ALIEN INVASIVE PLANTS IN SCHUINSDRAAI NATURE RESERVE: AN INVESTIGATION INTO THEIR EXTENT AND EFFECT

by

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DECLARATION

I, Sierk Joseph Sebastiaan Derks, hereby declare that the dissertation submitted to the University of Limpopo for evaluation purposes for the Master of Science degree in Botany, has not previously been submitted by me for the degree at this or any other University, that this is my own work in design and execution, and all material contained therein and assistance from individuals, has been acknowledged.

________________________________ (27 / 04 / 2022)

Sierk Joseph Sebastiaan Derks Date

DEDICATION

Herewith I dedicate this dissertation to those closest to me. Friends and family members have been instrumental in motivating me every step of the way and even though we may have been apart in these difficult times, they were always within reach to motivate and encourage. We may have been apart but never alone.

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ABSTRACT

Nature reserves are reservoirs for biodiversity. Their very purpose is to preserve indigenous fauna and flora and thus protect associated ecosystem services. The Schuinsdraai Nature Reserve of rural Sekhukhune District, Limpopo Province, is the focus of this study. Sekhukhune District is predominantly rural, with limited economic opportunities but rich mineral resources, the mining of which negatively impacts biodiversity. The Sekhukhune Centre of floristic endemism falls within this district and the nature reserve is thus an important factor in safeguarding a representative section of this floristic center. The veld type present in the reserve is central sandy bushveld. Although mining is prohibited within the reserve, invasive alien plants or (IAPs) pose as high a threat to biodiversity as does mining. The spread of IAPs in nature reserves is harder to control than mining which is prohibited outright whereas IAP spread is automatic and insidious. The management of IAPs is of concern to the government of South Africa and is an ongoing process. Rural areas and the nature reserves within them, such as the Schuinsdraai Nature Reserve, are often under studied or under managed with regards to IAPs. This study supplements the available but scarce data on IAPs for Schuinsdraai Nature Reserve.

The Schuinsdraai Nature Reserve is dominated by the Central Sandy Bushveld vegetation type. Rainfall is on average 470 mm per year and mean annual temperature varies from 24 ˚C in the summer, to 14 ˚C in the winter. The topography includes mountains, hills, plains, and the Flag Boshielo Dam.

The aims of the study were to establish the presence and extent of IAPs in the Schuinsdraai Nature Reserve and to determine whether the IAPs present negatively affect the biodiversity. Road-side inspections, road surveys and line transects were used to investigate presence and extent of IAPs. Modified Braun-Blanquet quadrates were used to compare the effect of the most prevalent IAPs on the plant biodiversity in the Schuinsdraai Nature Reserve. Quadrates were positioned in areas heavily infested by species of IAPs and these areas compared with untransformed areas within 10 m of the infested quadrates. Species richness, species evenness and biodiversity indices were calculated for transformed (control) areas compared with infested areas.

Roadside inspections and road surveys indicated the presence of IAPs. They revealed that most IAPs were present on the eastern side of the nature reserve closest to areas most visited by tourists. Roads and the movement of people therefore affect the spread of IAPs within the Schuinsdraai Nature Reserve.

The four most prevalent species identified from roadside inspections and road surveys were: *Opuntia stricta, Cylindropuntia fulgida, Cereus jamacaru* and *Boerhavia diffusa*. *Opuntia stricta* had the greatest negative effect and was also the most prevalent IAP on the Schuinsdraai Nature Reserve. The number of IAPs per transect observed in the area where access was unlimited was significantly higher than where access was limited. *Opuntia stricta* was the IAPs exhibiting the most significant (.00057) impact on species richness and species diversity and, where funds are limited, these should be targeted for eradication rather than other IAPs. From the results obtained, management recommendations were tabled including the most important, which is to clearly demarcate areas where public movement should be restricted, and meticulously patrol areas which are open to the public and remove IAP's immediately. In conclusion, IAPs are present and do cause deleterious effects on species richness, diversity and evenness within the Schuinsdraai Nature Reserve, however, the strict management of anthropogenic influences should be implemented to control their spread and increase.

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IAP	Invasive Alien Plant
IAPs	Invasive Alien Plant species
NEMBA	National Environmental Management: Biodiversity Act (No. 10 of 2004)
CARA	Conservation of Agricultural Resources Act (No.43 of 1983)
LEDET	Limpopo Department of Economic Development Environment and Tourism

Chapter 1: General Introduction and Literature Review

1.1 Foreword

Nature reserves form the framework to a country's biodiversity protection strategy, conserving the most vulnerable and valuable aspects of the environment (DeFries et al., 2007). Endemic species, fragile ecosystems, areas of particular aesthetic beauty and vegetation types most susceptible to extinction require a high level of protection, which is often only available within a legislated nature reserve (Araújo et al., 2008; Margules and Pressey, 2000). These areas face constant threats, one of which is the spread of invasive alien plants (IAPs) (Foxcroft et al., 2019, 2011). In this dissertation IAPs are defined as species multiplying exponentially in an area other than its natural range, after being transported by humans outside its distribution (Russell and Blackburn, 2017) Plants and animals from elsewhere in Africa as well as Europe and Asia have been introduced into South Africa from as early as 200 AD (van Wilgen et al., 2020). Since the mid-19th century, this rose exponentially and IAP infestations began disrupting ecosystem services (van Wilgen et al., 2020). Despite a global endeavor to manage IAPs in nature reserves, which began over thirty years ago, Shackleton et al., (2020) report that numbers of invasive plants continue to rise in these reserves with an increase of IAPs in 31 % of the world's protected areas. Approximately 55 % of South Africa's protected areas are proactively managed for IAP control, with 45 % of these having implemented additional focused programmes (Shackleton et al., 2020). However, with 759 documented naturalized and invasive alien plant species in South Africa (Richardson et al., 2020), it is important to investigate further management options for preventing their entry into protected areas and managing their proliferation if they are already present. Lists of IAPs present are vital, however, species numbers and names will fluctuate and therefore these lists will be dynamic and should be regularly updated which implies constant monitoring (van Wilgen et al., 2020). The spread of IAPs has severe consequences, both environmental and economical (O' Connor and van Wilgen, 2020). Invasive alien plant species threaten livelihoods by negatively affecting agriculture, forestry, and ecosystem services (Kumar Rai and Singh, 2020; Pimentel et al., 2001). The most severe threats though, are environmental, as IAPs disturb ecological stability (Pimentel et al., 2001) by driving the loss of species and leading to extinctions on sensitive ecosystems (Early et al., 2016). The reproduction and consequent spread of many IAP species is catalyzed by the actions of fire and grazing, two processes integral to the ecosystem functioning of most of South Africa's savannah biome and thus causing additional challenges to the management of these species (O'Connor and van Wilgen, 2020). The assumption that undisturbed land is robust enough to withstand infestation by IAPs has been shown to be incorrect (Shackleton et al., 2020) and therefore, in order to sustain nature reserves as reservoirs of biodiversity, active management against the intrusion of these plants is required. In addition, very few studies on IAPs within nature reserves offer any practical management actions, policies or plans to ensure that these IAPs are controlled (Hulme et al., 2014).

It is thus agreed that the invasion of ecosystems by IAPs should be managed in order to prevent loss of the biodiversity that these nature reserves support (Foxcroft and Freitag-Ronaldson, 2007). Published government policy specifically on biological invasions is scarce (Lukey and Hall, 2020), however, legislations regarding exotic species and in particular, IAPs, and their management is available (CARA, Act 43 of 1983, NEMBA, Act 10 of 2004). The updated NEMBA 2020 list of invasive alien organisms provides a comprehensive species list, however the exact scale of the invasion needs to be monitored and further research regarding these IAP species is essential to better understand how to manage the threat that they pose (Adam et al., 2017).The Biodiversity Act (Act 10 2004) is an overarching and important piece of legislation that, in addition, differentiates between 'alien species' and 'invasive species' as such:

An alien species is one that is not native; whereas an invasive species is a species that "(a) threatens ecosystems, habitats or other species or has demonstrable potential to threaten ecosystems, habitats or other species; and (b) may result in economic or environmental harm or harm to human health" (section 1). Regulations and notices specific to the implementation of this act include: Alien and Invasive Species Regulations (GNR 598, GG 37885, 1 August 2014) and the Alien and Invasive Species Lists (GN 599, GG 37885, 1 August 2014, as amended by GN 864, GG 40166, 29 July 2016). The regulations detail detailed rules and procedures that must be followed in respect of the control of alien and invasive species, and the Lists, or

Notices, document lists of taxa that are regulated and also note the appropriate control method (Lukey and Hall, 2020).

With the impact of IAPs within nature reserves having been documented to be as great as their negative impact outside these protected areas, it is clear that site specific and practical interventions are required for invasion management in nature reserves (Hulme et al., 2014). Nature reserves are also excellent sites to investigate ecological restoration projects due to the fact that disrupting ecosystem functioning in a protected area destroys one of the main reasons for proclaiming the area. Restoration projects in nature reserves are generally easier to implement than in other areas because a minimum staff capacity is present for the restoration actions required as well as for monitoring and follow up work. Most importantly, nature reserves are usually overseen by a scientific authority with the insight into the functioning of the relevant ecosystems and the knowledge on setting it on a trajectory to recovery (Homes et al., 2020). Within nature reserves, control methods and restoration projects must be chosen that are applicable to staff capacity, funding availability, IAPs present and the type of nature reserve, in order to halt the spread of IAPs and reduce the size of the populations already present (Reid et al., 2009). An understanding of the spread and effects of these species is also essential to prevent new infestations (Gordon, 1998).

1.2 Motivation for the Study

Although there is some IAP data available on IAPs in the Schuinsdraai Nature Reserve, the data is not comprehensive. The lack of an IAP species list severely curtails an understanding of the effect of IAPs on the indigenous vegetation as well as limiting the effectiveness of any control programme (Shackleton et al., 2020). Without an understanding of the suite of IAPs present in the nature reserve and their invasion pathways, reproductive strategies and the various control options open to managers, there is a real possibility that degradation of the Central Sandy Bushveld will occur with subsequent loss of indigenous species (Early et al., 2016; Kumar Rai and Singh, 2020; Pimentel et al., 2001).

Understanding the extent and effect of IAPs in the Schuinsdraai Nature Reserve will elucidate possible IAPs present in the Sekhukhune District as a whole, as well as the effect they could have on the landscape. Siebert and van Wyk (2001) list IAPs as one of the most problematic drivers that transform indigenous veld types.as there is a lack of information regarding species present and the effect of IAPs for this area. Information will be made available to the South African National Biodiversity Institute (SANBI) in order to feed into their early detection system, which logs IAPs present in South Africa. In addition, it has been shown that engaging with society and creating awareness around the impact of IAPs is vital to their control (Shackleton et al., 2020) and this study will add to such knowledge dissemination.

1.3 Literature Review

1.3.1 Introduction

Biodiversity can be defined as the number of different animal and plant species found within a defined region (Swingland, 2001). The biodiversity of a region interacts with abiotic factors creating ecosystems, which fulfil certain roles (Huston and Mcbride, 1994). The greater the number of species, the stronger the links in the food webs within, leading to greater stability within the ecosystem (Thébault and Loreau, 2005). Healthy ecosystems provide various benefits for humanity (Bolund and Hunhammar, 1999; Crossman et al., 2013). These are described as ecosystem services, which are the conditions and processes through which natural ecosystems, and the species of which they consist, sustain and fulfil human life (Daily, 1997). These services are, however, complex and can be obscure, with benefits only noticeable on more in-depth study, or once they are lost (Fisher et al., 2009). For example, insects pollinating flowers allow plants to reproduce (Galen, 1992) and these plants photosynthesize and produce oxygen, without which, life would not be possible. Complex wetland ecosystems provide the essential service of storing, cleaning and attenuating floodwaters (Clarkson et al., 2013), and the efficiency with which this is achieved, increases with increased indigenous wetland plant species number (Meli et al., 2014).

The higher the biodiversity, the greater the scope for the utilisation of biological resources from an area (Wood, 1997), which are resources that humans harvest directly from the environment. If the harvesting from the environment is managed sustainably, the environment can be utilised indefinitely to supply a number of services to the adjacent communities (Hernández-Barrios et al., 2015) such as medicinal and food plants (Crossman et al., 2013). Other examples of harvesting include food, wood for building and cooking fires and grass to feed livestock (Mertz et al., 2007). Furthermore, a high level of biodiversity yields greater tourism opportunities (Van Der Duim and Caalders, 2002).

Protected areas have long been a vital safe haven for animals and plants, protecting them from habitat loss and thus preserving biodiversity (Geldmann et al., 2013). The protection and conservation of these habitats in the form of nature reserves therefore preserves the fauna and flora that would typically have survived in the location of the nature reserve in the absence of human influence (Fredman et al., 2012). Depending on the type of protected area, ecosystem services can be supported while still allowing for the wise harvesting of natural resources and enabling visitors to enjoy the 'sense of place' that these unique areas offer (Eyles, 2020). The development of tourism facilities can ensure that nature reserves are more economically viable, thus directly benefiting biodiversity (Tisdell and Wilson, 2001). The above all depend on a rich network of indigenous flora and fauna, unaffected by exotic species (van Wilgen et al., 2020).

The Schuinsdraai Nature Reserve, in the Sekhukhune area of the Limpopo Province, is an environment within the Savanna Biome that is of particular conservation importance due to the fact that Sekhukhune is under great mining pressure (Besherati, 2014). Transformation of the natural environment in the Sekhukhune District is occurring at an unprecedented rate and nature reserves are the most powerful tool available to protect ecosystem services from impacts caused by destructive mining processes (Phillips, 2001). Conservation of biodiversity has been the emphasis of several important international organizations such as the International Union for Conservation of Nature (IUCN) and as a member, South Africa has a global obligation to protect its biodiversity using the most appropriate strategies (Hawkins et al., 2015).

South Africa is located on the southern part of the African continent and has a wide range of climates from Mediterranean summer rainfall and mist belts, which support forests, grasslands and deserts (Willis et al., 2001). Climate determines plant growth (Woodward and Williams, 1987) and the variety of climates in South Africa facilitates the occurrence of a diversity of plant species, supporting the formation of a myriad of ecosystems. Geographic isolation from other similar climatic zones is what facilitates the evolution of these unique ecosystems (Worsham et al., 2017). The most notable of these is the Cape Floristic Region, which is the only kingdom to fall entirely within the borders of a single country (Born et al., 2007). However, even within larger, more overarching biomes, such as the savanna, variations in climate influence biodiversity resulting in ecosystems within these biomes that occur nowhere else on the planet (Wieczynski et al., 2019). The South African climate is further affected by the presence of two oceans bordering the country, namely the Atlantic and Indian oceans, with their cold and warm water currents respectively (Walker, 1989). Rainfall in the country is driven by these currents, resulting in a summer rainfall region and a winter rainfall region (Jury and Pathack, 1993). These two rainfall regions diversify the precipitation received, allowing for a greater variation in habitats, as rainfall determines the structure of ecosystems, in particular, the savannah (Zhang et al., 2019).

The aforementioned factors have thus contributed to South Africa's ranking as the third most biodiverse country in the world (Maze et al., 2003) and one which contains a number of endemic species. These endemic species are prone to extinction and therefore require particular attention in order to support their continued existence (Işik, 2011). Examples of endemic or protected savannah species include *Adansonia digitata, Drimia sanguinea* and *Vachellia erioloba*. There are approximately fifty endemic plant species in Sekhukhune (Siebert and Van Wyk, 2001), all of which are vulnerable to habitat destruction via ill-advised development. Wise use of eco-tourism however, is one means of stimulating economic development without adversely affecting the biodiversity of the area (Brandt and Buckley, 2018).

Eco-tourism relies on ecosystems to generate income (Western, 1993). High biodiversity environments are drawcards for tourists due to the beauty and interest factor of the areas (Angulo and Courchamp, 2009; Siikamäki et al., 2015). The ecosystems in such environments are conserved in nature reserves, for which tourists are prepared to pay entrance fees and the funds generated from these reserves can then be used to further protect biodiversity (Tisdell and Wilson, 2001). Additionally, such reserves provide employment to local communities either through management actions required in the reserves or through catering and lodging (Van Der Duim and Caalders, 2002). This is to the advantage of communities that often suffer from a lack of employment opportunities (Van Der Duim and Caalders, 2002).

Eco tourism also leads to in situ conservation, which occurs in nature reserves, which preserves not only specific flora and fauna but entire ecosystems (Heywood, 2014). The preservation of a habitat allows for scientific research to take place within a properly functioning ecosystem (Heywood, 2014). Nature reserves are also important tools in education (Rome and Romero, 1998). Observing animals in their natural habitat may inspire young people to follow a scientific route in their studies or lead to them changing their opinion on the importance of natural areas (Rome and Romero, 1998). Broadening the scope of general knowledge around environmental issues is important as lack of information leads to the deterioration of wilderness habitats (Lindsey et al., 2005). Natural landscapes include more than the physical elements that are typically measured by science. The spiritual belief that all species have a right to exist even if they pose no obvious benefit to humans is another argument for the conservation of biodiversity (Turkelboom et al., 2015). Nature reserves therefore support various cultural beliefs and serve a bio-cultural role. Simply being in a natural habitat has a rejuvenating effect on human lives (Eyles, 2020).

Nature reserves also provide aesthetic value (Alho, 2008). This is enhanced when these areas are functioning optimally, with all ecosystems intact and as little impacted by alien vegetation as possible (Potgieter et al., 2019). Indeed, it has been recorded that ecological attractions of interest, or of an unusual nature, are one of the most important reasons for visiting nature reserves in Sub-Saharan Africa (Langholz, 1996). As such, well-functioning nature reserves play a vital role in society and are of great importance.

Schuinsdraai Nature Reserve, like most reserves of its kind, protects biodiversity in an area threatened by anthropogenic activities (Gardner et al., 2009). The most significant threats include climate change, deforestation, overexploitation, and alien invasive species. Climate change results in droughts, resulting in a dearth of indigenous vegetation and opening up opportunities for IAPs which are evolutionarily adapted to thrive in disturbed soil. Deforestation also destroys indigenous habitat, creating gaps in understories and undergrowth promoting IAP colonisation (Foxcroft et al. 2017).

The world's climate has been changing for several thousand years (Kotir, 2011), however in recent decades since industrialization, this has been more marked and is in response to anthropogenic activities (Jacob et al., 2007). The Intergovernmental Panel on Climate Change's (IPCC) sixth assessment report (Mc Elwee 2021), confirms and reinforces trends already in evidence over ten years ago (Kotir, 2011) which are resulting in serious environmental threats. Each species has a limited range of tolerance within its respective climate (Scheffers et al., 2016) and changes to this range can therefore contribute to increased rates of extinction and resultant biodiversity loss (Thomas et al., 2004). This biodiversity loss is compounded by the ability of IAPs to be more resilient to the effects of climate change than indigenous equivalents (Hulme, 2014), with their resultant accelerated spread altering ecosystems and degrading habitats (McElwee 2021). According to the IPCC Sixth Assessment Report, South Africa is a climate change hotspot and therefore subject to increased droughts and rapidly declining biodiversity (IPCC 2021) and within this context, managing protected areas for biodiversity, particularly Schuinsdraai which is in a drought prone area, is vital.

The expansion of agriculture into tropical forests is a driving factor for biodiversity loss (Newbold et al., 2015) through habitat destruction and fragmentation (Zhai et al., 2015). Further fragmentation of the environment takes place with human population growth and concomitant development of infrastructure (Owino and Ryan, 2007) and with these, the inevitable spread of IAP species (Spear et al., 2013). Human population growth results in expansion of homesteads into previously pristine natural areas, which are modified, often graded or otherwise disturbed thus promoting the colonisation of IAPs whose spread is supported by the movement of human populations through vehicular transportation and by foot (McLean 2018). People from lower income brackets modify the landscape primarily through expansion of subsistence agriculture, and those from more wealthy backgrounds modify untransformed land into the built environment, both of which destroy indigenous vegetation and promote IAP infestation through increases in disturbed land (Shackleton et al., 2019).

The over exploitation of ecosystems leads to a decline in natural vegetation (Okigbo and Ogbogu, 2008) and is therefore a driver for extinction (Giam et al., 2010). The introduction of IAPs to these already vulnerable ecosystems places added strain on indigenous vegetation through competition for light, water and nutrients (Mostert et al., 2017). These species erode natural ecosystems, negatively impacting stability and threatening their productivity (Brooks et al., 2004). The interplay between destruction of natural vegetation and increase in IAP species results in exponential devaluation of vital ecosystems through destruction of the biodiversity that enables the functioning of essential ecosystem services (van Wilgen et al., 2008).

1.3.2 Invasive Alien Plants

1.3.2.1 Definitions

Invasive alien plants (IAPs) are plant species that establish themselves and reproduce rapidly thereby transforming the environment in which they are located and producing monocultures which negatively affect natural species diversity of the area (Pyšek et al., 2020). A similar, but more workable definition, as supported by the International Union for Conservation of Nature (IUCN) is that IAPs are only those plant species that have a harmful effect on the economy, environment or health. Weeds is a term utilised by the public to describe a plant that is unwanted and negatively impacts the environment (Holzner, 1982; Randall, 1997). Problem plants are plants that have unwanted or undesirable effects on the environment (Bromilow, 2001). Exotic plants are another way of describing plants that are non-native (D’Antonio and Meyerson, 2002). In this dissertation, IAPs are predominantly discussed as these are the alien plants with the most deleterious effects within a nature reserve (Foxcroft et al., 2013)

1.3.2.2 Alien Invasion Pathways

In a globalised world, increasingly sophisticated transport networks which supply the demand for international commodities are the pathways for the spread of IAPs (Hulme, 2009). Although protected by law, nature reserves are not exempt from the entry of new IAPs, and an understanding of invasion pathways and their risk assessment is an important tool to use in the prevention of infestation (Hulme, 2015). For protected areas such as Schuinsdraai Nature Reserve, invasion can follow a number of pathways including: crop introduction, novel natural resources, ornamental plant cultivation, stabilising soil, or for windbreaks, as well as livestock containment and unintentionally through general travel (Shackelton et al., 2020).

Most crops originate from other countries and were introduced as a food source (Khoury et al., 2016). A number of *Opuntia* species, for example, were introduced to provide food (Walters et al., 2011), however their spread from agricultural fields into natural vegetation has become problematic due to their rapid propagation and the absence of indigenous herbivores (Walters et al., 2011). The Cactaceae family as a whole, is a well represented IAP family within nature reserves, Robertson et al., 2011, and fifty-seven species are listed around the world as invasive (Novoa et al., 2016, 2015).

Alien plants were also introduced as timber resources for building materials (Semenya and Maroyi, 2020), as well as for paper (Van Wilgen and Richardson, 2012). Species imported for these reasons include black wattle, *Acacia mearnsii*, (Chan et al., 2015), blue gum (*Eucalyptus* species), (Malan and Gerischer, 1987) and the *Pinus* genus (Van Wilgen and Richardson, 2012). Pine trees have been planted for agriculture in the northern hemisphere since ancient times and have been widely planted for the same reason in the southern hemisphere for the last 200-300 years (Moran et al., 2000). The cultivation of these alien *Pinus* species has led to afforestation and as a result, a loss in species richness in the areas that are cultivated. Propagules of *Pinus* species are dispersed by wind (Richardson et al., 1994) allowing for wide spread invasion even into nature reserves (Peña et al., 2008). Blue gum trees, particularly *E. camaldulensis*, have iconic as well as real economic and health benefits (Hirsch et al., 2020). Management of such trees is delicate in that, despite their well-documented positive aspects, the negative consequences are very real and include competition with natural vegetation thus decreasing biodiversity and ecosystem functioning due to their water uptake capacity, propensity for acting as vectors of disease and potential fire risk, as well as soil altering aspects (Hirsch et al., 2020).

The spread of IAPs is often augmented through the cultivation of ornamental plants in order to enhance the surroundings of humans (van Kleunen et al., 2018). The allure of possessing something out of the ordinary is a common human trait (Pearce, 2012), but was not considered a concern until such introduced IAPs began to aggressively invade pristine natural vegetation (Foxcroft et al., 2008; van Kleunen et al., 2018). The uncontrolled spread of IAPs and the subsequent decrease in biodiversity in such areas has resulted in a change of opinion, and species which were previously viewed as attractive ornamental plants, are now considered a risk to the existence of many indigenous species (Foxcroft et al., 2008). The spread of IAPs as ornamental plants is facilitated by the ornamental plant trade (Dehnen-Schmutz et al., 2007) that supplies people with plants without adequately informing them of the risks involved and the damage these plants may cause to the natural environment (Zengeya et al., 2017). Members of the public and employees in the horticulture trade are often either not aware of important legislation around alien plants, or choose to ignore it, thus creating avenues for these plants to spread unintentionally due to ignorance and illegal action (Dehnen-Schmutz et al., 2007; van Kleunen et al., 2018). These ornamentals are now found in nature reserves as garden escapees and as remnants of previous habitation or beautification sometimes deliberately introduced in the past around nature reserve staff accommodation (Foxcroft et al., 2008). One such ornamental that is rampant in South Africa is *Cereus jamacaru* that was imported into South Africa by collectors of succulents due to its beautiful flower (Klein, 2015).

Acacia species such as *Acacia saligna*, *Acacia cyclops* and *Acacia mearnsii*, which were introduced from Australia in 1845 for dune stabilisation, are major transformers of indigenous vegetation and are very difficult to eradicate (Avis, 1989, Le Maitre et al., 2011). Apart from destroying the sensitive natural dune environments, the aforementioned *Acacia* species have spread into pristine areas of natural vegetation and are now common throughout South Africa (Avis, 1989, Le Maitre et al., 2011). A number of ecosystem services within the Cape Floristic Region have been disrupted, including water storage capacity and soil retention (Mostert et al., 2017). This problem is not unique to the Cape Floristic Region but this is one of the first regions in South Africa to be impacted by IAPs and important lessons can be learned from understanding invasion patterns in this area and how they invade and impact nature reserves (Robinson et al., 2020). These plants that were intended to stabilise dunes are now destabilising natural environments in nature reserves (Robinson et al., 2020).

A number of IAPs have been introduced to South Africa with the intention of creating a physical barrier to contain livestock within preferred areas (Novoa et al., 2015). Examples include various *Opuntia* species, utilised because of their tendency to creep, their low water consumption, quick growth and the presence of spines to deter animal movement (Ranjan et al., 2016). Other popular barrier plants are from the genus Eucalyptus with *Eucalyptus grandis* as a popular example (Albaugh et al., 2013; Bennett, 2010). Legislation in the form of the National Environmental Management Biodiversity Act, NEMBA, does allow for these IAPs to be present in South Africa due to the fact that they are agriculturally important and there is therefore a category (category 2) making provision for these useful species. Only, however, where they do not have a negative impact, such as habitat transformation in nature reserves (Forsyth et al., 2004). In nature reserves, barrier plants are problematic if they were planted before the proclamation of the nature reserve and thus remain with the potential to reproduce and form large monocultures (Le Maitre et al., 2004).

Many species are introduced to countries unintentionally (Turbelin et al., 2017). The movement of goods and people facilitate the introduction of these organisms to regions where they are not native (Faulkner et al., 2017). Border control in South Africa is lacking, providing the perfect opportunity for stow away plants to enter (Faulkner et al., 2016). Furthermore, the 4862 kilometers of land borders in South Africa, are not efficiently managed and therefore form a weak point for the entry for IAPs (Faulkner et al., 2016). The management of these points of entry is vital to prevent the entry of alien species into South Africa and thus prevent their spread into other African countries. This is imperative as more IAPs spread from South Africa into other countries than enter from outside and collaboration between countries is thus essential (Faulkner et al., 2017). Border control is intrinsically linked to the spread of IAPs into nature reserves as one of the major attractions to tourists in South Africa is the pristine natural environment epitomised by reserves such as the Kruger National Park, Table Mountain Nature Reserve and its wealth of smaller proclaimed areas (Lindsey et al., 2007). Tourists may unknowingly carry propagules of invasive plants with them as they enter nature reserves facilitating the spread of these invasive alien plants (Carbutt, 2012).

Understanding pollination and dispersal mechanisms are crucial to breaking the cycle of alien spread into pristine vegetation such as that found in nature reserves and halting the reinforcement of this cycle by subsequent invasion incidences (Pyšek et al., 2002). These mechanisms are the principle means by which alien invasive plants first gain purchase into a nature reserve (Richardson et al., 2000) therefore disrupting these mechanisms is important in the management of these species (Richardson et al., 2000). Seeds may be ingested by frugivorous birds or baboons and deposited within nature reserves via the scat, thus precipitating population growth of the species (Foxcroft et al., 2019; Klein, 2015). The seeds may also attach to the bodies of animals via specialised attachment structures such as hooks, which are then brushed off onto fertile ground after entry into a nature reserve (Silvertown and Fenner, 1993).

Propagules from alien plants may attach to humans by means of clothes or shoes and can also be transported via car tyres (Foxcroft et al., 2019), resulting in increased IAP densities along road networks (Gelbard and Belnap, 2003). Human expansion also often results in degraded environments (Owino and Ryan, 2007). The creation of these new environments facilitates the establishment of IAPs, which are generally pioneer species thus thriving in disturbed areas (Okimura et al., 2016). Eco-tourism, which is an important economic driver in protected areas, can unfortunately also be a channel for IAP invasion and managers should be sensitive to managing the introduction an spread of IAPs (Pegas and Castley, 2014).

Seeds that are buoyant may be dispersed by water, which facilitates the spread of species over large areas through movement of rivers and streams (Cappers, 1993). Schuinsdraai Nature Reserve is particularly vulnerable to water dispersed alien plants due to the presence of the Flag Boshielo Dam. Watershed areas are therefore targeted for IAP control in South Africa (Foxcroft et al., 2009, Kotze et l. 2010), particularly by the Working for Water programme which works closely with the South African government in cleaning waterways of IAPs and in the process protecting the ecosystems along these water ways (Turpie et al., 2008). The eradication of IAP species along water-ways is important in a water scarce country such as South Africa due to the negative impact of many of these plants on water quantity and quality (Urgenson et al., 2013).

Wind dispersal of alien invasive plants is a particular challenge in mountainous and windy areas, especially where pine and eucalypt plantations abut untransformed natural vegetation, which frequently occurs where nature reserves border such plantations as in the Haenertsburg Nature Reserve in Magoebaskloof, Limpopo Province (Dzerefos and Witkowski, 2016). Seeds dependent on wind dispersal are typically very light and/or possess extensions that catch the wind such as those found on the Asteraceae or *Pinus* species (Greene and Johnson, 1993). When released into the breeze they can be carried great distances away from the parent plant thus infesting new areas when they land (Richardson et al., 1994). Plants on mountain-tops, where airflow is less restricted, are thus in a better position to disperse seeds in this manner (Richardson et al., 1994).

1.3.2.3 Effects of Invasive Alien Plants

Invasive alien plants degrade habitats in a number of ways and to counteract this, South Africa has implemented various programmes, chief of which is the Working for Water programme (Turpie et al., 2008). The control of these IAPs is extremely expensive, with the budget for clearing aliens and reducing their impact, roughly two billion rand per year. The total cost of clearing since 1995 is approximately fifteen billion but is considered worthwhile considering the negative impacts of IAPs (Morokong et al., 2016; van Wilgen et al., 2020).

Water is in short supply in South Africa, and many IAPs utilise significantly more water than indigenous plant species, thus impacting negatively on South Africa's water reserves (Görgens and Van Wilgen, 2004). The top 10 IAPs in South Africa are *Acacia cyclops*, *Prosopis spp, Acacia mearnsii, Acacia saligna, Solanum mauritianum, Pinus spp., Opuntia spp., Melia azedarach, Lantana camara* and *Hakea spp*. (Le Maitre et al., 2000). They are responsible for consuming 8.8% of the mean annual runoff of rain in Limpopo Province (Le Maitre et al., 2000). Together with biodiversity protection, safeguarding of water resources is another vital role that nature reserves perform and therefore the removal of IAPs is essential in all nature reserves, but particularly those in water catchments, or those that support wetlands such as Schuinsdraai Nature Reserve (Morokong et al., 2016), is vitally important.

Alien plants may also alter soil chemistry by changing the pH of the soil on which they grow (Osunkoya and Perrett, 2011; Ruwanza and Shackleton, 2016). *Lantana camara*, a plant native to South America, has a notable effect on soil chemistry by increasing the pH and changing nutrient levels of the soil that it grows on (Osunkoya and Perrett, 2011; Ruwanza and Shackleton, 2016). Indigenous plants are therefore negatively affected by the presence of *L. camara* due, not only to light and nutrient competition, but also to the soil chemistry for which they are not suited (Ruwanza and Shackleton, 2016). *Chromolaena odorata* and *A. mearnsii* have also been implicated in these changes, altering soil properties such as litter composition, soil temperature and energy flux, soil moisture, mineralization and microbial activity (Raizada, 2008).

Invasive alien plants have a negative effect on the carrying capacity of native vegetation because IAPs are more resistant to generalist herbivores as they are not generally consumed by indigenous fauna (Agrawal et al., 2005; Jogesh et al., 2008). Invasive alien plants thus reduce the carrying capacity of the ecosystem by forming swathes of a single species which does not support the suite of herbivores that would have been present before the indigenous vegetation was transformed (Yapi et al., 2018). Areas invaded by alien plants therefore possess a lower animal diversity than untransformed areas of the same ecosystem (Clusella-Trullas and Garcia, 2017).

Thus, the presence of IAPs in nature reserves will ultimately lower the carrying capacity of these nature reserves resulting in a less biodiverse nature reserve that is a direct contradiction of the purpose of nature reserves. The economic consequences of IAPs in protected areas are an increase in management costs, at the detriment of all environmental awareness, biodiversity monitoring and sensitive development within reserves (Moodley et al., 2021). The major impact is still considered to be direct competition for resources of nutrients, soil and light between IAPs and indigenous species, with IAPs generally outcompeting the latter and resulting in species poor monocultures (Foxcroft et al., 2017). These changes then directly impact species assemblages of the local flora, although after control measures these can be reversed (Foxcroft et al., 2017). Changes in ecosystem structure can be large scale and include alterations to the fire regimes of certain areas as well as more localized disruptions in the biogeochemical linkages between soils, flora and fauna (Yelenik et al. 2004).

It is important to consider that many IAPs were introduced for reasons that add economic value, such as *Pinus pinaster* and *Eucalyptus grandis* (Van Wilgen and Richardson, 2012). In addition, they are heavily utilised in rural areas as firewood, medicinal and edible herbs, as well as for timber (Semenya et al., 2012; Semenya and Maroyi, 2020). Thus, *Opuntia ficus-indica*, is used as a food source (Novoa et al., 2016), *P. patula* is utilised for timber (Mitchell et al., 2012), and *L. camara* is collected medicinally (Semenya et al., 2012). Notwithstanding these important uses, it is imperative that IAPs are well managed in nature reserves, and, if at all possible, initial invasion is prevented.

1.4 Aim and Objectives

1.4.1 Aim

This study aims to investigate the IAP species present, their occurrence, broad scale population structures and their effect on plant biodiversity within the Schuinsdraai Nature Reserve with a view to developing management guidelines for their control.

1.4.2 Objectives

i. To document IAP species in Schuinsdraai Nature Reserve.

ii. To determine which area of the Schuinsdraai Nature Reserve is most impacted by IAPs.

iii. To investigate IAP species population structure in order to determine whether these population are growing or stagnant.

iv. To compare biodiversity indices between areas infested by IAPs and those which are untransformed.

v. To formulate management guidelines for managing the IAPs

1.5 Research Questions

i. What is the extent, if any, of the IAPs in the Schuinsdraai Nature Reserve?

ii. If IAPs are present, which areas of the Schuinsdraai Nature Reserve are most impacted?

iii. Which IAP species have populations that are increasing?

iv. Are there differences in biodiversity indices between areas infested with IAPs and those that are untransformed?

v. What management guidelines should be formulated for IAP control?

1.6 Hypothesis

The Schuinsdraai Nature Reserve is not a pristine environment but is transformed by a number of species of IAPs, which have a negative effect on the biodiversity within the nature reserve.

1.7 Scope and Limitations of the Research

The Schuinsdraai Nature Reserve encompasses 9 129.562 hectares, and it was not feasible to conduct an analysis of the entire area due to time constraints. The focus area for this study was informed by a roadside inspection which indicated the section of the reserve which is most affected by IAPs and this was thus sampled to overcome the aforementioned limitation.

1.8 Research Assumptions

The methodology was chosen on the following assumptions:

i. The IAP population is dispersed evenly throughout the nature reserve.
ii. Invasive alien plants have an impact on the biodiversity of the Schuinsdraai Nature Reserve.
iii. The IAP species are not limited to those mentioned in anecdotal reports.

1.9 Outcome of the research

The outcome of this research documented the IAPs species present and gave an indication of their abundance within the Schuinsdraai Nature Reserve. Species present were linked to a map indicating the location of the IAPs found within the reserve. Analysis was conducted on the most prevalent IAPs to determine the effects that these IAPs have on the plant biodiversity of the environment. This information was utilised to draw up management recommendations for the Schuinsdraai Nature Reserve. It may also contribute to IAP management policy in other nature reserves in the Sekhukhune area such as Potlake Nature Reserve and assist private landowners in the region with information regarding IAPs that may be present on their land.

1.10 Layout of the Dissertation

This dissertation is laid out in the following manner: An introductory chapter that outlines and places relevant literature in the context of the study motivations. Chapter Two introduces the area where the study took place indicating the location of the Schuinsdraai Nature Reserve, the climate, vegetation types and topography. The third chapter contains data centered around the distribution of IAPs within the Schuinsdraai Nature Reserve and reasons for their location and potential spread. The fourth chapter focusses on the effect that the predominant IAPs have on the vegetation inside the

Schuinsdraai Nature Reserve. It includes data and discussion on species richness, diversity and evenness. The fifth chapter focuses on the management of IAPs, giving recommendations for their control and the prevention of further spread. It includes information on the legislation relating to IAPs. The final chapter serves as a general discussion and conclusion indicating links between the understanding of distribution and control of IAPs in protected areas. After each chapter, literature is cited in the reference sections.

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Chapter 2: Study Area

2.1 Introduction

The Schuinsdraai Nature Reserve is located in the north-eastern, summer rainfall area of South Africa, and within the Limpopo Province (Engelbrecht, 2015). The province is largely rural, with the greatest congregation of people (approximately 800 000) in the capital city of Polokwane (Statistics South Africa, 2016). The province has a rich natural history and many contrasting landscapes (Walz, 2014). The predominant biome covering most of the Limpopo Province, including Schuinsdraai Nature Reserve, is Savannah, with small pockets of Grassland and Forest (Mucina and Rutherford, 2006). The Savannah Biome is broadly defined as being a mixture of grass and trees, with the interaction between the grass and the tree components the defining element and differentiating savannah from grasslands or forests (Scholes and Archer, 1997). The Limpopo savannah is further divided into multiple vegetation types as described by Mucina and Rutherford (2006), with Schuinsdraai Nature Reserve covered by Central Sandy Bushveld.

The Schuinsdraai Nature Reserve hosts a host of mammal species with the most notable being the presence of the vulnerable *Hyaena brunnea*. Bordering the Flag Boshielo Dam is an additional habitat for a host of avian species with 11 of the confirmed species being threatened. Many reptile species occur in the reserve, the most notable being the Nile crocodile (LEDET 2012).

2.2 Threats

Despite the rural nature of the Sekhukhune District, it is rich in mineral resources, most notably platinum, resulting in numerous mines in the area (Besherati, 2014). The District also has a striking plant diversity and the floristic changes witnessed over short distances is comparable with that of the Cape Floristic Region, leading to part of it being designated as the Sekhukhune Centre of Endemism (Siebert and Van Wyk, 2001). The economic opportunities presented by mining in the area are important in combating unemployment and poverty (Besherati, 2014), however, the area's rich natural heritage is threatened by unprecedented mining development (Siebert and Van Wyk, 2001).

Habitat destruction is further promoted by the spread of IAPs. The Savanah biome has a high tourist influx and is mostly rural and under developed all of which facilitate the spread of IAPs (Foxcroft et al., 2006; Henderson, 2007; Semenya and Maroyi, 2020). In addition, the savannah climate is favourable for most IAPs, having warm, wet summers, which allow the plants to persist and naturalize (Pyšek et al., 2020). The savanna could thus lose a significant percentage of its biodiversity to IAP monocultures, which would transform the indigenous vegetation and disrupt water retention services and food webs (Clusella-Trullas and Garcia, 2017). In particular the most destructive IAPs in the savannah biome included *Datura ferox and D.*, *strominium*, as well as *Opuntia spp*. and *Chromolaena odoratum*. Biological control is available for *Chromolaena odoratum*m however, in Limpopo Province, mainly mechanical labour has been used due to the expense of biological control.

2.3 Vegetation in the Schuinsdraai Nature Reserve

The vegetation within the Schuinsdraai Nature Reserve is dominated by trees such as *Terminalia sericea* and *Acacia tortilis*, which are supported by low, undulating, sandy plains (Mucina and Rutherford, 2006). On the rocky areas, *Combretum* woodland dominates and *Acacia spp.*, *Ziziphus spp.* and *Euclea spp.* are more common on the flat and lower slopes, where soils are eutrophic and sandy (Mucina and Rutherford, 2006). Grasses, including *Brachiaria nigropedata*, *Eragrosis pallens* and *Themeda triandra*, and herbs with low basal cover, such as *Blepharis integrifolia* and *Crabbea angustifolia*, predominate on dystrophic soils (Mucina and Rutherford, 2006). The conservation status of Central Sandy Bushveld is classed as 'vulnerable' due to the fact that less than 3% is statutorily conserved in proclaimed nature reserves and about 24% is already transformed (Mucina and Rutherford, 2006). The conservation target is therefore 19% and nature reserves such as Schuinsdraai and Potlake Nature Reserve are important for biodiversity conservation (LEDET 2012). Control of IAPs is mandated by law as guided by the South African National Environmental

Management: Biodiversity Act (No. 10 of 2004) (NEMBA) which requires all organs of state at all spheres of government to develop invasive species monitoring, control and eradication plans.

According to anecdotal reports, the vegetation of Schuinsdraai Nature Reserve is impacted by a number of populations of *Opuntia ficus-indica* and *Cereus jamacaru* (LEDET, 2012) however, the density of these alien plants and their localities within the nature reserve are unknown. In addition, according to unofficial comments by rangers it appears that many more IAPs are present but not documented due to time limitations and the obscurity of some alien species. At present these are controlled on an ad hoc basis as insufficient information on population size, distribution within the reserve, invasion rate and their effect on biodiversity within the reserve is available (van Kleunen et al., 2018)

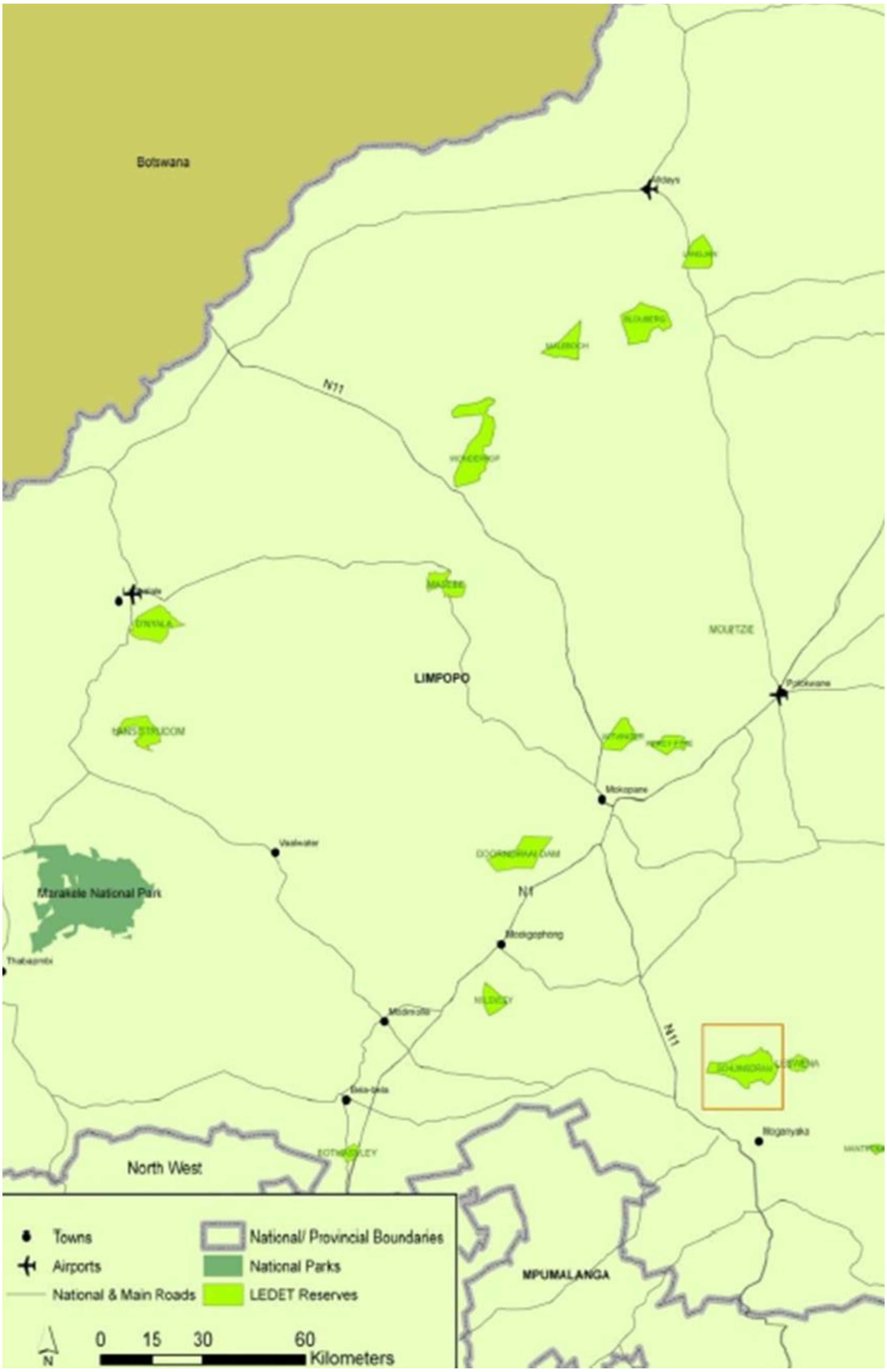

Figure 2.1: Map showing the location of the Schuinsdraai Nature Reserve (reprinted with permission from LEDET 2012)

2.4 Meteorology and Temperature

Schuinsdraai Nature Reserve receives an average annual rainfall of 648 mm per year supporting the persistence of the savannah biome in the area (Accatino et al., 2010; Engelbrecht, 2015). Winters are dry and cool, persisting from May until mid-August and followed by a hot dry season until October, after which the rains fall from November, ceasing in April (Mucina and Rutherford, 2006). Mean maximum temperatures is 35.5 ˚C and mean minimum, -3.1˚C (Mucina and Rutherford, 2006).

2.5 Topography and Geology

The Schuinsdraai Nature Reserve is located at 24°50'33.3"S and 29°23'02.3"E and is approximately 20 km northeast of Marble Hall in Limpopo (Botha, 2006). The elevation of the reserve, according to Google Earth© is, at its lowest point, 820 m above sea level and 1100 m above sea level at its highest point. The majority of the reserve is on a plain sloping downward towards the Flag Boshielo Dam, with a raised mountain plateau covering the remainder of the reserve. The soil is underlain by granite of the Lebowa Granite Suite. Sandstone, conglomerate and siltstone predominate in the north (Mucina and Rutherford, 2006) and Glenrosa and Mispah soil types are located closer to the dam, changing to freely draining red-yellow apedal soils in the immediate vicinity of the dam.

2.6 Human Settlement

The land within the boundaries of the Schuinsdraai Nature Reserve was previously utilised for agriculture, the remnants of which are still visible today (LEDET, 2012). The reserve also houses six graves belonging to members of the Pedi tribe. The land was purchased from local farmers in 1985 with the intention of adding it to the Lebowa homeland but was later transferred to the former Department of Development Aid in order to develop a nature reserve. The Schuinsdraai Nature Reserve was officially proclaimed on the 3rd of March 1993 (LEDET, 2012).

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Chapter 3: The Occurrence and Population Size Classes of Invasive Alien Plants in Schuinsdraai Nature Reserve

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3.1 Introduction

At the time of this study, no comprehensive list of IAPs or in-depth information on their distribution and population structure within the Schuinsdraai Nature Reserve was available. The impact of IAPs on nature reserves is not unique to this particular reserve, but is a global problem, impacting protected areas throughout the world (Dogra et al., 2010). Indeed, even in remote reserves at the extremes of human habitation, such as in the arctic, biological invasions are still a management concern (Hall et al., 2010). The closer the reserve is to anthropogenic activity the greater the impact of IAPs (Guo et al., 2017). In a protected area such as Schuinsdraai Nature Reserve, which is easily accessible to larger urban areas (Botha, 2006), the close proximity of tourists and local residents who uitlise the Flag Boshielo Dam for fishing and other activities, greatly facilitates the spread of IAPs.

The preliminary list of IAPs present in the Schuinsdraai Nature Reserve was informed by a single aerial survey, conducted by the Limpopo Department of Economic Development, Environment and Tourism (LEDET), in 2012. The above survey indicated that populations of *Cereus peruvianus*, *Opuntia ficus-indica*, *Sesbania punicea*, *Melia azedarach* and *Lantana camara* were present inside the reserve but gave no quantitative results regarding the most densely populated areas, nor localities of these species. Control programmes rely on information regarding populations, pathways and sites of IAP invasion (Foxcroft et al., 2019) and thus, to date, control has been sporadic and unfocussed.

Field data collection is costly and time-consuming and sampling strategies should be chosen to efficiently obtain objective results (Marchant and Ramos, 2012). Due to the fact that IAPs within the Schuinsdraai Nature Reserve had never before been quantitatively investigated, nor mapped, there was no baseline data from which to inform sampling strategy. Aerial surveys, which were utilised by LEDET (2012) for the first IAP survey, were prohibitively expensive (Baard and Kraaij, 2019), but an overview of the nature reserve was required to determine which area was most densely infested in order to focus most attention there. In addition, annual monitoring would be based on this initial survey and therefore it should be repeatable and inexpensive (Shackleton et al., 2020).

A species list and indication of relative population sizes, as well as the areas in which most IAPs occur is the minimum knowledge set required to begin an IAP management programme (Antonio and Meyerson, 2002). Another consideration is that the removal of certain IAPs could have negative consequences, depending on the plant species involved or the type of control measures utilised, such as, contributing to erosion, or disrupting a succession pathway (Antonio and Meyerson, 2002). In addition, funding for such IAP removal programmes is limited and it is therefore prudent to focus on those plants most likely to spread the fastest and to have the greatest impact, rather than randomly controlling any IAP species encountered (Antonio and Meyerson, 2002). It is important, however, to acknowledge that control of IAPs is mandated by law in terms of section 76 of the National Environmental Management: Biodiversity Act, 2004 (act no. 10 of 2004) and that if any of the species listed under this act occurs, they must be removed utilising the appropriate control method.

A rapid means of assessing which areas of the nature reserve were most impacted by IAPs, and what these IAPs were, was necessary. Convenience sampling or non-probability sampling is a rapid data collection method which is accessible, inexpensive, and can be used to determine future actions (Etikan, 2016; Given, 2008). It is a useful means of gaining an overview of the area to be investigated, in order to devise an effective sampling strategy depending on where the IAP populations are most dense (Huebner, 2007). A roadside inspection is a non-probability-based technique to gain baseline data on IAPs and relative abundance. It can easily be monitored on an annual basis, if necessary, by following the same route (Baard and Kraaij, 2019; Iftikhar et al., 2016). Roadside infestations would be the worst-case invasion scenario for any given area, due to the fact that roads are pathways of invasion for weed species and road verges would therefore be the first places to be colonised by IAPs (Foxcroft et al., 2019).

Conducting an initial roadside inspection is a rapid means of obtaining baseline information regarding the overall extent and occurrence of IAPs in order to inform a quantitative investigation. There is a strong correlation between anthropogenic activities and density of IAP infestation (Maitrea, Richardson and Chapman, 2004). Invasive Alien Plants need to be introduced in the first place and do not naturally occur in the area where they are viewed as IAPs (Pyšek et al., 2003; Pyšek and Prach, 2003). Due to this, human activity is generally the predominant source of IAP infestation (Vilà and Pujadas, 2001). The more human activity, the higher the density of IAPs (Chytrý et al., 2008; Fuentes et al., 2015) and particularly, an increase in human traffic through protected areas, results in an increase in density of IAPs in these places (Vilà and Pujadas, 2001). Thus, the initial investigation into IAPs within the Schuinsdraai Nature Reserve was conducted along the road network.

Fragmentation and accessibility of nature reserves facilitates the spread of IAPs (Baard and Kraaij, 2019). The Schuinsdraai Nature Reserve is bisected by a tar road effectively separating the nature reserve into two parts. The presence of this tar road probably contributes to the spread of IAPs as it generates a large corridor along which fruit and/or seeds can be transported via tyres and people (Kalwij et al., 2008; Rahlao et al., 2010). Thus, fragmentation of the reserve is a concern regarding spread of IAPs (Christen and Matlack, 2006). Additionally, fragmentation is undesirable due to the disruption caused to connectivity between habitats and decrease in their quality and it should therefore be avoided or, if possible rectified or mitigated (Wilson et al., 2016). Habitat fragmentation can result in bottlenecks that facilitate invasions into certain areas, but can also limit dispersal into distant or disconnected areas (Minor and Gardner, 2011). In addition, the increase in edge effects due to fragmentation, increases invasion potential (With, 2002).

Roadside inspections and rapid road surveys allow for the fast and efficient collection of data on weed species present in an area but are biased towards IAPs found alongside the roads as well as those which are more conspicuous (Baard and Kraaij, 2019). Transects, on the other hand, provide more in-depth data regarding species present and population structure but are time consuming to implement (Huebner, 2007). In this study, follow up investigations after the initial roadside inspection utilised transects and a quantitative roadside survey to investigate IAP densities and the effect of the road network on occurrence.

3.2 Aim and Objectives

3.2.1 Aim

The aim of this chapter is to investigate the occurrence and population structures of IAPs in the Schuinsdraai Nature Reserve.

3.2.2 Objectives

i. To document the species of IAPs present in the Schuinsdraai Nature Reserve.

ii. To determine the area of greatest IAP infestation in the Schuinsdraai Nature Reserve.

iii. To investigate the population structures of the most prevalent IAPs occurring in the Schuinsdraai Nature Reserve through determining size classes per species.

3.3 Materials and Methods

Convenience sampling by means of roadside inspections was conducted in order to determine which area of the nature reserve was most impacted by IAPs and therefore where more intensive sampling should be focused. This was followed by quantitative transect counts in the infested areas of the nature reserve. Thereafter a rapid roadside survey was completed to record occurrence of IAPs in the impacted area of the nature reserve. Permission to work on IAP species was provided by the Limpopo Economic Development, Environment and Tourism (LEDET, Resolutions 158/2019).

3.3.1 Road Inspections

The project was introduced to the management structure of the Schuinsdraai Nature Reserve, as well as to the game rangers that patrol the reserve. A ranger was assigned by management to assist with access to remote areas and with practical information. Maps and the assigned ranger's knowledge were utilised to plan a driving route covering as much of the nature reserve as possible in the shortest period of time. The IAPs list generated by LEDET 2012 was used as a guideline from which to build a more comprehensive list of IAPs.

Three people were involved in data collection, which was facilitated by driving the reserve road network at 20 km/h. The vehicle was stopped when either the driver, observer or the designated ranger noted any IAPs. At this point the roadside vegetation was perused on foot to more closely note IAPs that would not have been visible from the vehicle.

The following data were recorded at each IAP occurrence point: Species name or specimen number if unidentified, species GPS co-ordinates, life stage and number of individuals per population and any anthropological influence within sight. Specimens of plants that could not be identified in the field were collected for further identification at the Larry Leach Herbarium of the University of Limpopo. The data was presented by means of graphs, tables and maps. These results informed the location of the transects and rapid road survey which were placed in areas where the greatest IAP infestation occurred in order to quantify density and anthropological influence.

The eastern section of the reserve, which was the area most infested with IAPs, was targeted for line transects and a rapid road survey in order to quantify the extent and species diversity of the IAP infestation in this area.

3.3.2 Line Transects

In March 2018, the eastern area of Schuinsdraai Nature Reserve, was divided into broad sampling units using the road network as indicated in Figure 3.1 These were linked to the four official management sections within the nature reserve, in order that management recommendations could be collated with these sections. Point intercept transects as described by Godínez-Alvarez et al. (2009), and Okin et al. (2006) were completed in each of the selected sub-sections. Ten, 50 m long, randomly positioned transects per management section were sampled. Once an area was randomly selected for sampling, a GPS point was placed at the center of the selected area, using Google Earth ©. The dropped point was then used as the 0 m mark for the transect in question. From the 0 m mark, a 50 m measuring tape was extended randomly. On each meter interval the following was recorded: Plant present or not, and if present then species name or specimen taken, if the plant was an IAP as well as litter or bare ground. Litter and bare ground were also recorded where they touched the transect. Any anthropogenic activity close to each transect was also noted.

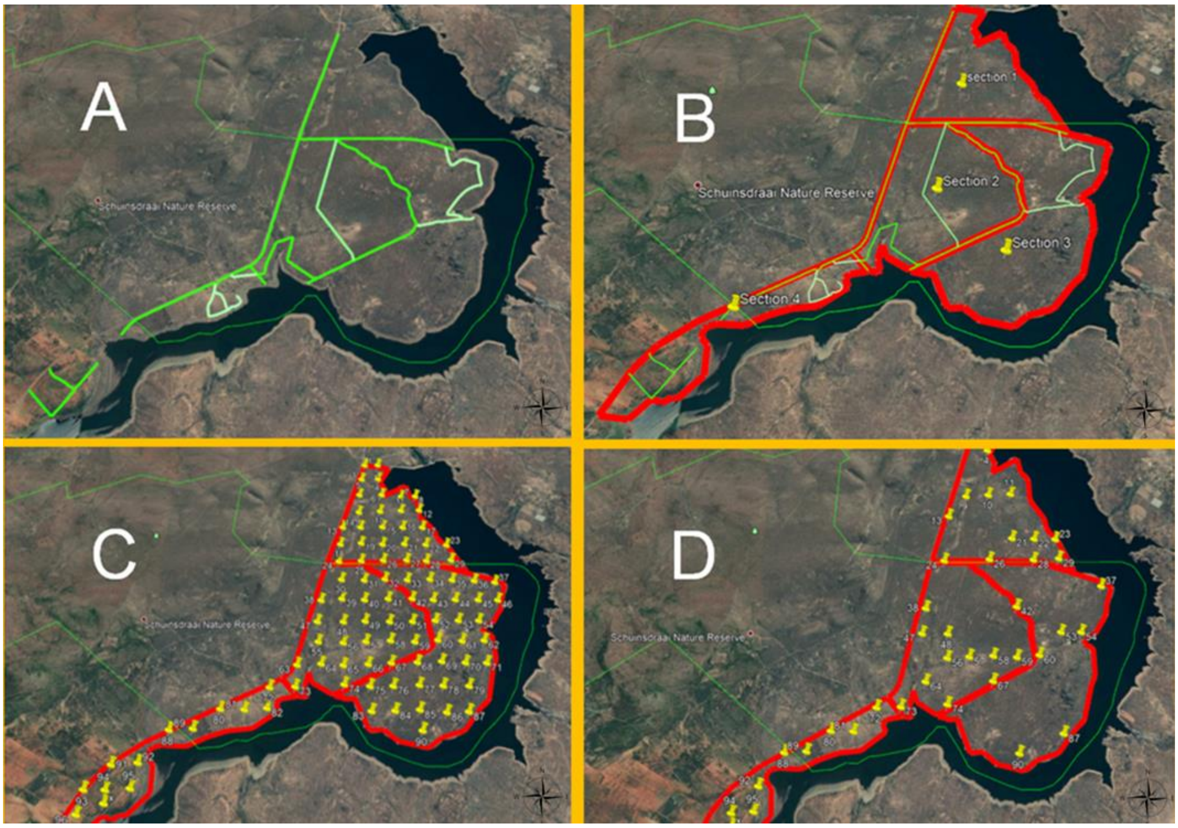

Figure 3.1: Map of the eastern area of the Schuinsdraai Nature Reserve overlayed onto a Google Earth © image (2018) indicating the planning for and final position of the transects utilised to determine occurrence and species of IAPs present. A) road network, B) sections C) possible transects and D) randomly selected transects

Transects were analysed according to the extent to which each sub-section was subjected to anthropogenic activity, as some subsections were closed to the public. Anthropogenic disturbances included litter, building rubble, ground disturbances such as holes and mounds made by means of spades, as well as ruins and discarded machinery and piping.

Two people conducted the data collection for each transect and these observers remained the same throughout the sampling period in order to avoid changes in observer bias (figure 3.2). Average number of aliens per transect were compared between sections, as well as between accessible to public vs inaccessible to public sections. A Kruskal-Wallis and post hoc Tukey test was conducted and analysed using the statistics program R.

Figure 3.2: Conducting data collection during sampling utilising the transect method

3.3.3 Rapid Road Surveys

To gain a further understanding of the distribution of the IAPs and to investigate pathways that may have led to their distribution, rapid road surveys were conducted on the road network inside the eastern section of the Schuinsdraai Nature Reserve during the summer of 2019 (Baard and Kraaij, 2019; Van Der Ree et al., 2015). The road network, as indicated in Figure 3.1 was traversed and the vehicle's odometer utilised to measure the distance travelled. The selected length of each roadside survey was 1 km and a rapid circular quadrate (Islam and Tsuiki, 2011; Mentis, 1981) was completed at the end of each 1 km section in order to capture data on IAPs that were not visible from the road.

In order to investigate anthropogenic influence on IAP occurrence, the road network accessible by the public was differentiated from the road network where access was limited. The coordinates of distance travelled were overlaid on a map indicating where the public had access and where this was not the case, in order to understand the influence of public access on IAP invasion status and extent. A Kruskal-Wallis test was utilised to determine whether differences in IAPs recorded in areas where the public had access or not, were significant at the 95 % level.

3.4 Results

In total, and using various methods, 17 IAP taxa were recorded in Schuinsdraai Nature Reserve, comprising four families and ten genera. The most abundant taxon was *Opuntia stricta*, followed by *Cylindropuntia fulgida*. Of the recorded species, 12 are regulated by the NEMBA A&IS regulations and are new records for Schuinsdraai Nature Reserve.

3.4.1 Roadside Inspections

The table below indicates the species that were recorded during the roadside inspection. *Cereus jamacaru* and *M. azedarach* were the only species previously recorded in the Schuinsdraai Nature Reserve (LEDET, 2012). The roadside inspection generated an inclusive view of the IAP population in the Schuinsdraai Nature Reserve, indicating that the most infested areas were those in the eastern region of the reserve, close to the dam. The survey confirmed that the western section, and indeed the largest proportion of the nature reserve, was impacted very little by IAP infestation and that the most impacted eastern region corresponded with human presence.

Table 3.1: Species list of IAPs located on road inspection route

Genus	Species	English Common name	Present or absent in LEDET 2012
Argemone	*ochiolenca*	Mexican poppy	Absent
Bidens	*pilosa*	Black-jack	Absent
Boerhavia	*diffusa*	Spreading hogweed	Absent
Bougainvillea	*glabra*	Paper flower	Absent
Cereus	*jamacaru*	Queen of the night	Present
Cylindropuntia	*fulgida*	Boxing glove cactus	Absent
Datura	*ferox*	Thorn apple	Absent
Flaveria	*bidentis*	Clustered yellow tops	Absent
Grevillea	*robusta*	Silver oak	Absent
Harrisia	*martinii*	Moon cactus	Absent
Jacaranda	*mimosifolia*	Blue jacaranda	Absent
Melia	*azedarach*	Syringa	Present
Opuntia	*stricta*	Prickly pear	Absent
Rosa	*rubiginosa*	Sweetbriar rose	Absent
Senna	*didymobotrya*	Peanut butter cassia	Absent
Tipuana	*tipu*	Tipu tree	Absent
Xanthium	*strumarium*	Large cocklebur	Absent

Figure 3.3 indicates the locations of the species in the table above and therefore the area of the reserve that is least impacted by IAPs. Note that a large cluster of species was found in a single location towards the southern part of the Schuinsdraai Nature Reserve, upstream of the dam wall. The red points mark areas of previous anthropogenic activity (agricultural infrastructure) the one cluster towards the south is

where the public had access and the cluster to the north is where the rangers' lodgings are located.

Figure 3.3: GPS locations of IAPs encountered on the road inspection and overlaid onto a Google Earth © image indicating areas of greatest density

Figure 3.4 Indicates that *Opuntia stricta* populations were the most commonly encountered IAPs, with *Cereus jamacaru* and *Cylindropuntia fulgida* were also more commonly encountered than other IAP species

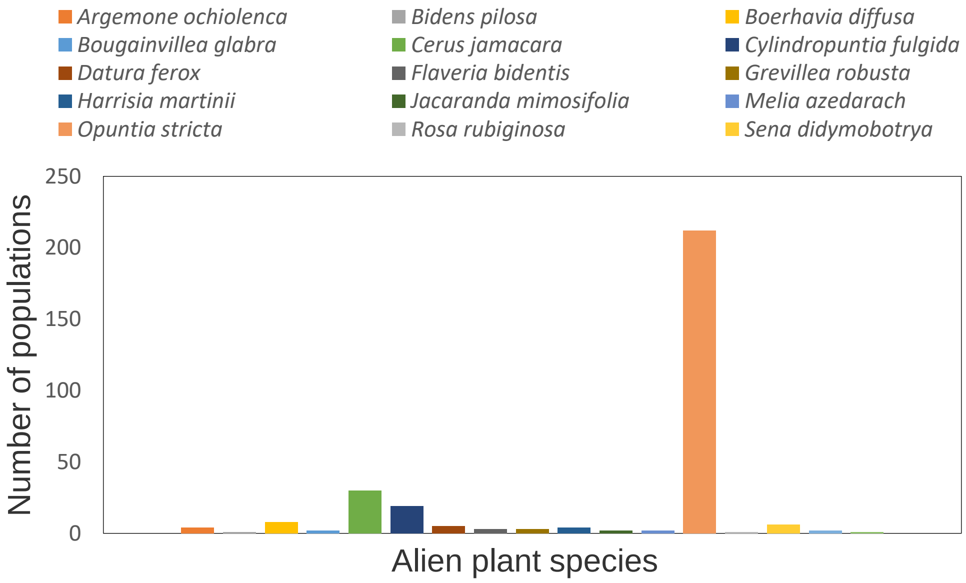

Figure 3.4: Number of populations per IAP

Opuntia stricta occurs in the greatest number of populations throughout the Schuinsdraai Nature Reserve and also possesses the highest number of individuals per population as indicated in Figure 3.5.

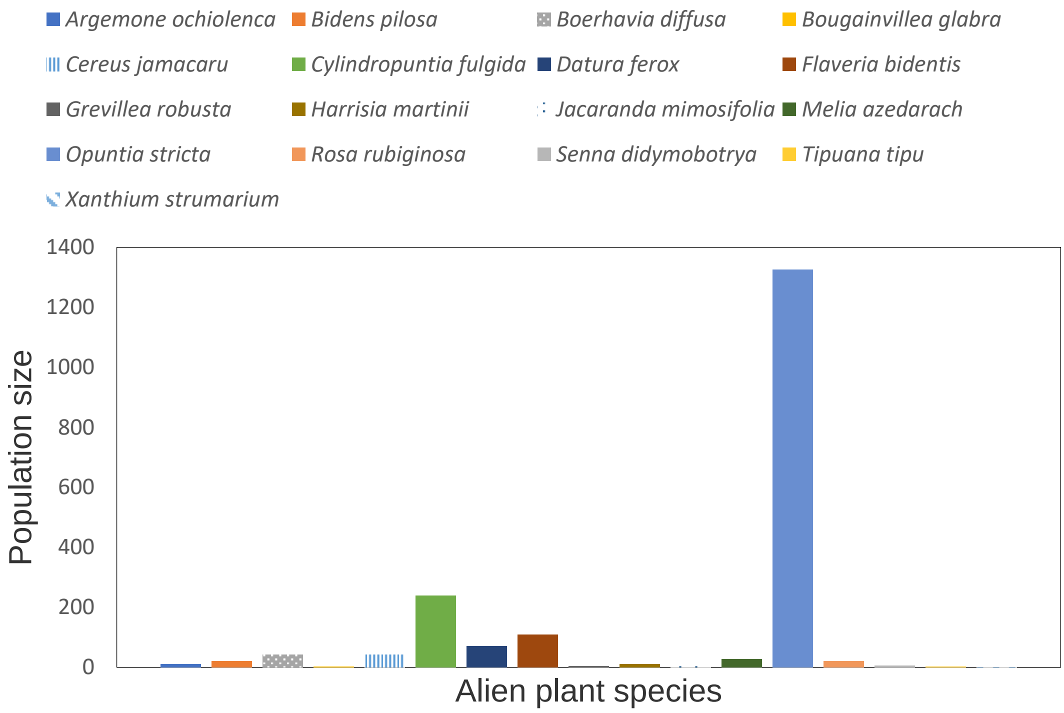

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Figure 3.5: Invasive Alien plant population size encountered on the road inspection

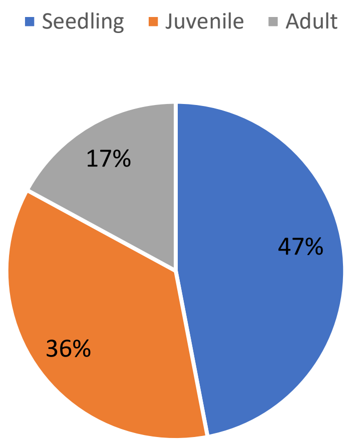

Figure 3.6: Percentage occurrence of three growth phases of invasive alien plant s proportions

The above figure indicates that the IAP populations in the Schuinsdraai Nature Reserve are not static and are growing due to the higher percentage of seedlings.

Table 3.2 illustrates that although encounters may be few, numbers per encounter are high. This serves as an indication of the tendency of IAPs to form monocultures.

Table 3.2: Average number of plants per population found in roadside inspection

Species name	Average number of plants per population plus standard deviation where applicable
Flaveria bidentis	34.33 +/- 55.14
Argemone ochiolenca	27.75 +/- 21.76
Rosa rubiginosa	21
Bidens pilosa	20
Datura ferox	14 +/- 18.06
Melia azedarach	14 +/- 7.07
Cylindropuntia fulgida	12.57 +/- 8.2
Boerhavia diffusa	5.25 +/- 3.33
Opuntia stricta	2.76 +/- 7.05
Harrisia martinii	2.75 +/- 1.26
Bougainvillea spectabilis	1.5 +/- 0.71
Tipuana tipu	1.5 +/- 0.71
Cereus jamacaru	1.4 +/- 0.72
Grevillea robusta	1.33 +/- 0.58
Senna didymobotrya	1.16 +/- 0.41
Xanthium strumarium	1
Jacaranda mimosifolia	0.66 +/- 0.71

3.4.2 Line Transects

No new IAP species were recorded from the line transects. The area was divided into sections where the public had unlimited access and those where access was limited. The area where access was limited was four times larger than where access was unlimited, with a correlated increase in road network. The average number of IAPs per transect observed in the area where access was unlimited was higher than where access was limited (Table 3.3) and according to the Kruskal-Wallis rank sum test, this difference is significant:

Chi square test: 12.554, degrees of freedom: 3 and p value: 0.005708. Thus, the line sections where access was limited yielded fewer IAPs than line sections where access was unlimited.

Table 3.3: Line transect results

	Size of sections (km^2)	Length of road network (km)	Number of IAPs recorded per transect	Average number of IAPs per transect
Public access (Section 4)	4	10	28	2.8
Limited access (Sections 1,2 and 3)	22	24	9	0.3

The results clearly indicated higher IAP infestations in areas open to the public.

3.4.3 Rapid Road Survey

During the rapid road survey, two IAPs that were not noted during the initial road inspection or transect counts, were documented. *Zinnia peruviana* and *Ipomoea congesta,* which are both from the United States.

The quadrates where access was unlimited, yielded more IAPs than where access was limited (Table 3.4).

Table 3.4 Rapid road survey results

	Number of IAPs observed in drive by survey	Average number of IAPs rerecorded per km of drive by survey	Total number of IAPs observed in quadrates	Average number ofIAPs recorded per quadrate
Public access (Section 4)	396	39.6	101	10.1
Limited access (Sections 1,2 and 3)	288	13.09	59	2.68

3.5 Discussion

Results of the road inspection give an overview of the distribution of IAPs within the Schuinsdraai Nature Reserve and some relevant information on their life history. This large concentration of IAPs was clumped together in a relatively small area and included 15 previously unrecorded IAP species. The majority of the IAPs are present on the eastern side of the reserve, despite the small size of this portion. They are particularly prevalent in the areas where the public has unlimited access, due to the particular invasion pathways that are supported by tourism activities. Thus, the area close to the dam exhibits the greatest IAP infestation, with the area to the west of the tar road that leads to Marble Hall, being markedly less infested, with few IAPs noted.

Water bodies are transporters of IAP seeds and cuttings (Oorschot et al., 2017) and therefore one of the most important reasons for the dense IAP infestation in the eastern sections can be explained by the proximity of the dam (red markers on Figure 3.3). In addition, day and overnight visitors are drawn to the dam for recreational reasons such as fishing and boating. The increase in vehicular traffic adds to the spread of IAPs (Lonsdale and Lane, 1994)

The area west of the tar road towards Marblehall was composed of untransformed indigenous vegetation, undisturbed by human intervention. The most common means of managing bush encroachment is by using fire (Trollope, 1980), and in the absence of regular burning on the western side of the reserve, the bush is thick and impenetrable thus not conducive to IAP establishment (Masocha et al., 2011). Similarly, the area where access is limited was also densely vegetated, indicating a lack of human intervention via fire or trampling. The area where the public has free access, as well as where the ranger lodgings are located (red markers on Figure 3.3), is far less densely vegetated and the habitat is fragmented, promoting the invasion of IAPs (Liu et al., 2018).

The top four most abundant IAPs encountered were *O. stricta, C. jamacaru, C. fulgida* and *B. diffusa*, thus Cactaceae was the best represented IAP family. *Opuntia stricta*, is a transformer species (Foxcroft and Freitag-Ronaldson, 2007) and thus alters the character, condition, form or nature of the ecosystem in which it is found (Catford et al., 2012; Richardson et al., 2000). The presence of this transformer species is concerning, as if it is left unchecked it could lead to reductions in indigenous plant populations, a decrease in veld condition and mobility of humans and animals around the reserve (Shackleton et al., 2017). In general, rampant growth of *O. stricta* will lead to a decrease in indigenous plant biodiversity of the Schuinsdraai Nature Reserve. *Cereus jamacaru* is a noted transformer of the South African savannah and although an effective biocontrol agent is available, this practise has not been effectively rolled out (van Wilgen et al., 2012). Kawanza et al., (2019) report that *Cylindropuntia fulgida* transforms African savannahs through the modification of soil nutrient concentrations, which results in changed grass species assemblage and decreases biomass yields.

Boerhavia diffusa is not listed as a transformer species and although it originates in South America it has become naturalised in South Africa (Bromilow, 2001). It is common in disturbed and rocky ground and its abundant presence in Schuinsdraai Nature Reserve may be an indication of poor veld management.

Other significant IAPs include *Datura ferox* and *Melia azedarach.* Both these species are poisonous to humans and livestock (Phua et al., 2010; Kerchner and Farkas, 2020) and their presence in areas populated by tourists is problematic. *Melia azedarach* is already listed as a savannah weed and but there is little information on *D. ferox'* impact on savannah vegetation (van Wilgen et al., 2012). There are no biological control agents listed for *M. azedarach* and the tree coppices vigorously, even from stumps cut close to the ground and burned. The use of herbicides in nature reserves is challenging in that diversity of indigenous vegetation should not be compromised by the use of poison (Landres, 2010). Hand pulling for post emergence *D. ferox* seedlings is possible but time and labour consuming therefore herbicide use is more effective despite the implications for indigenous flora (Bromilow, 2001).

Due to anthropogenic activity related to transportation. The line transect data indicates that in sector four, where the most anthropogenic activity occurred and where the general public had access, the number of IAP species encountered was higher, despite this area being smaller than any of the other sectors, with a more extensive road network. Furthermore, the road network that was open to the general public was much shorter than the road network where the access was limited. Anthropogenic activities influenced the invasion status of the road that was accessible to the general public, this influence is clearly visible by the average number of IAPs encountered whilst conducting the roadside survey. This claim that the roadsides where the general public has had access is more invaded than where access is limited is further supported by the results of the circular quadrates on the rapid road survey that indicate that the average number of IAPs per quadrate is higher where the general public had access compared with the area of limited access. This finding is supported by the outcome of similar investigations in the literature where human access causes an increase in the presence of IAPs (Le Maitre, 2004). These results are of relevance to managing the IAP populations, as roads provide opportunities for the IAPs to spread further into areas where anthropogenic activity is limited. The rapid road survey and quadrates were completed in summer in order to record additional summer flowering IAP species that might not have been visible during the line transects which were conducted in late autumn. The fact that only one IAP species was added to the list indicates that even though line transects were not conducted during the flowering season, this did not compromise the study to a great extent *Zinnia peruviana*, which was not found in the transects, was recoded from the circular quadrates and although it is a naturalised, exotic it has been listed as invasive in the Kruger National Park (Foxcroft et al., 2007) and its presence in Schuinsdraai Nature Reserve is therefore concerning and it should be eradicated before it spreads into untransformed areas of the reserve.

Data from the combination of roadside inspections, transects and rapid roadside surveys has been used to determine baseline information on the IAPs in the Schuinsdraai Nature Reserve, based on that are simple and rapid to complete, as well as inexpensive and therefore effective for long term monitoring programmes (Baard and Kraaij, 2019). They can be modified to include any group of species, such as sleeper weeds, which are those alien species with as yet unknown invasive potential (Baard and Kraaij, 2019). The combination of roadside and more in depth quantitative transects can be updated on a seasonal basis and supplemented with quantitative data collected in the summer months, as well as utilised to record the change in IAP lists and distribution after management interventions such as biocontrol, herbicide use and physical removal (Henderson, 2001).

Lists of IAP species should be supplemented by an indication of growth form of the IAP, as well as an indication of the state of the area the IAPs are located in and proximity of rare and endangered populations of indigenous plants, in order to create a priority listing (Westman, 1990). Those IAPs with creeping and twining characteristics, such as *Boerhavia diffusa*, should be targeted for removal first, and those habitats with vulnerable and threatened indigenous plant species should be prioritised for clearing (Westman, 1990).

Immediate control of the IAPs present in the areas most accessible to the general public is important both from a legislative perspective in terms of duty of care, as well as to prevent the infestation of the as yet untransformed areas of the majority of the Schuinsdraai Nature Reserve.

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Chapter 4: The Negative Impact of Alien Plant Species on Species Richness, Evenness and Diversity of the Indigenous Vegetation in the Schuinsdraai Nature Reserve

4.1 Introduction

Understanding the distribution of IAPs in a nature reserve is only one aspect of their management (Vicente et al., 2013). The effect that these IAPs have on the environment is equally important, as not all IAPs are equal in their disruptive capacity (Pyšek and Richardson, 2007). To investigate the disruption that IPAs cause, three indicators are considered: Species richness, species evenness and a biodiversity index that is used to assess environmental stability.

Species richness, referred to as (S), is the number of different species in a given environment (Brown et al., 2016) and thus the higher the number of species, the higher the species richness. Whereas species evenness, referred to as (E), is the measure of equality of abundance in an ecosystem (Alatalo, 1981; Mulder et al., 2004). Due to the fact that different species have different traits, the species that are more abundant will have a greater impact on the environment. If the species that is most abundant is an IAP, its impact on the environment will be greatest (Hillebrand et al., 2008). The impact that IAPs have on the environment is negative and increasing abundance of IAPs has significantly larger effects (Bradley et al., 2021). Composition and structure of indigenous vegetation is negatively affected by IAPs and therefore on the fauna who rely on this vegetation for food and shelter (Singh et al., 2014).

Generating a tool for diversity index is a useful measurement of biodiversity, and for the purposes of this study, the Shannon-Wiener index was used. This index takes into account species richness and evenness (Supriatna, 2018). Invasive alien plants have a negative effect on the Shannon-Wiener biodiversity index (Hejda et al., 2009). These effects are thus a culmination of the negative effects IAPs have on species richness and species evenness.

Indigenous plants are often displaced by alien plants because the alien plants compete for the same resources as the indigenous plants and this competition for resources is the driving force for indigenous plant displacement (Pyšek et al., 2017). The displacement results in the indigenous biodiversity being lowered and eventually the indigenous biodiversity is replaced with alien species (Reinhardt, 2012). This complete replacement of indigenous species turns the area that was productive, into a monoculture that is less productive (Dogra et al., 2010).

The effect of the continuous increase in human movement across the globe and within countries is a driving force for IAP spread and is vital to control (Vicente et al., 2013). Although protected areas are important tools for the protection of biodiversity and therefore ecosystem services, they are static, even when connected via corridors (Vicente et al., 2013). Anthropogenic influences on nature reserves are fluid and changeable and much more adaptable than the static species distributions and ecosystem networks within a reserve. Anthropogenic influences change more rapidly than biodiversity structures (Vicente et al., 2013). Conservation value of a protected area as well as within such an area, is also important to consider as this will influence the amount of time and funding inputs required (Vicente et al., 2013)

It is important to understand the nature of conflict that will undoubtedly arise when deciding on management strategies (Westman, 1990). Nature reserves rely on income from gate fees to justify their existence. Precluding members of the public from areas they favour could result in lower visitor fees. However, continuing to allow their access without modifying management strategies could result in decreased indigenous floral and therefore faunal diversity (Grosholz, 2002).

In some instances, it may be more detrimental to spend time and limited budget on removing IAPs from a habitat in which they do not have a high negative impact and it is thus important to understand which IAPs in a nature reserve are dominant and which are satellite species with limited impact (Denslow and Hughes, 2004)

4.2 Aim and Objectives

4.2.1 Aim

To investigate the effect of invasive alien plants on the indigenous plant diversity of the Schuinsdraai Nature reserve

4.2.2 Objective

To investigate the effect of IAP presence on:

i. indigenous species diversity
ii. indigenous species evenness
iii. Indigenous species richness

4.3 Materials and Methods

Indigenous floral species in four by four meter squared Braun-Blanquet quadrates were recorded with the assistance of staff from the Larry Leach Herbarium of the University of Limpopo. From the data collected in previous chapters, as well as from anecdotal accounts (LEDET, 2012), the four most prominent IAPs were selected for investigation. Areas in the Eastern section of Schuinsdraai Nature Reserve which were infested by monocultures of *Boerhavia diffusa, Cylindropuntia fulgida*, *Cereus jamacaru* and *Opuntia stricta*, were designated For each of the above four IAP infested areas, ten, 4 x 4 m quadrates (Braun-blanquet, 1932) were positioned in order to conduct vegetation cover analyses and species counts. A control group of ten quadrates was set up in an un-infested area within the same habitat type.

For each quadrate the following were recorded:

i. The GPS co-ordinates.
ii. The number of different plant species
iii. Percent cover of each indigenous species.

Herbarium voucher specimens were collected for identification and deposited at the Larry Leach Herbarium, University of Limpopo.

Figure 4.1: Image showing the completion of the quadrates

Care was taken to ensure that all the quadrates fell within the same habitat type in order for comparisons to be made. Species richness, species evenness and a biodiversity index (Shannon-wiener index) were calculated from the data.

Species evenness was calculated as follows: (Mulder et al., 2004).

$$E = \frac{D}{S} = \frac{\left(\frac{1}{\sum_{i=1}^{s} p_i^{\ 2}}\right)}{S}$$

Where,

$$p_i = \frac{cover\ of\ species\ in\ question}{total\ cover\ of\ all\ species}$$

Species evenness provides a value between 0 and 1 where the closer to 0, the more even the distribution and the less dominant a specific plant and the closer to 1, the less even and therefore more dominant a specific plant in the community (Mulder et al., 2004).

The formula used to calculate the Shannon-wiener index is as follows (Vahdati et al., 2016).

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$

Where,

$$p_i = \frac{cover\ of\ species\ in\ question}{total\ cover\ of\ all\ species}$$

For statistical analysis IBM's SPSS version 25 was used. The data collected was first tested for normality, after which a One-way Anova was conducted, with p = < 0.05 considered a significant difference. After a significant difference was obtained, a post hoc Tukey HSD test was conducted to determine where the differences lay.

4.4 Results

Invasive Alien Plant species negatively influenced the indigenous vegetation of the Schuinsdraai Nature Reserve. The severity of the effect is dependent on IAP species

4.4.1 Species Richness

Species richness for quadrates untransformed by IAPs, was larger than that of the IAPs, serving as an indication that IAPs negatively affect species richness. The figure indicates that the *Opuntia stricta* data set had the lowest species richness value and thus had the largest effect.

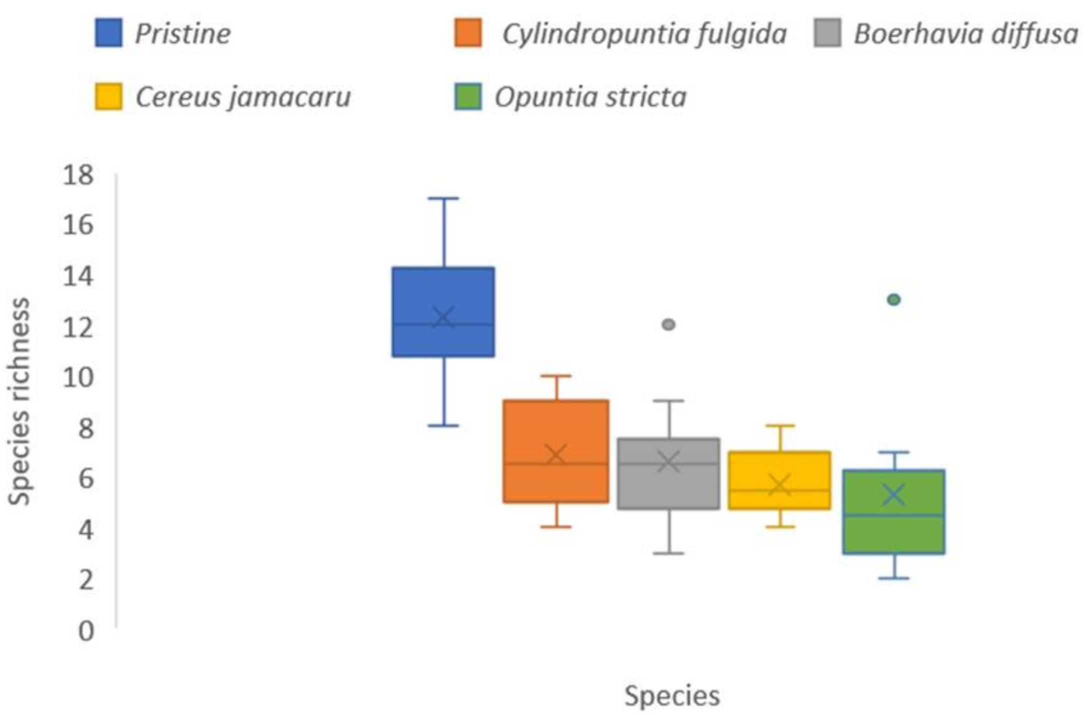

Figure 4.2: Figure indicating species richness comparisons

The data in the figure above was tested for normality, and obtaining a result that indicated normality the relevant statistical test, a one-way Anova, was conducted

Table 4.1 Result of one-way Anova for species richness

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	321.920	4	80.480	13.951	.0000001770
Within Groups	259.600	45	5.769		
Total	581.520	49			

Tukey post hoc analysis indicated a significant difference between all IAPs and the un infested quadrates.

Table 4.2 Result of the Tukey post hoc test for species richness

(I) plant	(J) plant	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Pristine	*Cylindropuntia fulgida*	5.40000*	1.07414	.0000794970	2.3479	8.4521
	Cereus jamacaru	6.60000*	1.07414	.0000018534	3.5479	9.6521
	Boerhavia diffusa	5.70000*	1.07414	.0000314637	2.6479	8.7521
	Opuntia stricta	7.00000*	1.07414	.0000005204	3.9479	10.0521

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4.4.2 Species Evenness

Figure 4.3 indicates how the (E) values for the IAPs are higher than that of the pristine group, serving as an indication of an uneven species distribution. *Opuntia stricta* has the highest species evenness value, indicating this species has the greatest impact on species evenness.

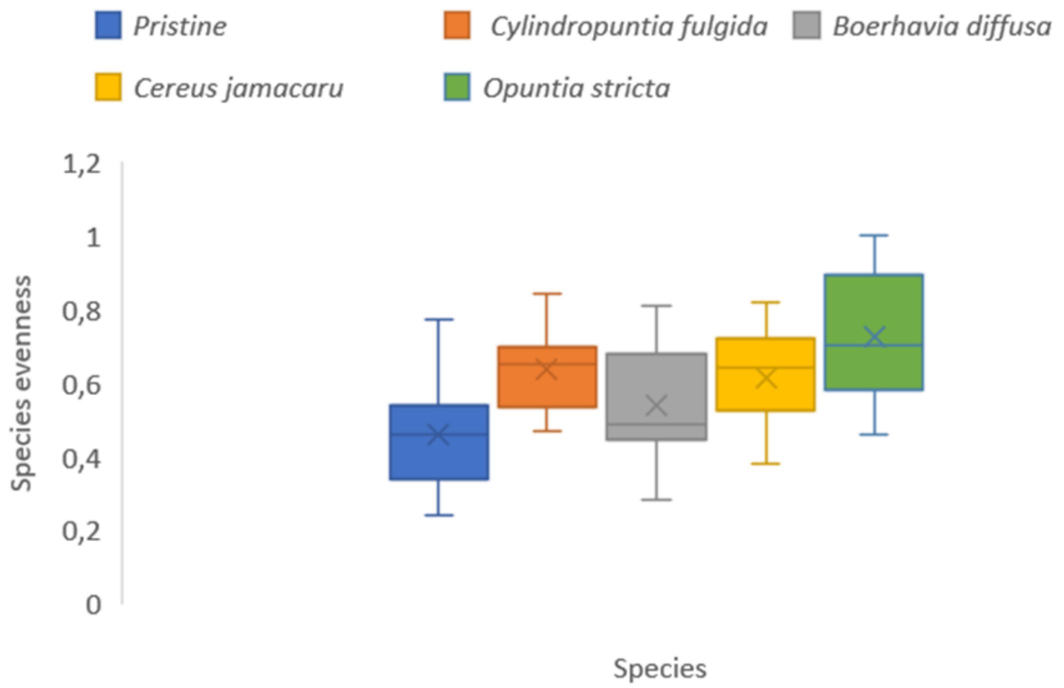

Figure 4.3: Result for species evenness

The data in Figure 4.3 was tested for normality, and a one-way Anova conducted indicating a significant difference for species evenness between all infested quadrates and untransformed quadrates.

Table 4.3: Result of one-way Anova for species evenness

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.420	4	.105	4.513	.0037656815
Within Groups	1.048	45	.023		
Total	1.469	49			

The one-way Anova indicated a significant difference, but the test does not indicate where this difference occurs. The Tukey post hoc analysis conducted indicated significant differences between all quadrates.

Table 4.4: Result of Tukey post hoc analysis for species evenness

					95% Confidence Interval	
(I) Plant	(J) Plant	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Pristine	*Cylindropuntia fulgida*	-.181200	.068253	.0772998220	-.37514	.01274
	Cereus jamacaru	-.157800	.068253	.1599922251	-.35174	.03614
	Boerhavia diffusa	-.083200	.068253	.7404633064	-.27714	.11074
	Opuntia stricta	-.271200*	.068253	.0022499850	-.46514	-.07726

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4.4.3 Shannon-Wiener Index

The chart below indicates how the (H) values for the untransformed quadrates were higher than *Cereus jamacaru, Boerhavia diffusa* and *Opuntia stricta* but only differed slightly in the case of *Cylindropuntia fulgida*.

In general, indigenous species were fewer in IAP infested plots than in untransformed. Biodiversity was greater in plots that were not infested by IAPs.

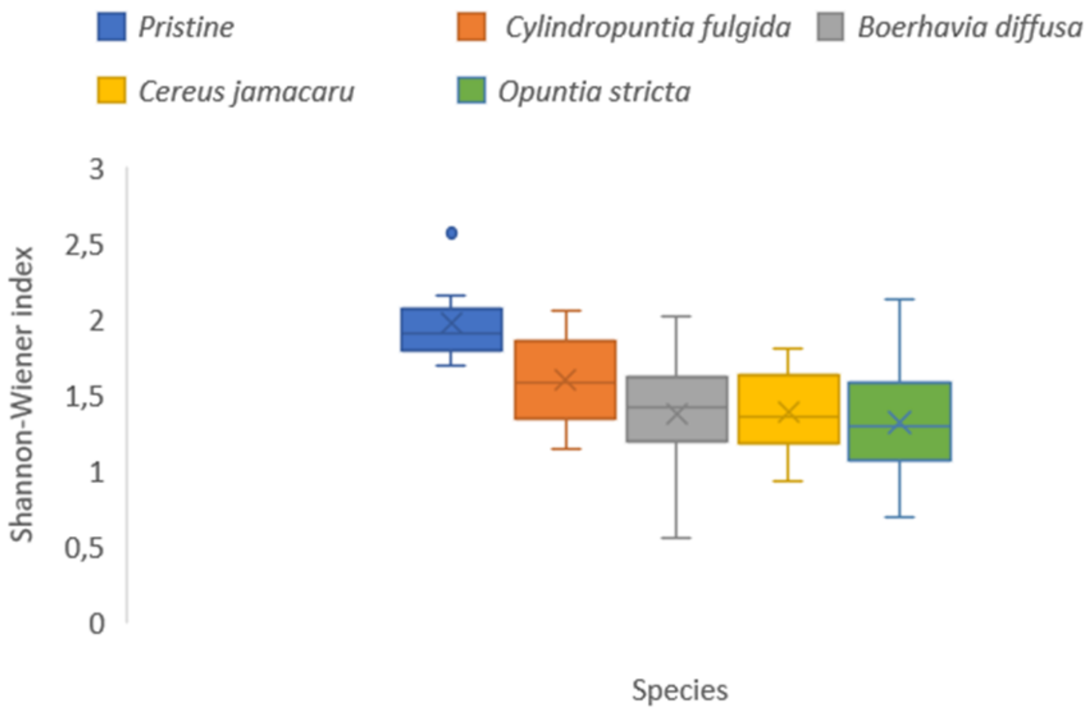

Figure 4.4: Results for Shannon-Wiener index

The data in the figure above was tested for normality, and obtaining a result that indicated normality the relevant statistical test, a one-way Anova, was conducted

Table 4.5: Result for one-way Anova on the Shannon-Wiener index

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.871	4	.718	6.583	.0002931234
Within Groups	4.906	45	.109		
Total	7.777	49			

The one-way Anova indicated a significant difference, but the test does not indicate where this difference occurs. To determine where the difference is a pot hoc test needs to be conducted. A Tukey post hoc analysis was conducted

Table 4.6: Results of the Tukey post hoc analysis for the Shannon-Wiener index

(I) Plant	(J) Plant	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Pristine	*Cylindropuntia fulgida*	.365200	.147669	.1150924306	-.05439	.78479
	Cereus jamacaru	.583500*	.147669	.0024042708	.16391	1.00309
	Boerhavia diffusa	.589500*	.147669	.0021273843	.16991	1.00909
	Opuntia stricta	.652100*	.147669	.0005736072	.23251	1.07169

4.5 Discussion

The results indicate that, overall, plant diversity, richness and evenness is negatively affected by the presence of IAPs. This will have implications on the fauna dependent on these plants for food and shelter (Yapi et al., 2018).

The first set of data showed that indigenous species were less prevalent in areas where IAPs were present, indicating that the IAPs outcompeted the indigenous vegetation, which is a commonly observed trend where IAPs establish in protected areas (Zengeya et al., 2020) . Fewer species present in an area leads to a monoculture being established (Dogra et al., 2010). Generally, a monoculture is not as productive as the original, indigenous vegetation that was present (Dogra et al., 2010; Mulder et al., 2004). The new monoculture may not be palatable to the herbivores in the ecosystem and this will disrupt the food chain from its lowest level upwards (Agrawal et al., 2005; Jogesh et al., 2008).

The second set of data that focused on species evenness also showed significant differences, however the results were not as clear-cut as the first set of data. The post hoc analysis indicated that there was a significant difference in plots that were infested with *O. stricta* and *C. fulgida* compared to the indigenous groups but not in the plots infested by *B. diffusa* and *C. jamacaru*. The reproductive strategies of the IAPs are responsible for this, as *O. stricta* and *C. fulgida* can reproduce readily from fallen cladodes of the mother plant, as well as from seeds (Reyes-Agüero et al., 2006; Vilà and Gimeno, 2003). *B. diffusa* (Aoyama et al., 2012; Clifford, 1959) and *C. jamacaru* (Gomes et al., 2014) do not readily follow this strategy but reproduce only from seeds, resulting in the spread of fewer offspring and less of an impact on species evenness.

The last set of data focused on the biodiversity index. Indications from this index are that as with the other results IAPs had a statistically significant impact except for *C. fulgida*. This indicated that the biodiversity in areas infected by *C. fulgida* is not as harshly impacted by its presence as the areas that are infested by the other IAPs. Competition and physical structure are important means by which the Cactaceae family affects the indigenous flora of an area (Foxcroft et al., 2019).Despite the fact that *C. fulgida* does not significantly affect biodiversity in Schuinsdraai Nature Reserve, the fact that this species has a large biomass and is listed as a transformer species elsewhere in South Africa points to a need to eradicate individuals before they increase in numbers (Bromilow, 2001), perhaps through biological control. *C. fulgida* individuals are not plentiful on the reserve, however, this species causes respiratory complications if they are physically removed, herbicides are not very effective and parts of the plant can sprout vegetatively so if they are cut out and moved this could catalyse further spread, thus biological control may be the most effective means despite low numbers (Shaw et al., 2014). The establishment of the IAP infested monocultures then outcompetes the indigenous vegetation (Dogra et al., 2010). The presence of the IAPs causes fewer nutrients to be available to the indigenous species and allows quicker growth of the IAP (Dogra et al., 2010). The growth of these alien species allows the species to establish a seedbank that will in turn result in more alien species germinating further developing the monoculture and in the process degrading the environment (Marchante et al., 2010).

The Cactaceae in this study were all introduced as ornamentals and as such are easier to control, as their spread is not linked to wind, animals or other uncontrollable factors (Bromilow, 2001). It is however noteworthy that the two most important pathways for transformer species to enter protected areas are through the ornamental trade and rivers, both of which have been utilised in the Schuinsdraai Nature Reserve and thus the possibility does exist for them to be used as entry points in the future if precautions are not in place to prevent this (Foxcroft, 2019).

These results can be incorporated into a management strategy that recognises that practises should vary depending on the dispersal characteristics of the IAPs and incorporates variation depending on whether these species can disperse over long distances or not and also what the impact of connectivity of the IAP populations are (Minor and Gardner, 2011). The management chain of actions should include the following steps: Education, prevention, detection or early warning, eradication, containment, and other forms of intervention (Wittenberg and Cock 2001).

4.6 References

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Chapter 5: Management Recommendations for Invasive Alien Plant Species in the Schuinsdraai Nature Reserve

5.1 Introduction

South Africa has a long history of IAP control (Holmes et al., 2008; Le Maitre et al., 2002; van Wilgen et al., 2012). A large parcel of legislation, known as the 2004 National Environmental Management of Biodiversity Act, has been developed to ensure that alien species are mandated by law and is (NEMBA, Act 10 of 2004). The act serves to provide for the management and conservation of South Africa's biodiversity and includes prohibited activities with respect to the possession and cultivation of IAP species (Cronin et al., 2017). In terms of this Act, and its 'Alien and Invasive Species Regulations' (2014), Management Authorities, including municipalities and districts, of protected areas, are required to draw up control plans to manage listed invasive species. These plans should include actions to ensure that regular monitoring of IAP species occurs and the plan should be flexible in order to remain adaptive to changes in vegetation structure and composition.

The NEMBA act places alien species into the following categories:

Category 1a

Alien species that fall within this category must be combated and eradicated. Any form of trade or cultivating or growing a plant within this category is strictly prohibited (NEMBA, Act 10 of 2004) such as *Acacia adunca.*

Category 1b

Alien species that fall within this category must be controlled and whenever possible be removed and destroyed. Any form of trade or planting a plant within this category is strictly prohibited (NEMBA, Act 10 of 2004) such as *Argemone ochroleuca.*

Category 2

Alien species that fall within this category require a permit to carry out a restricted activity. Species that are covered in this category are commercially important species used in forestry (NEMBA, Act 10 of 2004) such as *Acacia dealbata.*

Category 3

Alien species that fall within this category may remain in prescribed areas or provinces. Further trade or planting of the species that fall within this category is prohibited. Should the plant be located in a riparian area it is classified as category 1d and must be controlled (NEMBA, Act 10 of 2004) such as *Grevillea robusta.*

LEDET's (2012) Strategic Management report for Schuinsdraai Nature Reserve recommended only overarching and vague steps to be taken to ensure the control of IAPs. These actions were not based on a complete representation of IAPs occurrence and distribution and the following chapter aims to fill these gaps in order to assist management in conforming to the legal requirements of Sections 64-77 of NEMBA, in order that all declared IAP species occurring in the reserve are managed, in an environmentally responsible manner.

5.2 Invasive Alien Plant Control Methods

The management of IAP species is a priority for the South African government (NEMBA, Act 10 of 2004) but this should be conducted following best practice guidelines on their management (Bromilow, 2001). These species may be managed in the following ways.

Biological control replicates natural herbivory through anthropogenic intervention by introducing a natural predator or herbivore into the IAP population due to the fact that IAP plants can be resistant to herbivory by indigenous fauna (Jogesh et al., 2008) and thus the introduction of herbivores or predators from the IAP species' country of origin is necessary (Eilenberg et al., 2001). This could result in secondary challenges if this new import is not a strict specialist and damages indigenous plant species instead of the targeted IAP species (Simberloff and Stiling, 1996). The use of biological control is tightly regulated (Cock et al., 2010; Richardson et al., 2007; Zachariades et al., 2017). Rigorous research is conducted, under strict quarantine conditions prior to the introduction of these herbivores (Hill and Olckers, 2000; Van Wilgen et al., 2004). The advantage of biological control over mechanical and chemical control is that once the control population is established, there is little to no manpower required to control IAP populations, however this method should not be followed exclusively, but supplemented with additional control methods (Wilson, 1970). Disadvantages include the prolonged testing time frame before the introduction of a potentially new alien invasive plant predator, as well as the potential that the control agent could destroy natural vegetation if not thoroughly screened (Simberloff and Stiling, 1996).

Chemical control involves the use of herbicides to poison IAPs (Bromilow, 2001; Van Wilgen et al., 2001). This method is effective provided the relevant herbicides are used in the correct dosages (Bromilow, 2001; Van Wilgen et al., 2001). This method is the least appropriate for use in nature reserves as the introduction of an herbicide may have long lasting consequences negative consequences on local vegetation by poisoning and therefore denuding the surrounding soil and allowing for opportunistic invasion by novel IAPs (de Lange and van Wilgen, 2010). For instance, glyphosate, commonly known as Roundup© (Tsui and Chu, 2008), indiscriminately kills a wide variety of species and therefore, if not correctly used can have negative consequences on the adjacent indigenous vegetation (Tsui and Chu, 2008). Advantages of chemical control are that results are relatively rapid and less labour intensive and therefore can be less costly despite the price of the herbicide (Armstrong et al., 1968). It is important that those implementing chemical control methods are correctly trained and attend updated courses regularly, as registration of herbicides fluctuates (ARC 2021).

Physical control involves removing the plants physically from the environment and destroying them at a remote facility (Bromilow, 2001). This process is costly and labour intensive (McConnachie et al., 2012). Special care needs to be taken in removing plants and ensuring that no part, particularly the propagules, is left behind or lost in the process (Kollmann et al., 2009), as this may allow the plant to re-establish and spread as a result of the removal process (Wilson et al., 2007).

5.3 Present Management Practices

At present, management of the IAPs in the Schuinsdraai Nature Reserve is *ad hoc* and sporadic. Rangers report the presence of these plants when they come across them during their patrols, however, there is no formal management strategy in place. Reporting is random and the validity of the reports is varied, as rangers are not specifically trained on the identification of existing IAPs or those that may be a problem in the future. This is despite recommendations in LEDET's (2012) five year strategic management plan that advises IAP control using herbicides and active removal on an ongoing basis. Once IAPs have been reported, there are, however, efforts to control them manually. An additional strategy is that access to large portions of the Schuinsdraai Nature Reserve is restricted to the public (Figure 5.1).

Figure 5.1: Example of signage indicating restricted access

5.4 Previous Survey

The Schuinsdraai Nature Reserve has previously been investigated for IAPs (LEDET, 2012), however, the survey method used was aerial analysis. This provides a rapid means of obtaining an overall analysis of IAP distribution however, it is limited to identifying only the larger species of plants and overlooking the smaller species that ground surveys can identify. Plant specimen collection is not possible, and therefore early detection of IAPs in the reserve is impossible, nor can unidentified IAPs be verified, nor vouchers made and archived in a registered herbarium.

LEDET's 2012 report indicated that populations of *O. ficus-indica*, *C. jamacaru*, *M. azedarach*, *S. punicea* and *L. camara* were present in the reserve. The present sampling in this study did show the presence of *C.s jamacaru* and *M. azedarach,* however, the presence of *L. camara* was not confirmed. Discussions with the rangers indicated that the populations of *L. camara* were managed by means of physical removal to the point where they were no longer present in the reserve as far as known to the management. Unfortunately, the population of *C. jamacaru* was greater than the report indicated. This indicates that persistent manual control can achieve the desired effect of decreasing populations of IAPs on the reserve, however, this must be ongoing, sustainable and persistent. In addition, constant monitoring reveals changes in population structures and should be implemented regularly.

The report also indicated that *O. ficus-indica* was present, however, this was not confirmed during the current study however, *O. stricta* was located. This highlights the necessity of confirmation of identifications, early detection warnings and follow-ups and monitoring (Rainford et al., 2020).

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Figure 5.2: Image showing the mature fruit of *Opuntia stricta*

Regarding *S. punicea*, the report indicated that these plants were submerged by the water, however seeds in the ground may germinate after dam levels drop. *S. punicea* was, however, not encountered in the transects, but if the dam level decreases further, individuals of this IAP may indeed be located.

The LEDET (2012) five year strategic plan includes a map of current and proposed uses for various zones in Schuinsdraai Nature Reserve. Intensive and low use zones correspond to where IAPs were mapped on the road inspection, as well as with the rapid road survey. The gates to the reserve where visitors are permitted entrance, corresponds directly to where the highest rates of infestation are present. As noted earlier, access is limited to the majority of the reserve and the gates that fall in the areas where access is limited, have far less IAPs than where access is not restricted.

5.5 Recommendations

LEDET's five-year strategic report advised that IAPs be cleared in the most cost effective and environmentally responsible manner possible.

Table 5.1: Recommendations for Invasive Alien Plant control

Name	CARA category	Recommended action	Reference
Argemone ochroleuca	1	Physical control (weeding)	(Van Der Westhuizen and Mpedi, 2011)
Bidens pilosa	N/A	Physical control (weeding)	(Mashavakure and Mashingaidze, 2019)
Boerhavia diffusa	N/A	Physical control (weeding)	(Veeraputhiran, 2009)
Bougainvillea glabra	N/A	Physical control (cutting)	(NEMBA, Act 10 of 2004)
Cereus jamacaru	1	Biological control	(Paterson et al., 2011)
Cylindropuntia fulgida	N/A	Biological control	(Paterson et al., 2011)
Datura ferox	1	Physical control (weeding)	(Ballaré et al., 1987)
Flaveria bidentis	N/A	Physical control (weeding)	(NEMBA, Act 10 of 2004)
Grevillea robusta	3	Physical and chemical (cutting and treating)	(Baard and Kraaij, 2014)
Harrisia martinii	1	Biological control	(Paterson et al., 2011)

Name	CARA category	Recommended action	Reference
Ipomoea congesta	N/A	Physical control (weeding)	(Santos et al., 1992)
Jacaranda mimosifolia	3	Physical and chemical (cutting and treating)	(Bromilow, 2001; Macdonald, 1983)
Melia azedarach	3	Physical and chemical (cutting and treating)	(Bromilow, 2001; Macdonald, 1983)
Opuntia stricta	1	Biological control	(Paterson et al., 2011)
Rosa rubiginosa	1	Physical (cutting)	(Burrows, 2002)
Senna didymobotrya	3	Physical (weeding)	(Bromilow, 2001)
Tipuana tipu	3	Physical and chemical (cutting and treating)	(NEMBA, Act 10 of 2004)
Xanthium strumarium	1	Physical (weeding)	(Bromilow, 2001)
Zinnia peruviana	N/A	Physical and chemical (weeding and spraying)	(Bromilow, 2001)

For more detailed management options refer to the management plan set forth by the Limpopo Department of Economic Development environment and Tourism.

In the Schuinsdraai Nature Reserve there are a large number of different IAPs, all of which are a concern, however some are more problematic than others. Some IAPs were encountered far more frequently others with many of the encounters of different IAPs being only a few times and others very numerous. For example, *G. robusta* was only encountered once and is of little environmental concern as it does not seem to spread into the rest of the nature reserve. In contrast, *O. stricta* was encountered frequently and is of serious environmental concern as it can transform the area in which it is found in (Foxcroft et al., 2004). Species belonging to the Cactaceae family were the most widespread in the Schuinsdraai Nature Reserve, however, biological control to combat these species is available (Paterson et al., 2011) and agents can be released at regular intervals to maximise their efficiency. For *O. stricta, Dactylopius opuntiae*, which is a sap-sucking cochineal beetle, is the registered biocontrol agent and for *C. jamacaru* and *Hypogeococcus pungens*, a cactus mealy bug, can be used. *Hypogeococcus pungens* can also be used to control *Harrisia martinii* (Paterson et al., 2011). These biological control agents can be obtained from the Agricultural Research Council (ARC). Resources and manpower can then be shifted to other IAPs such as *Z. peruviana* that infest the roadsides within the Schuinsdraai Nature Reserve. These plants are susceptible to herbicides, but this is not the best treatment due to the environmental damage done by using the chemical (Kluge and Erasmus, 1991). Weeding is a better alternative as long as it takes place before the flowering season (Heleno et al., 2010) to prevent the weeding process precipitating weed dispersal. Follow-up weeding efforts should be conducted in the same manner due to the seedbank these IAPs build up in the soil (Heleno et al., 2010).

Finally, the area where the public has no access should be clearly demarcated, and repercussions for breaking the rules introduced in order to prevent people from passing into restricted areas. The area where the public does have access should be patrolled regularly to report IAPs and these IAPs must be eradicated swiftly to prevent them becoming problematic. Managing IAPs is a continuous effort but the benefit of an environment rich in biodiversity and well-functioning ecosystems outweighs the costs (van Wilgen and Richardson, 2014)

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Chapter 6: General Discussion and Conclusion

6.1 Introduction

Invasive alien plants are detrimental to the biodiversity of an area, and with South Africa ranked 3rd in the world with regards to biodiversity (Maze et al., 2003), these IAPs pose a severe threat to the functioning of ecosystems highlighted by this study. Due to this, the South African government has had a long history of resisting the spread of invasive alien plants and has, since 1995, spent ZAR 15 billion (unadjusted for inflation) on IAP control (van Wilgen et al., 2020). The extent and effect of these IAPs are documented internationally and locally, with significant broad scope research having been undertaken by Henderson and Bromilow (Bromilow, 2001; Henderson, 2001) which outlines the species present in the country, as well as their effect. Detailed studies on specific areas are however, important at a management level in order to tailor-make the correct interventions (Mavimbela et al., 2018).

6.2 Extent

Understanding the role of pathways in the spread of IAPs into Schuinsdraai Nature Reserve assists in the prevention, removal and monitoring of these species (Zengeya et al., 2020). Foxcroft et al., (2019) indicates that only eight are relevant in South Africa and in the Schuinsdraai Nature Reserve the following pathways were identified

6.2.1 Ornamentals

Ornamental plants are usually introduced with the intention of adding aesthetic value to an environment (Foxcroft et al., 2019, 2008; van Wilgen, 2012). These may be intentionally planted with the purpose of attracting tourists, providing shade, growing hedges, or they may be a remnant of former homesteads that are now incorporated into the nature reserve (Foxcroft et al., 2019, 2008; van Wilgen, 2012). In the case of the Schuinsdraai Nature Reserve, IAPs that were introduced as ornamentals include *T. tipu, M. azedarach, Bougainvillea glabra, G. robusta, Jacaranda mimosifolia, Senna didymobotrya* and *Rosa rubiginosa*. Of these, *R. rubiginosa* and *M. azedarach* present the most serious threat as these plants readily outcompete native flora.

6.2.2 Contaminants

Invasive Alien Plants may enter as contaminants (Pyšek et al., 2011). This may happen in a variety of ways but in the case of the Schuinsdraai Nature Reserve it is through agricultural contamination. *Datura ferox* was dispersed via seeds that were present as contaminates of the raw materials used for animal feed (Ballaré et al., 1987; Kovatsis et al., 1993). The dispersal pathway followed is via agricultural practice as the plant is toxic (Kovatsis et al., 1993) and therefore, the plant must have been present before the nature reserve was proclaimed.. It is unlikely that contaminants will enter via agricultural practise in the future, due to the fact that agriculture in the area is now obsolete due to the status of 'proclaimed nature reserve' which prohibits agriculture (Lausche, 2011).

6.2.3 Water

Water is essential for life, however the movement of water in the form of rivers can act as a method of dispersal for IAPs (Holmes et al., 2005; Richardson et al., 2007). The Schuinsdraai Nature Reserve borders the Flag Boshielo dam and seeds from IAPs that are located upstream from the Flag Boshielo Dam are carried by this water source into the Schuinsdraai Nature Reserve. Populations of *Flaveria bidentis* have been located on the banks of the Flag Boshielo dam inside the Schuinsdraai Nature Reserve. Management interventions should focus on the transition zone in order to manually extract IAPs present that may then infest the more internal areas of the reserve

6.2.4 Attachments

Plants have developed various mechanisms to disperse their seeds, including having burs that can attach to materials such as clothing (Budumajji and Solomon Raju, 2018; Foxcroft et al., 2019). These seeds are then carried as stowaways and dropped off at a later stage or physically removed by humans. The seeds then sprout and form IAP populations (Pyšek et al., 2011). Due to the close connection to humans the plants that use this pathway are often located close to areas where anthropogenic activity takes place (Hulme et al., 2008). In the Schuinsdraai Nature Reserve plants that utilize this pathway are *B. pilosa* and *B. diffusa* (Aoyama et al., 2012; Budumajji and Solomon Raju, 2018).

6.2.5 Edible Fruit

Some IAPs have edible fruits that are used for agriculture (Elbana et al., 2020) *O. ficus-indica* is an example of this, however, not all IAPs fruits are palatable for humans. This does not mean that animals do not eat these fruits (Gomes et al., 2014). Birds and primates often eat these fruits unintentionally dispersing seeds into vulnerable environments (Foxcroft et al., 2019; Gomes et al., 2014). Fruit dispersed IAPs found in the Schuinsdraai Nature Reserve include *C. jamacaru*, *O. stricta*, *C. fulgida* and *H. martinii*

6.2.6 Animal Mediated and Anthropogenic

Animals may also disperse IAPs in the same way that clothing does, not intentionally, but when the burs that attach the seeds wear out due to the animals' movement (Budumajji and Solomon Raju, 2018; Pyšek et al., 2020). Examples of IAPs in the Schuinsdraai Nature Reserve that use this pathway are *B. pilosa, B. diffusa* and *X. strumarium*. *Opuntia stricta* is of particular concern as the plant has the ability to become widespread, as this study has shown, and can cause havoc by transforming the environments that it invades (Foxcroft and Freitag-Ronaldson, 2021). The pant can however be successfully managed as biological control is available and regular application of the biological control agent can be of great assistance (Paterson et al., 2011).

The very purpose of roads is to facilitate human movement (Gelbard and Belnap, 2003; Okimura et al., 2016). This movement, however, generates a pathway for stowaways to enter fragile and important biodiversity reservoirs such as nature reserves (Foxcroft et al., 2019). Seeds from IAPs may be transported unknowingly via vehicles and become dislodged in the process of moving or stopping at a new site. The seeds are thus often dislodged close to the roads (Lonsdale and Lane, 1994). In the Schuinsdraai Nature Reserve, IAPs that were found to have used this pathway to gain entry were *Z. peruviana, I. congesta, B. diffusa* and *B. pilosa*. Of these *Z. peruviana* proved to be most numerous and a serious concern.

In Schuinsdraai Nature Reserve, the majority of the IAPs were located in areas to which the general public had access and their presence is thus probably a result of the movement of people into and out of the reserve (Foxcroft et al., 2019; Lonsdale and Lane, 1994; Pyšek et al., 2011). Although the differences observed between where the public could move freely and where access was limited did not yield a statistically significant result, a clear picture emerges. This statement is supported in literature as it is well documented that the movement of people is a major contributing factor to the spread of invasive alien species (Chytrý et al., 2005; Foxcroft et al., 2019; Hulme, 2009; Hulme et al., 2008; Pyšek et al., 2011).

This study does however show that the spread of IAPs can be limited if the general public is confined to a specific area and that steps taken to restrict the movement of people, such as having areas both accessible to the public and those of restricted access, in order to hinder the further spread of IAPs. The strategy of limiting the movement of people is however, reliant, enforcement of rules and regulations.

A wide variety of IAPs have been introduced into the Schuinsdraai Nature Reserve. According to available literature (Bromilow, 2001; Henderson, 2001), some of these species were to be expected in the Sekhukhune District, however, seven species have not yet been documented in the Sekhukhune area or may have been misidentified, as was the case with *O. stricta*. Notable new species were *B. diffusa* and *C. fulgida*. An interesting absence was *L. camara* that was reported in LEDET (2012) but was not encountered in this study. This study thus correlates with the literature but also serves in expanding the knowledge about the distribution of these invasive alien species.

The diversity of these IAPs is of further concern as each individual species has the potential for reproducing and thus expanding, with the Schuinsdraai Nature Reserve thus forming a launching pad into adjacent areas. Compared to the National P arks in Limpopo Province, the 19 IAPs species are found in approximately the same numbers as those found in the Marakele National Park but fewer than in Mapungubwe and Kruger National Park (Foxcroft et al., 2017), with some species such as *C. jamacaru* and *O. stricta* found in National Parks as well as in Schuinsdraai Nature Reserve.

The IAP populations in the Schuinsdraai Nature Reserve are increasing due to the presence of seedlings. The growth of such populations has severe consequences on indigenous vegetation, as all of these species have the potential to form monocultures if adequate measures are not undertaken (Dogra et al., 2010; Mulder et al., 2004). This study shows that on the species where effects were investigated, *O. stricta* and *C. fulgida* had statistically significant effects on species evenness indicating that monocultures will develop from them.

The findings correlate with available literature as reported by the Southern African Plant Invaders Atlas (Henderson and Wilson, 2017). Invasive alien species are also on the rise in nature reserves as reported by Foxcroft et al. (Foxcroft et al., 2019, 2013, 2004). Furthermore, this study adds to this information by confirming that IAPs population growth is taking place in the Sekhukhune region.

The most critical IAPs present in the Schuinsdraai Nature Reserve are those of the Cactaceae family due to the arid nature of the region (Novoa et al., 2016, 2015). Longer dry seasons favour the growth of these and this advantage is extended further by the lack of herbivory on these cactaceae species. Frugivory does take place, however, this frugivory is beneficial to the Cactaceae as it facilitates the spread of these invaders.

This success observed is consistent with literature, which indicates that cactus species success depends on climatic conditions such as those present in the Schuinsdraai Nature Reserve, and that these conditions are key to their success (Novoa et al., 2015). The benefit of this study is that it depicts the importance of such climatic influences in the spread of these invasive cacti species, due to the fact that the number of individual cacti are far greater than that of the invasive alien species that are not cacti. Additionally, it indicates how the spread of these cacti is facilitated by anthropogenic activity. Thus, the cacti species in the study are concentrated around where the public has had access. This finding highlights the importance of a management strategy that restricts or manages the flow of visitors through the reserve such that vulnerable areas are not impacted by this invasion pathway

6.3 Effect

Another aim was centred around how alien plants effect the biodiversity around them. The most damaging effects that IAPs have within any untransformed area is the impact on ecosystem health and Schuinsdraai Nature Reserve is no exception. Due to the fact that plants form the basis of any ecosystem, their composition and vigour impact on the functioning of the system as a whole. In the Schuinsdraai Nature Reserve, the IAP with the most detrimental effect on the indigenous vegetation is *O. stricta*. This statement will be supported by discussing species richness, species evenness and a biodiversity index in the sections below.

6.3.1 Species Richness

Species richness is the number of different species that are present in a given environment (Brown et al., 2016). The more diverse the environment, the higher the species richness value. This diversity is important, as a more diverse environment is more resilient to environmental stress and can support more species. Furthermore, a high species richness value is indicative of a healthy ecosystem.

Invasive alien species do have a significant, negative effect on the biodiversity of the Schuinsdraai Nature Reserve. Significantly lower species richness values were obtained in the infested plots compared to the plots that were pristine, thus invasive alien species have a negative effect on the proper functioning of the ecosystems present in the nature reserve (Mostert et al., 2017; Potgieter et al., 2019). It is clear that IAP species negatively affect species richness because the species richness observed in infested plots was significantly lower than the species richness in plots that did not have IAPs in them, This is concerning because species richness is vital to the functioning of an ecosystem (Chisholm et al., 2013) and its productivity (Waide et al., 1999). Species richness additionally contributes to a more resilient ecosystem (Vogel et al., 2012) and a reduction in species richness by IAPs will thus result in an environment that is less resilient than one with a diversity of indigenous species. This study adds value as one of the outcomes of the study were that by comparing the species richness of plots infested with IAPs with pristine plots, it was possible to show which of the IAPs lowered the species richness value the most, in this case *O. stricta*, and thus had the most drastic effect on the species richness in the Schuinsdraai Nature Reserve, thus earmarking these for most urgent actions

Additionally, these findings indicate how the Schuinsdraai Nature Reserve vegetation dynamics will change in the future, if IAPs are not managed. Overall plant species richness will continue declining, resulting in weaker functioning that will be more susceptible to environmental stress and lead to further degradation, including local extinctions (Bellard et al., 2016).

6.3.2 Species Evenness

Species evenness differs from species richness in that it focusses on how evenly the species in an area are distributed (Supriatna, 2018). Its added value to this study is that it serves as an indicator to the environmental processes taking place in the Schuinsdraai Nature Reserve. The species evenness distribution is used to indicate whether a particular species is dominant in a given area. This dominance generates a disrupted environment that is less capable of withstanding environmental stress and is thus more fragile as a result (Alpert et al., 2000). Therefore, the environment’s capacity to support multiple organisms is compromised due to this dominance.

Plots that had invasive alien species present had a poorer species evenness value than plots that did not have IAP species present. Hejda et al., (2009) attributed a decrease in species evenness to the presence of IAPs.

The dominant effect of this lower species evenness has, is a loss in diversity. This loss in diversity is attributed to the dominant species, in this case the IAP species, outcompeting the indigenous species. Resultantly the invasive alien species forms a monoculture that further lowers the number of species that can survive in the environment, effectively destroying the local ecosystem and concomitant functions

6.3.3 Shannon-Wiener Biodiversity Index

A biodiversity index adds a numeric value to the biodiversity in a given area. This allows for different areas to be directly compared. Each area has its own ecosystem so the biodiversity index can thus be used to compare different ecosystems with one another. In this case, ecosystems that are invaded by IAP species are compared to a pristine environment to indicate the effect of these IAP species on the ecosystems.

The biodiversity indices of invaded areas are significantly lower than those of the untransformed areas. Invaded ecosystems are thus weaker as a result of the invasion. This is due to the fact that the lower the biodiversity index, the fewer different species are present. An ecosystem that has very little diversity is very susceptible to stress (Jactel et al., 2017). This lack of diversity can lead to the collapse of the ecosystem that is invaded and result in a monoculture taking hold (Dogra et al., 2010) losing the ecosystem services that are currently available (Kremen and Miles, 2012). The formation of these monocultures are thus in direct conflict with the function of nature reserves, which is to protect diversity, thus promoting ecosystem services that are associated with high diversity (Jactel et al., 2017). Preventing monocultures from establishing will thus result in a stronger more resilient ecosystem within the nature reserve.

6.4 Limitations

6.4.1 Extent

The most problematic limitation was that the IAPs were clustered into communities, resulting in large standard deviations. The remaining limitations were that due to time constraints the observed growth of the IAPs population could not be investigated fully. The fluctuating water levels of the Flag Boshielo dam may have prevent species from being encountered either by submerging them or by inhibiting their sprouting by being too low as is the case with invasive reeds. Finally, the surrounding vegetation was not looked at as a plausible entry point for the IAPs to have invaded the Schuinsdraai Nature Reserve

6.4.2 Effect

The most prevalent of the limitations relating to the effect of the IAPs was the number of the plots used to investigate the effects. This was limited due to the amount of time available for the project and the clustered nature of the IAPs that may have resulted in plots being too close to each other. Rough, bush encroached terrain played less of a role in limiting the plots but was a further challenge.

The remaining limitations were that due to the fact that there were not enough populations of the lesser encountered IAPs, the number of quadrates needed for statistical analysis could not be reached and thus they were not investigated fully. There was also a lack of information on reserves in the Sekhukhune District that could be used to compare on a District level as an indication of how the Schuinsdraai nature reserve is doing in the area that it is located in whereas if comparison would be done with the national parks in Limpopo the information would not be as beneficial as an indication to the health of the smaller reserves such as the Schuinsdraai Nature Reserve and surroundings.

6.5 Future Research

The areas around the Schuinsdraai Nature Reserve and the Sekhukhune District as a whole has little information available on IAPs. Studies such as this one can be completed in the nature reserves in the District and local comparisons can then be made with the end result being a better understanding of IAPs in the Sekhukhune District that will be of benefit to managing these IAPs both in the nature reserves and surrounding communities.

Follow up research in the Schuinsdraai Nature Reserve should be conducted to indicate how the observations made in this study have changed over time. Population growth studies and follow up surveys will be advantageous, particularly if linked to historic data and climate change informationConclusion

6.6 Conclusion

The Schuinsdraai Nature Reserve is more infested with IAPs than was originally thought. More species and a higher density of these IAPs were found to be present than previously encountered (LEDET, 20212) These IAPs species were, however, confined to an area where the public has currently, and in the past had access and were a result of anthropogenic activities taking place.

Where these IAPs were found they had negative impacts on the environment. The species that were investigated all impacted the vegetation by lowering the species richness values. This had a domino effect on other measurements such as species evenness and the Shannon-Wiener biodiversity index. The area where the public has had access is less productive as a result of the IAP infestation. The fact that *L. camara* was found to be absent in the reserve indicates that control efforts are worth implementing and can be utilised to limit the spread of IAPs, particularly if excluding members of the public to certain areas. Novel alien eradication approaches should be investigated and piloted in the Schuinsdraai Nature Reserve to facilitate new ways of attending to this problem.

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