being located in agroforestry lands. Unlike the common property resource (CPR) status in the rangelands, field trees are protected from chopping by the general community (Chapter 6). In addition, juveniles are protected from livestock by the fences around fields (Chapter 5). The livelihood strategy of maintaining marula trees in fields offers fruit collectors some certainty of supply, as the fruit will not be removed (Shackleton et al. 2002). This is what Berkes (2007) refers to as the exclusion and subtraction problem in relation to communities and commons. Fences are a prime example of exclusion, by limiting access to the resource. The impact of different resource regimes, on the population

structure of the socio-economically important shea tree in Uganda (East Africa), support this statement (Byakagaba et al., 2011). The finding was that more intensive land-use practices, particularly in fields, reduced population stability and regeneration (Byakagaba et al., 2011). This demonstrates the transferability of key lessons pertaining to important socio-ecological species into other contexts where livelihoods are sustained by an important natural resource. Unfortunately, competition for space in fields means that usually there are only a few large marula trees per field, which still often requires the fruit collectors to utilise rangeland trees in order to obtain sufficient fruit quantities (Chapter 6).

High resource demand and the resultant overharvesting can lead to homogenous landscapes (Ticktin 2004). Species like marula are harvested less often for fuelwood than other woody savanna species, due to a combination of the soft wood as well as cultural taboos and regulations towards chopping marula. This means that these trees remain as part of a limited number of large tree species across these landscapes. In addition, marula is a strongly coppicing species (Kaschula et al., 2005; Shackleton et al., 2005). Coppicing responses to chopping usually result in more numerous stems, but in the smaller size classes (Chidumayo, 2002). This erroneously gives the impression that the harvesting activities, especially in rangelands, are sustainable (Neke et al., 2006). Smaller individuals are not considered viable replacements for the larger individuals selectively removed from the landscape, specifically due to the loss of these prolific seed sources from the population (Nghitoolwa et al., 2003). Coppicing does not guarantee the persistence of the population indefinitely if most, or all, of the large adults are removed and if the coppice stems are re-harvested and thus continually kept in a functionally juvenile phase (Twine et al., 2005).

Of further concern is the significant difference between adult and large adult densities across the land-use types in both locations (Chapter 5). While it is expected that large adults make up a smaller portion of the adult population, the sustained loss of many of the largest trees across the landscape, potentially due to drought, is concerning (Chapter 7). This was confirmed from the surveys where three quarters of the respondents over 50 years of age in Phalaborwa and Bushbuckridge indicated that the numbers of large adult trees have declined since their youth, supposedly due to a lack of rain (Chapter 7). Having this finding confirmed by the qualitative data, with older respondents claiming that the big trees are basically “no more”, can be understood through the lens of ‘cultural fragmentation’ with declining resources being described in terms of cultural attrition. This framing of the issue is usually due to the close connection between a resource and the cultural activities surrounding that resource. This means that a declining resource base directly results in a decline in the cultural activities associated with that resource (Rankoana, 2016). Cultural fragmentation is an important framing of environmental degradation, which can be used by researchers to understand local perceptions of environmental change (Kaschula et al., 2005). Rankoana (2016:677) confirms how climate change specifically is often explained “in terms of a cessation of cultural activities as well as livelihood patterns.” This is important for any context where community resource use is framed by local cosmologies, with the experiential concept of place being expressed through the cultural lens of environmental change (Riley & Harvey, 2007). In a context where climate change is likely to severely impact a NTFP, lessons around how local communities navigate resource variability are of crucial importance. This is what Anderson (2016:23) refers to as “weathering loss”; a social construct built around the enduring hardship and resilience required to deal with a changing climate by those living directly off the land.

In the past, customary laws enforced by traditional authorities ensured that marula trees were protected from being chopped down or removed across all land-use types (Kirkland et al. 2007). This protection was achieved with special tree police and a permit system ensuring that people obeyed these laws (Findlay & Twine, 2018). Cultural attrition, combined with increasing livelihood pressures, mean that economic factors, rather than customary law, are now the main drivers shaping decisions regarding marula utilisation (Chapter 6). This has led to potential overutilisation of the resource, including live marula trees being harvested for fuelwood (Matsika et al., 2012), with factors such as distance from village and size overshadowing species choice in terms of priority selection (Shackleton, 1993b). In addition to this, both recruitment as well as fruit yield is directly linked to rainfall; with soil moisture content as a result of the previous season's precipitation dictating fruit yield the next season (Shackleton, 2002). These yields in turn dictate the size of the seed bank, which forms from fallen fruit, with large mammals acting as a key dispersal agent (Helm et al., 2011).

In rangelands, where livestock are the only large mammals, the seed bank located under the parent tree is the key source of regeneration, with up to 25% of juveniles located beneath the parent tree compared to conservation areas (Helm et al., 2009). This means that resource practices involving the collection of all available fruit beneath the parent tree can severely hamper germination, and thus recruitment (Chapter 6; Djossa et al., 2008). Furthermore, recruitment and rainfall are inextricably connected, with rainfall acting as a key-limiting factor to successful recruitment for baobabs as well as marula trees (Venter & Witkowski, 2010; Helm, 2011). The negative impact of infrequent rainfall, on seedling and sapling baobabs in South Africa, was highlighted by Venter and Witkowski (2013). Further drought, specifically prolonged severe drought, could be responsible for large tree senescence and ultimately mortality, as demonstrated in baobabs by Patrut et al. (2018). As the most prolific source of seeds, loss of large individuals also adversely affects recruitment, due to a diminished seed bank in the soil (Helm, 2011).

8.2.4 Linking resource reliance with marula damage and mortality

Tree damage was more prevalent in Bushbuckridge than in Phalaborwa; not surprising considering the high human population densities in this area and the use of marula branches from rangelands for fuelwood (Chapter 6). However, the amount of damage to trees was far less than expected. This expectation was based on fuelwood studies, such as those conducted by Madubansi & Shackleton (2007) and Matsika et al. (2012) in the Bushbuckridge region. In addition, this expectation was also informed by the studies on resource degradation in the same region (Kirkland et al., 2008; Findlay & Twine, 2018). The lower levels of damage are likely in part due to the tree being considered inferior for fuelwood due to its poor burning properties, which include burning too quickly and giving off excessive smoke. These qualities are due to marula being a soft wood (den Adel, 2002). In addition to this, despite higher numbers of respondents confirming use of marula bark for medicinal purposes in Bushbuckridge, there is evidence of higher levels of bark removal within yards in Phalaborwa (Chapter 7). To add to the complexity, mortality was lowest in rangelands in both locations and highest in yards in Bushbuckridge but fields in Phalaborwa. While this would clearly undermine the theory of cultural conservation, it is not possible to take these findings at face value. Instead, the additional contextual information provided by the social data is required.

Respondents indicated that trees chopped in yards are usually fully removed in order to prevent any kind of regrowth, as well as to occasionally hide the evidence of the tree having been

chopped. This is due to the prohibition on cutting live marula trees (Twine & Findlay, 2018). The lack of physical evidence of tree chopping that results, suggests the true scope of tree removal in yards might not be apparent (Chapter 4). Similar practices pertaining to the removal of trees in yards resulted in similar adult mortality between locations (Chapter 4). This speaks to the pervasive characteristics or qualities of marula, across different contexts. In rangelands, the survey responses similarly indicated that whole trees are removed for fuelwood markets, as opposed to just a few branches being cut, as is often the case with household usage. This is especially relevant to fuelwood markets, as harvesting the whole tree ensures an adequate return on investment (Chapter 6). Fuelwood harvesting has resulted in two prominent patterns in terms of tree demographics across rangelands. The first pattern is the equal utilisation of both genders for fuelwood (Chapter 4), while the second is the relative abundance of very large trees being highest across rangelands (Chapter 5). This creates a complex outcome, with higher instances of mortality from chopping in yards being evident than in rangelands. However, this is likely not an accurate indication of the whole context. This removal of live trees means that the ecological indications of mortality are not immediately obvious in human altered landscapes. This differs from conservation areas where, for example, elephant pollarding of trees retains evidence of the destruction (Mograbi et al., 2017).

Trees which are already strained by prolonged drought are also likely to be less resilient to resource harvesting practices, such as the chopping of branches, either for fuelwood or to obtain green fruit for sale (Chapter 6). These negative resource practices further compromise older marula trees, increasing large tree senescence and ultimately mortality. Gadd (2002) showed that marula trees tolerated up to 50% ring barking and 100% of branch breakage before succumbing to mortality. This includes main stem breakage, with many coppicing in response. Increased rates of mortality in rangelands would therefore support increased levels of wood harvesting. However, reduced branch chopping, combined with the limited evidence of tree removals for fuelwood markets, results in an incomplete portrayal of marula resource reliance across this land-use type (Chapter 4). This is another key eco-social intercept, with resource practices affecting long-term population size-class profiles, highlighting the need for long-term research to track large trees removed from the population. Over time, these resource-use practices create a positive feedback loop with fewer large trees dropping less fruit (Chapter 5), which is subsequently collected by resource users in an attempt to meet livelihood quotas (Chapter 6). In turn, this leads to diminished fruit left on the ground for germination and therefore fewer successfully recruiting marula trees overall (Chapter 5).

In particular, heavily utilised trees suffer greater damage and may suffer higher levels of stress as a result. In multi-use species such as marula, fruiting females are also utilised for a variety of other resources, such as bark and wood. These individuals may succumb to a lower proportion of damage than lesser-utilised trees, as a consequence of the stress placed on the tree. In addition, on-going stress from overutilisation can be compounded by climate impacts such as drought, placing further stress on the tree. Female trees in dioecious species can be compromised in arid environments, leading to higher mortality rates, even without the severity of drought conditions (Verdu & Garcia-Fayos, 1998; Verdu, 2004). Over time, these stress factors result in higher mortality in female trees, resulting in male-biased populations and segregation of the species as a result (Verdu & Garcia-Fayos, 1998; Wheelright & Logan, 2004). Explanations of the consequences of damage causing practices could be incorporated into community outreach and awareness campaigns. These campaigns would aim to highlight the

importance of sustainable harvesting for the on-going integrity of not only the resource, but also the species as a whole. Shunula (2002) explored the success of awareness campaigns in Zanzibar (East Africa) in promoting mangrove conservation. Increased conservation of the mangroves was based on campaigns to create ecological links between the mangrove ecosystem and the resources provided (Shunula, 2002).

The social data regarding tree damage can help to contextualise the impacts of human resource harvesting, where ecological responses like early fruit abscission, do not assist the tree in preventing damage by humans. This illustrates a key theme in the NTFP literature, whether natural resource use can meet development and conservation objectives simultaneously (Arnold & Perez, 2001). In particular, literature focussed on NTFP reliance across African savannas and Brazil's Amazon Rainforest, argue that these examples of resource degradation support the need for the 'conservation through commercialisation' narrative to be revised (Marshall et al., 2003; Sunderland et al., 2004; Shackleton et al., 2007; Dovie, 2009; Shackleton et al., 2011). Instead, local nuanced socio-economic solutions are required to assist in reducing damaging practices such as branch cutting to obtain fruit.

8.2.5 Potential impacts of marula commercialisation on the resource base

As a natural resource outside of conservation areas, marula is still considered to be conserved in parts of Limpopo, where the beer is regarded as "social glue" (Nwonwu, 2017). Across these contexts, the elders in the community testify to the tradition of marula, resulting in its conservation (Sinthumule & Mzamani, 2019). The key question is whether the increasing levels of commercialisation in the Bushbuckridge and Phalaborwa regions mean that for these parts of the marula bioeconomy, the cultural heyday of marula has now passed. Or alternatively, whether a model of participatory commercialisation could mean that economic and cultural values co-exist to create greater resource resilience overall. Currently, the communities surveyed in this study mainly supplied fruit to Distell for the production of Amarula Cream, with Distell as the largest known off-taker in the region at the time. While there are numerous marula liqueur brands currently, other companies were not mentioned by respondents as purchasing the fruit. However, respondents did indicate that they were not always aware of which company the trucks collecting fruit were from, as these vehicles are not branded. The trucks from the Distell factory in Phalaborwa were purported to pay R38 per bag of fruit across both Phalaborwa and Bushbuckridge. However, respondents indicated being paid a range of prices, suggesting that the full price was only paid if fruit was sold directly at the factory gate. Community members indicated that this income is considered insufficient for the intense labour involved in collecting and carrying the quantities required to sustain a living through marula. However, as illustrated in Chapter 6, income from marula fruit sales make a huge contribution towards monthly household income for the duration of marula season and even though it may be hard earned, it is vitally important in sustaining livelihoods.

This raises the key concern around the Distell factory in Phalaborwa closing down in 2019. Due to this closure being after the fieldwork undertaken for this project, it was not possible to gauge the immediate implications of this development. However, a key consideration from the data gathered prior was the higher economic value attributed to marula in Phalaborwa, with higher fruit sales occurring here, compared to Bushbuckridge. In addition, this higher worth translated into seemingly greater levels of tree stewardship in the Phalaborwa context, with lower levels of tree chopping. The higher economic activity in Phalaborwa was attributed to the proximity of the Distell factory to the Phalaborwa villages. Respondents indicated that the unreliable truck

timetable meant selling directly to the factory guaranteed both income security as well as higher earnings. While fewer respondents sold fruit in Bushbuckridge, this was still an important income stream. One possible consequence of the factory closure is therefore that the Phalaborwa communities will likely continue to sell fruit to the truck, however they may incur diminished earnings as a result of the factory closing. It was not clear at the time of writing what alternatives Distell may put in place in lieu of the factory. While this closure is likely to adversely impact communities, the on-going sale of the fruit will ensure that households do not suffer large income losses. However, should Distell discontinue purchasing from these communities altogether, this would result in massive economic strain on those households reliant on this income. In addition, diminished economic value could also translate into a reduction in stewardship practices, resulting in higher levels of tree chopping in the Phalaborwa context.

Strengthening partnerships between private sector companies and marula reliant communities is a key aspect of sustainable development in this region. One avenue for this to be achieved is through the Marula Industrial Hub, an initiative by the Limpopo Department of Economic Development and Tourism (LEDET) (Limpopo Business, 2019). The aim of the multi-million rand Marula Industrial Hub, based in Lephalale (Limpopo), is to expand the range of marula fruit products and thus potential income from the resource. Current uses are largely confined to supplying Distell and making marula beer at present. It is estimated that marula currently provides R45 million annually for the Ba-Phalaborwa and Mopani Districts in Limpopo (Limpopo Business, 2019). The LEDET has also tasked the University of the Limpopo with expanding research into other uses of the fruit, including jam and cosmetics. One such initiative has been the development of a marula wine, developed by Professor Kgabo Moganedi and her research team at the University of Limpopo. The technology employed to make the wine is based on the traditional techniques used by local communities to make marula beer (Sunday Times, 2020). At present, the resource base appears sufficient to support both local as well as commercial needs, based on adequate fruit availability for community as well as commercial needs currently. It is not clear how much the Marula Industrial Hub might extend demand for marula products and if this could result in a situation of demand outstripping supply in the future. Fruit yield modelling in this region by Emanuel et al. (2005) indicated that 92% of the fruit could be removed from the system without impacting the current population profile. The authors indicated that more intensive marula resource uses, such as fuelwood or bark harvesting, needed to be carefully monitored. The findings from this study suggest that bark harvesting is limited and likely not leading to resource degradation (Chapter 3) but that fuelwood harvesting could be problematic if not carefully monitored going forward (Chapter 3; Chapter 5). While more recent fruit yield modelling is required to confirm current volumes, indications from respondents are that fruit volumes in the rangelands remain sufficiently plentiful to meet livelihood needs at present. If marula was to be domesticated and grown commercially, this would have a devastating financial impact on the communities relying on this resource for livelihood support (Shackleton et al., 2002; Wynberg et al., 2003; Shackleton & Shackleton, 2005). Ensuring that communities directly and adequately benefit from commercial initiatives is therefore the key issue at present. This will need to be the clear imperative of any commercialisation projects going forward, if abject poverty in the region is to be addressed.

8.2.6 Perceptions about climate change and behavioural responses

The selection by communities of trees with high-quality marula fruit in yards can be understood as a form of domestication (Thiong'o et al., 2002; Shackleton et al., 2003). However, the role of

humans in maintaining trees in more arid environments should not be overlooked, particularly where water is a key limiting factor. This scenario is likely to be exacerbated by climate change. While Akinnifesi et al. (2008) confirm that marula is adapted to infertile soil and unimodal rainfall, continued lack of rain will result in large tree mortality (O'Connor & Goodall, 2017), with juveniles struggling to establish in water-scarce environments. Climate change models project both hotter, as well as drier conditions, for the whole northern region of South Africa (Tshiala et al., 2011; MacKellar, 2014; van Wilgen et al., 2015; Engelbrecht & Engelbrecht, 2016), including the lowveld. The implications of a changing climate include the sustainability of marula being compromised, due to the negative impacts of increased heat and decreased rainfall. Maranz (2009) demonstrates the consequences of human-linked species distributions, with the senescing savanna parklands in the Sahel region, as a consequence of permanent shifts in climatic zones. The early warning lessons from the marula bioeconmy in South Africa are replicable to other developing country contexts where a key NTFP is potentially at risk from climate change. This raises key concerns over the vulnerability of the marula bioeconomy, with livelihoods at risk, should climate change cause species demise.

As with all socio-ecological systems, the impact of declining fruit productivity has a direct human impact, with respondents who collect marula fruit indicating that they need to walk longer distances, to a greater number of trees in order to meet their fruit quotas (Chapter 6). In addition to this, many of the key large trees that respondents had previously utilised are perceived to either be dying or to be producing less fruit. These changes are directly attributed by respondents to the lack of rain in recent years (Chapter 7). Rankoana (2018) confirms how rural communities are quick to notice local environmental changes as their livelihoods, culture and social systems are all inextricably connected to the local environment. This example demonstrates how closely related resource reliance and the ecological traits of a natural resource really are, with even slight declines in the larger, more prolific fruiters negatively impacting livelihood sustenance. The average household in both Phalaborwa and Bushbuckridge was found to be living well below the poverty line, relying on social grants, with supplementary income from marula contributing more than half the household monthly income (Chapter 6) during marula season. This makes marula not only a crucial component of livelihood sustenance, but it means these households are extremely vulnerable to any variability in fruit supply and thus earning potential. This is supported by Mbiba et al. (2019), who showed that in terms of buffering local livelihoods, natural capital is far more important than social capital.

Respondents indicated the immense difficulties inherent in needing to walk longer distances, collecting fruit in 50 kg or 80 kg bags, simply to procure a small amount of income in terms of the financial return on fruit and beer sales (Chapter 6). In addition to reduced fruit drop, lack of rain also leads to less water content in fruit, which is considered bad for beer making (Chapter 7). Respondents indicted that when people taste the beer, if it does not taste good then they do not buy it. This means that in years with little rain, respondents also struggle to make a living from selling beer (Chapter 6). In addition, increasing temperature patterns, as confirmed by respondents over ~20 and ~50 year periods, have likely contributed to the observed shifts in the marula season with fruit drop starting and ending earlier. Increasing temperatures over this period, for the Limpopo region of South Africa, have been indicated by numerous climate models and reconstructions (Tshiala et al., 2011; MacKellar, 2014; van Wilgen et al., 2015; Engelbrecht & Engelbrecht, 2016). Tshiala et al. (2011) confirm temperature increases of 0.12°C per decade from 1950-1999 for this region, which corroborates respondents findings of

temperature increases in both Bushbuckridge and Phalaborwa over the past ~50 years or more. These changes in phenology, fruit productivity and quality have led many survey respondents to suggest that the biggest and best fruit providers have died and disappeared from the landscape (Chapter 6). This means crucial lost earnings, increased food insecurity and reduced livelihood resilience. The reality is that while the trees may not have actually disappeared, many of the important traits that helped to sustain livelihoods in the past have now changed, along with a changing climate.

Numerous studies have explored climatic changes using meteorological data, yet far fewer studies have attempted to understand people's perceptions of climate, including how perceived changes lead to behavioural adjustments. Understanding local perceptions towards a natural resource or ecosystem are a key aspect of increasing participatory conservation initiatives (Bennett, 2016). This speaks to the numerous authors who have promoted the importance of combining local knowledge with scientific data in order to acquire a deeper understanding of complex socio-ecological systems, as well as the changes within these systems (Berkes, 2003; Bomuhangi et al., 2016; Reyes-Garcia et al., 2016; Rankoana, 2018). In this study, respondents were asked a set of questions based on their age categories in order to gauge perceived environmental changes in terms of marula population numbers, as well as temperature and precipitation changes over periods of approximately 5, 20 and 50 years. Further, changes in resource use practices in response to any observed environmental shifts were also gauged. There was consensus amongst respondents, which lends credence to the findings (Reser et al., 2014), that marula numbers as well as productivity have declined over all three periods, whilst rainfall has decreased and temperatures have increased. These trends in rainfall and temperature, as observed by local communities in this study, have been confirmed by climate studies. For example, several studies indicate that overall temperatures have increased and rainfall has decreased over Limpopo during these time-frames (Tshiala et al, 2011; MacKellar, 2014; Engelbrecht & Engelbrecht, 2016; Archer at el., 2017; Siderius et al., 2018). The consequences of these climatic changes are that the remaining large fruiters in the landscape are being heavily utilised, especially as the numbers of these trees continue to diminish, according to the resource users (Chapter 6). These resource use patterns, in isolation and coupled with physiological stresses, not only exacerbate the chances of large tree mortality occurring, but also reduce the available fruit for recruitment, impacting marula SCD profiles on both ends of the life cycle (Chapter 3).

Finally, this dissertation looked at whether these perceptions of environmental and climatic change are leading to concern about the resource base. Specifically, whether this concern, in turn, has inspired pro-environmental behavioural changes (Chapter 7). Despite the consensus amongst respondents regarding increasing temperature and declining rainfall, as well as respondents linking these variables to a decrease in the resource base, this did not inspire direct behaviour change at present. The main behaviour change patterns indicated by respondents were to adapt current collection strategies to incorporate new collecting grounds within their village rangeland, expand collecting ranges to cover a larger area, or to utilise the rangeland of a neighbouring village. Increased stewardship practices, such as planting new trees or watering current trees, also did not feature prominently. This is potentially due to the longer time-frames required to obtain the benefit of additional fruit. However, a few respondents indicated that if the drought continued they would need to start watering their yard trees. These behavioural changes suggest that respondents are motivated more by the fear of lost future income, rather

than the well-being of the species. This was confirmed by respondents in both locations indicating a preference for mango over marula, which was explained as owing to the higher economic returns for lower labour inputs associated with mango. The levels of concern for marula were higher in Bushbuckridge compared to Phalaborwa, with a higher number of respondents in the former indicating a decline in fruit yield, which possibly explains this outcome. Fruit yields equate to income generation and so greater perceptions of a declining resource base are likely to lead to increased levels of concern for the resource (Hunter et al., 2010). Overall, the value of marula appears to have shifted, from a store of social and cultural capital to a financial commodity. This shift has been prompted by the increasing commercialisation of the resource, which have negatively affected practices around stewardship and resource conservation in Bushbuckridge but also Phalaborwa to a lesser degree (Chapter 7). However, despite lower levels of concern in Phalaborwa, the economic value of the fruit appears to have resulted in higher levels of resource stewardship and conservation here (Chapter 6).

8.3 Recommendations

The first step in ensuring the sustainability of marula is to carefully manage harvesting of this bioresource, which involves measuring the current status. Essentially, you can only manage what you measure. A key lesson from linking the social and ecological variables together in this study has been to illustrate the key importance of understanding the complete context of marula resource reliance, in this case, a bioresource with an important cultural as well as economic nexus. The second step is the on-going monitoring of the resource, which has multiple facets due to the complex value nexus. The sometimes shifting cultural, as well as economic value of marula, requires monitoring perceptions about the resource as well as changes to the economic and cultural status to continually gauge how these impact the resource base.

Marula populations, specifically male and large adults, are facing a range of threats across the various land-use types. This is contrasted with the cultural conservation narrative driving higher female and juvenile densities in yards. The solutions to these threats therefore involve addressing the various social perceptions and certain misconceptions pertaining to marula across the different land-use types. At present, the perception that marula trees, although not the largest individuals, are numerous across rangelands is leading to heightened levels of harvesting. The misconception is that marula is flourishing due to its ability to coppice (Chapter 3). However, with many of these trees trapped as non-functional adults in smaller size classes as a result of continuous cutting, this belief is of concern. Specifically, strongly coppicing trees such as marula are repeatedly targeted, trapping them within this positive feedback loop over time, which in turn reduces recruitment (Twine, 2005; Neke, 2006). Added to this complexity are the issues around male trees being chopped due to their 'barren status' as non-fruiting adults (Chapter 4). This further exacerbates the lower value status attributed to males in comparison to their female counterparts. A woman in her mid-twenties from Benfarm (Phalaborwa) explained: *"People know the cultural importance of the tree. They cut the male tree and leave the female tree."*

A further cause for concern is the fact that juveniles are being removed due to the perception that they are always numerous, and therefore dispensable and disposable (Chapter 5). Finally, there is the additional issue of a supposed rapid decline in the numbers of large adults in the population (Chapter 5). Social data indicate that this is possibly due to the compounded effects of numerous drought years, with many older respondents explaining how the trees have

"become dry" (Chapter 7). Merging these factors, the issue is whether pockets of cultural conservation practices are sufficient to overcome knowledge deficits around marula population numbers, including re-sprouting, gender differences and juvenile stewardship. Combined these are leading to potentially concerning density patterns across the land-use types. This is specifically troubling in light of the increases in human population growth leading to residential expansion. Finally, these issues are coupled with the pressure of new economic drivers, such as rapidly expanding fuelwood markets and the increasing commercialisation of the resource (Chapter 6).

Since the publication of the Millennium Ecosystem Assessment in 2000, multiple strategies, proposals and solutions have been put forward to try address the main issues concerning ecosystem services (ES), natural resource management and poverty reduction. Two approaches have garnered much attention, both in academic circles as well as amongst the development practitioner community, due to their more nuanced and localised focus. These approaches are the Payment for Ecosystem Services (PES) and Community-Based Natural Resource Management (CBNRM) approaches. CBNRM works to decentralise management and institutional approaches in order to distribute both authority and benefits to the communities most directly affected (Kaschula et al., 2005; Sola, 2015). CBNRM or Participatory Forest Management (PFM) is only considered pro-poor if it actively enhances the livelihood approaches of the poorest participants (Schreckenberg & Luttrell, 2009). A key critique of CBNRM has been the homogenisation of the concept of 'community' which has led to misguided, and sometimes even damaging outcomes, for the entire SES context (Kaschula et al., 2005; King & Peralvo, 2010). PES works on the supposed link between livelihood generation and biodiversity, assuming income from natural resources incentivises conservation. Once again, without understanding the pluralistic and multi-level nature of community-based conservation, approaches often fail to address local heterogeneity (Berkes, 2007; Khalid et al., 2013). Appreciating this local heterogeneity is important, especially in relation to how common property resources are managed locally. Within the South African context, this specifically pertains to traditional authorities in the context of NTFPs, a source of natural as well as ecological capital, whose use and patterns of reliance are often not sufficiently understood at the local level. A third approach is cooperative conservation (CC) which promotes community-led conservation initiatives, which utilise management strategies built on collaboration and cooperation (Klinger et al., 2007; Curry et al., 2020). While CC approaches have often been applied within the context of managing marine ecosystems such as fisheries (Ovando et al., 2012), a key aspect of this approach which is useful in the context of harvesting marula, is the idea of minimum and maximum size on harvestable individuals as well as specific quota allowances. This is especially applicable to harvesting fruit from larger marula trees, in order to ensure that recruitment is not negatively impacted.

Macharia et al. (2010) promote the value of education and awareness campaigns, in promoting biodiversity conservation in highland wetlands in Kenya (East Africa). In particular, the opportunity to sustainably manage and conserve wetlands amidst increasing population numbers, limited resources and poverty (Macharia et al., 2010). These lessons are interchangeable with the marula savanna context, where awareness campaigns amidst increasing population numbers, poverty and a decreasing resource base would potentially reduce instances of unnecessary removal of marula trees in communities. Especially, where a perceived threat to a new or existing building posed by an established marula tree, does not actually exist. Schultz (2011) highlights how widespread changes in behaviour result from an

overemphasis on both knowledge and awareness. In particular, knowledge assists in addressing the social biases that result from misperceptions regarding the severity of environmental problems (Schultz, 2011). Key aspects of any awareness or education campaign addressing misconceptions would include: highlighting the importance of male trees in the overall population; the key importance of large adult trees as prolific fruiters; the necessity of leaving sufficient juveniles for recruitment in yards and fields; and the fundamental role the male trees plays in pollination and the importance of culture (and thus the female tree) in community and cultural life.

As marula is increasingly utilised for local livelihood sustenance as well as a growing demand by commercial enterprises, such as beverages and skin care products, ensuring that local communities do not lose out to complicated supply chains needs to be a key consideration. Local social development initiatives that prioritise community development, while ensuring sustainable utilisation of the resource so that demand does not outstrip supply, is a key priority for the region. In addition, community owned and run enterprises, working in conjunction with Traditional Authorities will help to ensure a more equitable division of the proceeds from marula across the bioeconomy, while also helping to ensure sustainable harvesting. This approach is best described as a Cooperative Community Custodian Model (CCCM). This model is a key output of this PhD, which combines aspects of CBNRM with cooperative conservation (CC) approaches, applying these specifically to resources that are both culturally and economically valuable to local communities. Applying a cooperative farming approach with a conservation angle is particularly useful for a wild grown commodity such as marula, combining the best aspects of CBNRM and CC to ensure sustainable harvesting and community development outcomes.

Conservation models are increasingly being adapted to local contexts, which importantly include local communities as a key component of the conservation solutions being introduced. Where conservation and community development initiatives are combined, this often falls under the broad banner of Ecosystem-based Adaptation (EbA). When placed within the context of EbA approaches, bioresources and prospects for biotrade, provide an opportunity for more holistic conservation models that are centred around communities as the custodians of these key commodities. The CCCM model advocated here is a context specific version of EbA, which is particularly relevant where resources have both cultural as well as economic value. The creation of marula biotrade supply chains invokes a unique opportunity to simultaneously meet community development and conservation objectives within areas as such as the Kruger to Canyons Biosphere Reserve (K2C). Organisations such as Conservation South Africa are already applying an EbA approach to cattle farming in rangelands in this region. Using the existing community based structures of organisation already working in the lowveld, such as Conservation South Africa or K2C allows for existing structures, policies and approaches to be utilised and adapted. While there are multiple success stories within the K2C portfolio of community development projects, often these are smaller off-takers such as Small, Medium and Micro Enterprises (SMMEs) who have a direct relationship with the community collectors. In contrast, coordinated initiatives such as the Marula Industrial Hub may address some of the larger economic development requirements for the region, but do not directly address how sustainably the resource is harvested locally. An alternative option to PES, CBNRM & CC solutions is the CCCM model proposed here, which aims to address cultural, economic and ecological objectives simultaneously. In short, this approach advocates socially beneficial,

community-led conservation by managing natural resources, such as marula, to meet supply and demand while safe-guarding biodiversity objectives.

A CCCM for marula would need to have certain structures as well as key components tailored to the local context. However, this can be applied to other rural contexts where a bioresource is valued both economically as well as culturally. A marula conservation cooperative that utilises traditional authority structures to engage community led-conservation in natural resource management would have the following objectives:

(i) Create a self-sustaining community-based governance structure utilising local traditional authority structures to manage local biodiversity with inclusive representation across the marula collecting communities.

(ii) The bargaining power of large-scale community representation (especially against larger commercial off-takers) providing faster benefit for communities who are members of this governance structure, thereby creating clear incentives for increased engagement.

(iii) The governance structures ensure monitoring of resource practices and offer services (such as environmental education but also customary law fines administered through Traditional Authority structures) that address biodiversity exploitation.

(iv) A fair price for fair practice reward rule is established which ensures remuneration when conservation objectives are achieved, with the cost being built into the final product, which is marketed for meeting green/sustainability goals.

As the cooperative grows, this increases potential funds both in terms of supply to off-takers as well as remuneration to community collectors. This increase is premised on the long-term sustainability of the resource base. In other words, the greater the conservation goals achieved, the higher the economic reward, which in turn incentivises practices such as planting trees in yards and fields to ensure key ecological indicators such as trees/ha are achieved. The conservation cooperative would be housed within traditional authority structures but would require representation from numerous regional organisations in terms of the lowveld marula bioeconomy. These would likely include: SANParks, Kruger to Canyons Biosphere (K2C), South African National Biodiversity Network (SANBI), South African Environmental Observation Network (SAEON), local NGOs working in this space (such as Wildlands), local universities and research institutions, local Government (LEDET and Mpumalanga Tourism and Parks Agency (MPTA) as well as the various Government district offices at the municipal level. It is important to state that this model is only likely to be successful where the resource forms part of established supply chains, yet is still valued culturally. This is because economic incentives alone have often proven insufficient, as the Payment for Ecosystem Services (PES) literature details. On the other end of the spectrum, one of the greatest critiques levelled against CBNRM and CC are that they fundamentally fail to address the plight of the rural poor, which are often classified as a homogenous group. CCCM differs from these approaches in that it focuses on contexts where a commodity is already conserved culturally. This means the added layer of economic value, specifically where a degree of income surety is provided, makes this approach far more likely to succeed.

Considering marula's range across Southern Africa, there are numerous contexts where this model could possibly be adapted locally, including in KwaZulu-Natal province. In addition, locations across the sub-continent, where baobabs are an important source of NTFP supplementary income, would also provide possible contexts. However, as highlighted in the baobab literature, cultural value must accommodate the economic value in order for conservation outcomes to be successful (Duvall, 2007; Venter & Witkowski, 2010). Other contexts across Africa identified in this study as being important hubs for NTFP usage and reliance include Benin, where NTFPs contribute around 39% of local household income and Cameroon, where NTFPs contribute 15% (Ambrose-Oji, 2003). In Zambia, NTFPs provide 34% of household incomes (Mulenga et al., 2011) and Sudan, supplementary NTFP income from fruiting tree species ranged from 26% to 51% (Adam et al., 2013). In Ethiopia, NTFPs contribute to almost half (47%) of household income (Melaku et al., 2014). In addition, communities relying on NTFPs in India, Indonesia as well as Brazil may also provide important contexts where a community custodian model of conservation may lead to sustainable harvesting of forest resources. In all these locations, the reliance on NTFPs as a key source of supplementary income is the first step, however this must be accompanied by a cultural appreciation of the species by a community that practices certain rites or rituals associated with the economically valuable resource.

In addition to the practical solutions proposed, this study also aims to promote social and environmental science approaches that emphasise how to integrate human dimensions to improve conservation are a key element of research agendas going forward (Bennett et al., 2017). By linking findings from the three ecological chapters with the economic and cultural drivers, this research has uncovered three key knowledge contributions. The first is the necessity of addressing the misconceptions around male trees being 'barren' and therefore not making an important contribution to marula populations, the removal of plentiful juveniles being justifiable and the resource being sustainably harvested for fuelwood in rangelands. These key points were highlighted when the social data was used to identify and explain patterns in the marula densities. The second key contribution was the reality of variable cultural conservation outcomes, highlighting how combining scientific approaches with narrative understandings require being cognisant that not all the outcomes are immediately apparent, co-dependent or quantifiable. However, contradictions can be resolved provided the knowledge is not taken out of the cultural context (Boillat & Berkes, 2013). The third knowledge contribution hinges on the value of not just combining different methodologies, but also different types of knowledge. Specifically, for marula populations, this entailed revealing how demographic data lent credibility to size-class distribution findings, which were further validated by local traditional knowledge. The value of combining social data with SCD profiles was promoted by Lykke et al. (1998).

Embedded within the three knowledge contributions are eight novel findings, relevant to the marula bioeconomy context, but pertinent to other ecosystems where a key NTFP is being overharvested and degraded. The key findings are as follows:

1. An updated inventory for marula, including the current resource status from an ecological as well as a social perspective.

2. Key insights into the contributions of NTFPs in livelihoods sustenance in non-conservation savanna areas, in particular the crucial supplementary income provided by marula resources.
3. The potential dire consequences of a changing climate for marula resource users, including the need to buffer natural capital from impacts such as reduced fruit yields and phenology changes.
4. The importance of economic and cultural values and data in contextualising ecological findings, specifically in terms of how behaviour patterns drive resource degradation.
5. The value of combining quantitative and qualitative research methodologies, as well as scientific and traditional knowledge systems to lend credence to data findings as well as produce more holistic insights.
6. Considering the overarching poverty levels of the communities in this study, the on-going commercialisation of a resource such as marula, needs to be carefully undertaken. This includes advocating for decent pay for the communities at the beginning of long and complicated supply chains, such as selling the fruit to large commercial enterprises.
7. The importance of preserving cultural traditions and customs, specifically those that may be retained and passed on orally. Recording these practices so they are not lost with the older generation is crucial.
8. To ensure equity of income, cultural conservation and sustainable harvesting requires local governance structures that promote participatory and inclusive management regimes, as well as the promotion of local cultures, practices and traditions.

Based on the above novel knowledge contributions, the following recommendations are made to ensure cultural diversity (social capital), economic stability (financial capital) and ecological integrity (natural capital) going forward:

1. **Outreach and awareness campaigns:** These are a crucial aspect of the future sustainability of this important NTFP resource. Specifically, community level programmes in schools that teach not only the importance of biodiversity conservations more widely, but specifically address the misconceptions around marula resource use. These include the importance of male trees in the population for pollination, the dangers of overharvesting trees in rangelands for fruit and/or wood, the necessity of large juvenile numbers to support population growth as well as the importance of maintaining large trees in yards wherever possible.

2. **Enhance local traditional governance and bolster customary practices**: Local governance approaches need to bolster the role of traditional structures in communities, including demarcating clear roles and responsibilities for local traditional authorities in policy approaches going forward. This will help to maintain important cultural practices that lead to marula conservation, as well as build social capital by reviving practices that involve communal harvesting, sharing and preparation of the beer.

3. **Quantify the financial contributions of marula**: The financial contributions of marula to lowveld household income need to be appropriately quantified and included in policy approaches that address the risks of climate change for the Limpopo and Mpumalanga provinces. The actual value of the resource remains speculative, meaning financial

resources are not sufficiently directed towards safe-guarding local supply chains at present. This is particularly important, with climate change set to decrease the resource base, thereby increasing vulnerability.

A key part of quantifying the financial value of the resource is to take into account the economies of scale afforded to large offtakers, when large tracts of communities essentially take on embedded cultivation costs by providing the inputs of land and water for free. The equivalent land required to provide the same return on investment would likely make the break-even costs insurmountable in the case of larger tree species such as marula or baobabs. It is important to remember that while the bioresources may come from transformed landscapes, such as yards and fields, the on-going cultivation of these key species depends on the anthropogenic value allocated to these resources (both financial as well as cultural/spiritual). Recognising that cultural practices are part of the solution but may also be endangered, requires investing in local communities so cultural practices (such as sharing the beer) can literally afford to continue. Many of these key cultural practices are being discontinued in lieu of selling all the available fruit as well as a general break-down in community structures, as indicated by many of the elders interviewed.

In this context, a holistic approach to conservation recongnises that in order to ensure a sustainable supply for economic purposes, the cultural value needs to be upheld, as this results in tree stewardship. Paying more for the fruit may enable community members to keep some aside for cultural practices.

4. **The Importanance of understanding a species holistically**: Multi-use species need to be the focus of studies that aim to uncover the nuances of these complexities, by measuring and monitoing the resource, then translating these into economic and social development terms and real-world deliverables. In relation to marula, ecological characteristics, such as the separate genders of the species, contribute to it's social value, which in turn determines how the resource is used, including for economic purposes.

   A key example of how this nexus impacts the species is the issue of recrutiment bottlenecks. In terms of population demography, bottlenecks limit the species ability to recruit, which means not only diminshed seedlings, but also fruit production in the long-term. While there are many factors leading to ecological bottlenecks, human resource use in the form of overharvesting fruit, can lead to an anthropogenic bottleneck. This is especially true in over-utilised habitats. However, anthropogenic factors can also result in the opposite. Where fruit production (based on gender) creates the valued bioresource, which is sold for profit, this can lead to protection (cultural conservation) or resource practices actually enhancing recruitment (such as beer making in yards). In these examples, monitoring life stages in non-conservation areas requires a comprehensive understanding of both resource use as well as value attribution (incluing cultural aspects). Understanding these in tandem can lead to more comprehenasive custodian models that are adapted to local contexts and therefore more likely to succeed in practice.

5. **Long-term data collection and studies:** This study provided an updated inventory of marula for the lowveld region of South Africa, which built on the previous work of Shackleton from 2002-2005. Ensuring that inventories for important NTFP such as marula are not only continued, but kept up to date, are crucial for the future sustainability of these important natural resources.

   A key aspect of this solution is climate niche modelling, specifically to understand where the species is likely to persist into the future on various timelines (20, 50 and 100 years). The GPS coordinates for several thousand marula trees from this study in the Lowveld can be used for running these models.

   Climate niche modelling also links to ecological thresholds (or rather the exceeding of ecological thresholds) and phenologies, such as seed thermal tolerance, germination requirements, flowering and fruiting as well as overlap with pollinators. These will all be crucial data points to understand, with climate change affecting edge of range provenance species such as marula.

6. **Cautionary commercialisation:** Commercialisation of NTFP resources, such as marula, have neither been proven to enhance biodiversity conservation, nor adequately sustain the communities who are the primary producers in long, complicated supply chains. In fact, communities are often left worse off than before, which is a concerning reality considering the extent of marula resource reliance in the lowveld bioeconomy. The potentially devastating socio-economic implications of the large-scale domestication or cultivation of marula, need to be carefully weighed up against the private commercial benefits to large-scale companies.

   A key aspect of this solution requires interrogating the interface, as well as power dynamics, between informal and formal industries. This is critical to ensure that livelihoods can be equitably obtained. Key elements to consider are the impact of the formal sector on resource value, positive and negative relationships with communities and fair treatment (including decent pay) of the informal sector by the formal industry partner.

   Ecologists wanting to protect a species often recommend removing the species from the context in which it is being overutilised. When it comes to NTFPs, this can include pressure to move away from using the natural resources. While initally, this may be a good strategy as it reduces harvesting pressure, often indigenous species are then removed and replaced by more lucrative/valuable cash crops, or other land-use practices that replace natural habitats. In the lowveld context, mango is a key example raised in competition to marula. Working with local communities, as well as larger off-takers both up and down the supply chain is far more desireable, as it affords an opportunity for equilibrium to be restored to the system.

8.4 Conclusion

The ecological indicators used to assess the status of the marula population in the species' bioeconomy catchment suggest that at present the populations are stable and recruiting across land-use types. However, certain findings indicate there could be cause for concern in terms of the sustainability of the resource, including overharvesting of marula for both fruit and wood in rangelands, as well as the large-scale removal of adult marula trees in yards and fields, for building houses and planting arable crops, respectively. In addition, male trees are often removed before female trees, deemed more valuable for their fruit, leading to skewed gender ratios, specifically in yards. Furthermore, the abundant germination of seedlings in yards, where marula kernels are discarded from making marula beer, has led to the misconception that juveniles are numerous and can therefore be removed en masse. The anecdote to many of these threats to marula populations is the cultural value of the tree, which leads to pockets of conservation across the landscape due to the inherent social value of the tree, the fruit and the beer made from the fruit. More recently, the economic value of the tree has begun to surpass the cultural value, with the financial value of the fruit defining resource use choices. Added to this, cultural values are declining in communities, along with the traditional authority of customary leaders, specifically amongst a younger generation who appreciate marula more for it's economic value. This increasing economic value can lead to the protection of marula, provided the resource base is not overharvested as a result. The best examples of protection occurred where both values were present. Combined with the cultural conservation of the species, this value nexus is based on the overall socio-economic value of the tree.

Educational campaigns in schools and in association with traditional leaders is one possible avenue for increasing awareness around the impacts of overharvesting on marula in rangelands, the necessity of stewardship and care for juvenile plants and the need to conserve male as well as female adults across all three land-use types, not just in yards where males receive some degree of protection when used for cultural ceremonies. In addition, on-going studies to keep marula inventories up to date, so that the status of the resource can be monitored on a continual basis will prove critical to ensuring the growing commercialisation of marula does not negatively impact either the resource, or the communities relying on this important resource. Finally, it is crucial that on-going studies are cognisant of the important interlinking features of the social and ecological aspects of the marula bioeconomy, ensuring that marula population demographics are understood as a key output of the socio-ecological system within which the resource is embedded. Studies that utilise social ecology approaches will remain most relevant and useful for tracking the trajectory of marula populations within the lowveld region of South Africa. The current plight of marula across these different land-use and settlement types can possibly be best summed up by an old woman from Hokwe village in Bushbuckridge who sadly explained: *"People are chopping marula trees down to make space to build houses or in their fields to plant crops. Domestic livestock eat the seedlings in yards and fields, which is killing the next generation, while humans destroy the older trees for wood. Soon we will have nothing left."*

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10. Appendix

10.1. Density Data: Descriptive Statistics, Tests of Normality and Histograms

10.1.1. Descriptive Statistics

					Statistic	Std. Error
Phalaborwa	OverallDensity	Yard (Y)	Mean		13,861	1,853
			95% Confidence Interval for Mean	Lower Bound	10,192	
				Upper Bound	17,531	
			5% Trimmed Mean		10,824	
			Median		8,094	
			Variance		412,131	
			Std. Deviation		20,301	
			Minimum		0,000	
			Maximum		122,549	
			Range		122,549	
			Interquartile Range		17,942	
			Skewness		3,131	0,221
			Kurtosis		12,407	0,438
		Field (F)	Mean		11,438	2,046
			95% Confidence Interval for Mean	Lower Bound	7,365	
				Upper Bound	15,510	
			5% Trimmed Mean		8,516	
			Median		4,604	
			Variance		334,945	
			Std. Deviation		18,302	
			Minimum		0,000	
			Maximum		123,865	
			Range		123,865	

			Interquartile Range		11,267	
			Skewness		3,898	0,269
			Kurtosis		19,319	0,532
		Rangelands (R)	Mean		6,593	0,801
			95% Confidence Interval for Mean	Lower Bound	4,916	
				Upper Bound	8,270	
			5% Trimmed Mean		6,448	
			Median		5,700	
			Variance		12,837	
			Std. Deviation		3,583	
			Minimum		1,600	
			Maximum		14,200	
			Range		12,600	
			Interquartile Range		6,050	
			Skewness		0,689	0,512
			Kurtosis		-0,506	0,992
	AdultDensity	Yard (Y)	Mean		8,995	0,992
			95% Confidence Interval for Mean	Lower Bound	7,030	
				Upper Bound	10,959	
			5% Trimmed Mean		7,622	
			Median		7,474	
			Variance		118,113	
			Std. Deviation		10,868	
			Minimum		0,000	
			Maximum		62,241	
			Range		62,241	
			Interquartile Range		13,367	
			Skewness		2,052	0,221
			Kurtosis		5,806	0,438

		Field (F)	Mean		3,391	0,506
			95% Confidence Interval for Mean	Lower Bound	2,383	
				Upper Bound	4,398	
			5% Trimmed Mean		2,815	
			Median		1,915	
			Variance		20,509	
			Std. Deviation		4,529	
			Minimum		0,000	
			Maximum		20,761	
			Range		20,761	
			Interquartile Range		4,466	
			Skewness		1,999	0,269
			Kurtosis		3,709	0,532
		Rangelands (R)	Mean		5,428	0,655
			95% Confidence Interval for Mean	Lower Bound	4,058	
				Upper Bound	6,799	
			5% Trimmed Mean		5,273	
			Median		4,900	
			Variance		8,570	
			Std. Deviation		2,927	
			Minimum		1,600	
			Maximum		12,061	
			Range		10,461	
			Interquartile Range		3,330	
			Skewness		0,963	0,512
			Kurtosis		0,262	0,992
	Larger43cm Density	Yard (Y)	Mean		4,925	0,563
			95% Confidence	Lower	3,811	

		Interval for Mean	Bound		
			Upper Bound	6,039	
		5% Trimmed Mean		4,267	
		Median		2,973	
		Variance		38,015	
		Std. Deviation		6,166	
		Minimum		0,000	
		Maximum		31,120	
		Range		31,120	
		Interquartile Range		8,488	
		Skewness		1,409	0,221
		Kurtosis		2,278	0,438
	Field (F)	Mean		1,966	0,343
		95% Confidence Interval for Mean	Lower Bound	1,283	
			Upper Bound	2,649	
		5% Trimmed Mean		1,452	
		Median		0,949	
		Variance		9,424	
		Std. Deviation		3,070	
		Minimum		0,000	
		Maximum		15,462	
		Range		15,462	
		Interquartile Range		2,791	
		Skewness		2,707	0,269
		Kurtosis		8,119	0,532
	Rangelands (R)	Mean		2,585	0,338
		95% Confidence Interval for Mean	Lower Bound	1,876	
			Upper Bound	3,293	

		5% Trimmed Mean		2,527	
		Median		2,100	
		Variance		2,292	
		Std. Deviation		1,514	
		Minimum		0,600	
		Maximum		5,600	
		Range		5,000	
		Interquartile Range		2,428	
		Skewness		0,473	0,512
		Kurtosis		-1,065	0,992
JuvenileDensity	Yard (Y)	Mean		4,867	1,434
		95% Confidence Interval for Mean	Lower Bound	2,026	
			Upper Bound	7,707	
		5% Trimmed Mean		2,099	
		Median		0,000	
		Variance		246,920	
		Std. Deviation		15,714	
		Minimum		0,000	
		Maximum		118,026	
		Range		118,026	
		Interquartile Range		0,000	
		Skewness		5,285	0,221
		Kurtosis		32,267	0,438
	Field (F)	Mean		8,064	1,832
		95% Confidence Interval for Mean	Lower Bound	4,418	
			Upper Bound	11,711	
		5% Trimmed Mean		5,247	
		Median		2,114	
		Variance		268,447	

			Std. Deviation		16,384	
			Minimum		0,000	
			Maximum		111,478	
			Range		111,478	
			Interquartile Range		9,114	
			Skewness		4,188	0,269
			Kurtosis		21,627	0,532
		Rangelands (R)	Mean		1,144	0,467
			95% Confidence Interval for Mean	Lower Bound	0,167	
				Upper Bound	2,122	
			5% Trimmed Mean		0,816	
			Median		0,337	
			Variance		4,359	
			Std. Deviation		2,088	
			Minimum		0,000	
			Maximum		8,200	
			Range		8,200	
			Interquartile Range		1,103	
			Skewness		2,682	0,512
			Kurtosis		7,192	0,992
	MaleDensity	Yard (Y)	Mean		3,393	0,534
			95% Confidence Interval for Mean	Lower Bound	2,336	
				Upper Bound	4,451	
			5% Trimmed Mean		2,572	
			Median		0,000	
			Variance		34,239	
			Std. Deviation		5,851	
			Minimum		0,000	
			Maximum		31,120	

		Range		31,120	
		Interquartile Range		5,221	
		Skewness		2,190	0,221
		Kurtosis		5,329	0,438
	Field (F)	Mean		1,599	0,328
		95% Confidence Interval for Mean	Lower Bound	0,946	
			Upper Bound	2,252	
		5% Trimmed Mean		1,139	
		Median		0,232	
		Variance		8,603	
		Std. Deviation		2,933	
		Minimum		0,000	
		Maximum		13,841	
		Range		13,841	
		Interquartile Range		1,760	
		Skewness		2,577	0,269
		Kurtosis		6,828	0,532
	Rangelands (R)	Mean		2,746	0,389
		95% Confidence Interval for Mean	Lower Bound	1,932	
			Upper Bound	3,560	
		5% Trimmed Mean		2,673	
		Median		2,400	
		Variance		3,027	
		Std. Deviation		1,740	
		Minimum		0,200	
		Maximum		6,600	
		Range		6,400	
		Interquartile Range		2,300	
		Skewness		0,656	0,512

		Kurtosis		-0,208	0,992
FemaleDensity	Yard (Y)	Mean		5,635	0,685
		95% Confidence Interval for Mean	Lower Bound	4,278	
			Upper Bound	6,992	
		5% Trimmed Mean		4,699	
		Median		3,556	
		Variance		56,366	
		Std. Deviation		7,508	
		Minimum		0,000	
		Maximum		31,270	
		Range		31,270	
		Interquartile Range		8,694	
		Skewness		1,652	0,221
		Kurtosis		2,474	0,438
	Field (F)	Mean		1,534	0,309
		95% Confidence Interval for Mean	Lower Bound	0,920	
			Upper Bound	2,148	
		5% Trimmed Mean		1,093	
		Median		0,406	
		Variance		7,617	
		Std. Deviation		2,760	
		Minimum		0,000	
		Maximum		15,462	
		Range		15,462	
		Interquartile Range		1,872	
		Skewness		2,977	0,269
		Kurtosis		10,371	0,532
	Rangelands (R)	Mean		2,568	0,331
		95% Confidence	Lower	1,875	

			Interval for Mean	Bound		
				Upper Bound	3,261	
			5% Trimmed Mean		2,481	
			Median		2,300	
			Variance		2,194	
			Std. Deviation		1,481	
			Minimum		0,400	
			Maximum		6,305	
			Range		5,905	
			Interquartile Range		1,789	
			Skewness		1,018	0,512
			Kurtosis		0,881	0,992
Bushbuckridge	OverallDensity	Yard (Y)	Mean		25,690	4,119
			95% Confidence Interval for Mean	Lower Bound	17,534	
				Upper Bound	33,846	
			5% Trimmed Mean		18,460	
			Median		8,963	
			Variance		2035,949	
			Std. Deviation		45,121	
			Minimum		0,000	
			Maximum		271,903	
			Range		271,903	
			Interquartile Range		23,418	
			Skewness		3,640	0,221
			Kurtosis		15,450	0,438
		Field (F)	Mean		7,367	0,726
			95% Confidence Interval for Mean	Lower Bound	5,922	
				Upper Bound	8,811	

			5% Trimmed Mean		6,782	
			Median		5,470	
			Variance		42,145	
			Std. Deviation		6,492	
			Minimum		0,000	
			Maximum		40,519	
			Range		40,519	
			Interquartile Range		8,072	
			Skewness		2,064	0,269
			Kurtosis		7,429	0,532
		Rangelands (R)	Mean		13,377	1,509
			95% Confidence Interval for Mean	Lower Bound	10,219	
				Upper Bound	16,535	
			5% Trimmed Mean		12,722	
			Median		12,400	
			Variance		45,523	
			Std. Deviation		6,747	
			Minimum		4,727	
			Maximum		33,810	
			Range		29,083	
			Interquartile Range		7,254	
			Skewness		1,412	0,512
			Kurtosis		3,356	0,992
	AdultDensity	Yard (Y)	Mean		8,897	1,045
			95% Confidence Interval for Mean	Lower Bound	6,828	
				Upper Bound	10,966	
			5% Trimmed Mean		7,435	
			Median		5,374	
			Variance		130,978	

		Std. Deviation		11,445	
		Minimum		0,000	
		Maximum		78,355	
		Range		78,355	
		Interquartile Range		14,152	
		Skewness		2,687	0,221
		Kurtosis		11,254	0,438
	Field (F)	Mean		4,747	0,509
		95% Confidence Interval for Mean	Lower Bound	3,734	
			Upper Bound	5,761	
		5% Trimmed Mean		4,298	
		Median		3,634	
		Variance		20,745	
		Std. Deviation		4,555	
		Minimum		0,000	
		Maximum		32,415	
		Range		32,415	
		Interquartile Range		5,238	
		Skewness		3,114	0,269
		Kurtosis		16,289	0,532
	Rangelands (R)	Mean		5,406	0,617
		95% Confidence Interval for Mean	Lower Bound	4,115	
			Upper Bound	6,697	
		5% Trimmed Mean		5,083	
		Median		4,787	
		Variance		7,610	
		Std. Deviation		2,759	
		Minimum		2,549	
		Maximum		14,067	

			Range		11,518	
			Interquartile Range		3,751	
			Skewness		1,759	0,512
			Kurtosis		4,037	0,992
	Larger43cm Density	Yard (Y)	Mean		3,124	0,408
			95% Confidence Interval for Mean	Lower Bound	2,315	
				Upper Bound	3,933	
			5% Trimmed Mean		2,580	
			Median		0,000	
			Variance		20,013	
			Std. Deviation		4,474	
			Minimum		0,000	
			Maximum		22,962	
			Range		22,962	
			Interquartile Range		5,240	
			Skewness		1,711	0,221
			Kurtosis		3,284	0,438
		Field (F)	Mean		2,088	0,321
			95% Confidence Interval for Mean	Lower Bound	1,449	
				Upper Bound	2,728	
			5% Trimmed Mean		1,793	
			Median		0,582	
			Variance		8,250	
			Std. Deviation		2,872	
			Minimum		0,000	
			Maximum		10,893	
			Range		10,893	
			Interquartile Range		3,273	

		Skewness		1,377	0,269
		Kurtosis		0,869	0,532
	Rangelands (R)	Mean		2,082	0,311
		95% Confidence Interval for Mean	Lower Bound	1,432	
			Upper Bound	2,732	
		5% Trimmed Mean		2,034	
		Median		1,834	
		Variance		1,929	
		Std. Deviation		1,389	
		Minimum		0,238	
		Maximum		4,800	
		Range		4,562	
		Interquartile Range		1,885	
		Skewness		0,779	0,512
		Kurtosis		-0,284	0,992
JuvenileDensity	Yard (Y)	Mean		16,703	3,729
		95% Confidence Interval for Mean	Lower Bound	9,319	
			Upper Bound	24,087	
		5% Trimmed Mean		9,506	
		Median		2,967	
		Variance		1668,670	
		Std. Deviation		40,849	
		Minimum		0,000	
		Maximum		259,819	
		Range		259,819	
		Interquartile Range		13,997	
		Skewness		4,342	0,221
		Kurtosis		21,068	0,438
	Field (F)	Mean		2,655	0,421

			95% Confidence Interval for Mean	Lower Bound	1,816	
				Upper Bound	3,493	
			5% Trimmed Mean		2,173	
			Median		0,805	
			Variance		14,196	
			Std. Deviation		3,768	
			Minimum		0,000	
			Maximum		16,240	
			Range		16,240	
			Interquartile Range		4,269	
			Skewness		1,805	0,269
			Kurtosis		2,918	0,532
		Rangelands (R)	Mean		7,951	1,102
			95% Confidence Interval for Mean	Lower Bound	5,644	
				Upper Bound	10,259	
			5% Trimmed Mean		7,676	
			Median		7,800	
			Variance		24,307	
			Std. Deviation		4,930	
			Minimum		1,112	
			Maximum		19,743	
			Range		18,631	
			Interquartile Range		7,055	
			Skewness		0,747	0,512
			Kurtosis		0,352	0,992
	MaleDensity	Yard (Y)	Mean		3,634	0,503
			95% Confidence Interval for Mean	Lower Bound	2,638	
				Upper	4,630	

			Bound		
		5% Trimmed Mean		2,867	
		Median		0,000	
		Variance		30,350	
		Std. Deviation		5,509	
		Minimum		0,000	
		Maximum		29,383	
		Range		29,383	
		Interquartile Range		5,758	
		Skewness		2,175	0,221
		Kurtosis		5,799	0,438
	Field (F)	Mean		2,459	0,316
		95% Confidence Interval for Mean	Lower Bound	1,829	
			Upper Bound	3,089	
		5% Trimmed Mean		2,107	
		Median		1,577	
		Variance		8,009	
		Std. Deviation		2,830	
		Minimum		0,000	
		Maximum		16,207	
		Range		16,207	
		Interquartile Range		2,968	
		Skewness		2,185	0,269
		Kurtosis		6,833	0,532
	Rangelands (R)	Mean		3,159	0,417
		95% Confidence Interval for Mean	Lower Bound	2,287	
			Upper Bound	4,031	
		5% Trimmed Mean		2,926	
		Median		2,400	

			Variance		3,472	
			Std. Deviation		1,863	
			Minimum		1,394	
			Maximum		9,131	
			Range		7,738	
			Interquartile Range		1,855	
			Skewness		2,013	0,512
			Kurtosis		4,702	0,992
	FemaleDensity	Yard (Y)	Mean		5,187	0,685
			95% Confidence Interval for Mean	Lower Bound	3,830	
				Upper Bound	6,544	
			5% Trimmed Mean		4,219	
			Median		2,383	
			Variance		56,359	
			Std. Deviation		7,507	
			Minimum		0,000	
			Maximum		48,972	
			Range		48,972	
			Interquartile Range		8,456	
			Skewness		2,520	0,221
			Kurtosis		9,546	0,438
		Field (F)	Mean		1,992	0,237
			95% Confidence Interval for Mean	Lower Bound	1,519	
				Upper Bound	2,464	
			5% Trimmed Mean		1,799	
			Median		1,373	
			Variance		4,503	
			Std. Deviation		2,122	
			Minimum		0,000	

			Maximum		8,104	
			Range		8,104	
			Interquartile Range		3,019	
			Skewness		1,091	0,269
			Kurtosis		0,549	0,532
		Rangelands (R)	Mean		2,066	0,265
			95% Confidence Interval for Mean	Lower Bound	1,512	
				Upper Bound	2,620	
			5% Trimmed Mean		2,021	
			Median		1,820	
			Variance		1,400	
			Std. Deviation		1,183	
			Minimum		0,000	
			Maximum		4,936	
			Range		4,936	
			Interquartile Range		1,864	
			Skewness		0,589	0,512
			Kurtosis		0,438	0,992

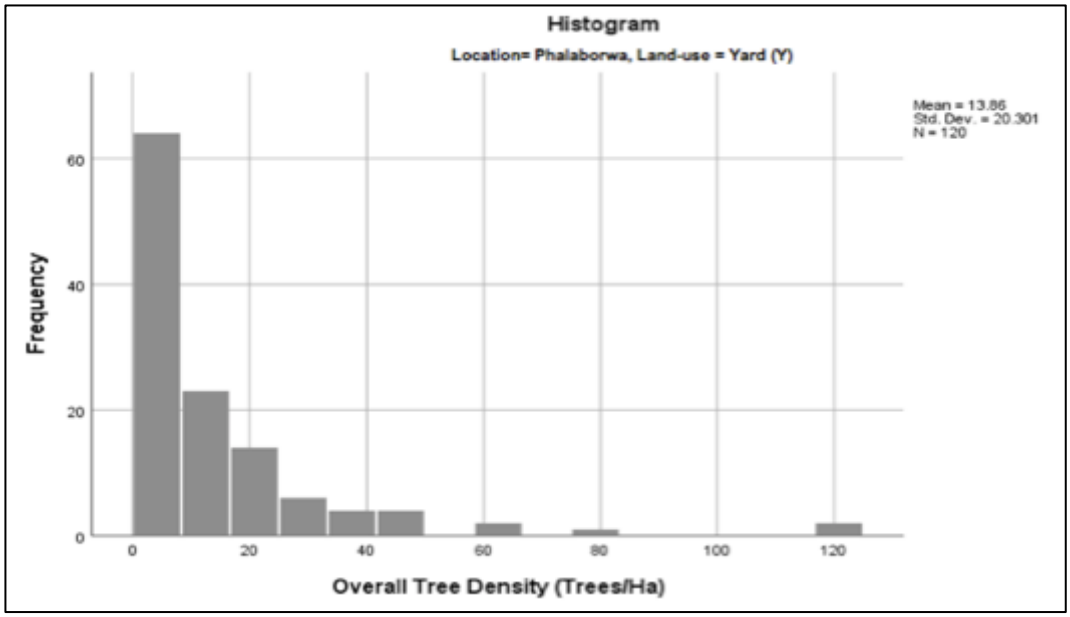
10.1.2 Tests for Normality

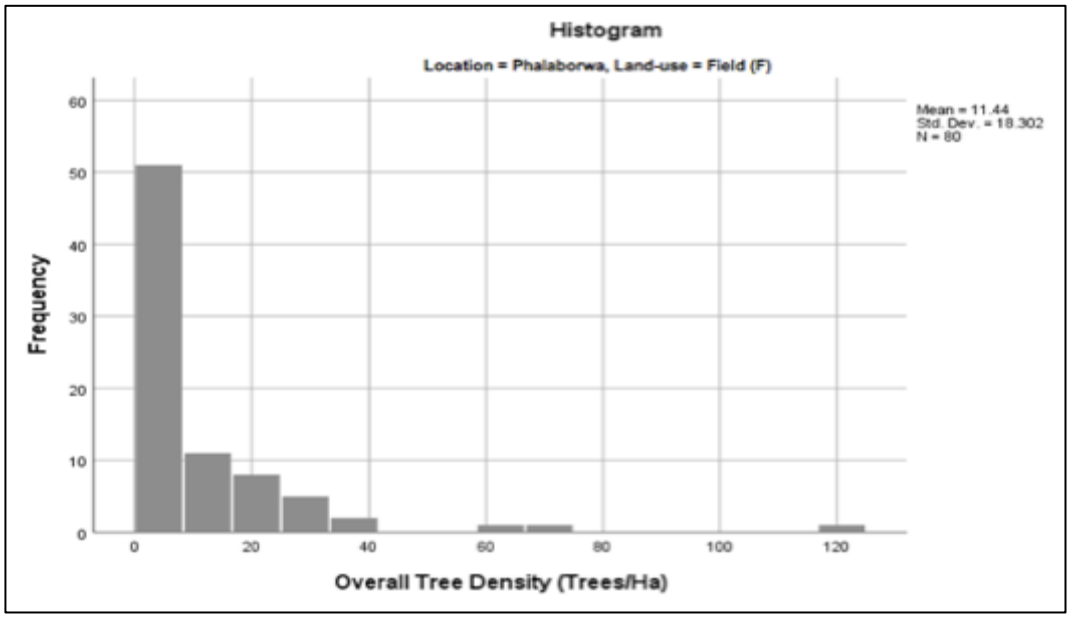
Location			Kolmogorov-Smirnov[a]			Shapiro-Wilk		
			Statistic	df	Sig.	Statistic	df	Sig.
Phalaborwa	OverallDensity	Yard (Y)	0,247	120	0,000			
		Field (F)	0,266	80	0,000			
		Rangelands (R)				0,929	20	0,150
	AdultDensity	Yard (Y)	0,204	120	0,000			
		Field (F)	0,227	80	0,000			
		Rangelands (R)				0,912	20	0,068
	Larger43cm Density	Yard (Y)	0,271	120	0,000			
		Field (F)	0,261	80	0,000			
		Rangelands (R)				0,921	20	0,104
	JuvenileDensity	Yard (Y)	0,397	120	0,000			

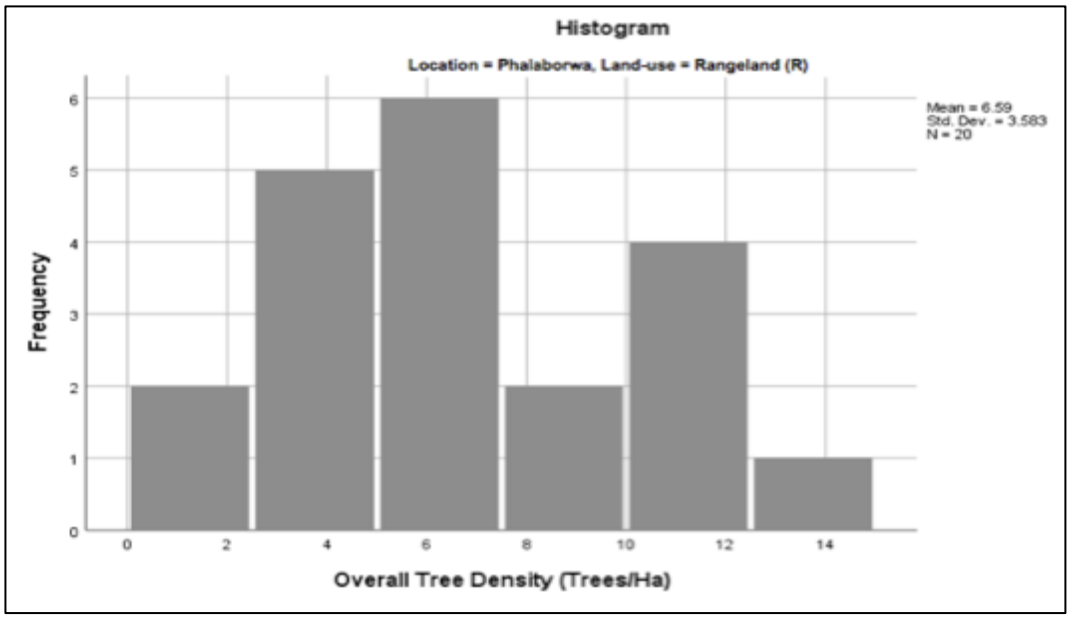
		Field (F)	0,311	80	0,000			
		Rangelands (R)				0,595	20	0,000
	MaleDensity	Yard (Y)	0,344	120	0,000			
		Field (F)	0,293	80	0,000			
		Rangelands (R)				0,950	20	0,365
	FemaleDensity	Yard (Y)	0,240	120	0,000			
		Field (F)	0,289	80	0,000			
		Rangelands (R)				0,926	20	0,131
Bushbuckridge	OverallDensity	Yard (Y)	0,285	120	0,000			
		Field (F)	0,139	80	0,001			
		Rangelands (R)				0,896	20	0,035
	AdultDensity	Yard (Y)	0,218	120	0,000			
		Field (F)	0,158	80	0,000			
		Rangelands (R)				0,839	20	0,004
	Larger43cm Density	Yard (Y)	0,299	120	0,000			
		Field (F)	0,234	80	0,000			
		Rangelands (R)				0,913	20	0,073
	JuvenileDensity	Yard (Y)	0,341	120	0,000			
		Field (F)	0,241	80	0,000			
		Rangelands (R)				0,937	20	0,213
	MaleDensity	Yard (Y)	0,270	120	0,000			
		Field (F)	0,192	80	0,000			
		Rangelands (R)				0,779	20	0,000
	FemaleDensity	Yard (Y)	0,245	120	0,000			
		Field (F)	0,174	80	0,000			
		Rangelands (R)				0,967	20	0,689

10.1.3 Histograms

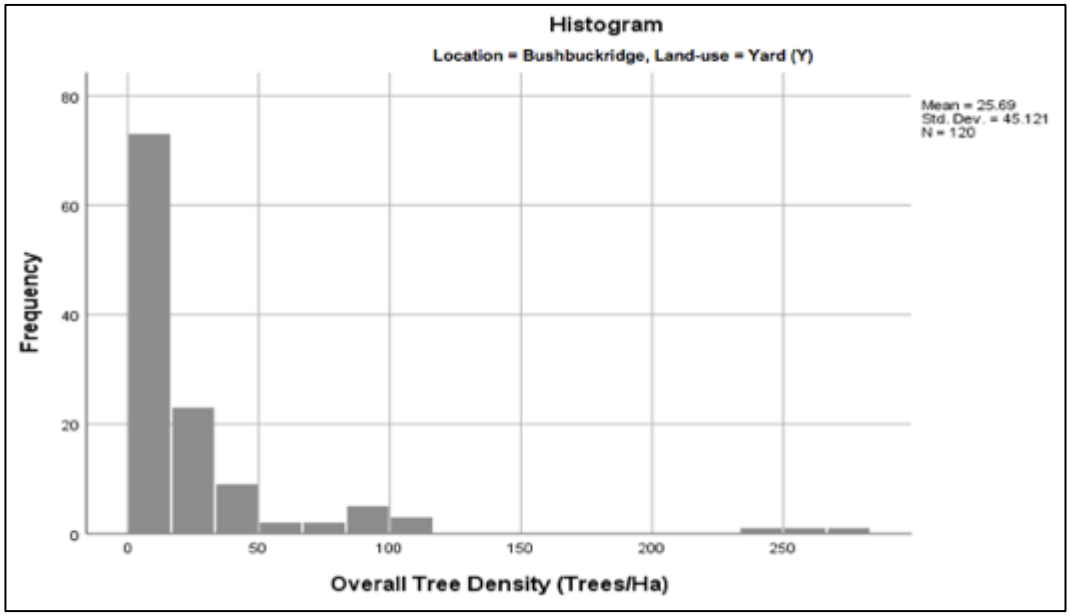
10.1.3.1 Phalaborwa Overall Density (Yards, Fields & Rangelands)

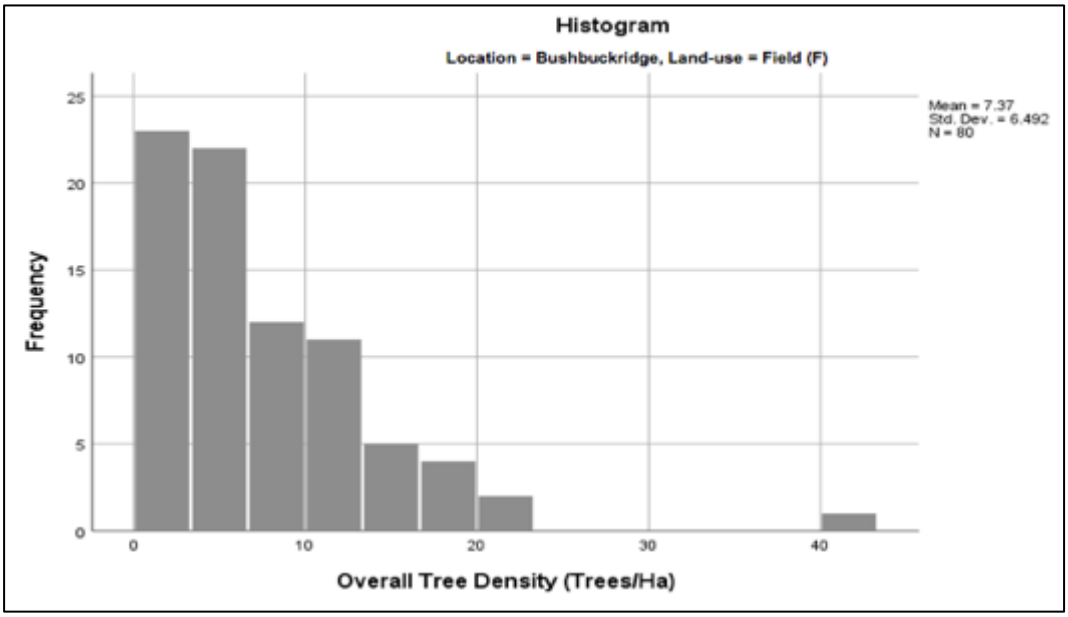


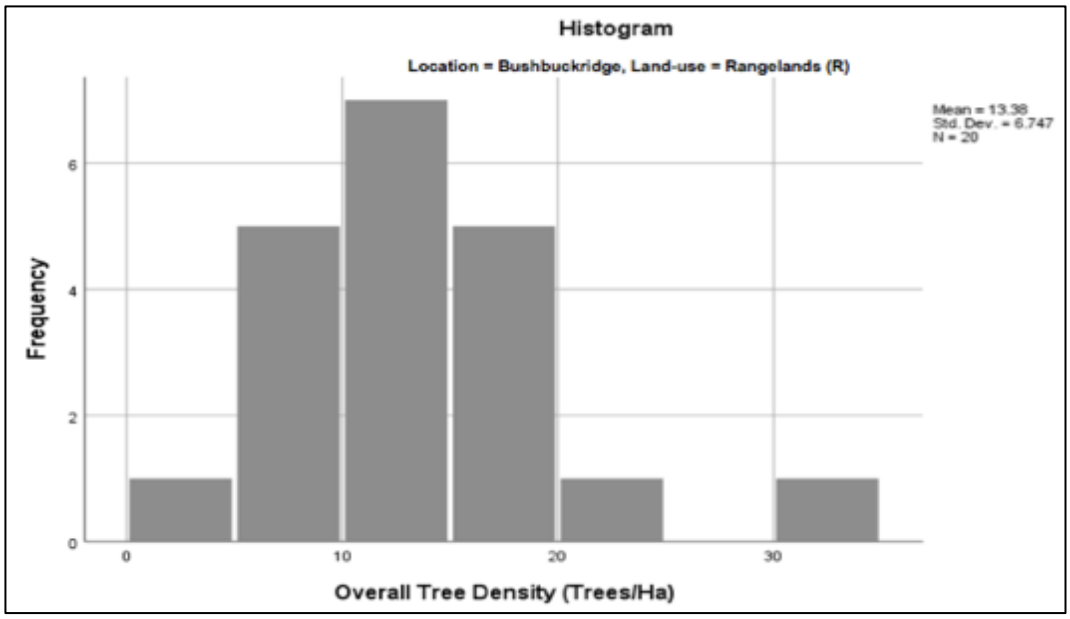




10.1.3.2 Bushbuckridge Overall Density (Yards, Fields & Rangelands)






Histogram
Location = Bushbuckridge, Land-use = Rangelands (R)
Mean = 13.38
Std. Dev. = 6.747
N = 20
Frequency
0
2
4
6
0
10
20
30
Overall Tree Density (Trees/Ha)

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Participant Information Sheet: Community Members (survey)

1 Jan Smuts Avenue
Braamfontein
Johannesburg
2000

Dear Sir/Madam

My name is Amy Marshall from the University of the Witwatersrand. I am completing a Doctor of Philosophy (PhD) degree in the School of Geography, Archaeology & Environmental Studies. As part of my studies I have to undertake a research project, and I am investigating the marula tree within the lowveld region of South Africa. The aim of this project is to assess the tree populations in and around selected local communities. This is done in order to establish the uses and values of the tree for local communities and to determine how important this tree is from an economic, social and environmental perspective.

As part of this project I would like to invite you to take part in answering a questionnaire (survey) on the above-mentioned topic. The information I am interested in include: (1) your use (or not) of marula fruit and other marula tree products; (2) your perceptions about the importance and role of the tree in your life (3) the cultural value of the marula tree to you and your family; and (4) the economic value of the marula tree to you and your household. In asking these questions, I want to assess the following: (1) if you utilise/use the marula tree for its natural products, including fruit (or not); (2) your thoughts and impressions of the importance of the tree within your community; (3) the cultural value of the tree in your life, and (4) the economic valuable of the tree toward your household income. This activity will involve having the questionnaire read to you by a translator and then answering the questions verbally one by one. Answering all the questions will take around 60 - 90 minutes of your time. With your permission, I would also like to record the interview using a voice recorder.

I need to let you know in advance that you will not receive any direct benefits (monetary or otherwise) from participating in this study. Also, there are no disadvantages or penalties for not participating. You may choose to withdraw at any time, or choose not answer particular question/s. The interview will be completely confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else. If you experience any distress or discomfort, we will stop the interview or resume another time.

If you have any questions afterwards, feel free to contact me. This study will be written up as published papers and a research report for the purposes of the PhD degree – a summary of which will be made available to the local tribal authority should you wish to view it any time after completion.

Your participation in my research is highly appreciated. Thank you for your time.

Yours sincerely,

Amy Marshall

Researcher: Amy Marshall (082 453 7400 or amym@icon.co.za) l **Supervisor**: Stefan Grab (011 717 6512 or Stefan.Grab@wits.ac.za) I **Human Research Ethics Committee (non-medical):** Shaun Schoeman (011 717 1408 or Shaun.Schoeman@wits.ac.za)

Consent Form

Title of the project:

The complex socio-ecological system of the lowveld marula bioeconomy catchment

I,……, agree to participate in the survey for this research project. The research has been explained to me and I understand what my participation involves.

I understand that my participation is voluntary	YES	NO	(please circle)
I understand that my participation will remain anonymous	YES	NO	
I agree that the researcher may use anonymous quotes in her research report	YES	NO	
I understand the risks of participation, which may include, but are not limited to negative responses from other community members	YES	NO	
I understand that there are no direct benefits, monetary or otherwise, for my participation	YES	NO	
I understand that I can withdraw at any time if I feel uncomfortable	YES	NO	
I agree that the survey may be audio recorded If NO is given as an answer: the survey may not continue.	YES	NO	

…… (signature of participant)

…… (name of participant)

…… (date)

Marula Utilisation and Value - Community Survey

(to be translated into the local vernacular)

Community: Allandale Survey (AS) ☐ Lulekani Survey (LS) ☐

Rolle A Survey (RS) ☐ Benfarm Survey (BS) ☐

Hokwe Survey (HS) ☐ Mbaula Survey (MS) ☐

Edinburgh (ES) ☐ Selwane Survey (SS) ☐

Participant no: ie. AS-1 (Allandale Survey 1)……

Date and time:……

Yard GPS Co-ordinate:……

Yard Tree/s Co-Ordinates:……

……..

Thank you for taking part in this survey. I will read the questions to you one at a time. Please remember that you can skip any questions you are not comfortable answering. You may also stop the survey at any time. Please ask for clarification if you do not understand a word/sentence or question, or if you would like the question repeated or rephrased. Please indicate if you are happy to begin.

Section A: Socio-Demographic Questions

1. What is your **gender**?

Male ☐ Female ☐

2. How **old** are you?

Between 18-24	☐	Between 25-34	☐
Between 35-44	☐	Between 45-54	☐
Between 55-64	☐	Between 65-74	☐
Between 75-84	☐	85 or older	☐

3. Are you the **head** (main income earner) of your household:

Yes ☐ No ☐

If **no**, please state **who** is the head (main income earner) of your household:

Your husband	☐	Your wife	☐
Your mother	☐	Your father	☐
Your aunt	☐	Your uncle	☐
Your brother	☐	Your sister	☐
Your son	☐	Your daughter	☐

Other (please state relationship to yourself):

…….....

4. How many people live in the same house as you?

……

5. How **long** have you lived in this village?

……weeks/months/years *[circle appropriate option]*

Section B: Marula Fruit Collection Questions

6. In which **months** of the year does the fruit collecting **start and end**?

……

7. Is there a marula tree/trees in your **household yard?**

Yes ☐ No ☐

How many trees?.....

8. Do **you/your household** (select) own or have access to a **field/fields outside of your yard**?

Yes ☐ No ☐

If **yes**, please specify the **number** of **fields**……..

If **yes**, please specify the **number** of **trees per field**……..

……

[ie. Field 1 = 3, Field 2 = 1]

9. Do the trees in the **household yards/fields** produce fruit in season?

……..

Are you aware that marula trees are either male or female?

Yes ☐ No ☐

If **no**, explain that female trees have fruit and male trees have no fruit

10. How many of the trees in your **household yard/field are** male or female?

	Male:	Female:
Yard:	☐	☐
Field:	☐	☐

11. If you have access to field/s, how long is the **walk** to the field/s?

[skip to **Q12** if no field access]

…….minutes/hours *[circle appropriate option]*

[ie. Field 1 = 30mins, Field 2 = 1hr]

12. Do you **collect** marula fruit currently?

Yes ☐ No ☐

If **no**, did you used to collect fruit in the past?

Yes ☐ No ☐

Why did you stop collecting?

……

If **no**, does **another member** of your household collect?

Yes ☐ No ☐

13. Please state **who** in your household does **most** of the marula fruit collecting?

……

*[If respondent, or household, **do not** collect any fruit, skip to **Section C, page 5**]*

14. **Where** do you go to **collect** marula fruit? *[select as many as appropriate]*

Household yard ☐

Field/s ☐

Communal rangeland ☐

Other (eg. road side): ☐

If other please specify:

…….....

15. **Where** do you collect **the most** marula fruit from? *[only select <u>one</u>]*

Household yard	☐
Field/s	☐
Communal Rangeland	☐
Other (as defined above):	☐

16. Do you **collect** from the communal rangeland **belonging** to your village, or belonging to **another village**?

Own village ☐ Another village ☐

*[If no collection from communal rangeland – skip to **Q19**]*

If **another village**, please specify which……

Please provide a **reason** for your answer……..

17. How **long** is the walk to the rangeland……minutes/hours

18. When the fruit is dropping, how many ……kg maize meal bags of fruit do you collect?

From your **household** tree/s……bags *[write N/A if not applicable]*

From your **field/s** tree/s……bags *[write N/A if not applicable]*

From **communal rangeland** trees……bags *[write N/A if not applicable]*

From **other**……bags *[write N/A if not applicable]*

Section C: Marula Tree Use Questions

19. Do you currently **harvest** any part (fruit, wood, bark) from the marula tree to use at **home**?

    Yes ☐ No ☐

    [If **no**, skip to **Q21**]

20. If you answered **yes** above, please tick which parts/products:

Fruit:

Eat fruit ☐

Make beer ☐

Make juice ☐

Make jam ☐

Other use/s……

Nuts/Kernels:

Eat nut whole ☐

Use oil for cooking ☐

Use oil for cosmetics ☐

Add to food dishes ☐

Other use/s……..

Wood:

Carve utensils ☐

Firewood ☐

Other use/s……

Medicinal:

Bark ☐

Roots ☐

Leaves ☐

Other use/s……

Other parts of the tree used or uses not covered above:

……

21. Do you currently **harvest** any part (fruit, wood, bark) from the marula tree to **sell**?

Yes ☐ No ☐

Which parts do you harvest?

Fruit ☐ Nuts ☐

Wood ☐ Leaves ☐

Bark ☐

[If **no to currently harvesting**, skip to **Section D, page 10**]

22. Do you sell **marula fruit specifically**?

Yes ☐ No ☐

If **no**, skip to **Q23**

If **yes**, in what bag/container?……

If **yes,** please state **who** you sell the fruit to: ……..

Who **buys** the most fruit:

Men: ☐ Women: ☐

Youth: ☐ Middle aged: ☐ Elderly: ☐

Locals: ☐ Tourists: ☐ Passer-by: ☐

Factory (formal): ☐ Market (informal) ☐

How many **…….kg bags** do you sell per week:

……

How much do you **charge (in Rands)** per bag:……

What is the main difficulty with **selling marula fruit**?

Getting fruit to market	☐	Price too low	☐
Too many sellers	☐	Time consuming	☐
Not allowed to sell fruit	☐	No difficulty	☐
Not enough fruit	☐	Too much fruit	☐
Not enough customers	☐		

Other:……..

23. Do you sell **marula beer**?

Yes ☐ No ☐

If **no**, skip to **Q24**

If **yes**, who **buys** the most beer:

Men:	☐	Women:	☐		
Youth:	☐	Middle aged:	☐	Elderly:	☐
Locals:	☐	Tourists:	☐	Passer-by:	☐
Factory (formal):	☐	Market (informal)	☐		

How many **500ml/ 1L/ 2L bottles** of beer do you sell per week:……

……

[ie. 500ml = 2, 1L = 1, 2L = 3]

How much do you **charge (in Rands)** per bottle:……

[ie. 500ml = R5, 2L = R25]

What is the main difficulty with selling **marula beer**?

Getting beer to market	☐	Price too low	☐
Too many sellers	☐	Time consuming	☐
Not allowed to sell beer	☐	No difficulty	☐
Not enough fruit	☐	Too much beer	☐
Not enough customers	☐		

Other:……..

24. Do you sell **marula jam**?

Yes ☐ No ☐

Who buys the most jam:……

How many **jars** of jam do you sell per week:……..

25. Do you sell **marula nuts**?

Yes ☐ No ☐

Who buys the most nuts:……

How **many packets of nuts** do you sell per week:……

26. Do you sell any other **marula products**?

Yes ☐ No ☐

Who do you sell the products to:……..

How **many** do you sell per week:……..

Section D: Economic value of Marula

*[Skip this section if **no** marula products are collected, used at home, or sold]*

27. Please choose which best describes your situation:

I harvest marula tree parts only for home use ☐ [Skip to **Q36**]

I harvest marula tree parts only to sell ☐

I harvest marula tree parts for home use and to sell ☐

28. Of the fruit collected each week –how many **bags** do you sell?

……

29. Of the fruit collected each week - how many **bags** do you **keep** for **home** use?

……

30. How much income do you make from **marula fruit sales** per month?

……

31. How much income do you make from **marula beer sales** per month?

……

32. How much income do you make from **marula jam sales** per month?

……

33. How much income do you make from **marula nut sales** per month?

……

34. How much income do you make from **other marula products** per month?

……

35. How much income does your household earn per month- including grants?

Under R500 ☐ Between R500 – R999 ☐

Between R1000 - R1999 ☐ Between R2000 - R2999 ☐

Between R3000 – R3999 ☐ Between R4000 – R4999 ☐

Between R5000 – R5999 ☐ More than R6000 ☐

Comments……..

Social Grant (R 1600) ☐ Child grant (R380) ☐

Section E: Cultural Value of Marula

36. Do you think marula is an **important** tree in your **culture**?

Yes ☐ No ☐

Please give reasons for your answer:……

……

Has this **level** of **importance** changed over time?

Increased: ☐ Decreased: ☐ Stayed the same: ☐

37. Have **you or anyone you know** ever been involved in or performed **cultural ceremonies/rituals** that involve the **marula tree** or parts/products of the marula tree?

Yes ☐ No ☐

Please describe these ceremonies or rituals:……

……

38. Have **you or anyone you know** ever been involved in or performed **cultural ceremonies/rituals** that involve **marula beer** specifically?

Yes ☐ No ☐

Please describe these ceremonies or rituals:……

……

39. Have you performed **Xikuha** (contributing a specific amount of beer to the headman or Nduna)?
Yes ☐ No ☐

Please provide more details:……..

……

40. Have you performed **Kuphala** (offering of marula beer to the ancestors)?
Yes ☐ No ☐

Please provide more details:……..

……

41. Have you performed **Xirhwalo** (involvement in festivities where beer is shared)?
Yes ☐ No ☐

Please provide more details:……..

……

Section F: Marula Access and Land Tenure Issues

42. Is it easy to **access land** where there are marula trees you can harvest?
Yes ☐ No ☐

Why?……

……

43. What **land** is most **accessible**?
Field/s ☐ Rangeland ☐ Other (roadsides) ☐

Please provide reasons:……..

……

44. If you have **access** to a field/s, how did you / your household (please select) - come to own/use this land?

[If more than one field then tick more than one option - skip if no field access]

Given by the Nduna	☐	Inherited from a family member	☐
Bought private land	☐	Share a communal village field	☐
Access a relative's field	☐	Access a non-relative's field	☐
Use an abandoned field	☐	Other	☐

Please provide more details:……

……

45. What are the **main difficulties** you face when harvesting fruits or parts from marula trees? *[select as many as applicable]*

Long distances (difficulty walking)	☐	Age or health related issues	☐
Difficulty accessing land due to physical obstacles as rivers or fences	☐	Ownership disputes over access to trees such	☐
Time required to go harvest	☐	Physical safety issues	☐
Difficulty carrying fruit	☐	Not enough fruit	☐
Access to wheelbarrows/ trolleys	☐	Too few trees	☐

If other, please specify:……..

Please explain your answer above: ……..

……..

Section G: Marula Management and Stewardship

46. Did you/someone (please select) in your household **plant** the marula tree/trees in your **homestead/yard**?

Yes ☐ No ☐

Please provide a reason for your answer:……..

……

47. Did you/someone in your household **plant** the marula tree/trees in the **field/s** you have access to?

Yes ☐ No ☐

Please provide a reason for your answer:……..

……

……

48. If you planted a marula tree in either your **homestead** or **field**:

Where did you get the **seed/sapling** *(select)* from?……

How did you **select** that seed/sapling?.....

……

49. What do you do to **look after** the marula tree/s in your **homestead**?

Fence/bricks around base ☐ Provide water ☐

Provide compost/manure ☐ Other ☐

Please explain:……..

……

50. What do you do to **look after** the marula tree/s in your **field**?

Plough around tree ☐ Provide water ☐

Protect seedlings from ploughing ☐ Other ☐

Provide compost/manure ☐

Please explain:……

……

51. Did you/someone in your household **plant** tree/trees other than marula in your yard or field?

Yes ☐ No ☐

What type of trees:……

Do you plant mango trees?……

Do you prefer mango to marula?

Yes ☐ No ☐

Please explain why?……

……

52. Do you **believe** marula trees are **protected** from being chopped down or damaged in your community?

Yes ☐ No ☐

Please provide more details:……

……

53. Have you, or someone you know, **damaged** a marula tree/trees in your **homestead**? If yes, indicate which?

Cut branches: ☐

Cut down and allowed to regrow: ☐

Cut down/ring barked and died: ☐

Please provide a reason for your answer:……

54. Have you, or someone you know, **cut branches, cut down or ring barked** a marula tree/trees in your **field**?

Yes ☐ No ☐

Please provide a reason for your answer:……

……

If 'yes' to damaging/cutting trees, what size trees:



A ☐ B ☐ C ☐ D ☐

55. What are there **implications** if you damage or cut down a marula tree?

Yes ☐ No ☐

Please provide more details:……

……

56. Who is **responsible** for ensuring marula trees in your community are not chopped down or damaged?

Community Members ☐ Induna or Tribal Authority ☐

Local Government ☐ National Government ☐

Comment:……

Section H: Resource Availability and Climate Change

If respondent is under 30 years: skip to **Q66 to Q69**

If respondent is between 30-50 years: answer **Q57-59** & **Q66 to Q69**

If respondent is over 50 years of age: answer **Q57 to Q69**

Note: Questions 57-65 are only for people **30 years and older**

57. Do you remember the big floods that happened in 2000? If you think of that time - are there **more, less or the same** number of marula trees now compared to that time?

More ☐ Less ☐ Same ☐

Why do you think this is the case?:……

……

……

58. Do you think the **rainfall** in your village has increased, decreased or stayed the same since those floods?

Increased ☐ Decreased ☐ Stayed the same ☐

Please provide more details:……

……

59. Do you think the **temperatures** in your village have increased, decreased or stayed the same since those floods?

Increased ☐ Decreased ☐ Stayed the same ☐

Please provide more details:……

……

If respondent is under 50 years of age then skip to Q66

Note: Questions 60-65 are only for people **50 years** of age and above

60. Think back 30 years– do you think there are more, less or the same number of adult marula trees now compared to then?

More ☐ Less ☐ Same ☐

Please provide more details:……..

……

61. Think back 30 years– do you think there are more, less or the same number of female marula trees now compared to then?

More ☐ Less ☐ Same ☐

Please provide more details:……..

……

62. Think back 30 years– do you think there are more, less or the same number of young marula trees now compared to then?

More ☐ Less ☐ Same ☐

Please provide more details:……..

……

63. Do you think the **rainfall** in your village has increased, decreased or stayed the same in the last 30 years

Increased ☐ Decreased ☐ Stayed the same ☐

Please provide more details:……..

……

64. Do you think the **temperatures** in your village have increased, decreased or stayed the same in the last 30 years?

Increased ☐ Decreased ☐ Stayed the same ☐

Please provide more details:……..

……

65. Do you think there was **more, less or the same** amount of fruit now compared to 30 years ago?

More ☐ Less ☐ Same ☐

Please provide more details:……..

……

66. Do you think there was **more, less or the same** amount of fruit this season compared to just 5 seasons ago?

More ☐ Less ☐ Same ☐

Please provide more details:……..

……

67. What are you the most concerned over?

Decreasing fruit drop: ☐

Decreasing number of trees: ☐

Increasing difficulty in finding trees/fruit? ☐

Too few small trees? ☐

Too few trees with fruit/female trees: ☐

Too few male trees? ☐

68. Are you observing more damage/cutting of trees in last decade?

Yes ☐ No ☐

Why?.....

.....

69. Are you observing more people picking marula fruit in last decade?

Yes ☐ No ☐

Why?.....

.....

Additional Comments:

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