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The distribution and perceptions of invasive alien plants in small towns in the Eastern Cape province, South Africa

By

Tshepiso Collen Seboko

Student Number: g16s2776

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Supervisor: Dr Sheunesu Ruwanza

Co-supervisor: Professor Charlie Shackleton

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Abstract

Invasive alien plants (IAP) of different life forms have major effects on biodiversity, ecosystem functioning, economies, and livelihoods worldwide. There is evidence that IAP are rapidly increasing around the world, and the negative impacts associated with them are expected to worsen due to continuing land transformation, climate change, and urbanisation. Yet, information on the distribution, abundance, knowledge, and perceptions of IAP is limited, especially in small towns. Most previous research has largely focused on rural settings and larger cities, thus hindering the effective control and management of IAP in smaller urban settings. It is therefore important to assess the distribution of IAP to provide useful information to guide clearing and mitigation efforts to reduce the impacts and proliferation of IAP in smaller urban settings. Consequently, the aim of the study was to determine the distribution, composition, abundance, and perceptions of woody IAP in small towns in the Eastern Cape province of South Africa and assess how and why they may differ within and between towns.

To achieve this aim, a drive by road survey was undertaken across all suburbs and land use types in 12 small towns located in the Eastern Cape province of South Africa. The 12 randomly selected small towns were, Adelaide, Alexandria, Barkley East, Bedford, Burgersdorp, Cathcart, Kirkwood, Middelburg, Paterson, Somerset East, St. Francis Bay and Willowmore. All woody IAP visible from the surveyed roads were counted across all suburbs and land use types within each town. A total of 38 427 woody IAP were enumerated, with 56 species across different land use types and suburbs in all towns. Affluent suburbs accounted for 58% of the IAP enumerated, while the Reconstructed Development Programme (RDP) suburbs accounted for only 5%. In terms of the land use type, most of the IAP were encountered in the residential areas (54%), as compared to, road verges (32%) and public urban green spaces (PUGS) (14%).

Of the 12 towns, Middleburg had the highest number of woody IAP, with 5 573 individuals, while Paterson had the lowest number with 947. The most common IAP species across all towns was *Melia azedarach* with 4 384 individuals, followed by *Pinus elliotti* (4 051), and *Jacaranda mimosifolia* (3 640). *Spathodea campanulata*, *Ardisia crenata,* and *Parkinsonia aculeata* had the lowest number of individuals with only two individuals each across all towns.

This study also assessed the knowledge, perceptions, and willingness of urban residents to control IAP in their home yards using household surveys. A total of 240 household surveys were administered in the 12 towns. The results showed that more than half of the respondents

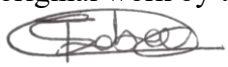
(59%) had no knowledge of IAP, while 14% had neutral knowledge and only 2% had high knowledge. Forty percent of the respondents agreed that IAP pose a problem to the environment whilst 11% did not think IAP posed a problem to the environment, and 49% stated that they do not know. Most of the respondents (91%) perceived IAP positively, and stated that they benefit from the IAP, with the most mentioned benefit being shade (50%). Almost two-thirds of the respondents (65%) were willing to report on the IAP in their yards to the relevant authorities that deal with the control and management of IAP. Over half (56%) of the respondents were willing to have the IAP removed from their gardens, with the most stated reason for removal was because the IAP caused damage to property (13%). Respondents thought that the local government (35%) or district government (30%) should be responsible for the control and management of IAP.

Overall, the study showed that IAP species were most common in residential land use type and affluent suburbs. These findings can assist the relevant authorities that deal with IAP, regarding which plant species, suburbs, and land use types to prioritise regarding awareness and investment for control and management. This will also help explore alternative indigenous species that can be used as replacements that may offer the same benefits derived from IAP by urban residents.

Keywords: control, invasive alien plants, knowledge, land use type, perceptions, removal, suburbs, urban settings.

Declaration

I, Tshepiso Collen Seboko, hereby declare that the work presented in this thesis was carried out in the Department of Environmental Science, Rhodes University, under the supervision of Dr Sheunesu Ruwanza and Professor Charlie Shackleton. The components of the thesis comprise original work by the author and have not been submitted to any other university.



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Chapter 1

1. Introduction

Biological invasions by invasive alien plants (IAP) are a major threat globally to biodiversity and ecosystem functioning (Hulme, 2009; Richardson and Rejmanek, 2011). According to the Convention on Biological Diversity (CBD, 2014) the risk of invasion by IAP is shown to increase with the increased rate of globalisation and urbanisation, which propagate and promote IAP establishment and potential spread (Hulbert et al., 2017). It was also noted by Seebens et al. (2017) that IAP are rapidly increasing in spatial extent, and the abundance of IAP has been increasing across different geographic areas and taxonomic groups. Turbelin et al. (2017) used global databases to map global invasion rates of IAP and showed that countries with the highest number of IAP species were the United States of America with 523 IAP species, New Zealand (329), Australia (322), Cuba (318), and South Africa (208). The above-mentioned study further reported that the IAP taxa with the greatest international occurrence were *Cyperus rotundus* which occurred in 37% of contries, *Lantana camara* (36%), *Ricinus communis* (31%) *Leucaena leucocephala* (27%) and *Cynodon dactylon* (20%) (Turbelin et al., 2017). These findings echo those of Hui et al. (2017) who ranked IAP spread among some global cities. In this study, the city of Johannesburg in South Africa was ranked 43 amongst the world's 100 most populous cities with a significant spread of IAP in urban green spaces (Hui et al., 2017). These results from the above-mentioned studies (Turbelin et al., 2017; Hui et al., 2017) further indicate that South Africa is one of the leading countries when it comes to the problem of IAP, therefore the assessment of IAP distribution and abundance is of outmost importance to avoid or mitigate the IAP impacts on the environment, economy, society, and livelihood conditions in different parts of the country.

Some IAP have resulted in widespread effects on the habitats or regions they have invaded (Kühn et al., 2017). This has resulted in the global environment, economy and human livelihoods being affected (Shackleton et al., 2016; Shackleton et al., 2019 a, b). Invasive alien plants tend to outcompete native species for resources and space, resulting in their establishment and spread (Shackleton et al., 2016). In the Western Cape province of South Africa, IAP such as *Pinus, Eucalyptus,* and *Acacia* species have presented challenges, such as the displacement of native species and the reduction of water resources through

increased water uptake (Le Maitre et al., 2020; van Wilgen, 2012). Sward (2012) found that in San Francisco, USA, *Eucalyptus* decreased the organic matter of the soil and caused loss of native wildlife habitat in urban parks and urban forests. Similarly, Casella and Vurro (2013) found that in the urban area of Bari, Apulia region in Italy, invasion by *Ailanthus altissima* resulted in various negative effects spanning infrastructure functioning, environmental, health, safety, and aesthetics, and these were occurring at various sites, such as, urban, industrial, street verges and railways. The above-mentioned study reported 35 different types of negative effects caused by the invasion of *Ailanthus altissima*, including 20 infrastructure functional damages (e.g., damage to building infrastructure, obstruction of road signs, and causing difficulties in infrastructure maintenance), three environmental (e.g., loss of biodiversity, habitat alteration and degradation), seven health and safety (e.g., risk of fire, skin irritation and allergies), and five aesthetic (e.g., signs of neglect in green spaces due to uncontrollable growth) (Casella and Vurro, 2013). Furthermore, the study also evaluated damages by *Ailanthus altissima* according to different sites, and reported that there were (46%) of damages in the urban districts (e.g., reduced street lighting), (11%) in the industrial areas (e.g., obstruction and damage to fence and railings), (20%) on the roads (e.g., difficulties in inspection and maintenance of transportation areas), (13%) on the railways (e.g., obstacle to railway switches) and (10%) at the airport (e.g., damage and obstruction to parking bays) (Casella and Vurro, 2013). The above-mentioned examples indicate that invasion by IAP in urban areas can cause significant negative socio-economic and environmental effects throughout the urban matrix.

International trade has been a key driver of IAP introductions across regions (Aronson et al., 2017; Hulme, 2009), having intensified the extent, occurrence and spread of IAP around the world (Packer et al., 2017; Cole et al., 2019; Faulkner et al., 2020). Roads, railways, and other transport networks are major and expanding pathways of IAP introductions, offering abundant opportunities for rapid distribution of IAP (Padayachee et al., 2017). For example, Hulme (2009) reported that approximately 90% of trade around the world is carried by sea, where goods are stored in containers, which also carry flora and fauna as stowaways inside and on the surface of the containers, contributing to the risk of introduction of IAP worldwide (Hulme, 2009). Ascensão and Capinha (2017) stated that research by Hansen and Clevenger (2005) showed that the frequency of IAP species in grasslands and woodlands along transects ranged from 0 – 150m from the boundary of

transport routes such as railways and highways, various locations away from transport routes and reported the types of traffic routes contained a higher frequency of IAP than the corresponding controlled areas.

The increase in urbanisation, coupled with human population growth, has also increased the chances of introduction, propagation and spread of IAP, especially in urban settings (Potgieter and Cadotte, 2020). For example, Gaertner et al. (2017) showed that as population in urban areas increase, urban landscapes become disturbed and fragmented, providing sites for IAP to establish, and as a result, urban areas have become hotspots for biological invasions. McLean et al. (2017) reported that city centres host many IAP due to high human population and high levels of landscape disturbance and fragmentation. Urban areas typically have a higher IAP richness than their surrounding rural areas because they are often the first places where alien plants are introduced (Pyšek et al., 2004; Kühn et al., 2004). However, Gulezian and Nyberg (2010) showed a different pattern, whereby the abundance of IAP declined with increasing anthropogenic activities in Chicago, USA. This was interpreted as not being any significant correlations with anthropogenic factors such as land use and income when correlated against IAP.

Invasive alien plants in urban areas pose risks not just in the urban environments, but also to their surrounding environments (Dodd et al., 2016). For example, Baard and Kraaij (2019) reported that the Garden Route National Park in the regions of the Western Cape and Eastern Cape provinces of South Africa, has a large edge-to-area ratio and is at a risk of IAP invasions. This is mainly because the Garden Route National Park is adjacent to different land uses such as urban areas and agricultural lands (Baard and Kraaij, 2019). Marco et al. (2008) emphasised that a high edge effect facilitates greater invasion risk, since the taxa introduced into smaller urban environments in gardens have proportionally greater interactions with adjacent natural areas, enabling them to naturalise, disperse and potentially spread into surrounding areas. The potential distribution and spread of IAP is a complex spatial process that is influenced and accelerated by multiple factors which vary according to space and time (Richardson et al., 2000; Ruwanza and Shackleton, 2016).

Several definitions have been proposed for IAP. The confusion around the definition is centred around invasion concepts and terms such as the distinction between naturalised and invasive (Richardson et al., 2000; Richardson et al., 2005). In trying to identify an acceptable definition, several authors have developed conceptual frameworks that try to

conceptualise the invasion sequence from introduction to invasion (Richardson et al., 2000; Blackburn et al., 2011). The current study adopts the definition of IAP proposed by Richardson et al. (2000) as "*species that are naturalised and can establish offspring at significant distances away from the parent plant and have the capacity to spread over extensive areas due to human actions, either intentional or accidental*". This definition was adopted because it encompasses all IAP and does not exclude species based on economic or human harm.

1.1. Invasive alien plants in urban settings

Studies in urban forestry and urban ecology have long documented the propensity of urban environments to have a high number of IAP due to intentional and unintentional alien species introductions and, disturbances associated with urbanisation (Moro and Castro, 2015; Shackleton and Shackleton, 2016). According to Salomon and Kull (2017), attitudes have shifted and embraced the fact that towns and cities are essential when it comes to the socio-ecological phenomena. And furthermore, acknowledging that there are invasion risks that must be addressed for environmental, economic, and cultural reasons (Salomon and Kull, 2017). Moreover, ethnic socio-economic differences, political will, financial growth, and institutional quality have a significant role in influencing the prevalence of IAP in urban settings (Salomon and Kull, 2017).

Urban settings differ in their key characteristics such as size, shape, and human population density (Liu et al., 2005). Consequently, the abundance, richness and density of IAP varies considerably between regions (Ricotta et al., 2017). Socio-economic and environmental factors, such as population density, degree of urbanisation and climate change have been found to correlate with IAP abundance and richness (Appalasamy et al., 2020; Rejmanek, 2000; Lubeck et al., 2019). For example, in China, Liu et al. (2005) reported that highly populated areas tend to have more IAP, because humans are mainly responsible for the dispersal of IAP. These results were supported by Ariori et al. (2017) who reported that towns with higher populations are prone to greater abundances of IAP. Pyšek (1998) showed that city or town size, area and population were better predictors of IAP abundance and richness than climatic variables in 54 European towns. In South Africa, McLean et al. (2017) found that IAP patterns in 12 small towns in the Western Cape province were influenced by town size. In contrast, Clements and Moore (2003) reported that factors such as town or city size were not correlated with IAP abundance and richness in eight USA cities, however, they were strongly correlated with the age of the town.

Dobbs et al. (2011) describe land use as a tool to measure the extent of urbanisation and predominance of different types of disturbances in any given area. Land use practices and other factors such as the extent of disturbed environments influence the establishment and spread of IAP in urban settings (Hui et al.,2017; Walker et al., 2017; Decker et al., 2012). Richardson (2011) highlighted that species richness and abundance of IAP varied between different land uses such as road verges, open spaces, and railways, which have been shown to host more IAP species. In the urban coastal habitats of the Mediterranean Basin, Basnou et al. (2015) found that the abundance of IAP was most strongly influenced by shape of the landscape, land use and land-cover changes within different patches, including the composition of the adjacent landscape. For example, McCarthy (2001) found that the abundance of IAP in Australian landscapes varied strongly with respect to landscape context and land use practices. The above-mentioned study further reported that there was more IAP in residential areas compared to other land use types (McCarthy, 2001). Kuruneri-Chitepo and Shackleton (2011) analysed the distribution, abundance, and composition of street trees in three towns in the Eastern Cape province of South Africa and reported that approximately 60% of the sampled street trees were alien plant species. Similar results were reported in Bangalore, India, by Nagendra and Gopal (2010) who found that about 67% of the street trees were alien species. The presence of alien plants is risky because with longer residence time, some of these IAP may become invasive (Ricotta et al., 2017). Land use practices are dynamic, and they can be used as indicators for understanding the interaction of human activities with the environment and how IAP are distributed across different land use types (Afonso et al., 2020).

Processes such as human disturbance, homogenisation of plant composition, pollution, and propagule pressure of IAP are synonymous with cities and towns (Pyšek et al., 2008). Moreover, the frequent disturbance of the urban environment provides favourable environmental conditions for the potential survival and spread of many IAP (Potgieter and Cadotte, 2020). Once introduced, IAP frequently establish and proliferate in highly disturbed areas (Cavin and Kull, 2017). For example, McLean et al. (2018) reported that IAP such as *Avena fatua* and *Echium plantagineum*, which are of agricultural origin in peri-urban areas are spreading and becoming more abundant towards the town and along disturbed roadsides. Borgmann and Rodewald (2005) found that land use changes caused by the invasion of *Lonicera* species was greater in urbanised areas, which they attributed to disturbance. In Aalborg, Denmark, Panduro and Veie (2013) found that most of the IAP

dominated disturbed landscapes such as vacant land, compared to other land use types such as green buffers and agricultural fields within and surrounding the city. Housing developments and road construction have also facilitated IAP invasion by disturbing soils and increasing seed dispersal along road-verges (Gravier-Pizarro et al., 2010).

Lovett-Doust et al. (2003) highlighted that land tenure plays a key role in determining the diversity and distribution of IAP in urban areas. For instance, in Radolfzell, Germany, Mayer et al. (2017) identified 1 268 garden-plant species in the public urban green spaces, private and residential gardens. The results showed that 954 species (55%) were invasive in Germany, of which, 462 were found in public urban green spaces and 775 in private and residential gardens, while 283 IAP were found in both. Similarly, in the Western Cape province of South Africa, McLean et al. (2018) reported that in Riebeek Kasteel, private gardens had the most IAP (84%). This can be problematic because such IAP may be protected by landowners, and they are likely to spread and invade the surrounding landscapes and natural areas (McLean et al., 2017).

1.2. Invasive alien plant introduction and pathways in urban settings

Turbelin et al. (2017) provided a global geographical pattern of origins and pathways and indicated that of the 1 517 IAP recorded, approximately 39% were introduced intentionally, 26% unintentionally, and 22% were introduced both intentionally and unintentionally and 13% were unknown. Potgieter et al. (2020) stated that factors such as human uses influenced the spatial extent and pattern of IAP in South African urban areas. They further reported that most initial introductions were mainly for utilitarian purposes (Potgieter et al., 2020). Richardson et al. (2004) noted several reasons for the introduction of IAP, namely, commercial activities, horticulture, agroforestry, fuelwood, food, erosion control, stabilisation of soils and improving air quality. The introductions and pathways of IAP are mostly driven by anthropogenic activities and human needs (Richardson et al., 2011; Richardson et al., 2004).

The drivers of introduction and use of IAP are vital in understanding the complexity and patterns of invasions (Gavier-Pizarro et al., 2010; Richardson et al., 2011). It has been shown that IAP richness increases with greater road network size and greater urban coverage, which tend to influence the success of IAP in urban settings (O'Sullivan et al., 2017). According to Irlich et al. (2017) there are many introduction routes, vectors and pathways in urban areas that lead to a higher propagule pressure of IAP. Urban landscape

features, such as roads, railways, and rivers, are often considered as corridors and pathways that facilitate the movement of IAP through favourable habitats and thus promote IAP establishment (McKinney, 2004; Hulme, 2009; van Wilgen et al., 2012). In South Africa, Rahlao et al. (2010) and Ruwanza and Mhlongo (2020) reported that both road-river interchanges and roadsides function as corridors and pathways for IAP invasion and spread.

Trade, traffic, ornamental horticulture, and natural dispersal are the most important dispersal pathways for the introduction of IAP (Hulme, 2009; Faulkner et al., 2017). Alien plants can be deliberately planted for agriculture, horticulture and ornamental purposes and urban greening, while some escape from private gardens (Marco et al., 2010; Shackleton and Shackleton, 2016). In South Africa, an evaluation of spread rates of 62 IAP by Wilson et al. (2007) indicated that IAP that were planted for ornamentals purposes spread rapidly and faster than those used for other purposes. According to Hulme (2009), ornamental horticulture facilitates IAP spread due to frequent and repeated local introductions, in addition, the selective breeding and selection of species that adapt to climate change might result in increased establishment and spread of IAP globally.

Invasive alien plants with longer residence times in a new environment are distributed more extensively (Richardson and Rejmanek, 2011). According to Richardson and Rejmanek (2011), residence time is often significantly correlated with IAP risk. The preadaptation to the environmental state of the invaded landscape is an important factor that promotes the establishment of IAP outside their natural environment (Pyšek et al., 2008). For example, Ricotta et al. (2017) demonstrated that in New Zealand cities, the turnover or "beta diversity" of IAP depends on their residence time.

Research is required to improve the understanding of the complexity of IAP introduction pathways and how they establish within urban environments (Kueffer et al., 2013). Spatial analysis of IAP can be a useful tool for assessing the distribution and extent of IAP in urban areas (McConnachie et al., 2008). McConnachie et al. (2008) used Geographic Information Systems (GIS) to determine the extent of public urban green spaces and IAP in those spaces, in ten towns in the Thicket biome, South Africa. The results showed that there were differences in the abundance and distribution of public urban green spaces and IAP across the different towns (McConnachie et al., 2008). Based on the differences in residential areas, they found that affluent areas had more public urban green spaces and IAP than the less affluent areas, which are mostly townships and the low-cost housing areas

(McConnachie et al., 2008). This can be further attributed to the historical injustices of the past during the apartheid era in South Africa (McConnachie et al., 2008).

Increasing development and demand for various resources and commodities have led to pathway risk assessments being at the forefront of mitigation efforts against IAP (Hulme, 2009). Management of IAP pathways is advocated by the International Convention on Biological Diversity (CBD). The Strategic Plan for Biodiversity Aichi Target 9, aimed to identify and prioritise IAP and pathways by the year 2020, and to further control and eradicate IAP by putting measures in place to manage and mitigate IAP pathways and prevent their introduction and establishment (McGeoch et al., 2016). However, according to Essl et al. (2020) and Tittensor et al. (2014) the efforts to identify and eradicate IAP have been inadequate, due to lack of quantification and specificity of the targets relating to eradication and reduction of impacts. It is of necessary concern to understand pathways and drivers of IAP, to inform policy and improve management strategies (Shackleton et al., 2019b).

1.3. Effects of urban invasive alien plants

1.3.1. Ecosystem services provided by IAP

There are a range of benefits derived from some IAP to some communities in the form of cultural, regulating, provisioning, and supporting ecosystem services (Potgieter et al., 2019). Invasive alien species have been valued by humans for centuries for different reasons (Castro-Díez et al., 2019). For example, some IAP are perceived to stabilise catchments, sequester carbon, trap dust and supply raw materials such as timber, fruits, firewood, shade, and habitat for animals (Potgieter et al., 2017; Shackleton et al., 2007). Invasive alien plants contribute to species diversity, which plays a major role in sustaining key ecosystem functions and processes (Shackleton et al., 2014). For example, Lubech et al. (2019) reported that IAP are useful in carbon sequestration in urban forests and parks in Florida, USA, whilst improving air quality. Similarly, van Wilgen (2012) reported that in an urban forest in Cape Town, South Africa, *Pinus, Eucalyptus,* and *Acacia* species provided a variety of benefits such as aesthetics and recreation opportunities due to the shade they provide. Urban trees, including IAP, also provide economic benefits, for example, in the poorer suburbs of some South African towns, the collection and use of wood and fruits from IAP in public urban green spaces saves considerable income for urban households (Kaoma and Shackleton, 2014).

Invasive alien plants, especially trees, also play a significant role in cooling urban environments, providing fresh air, reducing wind speed, buffering noise, filtering dust, and offering aesthetic appeal (Zengeya et al., 2017). For example, Australian *Acacia* trees are used extensively for multiple functions in Limpopo Province of South Africa. Uses include fuelwood, reduction of soil erosion, and provide services such as scenic and aesthetic value to the landscape (Shackleton et al., 2015). Similarly, some Australian *Acacias* and *J. mimosifolia* are valued for aesthetics in Pretoria, which is commonly known as Jacaranda City (Dickie et al., 2014).

Cultural services such as aesthetics are the most stated ecosystem service provided by IAP in urban areas, particularly in developed regions, whereas in developing countries provisioning services such as provision of food, fuelwood and medicine are the most important (Potgieter et al., 2017). For example, *Acacia saligna* serves an important role in sites for Xhosa initiation rituals around areas of Cape Town, South Africa, as it is used for medicinal and construction purposes (Potgieter et al., 2020). Dickie et al. (2014) noted that *Pinus* species have become important symbols and culturally imbedded "sense of place", and similarly they noted that in Argentina's Atlantic coast *J. mimosifolia* is also culturally imbedded as the town is named after the species *J. mimosifolia*.

1.3.2. Ecosystem disservices resulting from IAP

Shackleton et al. (2016) defined ecosystem disservices as "ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing". Ecosystem disservices caused by IAP includes damage to infrastructure by tree roots, drains blocked by leaf litter, allergens, biodiversity loss, water extraction, cover for criminals and threat to safety from wildfires (Shackleton et al., 2016; Dodd et al., 2016; Potgieter et al., 2020). This raises concern as IAP often constitute a high proportion of urban vegetation and thus result in considerable impacts on the natural environment and livelihoods (Castro-Díez et al., 2019; Witt et al., 2018).

Shackleton et al. (2007) presented a cost-benefit framework explaining how some IAP may initially have substantial benefits, but as the IAP density increases and spreads, the costs of controlling the IAP rises, leading to increased risks that might affect human livelihoods. Several studies report on negative impacts such as control and maintenance costs, and social nuisances such as safety hazards from damaged trees or harmful pollen (Vaz et al., 2017). Potgieter et al. (2019) conducted face-to-face and online interviews to assess and

analyse the perceptions of urban residents in Cape Town, South Africa, towards IAP, and their capacity to provide ecosystem services and disservices. Their results showed that a significant percentage of residents (83%) were generally concerned about the negative impacts of IAP on the displacement of native plants, along with impacts on human health, decreased water supply, and increased fire risk.

The displacement of native species by IAP is considered as an ecosystem disservice which constrains the supply of ecosystem services (Early et al., 2016; Hulme and Vila, 2017). For example, Potgieter et al. (2019) reported that in Cape Town, South Africa, *A. saligna* found near human settlements has displaced some of the fynbos vegetation, in addition they also reported that the presence of *A. saligna* in recreational areas may threaten the safety of urban residents. However, little is known on the significance of IAP in providing ecosystem disservices in urban areas, particularly in developing countries (Potgieter et al., 2017).

Rouget et al. (2016), and recently Diagne et al. (2021) estimated that the cost of controlling IAP summed to more than US$1.288 trillion per annum globally, which will result in a huge invasion debt. However, financial costs vary, depending on the IAP, the economy of the country, cost of control and land tenure (Diagne et al., 2021). The economic loss in China due to IAP was estimated to be US$15 billion annually (Liu et al., 2005). In the USA, the economic cost associated with IAP was approximately US$120 billion annually, although these estimates were done two decades ago (Pimental et al., 2000). In South Africa the cost of managing IAP was estimated to be US$12 billion annually (Richardson et al., 2004), with recent estimates by Le Maitre et al. (2020) suggesting that the financial and economic impacts of IAP is approximately US$ 65.58 billion annually. In South African urban areas, local municipalities are mandated by law to map, monitor and control IAP within their boundaries (Ruwanza and Shackleton, 2016). However, given the challenges that most municipalities face, especially smaller ones, in terms of finance, skills, and experience, many are unable to fulfil these legal mandated (Ruwanza and Shackleton, 2016; Irlich et al., 2017). However, there are several organisations in South Africa, such as, the South African National Biodiversity Institute (SANBI), and the Working for Water (WfW) Programme who play a key role in monitoring, eradicating and mitigating IAP in urban areas independently of municipal authorities (Richardson et al., 2004).

1.4. Management of invasive alien plants in urban settings

The frameworks and policy instruments for protecting urban environments from IAP are changing rapidly (Kendal et al., 2014). Urban areas have a high diversity and abundance of IAP. It is therefore important to locate and restore areas that are affected by IAP invasions (Kühn et al., 2017; Kowarik et al., 2013) and further protect the biodiversity, ecosystem functioning and the provisioning of ecosystem services in urban areas (Padayachee et al., 2017).

The management of IAP involves a variety of approaches in different regions of the world. South Africa has a long history of IAP management, which is backed by regulations and control programmes (Richardson et al., 2004; Ruwanza and Shackleton, 2016; Lukey and Hall, 2020). For example, IAP regulations are stipulated under the National Environmental Management: Biodiversity Act 10 of 2004 (NEM:BA), which calls on all landowners to control, monitor and manage IAP on their land. Furthermore, the (NEM:BA) requires "all organs of state in all spheres of government", including municipalities, to control IAP by "preparing an invasive species monitoring, control and eradication plan for land under their control" (NEM:BA, 2004). The control plan should include (a) details and description of IAP, (b) the type of land affected, (c) an evaluation of the extent of IAP, (d) past control measures, (e) procedures taken to control, monitor and mitigate the extent of IAP, (f) and indicators used for assessing management progress. The control and management of IAP in urban environments can be challenging (Zengeya et al., 2017). Irlich et al. (2017) highlighted that across South Africa there is limited ability by local municipalities to comply with the IAP regulations and legislation. This is mainly because the income of a municipality and its ability to generate revenue depends on the size and economic services of the municipality and the financial means of its residents (Ruwanza and Shackleton, 2016). In some cases, the challenges are associated with lack of environmental experts to deal with biological invasions, municipalities tend to priorities service delivery issues, and lack the political will to invest in IAP control and management plans (Ruwanza and Shackleton, 2016; van Wilgen et al., 2020).

Municipalities prepare budgets annually to meet necessary service delivery requirements (Ruwanza and Shackleton, 2016). Gwedla and Shackleton (2015) mentioned that some municipalities, especially in small towns, do not have enough funds for maintenance and often are not able to comply with the National Environmental Management Plan and IAP regulations. This may be due to socioeconomic pressures such as service delivery and infrastructure development (Gwedla and Shackleton, 2015). To date, no study has looked

at the efficiency of the capacity and different urban greening and management policies in urban areas (Gwedla and Shackleton, 2015). However, Ruwanza and Shackleton (2016) reported that large municipalities are better prepared to deal with IAP than small municipalities. For example, large metropolitan municipalities such as the City of Johannesburg, City of Cape Town, and eThekwini Municipality are a step ahead in developing these management and control plans due to their greater revenue and skills base (Ruwanza and Shackleton, 2016).

Urban settings have complex and diverse land tenure systems such as state, municipal, and private land that are managed by different users, creating complexities for IAP management (Nguyen et al., 2020; Shackleton and Shackleton, 2016). This further complicates the process of controlling, mitigating, and managing IAP (Shackleton and Shackleton, 2016). As a result of diverse landowners and small land parcels in urban settings, the incentives, and practices of managing IAP poses a strong likelihood of conflicts among multiple stakeholders (Gaertner et al., 2016). Dickie et al. (2014) reported that in Pretoria, South Africa, efforts to control and remove IAP were delayed due to their perceived importance in providing a variety of ecosystem services such as shade and aesthetics. Residents opposed the removal of *J. mimosifolia*, arguing that it is aesthetically pleasing and provides urban greenery (Dickie et al., 2014). This resonates with Sward (2012), who reported that in San Francisco, USA, the removal of IAP trees, mostly *Eucalyptus* species from urban parks, was opposed by residents and several organisations due to concerns related to loss of aesthetic and the loss of green infrastructure in the urban environment (Sward, 2012).

There has been recognition of the importance to engage affected parties in the management strategies of IAP in urban areas to limit or avoid conflicts (Nel et al., 2004; Zengeya et al., 2017). Effective strategies for managing IAP which limit conflict depend on the collaboration and support from all stakeholders (Zengeya et al., 2017). van Wilgen and Richardson (2014) developed a conceptual framework based on the negative and positive impacts of IAP. The framework divided IAP into four broad categories namely, (a) destructive species, (b) conflict generating species, (c) inconsequential species and (d) beneficial species (van Wilgen and Richardson, 2014). Zengeya et al. (2017) used the same framework to evaluate the positive and negative impacts of 552 IAP in South Africa. The results indicated that most IAP were categorised as inconsequential species (55%) or destructive species (29%), with far fewer beneficial species (10%) and conflict generating

species (6%). Attitudes towards IAP will vary depending on where they are found in the landscape and how long they have been there and consequently, the ecosystem services they most influence or provide (Shackleton et al., 2019a).

In many parts of the world, significant resources and expertise are allocated to control IAP associated with negative impacts, especially those that constrain vital ecosystem services such as water supply and displacement of native species (van Wilgen et al., 2012). The approaches used for setting priorities for development, access and availability of funding are often a challenge in urban settings, particularly in developing countries (Ruwanza and Shackleton, 2016). For example, in the developed world, most regions prioritise green infrastructure management, while in most developing countries most regions channel their limited funding to issues related to socio-economic challenges (Irlich et al., 2017). These differences have a bearing regarding how IAP are managed in urban areas.

Several studies have developed new frameworks for approaching IAP management and their spread in urban settings (Novoa et al., 2018; McLean et al., 2018; Shackleton et al., 2018). The conceptual framework by Shackleton et al. (2019a) identified multiple interacting factors that influence perceptions of IAPs over time, and further emphasise that these factors can have implications for IAP management interventions. These factors include "(a) individuals, (b) the plant species, (c) potential impacts, (d) socio-cultural characteristics, and (e) institutional, governance, policy context and landscape context" (Shackleton et al., 2019a). Novoa et al. (2018) formulated a step-by-step framework to engage different stakeholders in urban settings towards the control, monitoring, and management of IAPs at different institutional levels. The above-mentioned framework was mainly formulated because management of IAP can be challenging and might result in conflicts, especially when the people who benefit from IAP are different from those who incur costs (Novoa et al., 2018). Conflicts of interests among stakeholders mean that management plans may be delayed or not be executed (Novoa et al., 2017; Zengeya et al., 2017). Therefore, there is increasing interest in engaging various stakeholders impacted by IAP in developing effective control and management plans (Novoa et al., 2018). The framework offers a practical approach to minimise the impact of disputes created by differences in control and management of IAP (Novoa et al., 2018).

The management practices and policies for IAP in urban settings around the world require interdisciplinary approaches which intersect a wide range of issues while mitigating the

impacts of IAP (Wilson et al., 2013; Novoa et al., 2018). Consequently, new models are likely to be necessary for effectively conceptualising and combating IAP in urban settings (Shackleton et al., 2016). Managing IAP that have both positive and negative impacts requires engagement with all stakeholders (Gartner et al., 2016). For example, a technique presented by Woodford et al. (2016) indicated that structured stakeholder engagement and scenario-based planning (SBP) can enable the development of solutions in IAP management (Woodford et al., 2016). Furthermore, Gaertner et al. (2016) investigated different management approaches and strategies and proposed a framework which categorises IAP into three management strategies namely, (i) effective engagement from different stakeholders, (ii) importance of control, and (iii) tolerance of the IAP. Lastly, the control strategies and planning must be accessible to urban populations and focus on their needs and preferences rather than the views of the top management, which is often not the case (Gwedla and Shackleton, 2015).

1.5. Problem statement and research motivation

Several studies have highlighted that information on the distribution, abundance and status of IAP is limited, particularly in small urban settings (Shackleton and Shackleton, 2016; McLean et al., 2017; McLean et al., 2018). Invasive alien plants of different life forms can have major impacts on natural ecosystems. According to Richardson and Rejmanek (2011) IAP are rapidly increasing around the world and causing severe negative effects to natural ecosystems. Invasive trees are one of the most harmful IAP taxa due to their capacity to become structurally dominant in terrestrial conditions (Richardson and Rejmanek, 2011). Furthermore, because they have become increasingly common and widespread, the difficulties associated with IAP are expected to worsen as both globalisation and urbanisation increase (Richardson and Rejmanek, 2011).

The frequent disregard of the nature, complexities, challenges, and impacts of IAP in smaller urban centres is likely to have negative impacts on their inhabitants and the immediate surroundings, such as natural areas (McLean et al., 2017; Gaertner et al., 2016; Potgieter et al., 2017). The presence of IAP at various spatial and temporal scales, has a variety of socio-economic, and ecological consequences. (Shackleton et al., 2007; Potgieter et al., 2019). For example, invasion by IAP in some urban settings has been reported to reduce water resources and damage to infrastructure (Potgieter et al., 2017), and these consequences vary depending on the urban context. However, there is generally lack of

understanding of the patterns and processes of IAP in urban contexts (Gaertner et al., 2017; Jubase et al., 2021). This is further emphasised by Potgieter et al. (2017) who stated that little is known on the role of IAP in providing ecosystem services or disservices in urban environments, particularly in developing countries, where little research has been conducted.

As pointed out by Mabusela et al. (2021), most of the expertise and knowledge on IAP is from rural and natural landscapes, with relatively little knowledge and understanding derived from studies in urban settings. Small towns on the other hand, present a unique set of conditions that make the research and management of IAP a particularly pressing issue (Mabusela et al., 2021). Since it seems clear that there has been comparatively little research on IAP in small towns in developing countries, it can be argued that the need to assess the distribution, abundance and diversity of IAP is vital (Padayachee et al., 2017), particularly in South Africa where management of IAP by municipalities is advocated by law (Ruwanza and Shackleton, 2016). In the South African context, only a few studies by Mabusela et al. (2021), Jubase et al. (2021), and McLean et al. (2018) have been done with specific emphasis on IAP in small towns such as Port Alfred. The current study will therefore add new information in trying to understand the abundance and patterns of IAP in urban areas with an emphasis on small towns in the Eastern Cape Province of South Africa. One of the critical values is that the generated information on the distribution, abundance, and diversity of IAP within these small towns can be incorporated into the development of management and control plans by these small towns, as mandated by NEM:BA (Ruwanza and Shackleton, 2016).

The concern, research, management, and control programmes pertaining to IAP impacts have been focused in rural areas and large cities (McLean et al., 2017; McLean et al., 2018). This shortfall needs to be addressed because (a) many IAP can be found in small urban settings, (b) small urban settings may act as nodes for expansion or secondary introductions into surrounding areas, and (c) urban settings are very different to their rural surroundings in terms of tenure arrangements, the number of people and landowners involved, as well as ecological profiles (Shackleton and Shackleton, 2016; McLean et al., 2018; Jubase et al., 2021). Small urban settings often lack the capacity and the capability to manage and prevent the spread of IAP. Furthermore, understanding IAP distribution and abundance in South African urban areas creates an opportunity to generate key information that can be used to manage and control IAP (Ruwanza and Shackleton, 2016). Furthermore, an

inventory of urban residents' knowledge and perceptions on IAP in small towns is important if conflict generating IAP are to be managed and controlled effectively.

1.6. Aim and objectives

The aim of the research reported in this thesis was to determine the distribution, abundance, and perceptions of IAP in 12 small towns in the Eastern Cape province of South Africa and assess how and why they differ within and between towns. To achieve this aim, the research addresses the following questions:

1) What is the distribution and abundance of IAP within each town?
2) How does urban land use type (parks, road verges, residential areas) influence the diversity, distribution, and abundance of IAP?
3) How does the distribution, abundance and richness of IAP relate to town attributes?
4) What are the resident's knowledge, perceptions, and willingness to control invasive alien plant species in their private gardens?

1.7. Structure of this thesis

The overall aim of the research was based on the assessments of IAP distribution, abundance, and perceptions of IAP in 12 small towns in the Eastern Cape province, South Africa. This thesis is divided into four chapters.

Chapter 1: provides a general introduction, background, and detailed literature review of the research study. The chapter further presents the research motivation, aim, and research questions.

Chapter 2: presents the study area and methods used to address the first, second, and third research questions of the study. It further presents the results and discussion related to the distribution and abundance of IAP among the small towns and within the different land use types and suburbs.

Chapter 3: addresses the fourth objective on residents' knowledge, perceptions, and willingness to control invasive alien plants in their private gardens. The chapter also presents the methods and discusses the results relating to residents' knowledge, perceptions, and willingness to control IAP in their private gardens.

Chapter 4: provides a synthesis of the research chapters and brings together the key conclusions and recommendations regarding the distribution and perceptions of invasive alien plants in the 12 small towns.

Each empirical chapter (2 and 3) has its own introduction, results and discussion of the findings and a conclusion. All the cited references are provided at the end of the thesis. The description of the study area is only presented in chapter 2 to avoid repetition in chapter 3.

Chapter 2

The distribution and abundance of urban woody invasive alien plants

2.1. Introduction

Invasive alien plants (IAP) are spreading across different geographic ranges and causing a wide range of impacts (Hulme and Vila, 2017; Cepelovaa and Munzubergovaa, 2012). These IAP propagate across different landscapes with or without anthropogenic or natural interference (Aronson et al., 2015). The invasion success of IAP is characterised by the ability to outgrow, outcompete, and displace native species while affecting fundamental ecosystem processes (Blackburn et al., 2011). Environmental changes such as land use and fragmentation can also mediate the spread and spatial pattern of IAP, proliferating invasion extent (Hulme, 2009). The lack of preventive measures and mechanisms for the control of IAP in many settings aids successful competition with indigenous species leading to the rapid spread of IAP (Gioria and Osborne, 2014).

According to Richardson and Rejmanek (2011), trees represent a unique case of IAP for various reasons. Firstly, many invasive alien trees were intentionally introduced for forestry, horticultural and ornamental purposes (Richardson and Rejmanek, 2011). Secondly, there are often conflicts of interest in propagation, management, and control of tree IAP (Richardson and Rejmanek, 2011). Furthermore, many invasive tree species are commercially important and costly to manage, since they generally are long lived, produce high biomass, and can have substantive negative impacts on ecosystem services and livelihoods (Richardson and Rejmanek, 2011). In an overview presented by Mukul et al. (2020), some of the most popular IAP tree species, such as *Acacia*, *Eucalyptus*, *Pinus*, and *Swietenia* species were initially introduced for the provision of food, timber, and environmental benefits such as erosion control. It was found that some IAP were progressively harming local flora, fauna, and ecosystems as they outcompete native species for resources such as water and nutrients (Mukul et al., 2020; Richardson et al., 2015; Hossain and Hoque, 2013; Kull et al., 2011; Ameen, 1999). Similarly, Castro-Díez et al. (2019) presented a global assessment of alien tree species on multiple ecosystem services using meta-analysis techniques. They found that there are trade-offs on different ecosystem services, for instance, it was found that while alien tree species increase regulating

ecosystem services such as climate regulation, soil stabilisation and control of soil erosion, they decreased provisioning ecosystem services resulting in negative effects on livelihoods.

Globally, IAP are a prevalent and growing environmental problem with negative impacts on the environment and society, affecting the wellbeing of many people and threatening livelihoods (Shackleton et al., 2018). Invasions by IAP have been considered a leading cause of global environmental change (Cook et al., 2011) and amongst the leading causes of biodiversity loss, which in turn results in a decline in ecosystem services (Pejchar and Mooney, 2009; Shackleton et al., 2007). The steady increase in human population, human movement, and global trade, has intensified the impacts of biological invasions in various ecosystems and landscapes, which is exacerbated by climate change (Hulme, 2009).

The biological structure and composition of urban ecosystems around the world is becoming increasingly homogeneous, even though their physical and biological factors are changing consistently as urbanisation progresses (Aronson et al., 2015; McKinney, 2006). As the global urban population increases, urbanisation will further intensify resulting in the intensification of land use within urban areas (Freire et al., 2014; Gaertner et al., 2016). There is still a growing demand for more land for settlement, agriculture, transportation, and infrastructure. For instance, Rouget et al. (2015) highlighted that urban population growth has been accompanied by the introduction and increased presence of IAP in cities such as Durban in South Africa. Furthermore, it was reported that the proliferation of IAP in the city of Durban is linked to the expansion and growth of the city (Rouget et al., 2015). The urbanisation process is complex and varies across space and time, making it a common cause of land use change around the world (Afonso et al., 2020). The composition and frequency of IAP can be influenced by a range of aspects such as climate, geology, land use, landscape context, and natural or anthropogenic disturbance (Sharma et al., 2010; Gaertner et al., 2017). The construction and improvement of transport routes may provide preferential pathways for IAP propagation (Hulme, 2009). Intentional cultivation and movement of plants in urban environments have substantially facilitated the spread and dispersal of numerous IAP species across urban landscapes, and this cannot be understood without considering human behaviour (Sharma et al., 2010; Pyšek et al., 2012). Ariori et al. (2017) stated that in New England, USA, several studies indicated that anthropogenic variables such as construction activities, agricultural activities, being closer or adjacent to roadways, and socioeconomic variables such as level of education and income somehow

influence the distribution of IAP in urban areas. Similarly, Shrestha (2016) found that anthropogenic activities, natural processes, and the availability of resources increased propagule pressure of IAP, particularly in human concentrated landscapes such as human settlements. In Germany, Kühn et al. (2004) found that alien plant species increased with increasing urbanisation. On the other hand, Burton et al. (2005) found that the diversity of IAP species increased as urbanisation decreased, this was mainly because anthropogenic impacts decreased the diversity of IAP. These results seem to suggest that the relationship between urbanisation and IAP species richness is not consistent across landscapes, depending on their contexts (Sharma et al., 2010; Stajerova et al., 2017).

The problem of IAP is prevalent both in developed and developing countries, although their impact is likely to be higher in developing countries due to a common lack of expertise and limited resources for their control and management (Potgieter et al., 2017). The limited distribution of natural forest resources in South Africa led to the historical introduction of many IAP tree species for several benefits, such as timber and stabilising sand dunes (Bennett and Kruger, 2015). As a result, a significant number of IAP tree species have established and naturalised in South Africa (Bennet and Kruger, 2015). Many IAP species in urban areas play an important and useful role for urban residents in various ways such as providing multiple ecosystem services (Jubase et al., 2021). This is especially important for those who cannot travel to natural or green spaces outside of urban landscapes while also improving the aesthetic quality of cities (Gaertner et al., 2017).

Godefroid and Koedam (2007) found that in Brussels, Belgium, IAP were best represented in the city centre, and that the densification of buildings in already built-up areas was one of the main drivers of IAP species composition and abundance. The Apartheid legacy in South Africa has left apparent discrepancies in the distribution and diversity of urban greenery and the quantity of IAP found between and within municipalities (Venter et al., 2020; Gwedla and Shackleton, 2015). For example, Mabusela et al. (2021) found that within the residential land use zones, townships accounted for between 41 and 61 percent of all reported IAP per town, followed by affluent neighbourhoods (22% – 41%) and RDP neighbourhoods (6% –32%).

These disparities have resulted in the differences in the distribution of IAP between suburbs and land uses (Mabusela et al., 2021). Kuruneri-Chitepo and Shackleton (2011) highlighted that affluent suburbs, or historically white suburbs, have a wider distribution and abundance of street trees, including IAP, than both the townships and the RDP. The

townships and the RDP areas are where most of the population reside and are characterised by poverty, high-density housing, poor service delivery and limited commercial activities (Gwedla and Shackleton, 2015). On the other hand, affluent suburbs are distinguished by infrastructural attributes that are characteristic of first-world cities, such as well-planned and maintained urban greenery, low housing densities, well-maintained infrastructure, and effective service delivery (Gwedla and Shackleton, 2015).

Chishaleshale et al. (2015) and Gwedla and Shackleton (2015) highlighted that whilst there is a considerable number of government employees who are responsible for the regulation, control, and maintenance of urban greenery in urban areas, many often lack the capacity and necessary knowledge needed for the appropriate IAP control and maintenance. Furthermore, understanding how these IAP respond to different environments, land use zones, and suburbs is key in identifying factors influencing their distribution. Understanding these factors can be enhanced through early and routine detection, modelling and mapping the spatial distribution of urban greenery (Gwedla and Shackleton, 2015). Only limited work has been done on IAP distribution in the Eastern Cape (Mabusela et al., 2021), and therefore there remains a need to assess the distribution and abundance of IAP across different small towns to help develop accurate information that can be used to effectively manage and control IAP in the various towns within different land use types and suburbs. This chapter assess the distribution and abundance of woody IAP across different land uses and suburbs in 12 towns in the Eastern Cape province, South Africa.

2.2. Methods

2.2.1. Study area

The Eastern Cape province is in the south-eastern part of South Africa. It is the second largest province in South Africa, covering a total area of 169,580 km^2, which is (13.8%) of South Africa's land area (Statistics South Africa, 2016). The Eastern Cape borders four South African provinces, namely, Western Cape, KwaZulu-Natal, Free State, Northern Cape as well as the neighbouring country of Lesotho (Statistics South Africa, 2016). It has the third largest population in South Africa, with a population of approximately 6.9 million, and a population density of 39 people/km^2 (Statistics South Africa, 2016), which represents about (14%) of the national population of South Africa. The racial makeup of the province is Black Africans accounting for approximately 86%, Coloureds (8%), Whites (5%), Indians/Asians (0.4%), and others (0.3%) (Census 2011; Statistics South Africa, 2016).

Females make up (53%) of the population while males only make up (47%) (Statistics South Africa, 2016).

The dominant language is isiXhosa (Census, 2011), and major land uses found in the province are (a) subsistence farming, (b) livestock farming, (c) commercial arable agriculture, (d) ecotourism and game farms, and (e) industries (Statistics South Africa, 2016). The province has high poverty levels (61%), with low education levels and a high unemployment rate (Statistics South Africa, 2016). The mean annual rainfall varies from 300 mm to 1 000 mm characterised by high spatial and seasonal variability (Climate data.org, 2016). The average temperature ranges between 35°C in austral summer and 10°C in austral winter (Climate data.org, 2016). The province has eight biomes namely, Grassland (42%), Nama Karoo (20%), Albany thicket (16%), Savanna (11%), Fynbos (7%), Succulent Karoo (3%), Forest (1%), and Indian Ocean coastal belt (0.2%) (Mucina and Rutherford 2006).

The province has six district municipalities and 37 local municipalities (Gwedla and Shackleton 2015). According to recent estimates, 21% of the population resides in O.R. Tambo district municipality (City Populations Database, 2016). The Nelson Mandela Bay Metro is home to the second largest population in the Eastern Cape province, followed by the Amathole district municipality. The Joe Gqabi District municipality remains the least populated district, with only (5.4%) of the provincial population. The Eastern Cape province has 128 urban areas, the largest being Gqeberha (formerly Port Elizabeth) with 876 436 inhabitants, followed by East London with 295 644, whilst Hogsback has the smallest population of 1 029 (City Populations Database 2016).

This study was conducted in 12 small towns in the province. The randomly selected small towns were, Adelaide, Alexandria, Barkly East, Bedford, Burgersdorp, Cathcart, Kirkwood, Middelburg, Paterson, Somerset East, St Francis Bay, and Willowmore (Figure 2.1). For this research, small towns were defined according to Statistics South Africa (2016) as “areas that contain between 1 000 and 20 000 inhabitants”. Small towns were selected because relatively little research on IAP distribution has been conducted in small towns. The selection of the small towns was done randomly using the random function in Excel. Firstly, all towns in the province were extracted from the city population database (City population database, 2016). Secondly, there were 25 small towns in the province that conformed to the above definition (areas that contain between 1 000 and 20 000

inhabitants), which were listed in Excel. Of these 25, 12 were randomly selected. The physical characteristics of the 12 study towns are summarised in Table 2.1.

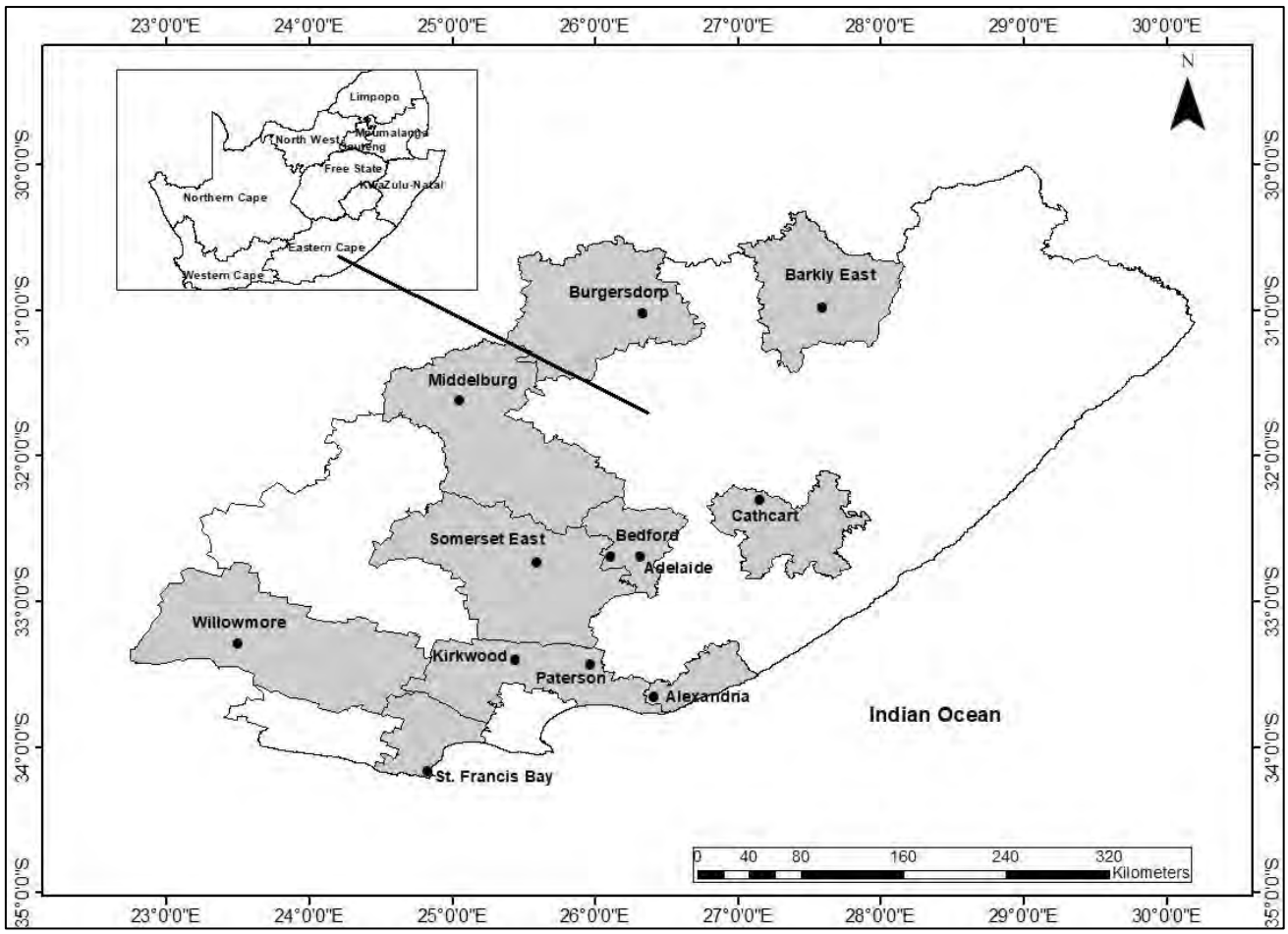

Figure 2.1: Location of the selected 12 small towns and their municipalities (shaded) in the Eastern Cape province, South Africa. The insert map indicates the location of the Eastern Cape province in South Africa.

Table 2.1: Physical characteristics of the selected 12 small towns in the Eastern Cape province, South Africa.

Town	Local Municipality	Location (coordinates)	Size (km^2)	Average temperature (°C)	Mean annual rainfall (mm)	Population (2011)	Population density (per km^2)
Adelaide	Inxuba Yethemba	33°42′00”S; 26°18′00”E	40.0	18	450	12 191	305
Alexandria	Ndlambe	33°39′00”S; 26°25′00”E	5.7	18	403	10 086	1 767
Barkly East	Senqu	30°58′05″S; 27°35′36″E	16.8	18	567	9 987	595
Bedford	Inxuba Yethemba	33°41′00”S; 26°5′00”E	14.6	17	489	8 769	601
Burgersdorp	Walter Sisulu	30°59′32″S; 26°19′29″E	30.9	15	482	15 991	520
Cathcart	Amahlathi	32°18′00”S; 27°08′00”E	30.1	15	561	7 360	245
Kirkwood	Sundays River	33°24′01”S; 25°26′33”E	7.2	18	451	13 765	1 900
Middelburg	Inxuba Yethemba	31°29′38”S; 25°1′2”E	44.8	14	356	18 680	417
Paterson	Sundays River	33°43′4”S; 25°16′5”E	4.3	18	462	5 582	1 291
Somerset East	Blue Crane	32°43′00”S; 25°35′00”E	72.8	17	349	18 824	259
St Francis Bay	Kouga	33°16’2”S; 30°24’8”E	10.0	17	736	4 933	491
Willowmore	Baviaans	33°17′00”S; 23°29′00”E	21.7	16	363	7 678	353

Source: Climate data.org (2016) and City and Population Database (2016).

2.2.2. Sampling procedure and data collection

Objectives one, two and three were addressed by using drive-by street surveys conducted between October 2020 and December 2020, with one field assistant navigating the streets using Google Maps, and two field assistants observing each side of the road (Shackleton and Shackleton, 2016; McLean et al., 2018; Mabusela et al., 2021). Google Earth was used to identify all the publicly accessible streets in each town. All publicly accessible roads in each town were surveyed and IAP were counted and recorded. If the IAP was a continuous hedge it was counted as one unit, and if there was a break in between the hedges, these were counted separately. With assistance from two observers, the IAP were sampled along both sides of each road, including all land uses namely residential areas, parks, road verges

and open areas (Cilliers et al., 2012). An IAP photo catalogue was used to help with the identification of IAP.

The IAP species were further categorised according to the four National Environmental Management: Biodiversity Act 10 of 2004 (NEM:BA) categories namely category 1a, category 1b, category 2 and category 3 in the different suburbs (i.e., affluent, township, CBD, and RDP) and land use types (i.e., residential, road verges and PUGS). According to the NEM:BA regulations, category 1a are "*IAP which must be combatted and eradicated, and any form of planting or trade is strictly prohibited"*. Invasive alien plants in Category 1b "*must be controlled, and where possible, removed and destroyed. Any form of planting or trade is strictly prohibited*". Invasive alien plants in Category 2 are "*deemed potentially invasive, and a permit is required to trade or plant them*". Invasive alien plants in category 3 are "*species which may remain in designated areas, and further planting, propagation or trade is strictly prohibited*."

The delineation for the land use types (i.e., residential, public urban green spaces and road verges) was done from the land cover classes from ArcGIS (see highlighted land cover classes in Appendix 3) and the different suburb types (i.e., affluent, township, CBD, RDP) delineation was obtained using the digitised Google Earth images. The latest aerial images of each study town were obtained from Google Earth, digitised, and saved as a KML (Keyhole Mark-up Language) file, to capture and classify different land uses within the boundary of each town. The South African landcover image version obtained from the Department of Environmental Affairs website (https://egis.environment.gov.za/gis_data_downloads) containing the South African National Landcover (TIFF) 2015 [Raster] 2015 version (Department of Environmental Affairs, 2015). Keyhole Mark-up Language (KML) file of each town were uploaded into ArcGIS version 10.4. and then clipped (in raster format). The attributes table of the clipped South African landcover image and KML file were converted from raster format to polygon format, and class names (see Appendix 3) were dissolved to categorise the town into different land use zones (i.e., settlements, industrial areas, commercial zones and urban green spaces), the industrial areas were not assessed but included in the maps because they are a part of the town boundaries (see Appendix 4 for the land use maps). Each IAP recorded was categorised according to land use and suburb types according to the land use categories found in the relevant literature (Mabusela et al., 2021). Road density was calculated by converting the KML file of each town into a shapefile using ArcGIS, after

the KML was converted into a shapefile, a density tool (line density) in ArcGIS was used to calculate the density of the road for each town.

Environmental and socio-economic indicators, namely town size, population, mean annual rainfall, unemployment rate, education, GDP, and altitude, were obtained for each town from the city population database, Statistics South Africa (2011) and Census (2016) South Africa database. These indicators were used to test for relationships that might influence the distribution and abundance of IAP (Appalasamy et al., 2020; Fuentes et al., 2015; McKinney, 2004) (Table 2.2). These indicators were used because the distribution, abundance, and diversity of IAP patterns tends to be influenced by a wide variety of social and environmental factors (Fuentes et al., 2015).

Table 2.2: List of variables related to environmental and socio-economic activities.

Measured Variable	**Description**
Human population (No. of people)	Total population of the town
Human population density (People per km^2)	The number of people per unit geographic area
Size/area of town (km^2)	Total geographic area
Mean annual temperature (°C)	Average temperature per annum
Mean annual rainfall (mm)	The amount of precipitation for a location over a year
Average income per town (ZAR)	The amount of money earned per person
Altitude (m)	Topographic height above sea-level
Contribution GDP per town (ZAR)	Total goods and services in a town in a given period of time
Unemployment rate (%)	No. of unemployed people as a percentage of the labour force
Tertiary education (%)	No. of people as a percentage of higher education
Secondary education (%)	No. of people as a percentage of secondary education

Source: (Climate data.org, 2016; City population database, 2016; Statistics South Africa, 2011).

2.2.3. Pitfalls

The research was conducted using a drive-by survey and ran the risk of miscounting and misidentifying some trees in areas that were not visible. For instance, in some of the open spaces, there were infestations of shrubs, and some IAP could not be counted due to visibility, we therefore estimated the number of woody IAP by walking the open spaces on foot. In other instances, visibility may be obscured by high walls, infrastructure, or hedges, resulting in under counts. Apart from that, the drive-by survey method does not differentiate between plant species that have been planted and those that established on their own through self- seeding. Regardless of these challenges associated with the drive-by survey, the survey approach used in this study can help identify IAP in urban settings,

thus providing valuable information that can be used for control and management of IAP in small towns.

2.2.4. Data analysis

The data were captured in Microsoft Excel 2016 and all descriptive statistical analysis were conducted using Statistica Version 13. Descriptive statistics were conducted to describe and summarise quantitative data. The number of the IAP species recorded in each town was used to calculate diversity indices (i.e., species richness, species evenness, Simpson diversity index and Shannon diversity index). The species richness was calculated by counting the individual number of different species in each town. The species diversity of the IAP was determined using the Simpson's index and Shannon diversity index. The overall Shannon diversity index was then calculated using the general formula **[H=∑pi x In (pi)]** for each town, where H=Shannon diversity, ∑pi=sum of proportion of species, In(pi)=natural log of proportion of species (Burton et al., 2005; Palaghianu, 2014). A high value of the Shannon diversity indicates that there is high diversity, while a lower Shannon diversity index shows less or limited diversity in the species composition.

To measure the Simpson diversity index, the general formula **D=∑ni(ni-1)/N(N-1)**, was used, where D=Simpson diversity index, ∑ni=sum of frequency of species, (ni-1) = frequency of IAP minus 1, N= total number of IAP, (N-1) =total number of IAP minus 1. The species evenness was determined by dividing the Shannon diversity index by the natural log of the species richness, this was calculated by using the general formula **SE=H/In (SR)**, where SE=species evenness, H=Shannon diversity index, In (SR)=natural log if species richness (Burton et al., 2005). The species evenness indices indicate how equally abundant each species is, a lower species evenness or an uneven distribution of species, while a higher species evenness shows that species are evenly represented (Set et al., 2013). To calculate the density for IAP, the number of IAP was divided by the area of the town, suburb or land use concerned. The species richness as density was calculated by dividing the species richness of each town with the population density of the town concerned. This was calculated to explore how population density influence the species richness. Towns with a higher density of IAP had a higher species richness as density, this indicated that there is an influence of density on the species richness.

The differences in means of continuous variables were analysed by chi-square test and presented as mean percentage for each suburb and land use in each town. Multiple

regression was conducted to analyse the relationships that might influence the distribution and abundance of IAP. Continuous variables used were primarily environmental and socio-economic indicators, such as town size, area, population, mean annual rainfall, unemployment rate, education, GDP-R (GDP by region) and altitude (Pyšek et al., 2010; Wilson et al., 2020). The area under each land use type per town were assessed using ArcGIS by using the data from the attribute tables in ArcGIS. The data from the attribute tables were then exported into Microsoft Excel where a chi-squared analysis to test if the relative proportion of IAP was in proportion to the various land uses.

Principal Component analysis (PCA) was used to determine the variation of IAP in various land uses (residential, road verge, and PUGS) and suburbs (affluent, township, CBD, and RDP). Multiple regression analysis was conducted to test for relationships between socio-demographics and environmental variables on the total number of individual IAP, species richness, and IAP density. Multiple regression was conducted using the Statistica Version 13.

2.3. Results

2.3.1. Distribution of woody IAP per town

A total of 38 427 woody IAP species were recorded across all towns. Middleburg had the highest number of IAP, with 5 573 individuals, followed by St Francis Bay (4 382) and Burgersdorp (4 211). The towns with the lowest number of IAP were Cathcart (1 699) and Paterson (947) (Figure 2.2). Somerset East and Alexandria had the highest species richness with 43 and 42 species respectively, whilst Paterson and St. Francis Bay had the lowest species richness 24 and 21 species respectively (Figure: 2.2).

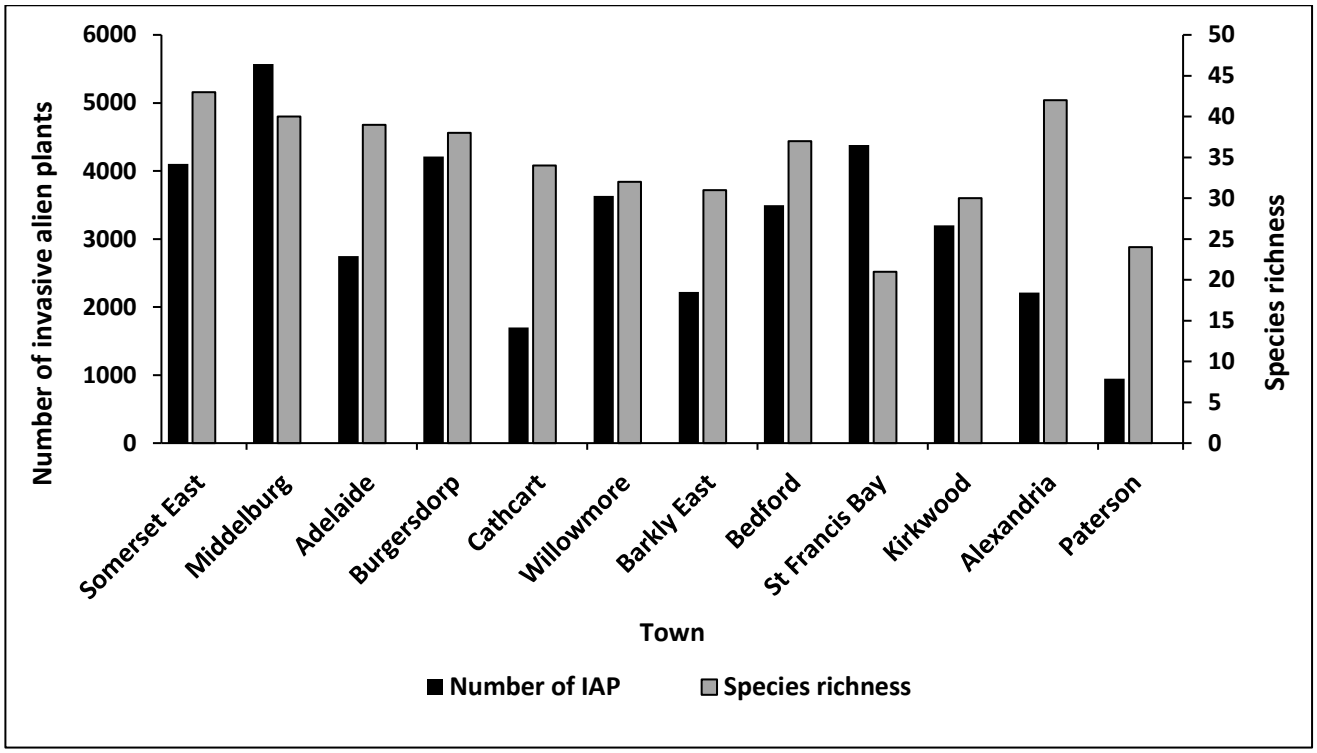

Figure 2.2: Total number of woody IAP and species richness per town (ordered based on town size, from large to small).

2.3.2. Distribution of woody IAP species across towns

Out of the 38 427 enumerated IAP, 56 different species were encountered, and identified to a species level. The most common woody IAP species were *Melia azedarach* with 4 384 individuals, *Pinus elliotti* (4 051) and *Jacaranda mimosifolia* with (3 640) with a mean of 365.3±104.8, 337.6±57.8, and 303.3±121.5 individuals per town, respectively (Table 2.3). *Spathodea campanulata, Acacia crenata, and Pakinsonia aculeata* had the lowest number of individuals with only three and two individuals across all towns for all the IAP respectively, averaging 0.25±0.12, 0.17±0 and 0.7±0.1, respectively (Table 2.3). *Leucaena leucocephala* had only one individual across all towns. The most common species accounted for 68.7% (26 395) of all the individuals recorded. In contrast, 32 species each contributed less than one percent (1%) (Table 2.3).

Table 2.3: Composition and distribution of woody IAP species across 12 towns in the Eastern Cape province, South Africa. (ordered from highest to lowest mean number). The cells indicate the number of individuals. The listings of IAP categories (NEM:BA) of each plant can be found in Appendix 2.

Species	Adelaide	Alexandria	Barkley East	Bedford	Burgersdorp	Cathcart	Kirkwood	Middleburg	Paterson	Somerset East	St Francis Bay	Willowmore	Mean±SE	Total
Melia azedarach	575	288	8	468	128	98	837	1 207	127	253	1	394	365.3±104.8	4 384
Pinus elliotti	241	239	577	418	451	384	142	739	68	204	137	451	337.6±57.8	4 051
Jacaranda mimosifolia	391	57	0	1 004	39	78	681	110	36	1184	32	28	303.3±121.5	3 640
Eucalyptus camaldulensis	128	440	32	420	245	237	4	430	105	544	0	895	290.0±77.3	3 480
Ligustrum lucidum	57	212	192	104	414	96	0	350	151	209	328	29	178.5±38.1	2 142
Schinus molle	149	8	6	118	48	48	61	400	37	110	0	659	137.0±56.9	1 644
Prunus serotina	0	0	0	0	0	0	0	0	0	0	1 481	0	123.4±123.4	1 481
Fraxinus americana	77	121	46	84	234	107	89	206	32	89	0	97	98.5±19.1	1 182
Fraxinus angustifolia	71	119	127	96	209	144	0	148	85	109	0	47	96.3±17.6	1 155
Ligustrum ovalifolium	46	109	210	48	126	0	0	158	71	114	243	31	95.9±22.7	1 151
Celtis australis	114	12	20	95	252	68	155	79	4	194	41	39	89.4±22.3	1 073
Grevillea robusta	90	65	0	95	4	66	409	16	29	56	0	182	84.3±33.1	1 012
Callistemon viminalis	51	115	0	40	7	47	203	74	4	179	147	84	79.3±19.8	951
Pinus canariensis	60	110	48	67	161	20	79	273	2	67	42	21	79.2±21.5	950
Acacia implexa	0	0	0	0	0	0	0	0	0	0	762	0	63.5±63.5	762
Albizia lebbeck	72	0	19	10	288	13	6	126	0	2	0	59	49.6±24.4	595
Senna didymobotrya	62	45	0	45	2	1	175	0	84	42	0	108	47.0±15.7	564
Gleditsia triacanthos	0	2	0	0	372	0	23	146	0	0	0	7	45.8±32	550
Ailanthus altissima	43	0	3	22	186	5	10	268	0	7	0	1	45.5±25.3	545
Tipuana tipu	24	0	249	23	5	18	90	3	13	55	0	5	40.5±20.4	485
Populus canescens	2	1	147	18	210	15	0	42	0	44	0	1	40.0±19.6	480
Schinus terebinthifolius	46	38	39	34	68	5	0	103	47	73	0	19	39.3±9.1	472
Morus alba	57	4	26	59	121	28	13	84	4	45	4	18	38.6±10.5	463
Robina pseudoacacia	1	0	113	3	156	1	2	92	0	0	0	91	38.3±16.6	459
Acacia saligna	0	6	0	0	0	0	0	1	0	0	373	0	31.7±31.1	380

Metrosideros excelsa	0	6	7	4	14	2	19	1	0	4	308	0	30.4±25.3	365
Pinus halepensis	13	6	25	47	58	2	6	54	0	4	145	0	30.0±12.2	360
Salix babylonica	38	23	65	28	94	29	0	23	20	40	0	0	30.0±8.1	360
Eucalyptus cladocalyx	24	0	156	11	56	20	3	7	0	57	0	4	28.2±13.1	338
Cinnamomum camphora	126	7	1	5	25	24	0	45	1	32	17	45	27.3±10.1	328
Cestrum laevigatum	10	4	4	7	12	5	29	109	0	24	55	33	24.3±8.9	292
Acacia melanoxylon	0	1	0	0	0	0	57	42	0	0	134	45	23.3±11.4	279
Eriobotrya japonica	25	9	3	27	29	7	3	14	0	103	9	26	21.3±8.0	255
Acacia decurrens	17	8	0	0	20	54	0	15	0	93	0	17	18.7±8.0	224
Ceratonia siliqua	0	0	0	0	136	0	7	64	0	0	0	1	17.3±12.1	208
Prosopis velutina	0	5	0	0	0	0	0	1	0	17	4	179	17.2±14.8	206
Hakea sericea	0	17	5	14	6	0	0	4	3	28	71	0	12.3±5.9	148
Triplaris americana	40	12	0	37	2	0	19	0	6	26	0	0	11.8±4.4	142
Spartium junceum	1	0	45	0	22	3	1	46	0	3	0	0	10.1±5.1	121
Acacia mearnsii	6	21	0	3	0	35	2	25	9	6	0	11	9.8±3.3	118
Acacia podalyriifolia	6	15	27	13	3	10	0	8	0	18	6	0	8.8±2.4	106
Solanum mauritianum	2	29	0	7	0	0	40	0	0	19	0	0	8.1±4.0	97
Syzygium paniculatum	0	5	1	0	0	23	0	0	0	1	42	0	6.0±3.9	72
Caesalpinia decapetala	28	1	0	1	0	0	31	4	0	2	0	0	5.6±3.3	67
Syzygium cumini	29	13	18	0	0	0	0	0	0	0	0	0	5.0±2.8	60
Psidium guajava	0	7	2	18	2	5	0	0	0	22	0	0	4.7±2.2	56
Caesalpinia gilliesii	7	2	0	0	5	1	0	36	0	0	0	5	4.7±2.9	56
Bauhinia purpurea	10	22	0	2	0	0	0	0	7	3	0	0	3.7±1.9	44
Bauhinia variegata	7	4	0	4	0	0	0	0	2	10	0	0	2.3±0.9	27
Acacia longifolia	0	0	0	0	0	0	5	20	0	0	0	0	2.1±1.7	25
Paraserianthes lophantha	0	0	0	0	0	0	0	0	0	11	0	0	0.92±0.01	11
Pinus patula	0	0	3	0	0	0	0	0	0	0	0	0	0.25±.0.01	3
Spathodea campanulata	0	2	0	0	0	0	0	0	0	1	0	0	0.25±0.12	3
Ardisia crenata	0	2	0	0	0	0	0	0	0	0	0	0	0.17±0.1	2
Parkinsonia aculeata	1	0	0	0	0	0	0	0	0	1	0	0	0.7±0.1	2
Leucaena leucocephala	0	0	0	0	1	0	0	0	0	0	0	0	0.08±0.001	1

There were variations in the species diversity indices of IAP across towns, with Somerset East having the highest species richness (43), followed by Alexandria (42), while Paterson (24) and St Francis Bay (21) had the lowest species richness. Burgersdorp had the highest Shannon diversity and Simpson index of 3.04 and 0.94, respectively, followed by Adelaide with a Shannon diversity index of 2.92 and a Simpson index of 0.91 and the third being Middleburg with a Shannon diversity index of 2.86 and a Simpson index of 0.91. Kirkwood had the highest density of IAP 444.6 km^{-2}, followed by St Francis Bay (438.2 km^{-2}). The lowest IAP density was recorded in Cathcart and Somerset East with an IAP density of 56.4 km^{-2} respectively. Although St Francis Bay had the highest number of IAP individuals, it had the lowest species richness compared to all towns (Table 2.4). Paterson had the highest species evenness of 0.28, followed by St. Francis Bay with a species evenness of 0.27, while Bedford and Somerset East had the lowest species evenness of 0.23 compared to all towns, the species evenness ranged from 0.23 to 0.28 across all towns, indicating that the IAP species were unevenly distributed across towns.

Table 2.4: Invasive alien plant species diversity indices across towns.

Species diversity indices	**Adelaide**	**Alexandria**	**Barkley East**	**Bedford**	**Burgersdorp**	**Cathcart**	**Kirkwood**	**Middleburg**	**Paterson**	**Somerset East**	**St Francis Bay**	**Willowmore**
Species richness	39	42	31	37	38	34	30	40	24	43	21	32
Shannon diversity	2.92	2.76	2.58	2.54	3.04	2.76	2.36	2.86	2.62	2.76	1.91	2.48
Simpson index	0.91	0.91	0.89	0.86	0.94	0.90	0.86	0.91	0.91	0.88	0.83	0.87
Species evenness	0.24	0.24	0.25	0.23	0.25	0.25	0.25	0.24	0.28	0.23	0.27	0.25
Density of IAP (km^2)	68.7	387.2	132.4	239.7	136.3	56.4	444.6	124.4	220.2	56.4	438.2	167.4
Species richness as density	1.0	7.4	1.8	2.5	1.2	1.1	4.2	0.9	5.6	0.6	2.1	1.5

The total number of IAP by NEM:BA listing category varied across the different suburbs with the affluent suburbs having the highest number of IAP listed in the NEM:BA categories, followed by township, CBD, and RDP. The highest category across all the towns was category 1b species, followed by category 3 species, with category 1a having the least number of species. The above was more visible in the affluent suburb as compared to the other suburb types (Figure 2.3).

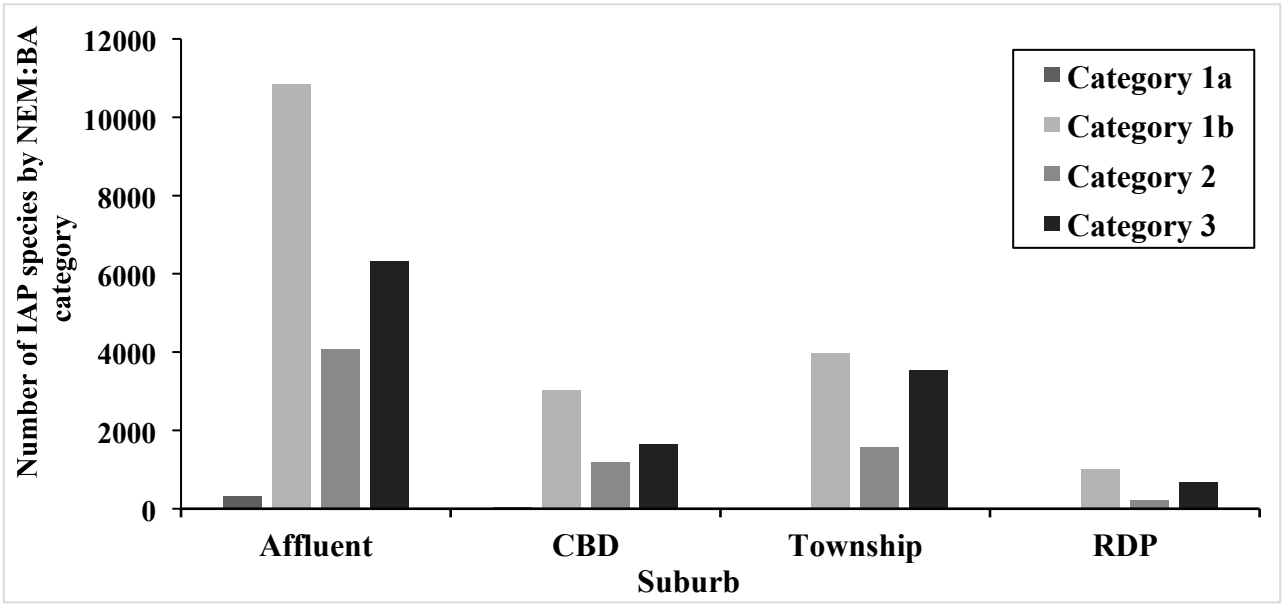

Figure 2.3: Invasive alien plants by NEM:BA listing category for suburbs across all towns.

With respect to land uses, the residential land use had the highest number of IAP for each NEM:BA category, followed by road verges and PUGS. Category 1b listed species were the highest across the three land use types, followed by category 3 and category 2 listed species. Across all land use types the category with lowest number of IAP species listed was category 1a (Figure 2.4).

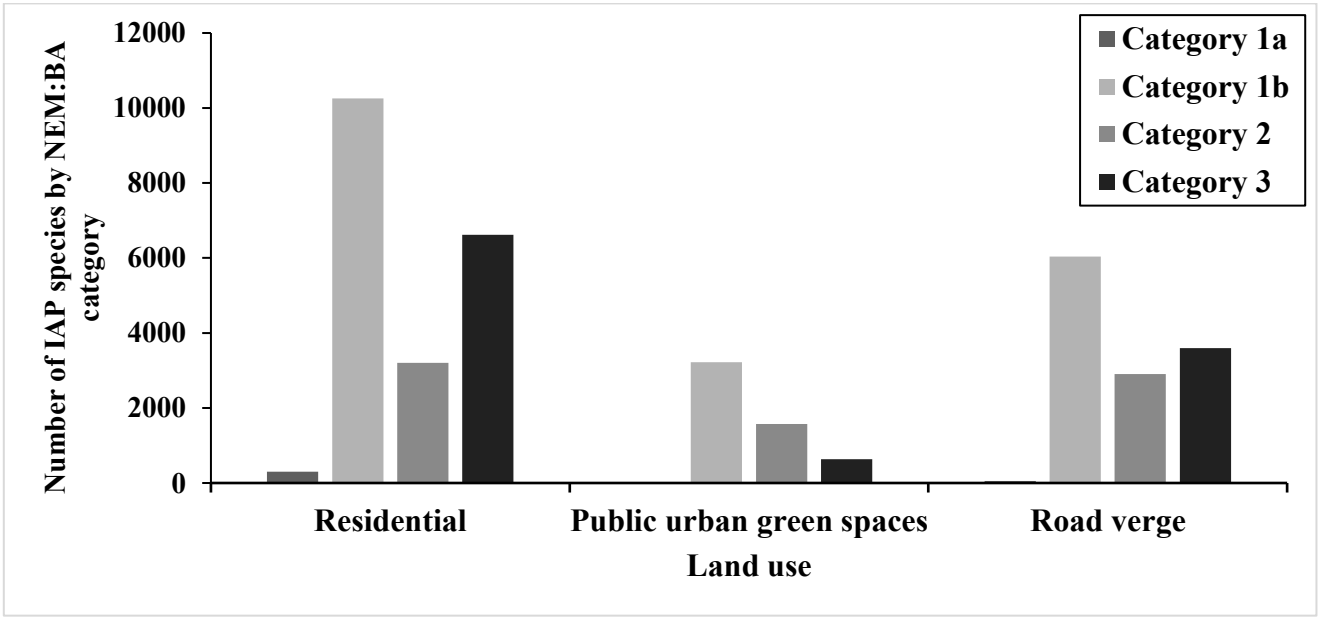

Figure 2.4: Invasive alien plants by NEM:BA listing category for land use type across all towns.

2.3.3. Distribution of woody IAP per land use and suburb

Comparison of the IAP among the different suburbs and land uses showed that most IAP were found in the affluent suburbs, compared to the CBD, township, and RDP suburbs (Table: 2.5). The affluent suburbs accounted for (58%) (56±15.2) while the RDP suburbs accounted for only 5% (5±1.02). The above-mentioned trends of having more IAP trees in the affluent suburbs as compared to townships and RDP areas were observed across the 12 towns. In terms of the land use, most of the IAP were encountered in the residential areas 54% (54±12.6), followed by road verges (32%) (32±8.3) and lastly with PUGS accounting for only (14%) (14±2.7) of the IAP encountered across all the towns. Statistical comparisons (chi-square analysis) showed significant differences across suburbs (χ^2=1134.4; p<0.05) and land use types (χ^2=850.0; p<0.05) across all towns.

Table 2.5: Distribution of IAP per land use and suburbs across all towns. The table indicates the number of IAP individuals across land use and suburbs.

Town	**Suburb**				**Land use**		
	Affluent	**Township**	**CBD**	**RDP**	**Residential**	**Road verge**	**PUGS**
Adelaide	1270	920	360	197	1760	706	281
Alexandria	1198	508	397	109	1139	697	376
Barkley East	1246	369	571	38	1046	850	328
Bedford	1529	928	790	252	1779	1131	589
Burgersdorp	2410	599	876	326	1965	1584	662
Cathcart	1233	214	252	0	732	686	281
Kirkwood	1702	941	402	156	1977	1103	121
Middleburg	3007	1622	806	138	3201	1617	755
Paterson	437	188	209	113	569	315	63
Somerset East	2096	1073	607	329	1927	1704	474
St Francis Bay	3331	401	523	122	2585	855	937
Willowmore	1871	1031	647	83	1955	1044	633
Total	21330	8794	6440	1863	20635	12292	5500
Mean±SE (%)	56±15.2	23±6.6	17±4.5	5±1.3	54±12.6	32±8.3	14±2.7

Regarding the distribution of IAP per suburb, the affluent and CBD suburbs had a high abundance of IAP compared to the township and RDP suburbs. However, considering the distribution in relation to the proportional area of the different suburbs, there was no significant association (χ^2= 4.9; p >0.05), indicating that the IAP were randomly distributed amongst the different suburbs (Table 2.6). The CBD and affluent suburbs had the highest

ratio (% of IAP/proportion of town) of IAP compared to the RDP and Township suburbs across all towns.

Table 2.6: Proportional distribution of IAP individuals and suburbs across all towns.

Suburb	% IAP	% Area	Ratio
Affluent	56	34	1.65
Township	23	38	0.61
CBD	17	10	1.70
RDP	5	17	0.29

With respect to land use, road verges and public urban green spaces had a higher proportion of IAP, although once again there was no significant association between land use and distribution of (χ^2= 3.6; p >0.05) (Table: 2.7).

Table 2.7: Proportions of IAP individuals in the different land use types across all towns.

Land use	% IAP	% Area	Ratio
Residential	54	68	0.79
Road verges	32	21	1.52
PUGS	14	11	1.27

2.3.4. Distribution of IAP species for land use and suburbs across all towns

Although the proportion of IAP was independent of land use, the distribution of particular species was not. The different land uses were associated with a particular species, with PUGS being associated mostly with *A. crenata, Solanum mauritianum, Bauhinia purpurea,* and *Triplaris americana.* In contrast, road verges were characterised by *P. patula, P. canariensis,* and *Spartium junceum* among other IAP species. Residential areas were associated with more IAP species than road verges and PUGS. Road verges and PUGS had different IAP species. There were also species such as *Salix babylonica, Grevillea robusta,* and *Morus alba* amongst others, which were randomly distributed across the residential and road verge land use types (Figure 2.5).

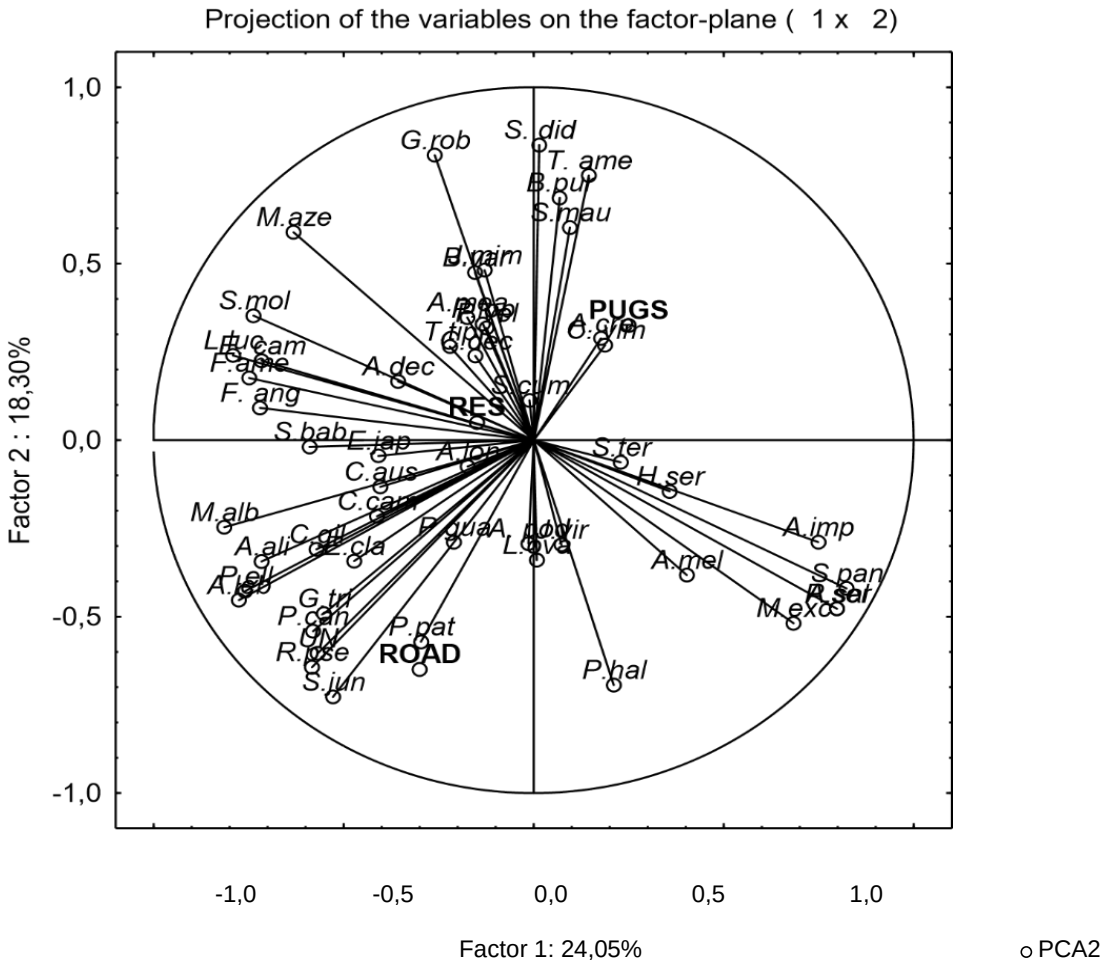

Figure 2.5: Principal Component Analysis (PCA) of the distribution of IAP species across land uses. Plant names are the first letter of the genus and first three letters of the specific epithet. Full names of the IAP species are provided in Table 2.3.

The affluent suburbs were associated with (56%) of the IAP species, such as *Salix babylonica*, *Pinus canariensis, Ligustrum lucidum* and *Celtis australis*, among others. The township were associated with 23% of the woody IAP species such as *M. azedarach*, *A. mearnsii*, *Caesalpinia decapetala* and *Schinus mole*, among others. The CBD were associated with IAP species such as *Syzygium paniculatum*, *A. saligna*, *A. melanoxylon* and *Hakea sericea*, while the RDP areas were associated with species such as *Callistemon viminalis*, *S. mauritianum*, *A. crenata*, and *Prosopis velutina*. Most of the species were also randomly distributed around the affluent and township suburbs (Figure 2.6).

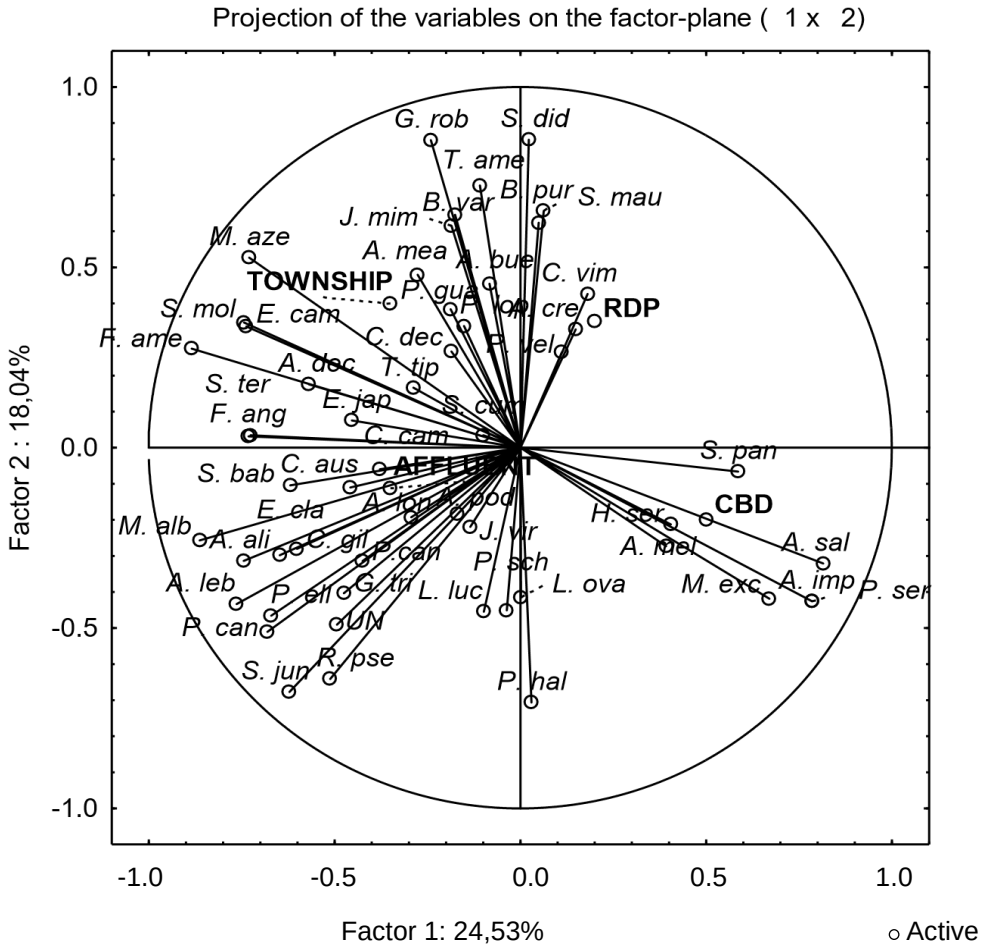

Figure 2.6: Principal Component Analysis of IAP species distribution across suburbs. Plant names are the first letter of the genus and first three letters of the specific epithet. Full names of the IAP species are provided in Table 2.3.

2.3.5. Relationship between IAP and socio-economic and environmental attributes.

Multiple regression was used to examine relationships between socio-demographic and environmental variables on the total number of individual IAP, species richness and IAP density (outlined in Tables 2.8, 2.9 and 2.10, respectively). There was a significant association between the number of IAP per town and the indicator variables (environmental and socio-economic) collectively ($F=9.92$, $p<0.05$, $r^2= 0.89$) (Table 2.8). However, there was no significant association between the total number of IAP and the ten indicator variables (environmental and socio-economic) individually. There was a significant association between IAP density and the independent variables collectively ($F=0.003$, $p<0.05$, $r^2=0.97$) (Table 2.9). The unique individual contributions of the indicator variables

against the total number of IAP, species richness, and species density are depicted in Table 2.8, 2.9 and 2.10, respectively.

Table 2.8: Relationship between environmental, socio-economic indicators and number of IAP determined using multiple regression.

	β *	Std.**Err*.**	***β***	Std.**Err.**	t(**1**)	p-value
Intercept			-19819.60	10498.36	-1.89	0.31
Mean Temp (°C)	0.20	0.23	174.40	198.13	0.88	0.54
Mean annual rainfall (mm)	0.19	0.20	2.10	2.20	0.94	0.52
Size (km^2)	-4.05	0.84	-257.60	53.37	-4.83	0.13
Population density (km^{-2})	-2.30	0.42	-6.20	1.14	-5.41	0.12
Altitude (m)	-0.48	0.23	-1.20	0.57	-2.07	0.29
Population (No. of people)	3.23	0.56	0.80	0.15	5.73	0.11
GDP-R (ZAR)	0.31	0.23	585.80	442.19	1.32	0.41
Unemployment rate (%)	0.84	0.36	294.40	127.58	2.31	0.26
Tertiary education (%)	-1.28	0.40	-395.10	122.28	-3.23	0.19
Secondary education (%)	2.18	0.64	561.00	165.16	3.40	0.18

Order of significance (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$)

There was a significant positive relationship between the IAP species richness and the predictor variables collectively (environmental and socio-economic) ($F=12.91$, $p<0.05$, $r^2=0.9$) (Table 2.9). For the IAP species richness, eight of the ten indicator variables namely, mean annual rainfall, size of town, population density, altitude, population, unemployment rate, tertiary education, and secondary education all showed a significant relationship. Mean temperature and GDP-R were the only indicator variables that showed no significant relationship with the IAP species richness.

Environmental and socio-economic indicators (mean annual rainfall, size, population density, altitude, population, unemployment rate, tertiary education, and secondary education) had an influence on IAP species richness across all towns (Table 2.9).

Table 2.9: Relationships between environmental, socio-economic indicators and IAP species richness derived from multiple regression.

	β *	Std.Err*.	*β*	Std.Err.	t (1)	p-value
Intercept			-0.85	1.90	-0.45	0.73
Mean Temp (°C)	0.02	0.01	0.10	0.04	2.56	0.24
Mean annual rainfall (mm)	-0.37	0.01	-0.02	0.00	-63.49	0.01*
Size (km^2)	0.78	0.02	0.27	0.01	32.40	0.02*
Population density (km^{-2})	0.79	0.01	0.01	0.00	61.49	0.01*
Altitude (m)	-0.30	0.01	0.00	0.00	-57.15	0.01*
Population (No. of people)	0.26	0.02	0.00	0.00	13.15	0.05*
GDP-R (ZAR)	0.00	0.01	0.01	0.02	0.46	0.72
Unemployment rate (%)	0.56	0.01	1.05	0.03	39.89	0.02*
Tertiary education (%)	0.81	0.01	1.33	0.01	113.53	0.01**
Secondary education (%)	-0.69	0.02	-0.95	0.02	-38.23	0.02*

Order of significance (*: p < 0.05; **: p < 0.01; ***: p < 0.001)

The results showed that IAP density was influenced by all the tested environmental and socio-economic indicators in the study (Table 2.10). All the relationships between the indicator variables and IAP density were highly significant, for instance, the strongest relationships were town size (km^2), population, and secondary education.

Table 2.10: Relationship between environmental, socio-economic indicators and IAP plant density.

	β *	Std.Err*.	*β*	Std.Err.	t (1)	p-value
Intercept			-6894.75		-2397.16	0.03***
Mean Temp (°C)	0.94	0.0004	120.24	0.05	2215.00	0.03***
Mean annual rainfall (mm)	0.06	0.0004	0.10	0.00	167.68	0.04**
Size (km^2)	-4.83	0.0015	-46.14	0.01	-3155.55	0.02***
Population density (km^{-2})	-1.89	0.0008	-0.76	0.00	-2430.71	0.03***
Altitude (m)	0.05	0.0004	0.02	0.00	115.53	0.06**
Population (No. of people)	2.69	0.0010	0.11	0.00	2614.06	0.02***
GDP-R (ZAR)	0.77	0.0004	222.40	0.12	1835.81	0.03***
Unemployment rate (%)	1.40	0.0007	73.77	0.03	2110.43	0.03***
Tertiary education (%)	-1.55	0.0007	-71.43	0.03	-2132.06	0.03***
Secondary education (%)	3.27	0.0012	126.59	0.05	2797.69	0.02***

Order of significance (*: p < 0.05; **: p < 0.01; ***: p < 0.001)

2.4. Discussion

2.4.1. Distribution of IAP suburbs and land use types across towns

The findings revealed that the distribution of IAP was not uniform across all towns, with some towns having a higher abundance and diversity of IAP than others. For example, the results show that the number of IAP were highest in Middelburg, St. Francis Bay, Burgersdorp and Somerset East, whilst the lowest counts were found in Cathcart and Paterson. Results of this study provide valuable insights into the structure and distribution of the urban IAP in small towns located in the Eastern Cape province. Invasive alien plants varied significantly between and within municipalities. McLean et al. (2018) surveyed all IAP in the different parts of Riebeek Kasteel in the Western Cape. Their results showed that 95% of the IAP were distributed unevenly across different land use types and occurred in different land uses such as gardens or connected road-sides (McLean et al., 2018).

The reported differences in distribution and abundance of IAP in this study could be explained by several factors such as town size, apartheid legacy effects, land use patterns, and to some extent, municipal interventions such as the control and management plans if there are any. With respect to the differences based on town size, a previous study by McLean et al. (2017) noted that bigger towns, in terms of their size or those who are more affluent, tend to have a higher number of IAP. In this study, results showed similar trends with bigger towns (e.g., Middleburg, Burgersdorp and Somerset East) having more IAP than smaller towns such as Paterson, although this was not the case for St. Francis Bay, it is a smaller town in terms of size, yet it was found to have a higher number of IAP. This could be attributed to most of St. Francis Bay being affluent areas and the fact that, coastal towns in the Eastern Cape province are characterised by reasonable rainfall, and a mild climate (Mabusela et al., 2021; Climate data, 2016) which is conduce for tree germination and growth. Furthermore, the results showed that the affluent suburb and PUGS in St. Francis Bay had the highest number of IAP compared to all other towns. The current study showed variation in IAP and abundance which was substantial in many towns, this is mostly attributed to a variety of factors such as affluence and size. McLean et al. (2017), found that IAP patterns in 12 small towns in the Western Cape province in South Africa was influenced by town size, however, in this study, this was different for St. Francis Bay, because town size did not seem to influence the number of IAP.

The results of the current study can also be explained by municipal plans, policies, and interventions with respect to street trees and urban green spaces. It is possible that some

towns do promote tree planting and maintenances as compared to other towns, which might contribute to variations in IAP abundance and diversity. But it was not possible to get records of IAP management from the towns. Conway and Urbani (2007) emphasised that most large towns usually have sufficient resources, skills, and efficient urban policies and plans to promote urban greenery, while poorer towns do not have such advantages. Though speculative, this could explain the observed differences between larger towns such as Somerset East and smaller towns such as Paterson. Equally, this could be the case for St. Francis Bay because it is one of the wealthiest towns in the Eastern Cape province (Statistics South Africa, 2016), and therefore there are more resources, skills and therefore perhaps strategies to maintain and promote urban greening, including the control of IAP.

It is also possible that the results of this study in relation to IAP distribution across suburbs could have been influenced by some past apartheid laws and policies such as, the planting of trees and the management of green spaces in affluent suburbs, compared to other neighbourhoods. Although in the past urban greening was promoted, and of late, it has been linked to the spread of IAP (Halford et al., 2014). As suggested in other studies, the disparities in the distribution of IAP across different land uses and suburbs (e.g., Mabusela et al., 2021; McConnachie et al., 2008) could be because of the segregation laws of the past (pre-1994) in South Africa (Venter et al., 2020). For example, there were fewer municipal services and environmental quality was often neglected, with poor service delivery in townships as compared to affluent suburbs (Gwedla and Shackleton, 2015). Furthermore, there was no incorporating environmental quality and other services such as urban greening, hence there are lower areas of green space and density of trees (including IAP) in the township suburbs (Gwedla and Shackleton, 2015; Venter et al., 2020). Moreover, poor planning and lack of incorporating urban greening has resulted in lower densities of greenery in RDP suburbs too (McConnachie and Shackleton, 2010; Gwedla and Shackleton, 2015). As a result, the findings of this study will further provide information on the variation, distribution, and abundance of IAP, within the different land use and suburbs for purposes of management and control.

Afonso et al. (2020) assessed and compared IAP composition between urban, peri-urban and rural environments in the city of Cape Town and showed that IAP were dominant in the urban and peri-urban environments, which was mainly correlated to the differences in habitat conditions. Most of the recorded IAP were present in every site, although some were in low numbers, this might be due to the variability in the environmental and socio-

economic conditions in the different sites. Even though 56 different IAP species were recorded across all towns, they were dominated by a relatively small number of highly abundant species including, *M. azedarach*, *P. elliotti*, *J. mimosifolia* and *E. camaldulensis*. This concurs with findings by Mabusela et al. (2021), who found that *M. azedarach* was the most abundant IAP (21%) in the five Eastern Cape towns they surveyed. Similar results were shown by Gairola et al. (2013), who reported that *M. azedarach* was common in green spaces and urban parks in Durban, South Africa. A potential explanation why *M. azedarach*, *J. mimosifolia* and *E. camaldulensis* dominate some urban spaces is that these species are fast growing species introduced as ornamental and used as wind break (Mabusela et al., 2021; Henderson, 2001). The first two are highly regarded by urban residents for their colourful flowers and substantial shade (Shackleton and Shackleton, 2016).

There was also a variation in the IAP diversity indices across all towns. The differences in species richness, evenness, and the Shannon diversity index indicated that there were differences across the different towns, suburbs, and land uses. For instance, the values for the Shannon diversity index ranged from 1.91 to 3.04 the values from the Simpson diversity index ranged from 0.83 to 0.94. For example, the Simpson diversity index was the higher in Alexandria, Adelaide and Burgersdorp compared to other towns. Also, all the towns with a high Simpson diversity index had a higher species richness. In contrast, towns with a low species richness such as St. Francis Bay had a lower Simpson diversity index, however, this was a different case for Paterson which had a low species richness but a higher Simpson diversity index, indicating that there was a greater evenness of species. The species evenness was low across all the towns which showed that IAP were unevenly distributed, with a few species dominating and the rest with low abundances. Results similar to this study have been observed in other studies, for example, Seta et al. (2013) sampled various sites in Dilla in Southern Ethiopia and reported that the town of Aroresa and Boyti have a lower Shannon diversity index compared to other sites which had a higher Shannon diversity index. In the same above-mentioned study, species evenness was found to be lower in highly invaded sites compared to the uninvaded sites (Seta et al., 2013). The density of IAP (km^2) was highest in the smaller towns, with a lower species richness. Similarly, species richness density per town was also highest where there was a higher species richness. There were differences in terms of the number of IAP species by NEM:BA category across the different suburbs and land uses. In all the different suburbs,

most IAP species were category 1b species, followed by IAP category 3. A similar pattern was found in the land uses, where IAP listed under category 1b and category 3 were the dominant across all the land use types. Maema et al. (2016) reported similar results in the Mogalakwena local municipality in Limpopo Province, where 70% of the IAP assessed were listed in category 1b species. A potential explanation to the dominance of category 1a, 1b, and category 3 species in the various suburbs and land use types can be attributed to the fact both category 1a and 1b should be removed, but the level of control is lower for 1b. Another reason category 1b dominates is simply because of the declared IAP species (and tree species) listed under the NEMBA regulations, whereby most are in category 1b. Given the financial limitations within municipalities, control, and management action against category 1b and category 3 species is potentially lower as compared to control and management action for category 1a species, which are an eradication target. The importance of eradication and control of IAP is crucial given that there is a high number of IAP that are found in category 1 (Maema et al., 2016). Nel et al. (2004) further emphasise that there should be a continuous effort to eradicate IAP in both category 1a, and category 1b given the negative effects that these species have on ecosystem services.

2.4.2. Urban land use type and influence on distribution and abundance of IAP

Results of this study showed variability in IAP distribution across different suburbs and land uses. Land uses varied considerably in the number and proportion of IAP they had, depending on land use context. For example, St. Francis Bay had the highest number of IAP in the affluent suburbs, and the highest residential land use compared to all the towns. Several socio-economic factors can explain the variations across suburbs and land uses. According to Landry and Chakraborty (2009) and McConnachie and Shackleton (2010), these differences are mainly due to the ethnic (race) and socio-economic differences within land uses and suburbs. Furthermore, McConnachie and Shackleton (2010) revealed that these variations at suburb level were exacerbated by the legacy of apartheid laws, which segregated most of the population regarding land occupation and ownership. Indeed, apartheid laws that favoured urban greening is some suburbs (e.g., affluent) as compared to others (e.g., township) could explain the observed results in this study. McConnachie and Shackleton (2010) reported the same patterns and accounted for these differences in the distribution and abundance of IAP across different suburbs to skewed apartheid laws that influenced the distribution of urban green spaces and species. For instance,

McConnachie and Shackleton (2010) assessed the distribution of PUGS across nine small towns in South Africa and found that affluent suburbs had more PUGS and IAP than townships and RDP. The above-mentioned study pointed out that this could be because of past laws and the fact that affluent suburbs have the lowest housing density and the highest area of green space per capita, compared to township and RDP suburbs (McConnachie and Shackleton, 2010).

Reynolds et al. (2020) found similar results after assessing the distribution, composition, and abundance of IAP across seven major metropolitan municipalities of South Africa. Results from the above-mentioned study showed noticeable differences in IAP distribution and species richness across suburbs, with the highest being in the more affluent suburbs and poorly represented in the low-income areas. In Brazil. Pedlowski et al. (2002) observed similar results when they found that wealthier suburbs had larger urban PUGS. In contrast, Lubbe et al. (2010) found more IAP abundance in low-income areas than affluent areas in the Northwest province of South Africa. This was similar to McConnachie et al. (2008), who examined PUGS across ten towns in the Eastern Cape province and reported that most woody IAP species were found in towns located in the former homelands. According to Shackleton and Shackleton (2016), a minimum of 44% of IAP in residential gardens in Grahamstown (now Makhanda) were most likely established as seedlings. Recently, Mabusela et al. (2021) found that in the residential zones, townships had the largest proportion of IAP per town, ranging from (41- 61%), followed by affluent neighbourhoods (22–41%), and finally RDP neighbourhoods (6–32%). However, this mirrored the relative size of suburbs, indicating that IAP were largely randomly distributed by neighbourhood (Mabusela et al., 2021).

2.4.3. Distribution and abundance of IAP in relation to town attributes

According to Bourne and Conway (2014), socio-economic factors play an important role in determining the distribution pattern of IAP. The results indicated that there might be strong links between IAP and socio-economic and environmental factors. Species richness and plant density were significantly associated with some socio-economic and environmental indicators, such as size of town, population, and income. Landry and Chakraborty (2009) pointed out that lower abundance in some suburb types is associated with low income and, to some extent, the lack of proactiveness of the authorities responsible for implementing urban greenery. Indeed, income does play a role regarding

urban greening, for instance, the willingness to control and manage urban plant species and investment in maintaining green spaces at a municipal level.

Shackleton et al. (2015) highlighted that in South Africa, the suburbs where low-cost housing is reserved for the economically disadvantaged are characterised by a lack of planning with response to recreational green space and visually appealing attributes such as street trees. The IAP were recorded in all the different urban land uses, and the results showed that residential land use had the highest proportion of IAP (54%), followed by road verges (32%) and PUGS (14%). This was expected because residential properties account for most urban land use area. Within the small town of Riebeek Kasteel, in South Africa, Mclean et al. (2017) reported the distribution of species richness and abundance of IAP across five land use types and reported that most IAP species was found in gardens around places of residence. Indeed, distribution and prevalence of IAP within a town is affected by land use type and the size of the land use. Land use type also influences the activities that happen within a land use, thus influencing the type and abundance of urban trees, and in this case, IAP. For example, residential areas constitute a large proportion of urban land area in most small towns and have occupants who have gardens where plants can be planted or self-established. Therefore, by virtue of size and uses (in this case gardens) they are more likely to have more IAP as compared to other land use types.

Roads, railways, and other modes of transportation of goods and people provide several opportunities for rapid dissemination and distribution of IAP propagules (Hulme, 2009; McKinney, 2004). Kowarik (2010) reviewed that rivers, roads, and railroads have been linked to a high number of IAP. Results of this study showed that road verges had the highest number of IAP after residential land use, and the highest ratio on relation to spatial area. A potential explanation is that road verges act as corridors, contours, and pathways of IAP distribution, and are subject to less frequent management actions than residential areas or public parks. In South Africa, Cilliers et al. (2008) investigated roadside vegetation along an urbanisation gradient and revealed that plant assemblages differed depending on time since the road was built, although other factors such as environmental and human conditions were also reported, including humidity, soil types, adjacent land use and disturbance intensity (Cilliers et al., 2008). Stajerov et al. (2017) found that cover of IAP and richness of IAP increased towards the city centre and increased with the proportion of specific habitats such as road margins, ruderal sites, and railway sites. The high density of roads and the high traffic volume in urban areas are anticipated to significantly impact

biodiversity and the invasion process, particularly urban vegetation by providing corridors for IAP (Aronson et al., 2017). According to Lubbe et al. (2010), urban areas revealed a high density of IAP and high species richness, they further emphasised that road verges may also provide corridors and safe sites for numerous IAP.

Urban areas, particularly roads, are a key invasion pathway for many IAP and a base for secondary release or escape into surrounding landscapes (Gaertner et al., 2017). Several factors have been found to influence the distribution of IAP in urban areas, these include both ecological and human factors. For example, Gaertner et al. (2017) found that various environmental and socio-economic factors such as the availability of impermeable surfaces, human population size and density are associated with the promotion of non-native species (Kuhman et al., 2010; Celesti-Grapow et al., 2006; Pyšek, 1998). The results from the current research showed that there was a positive association between IAP species richness and several environmental and socio-economic variables such as size of town and population. There was also a significant association between plant density and the selected environmental and socio-economic variables.

Ariori et al. (2017) found that housing construction, proximity to roadways, agricultural fields, as well as socio-economic variables such as income strongly influence IAP distributions in New England, particularly Connecticut, Hartford and Boston. The above observations were similar to those by Shrestha (2016), who reported human and natural activities best explained the observed variation in IAP diversity and distribution across the city of Nepal, India. The results of the current study showed noticeable differences in the distribution and abundance of IAP, confirming that IAP are abundant in urban areas and across the region, however their distribution is variable between towns and land uses within towns, highlighting the necessity for local-scale inventories and management of IAP across different land uses and suburb types. Therefore, it is important to view the urban ecology of towns and cities as diverse, dynamic landscapes and complex, adaptive, and socioecological systems, this is because there are different land tenure systems such as government land and private land, which results in the management of IAP being challenging within urban areas (Shackleton and Shackleton, 2016). These are context-dependent and connect society and ecosystems at various scales (Shackleton et al., 2018).

2.5. Conclusion

The study found an uneven spatial distribution of IAP and diversity among the different suburbs and land uses of small towns in the Eastern Cape. Firstly, IAP distribution, abundance and diversity variations at town level seem to follow town size, although this was not the case for St. Francis Bay. Secondly, affluent and township suburbs had more IAP as compared to CBD and RDP which had the least IAP. This was mirrored at town scale, with poorer towns (as indicated by unemployment rate and GDP-R) having a greater IAP richness and density. Lastly, residential land use had the most IAP, followed by road verges and lastly, PUGS. Assessing urban contexts to establish the distribution, availability, and composition of IAP is a critical activity, particularly in small towns. In addition, a growing number of studies in South Africa reveal that IAP are common and require attention, particularly in urban areas.

The results highlighted that the structure of the city land use (i.e., residential, PUGS, road verge) and suburb type (i.e., affluent, CBD, township, RDP) could be of importance in the distribution and composition of IAP in urban environments given how IAP are distributed across the different land use and suburb types. The towns that were assessed had different characteristics that could have attributed to the differences in the abundance of IAP, for instance, the regression analysis indicated that the socio-economic and environmental variables influenced the distribution of IAP across all towns. Municipal and environmental authorities should allow the national regulations to guide them, as they explicitly state that IAP must be managed, monitored, and controlled based on their IAP categories (Mabusela et al., 2021). From a management standpoint, human and financial resources should be allocated to manage IAP in the various suburbs and land use types that have more IAP. However, previous studies have shown that smaller municipalities do not have sufficient capacity and resources to manage IAP (Ruwanza and Shackleton, 2016). Given resource challenges (financial and expertise), small town municipalities must consider other avenues on how to control and manage IAP in their jurisdiction, for instance, partnering with local or existing environmental NGOs.

Chapter 3

Residents' knowledge, perceptions, and willingness to control woody invasive alien plants in their gardens

3.1. Introduction

At a finer scale, urban areas are biologically heterogeneous because of reasons such as, small scale land management units (e.g., gardens, parks, and roadsides), (b) a mosaic of different tenure systems which results in multiple owners or decision makers regarding what to plant and associated management practices, and (c) a great variety IAP planted for aesthetic purposes (Dolan et al., 2011). Invasive alien plants have become a significant component of urban flora that link urban dwellers with nature (Andrabi et al., 2015). The presence of IAP has shaped peoples' views and perceptions of nature generally and these species specifically (Shackleton and Shackleton, 2016; Shackleton et al., 2019b; Nguyen et al., 2020). However, these views and perceptions are often shaped by the socio-economic and the ecological contexts, including personal values, local knowledge, risk perceptions and familiarity with the IAP, land ownership and management policies, and ecosystem services or disservices resulting from IAP (Estévez et al., 2014; Shackleton et al., 2019a).

Urban residents vary in their interactions with the urban nature and individual species due to access, personal preferences, and the type of ecosystem services and disservices they seek or experience (Nagreda and Gopal, 2010). Perceptions on IAP are highly context specific and vary substantially between individuals, groups, communities, and areas, including countries and landscapes over time (Gwedla and Shackleton, 2019). For example, in Lijiang city, southern China, IAP such as *Pinus armandi* and *Quercus pannosa* have come to associate with residents' cultural and spiritual activities, resulting in these IAP being traditionally worshipped (Yang, 2011). In Scotland, Laing et al. (2009) reported that specific IAP trees provide screens that offer some privacy, and as a result, has created some resistance against their removal. In contrast, Kirkpatrick et al. (2013) found that while most residents in eastern Australian cities value trees, they are also more likely to remove healthy trees than IAP species due to aesthetic and lifestyle preferences. Therefore, it is

critical to understand how people perceive and respond to various IAP (Estévez et al., 2014; Shackleton et al., 2019a). Furthermore, understanding perceptions can help facilitate IAP management and control practices by enabling the design of environmental management policies and effective communication strategies that are more likely to be tolerated or accepted by the public when dealing with IAP (Potgieter et al., 2019).

Cordeiro et al. (2020) investigated the knowledge and perceptions of Portuguese citizens towards IAP, contrasting those with formal education and training to those with informal education. They found that those with formal education and training were more environmentally conscious and had greater knowledge and awareness about IAP than those with informal education and training (Cordeiro et al., 2020). Nevertheless, those with limited formal education and training still appreciated that IAP could have both negative and positive effects on the landscape (Cordeiro et al., 2020). Similarly, in Makhanda (formerly Grahamstown), Shackleton and Shackleton (2016) assessed people's knowledge, perceptions, and willingness to control IAP in their gardens, and reported that less than half of the people could identify the IAP in their property, and only one-third knew that they were alien. The same study also reported a positive association between income and education levels with exposure to media about IAP and knowledge of IAP, and willingness to control them (Shackleton and Shackleton, 2016). Jubase et al. (2021) showed similar results in the Western Cape province of South Africa and reported that most respondents (65%) have no knowledge of IAP.

Knowledge and awareness levels of IAP are often unequal across different contexts (Shackleton et al., 2018). This makes it critical to understand different stakeholders' knowledge and perceptions of IAP, not only to facilitate acceptance or tolerance of management measures, but also to develop better awareness and education strategies and programs that might encourage citizens to adopt practices to prevent or limit the introduction, spread, and impacts of IAP (Shackleton and Shackleton, 2016). There is a need to further engage the public with regards to the management and control of IAP, as also stipulated by the Convention on Biological Diversity (CBD, 2014). In South Africa, there are regulations under the National Environmental Management: Biodiversity Act 10 of 2004 (NEM:BA), which aim to regulate IAP distribution and impacts. The NEM:BA regulations stipulate that landowners and municipalities must report IAP species on their land and under their jurisdiction. Furthermore, the efforts to control IAP in South Africa have been boosted and supported by the Working for Water (WfW) program, which has

led to substantial media exposure and hence public awareness of the ecological and socio-economic impacts of IAP (van Wilgen et al., 2012). However, this awareness differs by species depending on the extent of invasion and their impacts (Shackleton and Shackleton, 2016).

Different interventions have generated either positive or negative outcomes (Novoa et al., 2017). This is because different communities may benefit from the reduction of IAP and restored biodiversity, whilst others might be negatively affected by interventions due to the loss of IAP species that are beneficial to them (Shackleton et al., 2018). Therefore, due to conflicts of interest, implementing IAP management measures can often become the subject of debate and resistance (Potgieter et al., 2019). For instance, Novoa et al. (2017) reported a lack of consensus and support amongst the public for the management of biological invasions in the United Kingdom and South Africa, mainly based on the moralistic value disagreements, whereas for some, it was based on opportunistic value disagreements (Novoa et al., 2017).

The support and participation of the public can determine whether IAP mitigation, control, and management methods succeed or fail (Lindemann-Matthies, 2016). According to Cordeiro et al. (2020), understanding knowledge and perceptions of IAP among the public and stakeholders is critical for facilitating acceptance of management and control measures and developing better awareness and education strategies. This includes programs that might encourage citizens to adopt practices to prevent IAP introduction, spread, and impacts. Despite the different regulations and frameworks developed to mitigate, manage, and control the negative impacts of IAP, the importance of societal participation in decision-making and implementation processes is widely acknowledged (Bremner and Park, 2007; Novoa et al., 2017; Shackleton et al., 2018). The effectiveness of such measures ultimately depends on the support of different stakeholders, including the public (Olszanska et al., 2016; Shackleton et al., 2018). However, external factors such as lack of funding, qualified human resources, time, and public engagement might challenge engagement among stakeholders (Robertson et al., 2003). This is mainly because encouraging stakeholder engagement activities can sometimes be costly, and certain stakeholders, public or private, might not be able to attend due to personal, economic, or logistic reasons (Shackleton et al., 2018). Therefore, management of IAP within the urban setting needs to be informed by knowledge, attributes and use of IAP whilst allowing

flexibility and adaptiveness towards different contexts (Shackleton and Shackleton, 2016). The chapter assess resident's knowledge, perceptions, and willingness to control designated invasive tree species in their private gardens in 12 small towns of the Eastern Cape province, South Africa.

3.2. Methods

3.2.1. Study area

Refer to Chapter 2 for study area description (section 2.2.1).

3.2.2. Data collection

In each of the 12 small towns, 20 residential households were randomly selected from a pool of households using Google Earth. Permission was asked from the owner to capture the information about IAP (whether IAP was present or not). Within the selected households, a willing adult respondent was interviewed to gather information on knowledge, perceptions, and willingness to control IAP. The interviews were conducted either in IsiXhosa, English, Afrikaans, or according to the respondent's preference. If the preference was another language, then a translator was hired to assist and recorded the responses which were later translated.

The structured questionnaire was divided into three sections and took approximately thirty minutes to complete. The first section covered topics on knowledge and perceptions of IAP. The second section of the questionnaire captured information about the willingness to have the IAP removed. The demographic profile of respondents was recorded in the last section of the questionnaire, which included age, gender, and level of education (see Appendix 1). In a situation where there was no answer from a randomly selected household, the next available household was selected for sampling. The questionnaires were conducted between 10am and 5pm (Central African Time) on weekdays and weekends, during February 2021 and March 2021. The research protocol and questionnaire were approved by the Rhodes University Ethics Committee. (Reference number is: 2020-1638-4758).

3.3. Data analysis

The data from the interviews were analysed in Statistica Version 13, by classifying nominal answers into numerical codes. The potential relationships (demographics) were assessed using correlation matrix with variables scaled between zero and one against the highest

value, mainly demographics and knowledge of IAP, the identification of IAP, willingness to remove IAP from garden and willingness to participate in an environmental initiative.

3.4. Results

3.4.1. Demographics of the sampled population

Most of the participants were females (58%), with males accounting for 42%. The most represented age group range was 51-60 (28%), whilst the least represented age group range was 18-30 (9%). The level of education varied among the participants, with 26% having primary education, 48% secondary education, and 27% tertiary education.

3.4.2. Knowledge and perceptions of woody IAP

The results indicated low levels of knowledge on IAP, with just under half of the participants, (43%) having heard of the term IAP before. Participants were also asked to rate their knowledge of IAP on a five-point scale (1 having no knowledge and 5 being highly knowledgeable) and over half of the participants, (59%) rated themselves as having no knowledge of IAP, 25% had poor knowledge, while 14% had neutral knowledge, and 2% had high knowledge. Over two thirds of the respondents (69%), had not seen any awareness campaigns about IAP, whereas 31% had. For those who had seen awareness campaigns before, the most common sources were the internet (digital media) (38%), television (35%), print material (19%) and radio (18%). Participants were asked if they had any IAP in their garden, 70% did not know, while 22% said yes and were able to name some of them. Over three-quarters of the respondents (78%), could not identify and name the IAP in their garden, and only 22% could successfully identify the IAP asked about in their garden. Only 16% of households had no IAP in their garden. The most mentioned IAP across all towns was *J. mimosifolia* (Table 3.1), followed by *Ligustrum ovalifolium* and *Melia azedarach*. The least common IAP were *Acacia saligna*, *Metrosideros excelsa*, and *Prunus serotine*.

Table 3.1: Invasive alien plant species in garden mentioned by respondents.

Species	Rank	(%) respondents mentioning IAP
Jacaranda mimosifolia	1	15.3
Ligustrum ovalifolium	1	15.3
Melia azedarach	2	13.4
Eriobotrya japonica	3	11.5
Eucalyptus species	4	9.6
Pinus species	5	7.7
Schinus molle	5	7.7
Acacia mearnsii	6	5.8
Acacia melanoxylon	6	5.8
Morus alba	7	3.8
Others**:** *Syzygium cumini, Psidium guajava, Grevillia robusta, Acacia longifolia, Tipuana tipu, Gleditsia triacanthos, Acacia saligna, Metrosideros excelsa, Prunus serotine.*		<10%
Unable to name IAP in garden		78%
No IAP in garden		16%

3.4.3. Costs and benefits of IAP mentioned by urban residents

Forty percent of the respondents agreed that IAP pose a problem to the environment, whilst 11% did not think so, and 49% stated that they do not know. The problems that were mentioned the most were, high water consumption, overgrows and damage to infrastructure, threat to other plants and health effects such as allergies (Table 3.2)

Table 3.2: The perceived negative effects of particular woody IAP species mentioned by 5% or more respondents.

IAP species	IAP Problem (%)			
	High water consumption (37)	Overgrows/damage infrastructure (28)	Threat to other plants (21)	Causes allergies (5)
Albizia lebbeck				
Acacia mearnsii				
Acacia melanoxylon				
Acacia podalyriifolia				
Celtis australis				
Cestrum laevigatum				
Callistemon viminalis				
Eucalyptus camaldulensis				
Eucalyptus cladocalyx				
Eriobotrya japonica				
Fraxinus americana				

Fraxinus angustifolia	■			
Grevillea robusta		■		■
Gleditsia triacanthos		■		
Jacaranda mimosifolia	■	■	■	■
Ligustrum lucidum	■	■	■	
Ligustrum ovalifolium	■	■	■	
Morus alba		■		■
Melia azedarach		■	■	■
Pinus canariensis	■	■	■	
Pinus elliotti	■	■		
Psidium guajava	■	■		
Prunus serotina	■		■	
Robina pseusoacacia	■		■	
Salix babylonica	■	■		
Senna didymobotrya		■	■	
Schinus molle	■	■	■	
Triplaris americana		■	■	
Tipuana tipu		■		■
Other reasons: Difficult to manage. Affects dry areas, and yet they still strive. Damage infrastructure. Harbour criminals. They don't have natural enemies/competition. They smell bad. Attracts thunder. Carries diseases. Intensify wildfires.				

Most of the respondents (91%) across all towns stated that they benefit from IAP in one way or another. The most mentioned benefits were shade (50%) and aesthetics (14%). Other benefits from IAP (Table 3.3) were also mentioned but by less than five percent of the respondents, such as, windbreak (4%), shelter (3%), firewood (3%), medicinal (3%), feed livestock (2%), financial gain (2%), sentimental value (2%) and fencing (1%).

Table 3.3: The perceived positive effects of particular woody IAP species mentioned by 5% or more respondents.

IAP species	**Benefits (%)**			
	Shade/fresh air (50)	**Aesthetics (14)**	**Traditional/cultural (8)**	**Fruits (5)**
Acacia implexa	■		■	
Albizia lebbeck	■		■	
Acacia mearnsii	■	■		
Acacia melanoxylon	■	■		
Caesalpinia gilliesii	■			■
Callistemon viminalis	■	■		
Eucalyptus camaldulensis	■	■	■	
Eriobotrya japonica	■	■	■	■
Fraxinus americana	■	■	■	
Fraxinus angustifolia	■		■	
Grevillea robusta	■	■		
Gleditsia triacanthos	■	■		
Jacaranda mimosifolia	■	■		
Ligustrum lucidum	■	■		■
Ligustrum ovalifolium	■	■		
Morus alba	■			■
Melia azedarach	■	■		
Metrosideros excelsa	■			■
Populus canescens	■		■	
Pinus elliotti	■	■	■	
Psidium guajava	■	■		■
Salix babylonica	■		■	
Senna didymobotrya	■	■		
Spartium junceum	■	■		
Schinus molle	■		■	
Triplaris americana	■	■		
Tipuana tipu	■	■		
Other reasons: Attracts bees, so we get honey. Keeps flies away. For my cat to develop skills. Hide flaws of my building. Security. Prevents my building from sea breeze "corrosion". Provides privacy, I have big windows. Bird sounds in the morning. I use cones from IAP for decorations.				

3.4.3. Willingness to control woody IAP in gardens

Only 18% of respondents stated that they have participated in any environmental activities before. Those who had participated reported different activities, such as, Working for Water, Working for Fire, Community Works Programme, and the Expanded Public Works Programme, with the most common being community work (39%). Most of the respondents (63%) were willing to participate in any initiative that is meant to control IAP, but 37% stated that they were not willing to participate.

Respondents stated different reasons for participation. Some respondents were willing to participate if they were paid (18%), while a few (4%) were willing participate during their spare time. Most of the respondents who were not willing to participate stated that they had no interest (31%), while for others, it was due to old age (19%) or having insufficient time due to other commitments (19%).

Respondents were given options to select who should be responsible for the management of IAP. Approximately one-third (35%) believed that the local government or district government (30%) should be responsible, whilst 21% stated that it is the sole responsibility of the landowner or user to manage IAP on their land. Almost two-thirds of the respondents (65%) were willing to report IAP in their gardens to the relevant authorities dealing with IAP management and control.

Thirty-five percent (35%) of the participants were not willing to report the IAP in their gardens to the relevant authorities, arguing that they can manage the IAP (41%), whilst 31% stated that they were not interested and 14% stated that they still benefit from the IAP, and 8% said it is not their responsibility because they rented the property. A few participants (8%) also stated other reasons, such as the municipality would take time to respond, or the municipality will do it at a cost. Some stated that they share the IAP with their neighbour and reporting it might cause a dispute.

Over half (56%) of the respondents were willing to have the IAP removed from their gardens. The respondents listed different reasons why they would remove or retain the IAP in their gardens (Table 3.4). The most stated reason for removal was that the roots caused damage to property (13%) or the mess made from the leaf litter (7%). Thirteen different reasons were stated for retaining IAP in their gardens, the most common being that they were not interested in having it removed.

Table 3.4: Common reasons why respondents were willing or unwilling to remove IAP in their gardens.

Willing to remove IAP	Reason	Proportion of respondents %
Yes	Damage to property	13
	They make a mess (leaf litter)	7
	I need to get a replacement first	4
	But it's expensive to remove	3
	Renovations	3
	Others (combined)	4
	Harbours criminals. I have been at the council offices for a long time, still no progress. Yes, there's too many of them now, they just keep on appearing. Makes my wife sick. I tried cutting the tree, but it won't just die.	
No	Not interested, I'll remove if I have to	27
	I still benefit from the tree	18
	Safety purposes	6
	Reduce, not remove	5
	I can manage the tree	3
	Sentimental	2
	Others (combined)	5
	No, I paid to have these trees. I share the tree with my neighbours so there's a dispute about tree removal. I follow the NEM:BA regulations, this is C3. It's the only tree I have. Might affect the value of my house. Planted a few years ago. Plants are just plants, I love my garden the way it is.	

The correlation matrix indicated that there was a positive association between the levels of education, income, and the impression that IAP pose a problem and being aware of the term IAP (Table 3.5), but not willing to report or remove. There was also a positive association between gender and engaging in environmental activities. The gender that participated the most in environmental activities were females (52%). The willingness to report and willingness to remove IAP had positive association however, there was a little influence of the respondents' age and the willingness to participate. There was a negative association between age and the willingness to report or remove IAP in gardens, indicating that older respondents were less willing to participate, reporting IAP, removing IAP or having heard of the term IAP.

Table: 3.5: Correlation matrix of relationships between respondents' demographics and willingness to remove IAP, knowledge of IAP and willingness to participate in environmental activity. (Correlations marked in bold are significant at p <,05000 or lower; N=14).

Variables	**Correlations (Demographics)**													
	Know	Age	Gender	Edu	Income	Will Parti in env	Report IAP	Remove IAP	Heard of IAP	ID IAP	Aware of IAP	Parti in env	IAP a prob	Benefit from IAP
Knowledge		**0,54**	**0.39**	**0,72**	**0,55**	**0,72**	**0,83**	**0,82**	**0,78**	**0,70**	**0,74**	**0,71**	**0,72**	**0,59**
Age	**0,54**		**0,55**	**0,75**	**0,71**	0,42	0,52	0,47	0,45	**0,57**	**0,63**	**0,56**	0,48	0,38
Gender	**0.32**	**0,55**		**0,74**	**0,60**	**0,77**	**0,84**	**0,85**	**0,82**	**0,71**	**0,77**	**0,73**	**0,75**	**0,65**
Education	**0,72**	**0,75**	**0,74**		**0,90**	**0,76**	**0,90**	**0,81**	**0,78**	**0,95**	**0,87**	**0,94**	**0,85**	**0,70**
Income	**0,55**	**0,71**	**0,60**	**0,90**		**0,84**	**0,78**	**0,81**	**0,82**	**0,86**	**0,88**	**0,87**	**0,84**	**0,83**
Will parti in env	**0,72**	0,42	**0,77**	**0,76**	**0,84**		**0,87**	**0,98**	**0,99**	**0,84**	**0,94**	**0,88**	**0,94**	**0,95**
Report IAP	**0,83**	0,52	**0,84**	**0,90**	**0,78**	**0,87**		**0,93**	**0,90**	**0,95**	**0,93**	**0,95**	**0,89**	**0,81**
Remove IAP	**0,82**	0,47	**0,85**	**0,81**	**0,81**	**0,98**	**0,93**		**0,50**	**0,88**	**0,96**	**0,91**	**0,95**	**0,90**
Heard of IAP	**0,78**	0,45	**0,82**	**0,78**	**0,82**	**0,99**	**0,90**	**0,60**		**0,85**	**0,95**	**0,89**	**0,94**	**0,92**
ID IAP	**0,70**	**0,57**	**0,71**	**0,95**	**0,86**	**0,84**	**0,95**	**0,88**	**0,85**		**0,90**	**0.63**	**0,93**	**0,76**
Aware of IAP	**0,74**	**0,63**	**0,77**	**0,87**	**0,88**	**0,94**	**0,93**	**0,96**	**0,95**	**0,90**		**0,92**	**0,91**	**0,91**
Parti in env	**0,71**	**0,56**	**0,73**	**0,94**	**0,87**	**0,88**	**0,95**	**0,91**	**0,89**	**0,73**	**0,92**		**0,96**	**0,78**
IAP a prob	**0,72**	0,48	**0,75**	**0,85**	**0,84**	**0,94**	**0,89**	**0,95**	**0,94**	**0,93**	**0,91**	**0,96**		**0,80**
Benefit	**0,59**	0,38	**0,65**	**0,70**	**0,83**	**0,95**	**0,81**	**0,90**	**0,92**	**0,76**	**0,91**	**0,78**	**0,80**	

(*Know=Knowledge; Edu=Education; Will Parti in env=Willingness to participate in environmental activity; ID IAP=can identify IAP; Aware of IAP=Awareness of IAP; Parti in env= Participated in environmental activity; IAP a prob=IAP pose a problem.)

3.5. Discussion

3.5.1. Knowledge and perceptions of IAP

The results showed that respondents had poor knowledge of IAP, with more than half of the respondents not being familiar with the term IAP. These findings are similar to those reported by Shrestha et al. (2019), who found that participants in Nepal did not understand what the term IAP meant, even when it was translated into the local language. Similarly, Lindemann-Matthies (2016) examined the knowledge and perceptions eight IAP in Switzerland and found that most participants (laypersons) were not familiar with the term IAP, but they were able to name the IAP in question. In the above-mentioned study, IAP were perceived as rather ordinary, familiar, and indigenous, but not invasive (Lindemann-Matthies, 2016). In contrast, in Colorado, USA, Daab and Flint (2010) reported that 93% of the respondents were familiar with the term IAP. Similarly, Verbrugge et al. (2013), found that 80% of the participants in the Netherlands were familiar with the term IAP. In this study, the lack of IAP knowledge could be a result of most respondents viewing IAP as native species. This could be because of the benefits that they receive from IAP, or because the species have been in the area for a long time to the extent that residents regard them as native. Indeed, some studies have reported that invasion extent and time, since invasion has an effect of IAP knowledge and perceptions (Jubase et al., 2021; Shrestha et al., 2019).

Over half of the respondents could not name the IAP present in their yard. This was expected as more than half of the respondents had no knowledge of IAP. Invasive alien plants are viewed as local native plants. For example, a recent study in Limpopo Province indicated that several people have *Lantana camara* in their property but could not name or identify it (Mhlongo, 2020). The failure to identify and name IAP in one's garden points to the need for further efforts to raise public awareness regarding problematic IAP in towns. The results of this research concur with previous work that has shown low levels of knowledge of IAP in Makhanda (Grahamstown) (Shackleton and Shackleton, 2016), with three-quarters of the respondents not knowing the IAP in their garden. Jubase et al. (2021) found similar results in the small towns in the Berg River catchment in the Western Cape where their results showed that 65% of the participants did not know what IAP were, while 10% were unsure of what the term IAP meant. In Colorado, Daab and Flint (2010) reported that only 34 - 62% of the respondents could name the specific IAP in question. Similarly,

in the Netherlands, Verbrugge et al. (2013) found that only half of their respondents could name the IAP. In contrast, Cordeiro et al. (2020) found that over eighty percent of the respondents in Portugal could name the IAP in question. However, the IAP name was known because all the selected plant species were common and well-known and easily recognised by residents across the country.

Dickie et al. (2014), Shackleton and Shackleton (2016) and Jubase et al. (2021) emphasised that the lack of knowledge, awareness and understanding of IAP and their potential threats and impacts can delay or hinder the effective implementation of policies, and control, or management strategies. There are underlying drivers that affect low levels of knowledge about IAP, including poor or lack of media coverage about IAP and their impacts (Shackleton and Shackleton, 2016). Information about IAP might be poorly distributed and received poorly by the public, and as a result, they might not relate to the information due to various factors such as education levels and language barriers (Shackleton and Shackleton, 2016; Jubase et al., 2021). For instance, the results of the current study showed that more than half of the participants could not recall any exposure to any awareness campaigns about IAP. This finding confirms that lack of exposure and awareness could be at play when it comes to knowledge about IAP in one's property. These findings support those by Bremmer and Park (2007), who found that only 32% of the respondents had heard of programs that control the IAP in Scotland. Knowledge and awareness vary widely between locations and depending on the IAP in question (Connelly et al., 2015) and could be equally linked to the costs and benefits associated with the IAP.

Shackleton and Shackleton (2016) indicated that despite South Africa's strong history of IAP management, particularly through the WfW programme and extensive media coverage of the ecological effects of IAP, public awareness of IAP remains low. This could indicate that while outreach initiatives effectively generated awareness, they were less successful in turning that awareness into knowledge and public action (Shackleton and Shackleton, 2016). This shows that citizen outreach initiatives should be customised to raise awareness of active management approaches (Lindemann-Matthies, 2016). Citizens who are already supportive of active management strategies may become even more so if they are taught about the specific IAP that pose a problem (Connelly et al., 2015; Le Maitre et al., 2020), and this needs to be geographically explicit.

Less than half of the respondents perceived IAP to pose a problem to the environment, and almost half of the respondents stated that they do not know if IAP posed a problem to the environment. The most common negative impacts mentioned were increased water consumption, taking over space (overgrows), and being a threat to other plants. Most of the negative impacts can be linked to ecosystem disservices (Dickie et al., 2014; Potgieter et al., 2017). High water consumption was perceived as the greatest problem associated with IAP, which corroborates the survey findings of Shackleton and Shackleton (2016) in Makhanda and Potgieter et al. (2019) in Cape Town. Similar results were also found by van Wilgen et al. (2012) in the Western Cape (South Africa), where IAP species such as *Pinus*, *Eucalyptus,* and *Acacia* presented challenges such as displacement of native species and reducing water resources.

The second-most common reason IAP posed a problem was that it takes up space and was a threat to other plants. These results echo those by Potgieter et al. (2019), who found that IAP species such as *A*. *saligna* were perceived as a threat to other plants as it displaced fynbos and other native vegetation in Cape Town, South Africa. Sward (2012) reported similar results in San Francisco, USA, indicating that *Eucalyptus* decreased the soil organic matter and caused loss of native wildlife habitat in urban parks and urban forests. The role of IAP having negative impacts is common in the responses given by the participants across all towns. Almost half of the participants stated that they did not know whether IAP posed a problem to the environment, which was expected as over 50% of the respondents had no knowledge of IAP. Cordeiro et al. (2020) showed similar results in Portugal, where people who lacked knowledge of IAP, were also unaware of the negative impacts of IAP. This is different to Potgieter et al. (2019), who found that 91% of their participants were aware that IAP poses a problem to the environment in and around the city of Cape Town.

Besides mentioning negative impacts, most (91%) respondents also claimed that IAP have some benefits. Most benefits mentioned included provisioning services like shade, aesthetics, and fruits. Indeed, most IAP are kept at properties for provisioning services that they provide thus making most of them conflicting species (Potgieter et al., 2019; Zengeya et al., 2017). Therefore, some respondents may perceive IAP to have both positive and negative impacts, implying that control interventions could be based on costs and benefits that residents derive from the IAP. For instance, previous studies have showed that just over half of the respondents in Cape Town appreciated the presence of IAP for providing ecosystem services such as, shade and fuelwood (Potgieter et al., 2019). Similar benefits

from IAP have been reported by Shackleton and Shackleton (2016), who reported that most common stated benefits were provisioning services such as, shade and aesthetic values. Therefore, perceptions of IAP are likely to be linked to benefits and costs (Shackleton et al., 2019a) that in turn are influenced by the traits and functional characteristics of the IAP (Potgieter et al., 2019). The awareness and understanding of IAP, including other environmental issues such as their impact, is important, especially when implementing policies and management strategies.

Results of this study showed that plant species like *A. mearnsii*, *A melanoxylon*, *J. mimosifolia*, and *P. canariensis* were commonly mentioned for negative costs, whereas species like *E. camaldulensis*, *E. japonica*, and *P. elliotti* were commonly identified with positive benefits. This result concurs with existing literature which show that Australian *Acacias* and *Pinus* species cause significant water loss and displace native species (van Wilgen et al., 2012). On the other hand, recent studies have confirmed that *E. camaldulensis* has several benefits to society and the environment (Hirsch et al., 2020).

3.5.2. Willingness to control woody IAP in garden settings

The results of the current study showed that only a few respondents had participated in any environmental activity, such as community work, farm work such as plant clearing, and government initiatives like the expanded public works programme and community works programme. Cordeiro et al. (2020) found similar results in Portugal, where few (21%) respondents participated in environmental programs and were members of an environmental organisation. However, despite the low levels of awareness, knowledge, and lack of participation in environmental activities towards IAP, the results showed that more than half of the respondents are willing to participate in environmental initiatives orientated at IAP control or eradication (Cordeiro et al., 2020). A result that was also reported in this study were the percentage of participants willing to participate in environmental activities is higher than the percentage of respondents who are currently participating. Similarly, Santo et al. (2015) reported that 74% of landowners in Tierra del Fuego, Argentina, were willing to participate under three conditions: namely, high compensation, high expectation of programme success, and a minimum level of involvement from the authorities. Junge et al. (2019) found that more members were willing to pay for, rather than participate in eradicating IAP in Switzerland. The differences in willingness and unwillingness illustrate that some public members are concerned about the control, management, and eradication of IAP.

The results showed that a significant number (65%) of respondents were willing to make a significant contribution to prevent, detect, manage, and control IAP. Interestingly, a greater percentage (56%) were willing to remove and control IAP on their property. There was a positive association between the willingness to report and the willingness to remove IAP. Furthermore, participants stated different reasons as to why they might retain, or remove the IAP, in this case, the most stated reason for removal was because they caused infrastructural damage and that they made a mess. It is clear for these results that most respondents are willing to act once they have knowledge regarding IAP. Similarly, those willing to remove or control IAP seem to associate them with negative ecosystem disservices. Shackleton and Shackleton (2016) reported similar results and found that 83% of the respondents were willing to remove or let relevant authorities remove the IAP in their garden, while 17% were unwilling due to the perceived benefits. These results were also echoed by Potgieter et al. (2019), who found that over 80% of respondents were not opposed to removing IAP in Cape Town, South Africa. In Portugal, Cordeiro et al. (2020) found that although 55% of respondents agreed that IAP should be controlled and removed, over 40% noted that *A. dealbata* populations should be increased, regulated, and maintained, mainly due to the benefits obtained. Also, Lindemann-Matthies (2016), found that in Zurich, Geneva, and Lugano, in Switzerland, most respondents felt that IAP should be eradicated due to the significant impacts and expenses they cause. However, in the same above-mentioned study, some respondents were hesitant to eradicate ornamental IAP such as *Buddleja davidii*, *Solidago canadensis*, and *Trachycarpus fortunei*, which were already established in settlement areas and gardens (Lindemann-Matthies, 2016). This speaks to issues of benefits as determinant of which IAP residents are willing to remove. Implications seem to suggest that costs are associated with willingness to remove IAP whilst benefits are associated with non-willingness to remove IAP. Bremner and Park (2007) found similar results in Scotland, where approximately half of the respondents (45%), supported the eradication of IAP to reduce costs such as safeguard native species and displacement, while (37%) were undecided but proposed eradicating IAP due to their negative impacts. Understanding the ideas and preferences of residents is crucial for evaluating proposed management and gaining public support for IAP management (Junge et al., 2019; Ryan, 2012).

The results of the current study showed that certain perceptions were related to emotional values such as liking or believing that a species is beautiful and aesthetically pleasing. Positive impacts of IAP, such as ecosystem services, were important and should be

considered in public awareness programs and citizen engagement campaigns for IAP. For instance, the most stated reason for retaining IAP is because they benefit from them. This suggests that removing IAP is a complicated social issue that may convey a variety of responses since local communities may be strongly opposed to the removal of IAP for cultural, recreational, and aesthetic reasons. Dickie et al. (2014) found that residents in Pretoria, South Africa, opposed the removal of *J. mimosifolia* because it is aesthetically pleasing and provides urban greenery. Understanding which benefits are valued can help underpin efforts to provide indigenous species as substitutes that offer similar benefits.

This resonates with Sward (2012), who reported that in San Francisco, USA, the removal of *Eucalyptus* species from urban parks was opposed by residents and several organisations, based on concerns regarding loss of aesthetics and green infrastructure in the urban environment. The removal of IAP can be a controversial issue where economic, socio-cultural, and ecological factors frequently pose challenges in environmental management (Bonanno, 2016). Strategies used by Cordeiro et al. (2020) to promote stakeholder engagement, such as institutions collaboration with local communities through field-work projects, and workshops to control IAP, as well as interactive activities such as citizen science, will be more engaging and efficient in raising awareness that can benefit and improve efforts to eradicate IAP, especially in urban areas.

3.6. Conclusion

The knowledge and perceptions of urban residents on IAP varied between different participants. One of the central findings of this study is the low level of knowledge and awareness of IAP amongst urban dwellers in these small towns. Invasive alien plants can be viewed from diverse perspectives, influenced by the uses, values, and experiences of the IAP. The results also highlight the need of addressing the general public's values for IAP management support. Most of the respondents recognised some benefits provided by IAP, however, problems associated with IAP were also noticed.

Most of the respondents were willing to participate in helping ensure that there is control and management of IAP in their gardens. The readiness to participate indicates that the respondents want to be actively involved in and aware of activities in their neighbourhoods. Public support is viewed as critical for IAP prevention and successful management (Brammer and Park, 2007). Local citizens will be willing and ready to engage if they are informed about IAP and their costs and benefits.

Most participants were willing and supportive of the removal of IAP in their gardens. However, the findings show that some respondents may overlook the ecological harm that IAP might cause and oppose their removal from settlement areas and gardens, particularly when they benefit from the IAP and do not directly affect them. As a result, information on IAP should focus on their negative impacts and the reasons for eradication and management, particularly in urban areas, as well as propose indigenous species as substitutes. Public awareness initiatives must be executed properly, considering the low levels of education and literacy among broad segments of the South African population and the multiple languages spoken in the country (Shackleton and Shackleton, 2016). Residents will be more willing to participate and volunteer in controlling and managing IAP in their gardens if they are educated about IAP and their negative and positive effects. These findings are crucial for policymakers to implement measures to prevent further introductions and the spread of IAP, especially in small towns which are at higher risk of invasion. A key message in this study is that residents need to be informed about IAP and all stakeholders need to be involved and consulted in developing management interventions given the varied costs and benefits associated with IAP. Furthermore, understanding stakeholder preferences is also important to develop interventions that factor in stakeholder views particularly for conflict generating species that have both costs and benefits.

Chapter 4

4.1. Synthesis, conclusion, and recommendations

Invasive alien plants have become a concern worldwide (Hui et al., 2017). The growing levels of urbanisation, coupled with increased populations and land transformation in urban areas, have impacted the quality of the natural environment and biodiversity (Godefroid, 2001; Grimm et al., 2008; Kühn et al., 2017). Various stakeholders have been identified as effective channels for addressing some of the positive and negative social, health and environmental impacts of IAP (Potgieter et al., 2019). There are multiple benefits derived from some IAP, for instance, the results showed that shade and fresh air, aesthetics and traditional and cultural use were some of the benefits from IAP appreciated by residents. On the other hand, the results showed that IAP can cause problems such as increased or high-water consumption, damage to infrastructure, cause allergies and biodiversity loss (threat to other plants).

The findings of this thesis were based on the distribution and quantity of woody IAP in 12 small towns in the Eastern Cape province according to land use type and suburb. Drive-by Street surveys were used to assess the distribution and abundance of woody IAP in different land uses and suburbs within each town. The study also sought to assess and gain better insight of urban residents on their knowledge, perceptions, and willingness to control IAP in their gardens, via means of household surveys. Urban areas are an essential part of the socio-ecological interactions among and between humans and other ecological factors (Salomon and Kull, 2017), therefore, the problem of IAP in towns and cities must be addressed for environmental, health, economic, and cultural reasons, through strategies such as eradication, management, and control. A key motivation of doing this study was to add new knowledge on IAP abundance and distribution in small towns, which until recently have been overlooked in IAP research. Also, results of this study can be used by municipalities to develop effective control plans that include the varied views of residents.

Urban areas, even small ones, are characterised by a high density of transport networks. Such networks provide corridors for the introduction and distribution of IAP. As a result, towns and cities are often perceived as problematic as they are often points of entry for IAP. Thus, human settlement patterns and characteristics are part of the IAP problem (Salomon and Kull, 2017). Building on the work of Shackleton and Shackleton (2016),

McLean et al. (2018) and Mabusela et al. (2021), who assessed the distribution of IAP in urban settings in South Africa, particularly in small towns, this echoed similar results which showed that the distribution and abundance of IAP vary across small towns, different land uses, and suburbs. Several factors were proposed to explain these variations, e.g., the apartheid legacy, size of the different suburbs, municipal laws that favour urban ecology investments in some areas more than others, residents' knowledge and perceptions, cost and benefits of IAP, and town budgets which can influence investment in IAP management. The study went a step further and engaged with environmental and socio-economic characteristics of urban areas that might influence the distribution and abundance of IAP.

4.2. General conclusions

4.2.1. Distribution and composition of woody IAP

The distribution and abundance of woody IAP varied across different land uses and suburbs across the 12 small towns in the Eastern Cape province of South Africa. The findings in chapter 2 revealed an unequal distribution of IAP between and within towns across different suburbs and land uses. The larger towns had more IAP than smaller towns, except for St. Francis Bay. The diversity of species varied across towns. Residential land use had more IAP in comparison to road verges and PUGS. Similarly, affluent suburbs had higher IAP densities than both the township and RDP suburbs. These results corroborate those of Mabusela et al. (2021), McLean et al. (2018) and Shackleton and Shackleton, (2016), whereby the majority of IAP were found in residential land use, affluent suburbs, and road verges. There were several characteristics (i.e., mean temperature, mean annual rainfall, size of town, population density, altitude, population, GDP by region, unemployment rate, tertiary education, and secondary education) that influenced the distribution of IAP at a town scale, as indicated by the multiple regression analysis in chapter 2. For instance, characteristics such as size of the town, population size, population density, altitude, and annual rainfall all positively influenced the density and/or species richness of IAP.

4.2.2. Urban residents' knowledge and perceptions of woody IAP in gardens

Public support is critical for the management and control of IAP in urban areas, it is therefore essential to assess citizens' knowledge, perceptions, and their willingness to regulate IAP in their properties. The focus of this study was on urban residents' knowledge, which was generally lacking. Furthermore, most respondents were not aware of the term IAP, and more than half of the respondents could not name the IAP in their yard. There

was a positive association between knowledge of IAP, and education and income, indicating that high earners and more educated individuals knew more about IAP. This has been shown in previous studies such as Shackleton and Shackleton (2016), Potgieter et al. (2019) and Jubase et al. (2021). There is a need to address the sort of information and awareness initiatives required to be implemented effectively amongst various education levels and age groups.

Most residents did not perceive IAP to be a serious problem. However, these perceptions were influenced by several factors. For example, most residents stated that they derived benefits from IAP such as, shade and fresh air, aesthetics, cultural and traditional use, and the provision of fruits. However, during IAP assessments, fruit provision was not widely recognised as a benefit from IAP because only a few fruiting IAP such as *Psidium guajava*, *Eriobotrya japonica*, and *Morus alba* were enumerated. Nevertheless, the provision of edible fruits by urban trees generally is greatly valued in Southern Africa (Kaoma and Shackleton, 2014; Shackleton and Mograbi, 2020).

Despite the benefits derived from woody IAP, people raised concerns that include high water consumption, damage to infrastructure and spoiling the landscaping and drain blockages due to leaf litter. Others complained that IAP causes allergies, attract pests, mosquitoes, and other unfavourable animals, and that branches of IAP trees occasionally fall on people or cars. Despite these issues, most respondents still wanted the IAP in their gardens. As noted by Shackleton and Shackleton (2016), there is a need to understand the motivations urban households have for retaining and maintaining IAP in their yards, even when they know about the negative ecological impacts, and whether it can be replaced by indigenous plants species (Shackleton and Shackleton, 2016). Residents' preference for IAP could be due to a familiarity with them and the multiple benefits they provide. Furthermore, people's limited knowledge and awareness of IAP may have influenced their perceptions, as a result, most preferences are based on IAP characteristics, costs, and benefits.

4.2.3. Urban residents' willingness to control woody IAP in their gardens

The results in chapter 3 showed that most residents were willing to control or remove the woody IAP on their properties if it was done by the relevant authorities. Although most respondents in this survey oversaw regulating and managing IAP in their yards, they were also eager to volunteer to help control and manage IAP in their towns, primarily because

they wanted to contribute and participate in community projects. Most respondents in this study reported that they had never seen or been contacted regarding awareness programs or IAP control operations in their communities. This confirms observations by Ruwanza and Shackleton, (2016) that consultation, which is regarded as a critical part of the Integrated Development Plan (IDP) process in South Africa, is not taking place, thus making it a major problem. It is important for the residents to have a say in IAP's management and control, and have their opinions heard and be informed about what is going on in their communities. This will give them an opportunity to engage in environmental initiatives focused on IAP management and control. The willingness of urban residents to participate in the eradication of IAP can play a major role in implementing relevant policies in urban areas (Salomon and Kull, 2017).

Limited funding for IAP control and management programs and a shortage of experienced staff and equipment suitable for control and management is a challenge. Such difficulties, however, are not limited to South Africa. Urban environmental management in both developed and developing countries are affected by financial shortages because of low budgetary priority (Ruwanza and Shackleton, 2016). Programs dealing with the management and control of IAP received the least support because there are no fully-fledged departments dedicated to IAP control and management (Ruwanza and Shackleton, 2016). Overall, the findings in chapter 2 can be used to understand the distribution and abundance of IAP in various suburbs and land uses. The findings in chapter 3 can further assist government and small-town municipalities in gaining a better understanding of residents' knowledge, perceptions, and willingness to control IAP in their properties.

4.3. Policy Implications and Recommendations

The study showed marked variation in the distribution and abundance of IAP between and within towns and across different land uses and suburbs. The study also reported that perceptions, knowledge, and views regarding IAP in urban communities was generally low and varied across towns and respondent attributes. Based on these results, the study recommends the following for consideration.

4.3.1. Recommendations on species distribution and abundance

1. The information on the distribution, abundance, and diversity of IAP of each town is crucial for conservation of biodiversity, ecosystem services, and socioeconomic conditions. It is therefore important to encourage research

within small towns to understand how IAP are distributed and get detailed information about IAP and the type of species found to improve the control and management of IAP in small towns. More research is therefore recommended in other small town to get a full picture of IAP distribution is urban areas of South Africa.

2. Adequate and effective control and management methods must be implemented, which will give high priority to the land use types and suburbs with high distribution, abundance, and diversity of IAP. For instance, the results showed that there is a high number of IAP in category 1b and category 3, that were dominant in the various land use (residential areas) and suburb types (affluent areas), which by law, are prohibited and must be eradicated and controlled to further prevent the negative impacts caused by IAP. The impacts of IAP must be clearly communicated before they are controlled and eradicated. In addition, concerns delaying the eradication and control of IAP should be communicated amongst different government authorities and sectors of government (Wilson et al., 2013).
3. Societal awareness on IAP and their impacts is key. Many times, people living around and benefiting from the IAP are not aware of the full costs and benefits as ecosystem services and disservices delivered by the IAP species. Therefore, for some members of the society to understand the impacts each IAP might have on the social and the ecological services they receive might be a challenge. The knowledge of linking and connecting biodiversity and ecological services is also a gap that should be addressed to better manage and control IAP within the various land uses and suburb types.

4.3.2. Recommendations on perceptions, knowledge, and willingness to control IAP

The survey results showed that most residents were willing to control and eradicate IAP in their gardens if the appropriate authorities do so. As a result, towns must take advantage of residents' desire to participate in IAP control and management operations, and therefore all the relevant organisations should be utilised to control and manage IAP where residents desire such.

1. Urban residents should be encouraged to report IAP for the sake of control and management. This strategy will be a fundamental approach to managing IAP,

especially those under private tenure (Shackleton and Shackleton, 2016), as most households in this study reported having IAP in their yards, and residential land use had the highest number of IAP compared to other land uses. The municipality also needs to be involved in projects and keep track of progress in managing and controlling IAP initiatives. Different stakeholders can set up competitions where residents learn about the control and management of IAP within different land uses and suburbs, this will encourage individuals to participate and offer residents something to look forward to during and after awareness campaigns.

2. Create awareness campaigns to implement relevant policies, using local language pamphlets, and manuals on how to control and manage IAP, along with community 'workdays' to identify and remove IAP. Furthermore, the information on awareness campaigns, and manuals of IAP (control, management, and eradication) should be translated into all the official languages for citizens of different ages and educational levels. For instance, the results showed that there were low levels of knowledge of IAP amongst the residents, therefore, the manuals should be easy to read and understand and focus on the most abundant and problematic IAP. Interestingly, majority of residents were willing to control and remove IAP in their yards, although this was centred on benefits issues. Therefore, before making an informed decision about whether to control or manage IAP, stakeholder consultation must be done so that the public receive relevant information required.
3. Given the limited human and financial resources that municipalities have, municipal managers must consider allocating the limited resources to suburbs and land use types that have the most IAP. Furthermore, effective prioritisation (of species, sites and/or pathways) incorporating detailed and comprehensive biological, social and economic criteria is required. A detailed IAP impact assessment should also be conducted. This will further help in creating employment and help urban communities to explore and use indigenous species as a replacement for IAP. This will further demonstrate the commitment to IAP control and management in urban areas, which will assist and address some of the impacts caused by IAP, and why their impacts must be mitigated.

Most of the above-mentioned recommendations will require human and financial resources, the limitations in which have already been identified as significant obstacles to

controlling and managing woody IAP in small towns. Municipalities must recognise the need to factor the cost of managing and controlling woody IAP into their regular budget. Consequently, government at a district and local level together with urban residents must focus on controlling regions where IAP are abundant, and further develop policies and clear management plans with well-defined and long-term objectives.

Suggestions for future recommendations is for researchers and interested stakeholders to further explore different mechanisms on how to consistently monitor the distribution and abundance of IAP in urban settings. In this age of technology, platforms such as iNaturalists (https://www.inaturalist.org) and PlantSnap (https://www.plantsnap.com) could be used as an aid for constant monitoring of IAP in urban settings. Furthermore, awareness campaigns and information on IAP need to be easily accessible to urban residents of different age groups and education levels. It is desirable to enforce strict control programmes on the introduction of IAP in urban settings through regular monitoring of IAP, this will help avoid problems that would arise from invasion by IAP (van Wilgen and Richardson, 2014). South Africa is amongst the most ecologically and biologically diverse countries in the world and is one of the leading nations in investigating biological invasions, their management and control (van Wilgen and Richardson, 2014). Research is required at a local level to help gain better insights that will assist, develop, and strengthen research and community-based management techniques that are best suited for dealing with IAP in urban settings.

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Appendices

Appendix 1: Survey Questionnaire

Date_____ Sample No_____ Town_____ Street name_____

My name is **Mr. Tshepiso Seboko,** I am currently doing my **MSc in Environmental Science at Rhodes University**. My research project is titled **Distribution of Invasive Alien plants in small towns in the Eastern Cape Province, South Africa.** The purpose of the research project is to: determine the distribution and abundance of IAP in small towns in the Eastern Cape Province of South Africa and how and why that differs within and between towns. I would like to have **20-30 minutes** of your time to answer the following questions. The purpose of the questionnaire is to help understand the knowledge, perceptions and willingness to control Invasive Alien Plants (IAP) in their gardens. Any further questions that you might have concerning the research or my participation will be answered by: **Dr Sheunesu Ruwanza (046 603 7009; s.ruwanza@ru.ac.za) and Professor Charlie Shackleton (046 603 7574 ; c.shackleton@ru.ac.za).**

Section A: Perceptions and knowledge of Invasive Alien Plants in garden.

1. Have you heard of the term Invasive Alien Plant (IAP) before? ***Yes*** [ ] ***No*** [ ]
2. If yes to question one, please provide source_____
3. On a scale of 1 to 5, how would you rate your knowledge of IAP? (1 being none; 5 being very high)

1.None	2.Poor	3.Neutral	4.High	5.Very high

4. Do you have any IAP in your garden? ***Yes*** [ ] ***No*** [ ] ***I Don't know*** [ ]
5. *If yes, can you identify and name (them)? _____

6. How long have you lived on this property? No. of years_____

7. Do you own or rent the property? _____

8. Do you generally think that IAP pose a problem to the environment? ***Yes*** [ ] ***No*** [ ] I
   Don't know [ ]

9. *If yes to the question above (8), please provide reason(s)_____
   ___
   _____
   ____
   _____
   ____

10. Does the IAP provide benefits to you in anyway? ***Yes*** [ ] ***No*** [ ]

11. *If yes, please provide reason(s)_____
    ___
    _____
    ____
    _____
    _____

____ 12. Have you seen any awareness campaigns or information about IAP? ***Yes*** [ ] ***No*** [ ] *If yes, please tick the relevant option.

a. TV [ ]
b. Radio [ ]
c. Internet [ ]
d. Print materials (Newspapers, magazines, awareness pamphlets) [ ]
e. Other_____
_____

14. What information would you need or would like to have about IAP?

a. Different types of IAP [ ]
b. Organisations dealing with IAP [ ]

c. Impact of IAP
[ ]
d. Spread of IAP
[ ]
e. Other_____

___ Section B: Willingness to control Invasive Alien Species in gardens.

15. Have you ever participated/volunteered in any work associated with the environment? ***Yes*** [ ] ***No*** [ ] *If Yes, How? (activity)_____

16. Are you willing to participate in a project or campaign that is meant to control and manage spread of IAP? ***Yes*** [ ] ***No*** [ ]*If not, please provide reason(s)_____
___

17. Who do you think should be responsible for the control and management of IAP?
    a. Local government
    [ ]
    b. District government
    [ ]
    c. Provincial government
    [ ]
    d. National government
    [ ]
    e. NGOs
    [ ]
    f. Private companies
    [ ]
    g. Land owner/users
    [ ]

18. As part of our survey we noticed that there is a (IAP name_____) tree growing in your garden. Do you know which tree this is (can you point it out)?
_____
____

19. Are you willing to report the IAP on your land to the relevant departments or institutions for control or management purposes? ***Yes*** [ ] ***No*** [ ]* If not, please provide
reason(s)_____
_____
____

20. Are you willing to have IAP removed from your property? ***Yes*** [ ] ***No***[ ]

21. Why? Please explain/provide reasons_____

_____

____

Section C: Respondents Profile

To further analyse and interpret the data from the survey, it will be useful to know more about your background. This information will be kept confidential and only be used in analysing broad patterns. Respondents are free to answer questions which they feel comfortable with or withdraw anytime without any reason.

22. Age? Please tick the relevant

a. 18-30	b. 31-40	c. 41-50	d. 51-60	d. 61-70	e. 71>

23. Gender: Male [ ] Female [ ]

24. What is your highest level of education?

a. Primary level	b. Secondary level	c. Tertiary level

25. Which category describes your approximate household annual gross income

a. Less than R25 000 p.a
[ ]
b. R25 001 – 50 000 p.a
[ ]
c. R50 001 – R100 000 p.a
[ ]
d. R100 001 – R200 000 p.a
[ ]
e. R200 001 – R300 000 p.a
[ ]
f. R300 001 –R400 000 p.a
[ ]
g. R400 001-R500 000 p.a
[ ]
h. Greater than R500 000 p.a
[ ]

Thank you for your time and participation.

Appendix 2: Invasive alien plants categories according to NEM:BA listings

Species	IAP NEM:BA category	Adelaide	Alexandria	Barkley East	Bedford	Burgersdorp	Cathcart	Kirkwood	Middleburg	Paterson	Somerset East	St Francis Bay	Willowmore	Total
Melia azedarach	Category 1b/3 in urban areas	575	288	8	468	128	98	837	1 207	127	253	1	394	4 384
Pinus elliotti	Category 2	241	239	577	418	451	384	142	739	68	204	137	451	4 051
Jacaranda mimosifolia	Category 1b	391	57	0	1 004	39	78	681	110	36	1184	32	28	3 640
Eucalyptus camaldulensis	Category 1b	128	440	32	420	245	237	4	430	105	544	0	895	3 480
Ligustrum lucidum	Category 1b in EC	57	212	192	104	414	96	0	350	151	209	328	29	2 142
Schinus molle	Category 1b	149	8	6	118	48	48	61	400	37	110	0	659	1 644
Prunus serotina	Category 1b	0	0	0	0	0	0	0	0	0	0	1 481	0	1 481
Fraxinus americana	Category 3 in EC	77	121	46	84	234	107	89	206	32	89	0	97	1 182
Fraxinus angustifolia	Category 3 in EC	71	119	127	96	209	144	0	148	85	109	0	47	1 155
Ligustrum ovalifolium	Category 1b in EC	46	109	210	48	126	0	0	158	71	114	243	31	1 151
Celtis australis	Category 3	114	12	20	95	252	68	155	79	4	194	41	39	1 073
Grevillea robusta	Category 3	90	65	0	95	4	66	409	16	29	56	0	182	1 012
Callistemon viminalis	Category 1b in EC	51	115	0	40	7	47	203	74	4	179	147	84	951
Pinus canariensis	Category 3	60	110	48	67	161	20	79	273	2	67	42	21	950
Acacia implexa	Category 1a	0	0	0	0	0	0	0	0	0	0	762	0	762
Albizia lebbeck	Category 1b	72	0	19	10	288	13	6	126	0	2	0	59	595
Senna didymobotrya	Category 1b in EC	62	45	0	45	2	1	175	0	84	42	0	108	564
Gleditsia triacanthos	Category 1b	0	2	0	0	372	0	23	146	0	0	0	7	550
Ailanthus altissima	Category 1b	43	0	3	22	186	5	10	268	0	7	0	1	545
Tipuana tipu	Category 3	24	0	249	23	5	18	90	3	13	55	0	5	485
Populus canescens	Category 2	2	1	147	18	210	15	0	42	0	44	0	1	480

Schinus terebinthifolius	Category 1b in EC	46	38	39	34	68	5	0	103	47	73	0	19	472
Morus alba	Category 3	57	4	26	59	121	28	13	84	4	45	4	18	463
Robinia pseudoacacia	Category 1b	1	0	113	3	156	1	2	92	0	0	0	91	459
Acacia saligna	Category 1b	0	6	0	0	0	0	0	1	0	0	373	0	380
Metrosideros excelsa	Category 1a	0	6	7	4	14	2	19	1	0	4	308	0	365
Pinus halepensis	Category 3 in EC	13	6	25	47	58	2	6	54	0	4	145	0	360
Salix babylonica	Category 2	38	23	65	28	94	29	0	23	20	40	0	0	360
Eucalyptus cladocalyx	Category 1b	24	0	156	11	56	20	3	7	0	57	0	4	338
Cinnamomum camphora	Category 1b in EC	126	7	1	5	25	24	0	45	1	32	17	45	328
Cestrum laevigatum	Category 1b	10	4	4	7	12	5	29	109	0	24	55	33	292
Acacia melanoxylon	Category 2	0	1	0	0	0	0	57	42	0	0	134	45	279
Eriobotrya japonica	Category 1b in EC	25	9	3	27	29	7	3	14	0	103	9	26	255
Acacia decurrens	Category 1b	17	8	0	0	20	54	0	15	0	93	0	17	224
Ceratonia siliqua	Category 1a	0	0	0	0	136	0	7	64	0	0	0	1	208
Prosopis velutina	Category 1b in EC	0	5	0	0	0	0	0	1	0	17	4	179	206
Hakea sericea	Category 1b	0	17	5	14	6	0	0	4	3	28	71	0	148
Triplaris americana	Category 1a	40	12	0	37	2	0	19	0	6	26	0	0	142
Spartium junceum	Category 1b	1	0	45	0	22	3	1	46	0	3	0	0	121
Acacia mearnsii	Category 2	6	21	0	3	0	35	2	25	9	6	0	11	118
Acacia podalyriifolia	Category 1b	6	15	27	13	3	10	0	8	0	18	6	0	106
Solanum mauritianum	Category 1b	2	29	0	7	0	0	40	0	0	19	0	0	97
Syzygium paniculatum	Category 2	0	5	1	0	0	23	0	0	0	1	42	0	72
Caesalpinia decapetala	Category 1b	28	1	0	1	0	0	31	4	0	2	0	0	67
Syzygium cumini	Category 1b	29	13	18	0	0	0	0	0	0	0	0	0	60
Psidium guajava	Category 3	0	7	2	18	2	5	0	0	0	22	0	0	56

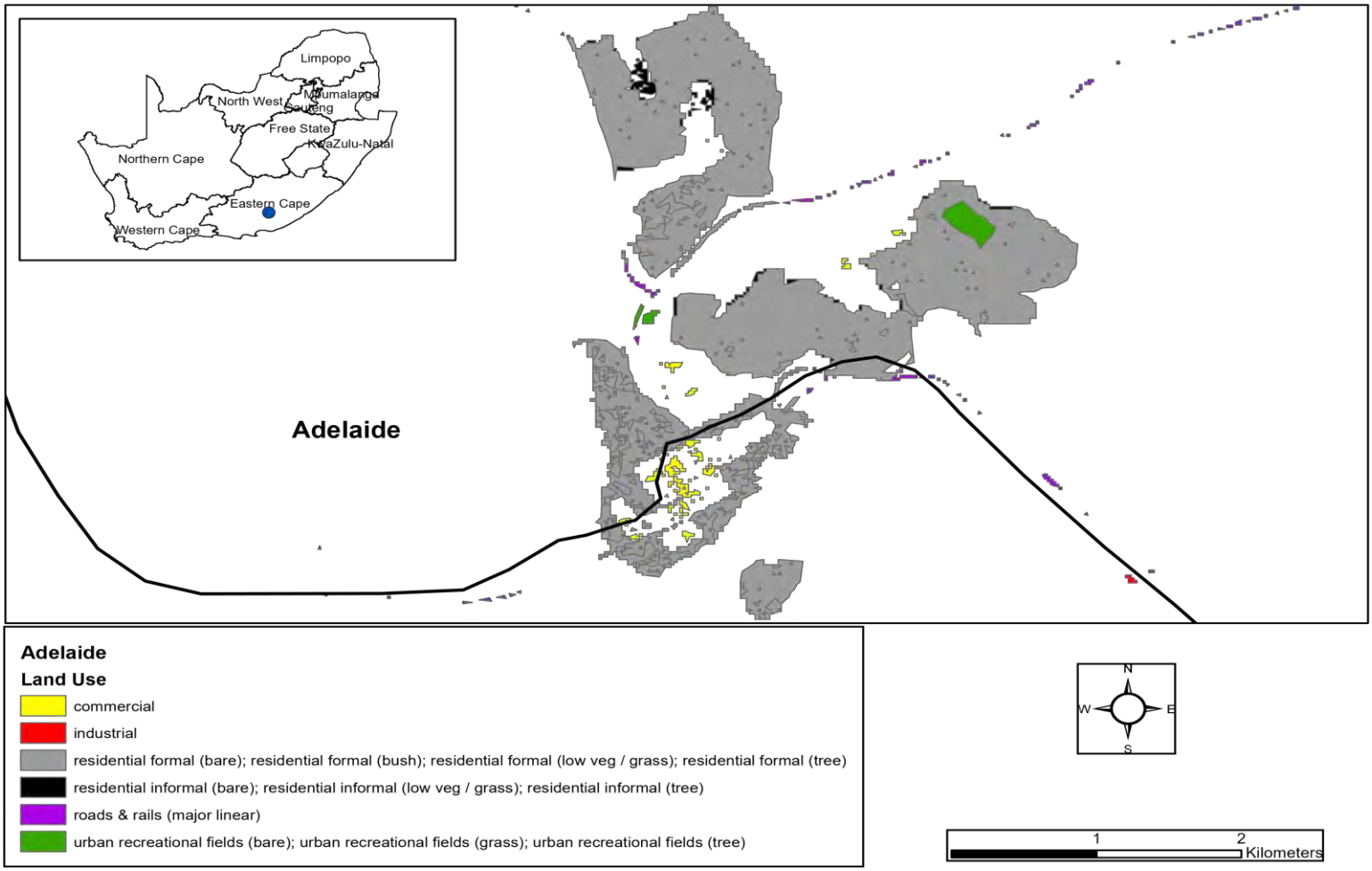
Caesalpinia gilliesii	Category 1b	7	2	0	0	5	1	0	36	0	0	0	5	56
Bauhinia purpurea	Category 1b in EC	10	22	0	2	0	0	0	0	7	3	0	0	44
Bauhinia variegata	Category 1b in EC	7	4	0	4	0	0	0	0	2	10	0	0	27
Acacia longifolia	Category 1b	0	0	0	0	0	0	5	20	0	0	0	0	25
Paraserianthes lophantha	Category 1b	0	0	0	0	0	0	0	0	0	11	0	0	11
Pinus patula	Category 2	0	0	3	0	0	0	0	0	0	0	0	0	3
Spathodea campanulata	Category 3	0	2	0	0	0	0	0	0	0	1	0	0	3
Ardisia crenata	Category 1b	0	2	0	0	0	0	0	0	0	0	0	0	2
Parkinsonia aculeata	Category 1b	1	0	0	0	0	0	0	0	0	1	0	0	2
Leucaena leucocephala	Category 2	0	0	0	0	1	0	0	0	0	0	0	0	1

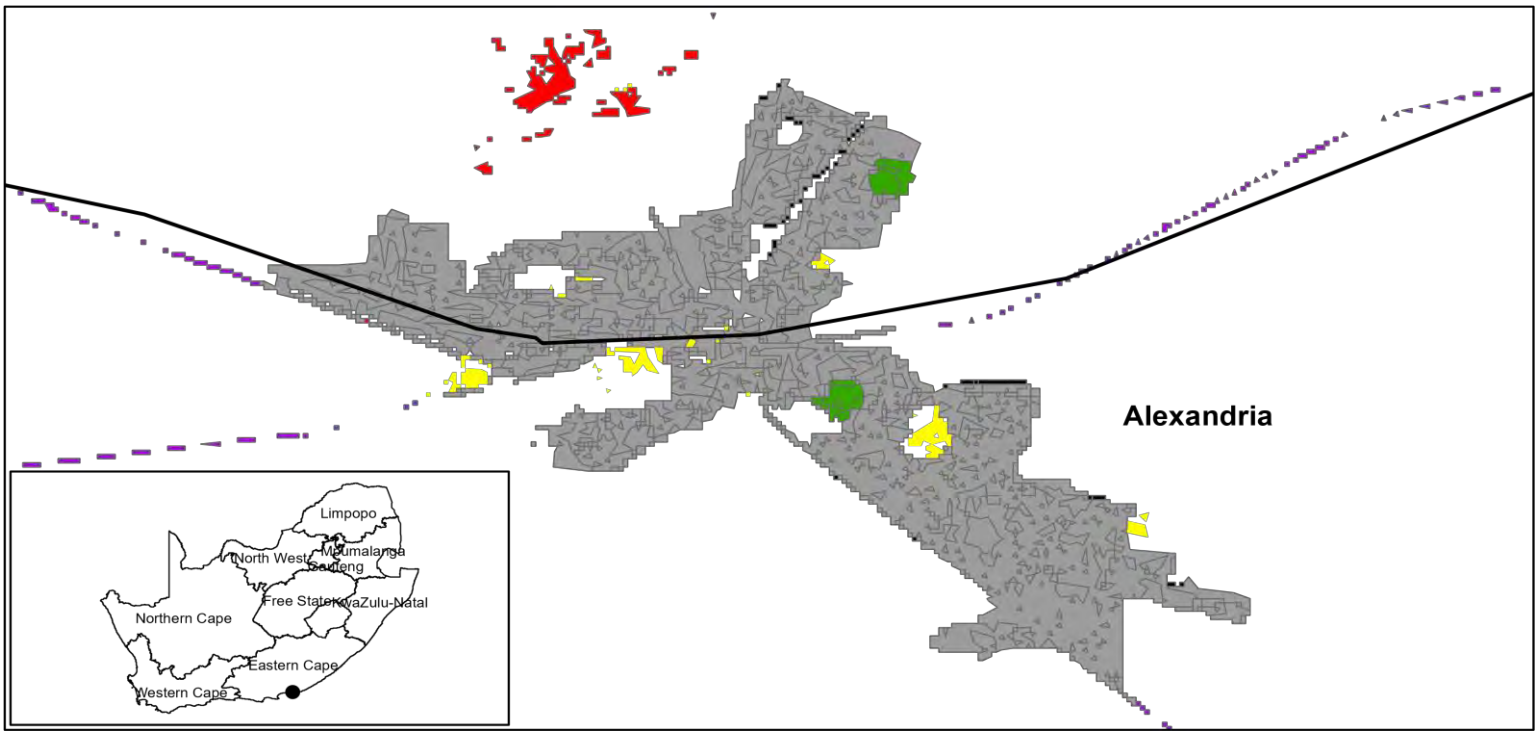
Appendix 3: Class names dissolved for land use zones in ArcGIS version 10.8.1

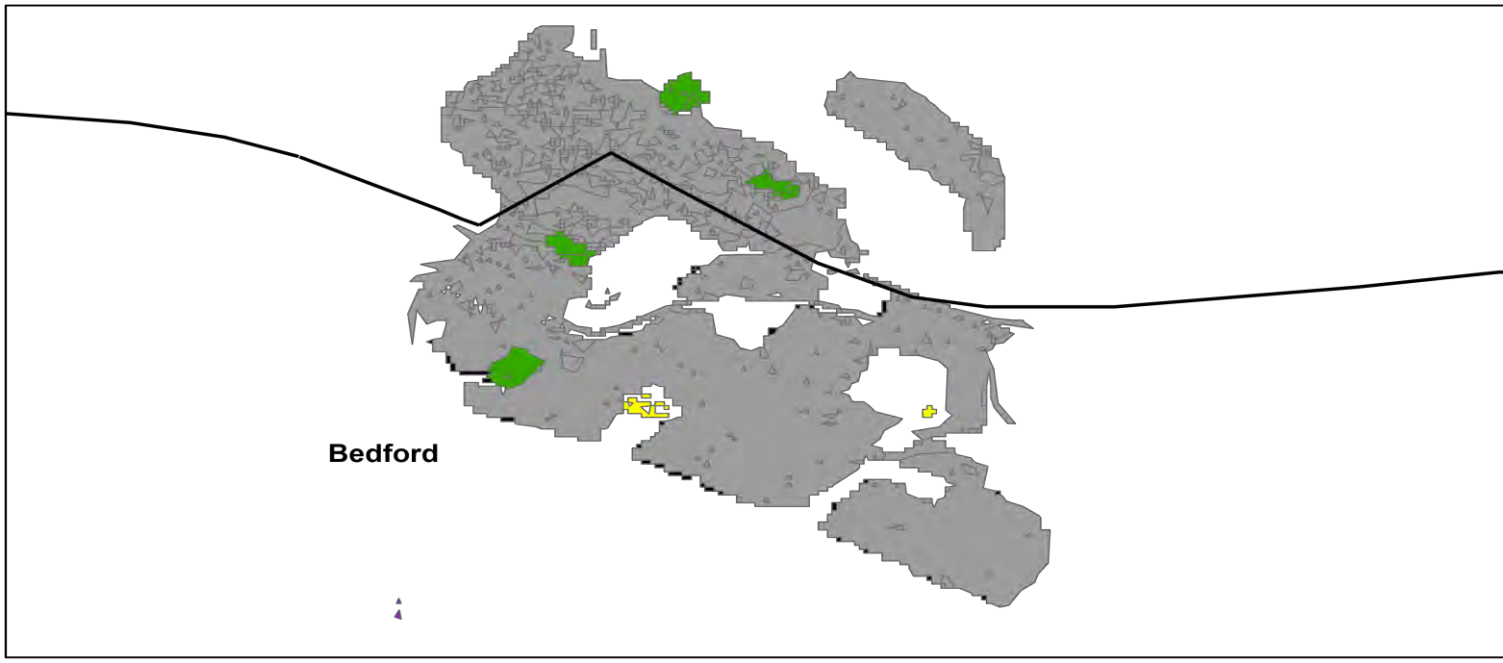
OID	Value	Class Name
1	1	contiguous (indigenous) forest
2	2	contiguous low forest & thicket
3	3	dense forest & woodland
4	4	open woodland
5	5	contiguous & dense plantation forest
6	6	open & sparse plantation forest
7	7	temporary unplanted (clear-felled) plantation forest
8	8	low shrubland (other)
9	9	low shrubland (fynbos)
10	10	low shrubland (succulent karoo)
11	11	low shrubland (nama karoo)
12	12	sparsely wooded grassland
13	13	natural grassland
14	14	natural rivers
15	15	natural estuaries & lagoons
16	16	natural ocean & coastal
17	17	natural lakes
18	18	natural pans (flooded @ observation times)
19	19	artificial dams (including canals)
20	20	artificial sewage ponds
21	21	artificial flooded mine pits
22	22	herbaceous wetlands (currently mapped)
23	23	herbaceous wetlands (previously mapped)
24	24	mangrove wetlands
25	25	natural rock surfaces
26	26	dry pans
27	27	eroded lands
28	28	sand dunes (terrestrial)
29	29	coastal sand & dunes
30	30	bare riverbed material
31	31	other bare
32	32	cultivated commercial permanent orchards
33	33	cultivated commercial permanent vines
34	34	cultivated commercial sugarcane pivot irrigated
35	35	cultivated commercial permanent pineapples
36	36	cultivated commercial sugarcane non-pivot
37	37	cultivated emerging farmer sugarcane non-pivot

38	38	commercial annual crops pivot irrigated
39	39	commercial annual crops non-pivot irrigated
40	40	commercial annual crops rain-fed / dryland
41	41	subsistence / small-scale annual crops
42	42	fallow land & old fields (trees)
43	43	fallow land & old fields (bush)
44	44	fallow land & old fields (grass)
45	45	fallow land & old fields (bare)
46	46	fallow land & old fields (low shrub)
47	47	residential formal (tree)
48	48	residential formal (bush)
49	49	residential formal (low veg / grass)
50	50	residential formal (bare)
51	51	residential informal (tree)
52	52	residential informal (bush)
53	53	residential informal (low veg / grass)
54	54	residential informal (bare)
55	55	village scattered (bare & low veg/ grass combo)
56	56	village dense (bare & low veg / grass combo)
57	57	smallholdings (tree)
58	58	smallholdings (bush)
59	59	smallholdings (low veg / grass)
60	60	smallholdings (bare)
61	61	urban recreational fields (tree)
62	62	urban recreational fields (bush)
63	63	urban recreational fields (grass)
64	64	urban recreational fields (bare)
65	65	commercial
66	66	industrial
67	67	roads & rails (major linear)
68	68	mines: surface infrastructure
69	69	mines: extraction pits, quarries
70	70	mines: salt mines
71	71	mine: tailings and resource dumps
72	72	land-fills
73	73	fallow land & old fields (wetlands)

Appendix 4: Land use maps







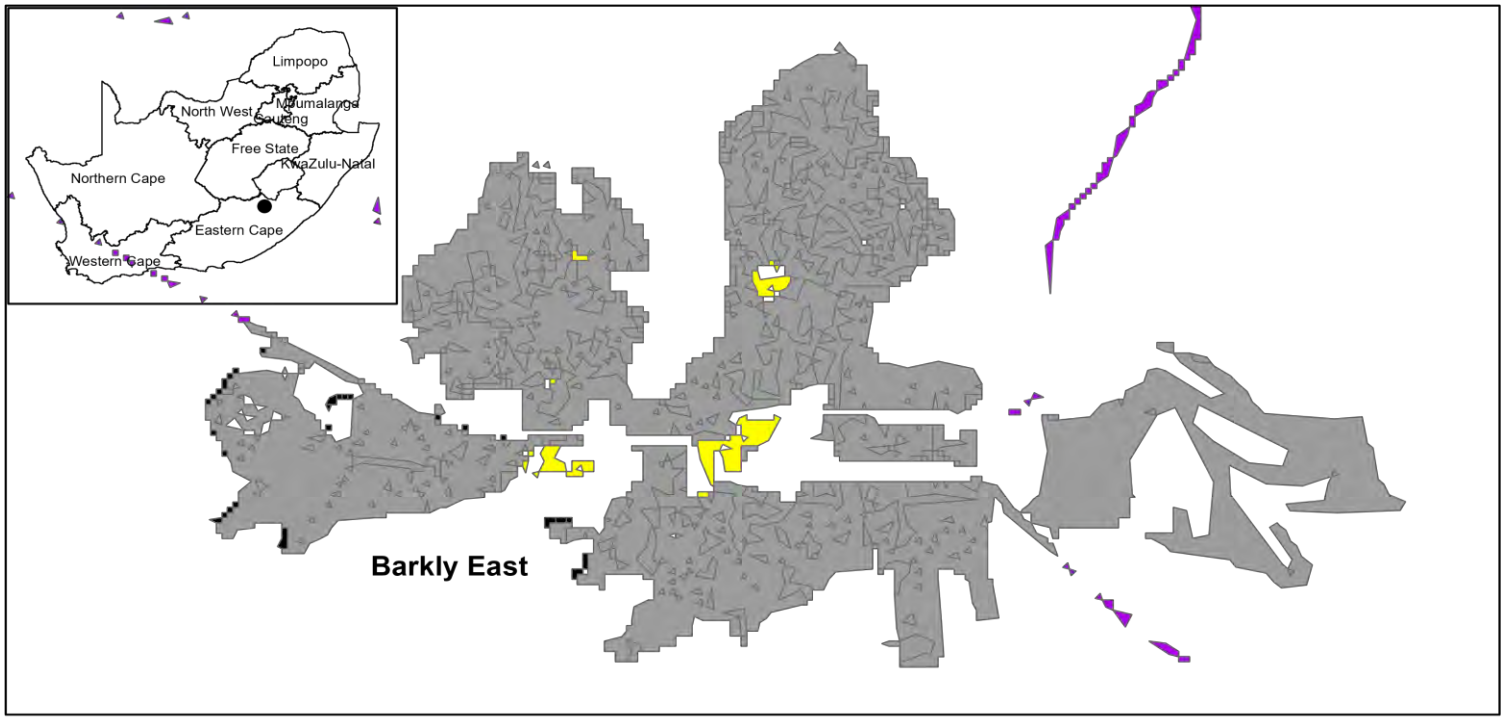
Bedford

Land Use

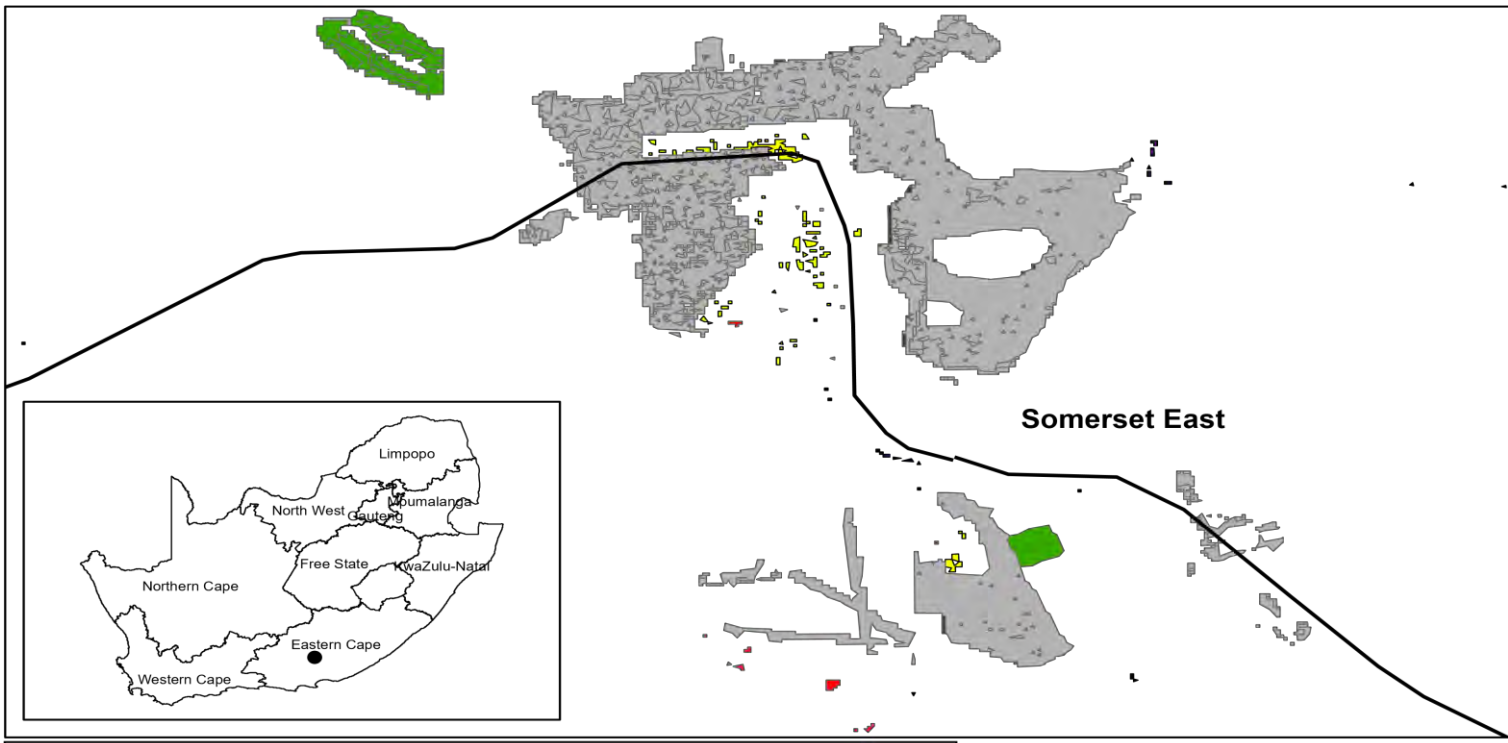
- commercial
- industrial
- residential formal (bare); residential formal (bush); residential formal (low veg / grass); residential formal (tree)
- residential informal (bare); residential informal (low veg / grass); residential informal (tree)
- roads & rails (major linear)
- urban recreational fields (bare); urban recreational fields (grass); urban recreational fields (tree)

N W E S

0,5 1 2 Kilometers



N W E S



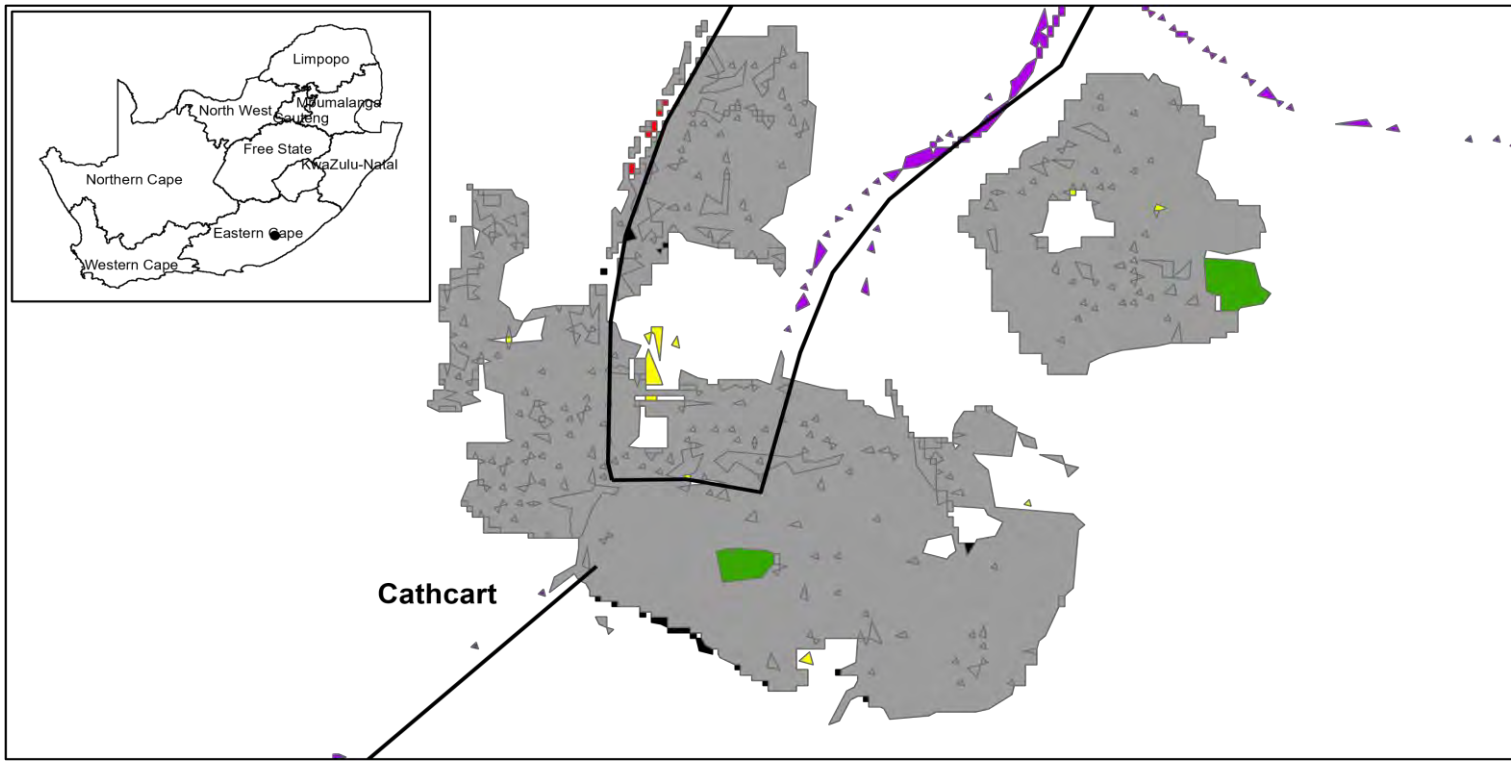
Somerset East

Land Use

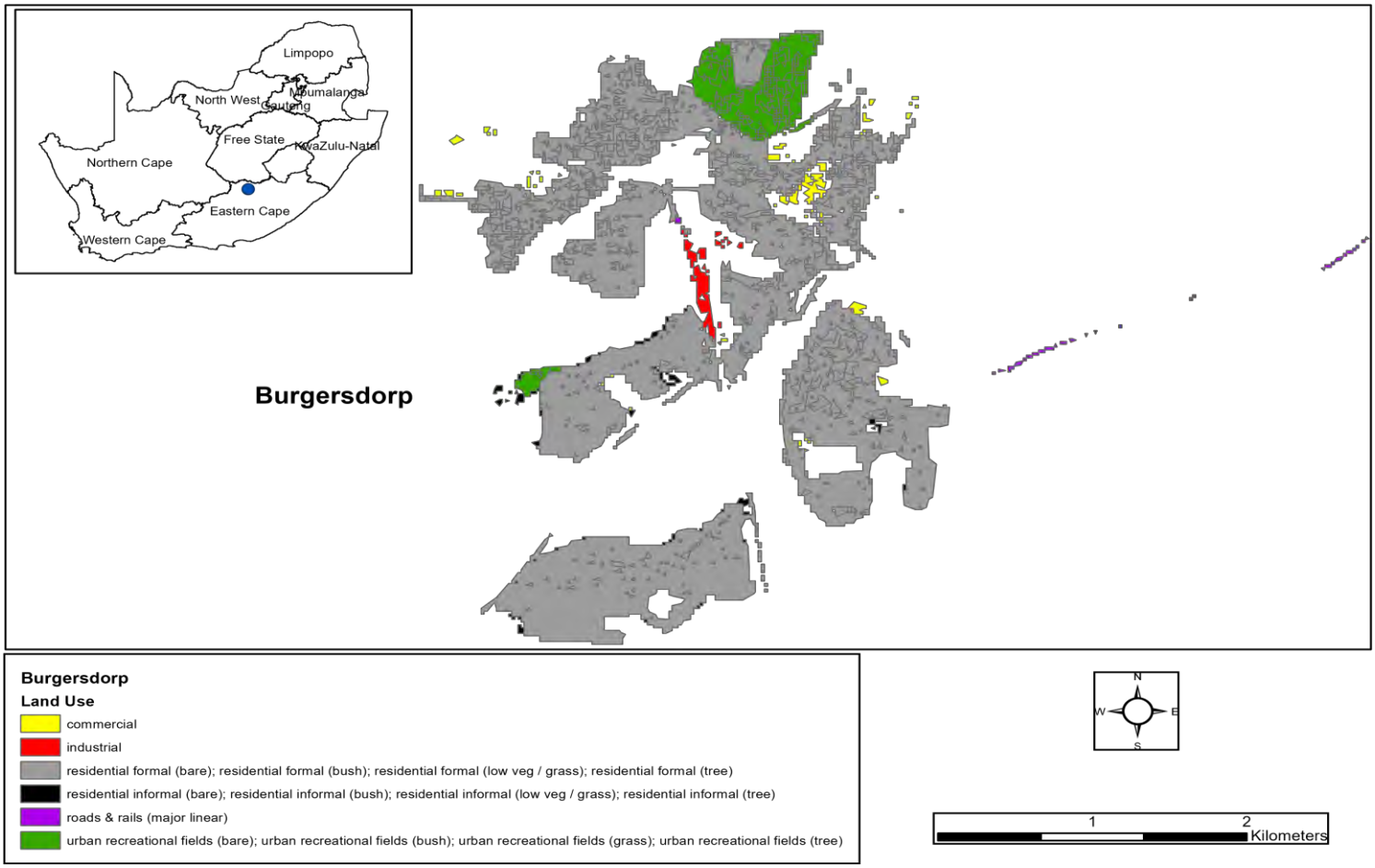
- commercial
- industrial
- residential formal (bare); residential formal (bush); residential formal (low veg / grass); residential formal (tree)
- residential informal (bare); residential informal (bush); residential informal (low veg / grass); residential informal (tree)
- roads & rails (major linear)
- urban recreational fields (bare); urban recreational fields (bush); urban recreational fields (grass); urban recreational fields (tree)

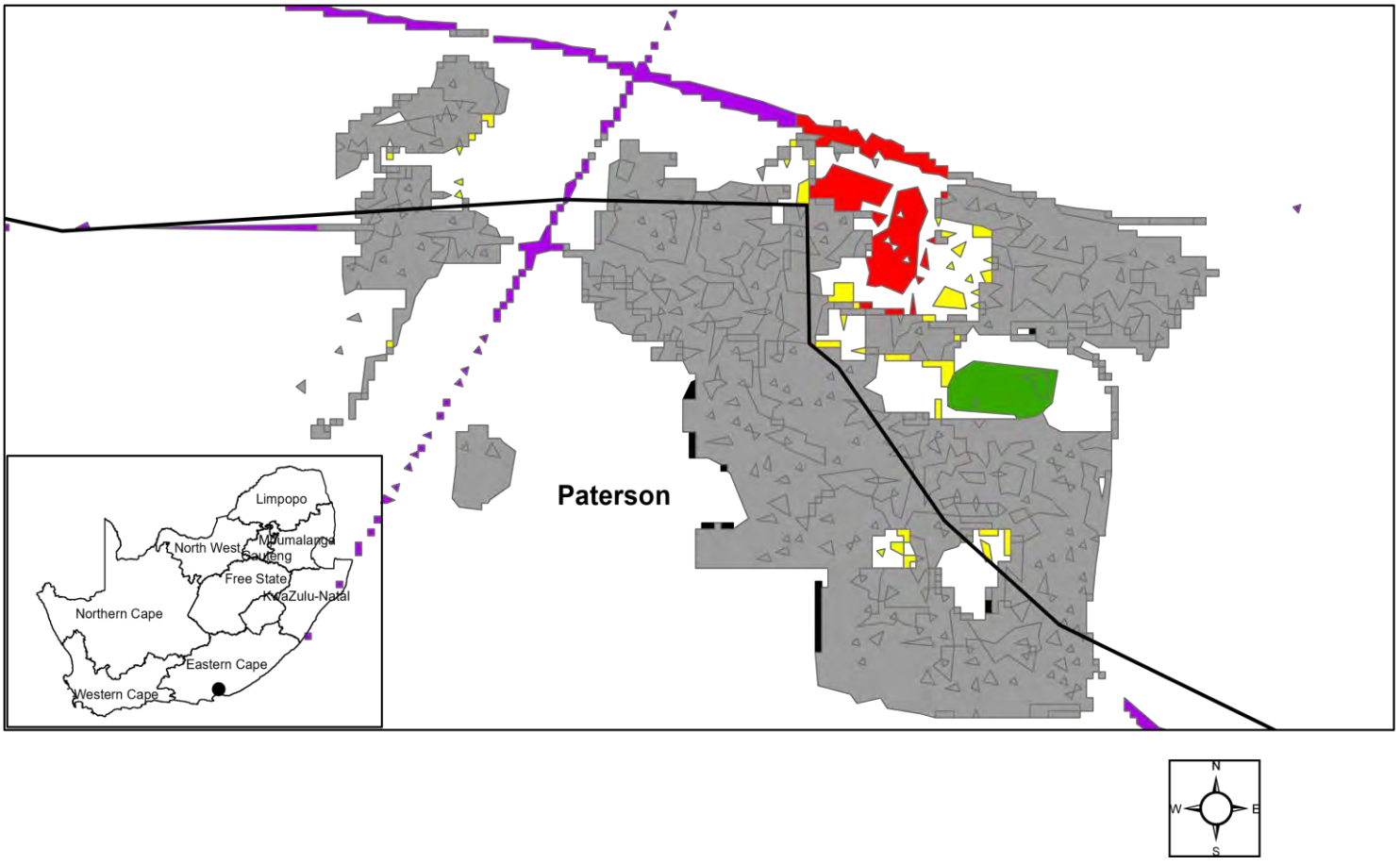
N W E S

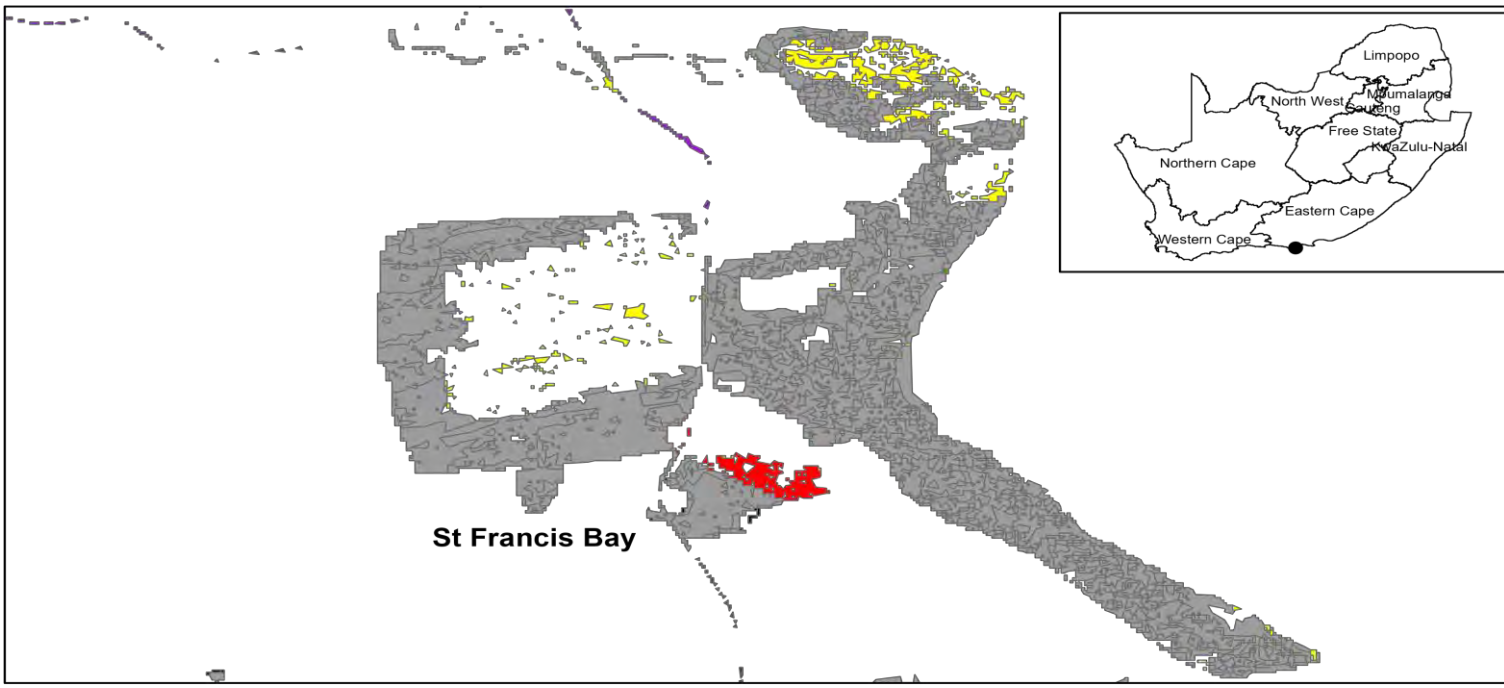
1,5 3 Kilometer



N W E S


Limpopo
North West
Mpumalanga
Gauteng
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
Burgersdorp
Burgersdorp
Land Use
commercial
industrial
residential formal (bare); residential formal (bush); residential formal (low veg / grass); residential formal (tree)
residential informal (bare); residential informal (bush); residential informal (low veg / grass); residential informal (tree)
roads & rails (major linear)
urban recreational fields (bare); urban recreational fields (bush); urban recreational fields (grass); urban recreational fields (tree)
N
W
E
S
1
2
Kilometers


Paterson
Limpopo
North West
Mpumalanga
Gauteng
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
N
W
E
S



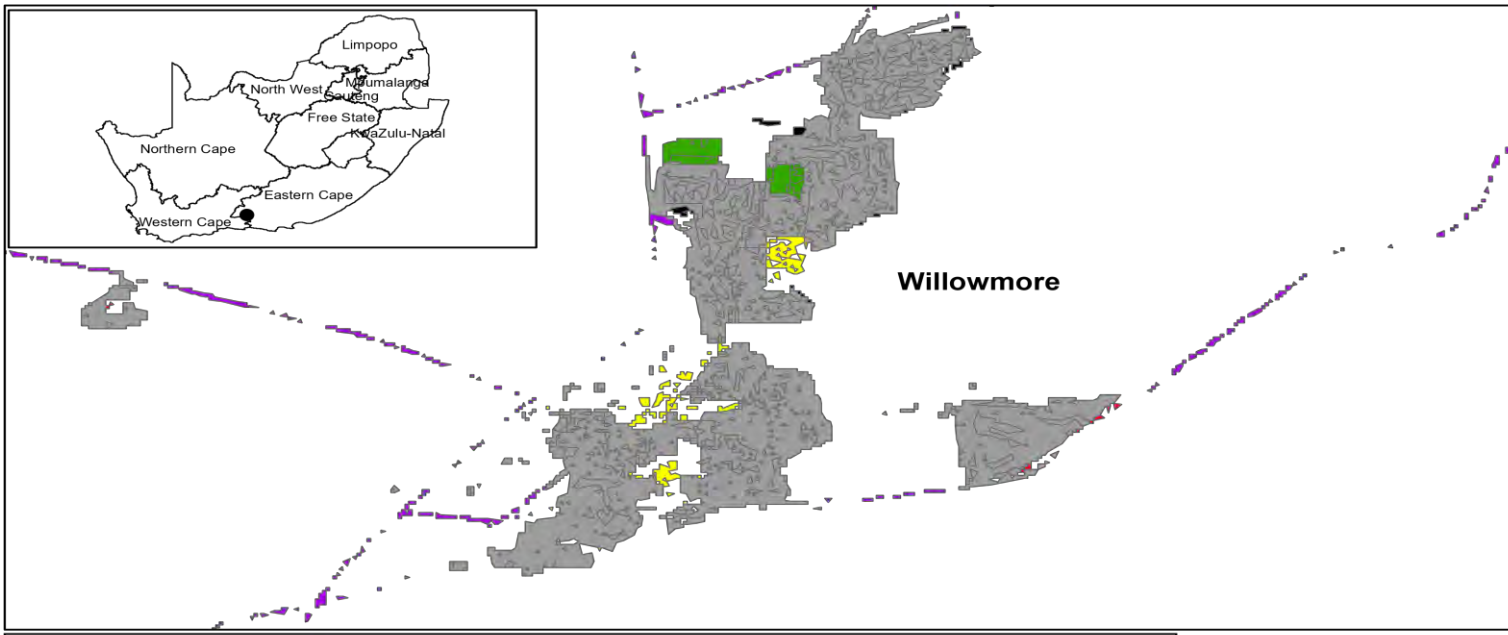
St Francis Bay

Land Use

- commercial
- industrial
- residential formal (bare); residential formal (bush); residential formal (low veg / grass); residential formal (tree)
- residential informal (bare); residential informal (bush); residential informal (low veg / grass); residential informal (tree)
- roads & rails (major linear)
- urban recreational fields (bare); urban recreational fields (bush); urban recreational fields (grass); urban recreational fields (tree)

N W E S

0,5 1 2 Kilometers



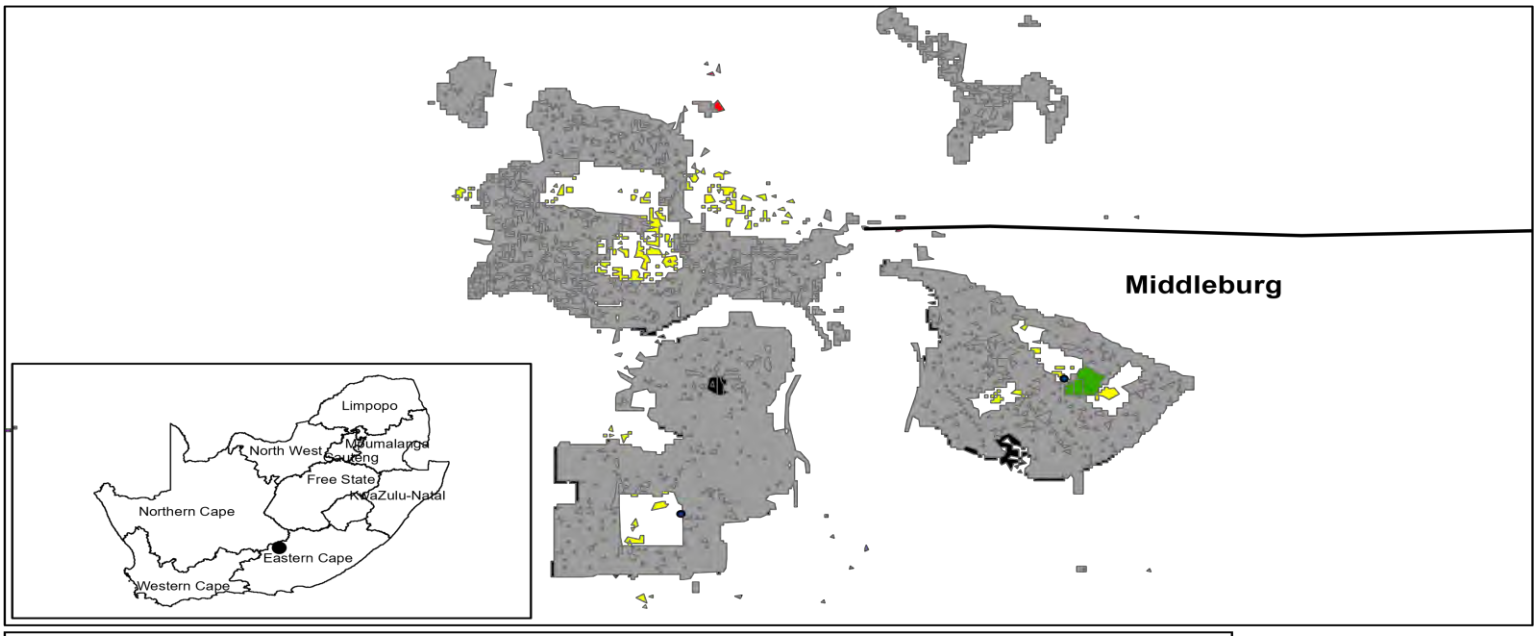
Willowmore

Land Use

- commercial
- industrial
- residential formal (bare); residential formal (bush); residential formal (low veg / grass); residential formal (tree)
- residential informal (bare); residential informal (bush); residential informal (low veg / grass); residential informal (tree)
- roads & rails (major linear)
- urban recreational fields (bare); urban recreational fields (bush); urban recreational fields (grass); urban recreational fields (tree)

N W E S

0,5 1 Kilometers



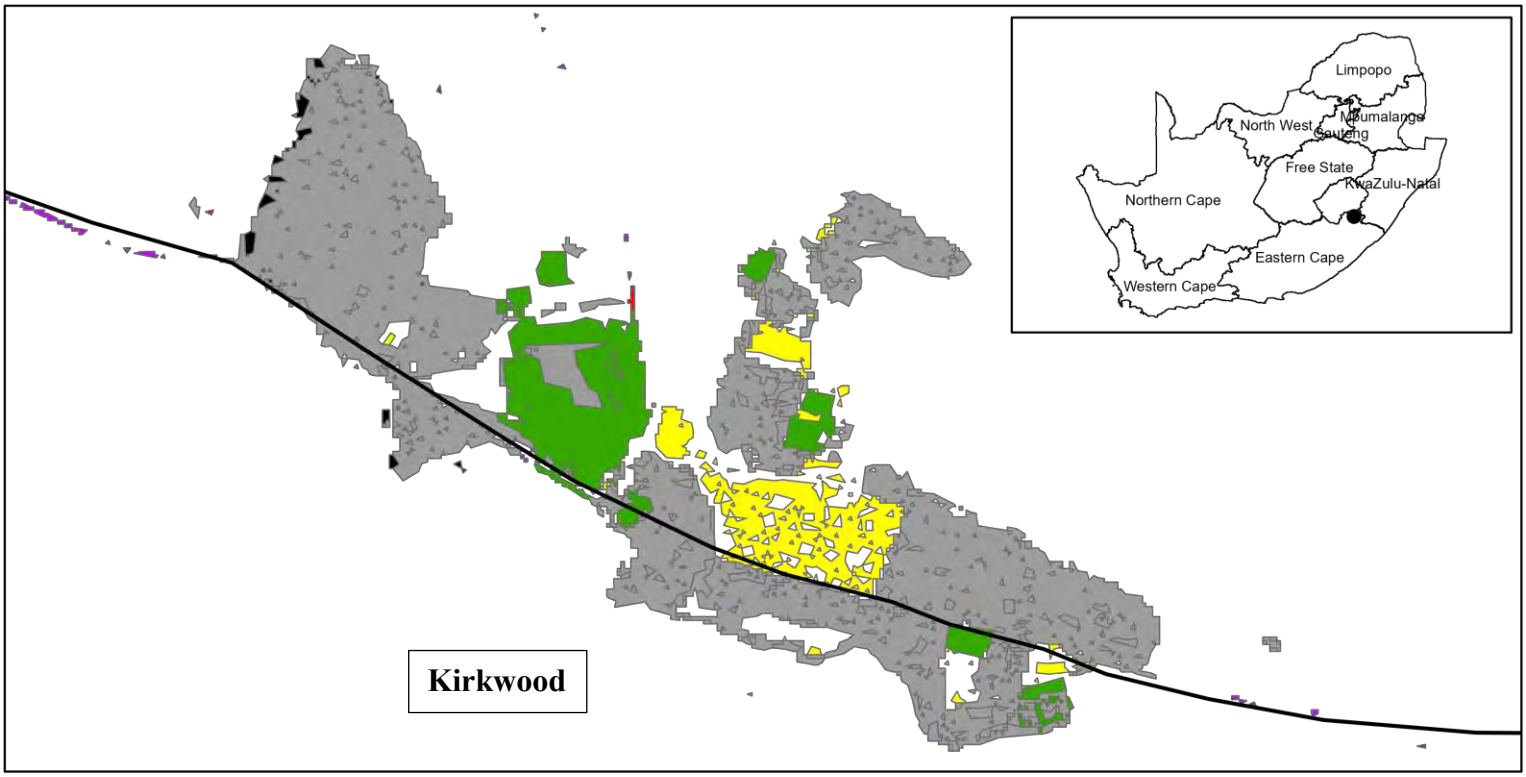
Middleburg

Land Use

- commercial
- industrial
- residential formal (bare); residential formal (bush); residential formal (low veg / grass); residential formal (tree)
- residential informal (bare); residential informal (bush); residential informal (low veg / grass); residential informal (tree)
- roads & rails (major linear)
- urban recreational fields (bare); urban recreational fields (bush); urban recreational fields (grass); urban recreational fields (tree)

N W E S

0,5 1 Kilometers



Kirkwood

Land Use

- commercial
- industrial
- residential formal (bare); residential formal (bush); residential formal (low veg / grass); residential formal (tree)
- residential informal (bare); residential informal (low veg / grass); residential informal (tree)
- roads & rails (major linear)
- urban recreational fields (bare); urban recreational fields (bush); urban recreational fields (grass); urban recreational fields (tree)

N W E S

0,5 1 2 Kilometers