Monkey Beetles on the Beat:

Urban Monkey Beetles Reveal Opportunities for Pollinator Habitat Management in a South African City

PhD Thesis

August 2021

Thesis presented for the Degree of Doctor of Philosophy in the Department of Biological Sciences, University of Cape Town, South Africa.

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1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
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Dedication

To all the big, little things which cannot be measured...

Midnight in the Emergency Room.
Her raised fingers are wide apart,
Demonstrating six millimetres.
I see the vastness of her miscalibration and pause.
Does it matter?

I contemplate the feet before me,
His in perpendicular geometry to my own,
Our lives tilted by those six.
Does their magnitude matter?

To a carpenter, scale matters.
To a scientist, validity.
In a sea of uncertainty,
We are those who navigate by numbers.

Measure twice. Cut once.

The raised fingers are mine this time: "This is six".
Says she:
"You may think it's small, but where it is it's huge!"

I swallow relativity, calibration, context, tolerances…

What are we measuring?
Tare six from the scale and it returns nothing.
Tare six from time when you cannot go back.
Tare six from life…
What are we measuring?

Six millimetres of bravery, when courage has no metric.

I dedicate this to the life returned, the courage that carries us through, and the six millimetres of joy we share.

Acknowledgements

An urban project which takes place in public space requires the co-operation and passive support of many. As such I have a very long list of people who played both big and small roles in making this project possible. I have tried as far as possible to be comprehensive and hope that I have not missed anyone important.

Firstly, thank you to my sponsors, the National Research Fund and the South African Systems Analysis Centre for the funding and capacity-building opportunities. Thank you also, to my supervisors Les Underhill, Kevin Winter, Jonathan Colville, for their generosity with their time, their considered commentary, and their invaluable guidance.

Land access and permission to carry out my research was an important hurdle and involved a myriad of individuals and the act of asking permission again and again. I am grateful to all the private land-owners who did not chase me away when I knocked on their doors. Especially those who made time to meet me and show me around their properties. This included the farmers and farm managers Oliver Parker at Altydgedacht, Johan De Swardt at Steenberg, Arno at Hillcrest, Karen and Nicol De Villiers at Roos en Boom, Craig Harris at Klein Constantia, Mr Cloethe on the Waarburgh Rd, the folks at Synsport, and the man whose name I forgot to write down who confronted a babbling woman on the forecourt of Carrotech but was mostly concerned about the security of my car.

Similarly, the work in Table Mountain National Park would not have been possible without the permits, support and assistance of those at SANParks, in particular Dr Deborah Winterton, Elmonique Pretorius and Chris Leech. I am indebted to those at Cape Nature, who smoothed my access to the city's nature reserves, particularly Penelope Glanville, Carlo Arendorf and the team at the permit office. Similarly, the Cape Town City officials Daniel Van Jaarsveld, Sihle Jonas, Sean Harold, Susan Steyn, Anneke Beskin, Lewis Afrika and Cliff Dorse were instrumental in obtaining city permission to conduct research in the community and district Parks.

I am humbled and grateful for the co-operation of the stewards and landscape managers who work and volunteer in a range of capacities caring for local and community parks. In particular Justine Thornton at Keurboom Park, Michal Muller at Kendal Rd Park, Francine Becker at Harfield Village Parks and Paul Barker at Arderne Gardens. I thank the contractors for their co-operation in sparing my observation patches the chop. In particular Francine Booyson, from Women on Board, who went so far as to phone me when she was working in the parks I was observing.

My field and lab assistants, Nazier, Unai Apodaka, Mat Arens, Andre Leith, Itxaso Quintana were each a boon in their own way, providing extra capacity when I needed it most. My work and life have been enriched by a fleet of anonymous souls who told me stories, wished me well, and replanted broken stakes in the ground when I was not looking. Your collective action has restored my faith in the goodwill of strangers.

There are some people whose roles shift so much over the years, that it is difficult to define what they are to you and one must be satisfied with the reductive term “Friend”. Those who I acknowledge now have variously been teachers, friends, confidants, fans, sounding-boards, counsellors and mentors. I therefore thank the “friends” who have each played unique roles in influencing or shaping my research. Especially Frances Taylor for continually pitching up and including me, David Gwynn-Evans for his botanical advice, Emma Aragundade for her courage and hugs, Pippin Anderson, Lizzy Kruger and Allesandro Ossola for reading my most wayward drafts, Firoz Khan for his continued encouragement of my research journey and Seth Musker for unlocking the world of R for me!

My parents raised me and always told me I was brilliant no matter how much I messed up. My father, whose office was filled with building plans, and head filled with dreams of new projects, inspired me to focus on the built environment, but he also loved *Leucadendron argenteum* (silver-leaf trees) and taught me how to use a field guide to identify my first bird (*Zosterops virens*). I am sure my parents believed they were long since rid of their responsibilities to me, yet they have continued to provide domestic and emotional support. Invaluably, they have provided endless help covering the gaps in childcare and generally been amazing grandparents!

Last, but not least, I must thank my family members. My children, Noah and Maia for the light they bring to my world, and my husband, Jo, who supports my 6 mm dreams and gently makes space for me, reconfiguring the dam and beavering our world into shape so I have everything I need to be able to shine.

Nomenclature/Glossary

Preamble: On Words and Their Adaptable Meanings

In the transdisciplinary space my work occupies, I have often noted how words take on different meanings in different mouths. To a statistician, “significant” requires a p-value. To a biologist, “fruit” is strictly a part of the plant containing seeds. When I first began talking about my research with conservation biologists, I would discuss the city in terms of “patches” and the conversation would migrate to “fragmentation”. I mention “city parks” to another colleague and notice the discussion focussing in on larger restorable fragments formally protected by the Cape Town City Council. It became a habit to notice words and specifically to notice how conversations pivot and tilt through mutual misinterpretation. Whilst it has often frustrated me and left me feeling like a victim of the fall of babel, it has also been a blessing. This awareness of different meanings and multiple options for selecting words has helped me to navigate cross-cultural spaces where English is even used differently in different regions by first-language speakers.

In order to orientate the reader to the use of language in this thesis, I have attempted to capture and define as many terms that have dichotomous meanings as possible. The list is not exhaustive, but exemplary. It has been generated based on questions arising from the review process by supervisors and colleagues from different backgrounds. Although the content has been read by people with backgrounds in sociology, geography, biology, urban ecology, and statistics, readers may also herald from different geographic regions where “turnover” may translate to “beta diversity”, or “garden” to “yard”, for example. Each reader comes with their own unique interpretation and perspective on what is “normal” and the “correct” meaning of a given word. These meanings often conflict with each other. I therefore ask that you read this thesis with a generous mindset for the contextual meanings and an awareness that I have grappled continuously and deeply with words, sub-texts, and confounded interpretations.

Nomenclature

- **Beta Diversity** The relationship between the total diversity (**Gamma diversity)** and the local site diversity **(Alpha diversity).** Beta diversity is a measure of species turnover.
- **City Park** Small to medium Public Open Space (POS) amenity, often including play facilities and street park amenities such as formalized paths and benches.
- **Extensive** a technical adjective. Extensive roof gardens have shallow soils <300 mm. extensive mowing regimes are infrequent, occurring a few times a year only.
- **Food Gardens** Community and residential subsistence and supplementary food production.
- **First event date** The earliest date at which a new observable phase in the life-cycle of an organism is observed. For example, the first flower to open in spring.
- **Fragment** An undeveloped patch of natural landscape with restoration or protection potential.
- **Gardens** Residential and commercial landscaped areas, managed predominantly for aesthetic and leisure purposes.
- **Green Infrastructure** Natural and planted landscapes within the city, including river and wetland systems, gardens and residential yards, greenbelts, POS, urban farms and tree canopies. Green infrastructure refers to all urban greening and is heterogeneous in its definition.
- **Heterogeneous** A group of components or individuals which possess distinct characteristics from each other. E.g. a heterogeneous landscape could encompass a complex patchwork of mixed uses, structures, coverings, vegetation, soil and socio-economic groupings.
- **Homogeneous** A group of components or individuals which are similar or the same. The opposite of heterogeneous.
- **Intensive** a technical adjective and synonum for deep, concentrated, or frequent. Intensive roof gardens have deep soils >300 mm. Intensive mowing regimes are frequent, occurring monthly or weekly.
- **Impervious** Does not allow water infiltration, root penetration, or faunal migration between layers.

- **Indigenous** Used to describe species that originate from the local, historical vegetation, biomes and ecosystems of South Africa. Describes first nation groups when attributed to humans (Indigenous people).
- **Mowing** Mechanical grass-cutting.
- **Multi-scalar** The analysis of one or more dimensions at categorical scales of assessment or interpretation. For example, short, medium and long-term temporal scale. Local, neighbourhood and regional scales.
- **Native** A wild and indigenous species of plant or animal. “Indigenous” is the preferred term by South Africans.
- **Patch** A piece of relatively homogeneous green infrastructure – in most instances, this refers to a city park or natural fragment.
- **Pollination syndrome** A suite of flower traits (e.g. bowl-shaped with a dark centre), that has evolved in response to natural selection by different pollen vectors. In the case of animal-aided pollination, in response to different animals.
- **Soil-sealing** A measure of impervious covering to the soil. This includes paving, asphalt and buildings.
- **Species Turnover** The change in species composition or community structure along an environmental gradient.
- **Urban Intensity** Similar to urban density but measured in percentage of soil sealing rather than building units per hectare.
- **Urbanisation** The transformation of land into urban cover over time.
- **Urban Adaptor** A species which has adapted its behaviour to anthropogenic landscapes and typically moves in and out of cities around the urban edge and suburbs.
- **Urban Avoider** A species which extirpates in the city or avoids urban environments by altering migratory routes.
- **Urban Exploiter** A resident urban species which take advantage of urban habitats and resources.
- **Yard** Small, landscaped area, associated with a residential dwelling. Usually referred to as a “garden” by South Africans.

Abstract

Against a backdrop of global declines in pollinators, evidence suggests that some guilds thrive in urban landscapes and relatively small interventions can provide habitat support in otherwise inhospitable urban landscapes. Despite this knowledge, there is a paucity of research on urban pollinators in Africa. This gap is noteworthy because Africa is a megadiverse region and southern Africa has three global biodiversity hotspots.

This thesis is a first step towards filling the Africa gap. It sought to do so by investigating urban monkey beetles (Coleoptera: Scarabaeidae: Hopliini) in two ways. Firstly, it relates Hopliini community structure to urban environmental gradients and local habitat composition. This was achieved by using pan traps to sample pollinators at 145 sites during two austral spring seasons in greater Cape Town in 2018 and 2019. The findings are that there were three divergent responses to urban landscape dynamics. 1) Those which exploited the urban environment. 2) Those which did not respond to an urban intensity gradient, but did respond to flower-richness, 3) Those which preferred larger, less disturbed sites at the edge of the city.

Secondly, ways that the management of Public Open Space (POS) and road verges can better support the connectivity of habitats containing endemic geophytes and spring annuals were considered. These flower populations provide breeding and foraging resources to Hopliini and other pollinators. They are an especially important resource to the group who are unable to move through or exploit the urban environment without them (Group 2 above). A mowing suspension was investigated to determine how long the indigenous spring show would take to complete the reproductive cycle and reach seed set. The study took a phenological approach to estimating the duration of the suspension. The findings indicate that mowing should be suspended for spring geophyte patches from the first week of August until after the first week of November. The charismatic *Baeometra uniflora* can be used as an indicator species for when the season has concluded. Methods of strategic landscaping and interplanting are discussed, noting that the peak flowering season in spring is followed by a lesser abundant summer show.

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Introduction and Background

Preamble

This is a thesis about pollinators in the urban environment of Cape Town. The research inevitably took me into several disciplines. It also is positioned at the interface between the natural sciences and the social sciences. My objective in this Introduction is to provide insights into each discipline, in such a way that whatever your main focus is, you will find here the background from other areas which are key to the arguments which follow. The background information is contextualized in the chapters which follow. You might find the introduction to your discipline pedestrian, but there will be readers who will need the detail to obtain the background.

Introduction

Pollinators are mainly insects and vertebrates (e.g. birds, bats and mice) which through their foraging or breeding behaviours visit flowers and transfer pollen from the anthers of one individual to the stigma of others thereby fertilizing the ovary so that plants can produce viable seed. Pollination services provided in this way are vital for the production of food and the reproduction of wild plant populations. Although many species pollinate by wind or are able to pollinate through autogamy (self-pollination), insects are responsible for up to 88% of wild plant pollination globally (Powney et al. 2019). Worldwide, the proportion of crops dependent on animal-aided pollination increased by 300% (by area) between 1961 and 2010, while managed beehives increased by 45% in the same period (Potts et al. 2010), leaving agricultural crops with a defecit in pollination services. This problem is compounded by overall global insect population decreases (Cardoso et al. 2020). In the last 20 years, insect biomass in Germany decreased by 75% (Hallmann et al. 2017) and a study in the UK measured widespread losses in a third of wild species of pollinators between 1980 and 2013 (Powney et al. 2019).

Loss of habitat, agrochemical-stress, fragmentation, disease, competition from aliens and climate change are listed as the nexus of interlinking threats to biodiversity and insect populations alike (Cardoso et al. 2020). Consequently, researchers are looking for ways to mitigate against losses and protect against population decreases (Samways et al. 2020). One area of research which provides some positive potential outcomes for the fate of pollinators (at least for some taxa), is in the refuge offered by cities. Cities have variously been touted as "refuges for pollinators", but "not a panacea for all insects" (Ives et al. 2015; Hall et al. 2017; Theodorou Radzevičiūtė et al. 2020), due to the mixed results rendered for different taxa and guilds (Wenzel et al. 2020).

While there is a relatively mature body of knowledge on urban pollinators from the temperate regions and the global north, studies are not represented evenly across regions and continents and there is a paucity of studies from Africa (Wenzel et al. 2020). Due to the concentrated biodiversity in South Africa, and specifically the biodiversity hotspot of the Western Cape (Mittermeier et al. 2011), agriculture in the region has an unusually large dependence on wild pollinator populations. Managed bees are not routinely used for apricot, peach and nectarine pollination and the declared reliance on managed hives was 41% of what is recommended in the international community in 2008 (Allsopp et al. 2008). The mega-diversity of the region presents an opportunity to understand how taxa, usually excluded from urban studies, respond to urban landscapes. The Cape Floristic Region (CFR) contains a centre of radiation for Hopliini (monkey beetles) (Goldblatt & Manning 2006; Ahrens et al. 2011), which are important pollinators for Aizoceae, Asteraceae and Iridaceae (Goldblatt et al. 2013; Kemp et al. 2019).

This study examines the potential that the Cape Town has for being a refuge for monkey beetles and makes management recommendations for urban landscapes so that they can support the floral and pollinator communities in the city.

Project Aims and Objectives

Aim One: To review the literature to identify opportunities for urban pollinator support/conservation in South Africa. The related objectives are to:

i. summarise pollinator studies from the South African context which have a landscape ecology component, including those from conservation, agriculture and ecosystem services backgrounds;
ii. systematically summarise global studies on urban pollinators; and

iii. compare and synthesize the global knowledge base with the body of knowledge from the South African context.

Aim Two: To investigate and compare monkey beetle species compositions across multiple land-cover gradients. The related objectives are to:

i. examine how monkey beetle community structure changes across urban environmental gradients of socio-economic status and urban intensity;
ii. compare monkey beetle communities in urban areas with natural and rural landscapes; and
iii. determine which flower communities are associated with monkey beetles in urban landscapes.

Aim Three: To determine a mowing suspension strategy for supporting the flowers associated with monkey beetles growing in Cape Town in community parks and public open space (POS). The related objectives are as follows:

i. identify common spring[1] bulbs, annuals and problem weeds flowering during spring in Cape Town's park lawns;
ii. determine a strategic duration for a mowing suspension in order that seed broadcasting can occur for spring geophytes growing in city parks; and
iii. determine the extent of phenological variability across land surface temperature gradients in the city.

[1] Seasons are austral. Spring occurs in September to November and autumn, March to May.

Chapter Layout and Structure of the Thesis

This chapter introduces the thesis, describes the theoretical framework, provides a background to the study of urban ecosystems and summarises the existing knowledge of monkey beetles. Chapters 2, 3 and 4 are arranged as journal papers. They can be read together as a series or separately. There is some overlap and a small amount of necessary repetition where concepts, theories, context and study rationale overlap – particularly in the introductory sections of each chapter. Chapter 5 presents an overview of the findings, a brief discussion, and recommendations for policy and future research. The paragraphs below provide more detailed orientation to Chapters 2, 3 and 4.

Chapter 2 synthesises two bodies of literature. Initially, a systematic review of the global studies on urban pollinators was undertaken, but this produced three urban pollinator studies from South Africa (Pauw & Louw 2012; Avuletey & Niba 2014; Mawdsley et al. 2016; Coetzee et al. 2018). This was inadequate to infer generalizations about South Africa. Thus, to compare and contextualize the global trends, it was written up as a synthesis review and related the international trends to knowledge about pollinators in agricultural and conservation contexts in South Africa. Searching for literature with keywords did not provide satisfactory results and so instead I searched reference lists for prominent authors, traced through appropriate papers. Appropriate literature was then extracted from their publication records. The chapter finds both similarities and contrasts between pollinator responses to urban and agricultural landscapes and discusses the potential for both habitat and floral resources in urban systems to support healthy pollinator communities in South Africa.

Chapter 3 presents findings on the distribution and drivers of monkey beetles across Cape Town. It maps community assemblages along urban intensity and socio-economic gradients and correlates monkey beetle species presence with flower communities. The findings suggest that urban environments can support healthy populations of monkey beetles and that landscape management with preferred flowers will improve habitats for both monkey beetles and indigenous flowering plant communities.

Chapter 4 proposes that strategic mowing practices can support the indigenous geophyte communities of Cape Town, most of which have documented mutualistic relationships with monkey beetles. Noting that seasons are austral; summer is November-February, autumn is March-April, winter is May to July and spring is August to October. It measured the duration of the reproductive cycle of common plants which emerge and bloom in road verges and POS during the late-winter to early-summer seasons and identifies a period for grass-cutting suspension. It then discusses the potential that this has for supporting plant-pollinator networks within the city and makes recommendations for management.

The thesis adopts a systems thinking approach (Meadows 2008) by considering the interactions between landscapes, habitats, flowers and pollinators, while remaining cognizant of the role that people play as active agents in altering and managing landscapes. People have the ability to adjust the conditions and management practices which determine species stocks and flows. The approach is best explained by unpacking the theoretical frameworks considered and adopted throughout the study to inform research direction, questions and thinking.

Key Concepts and Theoretical Frameworks

There are several theoretical concepts which were fundamental to the research design, analysis and discussion of this study. Two frameworks shape the context for the research. They were selected for their ability to identify and explain the processes and factors which are currently understood to influence urban pollinator assemblage and then synthesized into a holistic overview of the discipline, with specific focus on public parks and pollinators. The frameworks are the Mobile-Agent-Based Ecosystem Services model (MABES) (Kremen et al. 2007) and the hierarchical environmental filtering for cities framework (Aronson et al. 2016). Each chapter of the research draws on components of the synthesized framework in different ways so it is presented up-front to provide background information. The way in which it has informed the research is clarified progressively throughout the thesis.

Additionally, this section presents key concepts. Ecosystem Service (ES) emerges as a theme for the ways in which its assessment and valuation influences policy and design decisions. It is an integral concept for understanding the MABES framework in particular. The ES background information is therefore presented first, and briefly discussed for its role in decision-making and policy objective setting. Niche theory (Vandermeer 1972) is a key concept for interrogating habitat requirements and succession processes. It is introduced after the synthesized theoretical framework and, together with environmental gradient theory (Shochat et al. 2006) and the hierarchical filters framework (Aronson et al. 2016) is used to inform the research design and the analysis of the landscape effects on flower and pollinator communities.

Introduction to Ecosystem Services

Before introducing MABES, it is necessary to introduce the reader to ES. ES are defined as those “aspects of ecosystems utilized (actively or passively) to produce human well-being” (Fisher et al. 2009: 645) and therefore create an important link between ecosystem function and human well-being (Fisher et al. 2009). The *Common International Classification of Ecosystem Services* (CICES) was originally developed to ease the identification and communication of ES and to structure mapping, assessment and valuation studies (Czúcz et al. 2018). ES is commonly used as a concept for aiding environmental management decisions and policy making, and for setting objectives for the management of natural resources. The classification of ES should therefore be based on the characteristics of the ecosystem of interest and the decision context (Fisher et al. 2009).

Categories of ES are typically organized hierarchically under four main classifications. First, provisioning ES are the flows of energy and resources from which produce and materials are derived (e.g. food, industrial raw materials and building materials). Secondly, regulatory ES mediate the environment in which people live and benefit their physical health (e.g. clean air and pest control). Thirdly, cultural ES are aspects of the environment that are important to people's social and psychological well-being (e.g. aesthetics, spiritual meaning, leisure and social gathering). Lastly, supporting ES are those aspects upon which all other ES depend such as soil and oxygen production. The specifics of ES are organized into groups, types and categories in a hierarchical structure below these three classes (Czúcz et al. 2018).

Whether an ES is considered the final output or an intermediary in the ecosystem services production process depends on the benefits in which the study is interested. For example, clean water is the final product where the ES is water purification, however, it is the intermediary when freshwater fish is the ES of interest. Since different stakeholders may perceive different benefits from the same ecosystem, the benefit of interest can at times be in conflict and decision-makers may have to consider trade-offs for management applications (Fisher et al. 2009). Although the specific ways in which ES are valued is beyond the scope of this study, the trade-offs of ES decision-making are briefly revisited in Chapter 4, when a mowing strategy for the support of pollinator habitats in urban parks is discussed.

ES thinking is firmly located in the utilitarian value orientation to nature (Chan et al. 2016; Christie et al. 2019) and is thus solely based in measuring value through monetized and quantitative methods. Criticism of ES is based on this observation and acknowledges the role of both intrinsic value (the value of nature which is independent of human experience) and relational value (which is closely connected to biophilia, culturally generated and socially experienced) (Chan et al. 2016; Christie et al. 2019). People who are approaching ecosystem management from a relational or intrinsic value orientation, are likely to make different design and policy decisions, based instead on the ethic of "first do no harm", socio-cultural norms, identity, preferences or other social needs (Freeman et al. 2012; Chan et al. 2016), and more closely aligned with the observations made by environmental psychologists who study the ways and reasons people value their gardens (Freeman et al. 2012; Goddard et al. 2013). Key to MABES, are the economic and policy objectives for an ES. MABES is revisited in Chapter 2 (Figure 2.1.).

Mobile-Agent-Based Ecosystem Services (MABES)

In assessments of ES, the spatial arrangement of an ecosystem function is often geographically and temporally discrete from the location where the benefits of the service are felt (Fisher et al. 2009). Similarly, ecosystem services can be delivered by organisms which depend on habitats that are spatially or temporally separated from the location of the ecosystem service (Kremen et al. 2007). These organisms can be considered as mobile agents of ecosystem services. MABES is a conceptual model used to explore the ways in which changes in landscape cover, human activities, or policy frameworks can impact on those organisms providing the ecosystem service and although generalised to all agents of ecosystem services, the concept has its origins in assessing pollinator habitats, hence a critical component of the MABES model is the ES (pollination) output from the system (Kremen et al. 2007).

The usefulness of MABES is in the arrangement of the components of the system. It clearly makes the link between actions at the local site (land use and management), shaping the landscape structure, which in turn shapes the plant and pollinator communities. Interactions between the plant and pollinator communities produce pollination services (ecosystem services), which are of value to both food production and conservation outcomes. The ways in which ecosystem services are valued feed back into the economic and political systems of landscape management (Kremen et al. 2007). This circular model, with the human political and economic feedback loop, highlights the anthropogenic qualities of landscape management and provides valuable information for making policy and management decisions. The components of land use, landscape structure, plant communities, and policy and management decisions must therefore all be considered for their role in influencing pollinator communities and pollination service outcomes.

Environmental Filtering

The MABES model acknowledges the geographic context within which the system is situated (Kremen et al. 2007), however, it stops short of interrogating the landscape and geographic drivers of ecological assemblage. The hierarchical environmental filtering model synthesized by Aronson et al (2016) bridges this gap. It articulates landscape dynamics as nested, affecting community assemblages at various scales through environmental filtering. Aronson et al. (2016), identify three levels of species pools: 1. Regional species pool, 2. the urban species pool (city scale) and 3. the local community (habitat scale). Between each pool, there are inherent species characteristics and environmental factors which interact to filter out species presence. For species to be able to persist in urban environments, they need to be preadapted to urban conditions and elements of their existing habitats must remain intact within the urban landscape (McDonnell & Hahs 2015).

At the regional level, human facilitation creates a global biotic interchange between the regional species pool and the urban species pool. However, individual species traits, such as habitat selection and dispersal ability, determine whether or not they will extirpate, remain as urban residents, or invade from adjacent landscapes (McDonnell & Hahs 2015; Aronson et al. 2016). The likely separation of nesting and foraging habitats means that pollinator life-histories need to be clearly understood in order to determine their habitat requirements for nesting and the foraging ranges and trajectories for provision of ecosystem services in adjacent landscapes (Kremen et al. 2007; Langellotto et al. 2018; Zhao et al. 2019).

Within the urban environment, urban form and history, socio-economic conditions and cultural practices, species interactions and human facilitation determine the local community at habitat scale. These factors can make it difficult to compare cities because local city-scapes have different historical legacies of migration and trade, urban expansion and development land use succession processes which affect abiotic environments (Aronson et al. 2016).

In contrast to MABES, Aronsen's (2016) hierarchical filtering model gives only brief discussion of the role of policy-level decisions governing urban planning and landscape design. Instead, it draws on the body of literature emanating from the schools of environmental psychology and sociology, and frames the human drivers of local habitat structure and landscape dynamics as a socio-economic and cultural production (Clayton 2007; Gaston et al. 2007; Lubbe et al. 2010; Freeman et al. 2012; Mazumdar & Mazumdar 2012; Beumer & Martens 2014; Uren et al. 2015; Zhao et al. 2019). In contrast, MABES emphasises the way ecosystem services are valued and how this results in actions which drive a particular anthropocentric output. In this way, it makes explicit the role of policy and planning. In essence, the two models are looking at the same problem, but emphasise human facilitation at opposite ends of the “top-down”, “bottom-up” continuum of decision-making. Therefore, it is useful to combine both models into a consolidated framework for studying biodiversity and ecosystem services within urban landscapes (Figure 1.1).

A Theoretical Framework for Plant-Pollinator Assemblage in Urban Parks

The theoretical model (Figure 1.1) combines the elements of MABES and the hierarchical filters model with application to pollinators in urban parks. A more generalized model would include all categories of ecosystem services (ES): provisioning, regulating, supporting and cultural where this model includes the sub-classifications of pollination, and aesthetic, leisure and social (Czúcz et al. 2018). Aesthetics, leisure and social classifications represent the cultural ES of a city park, and pollination a regulating ES for the purposes of this study. Supporting and provisioning ES are beyond the scope of this study (examples of supporting ES in a park may include clean air and heat stress relief and a provisioning ES would come from foraged food).

Aesthetic, leisure and social considerations are the intended utilities of a city park and have direct implications for the design, layout and spatial arrangement of public space (Ahern, Cilliers & Niemelä 2014). These design aspects are indicated in Figure 1.1 notionally with “technical/ design specifications” as an outcome of policy decisions and the legislative environment and are an intermediary between objective setting and market forces. Specifications is the documentation which translates ES objectives into a park layout. In the case of pollination objectives, it would result in the specification of landscaping changes, such as the introduction of floral rich beds (Davis et al. 2017) or rehabilitated biodiversity areas (Anderson et al. 2014).

The second way in which ES objective-setting is noted in the framework is with “user requirements”. These are the bottom-up objectives which emerge through a stakeholder engagement process or individual agency such as over private land. Ahern, Cilliers & Niemelä (2014) proposed a transdisciplinary adaptive design and planning model which begins by defining the relevant urban ecosystem service goals for the plan. Their model encourages stakeholder engagement and co-production of urban planning, which has elsewhere been discussed as participatory action research (Borda 2001). Participatory action research is common practice among community development planners and change agents. The process of goal setting produces user requirements and policy objectives which act to inform the planning and design of community development projects (Ahern et al. 2014).

Management cycles are often a product of social norms and local cultural practices (Goddard, Dougill & Benton 2013; Tavasoliara and Bashiri 2015). Socio-economic status has been strongly correlated with biodiversity and tree canopy, but the reasons for the observable differences along socio-economic gradients are seldom unpacked (Melles 2005; Lubbe et al. 2010). Wealthier neighbourhoods are likely to be characterized by greater biodiversity due to larger residential plot sizes and greater resource availability (e.g. water availability and automated irrigation systems, garden staff, and time and means available to procure or propagate succession plants). Furthermore, there is a trend towards larger urban parks of better quality in wealthier neighbourhoods in South Africa (Venter et al. 2020) resulting in a “nature deprivation” at the poor end of the socio-economic gradient.

That urban landscapes are produced within a socio-cultural and economic context should not allow the role of the market forces of plant procurement to be overlooked. It presents a tension between cultural demand (preferences) for specific plants and the supply of what is sold in local garden centres (determined by logistical factors such as ease of propagation and growth speed) (Kendal et al. 2012; Garbuzov et al. 2017) as well as municipal procurement systems (Act 56 of 2003) and the related supply chains for the management of city land and public space. Any design aspirations are limited by the availability of materials in the marketplace, at the stage when they are translated into design specifications for procurement. Even rehabilitation efforts are mediated by propagation knowledge, germination and growing duration, available seed and parent plant stocks and prevailing paradigms about best practices. Thus, in this context, supply chain logistics mediate between ES and design or policy objectives and the landscape structure in urban landscapes (Aronson et al. 2016).

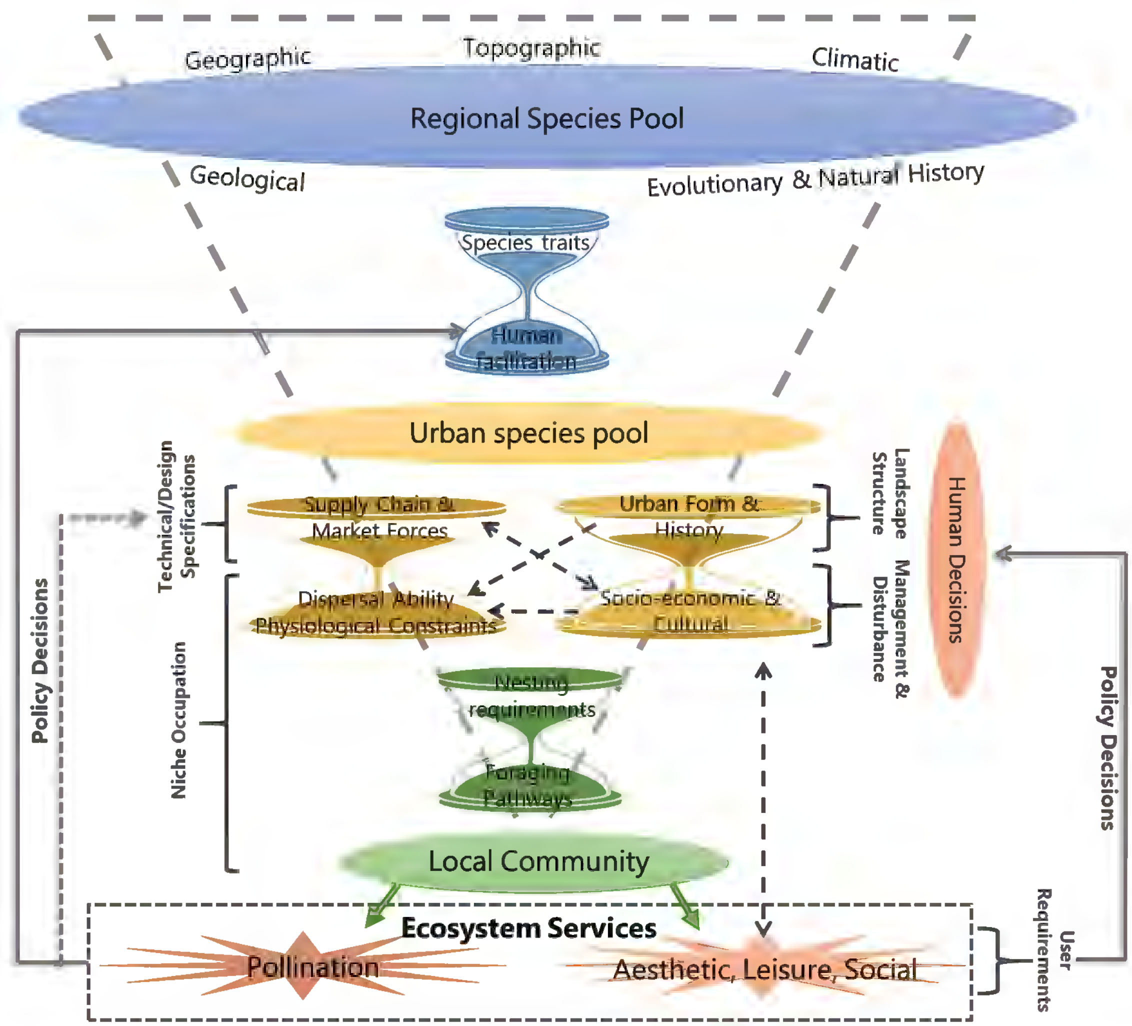


Figure 1.1 Theoretical framework for the study of plant-pollinator assemblages in urban and community parks

The theoretical framework (Figure 1.1.) illustrates the bigger picture background to this study and the study of urban ecology, more generally. This study focused on the role of city parks and public open space in supporting biodiversity. The MABES model is used on its own in Chapter 2 to structure the literature review on urban pollinators in South Africa. The hierarchical filtering model is used to generate hypotheses and methods in Chapter 3. Specifically, the landscape drivers and urban gradients drew directly from this framework. Mowing becomes a landscape-management leverage point which is targeted for consideration in Chapter 4, with the real-world objective of eventually influencing policy decisions. In Chapter 5, mowing is discussed with causal loop diagrams towards identifying a systems model for explaining the relationships in a bounded sub-system.

Niche Theory

Niche theory has also contributed to the understanding of how organisms assemble along the environmental gradients present in urban landscapes. Niche theory proposes that organisms arrange themselves in habitat niches to take advantage of gaps in resource availability which cannot be reached by competing species in the same environment (Grant & Grant 1982; Letten et al. 2017). Niches occur in both spatial and temporal dimensions (De León et al. 2014). An example of spatial dimensions are when birds forage from different parts of a large tree (Hirzel & Le Lay 2008), or a community of plants growing side-by-side have different root structures enabling them to access resources at different depths below the soil surfaces. In temporal dimensions, different organisms thrive in environments with different disturbance regimes or forage at different seasonal or diurnal patterns (De León et al. 2014). An extended definition of niche theory takes a systems approach and incorporates succession theory (Patten & Auble 1981). In Patten and Auble's (1981) conception of extended niche theory "Succession is the process of generating environ and realized niche dynamics in ecosystem development, leading to more exclusive organizations in mature stages" (Patten & Auble 1981: 893). After a disturbance, community assemblage changes through time as the environment becomes more stable. Consequently, environments which are disturbed too frequently are only able to support ruderal or pioneer species with short life-cycles and generalist organisms with a broad diet and non-specific habitat requirements.

Blair (1996) studied avian species along an urban-rural gradient and found that diversity peaked in suburban areas. He proposed the intermediate disturbance hypothesis could explain the observed phenomenon; moderate disturbance cycles allow for greater biodiversity to occur as both pioneering and slower-growing organisms sensitive to change in their environments would be able to take up occupation within a heterogeneous landscape (Connell 1978; Blair 1996).

Figure 1.1. depicts the graphical representation of the combined theoretical framework based on the works of Aronson et al., (2016) and Kremen et al. (2007). It has been updated from Aronson et al. (2016) to show the feedback loops which are facilitated by policy and individual decision making. In this instance the ES articulated are limited to cultural services and regulatory services, but it could include any of the values articulated by the IPBES as Natures Contribution to People (NCP) (Christie et al. 2019).

Background, Definitions and Principles of Urban Ecology

The study of nature was, for over 200 years, based on the ontological premise that it is something separate from human existence and that it would return to a state of equilibrium or balance driven by internal processes. By the late 1970s, a growing body of evidence demonstrated that the distinction between human and nature was erroneous and that human beings were intimately entwined in a system of dependency and influence (McDonnell 2011). We now see that human activities have irreversibly altered global meteorological patterns moving the planet from the Holocene to the age of the Anthropocene – an era in the earth's lifespan which is dominated by human activity (Crutzen 2002). The human-as-saparate-to-nature dichotomy in the study of nature was applied to the urban–wild continuum where urbanity was viewed as the antithesis of nature (McDonnell 2011). Consequently, conservation biologists and ecologists shied away from studying urban ecosystems preferring to focus on pristine landscapes representing the natural condition – a condition, it has been argued no longer exists in the purist sense anywhere on the planet (Corbyn 2010). In the 1970s, it became evident that nature within the urban context was not the depauperate system that was assumed, and that the ecological patterns and processes within cities were worth studying and considering for the potential that they held to support wildlife. Since then the field of urban ecology has grown globally and is becoming an integral part of city planning considerations in many parts of the world (Adams 2005).

Departing from traditional preservation and restoration approaches to natural landscapes, Roux *et al.* (2014) made the case for planning and management policies that retain and restore key habitat structures in urban environments. They found the probability of key habitats occurring within cities to be lower than reserves but comparable with agricultural landscapes (Le Roux et al. 2014). One area that could provide opportunities to supplement habitats, may lie in the management and design practices of city parks, private gardens and yards – collectively termed 'gardens' for convenience within this study. The idea that gardens could make a worthy contribution to urban biodiversity stewardship has been posited by many (Gaston Smith et al. 2005; Smith et al. 2006; Gaston et al. 2007; Davies et al. 2009; Doody et al. 2010; Goddard et al. 2010; Beumer & Martens 2016). In medium-density cities, gardens can represent a significant percentage of the urban green space (Gaston Warren et al. 2005). Dewaelheyns, Kerselaers, & Rogge (2016) propose that although the individual patch size of a garden is small, the collective land area is substantial enough to provide stepping stones within the urban fabric, contributing to a cumulative impact that makes for a "tyranny of small decisions". Although cummulatively important, they represent a challenge to biodiversity stewardship because they are subject to private property rights and conflicting citizen demands for utility or aesthetic. Thus, the structure of the garden habitat is determined by social drivers (Uren et al. 2015) and policy frameworks, and moderated by the supply-chain of the plant trade (Garbuzov et al. 2017). The drivers of garden design choice are seated both as factors of the social community and the autonomous individual. Community-level drivers include social norms and culture (Nassauer et al. 2009) and economic standing (Ikin et al. 2015), whilst individual drivers include personal values (Freeman et al. 2012), stage in life-cycle, attitudes and preferences (Kendal et al. 2012).

Urban ecology as a field has multiple and cross-disciplinary origins. Consequently, those who have sought to define urban ecology have done so from within the perspectives of the discipline(s) in which the respective research on urban ecology has been nested (McDonnell 2011). The changing perspectives have considered ecology within cities – focusing on non-human organisms - and the ecology of cities – which encompasses landscape ecology and social processes. Wu (2014) added a third characterisation to the sustainability of cities which includes issues of complex adaptive systems, resilience and ecosystem-service management. However, it is perhaps McDonnell's (2011: 9) definition that is most useful to this thesis:

“urban ecology integrates both basic and applied natural and social science research to explore and elucidate the multiple dimensions of urban ecosystems”. Wu (2014) attempted to merge all of these ideas and to unpack McDonnell’s “multiple dimensions of urban ecosystems”. He defined it as “The study of spatiotemporal patterns, environmental impacts and sustainability of urbanization with emphasis on biodiversity, ecosystem processes and ecosystem services.” and acknowledged that “Socioeconomic processes and urban planning practices profoundly influence urbanization patterns and thus contribute to, but cannot alone constitute, the scientific core of urban ecology”. In this way, Wu (2014) placed the discipline firmly within the realm of the life-sciences, viewing planning and sociological aspects as informants of the biological processes which are the primary focus.

In trying to characterise urban ecology, Pickett & Cadenasso (2017) (and earlier work: Cadenasso & Pickett, 2008) defined five meta-principles encompassing 13 nested principles that are deductive and focus on general ideas. The deductive principles are useful in establishing a mindset or approach towards the study of urban ecosystems. As many of the principles form the backbone of the assumptions which will be taken by this PhD it is worth reproducing them here:

1. “Cities and urban areas are human ecosystems in which social-economic and ecological processes feedback to one another.
2. Urban areas contain remnant or newly emerging vegetated and stream patches that exhibit ecological functions.
3. Urban flora and fauna are diverse, and this diversity has multiple dimensions (e.g. taxonomy, phylogenetics, function, geographic origin).
4. Human values and perceptions are a key link, mediating the feedbacks between social and ecological components of human ecosystems.
5. Ecological processes are differentially distributed across the metropolis and the limitation of services and excess of hazards is often associated with the location of human communities that are poor, discriminated against, or otherwise disempowered.
6. Urban form is heterogeneous on many scales, and fine-scale heterogeneity is especially notable in cities and older suburbs.

7. Urban form reflects planning, incidental and direct effects of social and environmental decisions.
8. Urban form is a dynamic phenomenon and exhibits contrasts through time and across regions that express different cultural and economic contexts of urbanization.
9. Urban designs and development projects at various scales can be treated as experiments and used to expose the ecological effects of different design and management strategies.
10. Definition of the boundaries and content of an urban system model is set by the researchers based on their research questions or the spatial scope of its intended application.
11. Urban comparisons can be framed as linear transects or as abstract gradients, and the abstract comparisons acknowledge the spatial complexity of urban heterogeneity.
12. Urban land covers and land uses extend into and interdigitate with rural or wild land covers and uses.
13. The flux of water including clean water supply, waste and stormwater management, is of concern to urban and urbanizing areas worldwide and connects them explicitly to larger regions."

In contrast to the inductive guiding principles put forward by Pickett & Cadenasso (2017), Forman (2016) generated deductive principles using a bottom-up approach grounded in a review of the empirical evidence of 70 years of research. The resulting 90 principles provide us with a resource documenting established patterns associated with the urban condition. These principles have more pragmatic applications for planning as opposed to framing research approaches and can provide us with a set of assumptions that can be used as inputs into models, as a basis for generating hypotheses and for decision-making. Whilst Pickett & Cadenasso's (2017) principles will be reflected throughout this thesis in the type of questions this research seeks to answer, Forman (2016) provided a sense of where the gaps in the collective understanding of process and pattern might lie or require refining against contextual nuance.

Wu (2014) further discussed four pattern themes under the banner of "... advances in urban ecology" providing background insights into some of the points expounded by Forman (2016), specifically:

1. Spatiotemporal patterns of urbanization, (the study of which has been aided by GIS and remote sensing technology): There is a global trend of decreasing landscape structural heterogeneity which is related to the homogenization of biological diversity worldwide. In short, cities in different geographic areas tend to be colonized by some common species. Furthermore, the fractal features of cities have been recognized when size-based scaling patterns have been investigated.
2. Urban biodiversity has been a major research focus. Urban development decreases the amount of habitat for native species and increases habitat fragmentation; however, the effects of urbanization vary with taxonomic groups, environmental conditions and socioeconomic settings. General findings include an increase in species richness and an increase in the number of exotics (alien species). Bird species richness tends to remain constant and soil microbe density tends to decrease. Richer neighbourhoods tend to have higher biomass and biodiversity – a phenomenon known as the "luxury effect".
3. Wu (2014) discusses ecosystem processes and conditions, including, Urban Heat Island Effect, the water cycle, and net primary product along urban-rural gradients, which together contribute to altered phenology within the urban landscape.
4. Lastly, the effect of urban ecosystem services on human well-being is discussed for the positive correlation of access with better health, while acknowledging the potential for crime and anti-social activities emerging within ecosystems that are under-utilized (ie, if a POS or green corridor is not used enough by people, it becomes a crime hotspot). Wu (2014) proposes that there is an optimal level of use that provides ecosystem service benefits whilst mitigating social risk.

Themes one, two and four vary with urban form, history and social dynamics, and therefore justify an in-depth consideration of the local context.

Study Area: Cape Town

The City of Cape Town (Cape Town) (Figure 1.2) is a major metropolitan municipality in the south-western corner of the Western Cape, South Africa. It is a coastal city, situated on a peninsula with 294 km of coastline. It has an estimated population of 4.4 million people, growing at a rate of 2% per annum, and is the second-largest economic hub in the country after Johannesburg (South Africa 2020).

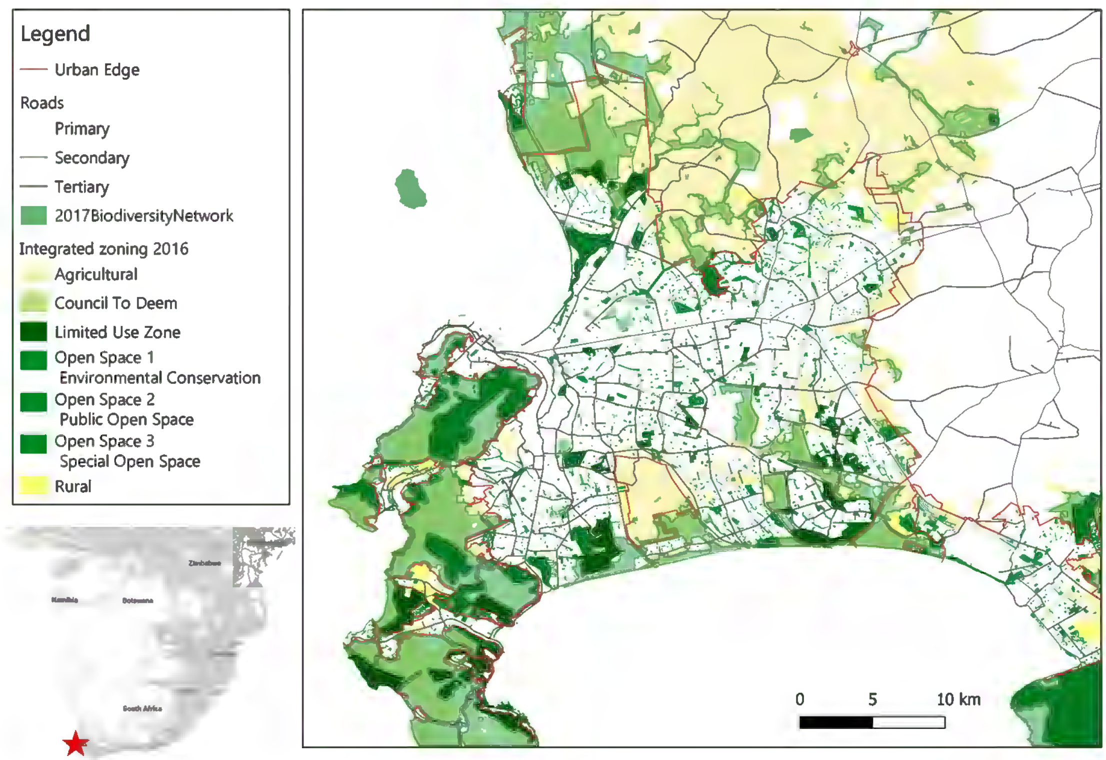


Figure 1.2 Cape Town City is located on a peninsular on the South West Coast of Africa. The map shows publicly accessible open space (in green) and rural and agricultural land (in yellow). The large green area to the West of the city and in the South Peninsular is the Table Mountain National Park. Study sites were selected from this map which has been generated from the City of Cape Town's zoning scheme (2017), and the Biodiversity Network (2017

Cape Town is situated within the Cape Floristic Region (CFR) which is a biodiversity hotspot (Cowling et al. 1996; Mittermeier et al. 2011). The plant species richness is due to the exceptional turnover between moderately species-rich sites in different habitats. The greatest beta diversity, encompassing almost complete turnover, occurs along soil fertility gradients. The flora is also characterised by a high degree of rarity (Simmons & Cowling 1996).

The city is home to 3250 native plant species, of which 13 have gone globally extinct and 319 are threatened on the IUCN Red List. This number represents 18% of the threatened red-list species in South Africa. Although 17% of the city area is formally conserved exceeding the national target of 10%. When the percentage of protected areas are measured for each of the 19 vegetation types occurring in the city, national targets are not met for eight (Rebelo et al. 2011). The most threatened ecosystems occur on the lowlands, known as the “Cape Flats”. Indeed Underwood et al. (2009) assessed global Mediterranean ecosystem threats and found that the lowlands were the most critically threatened Mediterranean ecosystem in the world.

The history of urban ecology in Cape Town has had a notable biodiversity emphasis. This began with the works of Tony Rebelo and Pat Holmes (Rebelo et al. 2011; Cilliers & Siebert 2012) and culminated in the establishment of the Biodiversity Network which was promulgated into the Municipal Spatial Development Framework (Holmes & Pugnalin 2016); a critical urban planning tool in the municipal legislative and policy frameworks. Although studies on urban biodiversity in Africa are rare, three studies have considered birds in Cape Town. Pauw & Louw (2012) established that the southern double-collared sunbird (*Cinnyris chalybeus*) was found throughout the city, but that malachite sunbirds (*Nectarinia famosa*) did not penetrate more than 1 km into the city, and orange-breasted sunbirds (*Anthobaphes violacea*) and cape sugarbirds (*Promerops cafer*) were absent across the entire urban gradient except in pristine natural environments. They suggested that the functional diversity of this guild could be restored across the city with strategic garden planting and the introduction of favoured plants (Pauw & Louw 2012). A more general study on birds in gardens emphasised supplementary feeding, the presence of nectar-carrying plants and improved density of indigenous flowering plants supported greater richness of nectarivorous birds, while opportunistic urban adjustment was facilitated by large vegetated areas in gardens and limited by the distance to the nearest natural habitat (Coetzee et al. 2018). In contrast, movement of weavers (Ploceidae) is not limited by urban land use. Instead, when compared with urban land use, the greater impact occurs from increased wetland isolation and a loss of wetland patches in the overall landscape network indicating that, in this context, wetland patch management will matter more for wetland passerines than urban landscape management (Calder et al. 2015).

In addition to local landscape variability, the city is home to socio-economic diversity (Wilkinson 2000; Rebelo et al. 2011). Cape Town has a long history of spatially planned social segregation, exclusionary control of movement and legislated dispossession of land (Table 1.1). The Gini coefficient is a measure of economic equality. The closer it is to 1, the more unequal the society, the closer it is to 0, the smaller the difference between the individuals with the highest income and the lowest income. In 2016, Cape Town's Gini coefficient was estimated at 0.62 against the national value of 0.63, ranking it as one of the most unequal societies in the world (South Africa 2020). Consequently the relative usage and ease of access to the city's natural resources is an important topic for restitution policy to consider in terms of extending the well-being benefits of nature access to impoverished communities (Donaldson et al. 2016). Donaldson et al. (2016) established disproportionate usage of Table Mountain National Park (TMNP) from the wealthiest communities living adjacent to the mountain and almost no routine access from communities on the Cape Flats. Although the city's population is predominantly non-white, only one quarter of the visitors to TMNP are black South Africans (Donaldson et al. 2016). The issue of lack of access to quality urban nature is further compounded by an unequal spatial distribution of city parks and other leisure POS resources within the city which are positively correlated with income and disproportionately available to "White" groups (Venter et al. 2020). Furthermore, the poorest communities regularly suffer ecosystem disservices, because they have settled on the Cape Flats, which, are prone to persistent seasonal flooding (Wilkinson 2000) in an ecosystem which is characterized by ephemeral flooding (Rebelo et al. 2006). This speaks to a nature impoverishment which disproportionately affects the poorest communities of Cape Town and should be viewed as a human rights violation.

Cape Town's long history of migration, colonization, slavery and contested territory (Table 1.1) have resulted in a city that is, today, a multi-cultural metropolis. The region has three official languages, including English and two local languages, Afrikaans and Xhosa.

Table 1.1 The political and socio-ecological history of Cape Town synthesised from Wilkinson (2000); Lubbe et al. (2010); Rebelo et al. (2011); Cilliers & Siebert (2012); Holmes & Pugnalin (2016) and updated with newspaper and legistlative sources post 2016.

DATE	HISTORICAL EVENT
1500s	Mostly occupied by agrarian indigenous people. Occasional bartering with passing ships.
1652	Established as a colony first by Portuguese then alternately by Dutch and British Occupation. Settlement is predominantly limited to Table Bay and Upper Table Valley.
1658	Expansion of farming along Eastern slopes of Table Mountain, disrupting traditional grazing routes of local people.
1700	No animals larger than 50 kg are found within 200 km of Cape Town.
1700s	British colonial rule benefits the colony with preferential trading arrangements and expanding imperial interests in the Far East. Slave trade brings skilled workers from Malaysia to help with construction and trades.
1800s	Small-scale enterprises begin emerging to compete with artisanal activities undertaken mainly by skilled Muslim craftsmen.
1894	Glen Grey Act (of 1894) establishes "Bantu Territories" aimed at promoting British labour interests in black communities. Black-owned land was declared commonage and could not be mortgaged.
1834	Emancipation of slavery
1901	First moves to segregate ethnic groups ostensibly to check the spread of bubonic plague in densely populated, racially-mixed, inner-city areas.
1902	End of the South African War between the British and the formerly Dutch, Afrikaans settlers.
1910	Formation of the first government under the Act of Union, unifying the white populations of the country and establishing centralized state and a common "Native Policy".
1913	Promulgation of the Native Land Act (27 of 1913) legislates land dispossession and spatial segregation. Prohibits "native" people from buying or hiring land in 93% of South Africa.

1923	Promulgation of the Natives (Urban Areas) Act (21 of 1923) which controlled and restricted the movement of "native" people within the city.
1927	Establishment of the first "Model Native Village" on the Cape Peninsula at Langa.
1920s	Municipality develops public housing estates on the Cape Flats specifically designated for "coloured", working-class families descended from the Khoi, San and Philippine/Malay brown-skinned groups.
1930	The first piece of Cape Town land is set aside for conservation at Cape Point
1930s	Haphazard growth is gradually replaced by systematic planning and development.
1948	Growing anxiety over mixed racial slums and "The native problem" fuel the narrow electoral victory of the National Party (NP).
1950	Promulgation of the Population Registration Act (30 of 1950) into law forces people to register their race classification as "Bantu" (South-Central African descent), "Coloured" (Malaysian, mixed-race, Khoi and San descent), or "White" (European descent).
1950	Promulgation of Group Areas Act(41 of 1950). Neighbourhoods are zoned by racial groups.
1958	Table Mountain is declared a National Monument
1960s	Forced removals of non-whites from "Whites only" areas and the relocation of an estimated 150 000 people to public housing estates and Townships built on the white sands of the Cape Flats.
1970-1990	Growing civil unrest in the struggle against Apartheid Planning.
1990	General election to end Apartheid.
1990s	Expansion along commercial corridors and establishment of decentralized commercial nodes.
1994	First completely democratic election in which all racial groups exercised their voting rights. The establishment of a new non-racial government and the electoral victory of the ANC.

1994–1999	Redistribution and Development Housing Policy (RDP) sees the large-scale roll-out of low cost-housing to the urban poor.
2001	Establishment of the urban edge in the Cape Town Spatial Development Framework to promote densification, access to well-located land for the urban poor and the protection of conservation areas.
2004–2008	The housing boom sees rapid urban expansion on the Cape Flats.
2010	2010 world cup financing is used to roll out infrastructure development and upgrade of public transport systems and the establishment of a Bus Rapid Transit system (BRT).
2011	Systematic assessment of biodiversity, conservation planning and initiatives to halt loss.
2011–2017	Housing delivery slows.
2012	Biodiversity Network is established and included in the urban planning framework for Cape Town.
2016	The urban edge is moved to accommodate informal settlement expansion into TMNP from Imizamo Yethu informal settlement and Sun Valley; and into the Atlantis and Philippi Horticultural areas respectively.
2016	Transit-orientated development strategic framework (Policy Number 46487) prioritizes public and non-motorized transit and accelerated development zones to incentivise urban densification and commercial development in priority areas.
2013–2020	Vandalism and theft on railways lead to the collapse of the Cape Town Metrorail infrastructure (Githahu, 2021).
2019	Cape Town declared the most biodiverse city in the world by the UN
2020	Housing delivery is suspended by national government and replaced with in-situ upgrades and site-servicing of informal settlements.
2021	Western Cape Government releases draft inclusionary housing policy for public comment, incentivising developers to make affordable housing available below market rates (Western Cape Government, 2021).

Both the social and ecological heterogeneity of Cape Town produce a complex and layered set of landscape dynamics which drive the biodiversity and community assemblages of the city. It is characterized by steep socio-economic gradients, social segregation and biodiversity heterogeneity. These spatial dynamics provide opportunities for study by stratified research design across different environmental gradients.

Monkey Beetles (Order: Coleoptera, Family: Scarabaeidae, Tribe: Hopliini)

A cantharophily (pollination by beetles) system in the temperate regions of the world has been described involving a generalist pollination system associated with odourless, bowl-shaped flowers with dark centres and "beetle spots" (Dafni et al. 1990; Picker & Midgley 1996; Van Kleunen et al. 2007). This system, also known as the painted bowl pollinator syndrom, is best exemplified by monkey beetles (Scarabaeidae: Hopliini) (Figure 1.3), a clade of flower-visiting beetles that show their greatest diversity in South Africa, with ~60% of the world's taxa (Colville et al. 2018). Pollination in this system occurs when beetles alight on flowers during feeding or mating activities. Hairs (setae) on the bodies of the beetles collect pollen and transport them between flowers as they move around. Contact with the stigma occurs as the beetle crawls across the flower into the floral cup (Bernhardt 2000; Van Kleunen et al. 2007; Goldblatt et al. 2013).

Picker & Midgley (1996) identified three guilds of monkey beetle based on behaviour and floral preference:

1. Embedding beetles attracted to long-wave colours (yellow, orange, red), the females embed themselves in the centre of the flower and the males fight over them until a successful male copulates with the female. Males fly around much more than females and are responsible for the majority of pollination services (Picker & Midgley 1996; Karolyi et al. 2016). This guild is relatively smooth-bodied, without setae on the elytra and with marked sexual dimorphism; seen and colour and hind legs (Picker & Midgley 1996; Colville et al. 2018).
2. A non-embedding guild that prefers long-wavelength colours and is more active in their behaviour than guild 1.
3. A non-embedding guild preferring short-wave (blue, violet, pink) colours (Picker & Midgley 1996; Van Kleunen et al. 2007; Colville et al. 2018).

Figure 1.3 Field photographs of monkey beetles. Top, Left to right: Males of Heterochelus sexlineatus *sp. On* Seneceo *sp. Flower; Two male* Heterochelus gonager *in an observation jar;* Platychelus lupinus *on* Moreae *sp. Bottom, left to right: A handful of* Heterochelus hybridus *collected on* Cotula turbinata *at Rondebosch Common; A female* Heterochelus *sp. buries her head in a* C. turbinata; *A sample of monkey beetles, sorted and drying for identificationin the laboratory; it contains a collection of* Lepithrix, Heterochelus *spp. and* Chasme jucunda.

Picker & Midgley (1996) investigated the relationship between pan-trap colour visitation and flower colour visitation and found that the pan trap colours in which monkey beetles were caught did not always match the flower colour that the beetles were visiting. They determined that monkey beetles visit flowers according to a hierarchy of preference and would visit a second-choice colour when their primary preference was unavailable (Picker & Midgley 1996; Van Kleunen et al. 2007). The choice of host flower, based primarily on colour, suggests that monkey beetles are mostly generalists. Steiner (1998) confirmed that each flower species tended to be visited by at least two species of monkey beetle. The number of monkey beetle species visiting an individual flower of a plant species varies according to attractiveness and specialization. The most attractive plant species are visited by up to five species of monkey beetle, while specialist flowers are dependent on a single species of monkey beetle for pollination services (Mayer et al. 2006).

Early observations of embedding behaviour assumed that the behaviour was destructive to flowers (Dafni et al. 1990); however, later studies established embedding species delivered effective pollination services (Steiner 1998; Mayer & Pufal 2007). On examination of the mouthparts and stomach contents of monkey beetles, Karolyi et al. (2016) found embedding species had pollen and nectar in their gut contents, suggesting that the embedding behaviour may be linked to other aspects, such as thermoregulation. Mayer & Pufal (2007) further established through pollinator exclusion, that beetle-pollinated Aizoaceae and Asteraceae require monkey beetles to facilitate pollination and are unable to self-pollinate (autogamy), concluding that they are "obligate out-crossers", dependent on monkey beetles, for pollination services (Mayer & Pufal 2007).

Monkey beetles in the winter-rainfall Cape region are most active between 11 am and 3 pm during the austral spring season (Goldblatt & Manning 2011). Although it is accepted that monkey beetles are effective at moving over relatively short distances (Goldblatt & Manning 2011), no studies have specifically explored the flight paths and foraging ranges of monkey beetles. Anecdotal observations from Colville et al. (2002) note that marked individuals of *Lepthrix* travelled at least 500 m in 1 hr and Mayer et al. (2006) observed that monkey beetles can fly 2 km in 60 min during times of flower shortages. It is unclear the extent to which landscape features and disturbance are limiting to monkey beetle mobility.

Two studies have examined the effects of grazing on monkey beetle community structure (Colville et al. 2002; Mayer et al. 2006). In the first, clear turnover of species occurred along a disturbance gradient as monkey beetle communities shifted from non-embedding guilds to embedding guilds (Colville et al. 2002). Both studies demonstrated that embedding monkey beetles were more closely associated with ephemeral and annual species of Asteraceae which flourish under disturbed conditions (Colville et al. 2002; Mayer et al. 2006). In contrast, non-embedding guilds were only found in low-grazed areas where perennial plants were able to persist (Colville et al. 2002), indicating a greater habitat sensitivity amongst this guild of monkey beetles (Goldblatt & Manning 2006). The blue and white flower pollination syndrome of the non-embedding monkey beetle guilds are typical of the painted bowl syndrome generally ascribed to monkey beetle pollination (Picker & Midgley 1996; Goldblatt & Manning 2011; Goldblatt et al. 2013). The flowers tend to be zygomorphic, varying in-depth in the corolla and tend towards longer flowering periods and herbaceous woody flower structures (Picker & Midgley 1996). Visitors of blue flowers are associated with bowl-shaped *Babiana villosa, Babiana nervosa* and the blue form of *Pauridia capensis* (Goldblatt & Manning 2011), as well as *Salvia africana-caerulea, Lebostemon* and *Pelargonium* (Picker & Midgley 1996), which have longer flowering seasons and are woody, perennial shrubs that do not persist in grazed landscapes.

Juvenile monkey beetle larvae are fossorial (life in the ground), feed on organic matter and emerge in the spring and summer as adults. The adult phase is short, spanning three to four months between August and January (Goldblatt & Manning 2011), necessitating that field observations are undertaken during this window. Some unusual fossorial and mating behaviour has been observed in two species of monkey beetles which occurred independently of flowers. *Platycheles brevis* have been observed emerging and swarming. As the females dig themselves back into open ground, the males compete to mate with them (Picker & Midgley 1994). In Renosterveld *Hoplocnemis crassipes* was observed alighting on the stems of *Eriocephalus ericoides* (wild rosemary), a dominant shrub species in Renosterveld, and crawling down to the ground and burying themselves (Picker & Midgley 1994). No male competition was observed. The beetles were uninterested in the arial parts of the plant and excavations around plants revealed that they congregated in the depth 2-8 cm from the surface and within a radius of 20 cm of the rootstock (Picker & Midgley 1994). Although *Hoplocnemis crassipes,* does not appear to be a pollinating beetle, its behaviour serves as a reminder of the importance of the sub-terranean part of monkey-beetle life, and the possibility of mutualistic relationships with plant root systems which are likely to be as important to ecosystem function as the pollination services.

Conclusion

The evidence from previous studies of monkey beetles suggests that some monkey beetle guilds present characteristics of tolerance to disturbance, and species assemblage is closely associated with specific flower communities. Together, these factors would make them likely to be present in urban environments. What is not known, is the extent to which monkey beetles might be able to seek refuge in urban landscapes and how they are limited or facilitated by the patterns of land use, and the available resources. Cape Town is a heterogeneous environment, with layered heterogeneity both in the underlying natural ecosystems and the socially and culturally produced landscapes of the city. Finding management solutions which can be applied across different contexts towards improving the quality of natural landscapes for both fauna and people is of paramount importance in this context.

- 2 -

A Review of the Opportunities to Support Pollinator Populations in South African Cities

Abstract

Globally insects are declining, but some guilds of pollinators are finding refuge in urban landscapes. Although the body of knowledge on urban pollinators is relatively mature, studies do not represent regions and taxa evenly and there is a gap in research from the African continent. This chapter aimed to identify opportunities to improve urban habitats for pollinators as well as the research gaps on urban pollination in South Africa. It reviewed the international literature on urban pollinators and the South African literature on pollinators with a landscape ecology focus, drawing on literature with an emphasis on agricultural and ecosystem services. The findings show that some taxa do well in urban environments only if local habitats are supportive of their needs. Potential interventions to improve habitat quality include strategic mowing practices, conversion of turf-grass to floral rich habitats, scientific confirmation of lists of highly attractive flowers, and inclusion of small-scale flower patches throughout the urban matrix. Further research is needed to fill the Africa gap for both specialized and generalized pollinators (Diptera, Halictids, Lepidoptera and Hopliini) in urban areas where ornamental and indigenous flowering plants are valued. Native, high-pollen carrying alternatives to Eucalyptus and non-native weeds e.g. Echium, need to be identified to support managed honey-bee hives year-round.

Introduction

Overall insect populations are in decline (Cardoso et al., 2020). In the last 20 years, insect biomass in Germany decreased by 75% (Hallmann et al., 2017) and a widespread study in the UK measured decreases in a third of wild species of pollinators between 1980 and 2013 (Powney et al., 2019). Loss of habitat, agrochemical-stress, fragmentation, disease, competition from aliens, and climate change are listed as the nexus of interlinking threats to biodiversity and insect populations alike (Cardoso et al., 2020), and researchers are looking for ways to mitigate against losses and protect against decreases (Samways et al., 2020). One area of research which provides some positive potential outcomes for the fate of pollinators (at least for some taxa), is in the refuge offered by cities. Cities have variously been touted as "refuges for pollinators", but "not a panacea for all insects" (Ives et al., 2015; Hall et al., 2017; Theodorou et al., 2020), due to the mixed results rendered for different taxa and guilds (Wenzel et al., 2020). Furthermore, the global increase in the proportion of land cultivated with pollinator-dependent crops, implies a greater reliance on managed pollinators (Aizen et al., 2019). The potential of urban environments to contribute to the conservation and management of pollinator habitats has therefore been highlighted as an important component in conservation planning (Hall et al., 2017). Investigating management interventions to support them in urban landscapes becomes paramount.

The body of knowledge on urban pollinators is relatively mature in the Global North and growing in the developing world, making it possible to systematically review the literature and begin to draw generalizations and comparisons (Wenzel et al., 2020). Unfortunately, regions are not evenly represented. In 2013 only 4% of data on pollination was produced from the entire continent of Africa (Archer et al., 2014). In consideration of ecosystem service and green infrastructure more generally, du Toit et al. (2018) found only 38% of sub-Saharan countries had carried out any research on the topic (du Toit et al., 2018). More recently, Wenzel et al. (2020) reviewed 141 studies of urban pollinators and found that most studies had been produced by temperate and developed countries (117 and 120 studies respectively) and tropical and developing countries have produced only a fraction of these (24 and 21). There is poor representation from Eastern Europe and the African continent, where they identified only a single study from Ghana (Guenat et al., 2019). To this, two studies on sunbirds can be added (Coetzee et al., 2018; Pauw & Louw, 2012) and one on butterflies (Avuletey & Niba, 2014) from South Africa. Due to regional differences, this lack of knowledge from the African continent leaves a gap in the understanding of how pollinators are responding to urban landscapes, particularly in the rapidly urbanizing context of the Global South (Wenzel et al., 2020).

The above gap makes it challenging to review potential opportunities for urban pollinator management in southern Africa. While developments in urban pollination studies have been nearly non-existent, there is a greater body of knowledge available from another landscape subject to anthropogenic change: Agriculture (Melin et al., 2014, 2018). Urban landscapes are one of several examples of near-total habitat transformation, in which the natural habitat is almost completely replaced. In the urban context, the replacement is by buildings, roads, and introduced plants. Similarly, agricultural landscapes have replaced natural habitats. The latter are destroyed and usually replaced by monocultures; the most extreme of which being cereal crops, which are wind pollinated and require no animal agents for reproduction. Like urban landscapes, agriculture produces fragmentation in the natural landscape, and generates barriers to sensitive faunal species movement through the introduction of pesticides and agro-chemical (Lenhardt et al., 2013). In comparison, barriers and extirpations are generated by road networks and buildings in urban landscapes. Another similarity between the transformation of urban and agricultural landscapes is the scale and intensity at which it occurs (Wellmann et al., 2018). Therefore, in the absence of regional studies of pollinators in urban landscapes, studies of pollinators in agricultural landscapes become useful for reflection on the impact of land cover transformation on pollination (Donaldson et al., 2002; Geslin et al., 2016) and the potential for mitigation and supplementation. This is not to claim that findings are transferable because agriculture and urban landscapes favour different taxonomic groups but rather that insights can be drawn by interrogating the broad patterns.

This chapter explores the potential role that urban landscapes can play in supporting pollinators in southern Africa. In the absence of a body of knowledge on urban pollinators in Africa, the topic is discussed by synthesizing what is known about pollinators in landscapes transformed by agriculture with studies discussing eco-system services in urban environments, and comparing the patterns observed in the region with what is known from global urban pollinator studies. Key themes are highlighted and discussed to identify areas for future research and opportunities for pollinator conservation which can inform policy. I discuss the ways social and plant patterns may be driving species assemblages and generating a demand for pollination services in South African cities.

Survey Method

An initial literature search was conducted using the search term: “TITLE-ABS-KEY (Urban AND pollinators AND NOT pesticides AND NOT insecticides)” in Scopus in order to take in the international body of knowledge on urban pollinators. Titles and abstracts were read. Studies which did not discuss urban landscape effects on pollinators were excluded. Papers which focused on taxonomic, phylogenetic, invasion biology or evolutionary traits, and mangroves were beyond the scope of this review. Six classes of paper were selected for thorough analysis: reviews, multi-city studies, multi-region studies, those papers grouped together by taxon, but for which contradictory responses to the urban gradient were recorded, longitudinal studies, and those with novel approaches or findings. The key findings of the remaining papers were extracted and tabulated and coded for positive negative and mixed responses to urbanization. This data represents a duplication of the work undertaken by Wenzel et al (2020) however we aim to investigate the implications for the Global South generally, and Sub Saharan Africa more specifically.

The initial search had produced just two urban pollination studies from South Africa (Coetzee et al., 2018; Pauw & Louw, 2012). Additional searches for the South African body of knowledge with keywords did not produce satisfactory results, so instead prominent researcher's publication lists were consulted. Their co-authors and authors from their reference lists were similarly searched. Key informants were approached to suggest additional authors and studies that may be of interest. Papers were selected for in-depth reading based on their focus on landscape ecology and pollination. The results are organized and discussed according to the Mobile Agent Based Ecosystem Services framework (Kremen et al., 2007).

Results

The initial search generated 356 documents. From those, 158 were within the scope of the study. A further 37 papers met the criteria for inclusion from the focused search on South African studies. The earliest paper was published in 1996, and the earliest within the scope in 1997. Publication rate grew exponentially from the start (Figure 2.1.A). In 2019, 60 papers met the search criteria. The percentage of relevant studies (Figure 2.1.B) was between 25% and 60%.

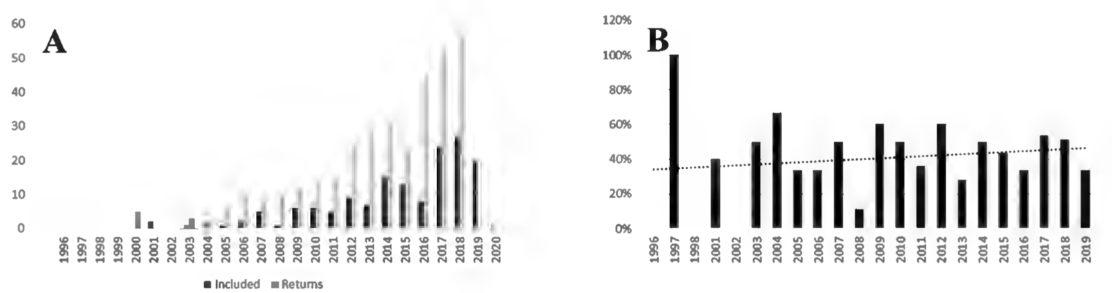


Figure 2.1 Temporal spread of urban pollination studies. A) Number of studies meeting search criteria against number of studies selected for inclusion in the review by year. B). Percentage of studies meeting the scope of the review by year.

Spatial Distribution:

The regional borders used to define and group studies are presented in Figure 2.2. Europe (EUR) and North America (NOA) combined accounted for 77% of the studies at 63 and 53 studies respectively; South, Central Americas (SCA) contributed 14 studies and Russia and Northern Asia (RUNA), Middle East and North Africa (MENA), Sub-Saharan Africa (SSA) and South East Asia (SEA) produced 1 - 9 studies each. Of the studies from SSA, four of the five, were from South Africa (Table 2.1).

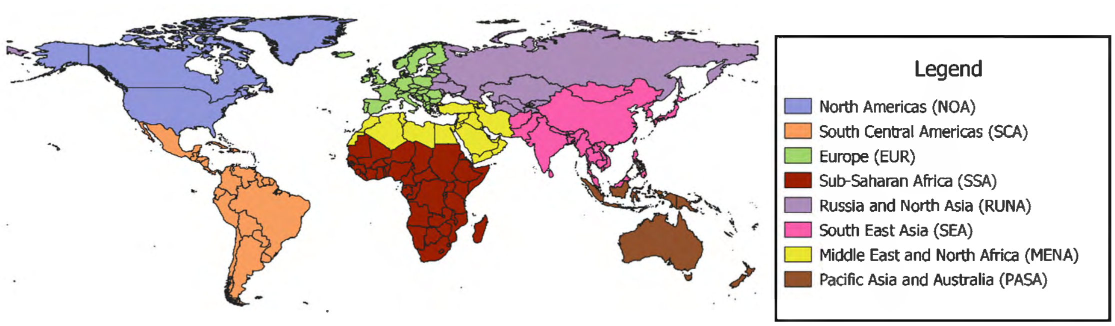


Figure 2.2 Regional borders used for grouping papers on urban pollination.

Species Representation

Of the 150 studies 105 included *Hymenoptera*, 18 *Lepidoptera*, 16 *Diptera*, eight birds, five mammal and five *Coleoptera*. 20 considered aspects relating to plant diversity, pollen trails or traits.

Whilst studies from temperate climates were dominated by *Hymenoptera*, those that focused on forest fragments, presented more varied pollinator mutualisms including nine studies on the effects of urbanisation on *Ficus* and the associated fig-wasp species, five on hummingbirds in South America (compared with two on sunbirds in South Africa and one on hummingbirds in North America), four studies on bats, and one compared flying foxes in Japan and Taiwan.

Response to Urban Gradients

Studies that rendered explicitly positive or negative associations with urban intensity were more likely to include a limited number of taxon or guilds, whilst those that reported mixed findings compared orders, or categorized groups according to functional response such as nesting strategy, or body size. Neutral findings found that variables other than urban intensity better explained the observed community structure patterns. 33 studies included some or all of the explanatory variables: amount of green space in the surrounding neighbourhood, patch size, and connectivity as positively affecting pollinator diversity or as a recommendation for urban pollinator conservation.

Table 2.1 Global distribution of papers that studies urban pollinators and reported responses to the urban gradient. More than two thirds of studies reported mixed findings or found that variables other than urbanization better explained the observed patterns observed patterns in cities.

Region	Number of papers	% of total	Positive	Negative	Neutral / Mixed
EUR	63	42.0%	12	6	46
NOA	53	35.3%	4	10	39
SCA	14	9.3%	3	1	11
PASA	9	6.0%	0	1	8
SSA	5	3.3%	0	2	3
SEA	4	2.7%	0	0	4
RUNA	1	0.7%	0	0	1
MENA	1	0.7%	0	1	0
TOTAL	150	100%	19	21	112

A Conceptual Model of the Interactions of Mobile Agents (Pollinators)

Several studies have highlighted the landscape and habitat drivers of urban pollinator communities which affect them across different scales (Plascencia & Philpott 2017; Bennett & Lovell 2019; Baldock 2020; Wenzel et al. 2020). They include local habitat structure, floral abundance and distribution, urban intensity and land use. However, few studies have attempted to place these components into a framework which gives an overview of the way they interact with pollinators and each other in cities. Aronson et al. (2016) discuss urban drivers of community assemblage from the perspective of hierarchical filtering theory, which demonstrates how landscape factors filter out species from the regional pool. Where the hierarchical filtering model falls short is that it does not account for upward flows, in which local interventions can positively affect regional abundances, nor for how connectivity between patches can promote mobility through otherwise hostile environments (Fuller et al. 2008; Zuckerberg et al. 2011). Although the concept of ecological filtering is universally applicable, the model as conceptualised by Aronson et al. (2016) was intended to guide urban ecologists in assessing the drivers of urban community assemblages and so is not easily transferred to agricultural and natural systems.

Melin et al. (2018) drew on Kremen et al.'s (2007) conceptual model of mobile agent-based ecosystem services (MABES). MABES conceptualizes mobile organisms (e.g. pollinators) as agents that provide ecosystem services. Melin et al. (2018) produced a framework based on MABES for assessing the role of dispersed floral resources for managed bees. Their adapted version looks specifically at the relationships between natural habitats, crop fields and natural, but human-modified habitats at different spatial locations and identifies the movement of wild pollinator and managed bees between floral resources and croplands. Although it is an updated model, it is specific to the interactions between natural, semi-natural and agricultural landscapes, and the pollinators of those habitats. This model emphasises the flows between spatially separated habitat resources, but excludes several components present in the MABES model which are relevant across landscape types more generally (Kremen et al. 2007).

MABES shows the flow of influences and interactions which are interchangeable between different landscape types and ecosystem services. It is therefore appropriate to use for identifying the components of the system which are influencing pollinator assemblages across urban and agricultural landscapes. The system does not assume a unidirectional flow between all components and includes a feedback loop in the form of policy and economic intervention. In this case, it is applied to the ecosystem service of pollination; however, the model can be generalized to all mobile agents of ecosystem provision (Kremen et al. 2007).

Pollinator efficacy is predicated on the distribution of resources at landscape scale and the foraging and dispersal movements of the pollinator. MABES proposes several levels of interaction between pollinators, plants and the environment. Land use, management and disturbance cycles (e.g. for urban landscape, change in private land ownership) shape the landscape structure and the biotic and abiotic environment, and influence both the plant and pollinator communities which are interacting with each other (Figure 2.1). The output is the pollination service required to produce crops and perpetuate local plant populations. How this service is valued by people impacts landscape management policy, which in turn shapes the landscape structure in a feedback loop (Kremen et al. 2007).

Humans therefore act as facilitation agents through their value-assessments and objective setting processes. Kremen et al. (2007) conceptualised the assessed value of an ecosystem service as influencing policy, but value-driven feedback loops at local scales can also inform both design and management decisions (Freeman et al. 2012; Goodness 2018). For example, in a garden setting the desired ecosystem services may include aesthetics, psychological well-being, thermal regulation (shade), social connection (gathering space) and leisure activities (Nahlik et al. 2012). Depending on the ecosystem service objectives of the garden owner, different design decisions and management practices may be implemented. This feedback and acknowledgement of humans as facilitation agents in objective setting for ecosystems services is fundamentally different to the passive and singular directional model of hierarchical filtering (Aronson et al. 2016).

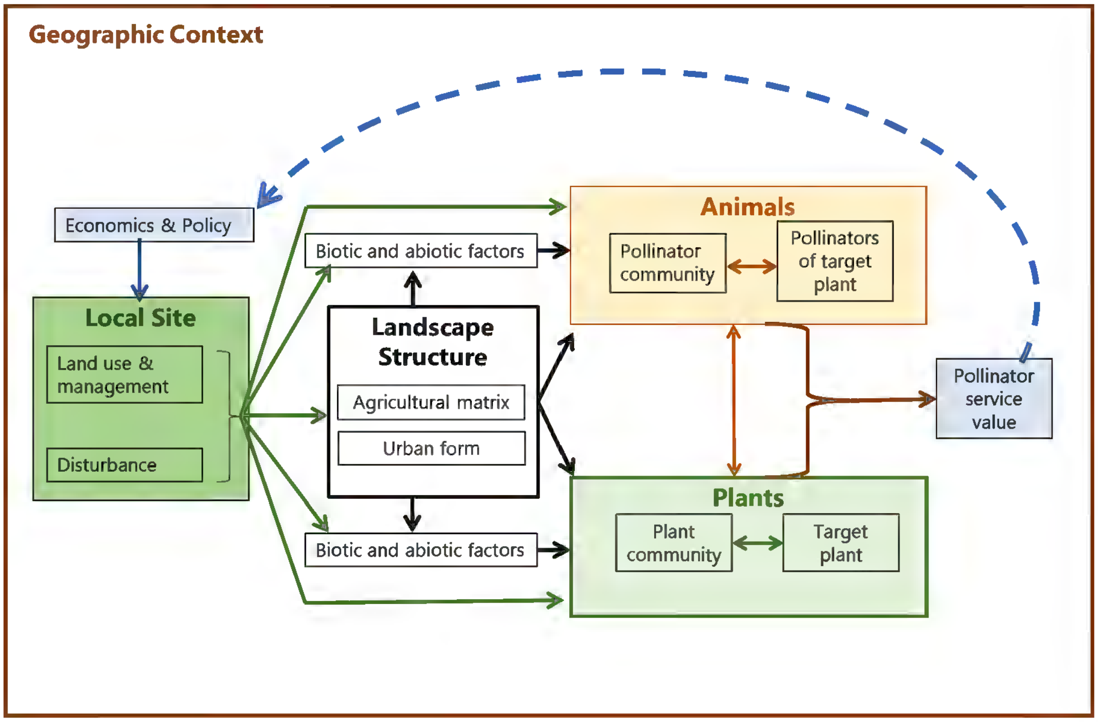


Figure 2.1 Mobile Agent-Based Ecosystem Services conceptual framework (Kremen et al. 2007) *showing the drivers of pollinator community assembly.*

The Discussion section is structured according to the components identified by the MABES conceptual model (Kremen et al. 2007). In the sections below, each of the components of landscape structure, pollinator assemblage, plant assemblage, local habitat and humans as agents of ecosystem service facilitation are considered. For each component, what is known about urban pollinators from the international research pool is compared with the agricultural studies on pollination in Africa. The urban study recommendations are then identified from the combined literature and tabulated as pollinator management opportunities. The chapter concludes by summarizing the research gaps and the ways in which cities might provide more hospitable landscapes and refuges for pollinators.

Discussion

The Importance of Wild Bees and Non-Bee Pollinators

Non-bees and wild bee species account for 39% of global pollination services (Rader et al. 2016), and several agricultural crops depend solely or heavily on pollination services from these taxa (Gemmill-Herren & Ochieng 2008; Martins & Johnson 2009; Rader et al. 2016).

Despite this, studies on both urban (Wenzel et al. 2020) and agricultural systems (Rader et al. 2016) have overwhelmingly focused on bees. Although urban studies generally include wild bees as well as (managed) *Apis melifera*, there is a paucity of information on non-bee taxa (Rader et al. 2016; Wenzel et al. 2020).

One area of research in South Africa which regularly considers other pollinators, is for crops which contribute to the biodiversity economy. In 2013, the total value added by bio-products to the domestic retail market was R1.5 billion (South Africa 2016). The two largest resources grown from indigenous plants, *Aloe ferox* (bitter Aloe) and *Aspalanthus linearis* (rooibos tea), are pollinated by birds in the case of aloes (Botes et al. 2009) and indigenous wasps in the case of rooibos (Gess 2000; Gess & Gess 2010). Although this is indicative of the importance of wild Hymenoptera and non-bee pollinators to local agricultural production, the importance is not limited to indigenous crops. The carpenter bees *Xylocopa caffra* and *Macronomia rufipes* are both important pollinators for eggplant crops in Kenya (Gemmill-Herren & Ochieng 2008). Papaya relies exclusively on pollination by hawkmoths (Martins & Johnson 2009) and blowflies are an effective alternative to bee pollination in mango plantations (Saeed et al. 2016). Syrphid flies are among the most important pollinators because they visit at least 72% of global food crops (Doyle et al. 2020; Raguso 2020). Studies which have focused on the above taxa have tended to discuss pollination efficacy (Saeed et al. 2016; Raguso 2020), distance to natural remnants or other habitats and relative penetration of agricultural crops (Geslin et al. 2016; Simba et al. 2018), and that in addition to floral resources, each of these taxa have differing brood and nesting requirements (Gess & Gess 2010).

Non-Bee Pollinators in Urban and Agricultural Landscapes

Pollination is not only important to agricultural production, but also to the conservation and the persistence of natural plant communities. South Africa has high degrees of endemism and several specialised pollinator systems (Johnson & Steiner 2003; Johnson & Wester 2017). The diversity of pollination systems in part explains the huge diversity of Iridaceae in the region (Goldblatt & Manning 2006). Two examples of non-bee pollinators which stand out include Diptera and Hopliini.

Long-proboscid fly pollination in southern Africa includes four separate syndromes using different sets of flies and plant species in different parts of the subcontinent (Goldblatt & Manning 2006). Internationally, there are few urban studies which have included Diptera in the analysis of pollinator responses to urban form. In Italy, Diptera visitation to wildflowers in urban systems are independent of urban intensity (Basteri & Benvenuti 2010), but hoverflies are negatively affected by urban intensity in the UK and Sweden (Salisbury et al. 2015; Persson et al. 2020). Thus, there is inadequate evidence to be able to draw generalizations on Diptera responses to urban environments which represents a gap in knowledge, despite their importance to pollination both in South Africa and globally (Barraclough & Slotow 2010; Saeed et al. 2016; Doyle et al. 2020; Raguso 2020).

Approximately 63% of the world's Hopliini (monkey beetles) species and 38% of genera are found in South Africa and over 50% of those are concentrated in the Cape Region, which is the global centre for monkey beetle radiation (Colville et al. 2018). No urban studies have been conducted on monkey beetles to date, however, they are the most abundant pollinator visitors to Asteraceae and Aizoceae in the succulent Karoo (Mayer et al. 2006) and are the primary pollinators for two genera of Hyacinthaceae, seven Iridaceae, one Hypoxidaceae, two Asteraceae, two Campanulaceae and one Droseraceae (Goldblatt et al. 2013). Studies on agricultural landscapes demonstrate beetle assemblage adjusts with flower community and disturbance patterns according to feeding guilds (Colville et al. 2002; Mayer et al. 2006). A similar study to establish monkey beetle distribution in urban contexts would provide insights into the conservation potential of Asteraceae, Aizoaceae and beetle-pollinated geophytes in urban landscapes.

Landscape Structure: Different Responses to Urban and Agricultural Landscapes

Different methods are used to quantify urban and agricultural intensity. The most common method for estimating urban intensity is to quantify the amount of soil-sealing in the surrounding landscape (Haase et al. 2012; Wellmann et al. 2018; Carlucci et al. 2019). Soil-sealing is the outcome of covering soil with buildings, paving and roadways (Concepción et al. 2016). It presents barriers to mobility (landscape permeability) and fragments floral stands into discrete patches. Furthermore, it removes nesting sites for ground-nesting species

(Wojcik & McBride 2012; Simao et al. 2018). In contrast, many agricultural landscapes are characterised by large stands of monoculture crops (noting that tillage crops have additional disturbance cycles which disrupt soil ecology). The large-scale use of pesticides and fertilizers present a different suite of barriers and stressors which fragment floral stands and limit landscape permeability (Lenhardt et al. 2013).

Studies which have compared the pollinator biodiversity between agriculture and urban landscapes have found them to rank similarly in diversity and richness but to contain different guilds in discrete communities (Sattler et al. 2011; Harrison et al. 2019; Wenzel et al. 2020), which are distinct from each other (Sattler et al. 2011). Similarly, natural landscapes are not necessarily more biodiverse than agricultural and urban landscapes (Collado et al. 2019), but have been shown to harbour a greater number of rare species (Harrison et al. 2019). While the importance of natural landscapes for conservation cannot be overstated (Collado et al. 2019), the protection of natural landscapes should be viewed as one of a suite of opportunities for providing suitable pollinator habitats. Therefore mitigation and restoration opportunities in other landscapes need to be utilized to counter overall losses.

Both agricultural and urban landscapes can disproportionately benefit specific groups or guilds of pollinators by providing resources favoured by those guilds (Stein et al. 2018). Urban habitats typically favour large-bodied insects which can range further between foraging resources (Merckx et al. 2018) and cavity-nesting guilds, which take up residence in fences, walls and roof eaves (Cane et al. 2006; Neame et al. 2013). Body size is also correlated with distance to fragments of natural habitat in agricultural landscapes (Geslin et al. 2016). This filtering occurs because larger-bodied insects can range further to find suitable food resources than smaller-bodied insects (Geslin et al. 2016). Generalists are more likely to take advantage of crop species in agricultural landscapes (Leong et al. 2014; Hopfenmüller et al. 2020). In their meta-analysis of studies conducted globally on crop-visiting pollinators, Kleijn et al (2016), found that the species pool in agricultural systems is made-up of a small subset of dominant species, and that the dominant crop pollinators persist under agricultural expansion and can easily be enhanced by simple conservation measures. In contrast, threatened species are rarely observed on crops (Kleijn et al. 2016). Similar patterns of generalization have been observed in urban landscapes (Leong et al. 2014; Lowenstein et al.

2019), but urban landscapes also act as a refuge for certain guilds of pollinators (Wenzel et al. 2020) and can provide supplementary seasonal foraging resources (Koyama et al. 2018) due to the marginally warmer climate, irrigation regimes and planting pallets which favour year-round floral displays (Koyama et al. 2018) – this is especially pertinent in Temperate climates with cold winters (Baldock et al. 2015).

Spill-over effects - in which wild bee and non-bee pollinators spill-over from natural fragments - have been observed in several studies in croplands. In these studies, pollinator populations spill-over from natural fragments where they are more readily able to find suitable nest sites and a wide range of flower resources (Ricketts et al. 2008; Simba et al. 2018; van Schalkwyk et al. 2020). Ricketts et al. (2008) synthesized the results of 23 studies to determine the landscape effects on crop pollination services and found strong exponential decreases in both pollinator richness and wild visitation rates with distance from natural and semi-natural vegetation (Ricketts et al. 2008). More specifically, in South Africa, flying insect abundance decreases in mango orchards with increasing distance to natural fragments (Geslin et al. 2016) and the proximity of natural patches to mango orchards benefits mango plantations both during flowering and when mangoes are not in flower. This is due to greater plant diversity in natural patches providing flowers over a protracted period (Simba et al. 2018). These phenomena make for a strong motivation to include natural corridors and patches between agricultural crop fields, especially when animal pollination is required by the crop (Ricketts et al. 2008; Carvalheiro et al. 2011; Geslin et al. 2016; Simba et al. 2018).

Spill-over effects have also been observed from urban domestic gardens into adjacent agricultural areas, where insects which find suitable nesting sites in gardens are able to supplement their diet from agricultural crops (Langellotto et al. 2018). This points to a complex pattern of exchanges in heterogeneous landscapes and indicates that urban landscapes are not necessarily as hostile as they appear at first glance (Groffman et al. 2014; Baldock et al. 2015; Theodorou Radzevičiūtė et al. 2020; Wenzel et al. 2020).

Studies describing spill-over effects into urban landscapes have had mixed results, as some species increase with urbanization, some decrease and others have no response (Wenzel et al. 2020). Urban landscapes are a complex patchwork of uses and local habitats, which do not always result in clear decreases in abundance and richness as distance to natural or agricultural landscapes increases (Theodorou et al. 2017). This is because other environmental gradients within the city do not necessarily follow the same spatial pattern as soil-sealing. For example, changes in biodiversity have been documented along socio-ecological gradients with greater biodiversity recorded at the wealthier end of the income gradient (Lubbe et al. 2010; van Heezik et al. 2013; Qureshi et al. 2014; Venter et al. 2020). Furthermore, residential gardens and community lots offer both nesting sites and abundant floral resources throughout the year (Glaum et al. 2017; Threlfall et al. 2015). As such, they can provide refuge for certain guilds of pollinators (Wenzel et al. 2020) and supplementary seasonal foraging resources year-round (Glaum et al. 2017; Koyama et al. 2018).

The negative effects of soil-sealing, are most prominently documented for ground-nesting, and small-bodied insects (Threlfall et al. 2015; Kratschmer et al. 2018; Simao et al. 2018; Bennett & Lovell 2019). Studies focusing on these taxa have identified several ways in which the negative impacts of both soil-sealing and monoculture landscapes can be mitigated. Firstly, corridors and regular patches of natural vegetation can facilitate movement through the landscape by providing nesting and supplementary foraging resources (Pauw & Louw 2012; Wojcik & McBride 2012; Cane 2015; Simao et al. 2018). Secondly, linear elements such as hedgerows and flower patches arranged in a linear pattern through the landscape further assist pollinators in orientating flight paths between larger natural or semi-natural patches (Cranmer et al. 2012), thus preserving and establishing ecological stepping-stones and corridors (Riitters et al. 1995; Cranmer et al. 2012; Pauw & Louw 2012; Vrdoljak et al. 2016; Knight et al. 2019; Ossola et al. 2019). Thirdly, where agricultural studies clearly articulate the value of natural remnants, urban studies have demonstrated that semi-natural and artificially landscaped areas can provide ecologically rich surrogates and refuges in urban landscapes (Anderson et al. 2014; Dewaelheyns et al. 2016; Zhao et al. 2019).

In many instances, the local land use and floral abundance have a greater influence on pollinator abundance and richness than landscape structure (Threlfall et al. 2015; Theodorou et al. 2017; Simao et al. 2018). MABES articulates this by placing the local site directionally ahead of the landscape structure so that land use and management and disturbance cycles are what determine the broader landscape structure and not the other way around (Kremen et al. 2007). This is noteworthy because it highlights the opportunities (and challenges) presented by the accumulation of small-scale interventions across a wider landscape, which are demonstrably able to improve pollinator biodiversity and overall urban habitat structure (Dewaelheyns et al. 2016; Davis et al. 2017).

Local Habitat: Opportunities to Improve Habitat Suitability for Urban Pollinators

Local habitats do not contribute equally to pollination ecosystem service because different land uses provide different levels of pollen resources (Davis et al. 2017; Zhao et al. 2019). Zhao & Hendrix (2019) determined whether pollinator supply in urban landscapes could meet demand for pollination services from urban agriculture. Using Iowa City, USA, as a case study, they established that pollinator surpluses occur in natural areas and heavily-vegetated residential neighbourhoods, and deficits occur in resource-poor lawns (Zhao et al. 2019). Converting turf-grass (lawns) to flower-rich gardens throughout the city would support increased supply of pollination services (Davis et al. 2017). This has been assessed in South Africa where civic-led groups restored urban sites (Anderson et al. 2014). The restored sites measured insect diversity comparable to adjacent conservation areas despite differing floral communities (Anderson et al. 2014). These studies point to the potential that even partially restored patches can generate ecological stepping-stones and refuges in the urban landscape for insect flower visitors (anthophiles), but also to the value that local-habitat level interventions can contribute towards mitigating the negative effects of urbanization.

Acknowledging that the amount of concrete in the surrounding landscape has a predominantly negative impact on most insect species at the most urbanized end of the urban gradient (Wenzel et al. 2020), studies which included multi-variate analysis of local habitats and landscape level patterns often found that the main drivers of urban pollinator communities were factors at local habitat scale (Wojcik & McBride 2012; Davis et al. 2017; Simao et al. 2018; Bennett & Lovell 2019), indicating that there are opportunities to supplement habitats at the local habitat scale.

Firstly, floral abundance plays a major role in pollinator assemblage. In New York, sunlight and floral abundance are the major factors predicting local bee and butterfly diversity in densely populated neighbourhoods (Matteson & Langellotto 2010) and Avuletey and Niba (2014) found strong influences of local habitat quality in Mthatha city, South Africa. They compared butterfly assemblage across sampling units from a nature reserve to an urban centre. Highly disturbed sampling units with fewer nectaring plant species attracted fewer butterfly species, but higher richness and abundance of butterflies were recorded outside of the reserve when compared with sampling units inside the reserve. They recommended improving the micro-habitat conditions in the nature reserve and the establishment of corridors into the city in order to attract the butterflies to the reserve (Avuletey & Niba 2014). Wojcik & McBride (2012) sum up the implications of these studies: "management strategies that provide dense and abundant floral resources should be successful in attracting [pollinators], irrespective of their location within the urban matrix" (Wojcik & McBride 2012: p. 581). Thus, the establishment of floral patches in the most urbanized parts of the city provides habitat resources for urban pollinators, especially if they are arranged to facilitate movement between larger floral-rich patches (Cranmer et al. 2012).

Secondly, patches of floral resources can be successful in supporting pollinator mobility even at very small scales. Simao et al. (2018) experimentally introduced potted *Lobularia maritima* (sweet alyssum) and monitored halictid visitation. They found that smaller flower plantings may have greater impacts on small pollinators than larger plantings, and suggested that small floral plantings across the landscape may provide a niche for small bees (Simao et al. 2018). This idea is reflected by Plascencia & Philpott (2017), who found that large stands had less richness than patchy floral stands. They attributed it to competition from managed hives at large sites (Plascencia & Philpott 2017). This lends itself to a conservation strategy which encourages citizens to adopt creative solutions such as butterfly balconies or planted roofs. Caution is offered, however, in the discussion of planted roof gardens because they favour thermophilic species and do not support succession processes (Mayer et al. 2006), and unless they provide a diversity of floral resources, the contribution to providing pollinator habitat performs no better than turf-grass (Tonietto et al. 2011; Williams et al. 2014; Kratschmer et al. 2018; Ksiazek-mikenas et al. 2018).

Flower Community Structure: Effects on Pollinator Diversity

In agricultural landscapes, studies which focused on supplementary floral resources emphasised promoting the health of managed honeybee hives by investigating seasonal food sources for when hives are not being deployed to pollinate croplands (Melin et al. 2014, 2020; Koyama et al. 2018; Langellotto et al. 2018). In South Africa, managed hives provide 50–98% of animal-driven pollination services in croplands (Melin et al. 2014; Rader et al. 2016) and are the dominant pollinator for most of the crops requiring animal-facilitated pollination (Melin et al. 2014). Peak requirements for pollination occur with the mass flowering of crops which are limited to specific times of the year (spring-autumn). To ensure that managed honeybee hives remain "strong" throughout the year, they are rotated between crops and "off-season" resources. Thus, when the crop season ends, commercial beekeepers routinely move hives to stands of *Eucalyptus* spp. or natural vegetation (Melin et al. 2014). *Eucalyptus* spp. have been targeted for invasive alien plant clearing by many programmes in South Africa under the umbrella of Working for Water (Forsyth et al. 2004). *Eucalyptus* spp.are preferred by *Apis melifera* as a resource in mixed landscapes, accounting for 41% of the pollen loads collected. An increase in the area of *Eucalyptus* spp. stands results in an increase in *Eucalyptus* spp. and wild pollen collection and a reduction in the proportion of exotic pollen collection (excluding *Eucalyptus* spp.) (Melin et al. 2020), pointing to other ways in which mass-flowering plants compete or facilitate pollination of their neighbours (Schmid et al. 2016).

That different species of flowers are preferentially utilized by anthophiles has been investigated across several urban studies (Garbuzov & Ratnieks 2014, 2015; Baldock et al. 2015; Garbuzov et al. 2017; Martins et al. 2017; Michołap et al. 2018; Lowenstein et al. 2019; Yang et al. 2019). In North America, one third of urban flowering plants are not visited by pollinators, and of those that are, 40% are visited more frequently than others (Lowenstein et al. 2019). When urban foraging patterns are compared with natural and agricultural landscapes, urban pollinators forage from a smaller proportion of available plant species (Baldock et al. 2015; Garbuzov et al. 2017; Martins et al. 2017). This is likely due to the high prevalence of introduced and exotic species in urban landscapes. For the same reason, urban landscapes have recorded higher visitation rates of individual plants, but lower rates of seed, with the net result of reduced pollination services to all plants (Leong et al. 2014). In other words, people are selecting highly diverse plant pallets for their gardens at the expense of the genetic pool in the local population (not enough of one species is planted together).

This can be explained by market forces which play out in the supply and demand of plants sold at garden centres and misinformation within the public domain (Garbuzov et al. 2017). Gardeners seeking to plant flowers to encourage and provide resources for pollinators are often given erroneous information, such that plants unattractive to wild pollinators are recommended by garden centre staff and marketing material, and those that are attractive are overlooked (Garbuzov & Ratnieks 2014). To address this phenomenon, several studies have identified subsets of flowers that are classified as "highly" attractive to pollinators. These lists provide scientifically verified recommendations of flower resources for a city or region (Garbuzov & Ratnieks 2014, 2015; Garbuzov et al. 2017; Michołap et al. 2018; Yang et al. 2019). Similar studies in the South African context are rare where the tendency is rather to study mutualisms, pollination syndromes and flower resource use in natural landscapes (Goldblatt & Manning, 2006; Johnson & Midgley, 2001; Johnson & Steiner, 2003; Johnson & Wester, 2017; Raguso, 2020). Regional information is therefore available, but has not been tested for preference and pollination loads with the rigour or intention that *Eucalyptus* spp. has, nor has it been curated for the purposes of informing gardeners, garden centres and staff. This represents an important gap in knowledge about the relative contribution which flowering plants can make to boosting pollinator populations both within the urban landscape and as a potential alternative to *Eucalyptus* spp. for managed hives.

Further to this, the potential contribution of "weedy" flowers and ruderal species should not be overlooked (Carvalheiro et al. 2011; Colville et al. 2002; Koyama et al. 2018; Lowenstein et al. 2019; Martins et al. 2017; Wilson & Jamieson, 2019). In sunflower fields, weed diversity increases anthophile diversity, thereby ameliorating the effects of distance to natural vegetation patches and increasing pollination success and seed set (Carvalheiro et al. 2011). In urban landscapes, the contribution of "weedy" and exotic species to pollination resources ranks below perennial and indigenous plants, but there are examples where individual species of exotic weeds receive disproportionate visitation rates in turf-grass and other urban landscapes (Larson et al. 2014; Lerman et al. 2018; Lowenstein et al. 2019). Proponents of the contribution that common "weeds" can make, advocate for reduced mowing frequency and lazy weeding of turf-grass as a landscape management strategy for supporting urban pollinators (Bertoncini et al. 2012; O'Sullivan et al. 2017; Russell et al. 2018; Yang et al. 2019).

Humans as Facilitation Agents

Whether or not urban landscapes can provide more connected landscape habitats for the support of healthy pollinator populations will depend on the implementation of pollinator-friendly landscape designs and maintenance practices (Mnisi et al. 2021; Kremen et al. 2007; Senapathi et al. 2017). Kremen et al. (2007) conceptualizes this in their MABES model as the valuation of the desired ecosystem service shaping policy; however, for POS and domestic gardens, different mechanisms are likely to be at play in informing design and management outcomes. Specifically, it depends on whether there is citizen buy-in for the implementation of landscaping practices which positively drive pollinator populations. In an agricultural landscape, pollination service delivery likely only competes with pest management and the trade-off between available land and crop carrying capacity. Ultimately the goal of increased yields and increased pollination services are aligned (Tamburini et al. 2019).

In urban landscapes, public parks, road verges, vacant plots, residential suburban gardens and community gardens provide various ecosystem services including cultural, social, recreational, provisioning and regulating services (Bolund & Hunhammar 1999). Some ecosystem services co-exist and overlap in space and time, whilst others are mutually exclusive in the apportionment of space. The provision of pollinator habitats will therefore have to compete against other community needs for dedicated space. Furthermore, whether or not a park manager or landscaping contractor is able to implement the planting of mass-flowering species, or reduced mowing frequency, depends on the community tolerance of the related ecosystem disservices, such as airborne pollen and long grass (Kremen et al. 2007).

Table 2.1 Summary of opportunities for supporting pollinators in urban habitats

MABES Component	Opportunity/Recommendation	Reference
Local Habitat	Small patches of abundant flowers interspersed throughout the landscape	Plascencia & Philpott, 2017; Simao et al., 2018
Flower community	Targeted species/pollinator syndromes to support mutualisms (e.g. red and orange tubular flower for sunbirds)	Pauw & Louw, 2012;
Local Habitat	Increased flower abundance	Bennett & Lovell, 2019; Theodorou, Radzevičiūtė, et al., 2020; Vrdoljak et al., 2016
Local Habitat	Semi-natural patch rehabilitation through citizen action	Anderson et al., 2014
Flower community	Produce attractive species lists of flowers for dissemination to the public	Garbuzov & Ratnieks, 2014; Michołap et al., 2018
Flower community	Altered mowing regimes to allow for lawn flowers to blossom	Bertoncini et al., 2012; Knight et al., 2019; Lerman et al., 2018; O'Sullivan et al., 2017; Yang et al., 2019
Flower community	Replace turf grass with floral rich landscapes	Davis et al., 2017; Zhao et al., 2019
Landscape structure	Corridors and linear elements	Avuletey & Niba, 2014; Cane et al., 2006; Cranmer et al., 2012; Wojcik & McBride, 2012 Knight et al., 2019
Landscape structure	Minimize impervious cover	Bennett & Lovell, 2019
Pollinator community	Establish the value of wild and non-bee pollinators and develop urban strategies to cater for the unique needs of different taxa	Botes et al., 2009; Gemmill-Herren & Ochieng, 2008; Gess, 2000; Martins & Johnson, 2009 Johnson & Steiner, 2003

Community parks are limited in space (especially at the low end of the socio-economic gradient (Venter et al. 2020)) and must be designed and managed with community aspirations for exercise, aesthetics and social gathering in mind (Bolund & Hunhammar 1999). Pollinator gardens are not necessarily in conflict with these uses, but where space is limited there could be trade-offs and other ecosystem services will need to be considered. Citizen engagement is therefore essential when proposing landscaping changes. In this respect, a "learning by doing" approach may be most appropriate way to implement urban planning and design. This would involve a process of engaging public participation to collaboratively value or rank the public goods and ecosystem services provided by POS (Cilliers & Siebert 2012; Ahern et al. 2014), and to develop an integrated plan for the management of parks and gardens. Successful examples of civic stewardship action already exist in South African cities (Cilliers & Siebert 2012; Anderson et al. 2014), implying that there are opportunities to engage the public in the production of pollinator habitats (Mnisi et al. 2021).

The discussion above has highlighted several recommended interventions for improving pollinator habitats in urban cities. Ultimately these are design and landscape management outcomes. Table 2.1 summarises the opportunities according to the components in the MABES model and provides the references where they are discussed in more detail.

Conclusion

This chapter set out to review the South African and international literature to determine the potential that urban environments have to provide refuge and supplementary foraging resources to both wild and managed pollinators. It compared and contrasted findings in an urban setting in international studies with those emerging from the agricultural landscapes in South Africa, noting the structural differences between agricultural and urban land use and management.

Evidence from international studies suggest that certain pollinator guilds can do relatively well in urban landscapes with potential for spill-over effects from urban habitats to adjacent agricultural croplands. Several management practices can be employed to boost the quality of foraging and ease of mobility through the city at different scales. At the landscape scale, providing corridors and natural patches will provide refuges for urban pollinators. But within the urban fabric at the local habitat scale, there are strategies which can mitigate the hostility of between-patch landscapes. These include replacement of turf grass with flower-rich resources, strategic grass-cutting practices to allow for “weedy” plants to grow, rehabilitation of areas adjacent to managed conservation areas and small-scale plantings in the most urbanized parts of the city.

The potential of South African cities to provide habitat for wild pollinator conservation and supplementary floral resources for managed honeybee hives remains unexplored to date. In South Africa, there are very few urban pollinator studies and therefore the potential they hold to support wild bee and non-bee pollinators is relatively unknown. Specific attention should be given to closing the gap in knowledge on Halictids, Diptera, Lepidoptera and Hopliini, both locally and internationally. In South Africa, there is a gap in knowledge of relative flower attractiveness to wild and managed pollinators and a need to verify the information being disseminated in garden centres and the public domain. Better understanding of the potential from individual indigenous plants to provide pollen at levels similar to *Eucalyptus* spp. is needed to determine if indigenous flowering trees can be used to supplement managed hives and wild-pollinator diets. Further research is needed to fill the Africa gap for both specialized and generalized pollinators in urban areas where ornamental and indigenous flowering plants are valued.

- 3 -

Monkey Beetles in the City: Investigating the Diversity of a Keystone Pollinator Across Urban Environments

Abstract

Urban landscapes present an important opportunity for pollinator conservation, but little is known about the status and distribution of pollinator populations in urban habitats in South Africa. This chapter used a model pollinator tribe (Coleoptera: Scarabaeidae: Hopliini) to investigate the community structure and species distribution of pollinators in a major metropolitan area in South Africa. A large number of sites (n=142) were surveyed at least twice each in the austral spring seasons of 2018 and 2019. Data were collected on habitat structure, flower diversity and pollinator diversity. Species were strongly associated with different historical vegetation types and ecosystems. Different guilds favoured different levels of urban intensity. Specifically, non-embedding guilds decreased with soil sealing and increased with site area and mean household income, while the embedding guilds increased with soil sealing and decreased with site size and mean household income. Monkey beetle richness correlated with flower-richness. Those with moderate sensitivity to urban intensity from both embedding and non-embedding guilds, benefitted from the presence of preferred species of flowers. Overall, the findings demonstrate the importance of plant community structure in supporting urban pollinators.

Introduction

Urban environments are important for the conservation and stewardship of healthy pollinator populations (Hall et al. 2017). Globally, studies which investigated the response of pollinators to urban gradients found that certain guilds and taxa are able to take advantage of the resources and habitat conditions available in cities (Glaum et al. 2017; Theodorou Radzevičiūtė et al. 2020; Wenzel et al. 2020). Others can do well when particular conditions are met, such as the provision of small scale floral patches or the introduction of plants from a particular pollination syndrome (Leveau 2013; Simao et al. 2018). A third group is negatively affected by urban intensity and avoids or extirpates in urban environments (Theodorou Herbst et al. 2020; Wenzel et al. 2020). A recent review found that the majority of studies conducted on urban pollinators to date, reported findings for Hymenoptera, temperate regions and in the global north (99, 117 and 120 studies respectively). A smaller number reported findings from tropical and developing regions (24 and 21 respectively) (Wenzel et al.

2020). There is still much to be learned about the responses of other taxa, such as Lepidoptera, Diptera, Aves, Chiroptera and Coleoptera, as well as cities in the global South and in under-studied climatic regions, (Tropical, Arid and Mediterranean) (Wenzel et al. 2020). Africa is the most poorly represented, with one urban pollination study published from Ghana (Guenat et al. 2019) and three from South Africa (Leveau 2013; Avuletey & Niba 2014; Coetzee et al. 2018). The African context offers an opportunity to add to the body of knowledge in predominantly arid and tropical contexts and from a rapidly urbanizing perspective (United Nations, Department of Economic and Social Affairs 2018).

In South African cities, the history of Apartheid spatial planning, renders today's cities with extreme stratified socio-economic gradients from the persistent legacy of racial and wealth segregation (Nicks 2003; Donaldson et al. 2016). Rapid urbanization has resulted in patchy expansion and a relatively porous urban form, which left intact natural fragments within many South African cities. Cape Town, in particular, has passed the protection of the remaining fragments into spatial planning law, which, in addition to the 22,100 ha Table Mountain National Park, includes several small (30 ha) to medium (300 ha) urban nature reserves (Holmes & Pugnalin 2016). Furthermore, the north-eastern city limits are flanked by commercial agricultural activities forming an agricultural-urban gradient (City of Cape Town 2012). This provides an ideal opportunity to investigate pollinator responses to urban gradients and land use patterns.

Monkey beetles (Hopliini), are part of a pollinator syndrome present in southern Europe, Madagascar, Asia and South Africa (Dafni et al. 1990; Ahrens et al. 2011). They are a model organism to use to test key questions of urban pollination in this context. They are highly diverse in southern Africa, providing adequate richness to observe beta-diversity patterns. South Africa is a centre of diversity for monkey beetles, where 65% of the world's species and 40% of the genera are concentrated (Colville et al. 2018). The greatest density of monkey beetle species is found in the winter rainfall region of Namaqualand and the Cape Floristic Region (CFR), where they are important pollinators of several plant families (Bernhardt 2000; Mayer et al. 2006; Goldblatt & Manning 2011). This includes many of the popular flowers which attract local and international botanical tourists during the austral spring season (Kruger et al. 2015). Monkey beetles are easy to collect due to their use of flowers as breeding platforms (Dafni et al. 1990; Bernhardt 2000), and preliminary evidence shows that they shift guild structure and host plant use along a disturbance gradient (Colville et al. 2002), pointing to their suitability for study in urban environments.

This chapter investigates the community composition and distribution of monkey beetles across income and urban intensity gradients, and plant community and historical vegetation composition in Cape Town. It compares the data with responses to local habitat and flower community structure. It tests several hypotheses summarized as follows. 1. Monkey beetle guilds will turnover along urban-agricultural, urban-natural gradients and socio-economic gradients; 2. They will associate with specific flower communities; and 3. There is a correlation between beetle diversity and flower diversity indices.

Methods

Study Area

Cape Town is the largest city in the Western Cape Province, South Africa, and it has an estimated population of approximately 4.5 million citizens (Statistics South Africa 2011). It falls within the Cape Floristic Region (CFR), a global biodiversity hotspot with two centres of endemicity (Mittermeier et al. 1999; Rebelo et al. 2011). Within the city metropole, there are 19 vegetation types (Figure 3.1, Map A), encompassing the sub-classification of three main vegetation types on five different soils across lowland, coastal and inland contexts (Rebelo et al. 2011). At 0.63, South Africa has the highest gini-coefficient in the world, and Cape Town, at 0.62, slightly below the national average is a highly unequal society presenting steep socio-economic gradients (Figure 3.1, Map B). Neighbourhood density varies from 1 du/ha (dwelling units per hectare) in the wealthiest neighbourhoods against the mountainside, to up to 160 du/ha in the informal settlements where the poorest citizens settle and build shacks from corrugated iron and timber (Wilkinson 2000; Turok 2011) (Chapter 1).

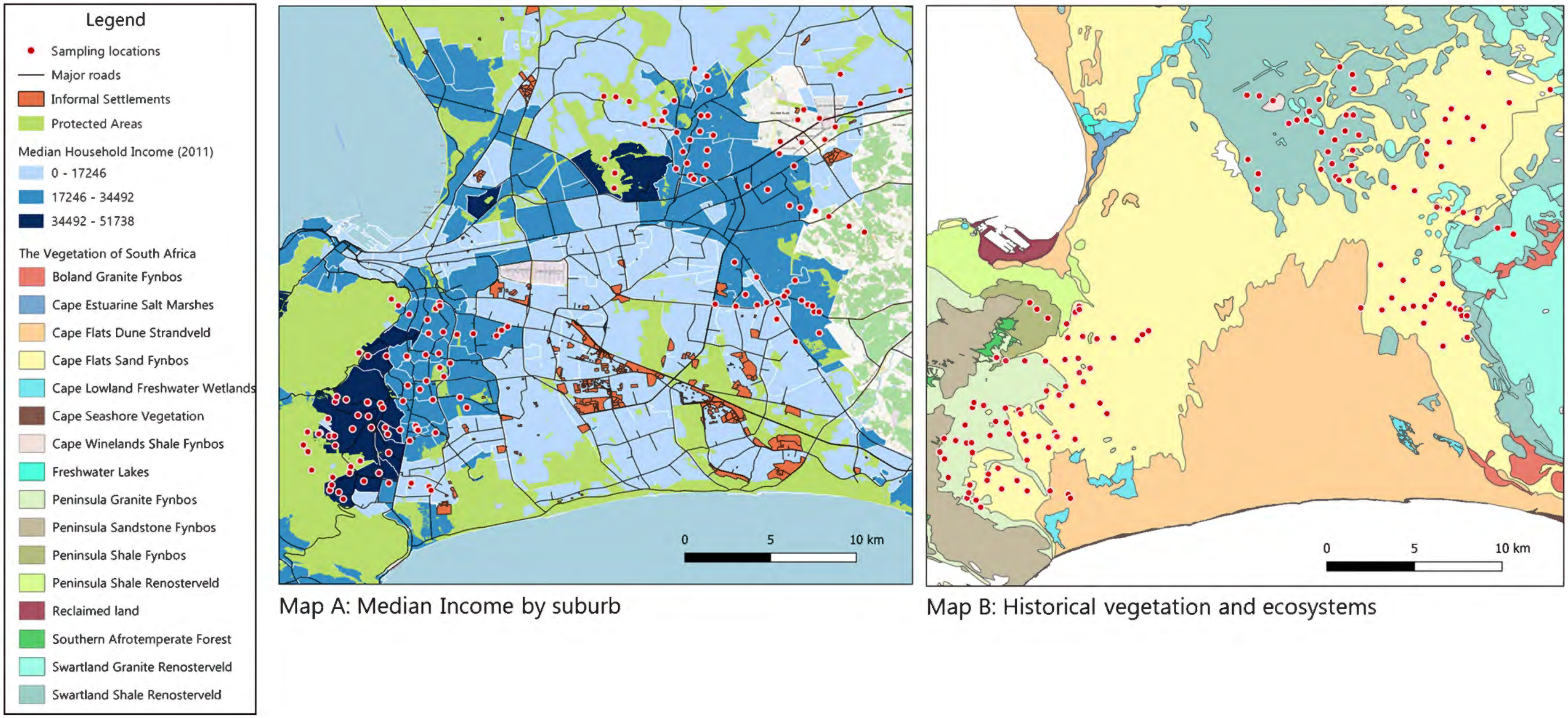


Figure 3.1 Monkey beetle sampling locations (n=142) in Cape Town's city parks and vacant lots from which data were collected during the austral spring of 2018 and 2019. The points are overlayed onto map A: median household income aggregated by suburb and classified into low income (R0 – R 17 246), medium-income (R 17 246 – R 34 492) and high income (R 34 492 and upwards) and based on 2011 census data (Statistics South Africa 2011); Map B: the underlying ecosystems per the Vegmap of South Africa (Mucina & Rutherford 2006). The area presented shows 16 of the 19 historical vegetation types present in the city.

Sampling Methods

Sites were selected for ease of access across a range of conditions along an urban intensity gradient. Due to personal safety threats associated with the Cape Flats gang-related violence and poverty, access to the poorest neighbourhoods was limited. The largest proportion of sites were community or district recreational parks, followed by vacant lots and road verges. These sites were predominantly grassed over, occasionally with formalized flower beds and less than 5 ha in area. For purposes of testing the hypothesis that guilds would turnover from agricultural and natural landscapes, sites in protected areas and cultivated farmland were included. Areas were considered natural, if they were un-mowed, contained historical vegetation and covered an area of 30 ha or more. Agricultural sites were located within or immediately adjacent to vineyards or rye fields (fallow crop to vineyards). Initially, linear transects were drawn from urban centres or corridors, to beyond the urban edge (Magle et al. 2010). Survey points were then selected at approximately 1 km intervals along those transects. Insects can be ecologically specialized and have narrow home ranges such that even small-scale spatial variation in environmental conditions (e.g. soil or vegetation) can add heterogeneity to census data (Wagner et al. 2021). It is not known how far monkey beetles range, however, anecdotal observations from Colville et al. (2002) note that marked individuals of *Lepthrix* travelled at least 500 m in 1 hr and Mayer et al. (2006) observed that monkey beetles can fly 2 km in 60 min when flower resources are sparse. Therefore, 1 km intervals provide a reasonable likelihood that pan traps would be detected by monkey beetles and the trends from the effects of the environmental gradients could be measured.

The initial linear transects generated statistical noise (unexplained error) from competing environmental gradients. This was because the transects spanned 16 ecosystem variations in the underlying soil and historical vegetation (Mucina & Rutherford 2006). Furthermore, Cape Town's spatial development has not followed the linear pattern of concentric development, and often industrial areas or new commercial nodes are situated near the city limits. Lastly, South Africa is a highly unequal society and Cape Town is no exception with extreme socio-economic disparity between and across neighbourhoods (Statistics South Africa 2011). In order to mitigate the effects of these conflicting environmental gradients, the sampling locations were stratified by historical vegetation type, household income and urban intensity in the second year of sampling. In 2018, 72 sites were visited and 70 in 2019; the total number of sites was 142. Sites were visited twice during the austral spring seasons of 2018 and 2019, and traps were left in place for a minimum of 48 hours.

Five sets of three pan traps (white, blue and yellow) of 75 mm diameter x 40 mm depth were laid out at 1.5–3 m distance from each other in a linear or zig-zag pattern depending on the size and layout of the site (Figure 3.2). Ideally, sets of traps were placed 1–2 m apart, but in areas where there was high-traffic, or no clear pedestrian footpaths, greater spacing was required to mitigate potential trap losses. Each trap received approximately 75 ml of 2:1 dilute propylene glycol. Because of permit conditions, traps placed at sites in the South African National Parks (SANParks) estate contained soapy water. The concentration was approximately 5 ml of liquid soap in 5 l of water to break the meniscus. The traps were left in place for two days, with at least one clear, warm, sunny day. On collection, the contents of like-coloured pan-traps were pooled. Each pooled sample was labelled with the collection date, the location code and the pan-trap colour.

Flower-visiting insects are either attracted to pink, purple and blue (cool colours), or yellow, red and orange (warm colours). Although fewer species are attracted to cooler colours (blues), they tend to be more specialised and have a strong preference in this direction (Campbell & Hanula 2007; Vrdoljak & Samways 2012; Roulston et al. 2018). Yellow traps tend to attract the greatest richness in pollinator species and only a small number of supplementary species are attracted to other colours (Vrdoljak & Samways 2012), Monkey beetles have three guilds, two of which are attracted to red, orange and yellow (warm colours). The third is attracted to blue, pink and white (cool colours) (Picker & Midgley 1996). It is therefore necessary to use sets of three different colours of traps: yellow, blue and white. This is adequate to ensure that representatives from guilds attracted to both warm and cool colours are collected (Vrdoljak & Samways 2012). Furthermore, Coleoptera show a strong preference for UV colours (Shrestha et al. 2019). UV painted pan-traps of 75 mm diameter were therefore deployed (Baum & Wallen 2011; Shrestha et al. 2019).

Permits were obtained from Cape Nature (permit number: CN44-28-9351), SanParks (permit number: CRC/2019-2020/007—2019/v1), and land-owner permission was sought from the

City of Cape Town area managers, superintendents and the parks and recreation Department of Biodiversity Management.

Local habitat data were sampled in 10 × 1 m^2 quadrats in a transect across each site at 2 m intervals (or in a randomized grid if the area of the site did not allow for a minimum 20 m transect). Data were collected on the habitat structure including percentage cover of bushes, herbaceous groundcovers, bare ground, stone, mulch and tree canopy. Counts of open flowers were recorded within each quadrat. Capitulate flowers were counted as one to the first joint with the main stem. Notes were made of species which were uncommon, but present outside of the sampled quadrats on the site. For 15 minutes, flowers in the surrounding 30 m radius of the traps were searched for monkey beetles. As far as possible three pairs of each species in copula were collected to provide a reference for the identification of male/female dimorphism. The flowers from which the monkey beetles were collected were identified to genus or species level, to provide evidence of the preferences of monkey beetles for colours and flower species.

Laboratory and Desk-top Processing

Monkey beetles were separated from the by-catch and were identified to morphospecies level. Representatives of each morphospecies at each site were pinned and an overall representative sample was pinned for cross-checking identification. Where possible, individuals were identified to species level and cross-checked using reference samples in the Iziko Museum of Natural History in Cape Town.

Landscape level patterns were quantified from aerial photographs. 1 × 1 km square photographs were extracted from the Google Earth Engine by loading the GPS coordinates of sampling locations into a semi-automated urban intensity scoring tool (Seress et al. 2014). The GPS points were centralized to the position where pan-traps were placed at each observation site (Figure 3.3). The urban scoring tool requires a minimum of three training points per image and quantifies the area under building, vegetation and roads; it next conducts Principal Components Analysis (PCA) to generate an urban index score. The output file contains data on vegetative cover, buildings, roads and a total PCA urbanization score

(Seress et al. 2014). Soil-sealing is the quantity of ground that is covered with building and hard surfaces, thereby preventing infiltration and soil penetration by living organisms. The amount of soil-sealing in the surrounding area is used as a proxy for urban intensity.

Income was estimated by importing census data aggregated to suburb (Statistics South Africa 2011) into QGIS (version 3.6.1) and using the point-picker tool to select the data which correspond with the GPS coordinates at each sampling location. The same process was followed for extracting historical vegetation data. The shapefile which was used for this was the South African Vegmap (Mucina & Rutherford 2006) downloaded from the South African National Biodiversity Institute's (SANBI) Biodiversity GIS web portal (www.bgis.sanbi.org). Site size was extracted in QGIS from the Cape Town City Council's 2016 Integrated Zoning Map (City of Cape Town 2017).

Figure 3.2 Top left: The 1 m^2 quadrat used to aid the sampling of local habitat and flower community structure. The flowers being surveyed here are Dimorphotheca pluvialis *and* Conicosia puginioformis. *Bottom left: The five sets of pan traps ready for their contents to be labelled and stored for later laboratory processing. Right: The typical set up of pan traps. Five sets of three were laid out at 1.5-2 m intervals, usually in a line as shown.*

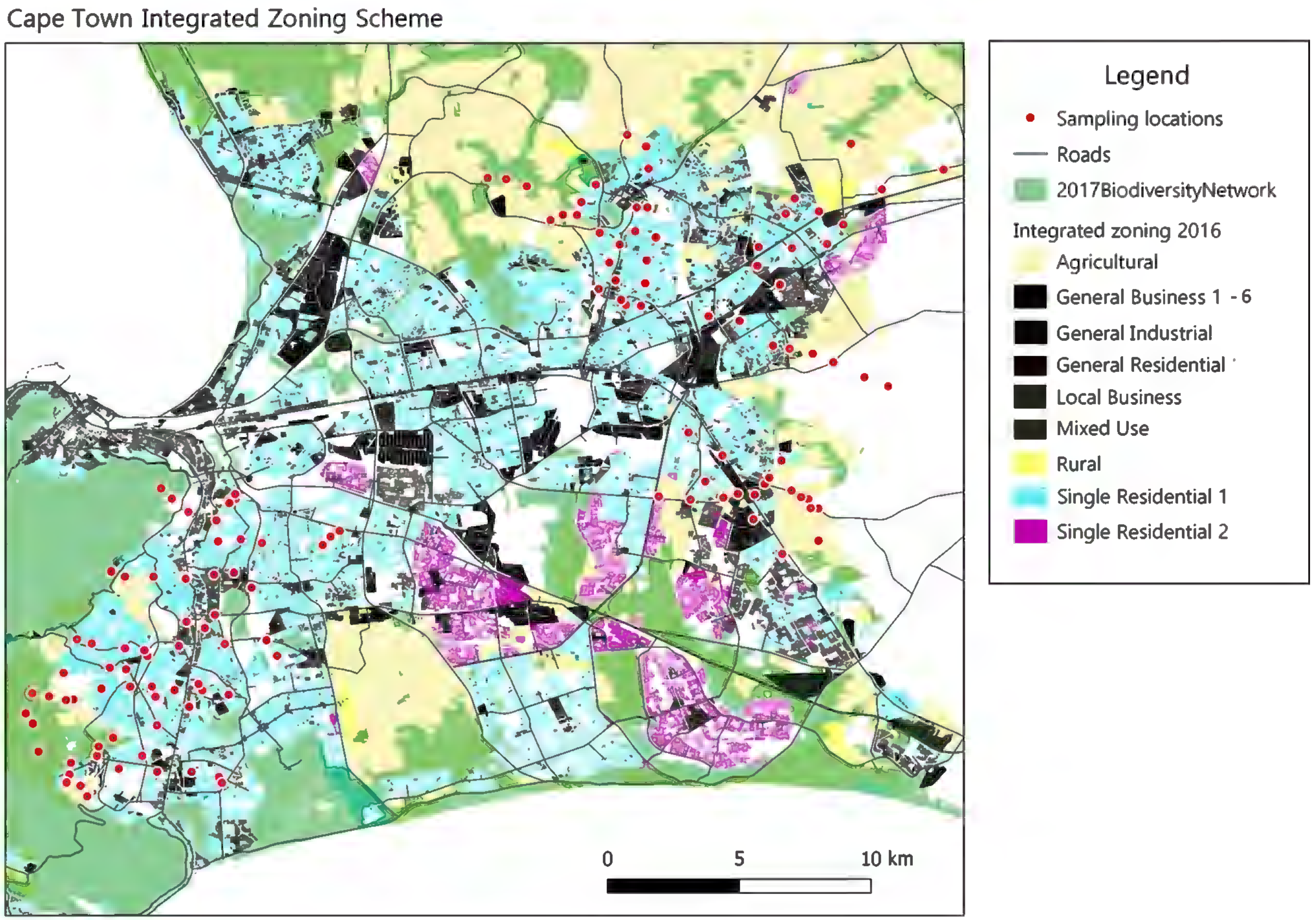


Figure 3.3: Monkey beetle sampling locations (n=142) overlaid on the Cape Town Metropolitan Integrated Zoning map of 2017. The map is colour coded to indicate urban intensity for the purposes of selecting sampling locations; black coloured sites allow a building coverage of 60% or more; purple is the location of informal settlement and incremental housing which the state subsidizes but which can be up to 160 du/ha and house the poorest citizens; blue sites are medium to low-density single residential buildings which are zoned for up to 50% coverage, but usually less; green indicates Public Open Space (POS), parks and nature reserves; yellow indicates agricultural usage.

Data Analyses

Two data matrices consisting of counts of monkey beetles at sites and flowers at sites were constructed. The matrix for the monkey beetles had 142 rows (sites) and 30 columns (morphospecies) and the flowers contained 140 rows (sites) and 81 columns (species). Species accumulation curves were plotted for the monkey beetles to confirm adequate sampling effort. The elements of the matrices were square-root transformed and two dissimilarity matrices were constructed using the Bray-Curtis index in Primer v 6.1.16 (Bray & Curtis 1957; Clarke & Gorley 2006). Both non-metric multi-dimensional scaling (NMDS) and hierarchical cluster analysis (group averages algorithm) were performed on both dissimilarity matrices (Kruskal, 1964). Cluster analysis was overlain over the two-dimensional configuration generated by the NMDS for group averages (Everitt et al. 2011). Monkey beetle and flower species which were seen to be outliers in the NMDS and cluster analysis were mostly species which were seldom recorded (<5 locations) and these rare species were removed from the dataset. The groups generated by the hierarchical cluster analysis were added to the NMDS configuration. Sets and subsets for both flowers and beetles were identified from the clustering, and species within each group were pooled into a single data vector. Kruskal-Wallis tests (Kruskal & Wallis 1952) were performed to test the null hypothesis that the species were randomly distributed across the levels of the environmental factors including mean household income, soil sealing, historical vegetation type, site area/size, and the percentage cover of tree canopy, grass, herbs, shrugs, rock, and bare ground at each site. Spearman rank correlations (Glasser & Winter 1961) were performed between the ranked sets and aggregated by each of the environmental factors for which statistical significance was demonstrated ($p<0.05$), in order to understand the direction of those relationships for which the null hypothesis could be rejected.

To examine the relationship between flower communities and monkey beetles*,* the null hypothesis that monkey beetles would be randomly distributed across the flower species was tested. A contingency table was generated for each monkey beetle species with cells containing the count of the number of sites at which each monkey beetle species was present or absent for each of the flower species. The chi-squared test of independence was performed on the table (Fisher 1922). If the test for a particular monkey beetle was significant, the frequency of co-occurrence with each flower species was ranked; this provides an indication of which flower species are associated with each monkey beetle. Because the data collection was done at the site level, it runs the risk of producing misleading results in the context in which two flower species co-occur, but only one is attractive to monkey beetles. Hence results were corroborated with field collections of monkey beetles collected off flowers and by examining the clustering of flower communities in the non-metric multi-dimensional scaling plots.

To investigate the relationship between the flower diversity and beetle diversity, three diversity indices (Shannon H-index, Inverse Simpson and species richness) (Hill 1973) were calculated at the 140 sites for both flowers and beetles, using the 'vegan' package (Oksanen et al. 2020) in RStudio version 3.6.0. Spearman's correlation was calculated for each diversity index.

Results

During the two sampling seasons, 19,387 individuals of monkey beetles were collected. They represented 30 morpho-species from 142 locations in and around Cape Town city metropolitan area. Non-metric multi-dimensional scaling and clustering produced two sets (Set A and Set B, Figure 3.4) of commonly co-occurring monkey beetles. Set A, included *Lepithrix ornatella* and *Heterochelus rufimanus*. The ranking of species abundance in Set A, (Figure 3.5), decreased with soil-sealing, increased with site area and increased with median neighbourhood income. Set B incorporated eight species of monkey beetles. Ranking of species abundance in Set B increased with soil-sealing and decreased with site size, however, when the subsets of Set B were assessed, only subset 1 incorporating *Heterochelus sexlineatus* sp. and *Heterochelus hybridus* showed any relationship with soil-sealing. The underlying ecosystem, (soil and historical vegetation) were the main drivers for subsets 2 and 3 (Figure 3.5).

Flowers and Beetles

Monkey beetle species composition was influenced by flower species assemblage at the site level. The null hypothesis that beetles were randomly distributed across flower communities was rejected for all species (Table 3.1). The flower communities formed four co-occurring sets containing a further four subsets (Figure 3.5). Their clustering is attributable both to growth form and to location. Set A consisted of ruderal species including exotic and invasive weeds and the most common indigenous annuals. Set B was a combination of annuals and indigenous perennials. Set C was predominantly indigenous annuals with the exception of *Conicosia puginioformis.* Set D was made up of indigenous geophytes. The clustering and histogram of the presence of flowers, ordered from most common to least common, shows them grouped by relative commonality and growth form (Figure 3.6 and Figure 3.7). Monkey beetle collections made from flowers provided insights into which of the flower species within sub-communities were most preferred by each of the monkey beetles species (Table 3.2).

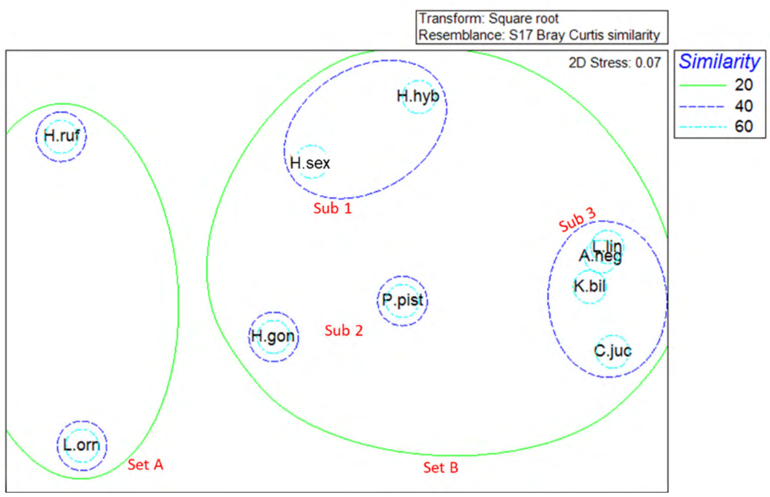


Figure 3.4 Clustering of monkey beetles collected in Cape Town during the austral spring seasons of 2018 and 2019. The plot is the non-metric multidimensional scaling of the most commonly occurring species in the sample set including Set A: Heterochelus rufimanus *and* Lepithrix ornatela*; Subset 1:* Heterochelus sexlineatus *sp. and,* Heterochelus hybridus*; Subset 2:* Heterochelus gonager *and* Peritrichia pistinaria*; Subset 3:* Lepithrix lineata, Anysochelus neglecta, Khoina bilateralis *and* Chasme jucunda*.*

When the subsets were cross-checked with the observed pairings of monkey beetles and plants, Subset 1, including *Heterochelus sexlineatus sp.* and *Heterochelus hybridis* showed a preference for the flowers *Cotula turbinata* and *Arctotheca calendula* and were collected across vegetation types and urban gradients. Subset 2, including *Heterochelus gonager* and *Peritrichia pistinaria* are generalists preferring Peninsula Granite Fynbos ecosystems and flower communities containing *Senecio* sp. in higher-income, suburban neighbourhoods. Subset 3 is associated with Cape Flats Sand Fynbos and showed a preference for *Conicosia puginiformis, Heliophila* spp. and *Carpobrotus edulis* (Figure 3.6 and Table 3.3).

Diversity Indices of Flowers and Beetles

There was no relationship between floral diversity and beetle diversity when comparing using Spearman's rank correlation for Shannon's inverse and Simspon's indices. Monkey beetle and flower species richness, however, showed a moderately positive correlation (rho=0.31, p<0.001) (Figure 3.8).

Hopliini (Monkey Beetles)

	Soil Sealing						Site Size					Historical vegetation					Income				
	Ex	P	S	U	p-value		S	M	L	p-value		CFSF	PGF	SSR	p-value		L	M	H	p-value	
Set A	88.2	77.9	68.8	52.4	<0.001	***	61.9	79.7	84.3	0.003	**	58.0	86.7	67.6	<0.001	***	57.7	61.5	83.8	<0.001	***
Set B	52.3	58.2	85.8	87.9	<0.001	***	85.7	58.4	53.5	<0.001	***	83.7	36.4	36.5	<0.001	***	96.9	78.0	54.8	<0.001	***
Sub 1	49.1	54.0	90.3	90.6	<0.001	***	90.8	51.4	49.5	<0.001	***	83.0	32.8	42.5	<0.001	***	96.5	79.0	54.0	<0.001	***
Sub 2	72.3	72.2	70.8	70.8	0.990		70.3	73.1	72.5	0.920		74.0	61.9	41.1	<0.001	***	82.2	75.9	63.7	0.039	*
Sub 3	69.0	67.0	76.0	73.0	0.600		73.1	65.5	74.3	0.400		76.0	49.6	47.9	<0.001	***	96.0	70.2	59.2	<0.001	***

Flowers

	Soil Sealing						Site Size					Historical vegetation					Income				
	Ex	P	S	U	p-value		S	M	L	p-value		CFSF	PGF	SSR	p-value		L	M	H	p-value	
Set A	56.0	62.3	78.8	95.1	<0.001	***	86.7	62.2	56.5	<0.001	***	72.5	42.4	77.4	0.001	**	81.1	78.0	67.8	0.615	
Set B	88.0	65.0	66.8	74.2	0.022	*	72.4	66.8	83.9	0.111		68.8	70.2	63.8	0.723		72.5	75.8	73.1	0.223	
Set C	74.4	76.9	70.5	72.8	0.864		74.9	68.6	75.8	0.562		72.3	52.7	69.1	0.019	*	76.3	84.3	67.6	0.915	
Set D	74.2	79.8	70.1	70.6	0.375		72.1	72.5	77.8	0.562		71.0	60.3	66.2	0.149		69.7	77.6	73.8	0.046	*
Sub 1	65.4	81.3	74.5	73.1	0.072		74.3	74.9	70.0	0.623		65.0	69.4	75.1	0.138		67.3	70.6	77.8	0.084	
Sub 2	54.0	60.7	82.6	94.6	<0.001	***	88.5	58.4	56.9	<0.001	***	73.5	39.9	76.7	<0.001	***	80.1	80.9	67.1	0.158	
Sub 3	88.3	68.4	68.0	69.6	0.010	*	71.1	66.6	86.9	0.013	*	68.1	70.2	65.8	0.857		73.2	71.6	74.4	0.905	
Sub 4	73.0	74.7	70.3	76.2	0.842		75.9	70.8	71.3	0.615		70.9	53.5	72.5	0.016	*	80.0	82.6	66.5	0.011	*

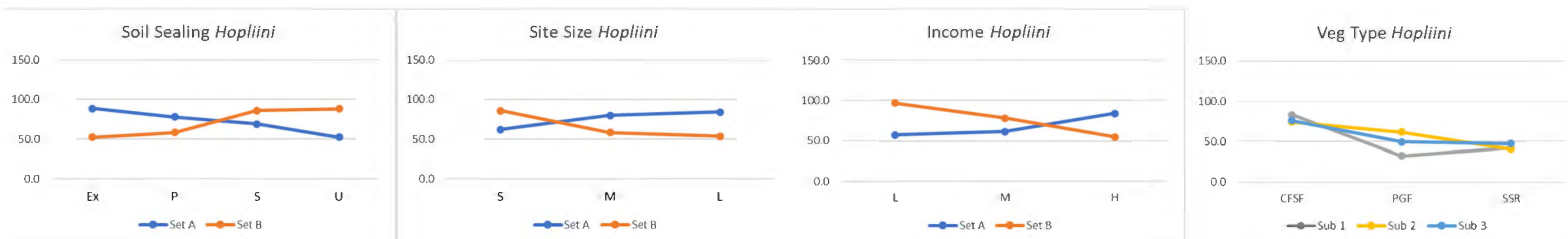


Figure 3.5 Summary of the relationships between environmental variables and the species communities identified using NMDS and cluster analysis. The p-values were determined using Kruskal-Wallis-tests. Group means of ranks of monkey beetle abundance in each subset of commonly co-occurring species of monkey beetles were plotted against environmental variables on the x-axis. Soil-sealing is aggregated by the groups ex-urban, peri-urban, suburban and urban. Site size is aggregated to small, medium and large. Income is aggregated to low, medium and high household income agrigated to neighbourhood, and historical vegetation type is assessed for Cape Flats Sand Fynbos, Peninsular Granite Fynbos and Swartland Shale Renosterveld. The plots were generated for those sets and subsets which demonstrated statistical significance (p<0.05, ** p<0.005, *** p<0.001) in order to determine the direction of the inference.*

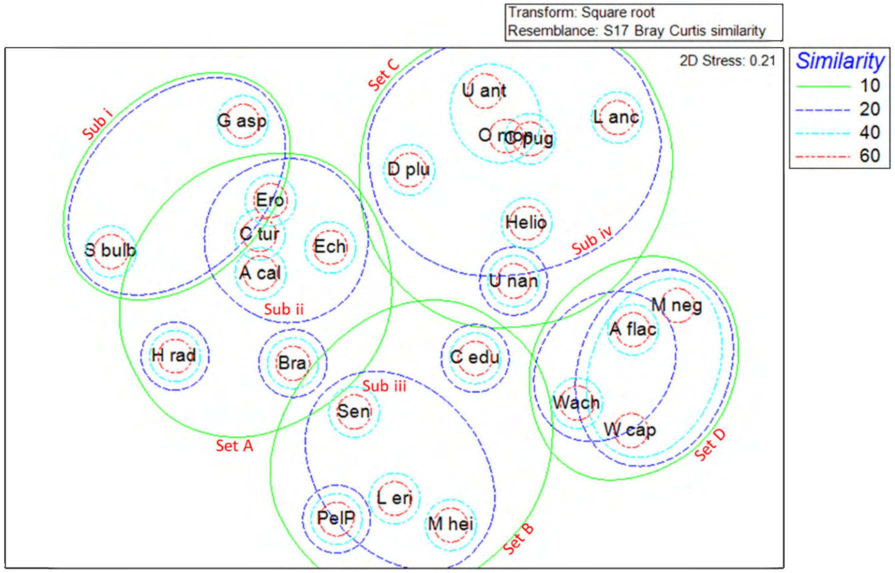


Figure 3.6 Clustering of flower abundance counts collected in Cape Town during spring season in 2018 and 2019. The plot represents the Non-metric multidimensional scaling of the most commonly occurring species in the sample set including Set A: Erodium *spp*. Cotula turbinata*,* Echium *spp.* Arctotheca calendula*, Yellow* Brassicaceae, Hypochaeris radicata*; Set B:* Pelargonium *spp (pink).,* Lobelia erinus*,* Senecio *spp.,* Muraltia heisteria *and* Carpobrotus edulis*; Set C:* Ursinia anthemoides*,* Dimorphotheca pluvialis*,* Osteospermum monstrosum*,* Conicosia pugioniformis*,* Lapeirousia anceps*,* Heliophila *spp.* Ursinia nana*; and Set D:* Wachendorfia multiflora*,* Wahlenburgia capensis*,* Moraea neglecta*,* Albuca flaccida.

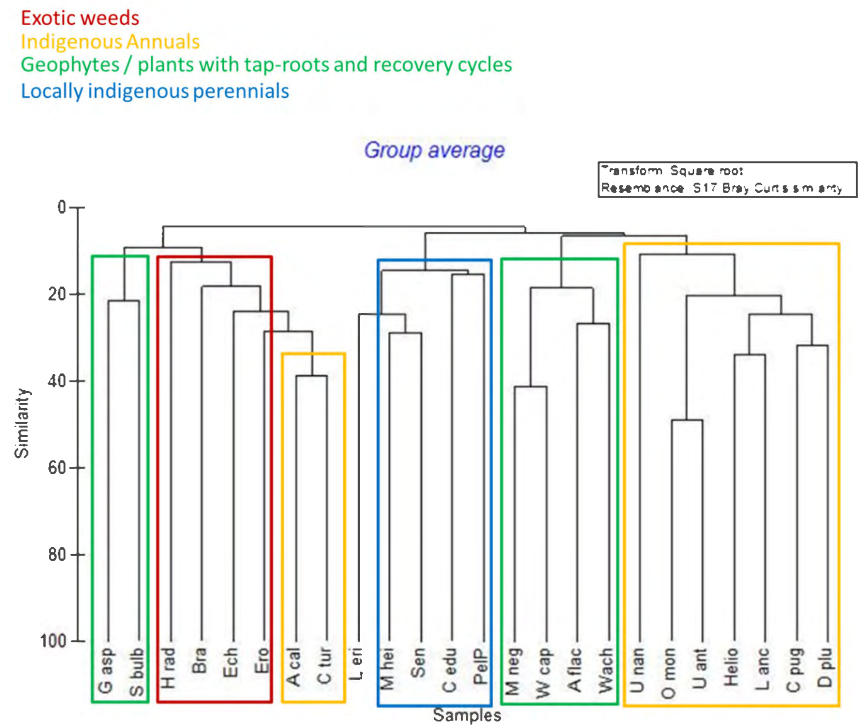


Figure 3.7 The group average clustering of flower species arrange according to growth form.

Table 3.1 Sites at which flower species were present and the percentage of those where each species of monkey beetle co-occurred. Percentages in the column are the percentage of flower presence sites where the monkey beetle species co-occurs. The pink highlights are the top three highest percentages in each column; the yellow highlights are the remaining two values in the top five of each column.

	No. of sites where flower occurred	*Lepithrix ornatella*	*Heterochelus sexlineatus sp.*	*Heterochelus hybridus*	*Khoina bilateralis*	*Heterochelus gonager*	*Anisochelus neglecta*	*Lepithrix lineata*	*Peritrichia pistinaria*	*Dolichiomicroscel is gracillis*	*Lepithrix lineata (DM)*	*Heterochelus gonager (DM)*	*Heterochelus rufimanus*	*Pachycnmea crssipes*	*Dicranocnemus*	*Heterochelus 3*	*Heterochelus 2*	*Chasme jucunda*	In top 3	In top 5	
		P	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**			
Arctotheca calendula	71	30%	82%	38%	8%	30%	18%	14%	32%	6%	4%	8%	23%	11%	8%	11%	11%	10%	0	1	*
Carpobrotus edulus	16	31%	75%	38%	31%	31%	31%	25%	50%	19%	0%	13%	25%	19%	13%	31%	0%	38%	2	4	*
Conicosia pugioniformis	14	21%	93%	64%	50%	36%	71%	57%	93%	36%	29%	7%	0%	0%	29%	7%	7%	43%	11	11	*
Cotula turbinata	64	33%	69%	41%	14%	25%	16%	13%	30%	3%	6%	9%	30%	8%	9%	14%	9%	8%	0	0	*
Dimorphotheca pluvialis	19	32%	68%	63%	32%	32%	47%	32%	63%	16%	21%	5%	32%	5%	21%	11%	21%	37%	3	9	*
Echium	47	34%	68%	40%	19%	32%	21%	19%	47%	6%	2%	9%	28%	9%	9%	13%	13%	13%	0	0	
Erodium	51	22%	71%	31%	8%	16%	16%	12%	24%	4%	6%	8%	25%	10%	8%	10%	20%	8%	0	1	
Geissorhiza aspera	12	58%	33%	33%	8%	33%	0%	8%	8%	0%	0%	17%	25%	0%	17%	17%	25%	8%	2	4	
Heliophila	9	11%	78%	78%	44%	56%	33%	33%	56%	33%	22%	0%	11%	0%	33%	22%	0%	56%	9	11	*
Lobelia erinus	9	44%	33%	11%	33%	11%	0%	11%	22%	0%	0%	22%	33%	0%	11%	11%	33%	11%	2	4	
Osteospermum monstrosum	10	30%	70%	60%	50%	60%	50%	40%	80%	30%	20%	0%	20%	10%	30%	10%	10%	50%	8	11	
Oxalis pes-caprae	21	19%	67%	52%	10%	24%	19%	5%	52%	10%	5%	0%	38%	14%	5%	5%	14%	14%	0	3	
Pelargonium (Pink)	14	50%	50%	29%	29%	29%	21%	14%	29%	14%	7%	14%	50%	0%	7%	14%	7%	14%	2	2	*
Romulea rosea	17	29%	82%	35%	6%	29%	6%	0%	41%	6%	0%	18%	24%	6%	18%	12%	0%	0%	0	3	
Senecio (yellow)	25	36%	60%	56%	28%	24%	20%	12%	48%	4%	8%	12%	20%	12%	8%	8%	8%	16%	0	1	*
Trachyandra ciliata	10	10%	90%	80%	10%	10%	40%	30%	50%	0%	20%	0%	20%	0%	10%	10%	10%	0%	2	7	
Ursinia nana	14	21%	86%	50%	36%	36%	21%	21%	29%	14%	14%	7%	21%	7%	14%	21%	7%	29%	2	4	*
Vicia	13	31%	38%	15%	15%	15%	8%	8%	23%	8%	0%	23%	38%	8%	0%	8%	0%	0%	2	2	
Brassicacea (yellow)	26	46%	62%	38%	23%	35%	15%	19%	42%	0%	0%	15%	35%	15%	8%	23%	4%	4%	2	5	*
Hypochaeris radicata	13	15%	69%	23%	8%	31%	15%	0%	23%	0%	0%	0%	15%	0%	0%	0%	8%	0%	0	0	
Lysimachia monelli	11	55%	9%	0%	18%	0%	0%	0%	36%	0%	0%	18%	64%	18%	0%	0%	27%	0%	5	5	

Table 3.2 List of monkey beetle species collected from flowers and the colours of the flowers on which they were most frequently found.

Hopliini	Flower	Flower colours
Embedding guild (long-wave colours)		
Heterochelus sexlineatus sp.	*Arctotheca calendula,* *Cotula turbinata,* *Dimorphotheca pluvialis*	yellow white
Heterochelus 2	*n/a*	
Heterochelus gonager	*Dimorphotheca pluvialis,* *Senacio sp.,* *Arctotheca calendula,* *Echium sp.*	white yellow, blue/violet
Heterochelus hybridus	*Cotula turbinata,* *Arctotheca calendula,* *Ursinia nana,* *Dimorphotheca pluvialis,* *Pauridia capensis (yellow)* *Senacio sp.*	white, yellow
Ishnochelus	*Hypochaeris radicata,* *Morea miniata*	yellow, salmon pink / yellow

Hopliini	Flower	Flower colours
Non-embedding guild (short-wave colours)		
Dolichiomicroscelis gracilis	*Heliophila africana*	blue/violet
Peritrichia pistinaria	*Pelargonium,* *Heliophila africana,* *Echium sp.*	pink, blue/violet
Non-embedding guild (long-wave colours)		
Anisochelus neglectus	*Conicosia pugioniformis,* *Carpobrotus edulis*	yellow
Bizanus	*Morea miniata*	salmon pink
Chasme jucunda	*Conicosia pugioniformis,* *Ursinia sp.*	yellow
Heterochelus rufimanus	*Bolusafra bituminosa* *Arctotheca calendula*	yellow
Dicranocnemus	*Ursinia*	yellow
Khoina bilateralis	*Conicosia pugioniformis*	yellow
Lepithrix lineata	*Arctotheca calendula,* *Conicosia pugioniformis,* *Senecio sp.*	yellow
Lepithrix ornatella	*Senecio sp.*	yellow
Pachycnema crassipes	*Carpobrotus edulis*	yellow
Platychelus lupinus	*Morea miniata*	salmon pink

Table 3.3 Number of monkey beetle species collected off each species of flower.

Flower Species	Flower guild	No. of monkey beetle species
Arctotheca calendula	Indigenous, annual	5
Cotula turbinate	Indigenous, annual	2
Dimorphotheca pluvialis	Indigenous, annual	3
Senacio sp.	Indigenous, annual	4
Ursinia nana	Indigenous, annual	3
Pauridia capensis	Indigenous, geophyte	1
Moraea miniate	Indigenous, geophyte	3
Heliophila	Indigenous, annual	2
Echium sp.	Invasive, annual	1
Conicosia puginioformis	Indigenous, perennial	4
Carpobrotus edulis	Indigenous, perennial	2
Pelargonium sp.	Indigenous, perennial	1

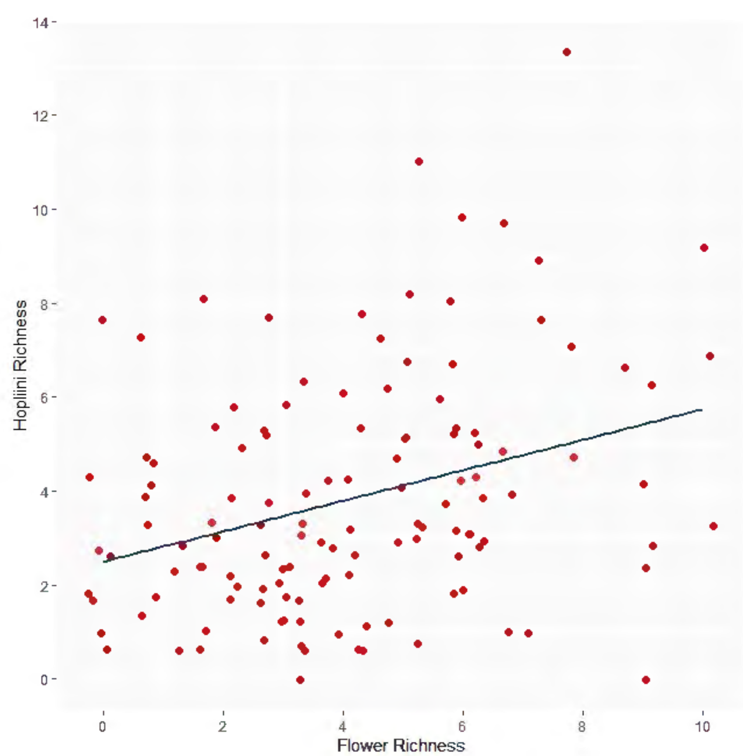


Figure 3.8 Corelation between beetle and flower-richness (rho-=0.31, P<0.001)

Discussion

This study revealed patterns in pollinator assemblage in response to urban landscape environmental gradients and composition. It also identified species of flowers which are favoured by a greater richness of pollinators. 1. Guild response, 2. Environmental gradients; and 3. Flower preference are discussed below.

Divergent Responses Between Guilds

In response to urban intensity, the findings of this study were consistent with those done in other parts of the world for Hymenoptera in that some species exploited urban conditions, some species avoided them and some species depended on connected flower communities to move through the urban landscape (Wenzel et al. 2020). This divergence in bees is associated with the differences in nesting requirements and life-histories of different feeding guilds (Cane et al. 2006; Shwartz et al. 2014; Merckx et al. 2018).

Not much is known about the life-histories of monkey beetles, but some understanding of their behaviour and feeding differences is known (Picker & Midgley 1996; Mayer et al. 2006; Karolyi et al. 2016; Colville et al. 2018) and other studies have demonstrated a shift in feeding guilds along disturbance gradients (Colville et al. 2002). Monkey beetles utilize flowers as a breeding platform during the austral spring floral flush (Goldblatt & Manning 2011). The mechanism for pollination is the presence of setea on the backs and bodies of the beetles which collect pollen loads as they move across the flower (Bernhardt 2000; Mayer et al. 2006; Mayer & Pufal 2007). Three feeding and breeding guilds have been identified according to feeding and behaviour (Picker & Midgley 1996; Colville et al. 2002; Karolyi et al. 2016). Adult mouthparts are evolved according to a diet of either pollen and nectar, or flower tissue (Karolyi et al. 2016). Behaviour is characterized either as embedding, in which the females bury their heads into the centre of the flower while males fly around and compete over them to mate. The males are predominantly responsible for the pollination as they move around between flowers looking for available females (Bernhardt 2000). Embedding guilds eat pollen and nectar and are attracted to long-wave colours (red, orange and yellow). The non-embedding guilds are split into two groups, by colour attraction. One non-embedding guild is attracted to short-wave (blue, pink, violet) coloured flowers, and the other is attracted to long-wave colours (Picker & Midgley 1996; Colville et al. 2018). *Lepithrix*, *Anisonyx* and *Peritrichia* are recorded as feeding on pollen and do not embed themselves, whereas species in the genus *Heterochelus* tend to embed themselves (Picker & Midgley 1996). The non-embedding group are characterized by being hairy and mobile, moving around between flowers more frequently than their embedding counterparts. For this reason, they are considered to be more effective pollinators (Goldblatt & Manning 2011).

Response to Urban Environmental Gradients

Comparisons between natural and agricultural landscapes have revealed that monkey beetle species compositions "turnover" along gradients of disturbance where a "shift away from perennial and bulb pollinator guilds towards those favouring weedy annuals" has been observed (Colville et al. 2002). Set A, included both non-embedding species and embedding species, but were only found in peri-urban areas. Set B, with three subsets, were found in more central and urban areas. The embedding *Heterochelus sexlineatus sp.* and *Heterochelus hybridis* of Subset 1, associated with ephemeral plants, including ruderal species and indigenous annuals and were abundant in urban landscapes close to commercial centres. This is consistent with Colville et al.'s (2002) study along disturbance gradients in agricultural landscapes in which this guild were found to associate with greater levels of disturbance (Colville et al. 2002). This indicates a behavioural and adaptive strategy of disturbance exploitation and this Subset 1 can therefore be considered as urban exploiters (Blair 1996). Subset 2 contained both non-embedding and embedding species which preferred Cape Flats Granite Fynbos and were common in suburban parks. *Chasme jucunde*, *Khoina bilateralis*, *Anisochelus neglecta*, *Lepithrix liniata* and *Peritrichia pistinaria* of Subset 3, are species of the "non-embedding" guild (Picker & Midgley 1996). They are typically sensitive to disturbance associating with established floral communities containing perennials and geophytes (bulbs) and were found in larger remnant patches with less disturbance (Colville et al. 2002), specifically, intact remnant patches of undeveloped land, with no or infrequent levels of disturbance. In terms of the model of urban adaptors, avoiders or exploiters, this group would be classified as urban adaptors (Blair 1996). It is therefore important to note their plant associations and the importance of the presence of preferred species of flowers for this group (discussed in more detail below).

The responses to urban intensity and socio-economic status correlated in this study. This could be explained by the fact that plot size is correlated with mean household income and the number of dwelling units per hectare (du/ha) increases with decreasing income (Turok 2011). The relationship between plot size, mean household income, and biodiversity is seldom discussed in structural terms (e.g. building form, density plot size and amount of green infrastructure) in the literature, however, the correlation of biodiversity with household income is well documented as the "luxury effect" (Wu 2014; Aronson et al. 2016). The deficit and lack of access to quality green infrastructure among the urban poor of South Africa has further been highlighted by several researchers and provides additional explanation for the observed patterns (Donaldson et al. 2016; Linkley et al. 2018; Venter et al. 2020).

This study found that there is an intact community of monkey beetles in the city and that there is a reliance on particular plant communities for breeding and foraging resources. This finding is promising for the conservation of rare bulbs within the urban landscape which rely on a healthy population of monkey beetles for pollination services (Steiner 1998; Johnson & Steiner 2003; Goldblatt & Manning 2006; Barraclough & Slotow 2010; Goldblatt et al. 2013).

The Role of Flower Preference

Monkey beetles are generalist pollinators and most species will visit at least two species of flowers (Steiner 1998; Mayer et al. 2006). Records of flower visitations by monkey beetles to date have peaked at a maximum of five monkey beetle species per flower species (Mayer et al. 2006). Determining the relative preference and attractiveness of different flowers to monkey beetles was outside of the initial scope and objectives of this study, however, the results of collections from flowers and field observations provide preliminary indications of the ways in which flowers are being used by monkey beetles in Cape Town. Further research investigating visitation rates is needed to confirm and clarify the relative importance of these species, however, when Table 3.1, 3.2 and 3.3 are read together, co-occurrence data and the number of monkey beetle species collected off flower species point to the relative preferences for flowers between the different monkey beetle guilds. *Heliophila* sp. (including *Heliophila africana* and *Heliophila coronopifolia*) is preferred by non-embedding monkey beetles which favour short-wave colours; *Conicosia punginioformis* was preferred by the non-embedding guilds which favour long-wave colours; *Dimorphotheca pluvialis* and *Ursinia nana* were visited by the embedding guild; and *Arctotheca calendula* and *Senecio* sp. which are both mass-flowering annuals and can cover entire parks, were favoured by embedding guilds.

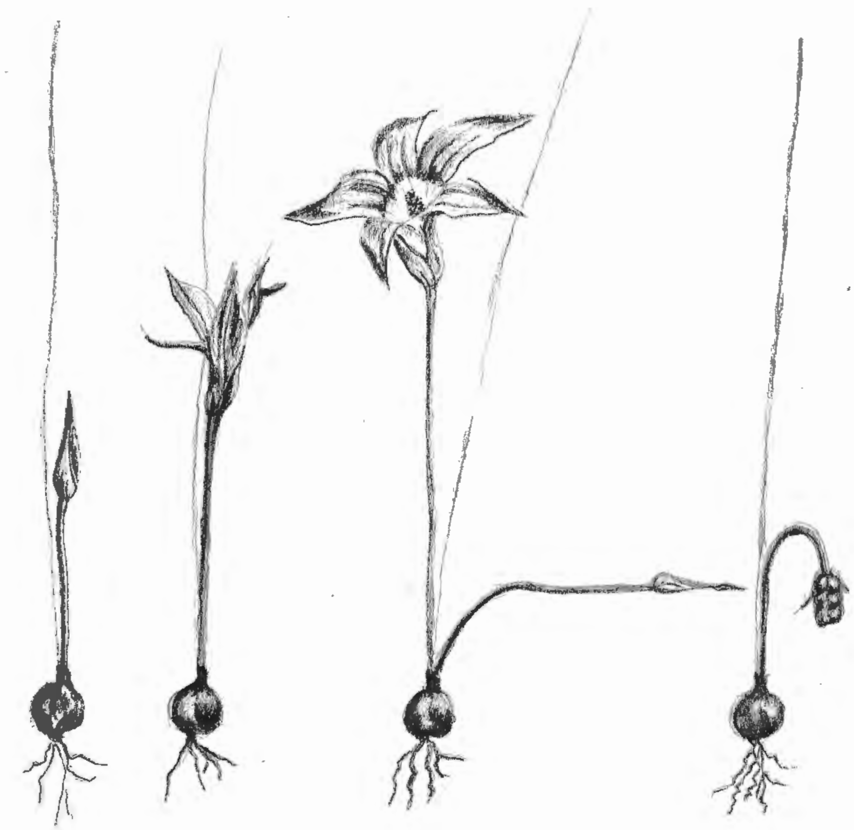
The occurrence of short-wave, non-embedding guilds was less common and associated with fewer flower species which were relatively isolated across the city. Sites where floral communities included the most popular species from all guilds, including *D. pluvialis, C. conicosia and Heliophila* sp., supported greater monkey beetle richness as reflected in the correlation between monkey beetle and flower species richness (Figure 3.8). It is therefore not only floral richness, but the presence of species preferred by the various guilds which drives monkey beetle richness. Therefore introductions of preferred species at regular intervals throughout the city, can aid monkey beetle mobility and provide stepping stones between larger fragments. This could potentially be achieved by strategically identifying suitable pathways and implementing targeted landscaping along those routes (Cranmer et al. 2012; Simao et al. 2018). Collections from *Conicosia puginioformis* (pig's root), consistently hosted the greatest number of monkey beetle species at any one site and was often found growing together with *Carpobrotus edulis*, a popular road verge plant for its hardiness, ease of propagation and bright flowers. *C. puginioformis* can easily be introduced as a co-plant to *C. edulis*, in road verges and city parks. Further research is needed to determine the extent to which the introduction of favoured short-wave plants (e.g. *Heliophila*), would restore the connectivity of landscapes for the non-embedding guild favouring blues and pinks.

Conclusion

In this chapter, the distribution of monkey beetles was sampled in a metropolitan city in the Cape Floristic Region of southern Africa. It aimed to determine how monkey beetles were responding to urban environmental gradients and local habitat communities. It found an established community of monkey beetles was responding in different ways to urban gradients. Embedding species were more tolerant of soil-sealing congregating on ephemeral species of Asteraceae and geophytes. Non-embedding species were associated with preferred flower species and reduced their abundance as soil-sealing increased in the surrounding landscape. *Conicosia puginioformis* (common names: pig's root, slime root) hosted the greatest richness of monkey beetles. The findings suggest that widespread introduction of a community of beetle-preferred flowers, including *C. puginioformis* as a cornerstone species, may provide stepping-stones through the urban matrix and aid species mobility.

- 4 -

A Mowing Strategy for Urban Parks to Support Spring Flower Populations and Their Pollinators



Abstract

Converting road verges and Public Open Space to floral-rich resources is an important strategy for supporting populations of urban pollinators. One of the ways this can be achieved is through adjusting mowing schedules, either with a “delayed start” after the end of winter, or a reduction in mowing frequency. In mediteranean ecosystems with mild, wet winters, plant growth continues through the winter season and the definition of a “delayed start” is unclear. This study sought to identify a strategic period for the suspension of mowing activities in a Mediterranean city in South Africa. It estimated the duration of the flowering to seed-broadcast season of 20 species of indigenous geophytes. Observations were made of phenological status from bud to seed broadcast in nine city parks in Cape Town during the spring-flowering seasons of 2019 and 2020. The Underhill & Zucchini (1988) Moult Model was employed to estimate the duration of the season. Model results showed that mowing should stop in the second week of August and should not resume until the second week of November. The results are discussed against the relative biodiversity contribution that different parks and verges make and the potential conflicts with the utility objectives of society.

Introduction

Parks form an important component of natural and green infrastructure in cities. They can attract a richness of fauna (particularly insects and birds) when the quality of the landscaping is favourable (Shwartz et al. 2013; Dylewski et al. 2020; Samways et al. 2020). As such, they can act as biodiversity “stepping stones” between larger nature parks and conserved natural areas (Goodness 2018), especially for insects and other pollinators (Threlfall et al. 2015; Hall et al. 2017; Banaszak-Cibicka et al. 2018).

There are a few ways in which city parks can be managed to provide favourable landscapes for pollinators (Davis et al. 2017). One of these ways, floral-rich lawns maintained with moderate to low frequency mowing events, demonstrably increases biodiversity and foraging resources for pollinators and represent a practical, timesaving intervention to support urban pollinator and plant populations (O’Sullivan et al. 2017; Lerman et al. 2018; Yang et al. 2019; Watson et al. 2020). In Europe, delaying the first post-winter mowing date from spring to summer has produced positive outcomes for local plant species richness (Humbert et al. 2012). Studies advocating for a "delayed start" to the mowing season were predominantly carried out in European and North American cities which experience freezing temperatures and snowfall in winter (Watson et al. 2020). In contrast, cities in Mediterranean climates tend to experience winter rainfall, (with snow limited to high-ground), and mowing can continue throughout winter. Thus, in these contexts, the notion of a "delayed start" to the mowing season is a misnomer. However, when moderate to low frequency mowing events are strategically aligned to the life-cycles of specific pollinators and plants, the population abundance of both is improved in the following year (Knight et al. 2019).

One such Mediterranean-climate area is in the Western Cape Province of South Africa. Cape Town's municipal horticultural landscaping management minimum standards (see Appendix D) lays out norms for the municipal contractors employed to maintain road verges and POS. Accordingly, they must be mowed at least 10 times a year, resulting in a grass-cutting schedule with intervals of four to six weeks. This schedule means that it is likely that mowing occurs at least once in spring, cutting plants before fruits have matured and seeds have been broadcast, and thereby interrupting the floral reproductive cycle for spring flowers (Manning & Goldblatt 2012). Consequently, this study aims to optimize the duration of a grass-cutting suspension during the austral spring season in Cape Town. Specifically, it provides an indication of the number of weeks for which regular grass-cutting should be suspended during spring. In contrast to the experimental patch and subsequent biodiversity measurements taken in Europe and North American studies to date (Wastian et al. 2016a; Sehrt et al. 2020; Watson et al. 2020), this study adopted a phenological approach to understanding the ecological processes which support floral diversity. By quantifying the duration of the floral reproductive season, an optimal mowing suspension window can be identified.

In this chapter, methods were developed to generate mowing policy recommendations for Cape Town. The first step is to develop an inventory of the species of flowering plants in each park and classify parks according to functional richness. For each indigenous geophyte species, the phenophases (observable stages in the annual life-cycle of a plant) from budding to seed set were investigated. An algorithm which was developed to quantify the duration of bird moult, The Underhill- Zucchini Moult Model (Underhill & Zucchini 1988), is used here to quantify the flower phenology (duration of flower reproduction) and, based on these results, recommendations are made for a period for each park (or group of parks) during which mowing should not take place.

Methodology

Phenophase Status as an Indicator of Phenology

Early scholars of phenology recorded first event dates to track phenology, however variations can be erroneously reported when there are differing population sizes or less frequent monitoring. First-event phenology data sets typically quantify the phenological status of the most extreme individuals with a population of unknown size. This loses the detail of information about the shifts across the population (Elmendorf et al. 2016). Capturing only the most extreme cases cannot produce recommendations for strategic management outcomes nor provide enough information to balance competing interests and park facility usage trade-offs. Status monitoring provides more detail about the progress of the life-cycle and can capture repeat events, such as a second flowering flush after a cold snap (Denny et al. 2014; Elmendorf et al. 2016). Furthermore, the adoption of phenophase status and intensity instead of traditional first-event monitoring protocols has several documented advantages. Firstly, events that sometimes occur more than once in a year can be monitored. Secondly, uncertainties in transition dates can be measured. Thirdly, the duration of phenophase can be quantified. Fourthly, monitoring small patches and marked individuals ensures that recorded dates are decoupled from population size. This overcomes the weaknesses of first-event monitoring and when coupled with regular sampling enables phenophase change estimates (Elmendorf et al. 2016). It is therefore preferable to track either peak events (Elzinga et al. 2007) or status monitoring (Denny et al. 2014).

The field observation terminology and protocols adopted in this study are based on the USA National Phenology Network (Table 4.1). This protocol describes a phenophase as "An observable stage or phase in the annual life-cycle of a plant or animal that can be defined by a start and end point. Phenophases generally have a duration of a few days or weeks. Examples include the period during which newly emerging leaves are visible, or the period in which open flowers are present on a plant“ (*Phenophase | USA National Phenology Network*, n.d., https://usanpn.org/taxonomy/term/16) (Table 4.1).

Table 4.1 Descriptions of the phenophases used in this study: Based on definitions from USA National Phenology Network (n.d.)

Phenophase	Description
Bud appearance	Green closed flowers.
Open Flower	Open or opening flower with petals at least partially open.
Senescence	Petals have changed colour and are beginning to droop, are wilted, closing, or falling off.
Fruit formation	The appearance of a hardened nodule within the flower, or the complete loss of all petals (depending on plant species).
Seed broadcast	Fruits are cracked or open, or seeds fall out when shaken.

Observation Season and Frequency

No standardised frequency of phenology monitoring has been recommended by the scientific community. Observation frequency requirements are instead determined by species, study objectives, budgetary and logistical constraints on a case by case basis (Elmendorf et al. 2016). Mazer et al. (2015), who studied four species in California across broad environmental conditions, considered that twice-weekly sampling is sufficient to detect onset dates of vegetation growth, flowering and fruiting. Miller-Rushing et al. (2008) recommend sampling every second day to ensure a 97% chance of detecting significant change in date of flowering, however less frequent sampling may be adequate for many species to determine simple trend detection. At the opposite end of the scale, sampling every two weeks has been recommended to monitor tropical tree phenology (Harrison et al. 2019). Because the purpose of this study is to give an indication of

Table 4.2 Common species of geophytes occurring in city parks and their flowering dates (Manning & Goldblatt 2012).

Species Name	Flowering Duration
Moraea miniata	Aug-Sept
Sparaxis bulbifera	Sept-Oct
Baeometria uniflora	Aug-Nov
Pauridia capensis	Jul-Oct
Geissorhiza aspera	Aug-Sept

the number of weeks for which regular grass-cutting should be suspended during spring, it was deemed adequate to monitor on a weekly basis.

Table 4.2 presents flowering seasons for expected species (Manning & Goldblatt 2012). This information was used to determine a suitable observation commencement date. Because the intention of this study was to make recommendations relating to park and road verge management practices in an urban context, it was consequently not concerned with the most extreme early flowering individuals but rather the peak bud events. Furthermore, the use of the Moult Model (Underhill & Zucchini 1988) adopted during the analysis phase can predict the start dates of the season, even if they have already started when observations begin.

Study Area and Site Selection

Cape Town falls within the Cape Floristic Region which contains Renosterveld, Strandveld and Fynbos vegetation types (Mucina & Rutherford 2006; Rebelo et al. 2011). Renosterveld and Fynbos are particularly rich in geophytes (Rebelo et al. 2006; Manning & Goldblatt 2012) the majority of which emerge and flower during August–December (Manning & Goldblatt 2012), the austral spring season. Cape Town is the major metropolitan of the region and has small (0.1 ha) to medium (10 ha) parks throughout the urban fabric (City of Cape Town 2012). Many of these retain populations of locally indigenous geophytes and annuals that emerge in the lawns and flower during the spring season (Manning & Goldblatt 2012; Figure 4.1).

Temperature (and rainfall) vary across the city (Cowling et al. 1996; Wilkinson 2000); the northern and eastern areas tend to be warmer (Figure 4.2). In order to capture this variability, two groups of parks were selected from contrasting parts of the city. Park area managers were approached to identify suitable parks under their jurisdiction where there was a known abundance of spring flowers and geophytes (Figure 4.3). The parks were then visited to establish and confirm suitability.

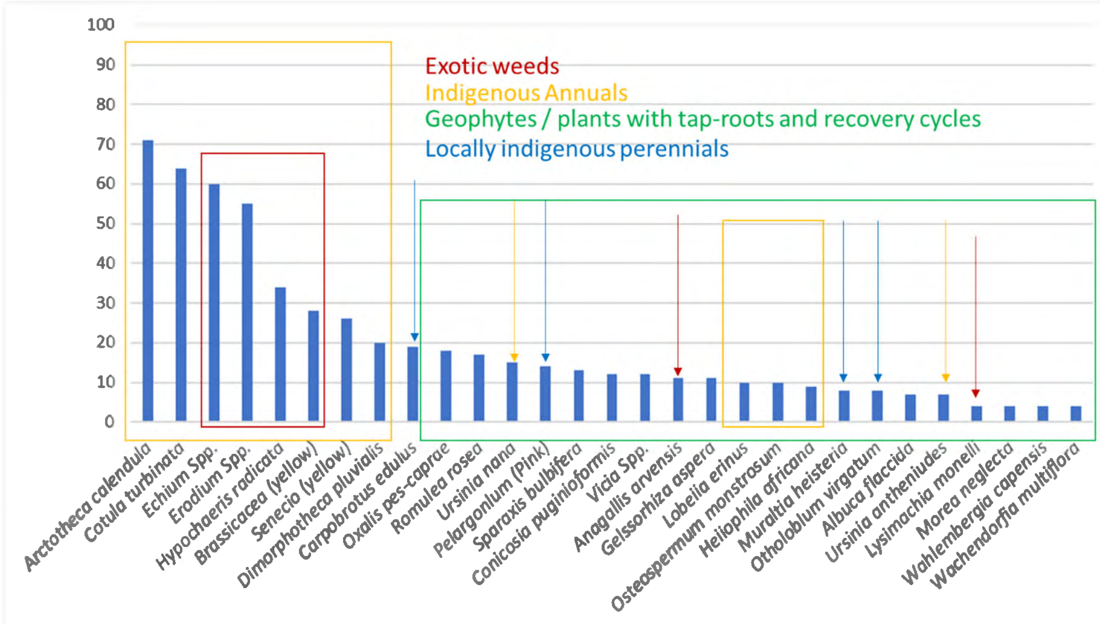


Figure 4.1 Frequency of occurrence (number of parks) of common flower species observed at 142 locations during the austral spring of 2018 and 2019 (See Chapter 3)

Neighbours and representatives from community stewardship groups were approached to obtain permission and co-operation in the project. Several of the larger park communities have formed “Friends of” groups or “Associations” which volunteer to advocate for park upgrades, or coordinate volunteer activities. Activities range from planting, weeding and clean-up days, to communicating community needs and aspirations for a particular park or, in the case of Harfield Village, set of parks. These groups were approached to notify them of the research activities and request co-operation. At Bowlers POS and Keurboom Park, representatives identified areas where stands of flowers were known to emerge. At Jack Muller Park, the superintendent put additional signage up at the observation plot. At Kendal Rd, the neighbours phoned when the contractors were working on-site, so that no-mow areas could be negotiated with the contractor.

Surrey Str, Rover Rd, Alphen Common and Keurboom Parks (n=4) were identified as suitable parks in the “cool” precinct of the city. Jack Muller Park, Green Sleeves Crescent POS, Valmary Park, Bowlers POS and Kendal Rd Park (n=5) were identified as suitable in the northern “warm” precinct of the city, (nine study parks in total).

Field Methods

At each park, two plots of 5 × 5 m were staked out and "Do not mow" signs were placed in the middle of the plots. A general information sign with contact details about the project was placed in or near to the plots. At Surrey Rd, Kendal Rd, Keurboom Park, Jack Muller and Green Sleeves, a third 5 × 5 m plot was staked out for a year of grass-cutting suspension. Plots were positioned to cover stands of lawn flowers. At Keurboom Park and Bowlers POS which were larger parks with a more abundant and diverse population of flowers and already benefitting from a mowing suspension during spring, a series of transects were marked out along which all flowers were counted in a 300 mm wide swathe. Each plot was visited weekly during spring. Observations began in the second week of August 2019 and 2020, allowing for mowing to occur in the first week of August. Observations continued until more than 50% of the fruit population had cracked open. Counts were recorded of the heads of buds, open flowers, senescent flowers, fruits and open seed capsules for each species in the plots. When they were at their most abundant, and counting individual flower-heads became challenging, 1 × 1 m quadrats were used to keep track of counts and make estimates for the study area. They were recorded on the field observation sheet (Appendix E) and tabulated in a spreadsheet. At the end of the observation season, the plots were removed and with the exception of those parks that contained a third no-mow plot, mowing resumed. The plots were re-established in August of 2020 for a second observation season and qualitative comparisons were made against the plots in which mowing had been suspended for a full year.

Analysis

An adaptation of the Moult Model of Underhill & Zucchini (1987) was used to describe flowering phenology. The model was developed to estimate the timing of primary moult in birds. In that application, birds are observed in one of three categories; each observation has a date attached to it: birds with old feathers, which will commence moult on some unknown future date; birds in which the stage of development of the feathers can be quantified through a moult index which measures the stage of progress; birds with new feathers, which completed moult at some unknown past date. The Moult Model uses the method of maximum likelihood to estimate three parameters: the average start date of moult, the variability in the average start date and the duration of moult. The statistical problem is unusual because no birds are actually observed starting moult, and the duration is therefore not observable either. The model undertakes the mathematical statistics required to estimate these parameters which are not directly observable. Erni et al. (2013) developed software in R (R Development Core Team 2021) which provides an algorithm which estimates the parameters of moult, and which enables model selection to be undertaken within a standard statistical framework. This Moult Model can be adapted to describe flowering phenology. The reason why it is applicable is that with weekly monitoring one does not necessarily observe the transitions between the phenophases in Table 4.1. What is observable is the phenophase of a particular flower. Thus a sample of plants at a site on each visit can be examined and the number of plants/flowers in each phenophase counted.

The key parameters in this case are the mean start date of budding and the variability of this start date, which measures how synchronized the phenomenon is. The data analogous to the moult data are (1) observations of plants which are not yet in bud and which will start some unknown time in the future (analogous to birds not yet started moult); (2) observations of plants which have completed seed set and have done this at some unknown time in the past (analogous to birds which have completed moult); (3) observations of plants in the phenophases of Table 4.1 (analogous to actively moulting birds). A phenology index, which plays the role of the moult index, was calculated by first plotting a bar graph of the percentages of each species in each phase weekly and estimating the proportional duration that each species spent in each phenophase. The indices (Table 4.3) were calculated by dividing the first proportion (bud) in two to find the midpoint value. The midpoint value for flower was calculated by adding the bud proportion to half the flower proportion. Then the bud and the flower proportion to half of the senescence proportional duration and lastly the value for achieving 50% seed broadcast is set at 1.

Twenty species of geophytes were selected for analysis based on the size of the populations (minimum 30 individual plants, and present in more than one observation park) and an upright growth form which would be negatively impacted by grass-cutting. The R package: Moult (Erni et al. 2013) was then used to compute the total duration of bud – 50% fruit-crack/seed broadcast. The Moult Model was run for the entire population first and then separately on all species individually allowing both the start date and duration of the season to vary. The R-script instructed the algorithm that the data were "type=4": A sample that identifies [flowers] which are in flowering phases and have completed broadcasting. No counts were made of numbers of plants in vegetative state prior to producing buds, thus this was the appropriate type to specify.

Table 4.3 Indices used in the Moult Model to estimate progress through the duration of the season of interest. In this case, the reproductive season of plants from bud to seed broadcast

	bud	flower	senescence	fruit	seed
Babiana ambigua	0.13	0.37	0.61	0.87	1.00
Babiana nervosa	0.14	0.39	0.61	0.86	1.00
Baeometra uniflora	0.12	0.35	0.54	0.82	1.00
Geissorhiza aspera	0.11	0.33	0.58	0.85	1.00
Gladiolis alatus	0.06	0.25	0.50	0.81	1.00
Gladiolis carinatus	0.14	0.36	0.59	0.86	1.00
Moraea flaccida	0.10	0.28	0.51	0.83	1.00
Moraea miniata	0.13	0.40	0.69	0.92	1.00
Moraea neglecta	0.12	0.33	0.53	0.82	1.00
Moraea tripitala	0.11	0.32	0.54	0.82	1.00
Moraea vegeta	0.09	0.29	0.52	0.82	1.00
Pauridia capensis	0.15	0.45	0.70	0.90	1.00
Pauridia serrata	0.12	0.38	0.67	0.90	1.00
Pterygodium catholicum	0.23	0.60	0.87	1.00	1.00
Romulea cruciata	0.09	0.30	0.57	0.87	1.00
Romulea obscura	0.09	0.29	0.53	0.83	1.00
Romulea rosea	0.11	0.43	0.72	0.91	1.00
Sparaxis bulbifera	0.10	0.32	0.56	0.84	1.00
Sparaxis villosa	0.11	0.36	0.61	0.86	1.00
Orthogalum thyrsoides	0.09	0.31	0.56	0.84	1.00
Wachendorfia multiflora	0.10	0.30	0.51	0.80	1.00

To determine if there was a meaningful difference between the phenophases of the warmer northern district population and the cooler south-western district, the model was run a further three more times on the total sample. It was first run holding the start date and the standard deviation of the start date constant whilst comparing the duration, then holding constant the duration and the standard deviation of the start date, and lastly, holding the duration and start date constant whilst comparing the standard deviations of the start date. A log-likelihood test was run on the results of the Moult Model to determine the model fit.

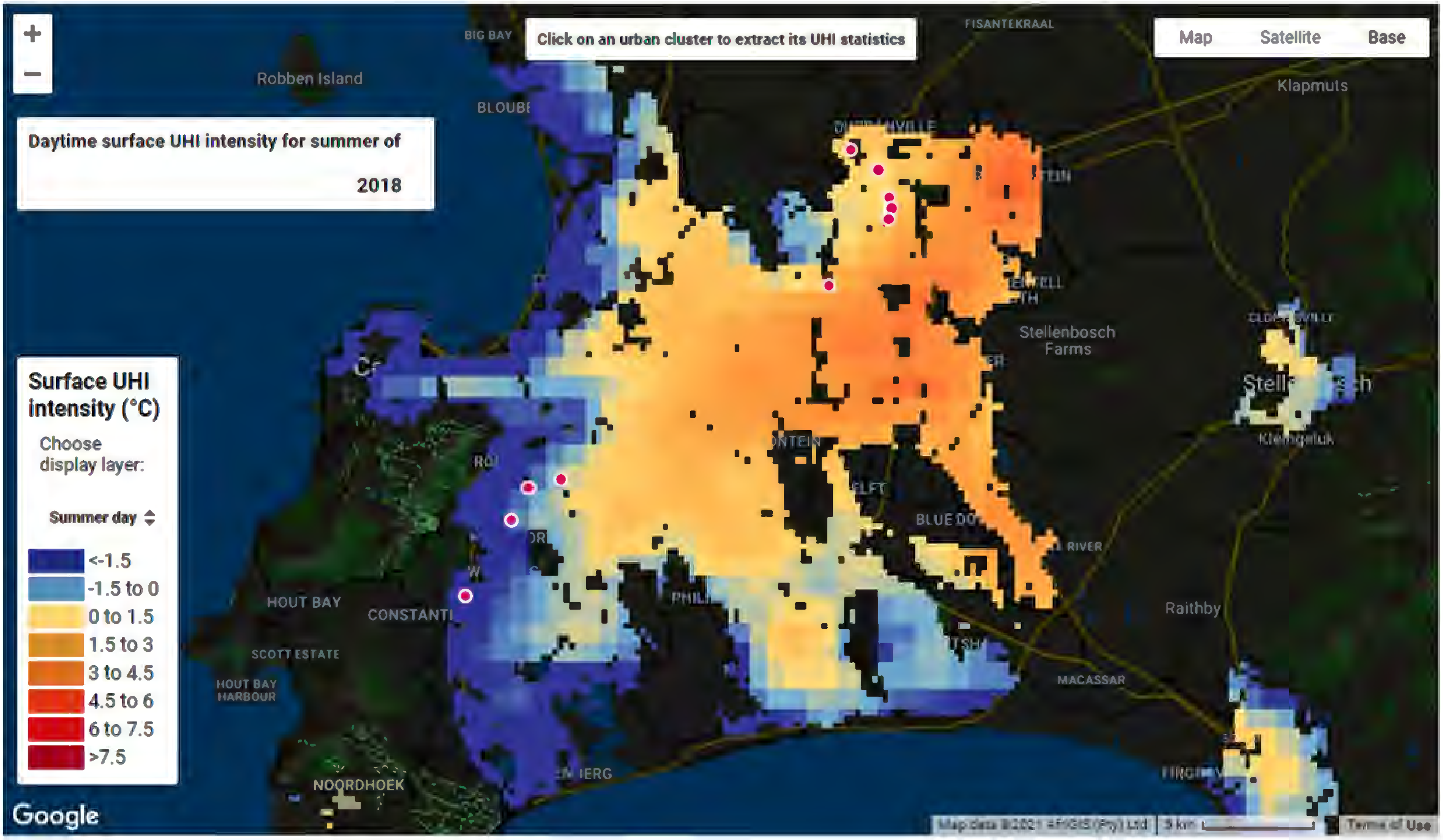


Figure 4.2 Study sites shown over the Yale Urban Heat Island (UHI) index based on the daytime summer land surface temperatures for 2018. The temperatures are mapped on a 1 km square grid derived from MODIS and AQUA satellite data and compiled by Yale Climate and Energy Institue for their global UHI Explorer App. The baseline is the average temperature in surrounding natural areas. https://yceo.yale.edu/research/global-surface-uhi-explorer extracted from the internet 25/06/2021.

Figure 4.3 Location of survey parks in Cape Town, South Africa, where experimental no-mow plots were established in the austral spring of 2019 and 2020. Observations were made of the phenophases of flower bud to the onset of seed broadcasting. A = Warm precinct, B = Cool precinct.

Results

Phenological observations were made on 20 focal species in nine parks during the austral spring seasons of 2019 and 2020 (Table 4.4). Each observation patch contained between three and 12 focal species. Six species occurred at only one park. The most widespread species were *Romulea rosea*, *Moraea miniata* and *Baeometra uniflora* which each occurred at eight of the 10 observed parks. The number of observations made per species across both seasons varied between 183 for the ellusive *Moraea tripitala* which had a small population that was difficult to track in Keurboom Park, to 12,005 observations for *Sparaxis bulbifera* which had strong populations at five of the parks.

Using the adapted Moult Model, the earliest estimated mean start date was 31 July for *Wachendorfia multiflora* and the latest mean start date was 22 September for *Ornithogalum thyrsoides* (Table 4.4). Half of the focal species (10), started budding in the fourth week of August. The standard deviation of the start dates was smallest for populations of *Gladiolis carinatus* (7), *Ornithogalum thyrsoides* (9) and *Pterygodium catholicum* (8). In contrast, the greatest standard deviation of the start date was recorded for *Pauridia capensis* (34), followed by 19 days for each *Wachendorfia multiflora*, *Pauridia serrata* and *Moraea neglecta.* The latest estimated mean seed broadcast date (more than 50% of fruiting bodies releasing seeds) was 22 November for *Pauridia capensis.*

The mean season duration across all species occurred between 14 August and 30 October with a standard deviation of 19 days. *Gladiolis carinatus* had the shortest mean season duration (28 days) and *Pauridia capensis*, *Moraea tripitala*, *Wachendorfia multiflora* and *Moraea neglecta* had the longest seasons at 85–98 days. With the exception of *Wachendorfia multiflora*, this group was relatively uncommon in city parks and tended to occur in sites with biodiversity stewardship plans in place, or low-intensity management practices (e.g. in vacant lots and undeveloped land). Parks with biodiversity stewardship plans in place had engagement from civil society for the protection of designated biodiversity areas during the flowering season. Of the common species (occurring at three or more parks), *Baeometra uniflora* had the longest seasonal duration at 84 days and was trailed by a cluster of seven species with durations of 60-70 days. Although the mean duration of the flowering season was 77 days, more than half of the species had durations between 50 and 70 days.

Observations of the impact of grass-cutting in late August and September on the remainder of the park (outside the no-mow plots) demonstrated that 30% of growing tips of *Sparaxis bulbifera*, *Baeometra uniflora* and *Moraea vegeta* were lost in August and a further 30% of the tops of plants were cut without removing the growing tip, the remainder were undamaged. In contrast, 100% of flowering heads were lost by the September cut. The plants cut in August grew new buds, but plants cut in September lost the reproductive season completely. By the beginning of November, most species had begun broadcasting seeds and had some opportunity for dispersion. Those species which had not started broadcasting by the second week of November occurred at sites of greater diversity and may be indicators for special management intervention.

The difference between the season in the warm district and the cooler areas was less than a week. This was not deemed to be biologically meaningful.

A Mowing Moratorium?

The plots which were left unmown for a year between 2019 and 2020 became overgrown with grass and the number of exotic and invasive weeds increased (Figure 4.5). The *Moraea miniata* population at Green Sleeves Crescent increased from three to seven plants in the no-mow plots and the yellow form of the flower bloomed in the second year, but not in 2019. The monkey beetle *Pachycnema lupinus* was regularly observed sitting on the flower or burying itself within the flower depths in 2020, but not in 2019. In contrast at Keurboom Park, where the ground is flat and poorly drained, the grass became dense and overgrown and reached a height of approximately 500 mm above the soil. *B. uniflora* did not appear in the second year of mowing suspension and the number of visible *S. bulbifera* flowers decreased. At Alphen Common, the invasive grasses along the berm where the no-mow patch was established grew to a height in excess of 1.5 m within three months.

Table 4.4 Estimates (and standard errors of the estimates) of the parameters of phenology (mean start date, standard deviation of start date and duration of the period: bud to the onset of seed-broadcast) for 20 species of geophytes growing in the community parks of Cape Town. In addition, the individual datasets were pooled, and estimates were derived from the overall dataset. Parameters were defined by the adaptation of the Underhill-Zucchini Moult Model described in the text, and estimated using the R-package: Moult (Erni et al. 2013).

	Model Parameters					
Species	Mean start date (SE)	Standard deviation of start date (SE)	Duration (days) (SE)	Mean end date	Sample Size	
Babiana ambigua	14 Aug (1.8)	13 (3.4)	57 (3.7)	11 Oct	403	
Babiana nervosa	02 Sep (1.2)	11 (2.1)	57 (1.8)	30 Oct	704	
Baeometra uniflora	12 Aug (0.6)	17 (1.9)	84 (0.9)	05 Nov	9878	*
Geissorhiza aspera	27 Aug (1.1)	17 (2.6)	60 (1.5)	27 Oct	2878	
Gladiolis alatus	25 Aug (2.1)	14 (3.2)	62 (3.1)	26 Oct	601	
Gladiolis carinatus	29 Aug (1.9)	7 (1.9)	28 (2.2)	05 Sep	322	
Moraea flaccida	20 Aug (1.3)	15 (2.6)	57 (1.7)	16 Oct	2121	
Moraea miniata	26 Aug (1.0)	13 (2.1)	46 (1.3)	11 Oct	1740	
Moraea neglecta	25 Aug (2.5)	19 (4.0)	85 (3.5)	18 Nov	886	**
Moraea tripitala	08 Aug (7.8)	18 (6.5)	91 (10)	07 Nov	183	
Moraea vegeta	09 Aug (0.9)	14 (2.1)	69 (1.3)	16 Oct	2302	
Ornithogalum thyrsoides	22 Sep (1.1)	9 (1.8)	52 (1.6)	14 Nov	609	**
Pauridia capensis	16 Aug (7.7)	34 (11.4)	98 (11.8)	22 Nov	470	**
Pauridia serrata	26 Aug (4.4)	19 (6.4)	47 (7.0)	12 Oct	259	
Pterygodium catholicum	23 Aug (0.7)	8 (1.3)	57 (1.1)	19 Oct	829	***
Romulea cruciata	19 Aug (1.4)	12 (2.5)	61 (2.1)	19 Oct	591	
Romulea obscura	23 Aug (1.5)	14 (2.6)	62 (2.1)	24 Oct	932	
Sparaxis bulbifera	27 Aug (0.4)	15 (1.5)	62 (0.6)	28 Oct	12005	
Sparaxis villosa	06 Aug (1.4)	10 (1.9)	65 (1.7)	09 Oct	754	
Wachendorfia multiflora	31 Jul (1.4)	19 (3.1)	88 (1.9)	28 Oct	2395	
Full season (all species)	**14 Aug (0.3)**	**19 (1.5)**	**77 (0.5)**	**30 Oct**	**41607**	

* Charismatic indicator species for the spring season

** Late spring flowers

*** No fruit phase detected.

Summer Flowers

After the conclusion of the spring, a smaller number of summer-flowering species began their season. Common species observed peaking in December and January included *Wahlenburgia capensis*, *Albuca flaccida*, *Heliophila africana*, *Heliophila conopifolia* and *Cyanella hyacinthoides.*

Figure 4.4 The plot on the left at Kendal Road had not been mowed for a year. The grass growth at this plot was moderate in comparison to many of the other locations where seeps and low-lying areas received water run-off.

Discussion

A city park is a leisure utility providing for the relaxation and recreation of local citizens. For many urban-dwellers parks are the most accessible opportunity for experiencing and connecting to nature (Hand et al. 2017). A sense of connection to nature fosters cues to care and fuels a biophilic value set which can lead to pro-environmental behavioural outcomes (Martin & Czellar 2017). Time spent connecting with nature has psychological and physiological benefits too. It decreases hypertension, increases cognitive function and can reduce obesity in those communities with better access to recreational activities in natural settings (Hartig et al. 2014; Restall & Conrad 2015). What constitutes "better access" is not limited to proximity and convenience, but also a function of the quality of the natural spaces. Although aesthetic quality and biodiversity both contribute to positive nature experiences (Taylor & Hochuli 2015), safety is also of importance to determining use and access.

Safety within an urban setting, is strongly related to crime prevention which is predicated on the opportunity for legitimate passive surveillance from individuals who feel a sense of ownership and territoriality about the park – most notably neighbours, parents or child-minders and concerned citizens. Passive surveillance is achieved by maintaining sightlines and ensuring optimum usage (Zavadskas et al. 2019). Sightlines can become obscured by long grass (and over-grown shrubs) which provide a screen for vagrancy and crime. Under-usage often leads to degradation of public space and an increase in illicit activities (Wu 2014; Zavadskas et al. 2019). In short, regular mowing is required in public parks because un-mowed grass and over-grown shrubs obscure sightlines, obstruct passive surveillance and fuel the perception of degradation and lack of care (Türkseven Doğrusoy & Zengel 2017; Zavadskas et al. 2019). Parks should therefore aspire to a balance between utility, aesthetics, conservation and cues to care. This is not always easily achieved, particularly when differing values, aesthetic appreciations and social norms come into competition with each other. For example, the perception of ecological garden practice can be one of being "unkempt" or "wild" in a community with a high degree of psychological need for structure (van den Berg & van Winsum-Westra 2010), or where community norms support a maintained lawn aesthetic, in which case no-mow areas may be met with civic opposition (Marshall et al. 2020).

Venn & Kotze (2014) in considering no-mow areas as a biodiversity supporting solution, acknowledge the potential loss of utility to parks and propose a strategic mowing schedule by first identifying lawns required for sitting or play and distinguishing them from lawns which can be landscaped as biodiversity meadows. The latter group can then be maintained with "benign neglect" to encourage biodiversity (Venn & Kotze 2014; Wastian et al. 2016a,b). They propose a two-tier strategy where leisure lawns are intensively mowed (7–10 times per year) and biodiversity lawns are extensively mowed (bi-annually) (Venn & Kotze 2014). This strategic categorization is similar to the strategy adopted by the minimum horticultural maintenance standards for Cape Town, which distinguishes between community parks and greenbelts in a similar way (Appendix D). Furthermore, a mowing suspension is included in the City's horticultural maintenance standards, but for category seven areas "nature sensitive biodiversity areas". This is described as POS but differentiated from community parks, district parks, greenbelts and road verges, excluding them from the definition by default. The mowing suspension in these areas is currently set to "August–October" which is interpreted as mowing may take place in August and October. Furthermore, it only applies to areas identified as being "nature sensitive biodiversity areas", when a more widespread approach is required to include community and district parks to support an integrated nexus of biodiversity across the city.

The proposed strategic halt for the duration of the flower to seed broadcast cycle, would be in-line with the "delayed start" mowing philosophy (Humbert et al. 2012). Studies on South African fruit phenology are under-represented and accurate records of fruit-duration for spring flowers in the Cape Town do not appear to exist (Manning & Goldblatt 2012). Therefore, this study set out to establish the length of time it takes for seed broadcast to begin in spring geophytes in order to inform better mowing practices for supporting urban populations of spring-flowering geophytes and their pollinators. The study adopted a model originally designed to estimate the duration of the moult season for waders. (Underhill & Zucchini 1988). Unlike passerine birds, the growth period for each phenophase of feather growth does not occur in a straight line. Therefore, the Moult Model introduces an index of assumed proportion of time that each phase of feather growth occupies within the greater progress of moult (Underhill & Zucchini 1988). This offers a level of flexibility for calculating phenological duration which, through the use of the estimated index, is adapted to different species. Instead of stages in feather development, stages in seed development were identified making it possible to transfer the algorithm and apply it to plants. This was a novel approach to the study of plant phenology and provides a valuable backbone for being able to estimate seasonal duration.

Developing a Strategic Approach

The first step in this process was to document the flowers occurring in park lawns across the city of Cape Town (Figure 4.1). This was carried out in Chapter 3 of this thesis and highlighted the prevalence of spring geophytes, many of which are explicitly listed for pollination mutualisms with monkey beetles (Goldblatt et al. 2013). Further studies on visitation rates and the pollination success of populations under different conditions would make a valuable contribution to future research.

The approach:

- Determine the biodiversity quality of the park by conducting a survey of spring flower presence.
- Classify the parks:
  1. <3 species.
  2. 4<10 species of spring flowers.
  3. >10 species
  4. Presence of summer species and perennials.
- If type 1, continue intensive mowing regime.
- If type 2, suspend mowing for spring.
- If type 3, assess for suitability as declared biodiversity area.
- If type 4, set aside as biodiversity area.

This chapter proposes that an assessment of the relative quality and usage of each park is carried out. Citizen science can be mobilized as a powerful resource for determining the floral richness of each park and developing an inventory of indigenous bulbs and annuals. The availability of crowd-sourced, geo-spatially available data, makes the logistics of urban plant inventories accessible for this kind of biodiversity classification (Barve et al. 2020). In Chapter 3, flowers were ranked according to their relative commonality at 142 randomly selected observation sites. From that data, parks can be classified into four categories: 1. Parks which contained three or fewer species of flowers from the most common group including *Erodium* sp. *Arctotheca calendula, Romulea rosea, Cotula turbinata, Oxalis purpurea* and *Oxalis pes-caprea;* Type 2. Parks which contained between three and 10 species of indigenous angiosperms, the majority of which are geophytes; Type 3. Parks which contained more than

10 species of indigenous flowers; Type 4. Parks which contained summer species and/or perennials.

Type 1 requires no grass-cutting suspension unless it is undergoing specific landscaping or rehabilitation treatments. This is because the common plants in this group have recovery strategies which make them well adapted to surviving frequent disturbance, over-grazing and mowing events Appendix F). Type 2 will benefit from the grass-cutting suspension window identified within the results of this study, namely August–mid-November. Type 3 would benefit from conservation or management interventions, rehabilitation and invasive species management. Type 4 requires further research and assessment for either a second mowing suspension window or alternative management strategies.

Provisionally, parks of Type 4 were identified to include *inter alia Wahlenburgia capensis, Albuca flaccida, Heliophila* spp., *Cyanella hyacinthoides and Moraea papilionacea.* It was beyond the scope of this study to monitor these "poor cousins" of the spring flush, however, it was noted that only the most biodiverse sites contained both spring and summer flowering geophytes or that it may be possible to distinguish between "spring" parks and "summer" parks. It must be noted that a spring mowing suspension is likely to cut summer flowers at a critical point in their seasonal cycle and so it is important that further research is undertaken to identify the prevalence and presence of spring-flowering plants and determine a second mowing suspension window for the summer-flowering populations.

Four species within the study broadcast seed in late spring, and were outliers to the median season of the focal species. Most notable was *Moraea neglecta*, a charismatic species which was enthusiastically pointed out by interested citizens at the parks where it occurred. The species is both relatively uncommon in the city and tends to occur on Type 3 parks justifying citizen stewardship. A charismatic species, it can be managed with engagement from the local community and volunteer stewards with ease; however, seed broadcast had already begun by the end of the recommended mowing suspension window and so even without special management, populations would benefit from the proposed suspension.

For less charismatic species, a more creative intervention may be required. Visibility of plants from the tractor seat is a likely impediment to the success of a limited area mowing suspension and a clear landscape architectural language needs to be developed to signal different mowing responses. For example, at the St Marks section of the Kendal Rd Park, the early onset of the *Dimorphotheca pluvialis* (Figure 4.6) season provided a visible marker for communicating to the contractor the area where the community regularly encountered a flush of spring flowers. Boosting lawns with bold floral markers, easily recognizable in the field could provide an affordable and simple way of signalling no-mow areas if patches were systematically sewn with species that flowered for the full duration of the season. Unfortunately, no single flower is in bloom for the entire season and so using floral markers would require a mix of species flowering at different times in order to support seed set success. *Ursinia nana* follows *Dimorphotheca pluvialis* and the parasol seeds have a structure which resembles flowers. A mix of these two abundant, rapid-reseeders, may provide the markers needed to protect geopyte-rich lawns through the spring season.

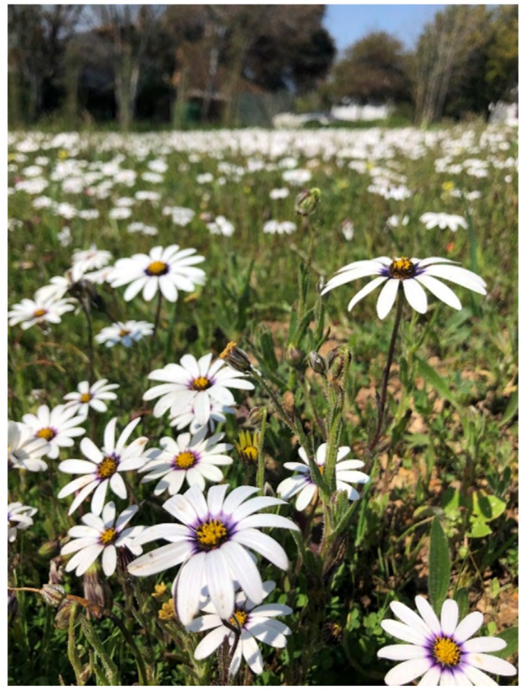


Figure 4.1 A field of the annual Dimorphotheca pluvialis *was used to communicate to the tractor driver by community members where the boundaries of a spring no-mow test site should start.*

Beaometra uniflora – *A Common Charismatic Indicator Species*

The combination of *B. uniflora*'s commonality, charismatic growth form (Figure 4.6) and long fruiting phase (mean end date 5 November), make this a suitable plant to use as an indicator species for capturing the local variation in phenological occurrences. The thick fruiting bodies are easy to identify and take longer to mature than most of the other focal species. These qualities mean that attentive contractors can wait for *B. uniflora* to open as an indicator for when the common bulbs and annuals have already begun seed broadcasting.

Figure 4.6: Baeometra uniflora *in bud, flower and fruit phenophases.*

Management of Echium *spp. – An Urgent Need for Further Research*

Echium plantageneum and *Echium vulgaris* are abundant throughout the road verges and parks of Cape Town (Figure 4.1). Both are listed as Category 1b Invasive Species (National Environmental Management: Biodiversity, Act 10 of 2004) in South Africa. Originating in south-western Europe around Spain and Portugal, they have been introduced to South Africa and naturalised in parts of Lesotho and northern South Africa. *E. plantegeum* and *E. vulgaris*,. flowered in late spring and peaked in mid-summer (Retief & Van Wyk 1998). Thus, for both species, peak flowering occurred after the conclusion of the observation period of this study. However, seed set occurred almost simultaneously with senescence (pers. obs). In addition, they are mass-flowering species and can carry in excess of 200 flowers per plant in peak season (pers. obs – counts made during data collected for Chapter 3).

E. plantageum and *E. vulgaris* grow abundantly in road verges and neglected park lawns and are common in grazed fields. The flowers which naturally select to grow in lawns are adapted to habitats that would be grazed by medium and large mammals in the natural environment and subject to periodic fires (Rebelo et al. 2006). Mowing therefore maintains a habitat conducive for supporting these species (Middleton et al. 2006). However, mowing at the beginning of summer could mitigate the spread of *Echium* spp. weeds providing the timing of grass-cutting is based on a solid ecological knowledge of the target species (Song et al. 2018). City parks are vulnerable to invasion by exotic weeds and mowing has been adopted as a strategy for managing them. Frequent mowing may be effective in limiting some invasive species, but there have been mixed success rates from different species in greenhouse studies which tested the impact of frequent mowing regimes on weeds (Butler et al. 2013). Mowing regimes can drive the spread of some invasive species when seeds are caught in the mechanisms of machinery and gardening implements (Song et al. 2018), the prolific spread of

Echium spp along road verges and park lawns suggests that seeds are being spread in mechanical machinery by grass-cutting activities (Song et al. 2018). It is therefore unclear if frequent mowing through the summer season would be adequate as a management strategy and further investigation is required to find limiting solutions to the spread of this invasive weed while protecting the indigenous summer bulb population.

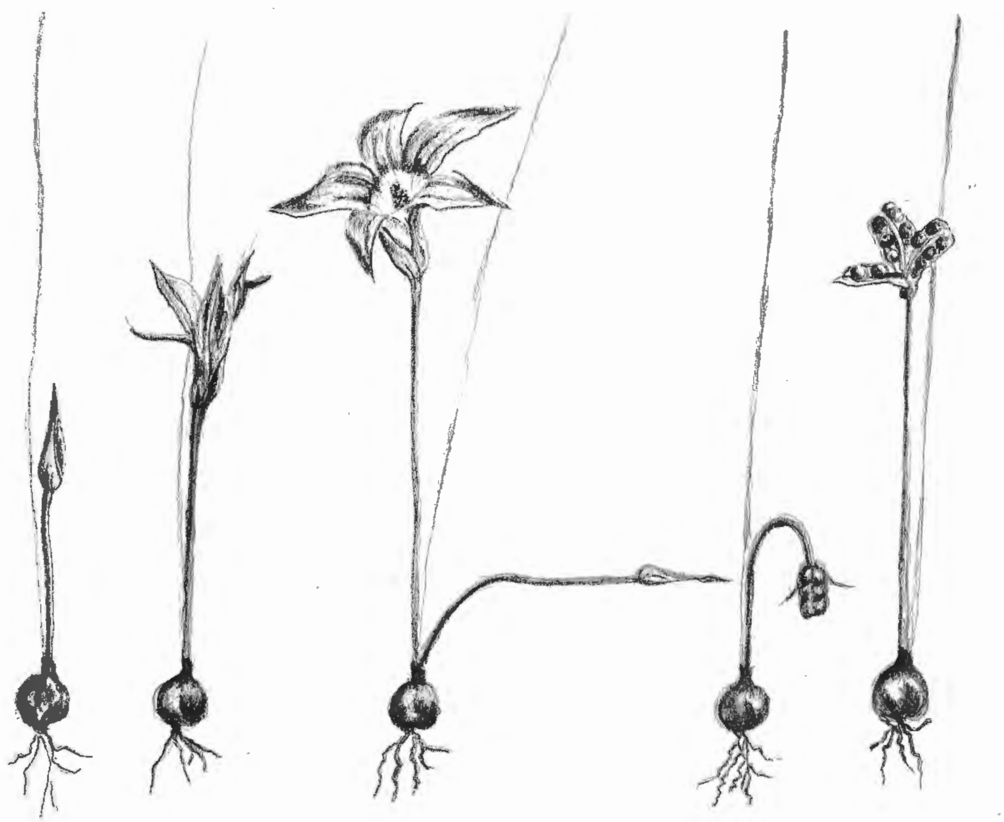
This study focused exclusively on those species which flower during the peak spring season. The recommended window of mowing suspension therefore favours a particular subset of plants which peak during this time. These are not the only geophytes and annuals occurring in park lawns, but rather the most abundant and most common. The strategic assessment of park lawns for their biodiversity contribution is an important component in developing a biodiversity stewardship plan for city parks.

Recommendations

Grass-cutting in Cape Town needs to be deferred until after seed broadcast of indigenous geophytes has begun. In the case of the commonly-occurring spring-flowering species, this has occurred for most species by the second week of November. One species, *Beaometra uniflora* can be used as an indicator for when the season is over because it is charismatic, relatively common and has the longest fruiting period of the spring geophytes. Engagement with community organisations such as park associations or “friends of” groups can boost the City’s capacity for fine-tuning mowing and maintenance practices to balance potentially conflicting community needs for utility and environmental stewardship.

- 5 -

Summary of Findings and Recommendations for Future Research



Introduction

This study examined the potential that the Cape Town has for being a refuge for monkey beetles and identified management options for supporting pollinators in urban landscapes. Specifically, it addressed the mowing of road verges and public open space. In Chapter 1, a theoretical framework was developed by consolidating and adapting the MABES and environmental hierarchical filtering models (Kremen et al. 2007; Aronson et al. 2016). This framework provided background insight into the drivers of urban biodiversity and pollination, and made the link between the biophysical and socio-political contexts of decision-making. These decision-making incidents allow for the identification of feedback loops and leverage points for intervention.

Three main aims were identified which were investigated in Chapters 2-4. Chapter 2 reviewed the global literature on urban pollinators and the local pollination literature focusing on studies which emphasised landscape ecology. It did so to identify opportunities to support pollinators in urban environments alongside areas for future research. This provided a summary of potential interventions for improving the quality and connectivity of pollinator habitats in urban landscapes. These interventions resulted in a list of opportunities for further investigation and implementation. One of these interventions, strategic mowing, was investigated in Chapter 4 within the context of Cape Town.

Chapter 3 documented patterns of monkey-beetle assemblage in Cape Town. It established that monkey beetles are found throughout the city but that certain taxa would benefit from additional support interventions.

Chapter 4 investigated a strategic mowing suspension duration during spring for the common bulbs growing in road verges and lawns to be able to complete their reproductive cycle and begin broadcasting seeds. The aim of this mowing suspension is to increase the stocks of indigenous flowering plants which are able to grow in road verges and parks. The focal taxa of this study are pollinated (among others) by monkey beetles. In order to identify a strategic mowing suspension, a model developed for quantifying moult duration was adopted

(Underhill & Zucchini 1988) and applied to the flowering and fruiting season of common spring geophytes.

Summary of Findings

Among the opportunities to support pollinators in the urban environment, is first to recognize the exchange along urban edges with adjacent wildlife habitats and agricultural landscapes (Ives et al. 2015; Langellotto et al. 2018). Pollinator communities in urban, natural and agricultural landscapes tend to favour distinct guilds from each other and offer similar opportunities to support biodiversity. The notable difference is that natural landscapes support a greater number of rare and specialized species (Eremeeva & Sushchev 2005; Kearns & Oliveras 2009; Deguines et al. 2012). The interplay of spill-over along edges means that foraging and nesting can be separated between two different land-cover types, with one habitat type supplementing the shortfalls of the other (Kremen et al. 2007; Langellotto et al. 2018).

This is important because, in the last few decades of the 20th centuray, global managed beehive demand, which expanded by 300%, has far outstripped the rate at which hive managers are able to meet expanding demand (40% increase over the same period) (Aizen et al. 2019) placing pressure on the local agricultural systems to supplement pollination ecosystem services. Three strategies are employed: 1. Managed bees are placed in high-pollen producing *Eucalyptus* spp. stands or natural areas to ensure they retain their strength between pollination seasons. 2. Natural corridors are retained in farmlands so that wild pollinators, including Hymenoptera, Diptera, Lepidoptera and Coleoptera spill over into agricultural croplands. 3. Weeds are encouraged to grow between rows or crop fields (Melin et al. 2020). Exchanges have been explored to determine the spill-over rate of nectarivorous birds into urban environments (Coetzee et al. 2018), but nesting and foraging exchanges between urban and agricultural landscapes as well as the city's potential as off-season foraging resources for managed hives, have not been explored in urban contexts in South Africa.

Urban environments present different levels of mobility limitation to different taxa. Some species will avoid cities altogether, others are able to do well in cities when specific habitat and mobility requirements are met and a third group thrives on the conditions which are created by urban environments (Wenzel et al. 2020). The second group, those which require specific habitat and mobility requirements, can be supported and facilitated through landscape management interventions. For pollinators, proven interventions include creating small-scale stepping stones of floral stands, transforming turf-grass (lawns) into floral rich habitats, adjusting mowing schedules to allow for lawn flowers to bloom, and encouraging landscaping with preferred or nectar-rich species (Vrdoljak et al. 2016; Wastian et al. 2016b; Davis et al. 2017; Simao et al. 2018).

Chapters 3 and 4 investigated the above themes in more depth using Monkey Beetles and the flower resources which grow in city park lawns as the taxa through which to interrogate the patterns and consider management solutions respectively. In Chapter 3 the data revealed that, as with studies on other taxa in urban environments, monkey beetle responses to urban intensity varied by guilds and community assemblages along urban intensity gradients and were mediated by income and the historical vegetation/ecosystem. I tested the hypothesis that monkey beetle communities are associated with different flower species. Here collections from flowers, a correlation between monkey beetle richness and flower-richness, and the association of monkey beetle species with different communities of flowers, presented evidence of preferences for a subset of flowers. Preferred flowers can therefore be encouraged to grow, or planted between larger fragments of natural vegetation in order to provide stepping-stones which link isolated metapopulations and facilitate mobility across the urban landscape (Vrdoljak et al. 2016; Davis et al. 2017; Coetzee et al. 2018).

Chapter 4 identified a strategic window for suspending municipal grass-cutting in the spring season. Adjusting mowing schedules is a simple intervention which, if applied across the city by the councillors who manage parks and road verges, can have an immediate and widespread positive impact on pollinator and wild plant populations respectively (Wastian et al. 2016b; Davis et al. 2017; Watson et al. 2020). The natural vegetation of Cape Town includes an abundance of geophytes and rapidly-reseeding annuals. Many of these plants persist in park and road-verge lawns and emerge in great numbers during the spring season. Anecdotal observations of mowing practices revealed that even when contractors were instructed not to mow the flowers, they returned the following month and mowed the immature fruiting bodies. Thus, data were gathered on the average durations of different spring geophyte species for the phenophases of bud-appearance to seed-broadcast in order to determine the timing and duration of a strategic grass-cutting suspension which will support an increase in wild bulb populations. I found that grass-cutting should be suspended in Cape Town between the second week of August and the second week of November. These recommendations are consistent with European studies which defined this window as a delayed start to mowing after winter and noted increases in biodiversity in experimentally delayed plots (Humbert et al. 2012).

The relationship between mowing, pollination, biodiversity and the policy and contractual environment is presented in a causal loop diagram (CLD) (Figure 5.1) (Meadows 2008). This CLD is a closely bounded sub-system within the broader framework presented in Chapter 1. It summarises the findings in Chapter 4. When indigenous flowers are successfully pollinated, the seeds produced from this process are critical for biodiversity, but this is negatively impacted by feedback loops in management inefficiencies, social insecurity, and public perceptions which drive demand for mowing services. The relationship between mowing and the indigenous geophytes and annuals which emerge in road verges and POS is that indigenous flower population stocks are inversely related to mowing frequency (mowing disrupts the pollination and reproductive cycle of flowers). However, a simple reduction in mowing frequency does not necessarily result in an increase in indigenous flowers because timing is important for the success of reproduction. Specifically, there is a critical delay between the production of flowers and the maturation of fruit, and should mowing take place during this time period, then seed production for the season is forfeited. Thus, implementing a strategic delay in the system (mowing suspension) is proposed and will trigger the positive reinforcing feedback loop between plants and pollinators.

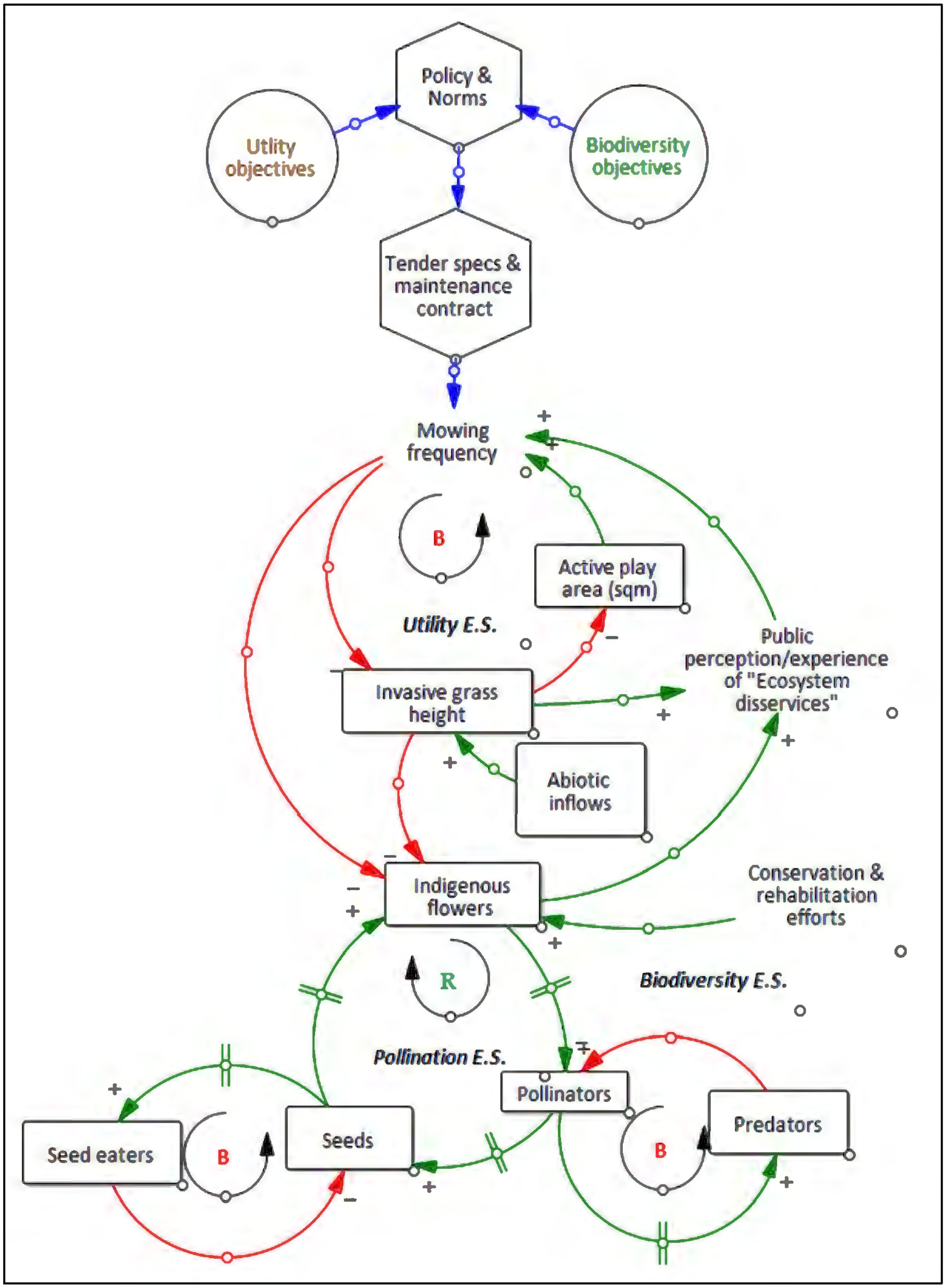


Figure 5.1 Causal loop diagram illustrating the links between pollination, utility and policy objectives in public open space and road verges. It is a sub-system of the framework presented in Figure 1.1. B = balancing feedback loop, R = reinforcing feedback loop. Red arrows indicate negative relationships and green indicate positive. The double vertical breaks indicate a time-delay. Neutral inputs are blue. Items in blocks are "stocks".

Reduced mowing frequency will also result in increased invasive grass growth, particularly in parks which receive influxes of nutrients and water (e.g. through stormwater runoff and pet animal waste). At its most straightforward level, the extent of un-mowed landscape or biodiversity area, directly reduces the percentage of the park which can be used for active play or sport (or other social gathering activities), which can have negative consequences for the usefulness of a park space for the community (Venn & Kotze 2014). A less straight-forward relationship is that long grass is negatively perceived for its potential to reduce property values and can provide a screen for illicit activities, shielding vagrancy and crime (Türkseven Doğrusoy & Zengel 2017; Zavadskas et al. 2019). Crime is a complex social issue produced by poverty and inequality, and the association with long grass (or shrubs and thicket) is coincidental rather than causal, however, the localised association (or perceived association) drives a demand for mowing and increased maintenance activity.

The negative consequences (to humans) of human interaction with ecosystems are described as “ecosystem disservices” and need careful consideration in the management of urban ecosystems (Cilliers & Cilliers 2016). The erosion of perceived security or property values, is not the only “ecosystem disservice” associated with reduced mowing. Other examples (also associated with an increase in undergrowth and natural vegetation) include an increase in pollen allergies (and unpopular species of fauna, perceived as “pests” or “dangerous” such as ticks and snakes) (Kremen et al., 2007),which can all drive demand for mowing services. Consequently, the perception or experience of “ecosystem disservices” represents a complicating distortion in the sub-system driven by utility objectives.

When a system swings between balancing and reinforcing feedback loops under the driving forces of conflicting objectives, the stocks[2] oscillate as the conflicting objectives pull in opposite directions. Consequently, policies implemented in service of one of the objectives (e.g. biodiversity) are frustrated or appear to continuously fail (Meadows 2008). There are

[2] “Stocks” is a generic term used in economics and systems analysis to describe a total measurable accummulation of a resource. In this case stocks may be the total count of a of a given species in a metapopulation, or the total number of seeds produced in a season, or the length of the grass, or the build up of nutrient. What is important is to note that the item must be quantifyable in order to be defined as a stock within the system. Arrows indicate flows.

several ways in which the intensity of oscillations can be reduced, starting with clear information flows and the negotiated alignment of system objectives (Meadows 2008). When applied to the system in Figure 5.1, clear information flows can be achieved through: 1. adjusting clauses in the tender documentation and maintenance contracts to better communicate biodiversity aims; 2. installing cues, features, or markers in the landscape which communicate mow-suspension areas, or prevent tractor access; 3. Classification of parks, or delimited park areas according to their biodiversity contribution.

The ways in which biodiversity aims and utility aims can be better aligned would best be established in negotiation with stakeholders (Ahern et al. 2014), however, green spaces within the city do not contribute to urban biodiversity stewardship equally and so a one-size-fits-all approach would be counter-productive. The quality of urban green space varies according to size, quality and economic inputs (Lepczyk et al. 2017) and traverse a spectrum from intact remnant patches of historical vegetation, gardens and brownfields, to terraformed patches of vegetation (Lepczyk et al. 2017). This warrants the employment of different management strategies in different quality landscapes.

In Chapter 4, an assessment of the flower communities provided insight into a classification system which would lend itself to different management strategies. The relative commonness of lawn flowers revealed that there is a guild which requires no special treatment to be able to survive in park and road verge lawns and will persist despite monthly grass-cutting activities. The characteristics which make these species particularly resillient to regular grass-cutting are described in Appendix F. Parks limited to common lawn flowers tend to host up to four species of flowers (indigenous species include *Romulea rosea*, *Cotula turbinata* and *Arctotheca calendula*). The second guild, is dormant for most of the year and emerges seasonally for three to five months. This guild will benefit from seasonal grass-cutting suspension to complete its reproductive cycle. Parks which contain this guild to host the focal species studied in Chapter 4. Park lawns hosting in excess of ten species of flowers or any indigenous perennial species, require special assessment to determine if they are suitable for rehabilitation as a nature park, or biodiversity island. The strategic classification of spaces in alignment with management and biodiversity aims will be a useful tool for councillors to make management decisions and to communicate with the public about biodiversity management practices.

This study, particularly Chapter 4, was transdisciplinary with an applied science bias. It provided pragmatic outcomes which can readily be implemented across several scales by citizens and councillors and can be used to inform policy decisions and landscape management practices in the City of Cape Town.

Limitations, Gaps and Directions for Future Research

Fieldwork in the most impoverished communities was limited by safety concerns and available park space. Most fieldwork was carried out single-handed due to resource constraints. This limited access to most of the poorest communities, however, I was able to recruit an assistant from the local community of Kuilsriver for the days when I was surveying the East City in 2019. Parks in the poor neighbourhoods I did manage to access, decreased in size as density and poverty increased (Venter et al. 2020). Furthermore, they were subjected to high rates of foot traffic from children gathering after school or walking through public space on their journey home from school. In these neighbourhoods I was most likely to lose samples to trampling and vandalism, particularly in Steenberg and Kraaifontein. Most notable of all at the lower end of the socio-economic spectrum, was the lack of access to quality, safe nature resources and green infrastructure, which limited the availability of suitable sites for sampling. It is a serious problem in densely populated, poor communities in South Africa (Donaldson et al. 2016; Venter et al. 2020) and a critical matter which requires urgent attention from planners and urban ecologists in South Africa (Lindley et al. 2018).

I consciously limited the investigation on monkey-beetles to their above-ground needs and associations. Monkey beetle species composition aligned strongly with natural vegetation types – so much so that the strength of other influences were dwarfed during preliminary analysis in 2019. Although there are close associations with different plant communities (Johnson & Midgley 2001; Colville et al. 2002; Mayer & Pufal 2007; Goldblatt & Manning 2011; Goldblatt et al. 2013), shifts along soil gradients seem to play an important role. Given that the greatest proportion of a monkey beetle's lifetime is spent below the surface of the ground, their soil and subterranean needs require further research if we are to be able to fully appreciate their habitat requirements (Picker & Midgley 1994; Goldblatt & Manning 2011). Appreciation of the full life-history and habitat requirements of all urban pollinators is an important area for research development and will provide valuable insight into potential landscaping opportunities to support nesting and brood sites (Cane 2015).

Relative attractiveness and pollinator preference is a potentially useful concept to interrogate across a variety of pollinator syndromes for plant selection in managed and anthropogenic landscapes (Picker & Midgley 1996; Basteri & Benvenuti 2010; Garbuzov & Ratnieks 2014; Sikora et al. 2016; Garbuzov et al. 2017). This study was limited to monkey beetles, a taxon which is concentrated in South Africa (Ahrens et al. 2011). It identified a few flower species which were visited by several species of monkey beetles and which could be planted to mitigate the negative effects of soil-sealing and provide pollen trails through the landscape in Cape Town. In another study which considered the attractiveness of flowering plants to monkey beetles, *Arctotis laevis and Arctotis gumbletonii* were visited by four and five species of monkey beetle respectively (Picker & Midgley 1994). Similar studies on the associations and visitation rates in other pollination syndromes and in other contexts, can provide us with a broader understanding of how to provide targeted resources for supporting pollinator populations in urban contexts (Sikora et al. 2016), and potentially for the support of managed hives in agricultural settings (Melin et al. 2020). Research into attractiveness and preferences should however be cognizant of the community dynamics within sugar landscapes. Mass flowering and nectar-heavy plants, both facilitate and compete with other plants for pollination services (Schmid et al. 2016; Vrdoljak et al. 2016). Therefore, supporting pollinators with targeted species requires further research, both to verify and identify preferred flower species and to unpack the complexities of competition and facilitation in sugar landscapes.

Lastly, the phenology chapter was limited to spring-flowering geophytes growing through lawns in road verges and public parks. I targeted the time of year when the flowering season peaked (Manning & Goldblatt 2012) and ignored the "lesser" display of summer geophytes. Dr Clive McDowell, a senior research botanist who has specialised in conservation management of the fynbos biome, offered verbal criticism that a targeted window would favour specific species at the expense of others which could drive extirpation of other guilds. Summer flowers were comparatively uncommon with fewer individuals per population and management of summer flower populations may have a greater variety of options available to explore. Further investigation is needed to determine if it is feasible to identify “summer parks” with a different mowing strategy and grass-cutting suspension window, or whether other landscaping options such as transplanting may be viable. Similar work in road verges, electrical servitudes and under other climatic and vegetation conditions would be beneficial to the conservation of pollinators and wild-flowers in anthropogenic landscapes across the country.

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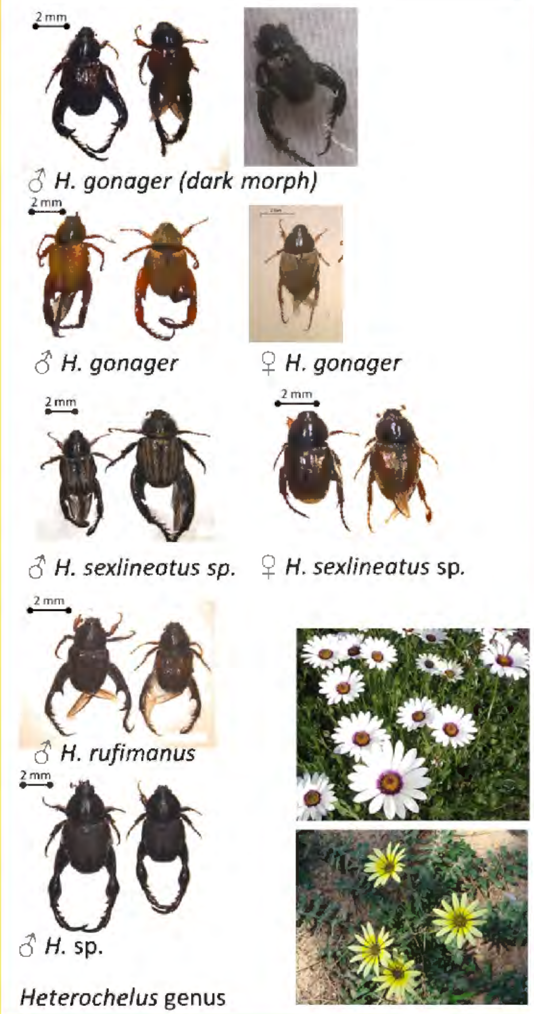
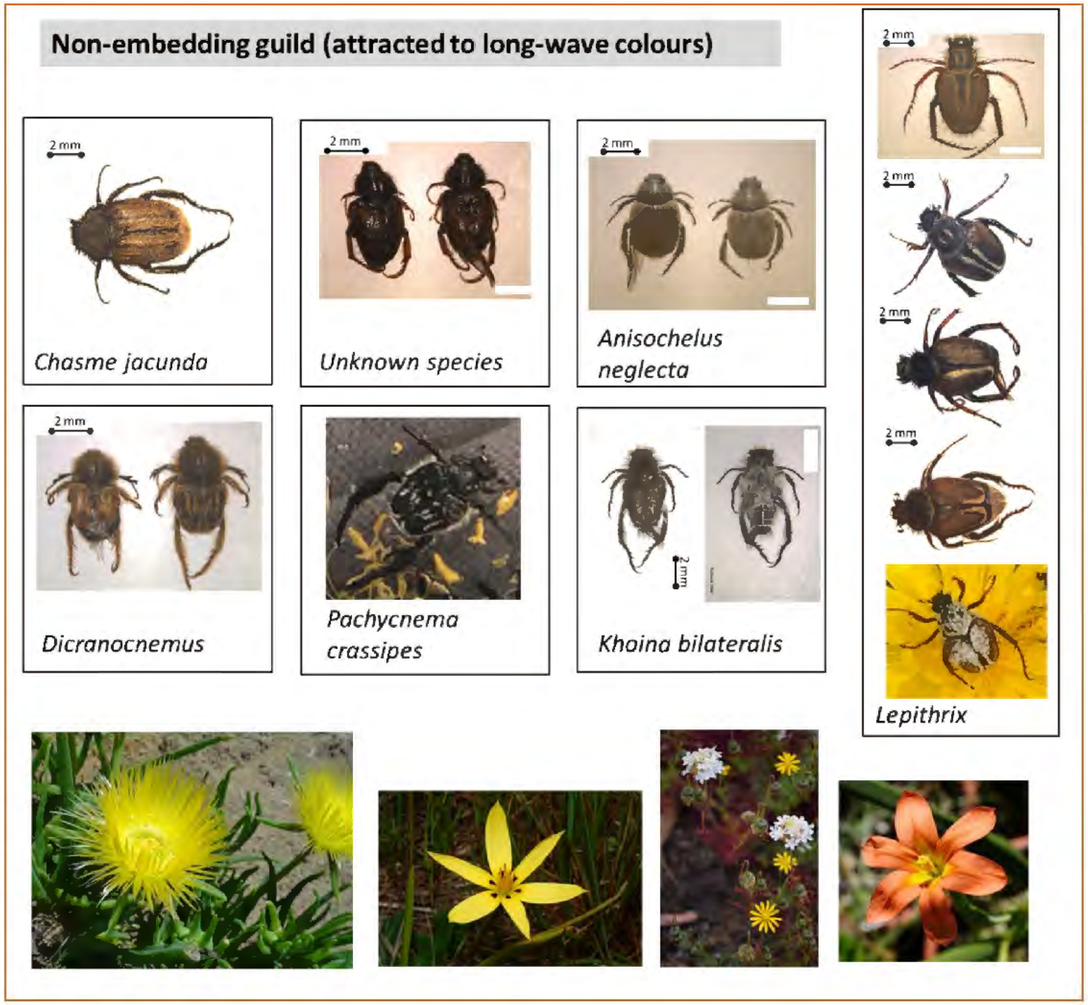
Appendix A: Examples of Monkey Beetlespecies Collected in the Cape Town Metropolitan Area during spring field work.

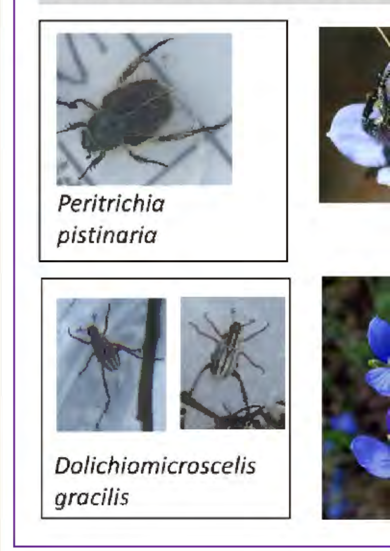
Embedding Guild



Non-embedding guild (attracted to long-wave colours)



Non-embedding guild (attracted to short-wave col



Appendix B: Supplementary Data

Table 3.4 Contingency table of monkey beetles to flower species presence.

	No. of sites where flower occurs	*Lepithrix ornatella*	*Heterochelus sexlineatus sp.*	*Heterochelus hybridus*	*Khoina bilateralis*	*Heterochelus gonager*	*Anisochelus neglecta*	*Lepithrix lineata*	*Peritrichia pistinaria*	*Dolichiomicroscelis gracillis*	*Lepithrix lineata (DM)*	*Heterochelus gonager (DM)*	*Heterochelus rufimanus*	*Pachycnmea crassipes*	*Dicranocnemus*	*Heterochelus 3*	*Heterochelus 2*	*Chasme jucunda*
Arctotheca Calendula	71	21	58	27	6	21	13	10	23	4	3	6	16	8	6	8	8	7
Carpobrotus edulus	16	5	12	6	5	5	5	4	8	3	0	2	4	3	2	5	0	6
Conicosia pugioniformis	14	3	13	9	7	5	10	8	13	5	4	1	0	0	4	1	1	6
Cotula turbinata	64	21	44	26	9	16	10	8	19	2	4	6	19	5	6	9	6	5
Dimorphotheca pluvialis	19	6	13	12	6	6	9	6	12	3	4	1	6	1	4	2	4	7
Echium	47	16	32	19	9	15	10	9	22	3	1	4	13	4	4	6	6	6
Erodium	51	11	36	16	4	8	8	6	12	2	3	4	13	5	4	5	10	4
Geissorhiza aspera	12	7	4	4	1	4	0	1	1	0	0	2	3	0	2	2	3	1
Osteospermum monstrosum	10	3	7	6	5	6	5	4	8	3	2	0	2	1	3	1	1	5
Oxalis pes-caprae	21	4	14	11	2	5	4	1	11	2	1	0	8	3	1	1	3	3
Pelargonium (Pink)	14	7	7	4	4	4	3	2	4	2	1	2	7	0	1	2	1	2
Romulea rosea	17	5	14	6	1	5	1	0	7	1	0	3	4	1	3	2	0	0
Senecio (yellow)	25	9	15	14	7	6	5	3	12	1	2	3	5	3	2	2	2	4
Trachyandra ciliata	10	1	9	8	1	1	4	3	5	0	2	0	2	0	1	1	1	0
Ursinia nana	14	3	12	7	5	5	3	3	4	2	2	1	3	1	2	3	1	4
Vicia	13	4	5	2	2	2	1	1	3	1	0	3	5	1	0	1	0	0
Brassicacea (yellow)	26	12	16	10	6	9	4	5	11	0	0	4	9	4	2	6	1	1
Hypochaeris radicata	13	2	9	3	1	4	2	0	3	0	0	0	2	0	0	0	1	0
Lysimachia monelli	11	6	1	0	2	0	0	0	4	0	0	2	7	2	0	0	3	0

Appendix C: Permits

Western Cape Province

Telephone No: (027) 021 483 0000
E-mail: permits.fax@capenature.co.za
PGWC Shared Services Centre
cnr Bosduif and Volstruis Streets
Bridgetown
7764

CapeNature

Facsimile No: (027) 0865567734
Internet: www.capenature.co.za
Private Bag X29
Gatesville
7766

PERMIT TO
HUNT WITH PROHIBITED HUNTING METHOD OF WILD ANIMALS – RESEARCH PURPOSES

Issued in terms of the provisions of the Nature Conservation Ordinance 1974, (Ord 19 of 1974)(Section 29 & 33)
Not Transferable

HOLDER			
Full Name:	Mrs. P D D Brom	Identity No:	8004220209088
Trade Name:	University of Cape Town	Registration No:	
Postal Address	Private Bag X3	Physical Address:	
City / Town:	Rondebosch	City / Town:	
Province / State:	Western Cape	Province / State:	
Country:	South Africa	Country:	
Postal / Zip Code:	7701	Longitude:	
		Latitude:	

In terms of and to the provisions of the abovementioned Ordinance and the Regulations framed thereunder, the holder of this permit is hereby authorised to Hunt (capture/disturb/stampede/kill) the protected wild animal(s) specified below on the property mentioned on this permit. See conditions on last page.

DETAILS		
Permit / License No:	CN44-28-9351	Stamp: CapeNature FAUNA • FLORA • HUNTING • CITES
Expiry Date:	31/12/2020	
Date Issued:	31/05/2019	
Amount Paid:	R 0.00	
Reference:		
File Code:	1/2/1/6/5/F6	

DESCRIPTION	PROPERTY
Organization	University of Cape Town
Full Name:	Mrs. P D D Brom
Identity Number:	8004220209088
Postal Address	See special conditions for property deta
City / Town:	NA
Province / State:	Western Cape
Country:	South Africa
Postal / Zip Code:	NA
Longitude:	
Latitude:	

SPECIES (SCIENTIFIC NAME)		QTY	NOTE
A) None	(A) None)	0	See special conditions; special conditions apply
Monkey Beetles	(Hopliini)	1000	specimens per population or locality may be collected.

To develop, expand, manage and promote a system of sustainable national parks that represent biodiversity and heritage assets, through innovation and best practice for the just and equitable benefit of current and future generations.

South African NATIONAL PARKS

Permit number: CRC/2019-2020/007--2019/V1
CAPE RESEARCH CENTRE
P.O. Box 216, STEENBERG, 7947
Tel: +27 (0)21 713 7511; Fax: +27 (0)21 712 0131

Research Permit: TABLE MOUNTAIN NATIONAL PARKS

30 May 2019

Mrs Peta Brom – "Monkey beetles in the city – Patterns of biodiversity, urban landcover and people"
Co-workers: NA

University of Cape Town, Department of Biological Sciences

Herewith your research permit valid from **30 May 2019** until **30 June 2020**.
Please familiarize yourself with the following conditions. Please contact Park Management staff prior to entry into the park (see list of relevant staff members below) and with due advance notice. You are allowed access to **all areas of the National Parks.**

Standard Conditions:

- The use of non-demarcated areas will lead to the disturbance of animals and eco-systems, trampling of vegetation and soil erosion and only the use of accepted pathways and areas is therefore permitted, UNLESS BY SPECIAL ARRANGEMENTS. PLEASE CONTACT THE PARK MANAGEMENT STAFF IF RESTRICTED AREAS NEED TO BE ACCESSED.
- No damage shall be permitted to any natural vegetation, environment or property.
- Animals may not be disturbed in any way.
- Uncontrolled vehicle access and parking could cause damage to vegetation and soil erosion and therefore only the use of approved vehicles routes and parking areas is allowed.
- Fires can cause loss of vegetation, soil erosion and life and therefore fires, and braai's are not permitted unless in dedicated braai areas.
- Remove all rubbish and waste as it has an effect on the health of visitors, animals and plants.
- Other visitors to the area and or neighbours may not be hindered in any way.
- Pollution affects the health and safety of animals, plants, visitors and neighbours and is not permitted.
- Excessive noise affects animals (e.g. birds nesting in the areas), visitors and or neighbours and is not permitted.
- Your permit and identification must be retained and kept on your person at all times, and produced on request.
- The areas under the control of SANParks are used entirely at your own risk. South African National Parks, its Board, directors, employees and agents are not liable for any loss or damage to the property or possession of any guest or participant (or accompanying minor) whether such damage is caused by the negligent act or omission of South African National Parks; arising from death or any bodily injuries of whatsoever nature sustained by a guest or participant (or accompanying minor) whether such injuries are caused by the negligent act or omission by South African National Parks, and/or by the defective functioning of any apparatus. The guest or participant and/or his/her/their estate hereby indemnifies South African National Parks against any claim, action, judgment, costs and/or expenses which may be made against South African National Parks and as may in any way be related to the above. The onus lies with the company or applicant to ensure that they are adequately insured.

addo elephant
golden gate highlands
mokala
table mountain
west coast
wilderness

- Please note that you (your staff etc) are subject to the conditions of Section 86 of the National Environmental Management Act (107 of 1998) and the National Environmental Act: Protected Areas Act (Act 57 of 2003) and any other relevant legislation for the duration of your stay in the National Park (e.g. adherence to the Registrar's requirements for guides)
- SANParks staff's instructions, notices, regulations and signs must be complied with.
- The activity shall be restricted to the area applied for.
- Gate and operating times to be complied with.
- NO PETS ALLOWED

Special Conditions:

- The researchers are permitted to walk off trail collecting plant material and set pan traps in transects to collect monkey beetles.
- Only soapy water will be permitted at all sites in the park for use in the pan traps.
- Citizen science days may be conducted at Lower Tokai only and all participants must remain on designated trails. Participants also need to sign the SANParks indemnity forms.

TMNP – Central senior section ranger	Jannie du Plessis
Telephone:	021 789 2456
Email:	jannie.duplessis@sanparks.org
TMNP – North senior section ranger	Jaclyn Smith
Telephone:	+27 21 422-1601
Email:	jaclyn.smith@sanparks.org
TMNP – South senior section ranger	Justin Buchmann
Telephone:	021 780 9101
Email:	Justin.Buchman@sanparks.org

Yours faithfully,

Debbi Winterton, Science Liaison Officer; E-mail: deborah.winterton@sanparks.org

PO Box 787
Pretoria
tel: 012 426 5000
fax: 012 343 0905

TDA
CAPE TOWN
The City of Cape Town's Transport and Urban Development Authority

Clifford Dorse
Biodiversity Coordinator Transport for Cape Town

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Peta Brom
PhD Candidate
UCT Student number: BRMPET006
Supervisor: Prof. Les Underhill
University of Cape Town
Tel:

09 November 2018

LAND OWNERS PERMISSION TO CONDUCT RESEARCH ON SPECIFIED CITY OF CAPE TOWN NATURE RESERVES

Proposed research title: "Monkey beetles in the city – Patterns of biodiversity, people involvement and urban landcover"

The City of Cape Town Biodiversity Management Branch (the Branch) has no objection to the use of several city sites to conduct beetle trapping for the above research purposes on condition that the research results are submitted to the Branch within 3 months of project completion, and data is made available for ongoing monitoring and management purposes.

Sites approved for this activities are:

1. Rondevlei Section of False Bay Nature Reserve (trapping only): Shihabuddeen Khan – Shihabuddeen.Khan@capetown.gov.za; 021 400 3443
2. Plattekloof Section of Tygerberg Nature Reserve: Ashton Mouton – Ashton.Mouton@capetown.gov.za; 021 444 9747
3. Brackenfell Nature Reserve: Vibeke Maass or Eric Bunu – Thobela.Bunu@capetown.gov.za; 021 444 7546

Permission is granted with the following conditions:

1. All relevant permits are obtained from CapeNature.
2. As per correspondence the methodology be revised to use propylene glycol or soapy water for the trapping of beetles.
3. The traps not be left unserviced for longer than 24 hours at a time.
4. The trapping days be reduced to 4 per month per site.

Westlake Conservation Centre
Steenberg Drive, Tokai, 7945 PO Box 11, Maitland, 7404

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD

SOCIAL SERVICES
RECREATION AND PARKS

Daniel van Joorsveld
Superintendent

T: 021 444 4700 M: [illegible]
E: [illegible]

18 September 2018

Mrs. Peta Brom
ID: [illegible]
Student No: BRMPET006
University of Cape Town
Rondebosch
7701

Land Owners Permission to conduct monitoring activities on City of Cape Town property as listed:

- **Erven 54161 (Ardern Gardens)**
- **Erven 44305 (Rondebosch park)**
- **Erven 98466 (Mayfield park)**
- **Erven 52023 (Cnr. Treehaven Rd and Garfield Rd)**
- **Erven 53555 (Hamstead park)**
- **Erven 56475 (Forest Avenue)**
- **Erven 212 (Arboretum)**
- **Erven 459 (Alphen common)**
- **Erven 1281 (Parish park)**
- **Erven 6605 (Bel Ombre)**
- **Erven 857 (Southern Cross, open space)**
- **Erven 44306 (Rondebosch common)**

Mrs. Peta Brom conducting research activities on City property as listed. "Research Title – Monkey beetles in the city – Patterns of biodiversity, people involvement and urban land cover". Supervisor Prof. Les Underhill and Cosupervisors: Dr Kevin Winter, Dr Jonathan Colville

Please note that your permit has been approved until the 31 December 2018 to conduct monitoring activities on the City's property as listed above. The City of Cape Town Recreation and Parks Department hereby grants permission which will be valid from the 20 September 2018 to 31 December 2018.

Permission is granted under the following special conditions:

1. That the monitoring activity is only restricted to the listed properties.
2. Notify the relevant official before commencing work on any listed property at least 24 hours in advance.
3. Extreme care must be used so as not to move or bring in invasive fauna or flora to site.
4. Every effort must be made not to disturb the current indigenous vegetation where applicable and or flowerbeds.
5. No vehicles are allowed on site.
6. No fires are permitted.
7. No littering is allowed; please ensure that whatever is brought to site is removed upon exiting the site.

Making progress possible. Together.

Appendix D: Cape Town Municipal Horticulture Maintenance Standards

HORTICULTURE: MAINTENANCE STANDARDS
FUNCTION 1 of 8: MOWING

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
1. District Parks	Land zoned "Public Open Space" (POS). Usually a large park with a variety of recreational facilities, which serves the needs of several surrounding local communities or suburbs and to which people may be prepared to travel some distance. These parks are generally multi-functional and may include active and passive recreational facilities, informal sports facilities such as kick-about areas,	1-2 weekly	• Removal of all cuttings immediately • Planted areas next to kerb: growth over kerb: zero	Visual assessment/checklist Spot Checks	• Annual plan of operations reflecting planned programme • Dates of actual maintenance vs planned dates • Dates of actual inspections • Photographic evidence - before and after photos • Signed off invoices/works orders

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
	multipurpose hard surfaces and playground equipment. The diversity of activities caters for different age groups and may include a special interest component and/or a "natural feature", such as a river, water body, wetland or biodiversity area. These parks may be accessed by visitors on foot, bicycles, public transport and/or private vehicles. They are regularly visited by the surrounding communities and may from time to time host an organized event that attracts people from the				

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
	broader metropolitan area.				
2. Community Parks	Land zoned "Public Open Space" (POS). A smaller scale of park, which serves the needs of the immediate local community or neighbourhood. These parks may include passive and active recreation areas, kick-about areas, multi-purpose hard courts and playground equipment. The number and variety of components depends on the size of the park,	7 - 12 cuts per annum	• Removal of all cuttings • Planted areas next to kerbs: Growth over the kerb: zero	Visual assessment/checklist Spot Checks	• Annual plan of operations reflecting planned programme • Dates of actual maintenance vs planned dates • Dates of actual inspections • Photographic evidence - before and after photos • Signed off invoices/works orders

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
	but the facilities usually cater for two or more age groups. In its simplest form this category may be no more than a couple of items of play equipment These parks are usually accessed by foot or motorized transport				
3. Greenbelts	Land zoned "Public Open Space" (POS). A greenbelt usually follows the route occupied by natural watercourses or man-made canals (including retention ponds) and is often associated with areas rich in biodiversity or heavily planted with trees. Where greenbelts are utilised as POS more	6 - 12 weekly intervals or 2 - 6 cuts per year	• Rough cut with "bossie kapper" • Planted areas next to kerbs: Growth over kerb should be no higher than 10-20cm. • Grass clipping to be left (not in	Visual assessment/checklist Spot Checks	• Annual plan of operations reflecting planned programme • Dates of actual maintenance vs planned dates • Dates of actual inspections • Photographic evidence - before and after photos

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
	frequent mowing required.		bags) - biodegradable		• Signed off invoices/works orders
4. Undeveloped POS	Land zoned "Public Open Space" (POS) that has not been developed (for whatever reason)	6 - 12 weekly intervals or 4 - 6 cuts per year	• Rough cut with "bossiekapper” • Planted areas next to kerbs: Growth over the kerb should be <25cm • Grass clipping to be left	Visual assessment/checklist Spot Checks	• Annual plan of operations reflecting planned programme • Dates of actual maintenance vs planned dates • Dates of actual inspections • Photographic evidence - before and after photos • Signed off invoices/works orders

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
5. Cemeteries	Land zoned "Public Open Space" (POS) falling under the jurisdiction of Recreation and Parks Department and set aside specifically for burial purposes e.g. cemeteries, crematoria, mausoleums.	7 - 12 cuts per annum	• Clippings to be removed • Planted areas next to kerbs: Growth over the kerb should be: zero	Visual assessment/checklist Spot Checks	• Annual plan of operations reflecting planned programme • Dates of actual maintenance vs planned dates • Dates of actual inspections • Photographic evidence - before and after photos • Signed off invoices/works orders
6. Road Amenities	Land zoned 'Road Reserve' for which Recreation and Parks has some maintenance responsibility The road reserve may be undeveloped, alternatively Recreation and Parks could be responsible for	12 cuts per year - high profile areas 6 cuts per year - low profile areas	• Dependant on season and influenced by Mayoral events • High and low profile scenic routes and other main roads in towns	Visual assessment/checklist Spot Checks	• Annual plan of operations reflecting planned programme • Dates of actual maintenance vs planned dates • Dates of actual inspections

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
	maintaining trees, shrubs, grass or elements of hard landscaping. These areas are sometimes not fully accessible to the public, but contribute to the visual attractiveness or environmental amenity of an area		• Smooth Cut/Rough cut areas • Clippings to be removed at high profile sites, not low profile sites. • Where kerbs occur - Growth next to kerb should be less than 10cm		• Photographic evidence - before and after photos • Signed off invoices/works orders
7. Nature Sensitive Facilities	Land zoned "Public Open Space" (POS). This can be any category of zoned public open space that has been identified in terms of unique biodiversity features and where ecological	Do not cut between August and October in order to allow spring plants to flower and	• Depending on the conservation element that needs to be protected - mowing programs to	Visual assessment/checklist Spot Checks	• Annual plan of operations reflecting planned programme • Dates of actual maintenance vs planned dates

CATEGORY	DEFINITION	**FREQUENCY** Dependant on seasonal and other environmental conditions e.g. spring flowers	STANDARD: THE AIM IS TO MAINTAIN ALL FACILITIES ACCORDING TO THESE STANDARDS	HOW MEASURE	EVIDENCE
	processes have largely remained intact and comprise of remnants of threatened vegetation units in relatively good condition, and some sites harbouring Red Data Book listed animal and/or plant species. These sites include Biodiversity Agreement sites.	release seed 2 - 6 cuts per annum	take conservation principles into account		• Dates of actual inspections • Photographic evidence - before and after photos • Signed off invoices/works orders

FUNCTION 2 of 8: IRRIGATION

CATEGORY	DEFINITION	FREQUENCY	STANDARD
1. District Parks	As per previous definition	Season dependant	Use only non-potable water No run offs onto hard surfaces
2. Community Parks	As per previous definition	Seasonal dependant	Use only non-potable water No run offs onto hard surfaces
3. Greenbelts	As per previous definition	N/A	No irrigation on low profile greenbelts, except focal points Maintain natural status Use only non-potable water
4. Undeveloped POS	As per previous definition	N/A	N/A

5. Cemeteries	As per previous definition	Season dependant	Use only non-potable water No run offs onto hard surfaces
6. Road Amenities	As per previous definition	Season dependant	Use only non-potable water No run offs onto hard surfaces
7. Nature Sensitive Facilities	As per previous definition	Only where restoration programs are introduced	Use only non-potable water No run offs onto hard surfaces

FUNCTION 3 of 8: REFUSE REMOVAL

CATEGORY	DEFINITION	FREQUENCY	STANDARD
1. District Parks	As per previous definition	Daily cleaning of bins	No bins overflowing. Appropriate signage to be installed. All litter removed.
2. Community Parks	As per previous definition	Twice a week	All litter removed. Appropriate signage to be installed. No bins overflowing.
3. Greenbelts	As per previous definition	As and when required	All litter removed. No bins overflowing.
4. Undeveloped POS	As per previous definition	As and when required	Refuse removal to be done once a week. Appropriate signage to be installed. Law enforcement to be engaged where problem areas arise
5. Cemeteries	As per previous definition	Twice a week	All litter removed. No litter bins overflowing. Appropriate signage to be installed.
6. Road Amenities	As per previous definition	Twice a week at focal points Otherwise as and when required	All litter remove in flowerbeds, etc. No paper laying within road reserves

7. Nature Sensitive Facilities	As per previous definition	As and when required	No bins overflowing. All litter removed Install appropriate signage Recycle waste where possible

FUNCTION 4 of 8: TREE MAINTENANCE

CATEGORY	DEFINITION	FREQUENCY	STANDARD	MEASURE	EVIDENCE
1. District Parks	As per previous definition	As and when required	• All tree maintenance to be undertaken in line with the provisions of the Tree Work Procedures • Pruning/felling to be done in accordance to the tree maintenance plan for specific district park • No weeds in demarcated area around the tree - Tree basins • Trees 80% healthy • Repair/replace tree stakes/cages when required • No root problems apparent • Mulching to be done at least once a year for newly planted trees • All felled (pruned) branches to be removed or chipped • Trees to be disease free	Compliance with Tree Policy	Minimum records to be kept as per Tree Work Procedures: Tree Planting (Annexure E), Tree Work Register (Annexure G), Tree Inspection (Annexure I)

CATEGORY	DEFINITION	FREQUENCY	STANDARD	MEASURE	EVIDENCE
2. Cemeteries 3. Community Parks 4. Greenbelts 5. Undeveloped POS 6. Road Amenities	As per previous definitions	As and when required Pro-active within Autumn on selected trees	• Tree policy to be considered to ensure compliance • Pruning/Felling to be done in accordance to acceptable arboriculture standards • All cut tree branches to be removed or chipped • Adhere to appropriate health & safety standards when doing tree maintenance • Repair/replace tree stakes/cages when required • Mulching to be done at least once per year for newly planted trees • No weeds in demarcated area around the tree <100cm • Trees to be disease free	Compliance with Tree Policy	Minimum records to be kept as per Tree Work Procedures: Tree Planting (Annexure E), Tree Work Register (Annexure G), Tree Inspection (Annexure I)

CATEGORY	DEFINITION	FREQUENCY	STANDARD	MEASURE	EVIDENCE
7. Nature Sensitive Facilities	As per previous definition	As and when required	• Subject to conservation guidelines and plans as outlined in Annual Operational Plan and Environmental Management plan	Compliance with Tree Policy	

FUNCTION 5 of 8: PUBLIC TOILETS

CATEGORY	DEFINITION	FREQUENCY	STANDARD
All Park Categories	As per previous definitions	Daily where toilet facilities occur on POS	• Ensure acceptable health standards • Male/Female/Disabled facilities to be properly indicated by relevant signs • Toilet paper to be supplied at all times • Clean urinals and mop floors • Use of Sanitizer encouraged • Paint as and when required • Clean and graffiti free walls • Toilet seat to be fitted at all times • All doors and windows to be in good condition • Replace/report any vandalised or stolen items within the facility • Toilets: Open during peak hours. Cleaned and checked continuously • Tiles without cracks • Open & Closed times to be indicated by means of signage

FUNCTION 6 of 8: WEED CONTROL

CATEGORY	DEFINITION	FREQUENCY	STANDARD	HOW MEASURE	EVIDENCE
All Park Categories	As per previous definition	Continuous (at least 2 x annually)	• District Park: 0% cover of weeds (annual or perennial) Other Categories: less than 20% cover of weeds (annual or perennial) • To maintain healthy growth of turf and plants • Mulching to be done at the same time to reduce weed growth • Alien vegetation such as Port Jackson, etc to be treated in accordance to an alien vegetation plan - different to weed control	Inspections	Annual plan of operations Signed off invoices work done by Contractors Dates of actual maintenance vs planned dates Dates of actual inspections Photographic evidence

FUNCTION 7 of 8: DUMPING REMOVAL

CATEGORY	DEFINITION	FREQUENCY	STANDARD
District Parks	As per previous definition	Weekly or as required.	• Ensure all dumping is removed within a week • Install appropriate "No dumping" signs • Advise law enforcement/compliance monitors where continuous problems occur
Community Parks Greenbelts Undeveloped POS Cemeteries Road Amenities Nature Sensitive Facilities	As per previous definition	Within 5 days of notification	• Ensure all dumping removed • Install appropriate "no dumping" signs • Advise law enforcement/compliance monitors where continuous problems occur • Make public aware of the areas where they can dispose of green material

FUNCTION 8 of 8: PLAY EQUIPMENT/FACILITY CHECKS/HARD SURFACES/FURNITURE

CATEGORY	DEFINITIO N	FREQUENCY	STANDARD	HOW MEASURE	EVIDENCE
1. District Parks	As per previous definition	Weekly	• Ensure compliance of health & safety standards • Replace or remove any damaged or broken play equipment, furniture, bins, etc. • Graffiti: None. • Sweeping of hard surfaces to ensure clean surface • Hard surfaces, bins and furniture: No damage	Safety Maintenance Standards for playing equipment	Playground Safety Equipment Checklist **Routine** - to check basic condition of equipment, especially faults due to recent vandalism, wear or weather conditions - check: cleanliness of surfacing, integrity and minor and major wear of the equipment, foundations and safety of playground in general.
2. Community Parks 3. Greenbelts	As per previous definition	Monthly, as per play park safety checklist	• Ensure compliance with health and safety standards		

4. Undeveloped POS 5. Cemeteries			• Remove or repair any damaged or defected play equipment, furniture, bins etc. • Report/Repair any defaults to Area Manager • Paint play equipment at least every 3 years • Sweeping of hard surfaces to ensure clean surface • Graffiti: Non • Hard surfaces, bins and furniture: No damage		**Operational** - more detail functionality and stability, essentially at vandalism and certain types of minor wear. Includes inspecting play area regulations, fencing, surfacing, safety ones, positioning of equipment and supportive elements of the play area, markings etc. **Annual Main inspection** - in depth investigation that includes longer term structural problems.

Appendix E: Field Observation Sheet

Park Name ______________________ Date ______________________

General Notes: (provide actual counts or percentage estimates on the basis of a minimum of 4 plants where abundance is high.)

Plot #/ Plant name	Bud (closed)	Flower (partial/fully-open flower)	Senescence (wilted/dried)	Fruit (green seedpod)	Seed (open/dispersing seed)

Appendix F: Descriptive observations: The strategies of common species surviving in regularly mowed lawns

The most common species found in urban park lawns were ground-covers or had a substantial portion of the plant leaf area which was flat on the ground (Chapter 3). Consistent with this growth form, the *Erodium* spp., *Cotula turbinate* and *Oxalis* spp. are ground covers with flowers that emerged from close to the ground. Mowing was observed to remove the upper-most flowers and seeds on the stems, but the majority of flowers and seeds remained on the plant below where cutting had occurred.

Romulea rosea produced buds on stems emerging straight out of the ground (Figure F.1). The bud took approximately three days to reach full height, then opened and reached senescence within a single day. The wilted flower lay flat along the ground while the fruit formed. The weight of the growing fruit caused the stem to bend over into the ground often burying it slightly below the surface. While it dried, the stem gradually straightened out and began to lift. On the day that it was dry enough to crack open, the stem was raised above the plant and open to the wind. Should mowing have occurred during the bud phase, most of the buds were below the mechanical blades, providing back-up for cut flowers, while developing fruit was tucked safely into the upper layer of soil. Only open flowers were lost to mowing. Once the fruits had opened, knocking or cutting them aided dispersion. *R. rosea* grew abundantly in high-traffic areas (subjected to trampling and soil compression) and favoured the areas around gates and park entry-points.

Figure F.1: Growth stages of Romulea rosea showing how developing flowers (in bud) fruit are protected from grazing and mowing activities close to the soil-surface.

Arctotheca calendula (Figure F.2) had a similar "back-up" mechanism. The flowers were numerous and abundant. For each open flower there were 4–6 smaller buds developing lower down the stem closer to the ground. If mowing trimmed the top flowers then new ones emerged from below. As with *R. rosea* in the senescence phenophase, the wilted flowers lay flat upon the ground, however, there was no visible fruiting phase for this plant, wilted flowers seem to metamorphosize directly into dispersing seeds.

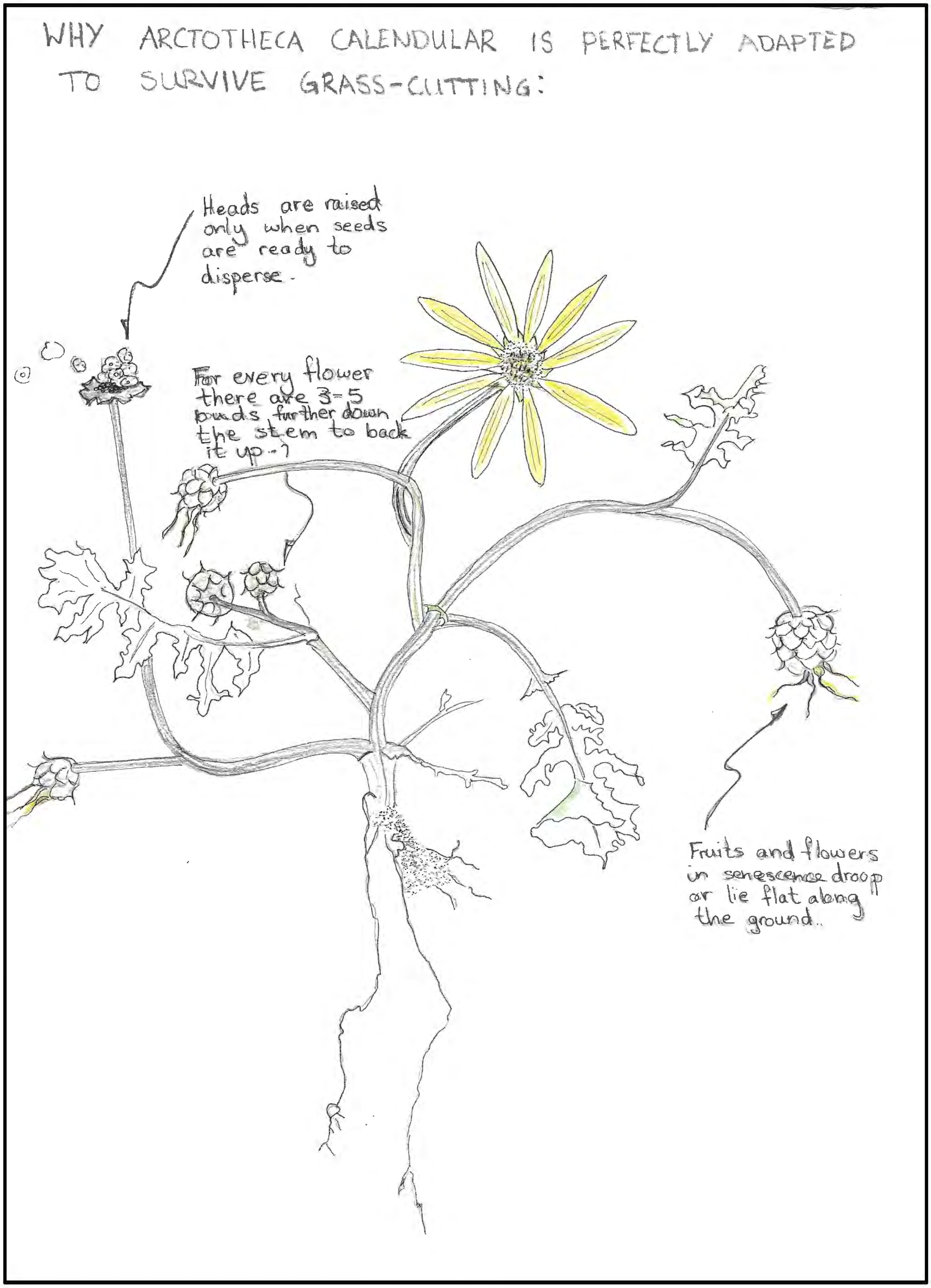

Figure F.2: Structural characteristics which make Arctotheca calendula well-suited to survive areas subjected to frequent grass-cutting or grazing.

Appendix G: Part 1, 2018 pollinator sample set 1.

Point Code	Trap colour	Y	X	Collection Date	Coleoptera	Diptera	Hymenoptera	Lepidoptera	Abundance	Richness	*Anisochelus neglecta*	*Anisonyx ditus*	*Bizanus* sp.	*Chasme jucunda*	*Dicranocnemus* sp.	*Dolichiomicroscelis gracilis*	*Heterochelus sexlineatus* sp.	*Heterochelus gonager* (dark morph)	*Heterochelus hybridus*	*Heterochelus rufimanus*	*Heterocheuls gonager*	*Heterochulus* 2 (Koekemoers)	*Ishnochelus* sp.	*Khoina bilateralis*	*Lepithrix lineata*	*Lepithrix lineata* (Dark morph)	*Lepithrix ornatella*	Novel 1.	Novel 2.	*Pachycnema cressipes*	*Peritrichia pistinaria*	*Peritrichia* sp. (brown oval)	*Peritrichia cineria* (black oval)	*Platychelus lupinus*
F1	Y	-34,0365	18,45203	2018/10/20	75	2	1	1	33	4				17			2		13										1					
F1	W	-34,0365	18,45203	2018/10/20	98	2			11	2				3			8																	
F1	B	-34,0365	18,45203	2018/10/20	23				4	1							4																	
T1P1a	Y	-33,9684	18,52787	2018/10/15	71	18	10		10	2							9		1															
T1P1a	W	-33,9684	18,52787	2018/10/15					10	1							10																	
T1P1a	B	-33,9684	18,52787	2018/10/15					0	1							0																	
T1P2	Y	-33,9742	18,52085	2018/10/15					17	1							17																	
T1P2	W	-33,9742	18,52085	2018/10/15	7	2	4		0	0																								
T1P2	B	-33,9742	18,52085	2018/10/15			6		3	1							3																	
T1P3	Y	-33,9742	18,52085	2018/10/18					0	0																								
T1P3	W	-33,9742	18,52085	2018/10/18					0	0																								
T1P3	B	-33,9742	18,52085	2018/10/18					0	0																								
T1P4	Y	-33,9734	18,49588	2018/10/15	14	1	4		383	7	169			9		2	4		4						35	160								
T1P4	W	-33,9734	18,49588	2018/10/15		3	3	1	37	4	1			4		1									31									
T1P4	B	-33,9734	18,49588	2018/10/15	1		2		7	3	3					3									1									
T1P5	Y	-33,9718	18,48714	2018/10/15	3	17	17		789	3									734	50					5									
T1P5	W	-33,9718	18,48714	2018/10/15	1	15	6	3	141	4							30		109	1					1									
T1P5	B	-33,9718	18,48714	2018/10/15	2	10	8	1	56	2							22		34															
T1P6	Y	-33,9641	18,47712	2018/10/18	18	30	15		30	2	9									21														
T1P6	W	-33,9641	18,47712	2018/10/18	6	33	13		18	2										16			2											
T1P6	B	-33,9641	18,47712	2018/10/18	1	11	2	0	10	2									1	9														
T1P7	Y	-33,9606	18,46558	2018/10/15	1	12	20	3	1	1										1														
T1P7	W	-33,9606	18,46558	2018/10/15					0	1										0														
T1P7	B	-33,9606	18,46558	2018/10/15					0	1										0														
T1P8	Y	-33,9551	18,45879	2018/10/15	1	1	1	1	1	1										1														
T1P8	W	-33,9551	18,45879	2018/10/15	4		2	1	1	1													1											
T1P8	B	-33,9551	18,45879	2018/10/15	2	3	2	1	0	0																								
T1P9	Y	-33,9509	18,45435	2018/10/15	5	1		1	2	2										1			1											
T1P9	W	-33,9509	18,45435	2018/10/15	7	23			0	0																								
T1P9	B	-33,9509	18,45435	2018/10/15			28		0	0																								

Appendix G: Part 1, 2018 pollinator sample set 1.

T2P1	Y	-33,9854	18,48434	2018/10/18	3	5	2	1		124	1								124																
T2P1	W	-33,9854	18,48434	2018/10/18	6	5	6			32	1								32																
T2P1	B	-33,9854	18,48434	2018/10/18	5	1	3	1		20	1								20																
T2P2	Y	-33,9862	18,47611	2018/10/15	1	27	11			37	1								37																
T2P2	W	-33,9862	18,47611	2018/10/15	2	30	3			6	1								6																
T2P2	B	-33,9862	18,47611	2018/10/15		6	3			4	2								3						1										
T2P3	Y	-33,9871	18,46412	2018/10/15	3	2	11	1		6	1								6																
T2P3	W	-33,9871	18,46412	2018/10/15				1		2	1								2																
T2P3	B	-33,9871	18,46412	2018/10/15			2			0	0																								
T2P4	Y	-33,987	18,45126	2018/10/16			5			0	0																								
T2P4	W	-33,987	18,45126	2018/10/16						0	0																								
T2P4	B	-33,987	18,45126	2018/10/16	1		1			0	0																								
T2P5	Y	-33,987	18,43951	2018/10/19		2				1	1											1													
T2P5	W	-33,987	18,43951	2018/10/19	1	2	1			0	0																								
T2P5	B	-33,987	18,43951	2018/10/19	1	8				0	0																								
T2P6	Y	-33,985	18,43383	2018/10/12	22	1	9			5	1																		5						
T2P6	W	-33,985	18,43383	2018/10/12						12	1																		12						
T2P6	B	-33,985	18,43383	2018/10/12	17	3	3			3	1											3													
T3P1	Y	-34,0196	18,50208	2018/10/16	14	8	3			350	3					1			190	159															
T3P1	W	-34,0196	18,50208	2018/10/16	5	12	1	1		54	1								54																
T3P1	B	-34,0196	18,50208	2018/10/16	24	21	8			25	1								25																
T3P2	Y	-34,0132	18,49776	2018/10/16	0	6	5			40	1								40																
T3P2	W	-34,0132	18,49776	2018/10/16	6	4	6			11	1								11																
T3P2	B	-34,0132	18,49776	2018/10/16	1			1		1	1								1																
T3P3	Y	-34,0148	18,48057	2018/10/16		2	1	1		50	1								50																
T3P3	W	-34,0148	18,48057	2018/10/16	1	3	3			17	1								17																
T3P3	B	-34,0148	18,48057	2018/10/16		3	1			14	1								14																
T3P4	Y	-34,0082	18,47237	2018/10/16			3			40	1								40																
T3P4	W	-34,0082	18,47237	2018/10/16	1	1	3			15	1								15																
T3P4	B	-34,0082	18,47237	2018/10/16						6	1								6																
T3P5	Y	-34,0156	18,46167	2018/10/16		4	17			5	1								5																
T3P5	W	-34,0156	18,46167	2018/10/16	2	2	12	1		6	1								6																
T3P5	B	-34,0156	18,46167	2018/10/16	2	1	10	1		1	1								1																
T3P6	Y	-34,0198	18,44877	2018/10/16	1	2	3	4		42	1																		42						
T3P6	W	-34,0198	18,44877	2018/10/16	403		3	1		20	1																		20						
T3P6	B	-34,0198	18,44877	2018/10/16	7	1	2	1		4	1																		4						
T3P7	Y	-34,0163	18,43926	2018/10/16	5	16	28	2		49	2								47										2						
T3P7	W	-34,0163	18,43926	2018/10/16	8	11	10			16	3								13			1							2						

Appendix G: Part 1, 2018 pollinator sample set 1.

T3P7	B	-34,0163	18,43926	2018/10/16	1	19	8	1		3	1																	3							
T3P8	Y	-34,0146	18,42583	2018/10/16	5	5	6	2		0	0																								
T3P8	W	-34,0146	18,42583	2018/10/16	2		3			0	0																								
T3P8	B	-34,0146	18,42583	2018/10/16	1	4	6	1		0	0																								
T3P9a	Y	-34,0128	18,41976	2018/10/16	7	1	2	1		0	0																								
T3P9a	W	-34,0128	18,41976	2018/10/16	7	2	5	1		5	2																	1		4					
T3P9a	B	-34,0128	18,41976	2018/10/16	4	2				1	1								1																
T4P1	Y	-34,0356	18,48239	2018/09/25	24	16	3			186	4	14			99					24						49									
T4P1	W	-34,0356	18,48239	2018/09/25	25	26	2	2		10	2							4								6									
T4P1	B	-34,0356	18,48239	2018/09/25	88	8	4	3		11	2				4				7																
T4P2a	Y	-34,0335	18,47061	2018/09/25	3	3	3	1		165	1									165															
T4P2a	W	-34,0335	18,47061	2018/09/25	19	12	3			3	1							3																	
T4P2a	B	-34,0335	18,47061	2018/09/25	4	1	1	1		0	0																								
T4P3	Y	-34,0338	18,4599	2018/09/25	5	8	18			3	1							3																	
T4P3	W	-34,0338	18,4599	2018/09/25	6	13	4	2		1	1	1																							
T4P3	B	-34,0338	18,4599	2018/09/25	5	9	7	1		0	0																								
T4P4	Y	-34,0323	18,45057	2018/09/25	22	18	17			49	5							37	6	4	1								1						
T4P4	W	-34,0323	18,45057	2018/09/25	51	10	18			8	2							6			2														
T4P4	B	-34,0323	18,45057	2018/09/25	9	23	11	1		3	2							2				1													
T4P5	Y	-34,0323	18,44164	2018/09/25		10	9			0	0																								
T4P5	W	-34,0323	18,44164	2018/09/25		5	1	1		1	1										1														
T4P5	B	-34,0323	18,44164	2018/09/25	2	6	4			0	0																								
T4P6	Y	-34,0332	18,4298	2018/09/25	2	2	2	1		0	0																								
T4P6	W	-34,0332	18,4298	2018/09/25	2	12	4			0	0																								
T4P6	B	-34,0332	18,4298	2018/09/25	1		5			0	0																								
T4P7	Y	-34,0377	18,41833	2018/09/25		4	1			0	0																								
T4P7	W	-34,0377	18,41833	2018/09/25		3				1	1																					1			
T4P7	B	-34,0377	18,41833	2018/09/25		8	3	2		0	0																								
T4P8a	Y	-34,0358	18,40924	2018/09/26		11	14			1	1								1																
T4P8a	W	-34,0358	18,40924	2018/09/26		17				0	0																								
T4P8a	B	-34,0358	18,40924	2018/09/26	1	1	4			0	0																								
T4P9	Y	-34,0351	18,40134	2018/09/26	3	2	5	4		1	1										1														
T4P9	W	-34,0351	18,40134	2018/09/26						0	0																								
T4P9	B	-34,0351	18,40134	2018/09/26						0	0																								
T5P1	Y	-34,0694	18,4782	2018/10/17		1				6	1							6																	
T5P1	W	-34,0694	18,4782	2018/10/17		6	1			7	1							7																	
T5P1	B	-34,0694	18,4782	2018/10/17		8	2			3	1							3																	
T5P2	Y	-34,0673	18,46691	2018/10/16		16	14			7	1							7																	

Appendix G: Part 1, 2018 pollinator sample set 1.

T5P2	W	-34,0673	18,46691	2018/10/16	3	17	9			3	1							3																	
T5P2	B	-34,0673	18,46691	2018/10/16	2	18	2			0	0																								
T5P3	Y	-34,0673	18,45276	2018/10/19	1	9	7			80	1							80																	
T5P3	W	-34,0673	18,45276	2018/10/19	7	30	5			14	1							14																	
T5P3	B	-34,0673	18,45276	2018/10/19	3	16				10	1							10																	
T5P4	Y	-34,0609	18,44645	2018/10/16	6	15	10	1		562	3							302		259	1														
T5P4	W	-34,0609	18,44645	2018/10/16	6	6	2	1		148	3							98		43	7														
T5P4	B	-34,0609	18,44645	2018/10/16	5	3	3	3		63	4							42		19	1											1			
T5P5	Y	-34,0608	18,42795	2018/10/16	10	21	2			10	3							6		1	3														
T5P5	W	-34,0608	18,42795	2018/10/16						1	1									1															
T5P5	B	-34,0608	18,42795	2018/10/16	2					0	0																								
T5P6	Y	-34,0685	18,41665	2018/10/16	3	14	3			45	2									37		8													
T5P6	W	-34,0685	18,41665	2018/10/16	3	4				1	1									1															
T5P6	B	-34,0685	18,41665	2018/10/16		2		1		4	1									4															
T6P1	y	-33,8756	18,65182	2018/10/25	140	2	9			22	1							22																	
T6P1	w	-33,8756	18,65182	2018/10/25	6	1	1			3	1							3																	
T6P1	b	-33,8756	18,65182	2018/10/25			1			0	1							0																	
T6P1.1	y	-33,8752	18,64565	2018/10/25	246		27			53	1							53																	
T6P1.1	w	-33,8752	18,64565	2018/10/25			4			10	1							10																	
T6P1.1	b	-33,8752	18,64565	2018/10/25	1		3			0	1							0																	
T6P10	y	-33,8101	18,65396	2018/10/24	17	2		3		65	2							64					1												
T6P10	w	-33,8101	18,65396	2018/10/25	26	4	1	3		10	2							9					1												
T6P10	b	-33,8101	18,65396	2018/10/26	8		2	1		0	1							0																	
T6P2	y	-33,8663	18,65354	2018/10/25	174	1	26			4	2							2					2												
T6P2	w	-33,8663	18,65354	2018/10/25	46	5	10	1		0	1							0																	
T6P2	b	-33,8663	18,65354	2018/10/25						0	1							0																	
T6P3	y	-33,8568	18,65409	2018/10/25	13		2			143	2							66					77												
T6P3	w	-33,8568	18,65409	2018/10/25	2	1		1		4	1							4																	
T6P3	b	-33,8568	18,65409	2018/10/25			1			1	1							1																	
T6P4	y	-33,8474	18,65795	2018/10/25	94	4	30			279	3							30					158					91							
T6P4	w	-33,8474	18,65795	2018/10/25	115	1	3			30	2							3										27							
T6P4	b	-33,8474	18,65795	2018/10/25	1		4			2	2												1					1							
T6P5	y	-33,835	18,6545	2018/10/24	16		3	1		32	2							2					30												
T6P5	w	-33,835	18,6545	2018/10/25	95	3	5	1		0	0																								
T6P5	b	-33,835	18,6545	2018/10/24			1			0	0																								
T6P6	y	-33,835	18,65009	2018/10/25	41	1	1			0	0																								
T6P6	y	-33,835	18,65009	2018/10/25	14		5			0	0																								
T6P6	w	-33,835	18,65009	2018/10/25	62	1	3	1		44	2							16					28												

Appendix G: Part 1, 2018 pollinator sample set 1.

T6P6	w	-33,835	18,65009	2018/10/25	21		3			0	0																								
T6P6	b	-33,835	18,65009	2018/10/25						0	0																								
T6P7	y	-33,819	18,65491	2018/10/25	353	2	8			15	1												15												
T6P7	w	-33,819	18,65491	2018/10/25	6	1	3			0	0																								
T6P7	b	-33,819	18,65491	2018/10/24			1			0	0																								
T6P8	y	-33,8101	18,65396	2018/10/24	21		3			0	0																								
T6P8	w	-33,8101	18,65396	2018/10/24	19	1	6			0	0																								
T6P8	b	-33,8101	18,65396	2018/10/25		1	1	2		0	0																								
T6P9	y	-33,8054	18,64614	2018/10/25						53	2	14											39												
T6P9	w	-33,8054	18,64614	2018/10/25						3	1	3																							
T6P9	b	-33,8054	18,64614	2018/10/25						2	1	2																							
T7P1	Y	-33,8799	18,67962	2018/10/26	1		3			146	2							60		86															
T7P1	W	-33,8799	18,67962	2018/10/26	13	3	1			14	2							13														1			
T7P1	B	-33,8799	18,67962	2018/10/26						8	3							4		3												1			
T7P2	Y	-33,8818	18,6924	2018/10/26		1	8	1		4	1							4																	
T7P2	W	-33,8818	18,6924	2018/10/26	9	4	1			5	1							5																	
T7P2	B	-33,8818	18,6924	2018/10/26						10	2							1														9			
T7P3	Y	-33,892	18,70618	2018/10/26	9	2	8			0	0																								
T7P3	W	-33,892	18,70618	2018/10/26	1	1				45	2							3														42			
T7P3	B	-33,892	18,70618	2018/10/26		1	2			0	0																								
T7P4	Y	-33,8933	18,71297	2018/10/26	1	4	5	1		6	4	1						3	1	1															
T7P4	W	-33,8933	18,71297	2018/10/26	1	1	6	2		33	6	9			1			12				3				3						5			
T7P4	B	-33,8933	18,71297	2018/10/26			7			5	2							1		4															
T7P5	Y	-33,8953	18,72254	2018/10/26	5	1	2			2	1							2																	
T7P5	W	-33,8953	18,72254	2018/10/26	1		1			0	0																								
T7P5	B	-33,8953	18,72254	2018/10/26	5	2	9			0	0																								
T7P6	Y	-33,8988	18,731	2018/10/26						0	0																								
T7P6	W	-33,8988	18,731	2018/10/26						0	0																								
T7P6	B	-33,8988	18,731	2018/10/26						0	0																								
T7P7	Y	-33,905	18,74379	2018/10/26	2	9	3			0	0																								
T7P7	W	-33,905	18,74379	2018/10/26		3	5	1		0	0																								
T7P7	B	-33,905	18,74379	2018/10/26	1	3	3	1		0	0																								
T7P8	Y	-33,9087	18,75353	2018/10/26	2		4			0	0																								
T7P8	W	-33,9087	18,75353	2018/10/26	2	1	1			0	0																								
T7P8	B	-33,9087	18,75353	2018/10/26			1			0	0																								
T8P1	y	-33,9542	18,65914	2018/09/25		2	1			46	2							4								42									
T8P1	w	-33,9542	18,65914	2018/09/25	6	4				8	2							5								3									
T8P1	b	-33,9542	18,65914	2018/09/25		1				2	2									1						1									

Appendix G: Part 1, 2018 pollinator sample set 1.

T8P2	y	-33,9555	18,67223	2018/09/25		1				3	1															3									
T8P2	w	-33,9555	18,67223	2018/09/25						0	0																								
T8P2	b	-33,9555	18,67223	2018/09/25	1					0	0																								
T8P3	y	-33,9547	18,68571	2018/09/25	10	1				272	5	105			9			34		74						50									
T8P3	w	-33,9547	18,68571	2018/09/25	1006					14	5	5						1		6						1						1			
T8P3	b	-33,9547	18,68571	2018/09/25	49	3	1			148	3	64								81						3									
T8P4	y	-33,9531	18,69168	2018/09/25		3	19			5	3	2						1		2															
T8P4	w	-33,9531	18,69168	2018/09/25	4	1	9			0	0																								
T8P4	b	-33,9531	18,69168	2018/09/25	1	3	3			0	0																								
T8P5	y	-33,9491	18,70278	2018/09/25	1	3	1			1	1			1																					
T8P5	w	-33,9491	18,70278	2018/09/25						0	0																								
T8P5	b	-33,9491	18,70278	2018/09/25						1	1																					1			
T8P6	y	-33,9517	18,71375	2018/09/25	2	4				37	2	1			36																				
T8P6	w	-33,9517	18,71375	2018/09/25	2					5	3	1			3		1																		
T8P6	b	-33,9517	18,71375	2018/09/25	4	2	1			4	2			1	3																				
Total					**3908**	**915**	**828**	**81**		**5597**		**404**	**0**	**2**	**189**	**0**	**7**	**1945**	**175**	**1712**	**122**	**12**	**352**	**5**	**0**	**234**	**160**	**210**	**1**	**5**	**0**	**62**	**0**	**0**	**0**

Appendix G: Part 2, 2018 pollinator sample set 2.

Point Code	Trap Colour	Y	X	Collection Date	Coleoptera	Diptera	Hymenoptera	Lepidoptera	Abundance	Richness	*Anisochelus neglecta*	*Anisonyx ditus*	*Bizanus* sp.	*Chasme jucunda*	*Dicranocnemus* sp.	*dolichiomicroscelis gracilis*	*Heterochelus sexlineatus* sp.	*Heterochelus gonager* (dark morph)	*Heterochelus hybridus*	*Heterochelus rufimanus*	*Heterocheuls gonager*	*Heterochulus* 2 (Koekemoers)	*Ishnochelus* sp.	*Khoina bilateralis*	*Lepithrix lineata*	l (Dark morph)	*Lepithrix ornatella*	Novel 1.	Novel 2.	*Pachycnema cressipes*	*Peritrichia pistinaria*	*Peritrichia* sp. (brown oval)
F2	Y	-33,9553	18,48503	2018/11/03	5	1	7	1	127	5								23	100		2			1		1						
F2	W	-33,9553	18,48503	2018/11/03	26		4	7	20	4								1						15		1					3	
F2	B	-33,9553	18,48503	2018/11/03	9		2	8	8	2														3							5	
T1P1b	Y	-33,9707	18,52408	oct - nov					30	1							30															
T1P1b	W	-33,9707	18,52408	oct - nov		11	5		6	1							6															
T1P1b	B	-33,9707	18,52408	oct - nov		4	3	2	1	1							1															
T1P2	Y	-33,9742	18,52085	oct - nov	3		4		3	1							3															
T1P2	W	-33,9742	18,52085	oct - nov		2	3		1	1							1															
T1P2	B	-33,9742	18,52085	oct - nov	1		3		0	0																						
T1P3	Y	-33,9742	18,52085	oct - nov		1	9		7	1							7															
T1P3	W	-33,9742	18,52085	oct - nov		1	5		8	1							8															
T1P3	B	-33,9742	18,52085	oct - nov			1	1	0	0																						
T1P4	Y	-33,9734	18,49588	oct - nov	2		1		13	1														13								
T1P4	W	-33,9734	18,49588	oct - nov			2		11	1														11								
T1P4	B	-33,9734	18,49588	oct - nov	1	2	11		27	3	3						1							23								
T1P5	Y	-33,9718	18,48714	oct - nov		5	45	1	74	3							21		8	45												
T1P5	W	-33,9718	18,48714	oct - nov					10	1							10															
T1P5	B	-33,9718	18,48714	oct - nov		2	5		1	1								1														
T1P6	Y	-33,9641	18,47712	oct - nov		2	20		213	2									1		212											
T1P6	W	-33,9641	18,47712	oct - nov		1	11		2	1											2											
T1P6	B	-33,9641	18,47712	oct - nov		1	4		2	1							2															
T1P7	Y	-33,9606	18,46558	oct - nov		2	11		3	1																3						
T1P7	W	-33,9606	18,46558	oct - nov	1	1	2		2	1																2						
T1P7	B	-33,9606	18,46558	oct - nov		1	1		1	1																1						
T1P8	Y	-33,9551	18,45879	oct - nov					5	1																	5					
T1P8	W	-33,9551	18,45879	oct - nov			1		8	1																	8					
T1P8	B	-33,9551	18,45879	oct - nov					1	1																	1					
T1P9	Y	-33,9509	18,45435	oct - nov			2		12	2										11							1					
T1P9	W	-33,9509	18,45435	oct - nov			2	1	8	2										3							5					

Appendix G: Part 2, 2018 pollinator sample set 2.

T1P9	B	-33,9509	18,45435	oct - nov					2	2										1							1					
T2P1	Y	-33,9854	18,48434	oct - nov					38	1							38															
T2P1	W	-33,9854	18,48434	oct - nov					13	1							13															
T2P1	B	-33,9854	18,48434	oct - nov					3	1							3															
T2P1-1	Y	-33,9915	18,49157	oct - nov					11	1							11															
T2P1-1	W	-33,9915	18,49157	oct - nov					5	1							5															
T2P1-1	B	-33,9915	18,49157	oct - nov					6	1							6															
T2P2	Y	-33,9862	18,47611	oct - nov					13	1							13															
T2P2	W	-33,9862	18,47611	oct - nov					2	1							2															
T2P2	B	-33,9862	18,47611	oct - nov					0	1							0															
T2P3	Y	-33,9871	18,46412	oct - nov					7	2							1				6											
T2P3	W	-33,9871	18,46412	oct - nov					0	0																						
T2P3	B	-33,9871	18,46412	oct - nov					0	0																						
T2P4	Y	-33,987	18,45126	oct - nov		2	17		76	2											17						59					
T2P4	W	-33,987	18,45126	oct - nov					36	2											8						28					
T2P4	B	-33,987	18,45126	oct - nov					0	0																						
T2P5	Y	-33,987	18,43951	oct - nov	1		5		93	3								1			80						12					
T2P5	W	-33,987	18,43951	oct - nov					23	3								1			15						7					
T2P5	B	-33,987	18,43951	oct - nov					4	1											4											
T2P6	Y	-33,985	18,43383	oct - nov					5	3														1		1	3					
T2P6	W	-33,985	18,43383	oct - nov	8	5	9	1	13	3													1	1			11					
T2P6	B	-33,985	18,43383	oct - nov					0	0																						
T3P1	Y	-34,0196	18,50208	oct - nov	3	4	13		3	1							3															
T3P1	W	-34,0196	18,50208	oct - nov		5	6		1	1							1															
T3P1	B	-34,0196	18,50208	oct - nov		3	4		0	0																						
T3P2	Y	-34,0132	18,49776	oct - nov	1	4	5		6	1							6															
T3P2	W	-34,0132	18,49776	oct - nov					0	0																						
T3P2	B	-34,0132	18,49776	oct - nov	1	1	6	2	2	1							2															
T3P3	Y	-34,0148	18,48057	oct - nov		14	15		6	1							6															
T3P3	W	-34,0148	18,48057	oct - nov		11	17		3	1							3															
T3P3	B	-34,0148	18,48057	oct - nov		6	8	1	0	0																						
T3P4	Y	-34,0082	18,47237	oct - nov		1	14		4	1							4															
T3P4	W	-34,0082	18,47237	oct - nov					0	0																						
T3P4	B	-34,0082	18,47237	oct - nov	1	2	3		0	0																						
T3P5	Y	-34,0156	18,46167	oct - nov	4	1	11	1	26	2											15						11					
T3P5	W	-34,0156	18,46167	oct - nov		6	6		3	1											3											
T3P5	B	-34,0156	18,46167	oct - nov	4	2	8		4	1																	4					
T3P6	Y	-34,0198	18,44877	oct - nov					0	0																						

Appendix G: Part 2, 2018 pollinator sample set 2.

T3P6	W	-34,0198	18,44877	oct - nov						0	0																						
T3P6	B	-34,0198	18,44877	oct - nov						0	0																						
T3P7	Y	-34,0163	18,43926	oct - nov	22	5	7			0	0																						
T3P7	W	-34,0163	18,43926	oct - nov	7	1	3	1		0	0																						
T3P7	B	-34,0163	18,43926	oct - nov	3		2			0	0																						
T3P8	Y	-34,0146	18,42583	oct - nov	7	7	7	1		9	2											8						1					
T3P8	W	-34,0146	18,42583	oct - nov	7	1	3	1		6	1																	6					
T3P8	B	-34,0146	18,42583	oct - nov	1	1	5			8	2								5									3					
T3P9b	Y	-34,0146	18,42583	oct - nov						0	0																						
T3P9b	W	-34,0146	18,42583	oct - nov						8	1																	8					
T3P9b	B	-34,0146	18,42583	oct - nov						0	0																						
T4P1	Y	-34,0356	18,48239	oct - nov						87	5	5			9			9							39		25						
T4P1	W	-34,0356	18,48239	oct - nov						85	4					21		1						21	42								
T4P1	B	-34,0356	18,48239	oct - nov						22	4					3		2							12							5	
T4P2b	Y	-34,034	18,47122	oct - nov						26	5					1		4							6		14					1	
T4P2b	W	-34,034	18,47122	oct - nov						10	4					3		2							4							1	
T4P2b	B	-34,034	18,47122	oct - nov						11	2					9		2															
T4P3	Y	-34,0338	18,4599	oct - nov						244	3							198				45						1					
T4P3	W	-34,0338	18,4599	oct - nov						52	3					1		50				1											
T4P3	B	-34,0338	18,4599	oct - nov						16	2							6				10											
T4P4	Y	-34,0323	18,45057	oct - nov						200	2							91				109											
T4P4	W	-34,0323	18,45057	oct - nov						40	3					1		38										1					
T4P4	B	-34,0323	18,45057	oct - nov						1	1							1															
T4P5	Y	-34,0323	18,44164	oct - nov						0	0																						
T4P5	W	-34,0323	18,44164	oct - nov						0	0																						
T4P5	B	-34,0323	18,44164	oct - nov						0	0																						
T4P6	Y	-34,0332	18,4298	oct - nov						16	2							4				12											
T4P6	W	-34,0332	18,4298	oct - nov						4	1											4											
T4P6	B	-34,0332	18,4298	oct - nov						0	0																						
T4P7	Y	-34,0377	18,41833	oct - nov						2	1								2														
T4P7	W	-34,0377	18,41833	oct - nov						2	1								2														
T4P7	B	-34,0377	18,41833	oct - nov						0	0																						
T4P8b	Y	-34,0364	18,40845	oct - nov						53	2								1									52					
T4P8b	W	-34,0364	18,40845	oct - nov						39	1																	39					
T4P8b	B	-34,0364	18,40845	oct - nov						5	1																	5					
T4P9	Y	-34,0351	18,40134	oct - nov						7	1																	7					
T4P9	W	-34,0351	18,40134	oct - nov						10	1																	10					
T4P9	B	-34,0351	18,40134	oct - nov						0	0																						

Appendix G: Part 2, 2018 pollinator sample set 2.

T5P1b	Y	-34,0719	18,47944	oct - nov			10		0	0																						
T5P1b	W	-34,0719	18,47944	oct - nov		2	5		0	0																						
T5P1b	B	-34,0719	18,47944	oct - nov					0	0																						
T5P2	Y	-34,0673	18,46691	oct - nov	3	2	22		2	1							2															
T5P2	W	-34,0673	18,46691	oct - nov		6	8		0	0																						
T5P2	B	-34,0673	18,46691	oct - nov		2	8		0	0																						
T5P3	Y	-34,0673	18,45276	oct - nov	2	1	7	1	8	1							8															
T5P3	W	-34,0673	18,45276	oct - nov	1	3	7		2	1							2															
T5P3	B	-34,0673	18,45276	oct - nov			7	1	1	1							1															
T5P4	Y	-34,0609	18,44645	oct - nov					11	1							11															
T5P4	W	-34,0609	18,44645	oct - nov	3	9	7		4	1							4															
T5P4	B	-34,0609	18,44645	oct - nov	2	6	6		1	1							1															
T5P5	y	-34,0608	18,42795	oct - nov					60	3							14				45						1					
T5P5	W	-34,0608	18,42795	oct - nov	2		5		7	2							2				5											
T5P5	w	-34,0608	18,42795	oct - nov					0	0																						
T5P6	y	-34,0685	18,41665	oct - nov	1	4	16		89	2							29				60											
T5P6	w	-34,0685	18,41665	oct - nov		5	6		7	2											4						3					
T5P6	b	-34,0685	18,41665	oct - nov	2	6	6		0	0																						
T6P1	y	-33,8756	18,65182	oct - nov					0	0																						
T6P1	w	-33,8756	18,65182	oct - nov					0	0																						
T6P1	b	-33,8756	18,65182	oct - nov					0	0																						
T6P1.1	y	-33,8752	18,64565	oct - nov					0	0																						
T6P1.1	w	-33,8752	18,64565	oct - nov					0	0																						
T6P1.1	b	-33,8752	18,64565	oct - nov					0	0																						
T6P10	Y	-33,8101	18,65396	oct - nov		1	13		1	1							1															
T6P10	W	-33,8101	18,65396	oct - nov			2		0	0																						
T6P10	B	-33,8101	18,65396	oct - nov		2			0	0																						
T6P2	y	-33,8663	18,65354	oct - nov			16		0	0																						
T6P2	w	-33,8663	18,65354	oct - nov	3	1	7		0	0																						
T6P2	b	-33,8663	18,65354	oct - nov	3		2		0	0																						
T6P3	y	-33,8568	18,65409	oct - nov					0	0																						
T6P3	w	-33,8568	18,65409	oct - nov					0	0																						
T6P3	b	-33,8568	18,65409	oct - nov					0	0																						
T6P4	y	-33,8474	18,65795	oct - nov					0	0																						
T6P4	w	-33,8474	18,65795	oct - nov					0	0																						
T6P4	b	-33,8474	18,65795	oct - nov					0	0																						
T6P5	y	-33,835	18,6545	oct - nov					0	0																						
T6P5	w	-33,835	18,6545	oct - nov		1	5		0	0																						

Appendix G: Part 2, 2018 pollinator sample set 2.

T6P5	b	-33,835	18,6545	oct - nov			1			0	0																						
T6P6	y	-33,835	18,65009	oct - nov						0	0																						
T6P6	w	-33,835	18,65009	oct - nov						0	0																						
T6P6	b	-33,835	18,65009	oct - nov						0	0																						
T6P7	y	-33,819	18,65491	oct - nov		2	24			0	0																						
T6P7	w	-33,819	18,65491	oct - nov						0	0																						
T6P7	b	-33,819	18,65491	oct - nov						0	0																						
T6P8	y	-33,8101	18,65396	oct - nov						0	0																						
T6P8	w	-33,8101	18,65396	oct - nov						0	0																						
T6P8	b	-33,8101	18,65396	oct - nov						0	0																						
T6P9	y	-33,8054	18,64614	oct - nov		3	8	1		1	1							1															
T6P9	w	-33,8054	18,64614	oct - nov	1	1	7	1		0	0																						
T6P9	b	-33,8054	18,64614	oct - nov			5			0	0																						
T7P1	Y	-33,8799	18,67962	oct - nov						0	0																						
T7P1	W	-33,8799	18,67962	oct - nov						0	0																						
T7P1	B	-33,8799	18,67962	oct - nov						0	0																						
T7P2	Y	-33,8818	18,6924	oct - nov						0	0																						
T7P2	W	-33,8818	18,6924	oct - nov						0	0																						
T7P2	B	-33,8818	18,6924	oct - nov						0	0																						
T7P3	Y	-33,892	18,70618	oct - nov						0	0																						
T7P3	W	-33,892	18,70618	oct - nov						0	0																						
T7P3	B	-33,892	18,70618	oct - nov						0	0																						
T7P4	Y	-33,8933	18,71297	oct - nov						0	0																						
T7P4	W	-33,8933	18,71297	oct - nov						0	0																						
T7P4	B	-33,8933	18,71297	oct - nov						0	0																						
T7P5	Y	-33,8953	18,72254	oct - nov						0	0																						
T7P5	W	-33,8953	18,72254	oct - nov						0	0																						
T7P5	B	-33,8953	18,72254	oct - nov						0	0																						
T7P6	Y	-33,8988	18,731	oct - nov						0	0																						
T7P6	W	-33,8988	18,731	oct - nov						0	0																						
T7P6	B	-33,8988	18,731	oct - nov						0	0																						
T7P7	y	-33,905	18,74379	oct - nov						0	0																						
T7P7	W	-33,905	18,74379	oct - nov						0	0																						
T7P7	w	-33,905	18,74379	oct - nov						0	0																						
T7P8	y	-33,9087	18,75353	oct - nov						0	0																						
T7P8	w	-33,9087	18,75353	oct - nov						0	0																						
T7P8	b	-33,9087	18,75353	oct - nov						0	0																						
T8P1	y	-33,9542	18,65914	oct - nov	1		6			143	4							66				72			3							2	

Appendix G: Part 2, 2018 pollinator sample set 2.

T8P1	W	-33,9542	18,65914	oct - nov	1	2	2	3		60	2							26							34								
T8P1	b	-33,9542	18,65914	oct - nov		1		1		14	2							4							10								
T8P2	Y	-33,9555	18,67223	oct - nov	2		5			19	3							16							1	2							
T8P2	W	-33,9555	18,67223	oct - nov	1	2	1			14	2							13							1								
T8P2	b	-33,9555	18,67223	oct - nov	5	1	4			1	1							1															
T8P3	y	-33,9547	18,68571	oct - nov	6	4	10			56	3							21							34							1	
T8P3	w	-33,9547	18,68571	oct - nov	15	4				118	4							8						9	91							10	
T8P3	b	-33,9547	18,68571	oct - nov	2			1		31	2							2							29								
T8P4	y	-33,9531	18,69168	oct - nov	4		7			7	2							3														4	
T8P4	w	-33,9531	18,69168	oct - nov	6	1	5	1		17	2														7							10	
T8P4	b	-33,9531	18,69168	oct - nov	3		2			12	2							6														6	
T8P5	y	-33,9491	18,70278	oct - nov	1		4			15	3							11				3			1								
T8P5	w	-33,9491	18,70278	oct - nov			6			4	2							3														1	
T8P5	b	-33,9491	18,70278	oct - nov						1	1																					1	
T8P6	Y	-33,9517	18,71375	oct - nov	2		7			178	3							107				35										36	
T8P6	W	-33,9517	18,71375	oct - nov	3	4	4			67	4							26				3			25							13	
T8P6	b	-33,9517	18,71375	oct - nov	4	2	4			65	3							2				3										60	
T8P7	Y	-33,9552	18,72072	oct - nov	1		6			28	3							3				3						22					
T8P7	W	-33,9552	18,72072	oct - nov			3			6	1																	6					
T8P7	B	-33,9552	18,72072	oct - nov		1	1			11	2																	4				7	
T8P8	Y	-33,9591	18,72485	oct - nov			5			128	3							1				5						122					
T8P8	W	-33,9591	18,72485	oct - nov	2	3	6			115	4							6				3						88				18	
T8P8	B	-33,9591	18,72485	oct - nov	1		4			26	1																	26					
Total					**201**	**201**	**640**	**39**		**3305**		**8**	**0**	**0**	**9**	**39**	**0**	**1016**	**37**	**109**	**60**	**794**	**0**	**31**	**407**	**2**	**48**	**561**	**0**	**0**	**0**	**184**	**0**

Appendix G: Part 3, 2019 pollinator sample set 1.

Point Code	Trap Colour	Y	X	Collection Date	Coleoptera	Diptera	Hymenoptera	Lepidoptera	Other including bugs, blattideae & grasshoppers.	Abundance	Richness	*Anisochelus neglecta*	*Anisonyx ditus*	*Bizanus* sp.	*Chasme jucunda*	*Dicranocnemus* sp.	*Dolichiomicroscelis gracilis*	*Heterochelus Sexlineatus* sp.	*Heterochelus ganager* (dark morph)	*Heterochelus hybridus*	*Heterochelus rufimanus*	*Heterocheuls gonager*	*Heterochulus* 2 (Koekemoers)	*Heterochelus* 3 (hooked leg)	*Heterochelus* 4 "neroli" (red legs, orange peel texture)	*Heterochelus* 5 (brown w. hooked legs, female very hairy legs	*Ishnochelus* 1 (small, plain)	*Ishnochelus* 2 (large, yellow back, hairy thorax)	*Khoina bilateralis*	*Lepithrix lineata*	*Lepithrix lineata* (Dark morph)	*Lepithrix ornatella*	Novel 1.	Novel 2.	*Pachycnema cressipes*	*Peritrichia pistinaria*	*Peritrichia* sp.	*Platychelus lupinus*	*Peritrichia cineria* (black oval)
BRA-PU-1	W	-33,831272	18,715153	05/09/2019	1	1	1			0	0																												
BRA-PU-1	Y	-33,831272	18,715153	05/09/2019			15			5	3				2			1			2																		
BRA-PU-2	W	-33,83662	18,725054	05/09/2019						1	1							1																					
BRA-PU-2	B	-33,83662	18,725054	05/09/2019		1	1	1		0	0																												
BRA-PU-2	Y	-33,83662	18,725054	05/09/2019		4	1			2	1							2																					
BRA-PU-3	W	-33,8421	18,7351	05/09/2019	4	5	1			2	1							2																					
BRA-PU-3	B	-33,8421	18,7351	05/09/2019						1	1							1																					
BRA-PU-3	Y	-33,8421	18,7351	05/09/2019		2	5		1	6	2				3			3																					
BRA-RU-1	B	-33,827527	18,751005	05/09/2019	3		5			0	0																												
BRA-RU-1	Y	-33,827527	18,751005	05/09/2019	1	1	19			0	0																												
BRA-RU-1	W	-33,827527	18,751005	05/09/2019	4	9	9		1	0	0																												
BRA-RU-2	B	-33,819447	18,776317	05/09/2019	1	19	25		1	3	2			1							2																		
BRA-RU-2	Y	-33,819447	18,776317	05/09/2019	1	10	131			119	1										119																		
BRA-RU-2	W	-33,819447	18,776317	05/09/2019		96	58		3	1	1										1																		
BRA-RU-3	W	-33,808942	18,738262	05/09/2019	18	7	11			2	1							2																					
BRA-RU-3	Y	-33,808942	18,738262	05/09/2019	16	5	29			3	2	1						2																					
BRA-RU-3	B	-33,808942	18,738262	05/09/2019	1	4	5			1	1																1												
BRA-SU-1	B	-33,850106	18,728416	05/09/2019	1		4			0	0																												
BRA-SU-1	W	-33,850106	18,728416	05/09/2019	2		1			0	0																												
BRA-SU-1	Y	-33,850106	18,728416	05/09/2019		2	9			2	1							2																					
BRA-SU-2	W	-33,851824	18,713944	05/09/2019	1	9	4			1	1							1																					
BRA-SU-2	B	-33,851824	18,713944	05/09/2019		5	7			0	0																												
BRA-SU-2	Y	-33,851824	18,713944	05/09/2019		4	18			0	0																												
BRA-SU-3	W	-33,837563	18,711384	05/09/2019	12	3	2			3	1							3																					
BRA-SU-3	B	-33,837563	18,711384	05/09/2019			3			0	0																												
BRA-SU-3	Y	-33,837563	18,711384	05/09/2019		1	4		1	9	1							9																					
BRA-UR-1	W	-33,859055	18,699684	2019/05/09		4	6			0	0																												
BRA-UR-1	B	-33,859055	18,699684	2019/05/09			1			0	0																												
BRA-UR-1	Y	-33,859055	18,699684	05/09/2019			8			0	0																												
BRA-UR-2	W	-33,851327	18,70027	2019/05/09	14	7	10			0	0																												
BRA-UR-2	Y	-33,851327	18,70027	05/09/2019		2	15			2	2																			1					1				
BRA-UR-2	B	-33,851327	18,70027	05/09/2019	2	1	5			0	0																												
BRA-UR-3	W	-33,866848	18,709017	05/09/2019	11	11	12			0	0																												
BRA-UR-3	B	-33,866848	18,709017	05/09/2019	1	2	2			0	0																												
BRA-UR-3	Y	-33,866848	18,709017	05/09/2019		3	4			3	1							3																					
DUR-NA-1	W	-33,82289	18,588735	12/9/2019		18	9			17	4		2																			7					6		2
DUR-NA-1	B	-33,82289	18,588735	12/9/2019		5	4			44	3		31																			3							10

Appendix G: Part 3, 2019 pollinator sample set 1.

DUR-NA-1	Y	-33,82289	18,588735	12/9/2019		20	6			29	2																					14							15
DUR-NA-2	B	-33,823323	18,596316	12/9/2019		1				2	1		2																										
DUR-NA-2	W	-33,823323	18,596316	12/9/2019		1				1	1																												1
DUR-NA-3	W	-33,826265	18,604817	12/9/2019		3	7			0	0																												
DUR-NA-3	B	-33,826265	18,604817	12/9/2019		6	2	1		0	0																												
DUR-NA-3	Y	-33,826265	18,604817	12/9/2019	7		2	2	1	0	0																												
DUR-PU-3	B	-33,845497	18,634831	12/9/2019	14		3			2	1										2																		
DUR-PU-3	Y	-33,845497	18,634831	12/9/2019	29	6	5			4	1										4																		
DUR-PU-3	W	-33,845497	18,634831	12/9/2019	28	6	6	1		1	1										1																		
DUR-RU-1	B	-33,840212	18,6146	12/9/2019	13	1	6			2	1																										2		
DUR-RU-1	W	-33,840212	18,6146	12/9/2019	3	8	3			1	1			1																									
DUR-RU-1	Y	-33,840212	18,6146	12/9/2019	8		3			1	1										1																		
DUR-RU-2	B	-33,838016	18,619687	12/9/2019	3	1	1		1	0	0																												
DUR-RU-2	W	-33,838016	18,619687	12/9/2019	16	16	2	1		2	1																					2							
DUR-RU-2	Y	-33,838016	18,619687	12/9/2019	14	2	3			3	1										3																		
DUR-RU-3	B	-33,838138	18,625528	12/9/2019	3	6				0	0																												
DUR-RU-3	W	-33,838138	18,625528	12/9/2019	6	6	2			1	1																					1							
DUR-RU-3	Y	-33,838138	18,625528	12/9/2019	4	3	5			3	2										2																1		
DUR-SU-1	W	-33,850313	18,64309	12/9/2019	1	1	4			1	1			1																									
DUR-SU-1	Y	-33,850313	18,64309	12/9/2019	3	2	1			0	0																												
dur-su-1	b	-33,850313	18,64309	12/9/2019	2		2			0	0																												
DUR-SU-2	B	-33,857741	18,638792	12/9/2019	1					0	0																												
DUR-SU-2	W	-33,857741	18,638792	12/9/2019		1	1			2	1										2																		
DUR-SU-2	y	-33,857741	18,638792	12/9/2019			1			1	1										1																		
DUR-SU-3	B	-33,844823	18,649453	12/9/2019	1		1			0	0																												
DUR-SU-3	W	-33,844823	18,649453	12/9/2019		3	1		2	0	0																												
DUR-UR-1	W	-33,865107	18,641352	12/09/2019		7	6			0	0																												
DUR-UR-1	Y	-33,865107	18,641352	12/9/2019		5	5			1	1			1																									
DUR-UR-1	B	-33,865107	18,641352	12/9/2019	1	2	2			0	0																												
DUR-UR-2	W	-33,868599	18,634439	12/9/2019						1	1							1																					
DUR-UR-2	B	-33,868599	18,634439	12/9/2019						1	1							1																					
DUR-UR-2	Y	-33,868599	18,634439	12/9/2019			2			1	1							1																					
DUR-UR-3	Y	-33,8731	18,643635	12/9/2019			5		1	0	0																												
DUR-UR-3	W	-33,8731	18,643635	12/9/2019		2	8	1		1	1			1																									
DUR-UR-3	B	-33,8731	18,643635	12/9/2019			3			0	0																												
DUR-NA-2	Y	-33,823323	18,596316	13/9/2019			3			0	0																												
EAS-PU-1	W	-33,946437	18,704651	19/09/2019		10	4			7	1							7																					
EAS-PU-1	Y	-33,946437	18,704651	19/09/2019		6	7			21	2	1						20																					
EAS-PU-1	B	-33,946437	18,704651	19/09/2019		3	1			1	1							1																					
EAS-PU-2	Y	-33,939268	18,709678	19/09/2019	1	2	11			3	1									3																			
EAS-PU-2	B	-33,939268	18,709678	19/09/2019	3	6	4			4	2																2	2											
EAS-PU-2	W	-33,939268	18,709678	19/09/2019		1	11			0	0																												
EAS-PU-3	W	-33,97786	18,709968	19/09/2019		2	13	2		7	3	1			4												2												
EAS-PU-3	Y	-33,97786	18,709968	19/09/2019	4	3	13			64	4	26			35												2				1								
EAS-PU-3	B	-33,97786	18,709968	19/09/2019	2	1				6	3				1				4	1																			
EAS-RU-1	B	-33,958973	18,721667	19/09/2019	2		18			14	2					12				2																			

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EAS-RU-1	W	-33,958973	18,721667	19/09/2019	11	7	57			21	3				1	13															7								
EAS-RU-1	Y	-33,958973	18,721667	19/09/2019		2	78			68	6	23			10	2				6							1			26									
EAS-RU-2	W	-33,954481	18,717699	19/09/2019	11		6			1	1					1																							
EAS-RU-2	B	-33,954481	18,717699	19/09/2019	7		4			4	1																4												
EAS-RU-2	Y	-33,954481	18,717699	19/09/2019	1	1	5			5	1																5												
EAS-SU-1	B	-33,948017	18,678291	19/09/2019						2	2									1							1												
EAS-SU-1	Y	-33,948017	18,678291	19/09/2019	1		7			1	1							1																					
EAS-SU-1	W	-33,948017	18,678291	19/09/2019		2				3	1							3																					
EAS-SU-2	Y	-33,955472	18,67223	19/09/2019		3				4	3	2								1										1									
EAS-SU-2	W	-33,955472	18,67223	19/09/2019		3	3			2	2							1		1																			
EAS-SU-2	B	-33,955472	18,67223	19/09/2019		1	1			2	2									1																1			
EAS-SU-3	W	-33,927803	18,671392	19/09/2019	100	2	39			30	2							28		2																			
EAS-SU-3	B	-33,927803	18,671392	19/09/2019	4	1	9			10	2							9		1																			
EAS-SU-3	Y	-33,927803	18,671392	19/09/2019	36	1	67			82	3	1						80													1								
EAS-UR-1	Y	-33,937289	18,685345	19/09/2019	11	2	7			65	4	1						12		47										5									
EAS-UR-1	B	-33,937289	18,685345	19/09/2019	2	2				29	2									28																1			
EAS-UR-1	W	-33,937289	18,685345	19/09/2019		2	3			4	3							2		1										1									
EAS-UR-2	W	-33,953446	18,698632	19/09/2019	2		1			1	1							1																					
EAS-UR-2	Y	-33,953446	18,698632	19/09/2019						4	2							2												2									
EAS-UR-2	B	-33,953446	18,698632	19/09/2019	3		4			2	2						1	1																					
EAS-UR-3	Y	-33,963627	18,698094	19/09/2019	3	3	7			30	3	9						13												8									
EAS-UR-3	B	-33,963627	18,698094	19/09/2019	1		4			5	3	1								2																2			
EAS-UR-3	W	-33,963627	18,698094	19/09/2019		6	4			5	2							3																		2			
TOK-NA-2	Y	-34,056925	18,428676	27/09/2019	13		1			76	3				2			3		71																			
TOK-NA-2	B	-34,056925	18,428676	27/09/2019	4					1	1									1																			
TOK-NA-2	W	-34,056925	18,428676	27/09/2019	2					1	1									1																			
TOK-NA-3	B	-34,063623	18,417249	27/09/2019	7		3	1		13	2										12			1															
TOK-NA-3	W	-34,063623	18,417249	27/09/2019	7		5			10	1										10																		
TOK-NA-3	Y	-34,063623	18,417249	27/09/2019	6		8			8	2							2			6																		
TOK-RU-1	B	-34,071762	18,415493	27/09/2019	1		1			5	2								1																	4			
TOK-RU-1	Y	-34,071762	18,415493	27/09/2019			3			0	0																												
TOK-RU-1	W	-34,071762	18,415493	27/09/2019	3	1	4			3	2										1															2			
TOK-RU-3	W	-34,077428	18,423937	27/09/2019	3					0	0																												
TOK-RU-3	Y	-34,077428	18,423937	27/09/2019	2	1	2			0	0																												
TOK-RU-3	B	-34,077428	18,423937	27/09/2019		1	1		1	1	1										1																		
TOK-SU-1	W	-34,048258	18,452644	27/09/2019	4		7		1	15	4				1			13	.	1																			
TOK-SU-1	B	-34,048258	18,452644	27/09/2019	3	1	2		2	32	4							24		1				5												2			
TOK-SU-1	W	-34,048258	18,452644	27/09/2019	2	2	4		1	97	4							88			4			4											1				
TOK-SU-1	Y	-34,048258	18,452644	27/09/2019	3	4	6		2	156	6							56		5	8			79	1										7				
TOK-SU-2	B	-34,060779	18,446615	27/09/2019	7	1	2			30	2							29																		1			
TOK-SU-2	Y	-34,060779	18,446615	27/09/2019	15	1	6			53	3							31		21															1				
TOK-SU-3	B	-34,066101	18,436961	27/09/2019	4	1	4			29	4							21		3		3		2															
TOK-SU-3	W	-34,066101	18,436961	27/09/2019	3		6			93	5							77	1	10		4													1				
TOK-SU-3	Y	-34,066101	18,436961	27/09/2019	2	1	9			260	5							42		185	2	27													4				
TOK-SU-4	W	-34,03392	18,47132	27/09/2019	66	2	1			55	6				2	2		33		11				2						5									
TOK-SU-4	B	-34,03392	18,47132	27/09/2019	7		1		1	63	4							12		46										4						1			

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TOK-SU-4	Y	-34,03392	18,47132	27/09/2019			3				210	5				1			35		129				8						37									
TOK-UR-1	W	-34,040677	18,465947	27/09/2019	1	1	4				0	0																												
TOK-UR-1	Y	-34,040677	18,465947	27/09/2019		5	10		2		49	5	1						32		1				14						1									
TOK-UR-1	B	-34,040677	18,465947	27/09/2019	1		2				6	2							5			1																		
TOK-UR-2	Y	-34,031259	18,46978	27/09/2019	38	1	6		2		190	5	1						23	125	39										2									
TOK-UR-2	B	-34,031259	18,46978	27/09/2019	1						6	2							4		2																			
TOK-UR-2	W	-34,031259	18,46978	27/09/2019	1				1		38	3							13		3				22															
TOK-UR-3	Y	-34,035714	18,482158	27/09/2019	51	3	1				513	6	23			355	1		18		78										38									
TOK-UR-3	B	-34,035714	18,482158	27/09/2019	29		1				111	6	1			3	21		10		75																1			
TOK-UR-3	W	-34,035714	18,482158	27/09/2019	1000	1	3				270	7	1			145	55		41		8				7						13									
TOK-UR-3	Y	-34,035714	18,482158	27/09/2019	31	1					415	6	20			247	2		13		96										37									
RON-NA-1	B	-33,9532	18,48485	2/10/2019	1	2	6				3	2									2																	1		
RON-NA-1	W	-33,9532	18,48485	2/10/2019	2	5	4				8	3									2		2															4		
RON-NA-1	Y	-33,9532	18,48485	2/10/2019	1	2	4				35	2									34					1														
RON-NA-2	B	-33,95694	18,48244	2/10/2019	4		10	1			30	1																										30		
RON-NA-2	Y	-33,95694	18,48244	2/10/2019	14	2	23				29	3											1				12											16		
RON-NA-2	W	-33,95694	18,48244	2/10/2019	15	1	11	1	3		25	2															5											20		
SOU-NA-1	Y	-34,043375	18,398689	2/10/2019	5	6	2		1		0	0																												
SOU-NA-2	W	-34,04752	18,40161	2/10/2019		5	6				0	0																												
SOU-NA-2	B	-34,04752	18,40161	2/10/2019		2					0	0																												
SOU-NA-3	Y	-34,059031	18,403953	2/10/2019	4	3	5	1			0	0																												
SOU-NA-3	W	-34,059031	18,403953	2/10/2019	1	4	6	1	32		0	0																												
SOU-NA-3	B	-34,059031	18,403953	2/10/2019		1	5		7		1	1															1													
SOU-NA-3	Y	-34,059031	18,403953	2/10/2019		1	3				0	0																												
SOU-PU-1	B	-34,024524	18,433256	2/10/2019		2		1			4	2							3			1																		
SOU-PU-1	Y	-34,024524	18,433256	2/10/2019	2	2	1	1			4	2							3						1															
SOU-PU-1	W	-34,024524	18,433256	2/10/2019	6	12	6				42	3							1						40											1				
SOU-SU-1	B	-34,016561	18,439518	2/10/2019			5	1			17	1							17																					
SOU-SU-1	Y	-34,016561	18,439518	2/10/2019	2	3	3				33	3							21			3			9															
SOU-SU-1	W	-34,016561	18,439518	2/10/2019		2	1				2	2							1			1																		
SOU-SU-2	B	-34,017305	18,447538	2/10/2019			1				0	0																												
SOU-SU-2	W	-34,017305	18,447538	2/10/2019	2	2	4				9	2											1										8							
SOU-SU-2	Y	-34,017305	18,447538	2/10/2019			3				9	2													2								7							
SOU-SU-3	B	-34,02521	18,439912	2/10/2019	1						0	0																												
SOU-SU-3	Y	-34,02521	18,439912	2/10/2019	1						6	2										1			5															
SOU-SU-3	W	-34,02521	18,439912	2/10/2019			1				2	2										1			1															
SOU-UR-1	B	-34,005592	18,46476	2/10/2019		5	1	1			37	2							31			6																		
SOU-UR-1	Y	-34,005592	18,46476	2/10/2019		4	7	1			182	3							141			11			30															
SOU-UR-1	w	-34,005592	18,46476	2/10/2019	1	8	11	1			116	3							108			7			1															
SOU-UR-2	W	-34,00275	18,47656	2/10/2019				1			1	1							1																					
SOU-UR-2	Y	-34,00275	18,47656	2/10/2019							5	1							5																					
SOU-UR-3	W	-33,987869	18,464503	2/10/2019	2	51					2	2													1				1											
SOU-NA-1	W	-34,043375	18,398689	11/10/2019	12	5	2				0	0																												
SOU-PU-2	W	-34,026724	18,414301	11/10/2019	1						0	0																												
SOU-RU-1	W	-34,036376	18,408246	11/10/2019		2	3	1			0	0																												
SOU-RU-1	B	-34,036376	18,408246	11/10/2019			3	2			2	2								1																	1			

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SOU-RU-1	Y	-34,036376	18,408246	11/10/2019	1	4	15				2	1								2																				
SOU-RU-3	W	-34,037843	18,415211	11/10/2019		9	15	1			3	2										2															1			
SOU-RU-3	Y	-34,037843	18,415211	11/10/2019	1	3	2				0	0																												
SOU-RU-3	B	-34,037843	18,415211	11/10/2019	1	1	5				1	1																								1				
SOU-UR-3	Y	-33,987869	18,464503	11/10/2019		58	5	2			10	1													10															
SOU-UR-3	B	-33,987869	18,464503	11/10/2019		33	2				0	0																												
Total					**1853**	**690**	**1220**	**27**	**68**		**4224**		**113**	**35**	**5**	**812**	**109**	**1**	**1176**	**134**	**922**	**218**	**38**	**0**	**244**	**2**	**18**	**18**	**3**	**0**	**181**	**9**	**42**	**0**	**0**	**17**	**19**	**80**	**0**	**28**

Appendix G: Part 4, 2019 pollinator sample set 2.

Point Code	Trap Colour	Y	X	Collection Date	Coleoptera	Diptera	Hymenoptera	Lepidoptera	Abundance	Richness	*Anisochelus neglecta*	*Anisonyx ditus*	*Bizanus* sp.	*Chasme jucunda*	*Dicranocnemus*	*Dolichiomicroscelis gracilis*	*Heterochelus sexlineatus* sp.	*Heterochelus ganager* (dark morph)	*Heterochelus hybridus*	*Heterochelus rufimanus*	*Heterocheuls gonager*	*Heterochulus* 2 (Koekemoers)	*Heterochelus* 3 (hooked leg)	*Heterochelus* 4 "neroli" (red legs, orange peel texture)	*Ishnochelus* 1 (small, plain)	*Ishnochelus* 2 (large, yellow back, hairy thorax)	*Khoina bilateralis*	*Lepithrix lineata*	*Lepithrix lineata* (Dark morph)	*Lepithrix ornatella*	Novel 1.	Novel 2.	*Pachycnema cressipes*	*Peritrichia pistinaria*	*Platychelus lupinus*	*Peritrichia cinerea* (black oval)	*Heterochelus* (grey w red legs)
BRA-PU-1	Y	-33.831272	18.715153	16/10/2019		1	2		25	5	1						11		11						1									1			
BRA-PU-2	W	-33.836620	18.725054	16/10/2019					19	2						2																		17			
BRA-PU-2	Y	-33.836620	18.725054	16/10/2019	32	1	11		65	4							37								18								1	9			
BRA-PU-2	B	-33.836620	18.725054	16/10/2019		3	2		18	3						1	5																	12			
BRA-PU-2	W	-33.836620	18.725054	16/10/2019		4	6		73	2							33																	40			
BRA-PU-3	W	-33.842100	18.735100	16/10/2019	3	1	4		0	0																											
BRA-PU-3	Y	-33.842100	18.735100	16/10/2019	3	3	2		25	3							20				2													3			
BRA-PU-3	B	-33.842100	18.735100	16/10/2019		1	3		12	3						1	2																	9			
BRA-PU-1	W	-33.831272	18.715153	16/10/2019		7	4		0	0																											
BRA-PU-1	B	-33.831272	18.715153	16/10/2019	0		0		6	3							3		2															1			
BRA-RU-1	B	-33.827527	18.751005	16/10/2019	7	1	14	1	173	5								13	3					6			2							149			
BRA-RU-1	Y	-33.827527	18.751005	16/10/2019	22	3	10		117	3							57		28															32			
BRA-RU-1	W	-33.827527	18.751005	16/10/2019	22	4	7		202	3							36		10															156			
BRA-RU-2	B	-33.819447	18.776317	16/10/2019		2	4	1	11	3							2		2															7			
BRA-RU-2	W	-33.819447	18.776317	16/10/2019	2	8	1		51	4							15				14									1				21			
BRA-RU-2	Y	-33.819447	18.776317	16/10/2019		11	5	1	58	3							42				9													7			
BRA-RU-3	B	-33,80894	18,73823	16/10/2019		1			0	0																											
BRA-RU-3	W	-33,80894	18,73823	16/10/2019	6	2	1		13	5		2					4		1						4									2			
BRA-RU-3	Y	-33,80894	18,73823	16/10/2019		6			136	5		113				2	17								2									2			
BRA-SU-1	B	-33.850106	18.728416	16/10/2019			0		5	2							4																	1			
BRA-SU-1	W	-33.850106	18.728416	16/10/2019	1	4	2		14	2							11		3																		
BRA-SU-1	Y	-33.850106	18.728416	16/10/2019		3			66	2							36		30																		
BRA-SU-2	W	-33.851824	18.713944	16/10/2019	1	1	9		0	0																											
BRA-SU-2	Y	-33.851825	18.713945	16/10/2019	3	2	16		33	3							4		16		13																
BRA-SU-2	B	-33.851826	18.713946	16/10/2019			9		2	2							1																	1			
BRA-SU-3	W	-33.837563	18.711384	16/10/2019		2			68	2							66		2																		
bra-su-3	y	-33.837563	18.711384	16/10/2019		3	1		81	2							56		25																		
BRA-SU-3	B	-33.837563	18.711384	16/10/2019			1		8	3							6		1															1			
BRA-UR-1	B	-33.859055	18.699.684	16/10/2019		1	2		7	1							7																				
BRA-UR-1	W	-33.859056	18.699.685	16/10/2019		2	4		73	2							72																				1
BRA-UR-1	Y	-33.859057	18.699.686	16/10/2019		5	1		108	2							96		12																		
BRA-UR-2	B	-33.851327	18.700270	16/10/2019		1	1		6	1							6																				

Appendix G: Part 4, 2019 pollinator sample set 2.

BRA-UR-2	W	-33.851328	18.700271	16/10/2019		7	3		30	2							29																	1			
BRA-UR-2	Y	-33.851329	18.700272	16/10/2019		1	2		33	1							33																				
BRA-UR-3	B	-33.866848	18.709017	16/10/2019			5		2	1							2																				
BRA-UR-3	W	-33.866849	18.709018	16/10/2019	12	18	2		9	1							9																				
BRA-UR-3	Y	-33.866850	18.709019	16/10/2019		10	6		41	3							32		8																		1
DUR-NA-1	B	-33,82289	18,588735	24/10/2019	12		2		0	0																											
DUR-NA-1	Y	-33,82289	18,588735	24/10/2019	9	1	3		0	0																											
DUR-NA-1	W	-33,82289	18,588735	24/10/2019	7		1		0	0																											
DUR-NA-2	B	-33,823323	18,596316	24/10/2019	3	1			0	0																											
DUR-NA-2	W	-33,823323	18,596316	24/10/2019	2		1		0	0																											
DUR-NA-2	Y	-33,823323	18,596316	24/10/2019	1	2	1		1	1												1															
DUR-NA-3	W	-33,826265	18,604817	24/10/2019	3	2	1		0	0																											
DUR-NA-3	B	-33,826265	18,604817	24/10/2019	3	1	1		0	0																											
DUR-PU-1	W	-33,832802	18,627288	24/10/2019			5	3	0	0																											
DUR-PU-1	B	-33,832802	18,627288	24/10/2019		2	4	3	0	0																											
DUR-PU-1	Y	-33,832802	18,627288	24/10/2019		1	2	2	1	1															1												
DUR-PU-2	W	-33,825575	18,633242	24/10/2019		5	1	1	0	0																											
DUR-PU-2	B	-33,825575	18,633242	24/10/2019		4	1		0	0																											
DUR-PU-2	Y	-33,825575	18,633242	24/10/2019		3	9		0	0																											
DUR-PU-3	W	-33,845497	18,634831	24/10/2019		4	4		26	1																				26							
DUR-PU-3	B	-33,845497	18,634831	24/10/2019		2	2		1	1																				1							
DUR-PU-3	Y	-33,845497	18,634831	24/10/2019		5	4	2	24	2												1								23							
DUR-RU-1	w	-33,840212	18,6146	24/10/2019		10	1		9	1															9												
DUR-RU-1	B	-33,840212	18,6146	24/10/2019	3	2			0	0																											
DUR-RU-1	Y	-33,840212	18,6146	24/10/2019		1	3		10	1																				10							
DUR-RU-2	W	-33,838016	18,619687	24/10/2019	1	3	2		2	1																				2							
DUR-RU-2	Y	-33,838016	18,619687	24/10/2019	1	4			0	0																											
DUR-RU-3	Y	-33,838138	18,625528	24/10/2019		3	2	4	6	2															1					5							
DUR-RU-3	W	-33,838138	18,625528	24/10/2019		2			2	1																				2							
DUR-RU-3	B	-33,838138	18,625528	24/10/2019	1	15			0	0																											
DUR-SU-1	Y	-33,850313	18,64309	24/10/2019		5	5	2	1	1												1															
DUR-SU-1	W	-33,850313	18,64309	24/10/2019	1	1	3		1	1												1															
DUR-SU-1	B	-33,850313	18,64309	24/10/2019		17	3		0	0																											
DUR-SU-2	Y	-33,857741	18,638792	24/10/2019		2	1	2	192	1												192															
DUR-SU-2	B	-33,857741	18,638792	24/10/2019		2	1		1	1												1															
DUR-SU-2	W	-33,857741	18,638792	24/10/2019				1	2	1															2												
DUR-SU-3	Y	-33,844823	18,649453	24/10/2019		2	9		26	2							17													9							
DUR-SU-3	W	-33,844823	18,649453	24/10/2019	1	4	9		38	2															9					29							
DUR-SU-3	B	-33,844823	18,649453	24/10/2019			2		1	1																				1							
DUR-UR-1	Y	-33,865107	18,641352	24/10/2019				1	0	0																											
DUR-UR-1	W	-33,865107	18,641352	24/10/2019		1	2		0	0																											
DUR-UR-2	B	-33,868599	18,634439	24/10/2019		1	1		0	0																											

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DUR-UR-2	Y	-33,868599	18,634439	24/10/2019		2				6	2									4			2															
DUR-UR-2	W	-33,868599	18,634439	24/10/2019			2			2	1							2																				
DUR-UR-3	B	-33,8731	18,643635	24/10/2019		5	2			0	0																											
DUR-UR-3	W	-33,8731	18,643635	24/10/2019		13	13			0	0																											
DUR-UR-3	Y	-33,8731	18,643635	24/10/2019		2	9			17	1							17																				
EAS-PU-1	B	-33,946437	18,704651	29/10/2019		15	3			48	4							33		7		5													3			
EAS-PU-1	W	-33,946437	18,704651	29/10/2019		26	3			127	4							119		2		2													4			
EAS-PU-1	Y	-33,946437	18,704651	29/10/2019		6	2			83	4							75		3		4													1			
EAS-PU-2	B	-33,939268	18,709678	29/10/2019		1	6			84	5					4		52				18						2							8			
EAS-PU-2	W	-33,939268	18,709678	29/10/2019		9	9			70	3					7						50													13			
EAS-PU-2	Y	-33,939268	18,709678	29/10/2019		7	11			544	5							163		70		305						3							3			
EAS-PU-3	Y	-33,97786	18,709968	29/10/2019	3	25	16			53	5	9			5			3										19							17			
EAS-PU-3	W	-33,97786	18,709968	29/10/2019	1	11	7			58	5				1	3		1										37							16			
EAS-PU-3	B	-33,97786	18,709968	29/10/2019	4	5	3			25	3						1											8							16			
EAS-RU-1	B	-33,958973	18,721667	29/10/2019	4	3	2			66	3					23												26							17			
EAS-RU-1	W	-33,958973	18,721667	29/10/2019	6	14	9			154	5	1				62												40							49			2
EAS-RU-1	Y	-33,958973	18,721667	29/10/2019	4	9	23			118	7	13				2						11	2					65	17						8			
EAS-RU-1	W	-33,958973	18,721667	29/10/2019	2	9	7			97	3											7									70				20			
EAS-RU-2	B	-33,954481	18,717699	29/10/2019	1	1	4			86	5					1		23				5									28				29			
EAS-RU-2	Y	-33,954481	18,717699	29/10/2019	2	4	2	1		214	5							88		2		50									72				2			
EAS-RU-3	W	-33,97245	18,72497	29/10/2019		5	6			99	3							78										2							19			
EAS-RU-3	Y	-33,97245	18,72497	29/10/2019	1		1			217	4							180		6		27													4			
EAS-SU-1	b	-33,948017	18,678291	29/10/2019		1	1			0	0																											
EAS-SU-1	W	-33,948017	18,678291	29/10/2019		8	5			7	1							7																				
EAS-SU-1	Y	-33,948017	18,678291	29/10/2019		2	1			10	1							10																				
EAS-SU-2	W	-33,955472	18,67223	29/10/2019		2	2			10	1							10																				
EAS-SU-2	Y	-33,955472	18,67223	29/10/2019		6	1			13	1							13																				
EAS-SU-2	B	-33,955472	18,67223	29/10/2019		4				0	0																											
EAS-SU-3	Y	-33,927803	18,671392	29/10/2019		5	9			17	1							17																				
EAS-SU-3	B	-33,927803	18,671392	29/10/2019		2				1	1							1																				
EAS-SU-3	W	-33,927803	18,671392	29/10/2019		3	4			3	1							3																				
EAS-UR-1	B	-33,937289	18,685345	29/10/2019		2	4			11	2							10																	1			
EAS-UR-1	Y	-33,937289	18,685345	29/10/2019		3	6			46	3							44		1															1			
EAS-UR-2	B	-33,953446	18,698632	29/10/2019		1	17			30	2							11																	19			
EAS-UR-2	Y	-33,953446	18,698632	29/10/2019		4	29			55	4	14		2				33																	6			
EAS-UR-2	W	-33,953446	18,698632	29/10/2019		6	14			93	3							84				2													7			
EAS-UR-3	B	-33,963627	18,698094	29/10/2019	1	1	2			39	4							21		4		2													12			
EAS-UR-3	Y	-33,963627	18,698094	29/10/2019	1	5	13			45	5	3						24										3	2						13			
EAS-UR-3	W	-33,963627	18,698094	29/10/2019		2	9			64	3							15										4							45			
TOK-NA-1	Y	-34,053277	18,434665	11/11/2019		4	10			83	4											58						23			1			1				
TOK-NA-1	W	-34,053277	18,434665	11/11/2019		6	10			3	2							2				1																
TOK-NA-1	B	-34,053277	18,434665	11/11/2019		4	10	1		43	2													2				41										

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TOK-NA-2	W	-34,056925	18,428676	11/11/2019			9	1		56	3							2				18						36										
TOK-NA-2	B	-34,056925	18,428676	11/11/2019	1	1	2			14	2											2						12										
TOK-NA-2	Y	-34,056925	18,428676	11/11/2019		8	15			31	2											12						19										
TOK-NA-3	Y	-34,063623	18,417249	11/11/2019	4	3	7			4	3						1														2			1				
TOK-NA-3	B	-34,063623	18,417249	11/11/2019	9	1	1			0	0																											
TOK-NA-3	W	-34,063623	18,417249	11/11/2019	2	3	6	2		5	1																				5							
TOK-RU-1	B	-34,071762	18,415493	11/11/2019		1	3			1	1																				1							
TOK-RU-1	W	-34,071762	18,415493	11/11/2019		9				65	2																	2			63							
TOK-RU-1	Y	-34,071762	18,415493	11/11/2019		8	3			21	1																				21							
TOK-RU-2	B	-34,073026	18,421115	11/11/2019		1	2			0	0																											
TOK-RU-2	Y	-34,073026	18,421115	11/11/2019			1			0	0																											
TOK-RU-2	W	-34,073026	18,421115	11/11/2019		2	4			3	1																				3							
TOK-RU-3	Y	-34,077428	18,423937	11/11/2019		13	8			4	3							2													1				1			
TOK-RU-3	B	-34,077428	18,423937	11/11/2019		7	3	1		0	0																											
TOK-RU-3	W	-34,077428	18,423937	11/11/2019		26	3	1		6	3							1													3				2			
TOK-SU-1	B	-34,048258	18,452644	11/11/2019	1	7	11			11	2							8													3							
TOK-SU-1	Y	-34,048258	18,452644	11/11/2019		4	18			210	3							19				8									183							
TOK-SU-1	W	-34,048258	18,452644	11/11/2019		13	18			124	2							50													74							
TOK-SU-2	B	-34,060779	18,446615	11/11/2019			22			16	2							14																	2			
TOK-SU-2	W	-34,060779	18,446615	11/11/2019		17	28			129	2							128																	1			
TOK-SU-2	Y	-34,060779	18,446615	11/11/2019	2	13	54			122	1							122																				
TOK-SU-3	B	-34,066101	18,436961	11/11/2019	1	7	30	1		8	1							8																				
TOK-SU-3	W	-34,066101	18,436961	11/11/2019		29	28			68	4							42				24												1	1			
TOK-SU-3	Y	-34,066101	18,436961	11/11/2019	2	7	42			54	3							23				29									2							
TOK-SU-4	Y	-34,03392	18,47132	11/11/2019		14	17			4	2																	2	2									
TOK-SU-4	W	-34,03392	18,47132	11/11/2019		7	5			20	4					7		3										9							1			
TOK-SU-4	B	-34,03392	18,47132	11/11/2019		1	9			4	2											2						2										
TOK-UR-1	B	-34,040677	18,465947	11/11/2019		9	13			5	1							5																				
TOK-UR-1	W	-34,040677	18,465947	11/11/2019		25	37	1		37	1							37																				
TOK-UR-1	Y	-34,040677	18,465947	11/11/2019	2	16	29			28	2					1		27																				
TOK-UR-2	w	-34,031259	18,46978	11/11/2019		3	1			38	1							38																				
TOK-UR-2	B	-34,031259	18,46978	11/11/2019			9			6	1							6																				
TOK-UR-2	Y	-34,031259	18,46978	11/11/2019		6	9			17	1							17																				
TOK-UR-3	B	-34,035714	18,482158	11/11/2019		2	9			28	4	1						1										8							18			
TOK-UR-3	W	-34,035714	18,482158	11/11/2019		3	6			29	4					2		9										8							10			
TOK-UR-3	Y	-34,035714	18,482158	11/11/2019	1	5	32			42	5	8						8										19	3						4			
KEURBOOI	B	-33,9727	18,47786	13/11/2019		4	5			8	3							2	3	3																		
KEURBOOI	Y	-33,9727	18,47786	13/11/2019		6	4	2		128	3							25	55	48																		
KEURBOOI	W	-33,9727	18,47786	13/11/2019		15	14	1		1	1											1																
SOU-NA-1	W	-34,043375	18,398689	14/11/2019		2		2		6	2								3												3							
SOU-NA-1	B	-34,043375	18,398689	14/11/2019			7			2	1								2																			
SOU-NA-1	Y	-34,043375	18,398689	14/11/2019		3	4	1		16	3								11									1			4							

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SOU-NA-2	W	-34,04752	18,40161	14/11/2019		7	2			11	2								2												9							
SOU-NA-2	B	-34,04752	18,40161	14/11/2019		1	1			1	1																				1							
SOU-NA-2	Y	-34,04752	18,40161	14/11/2019		3	1			5	1																				5							
SOU-NA-3	W	-34,059031	18,403953	14/11/2019	3	8	2	1		1	1																				1							
SOU-NA-3	B	-34,059031	18,403953	14/11/2019		1	1			0	0																											
SOU-NA-3	Y	-34,059031	18,403953	14/11/2019	3	4	5			1	1																				1							
SOU-PU-1	Y	-34,024524	18,433256	14/11/2019	6	3	3			8	3							2				4									2							
SOU-PU-1	B	-34,024524	18,433256	14/11/2019			4			0	0																											
SOU-PU-1	W	-34,024524	18,433256	14/11/2019		5	14			6	2							2													4							
SOU-RU-1	Y	-34,036376	18,408246	14/11/2019		2	7			5	2								2												3							
SOU-RU-1	W	-34,036376	18,408246	14/11/2019		6	1	2		5	2										1										4							
SOU-RU-1	B	-34,036376	18,408246	14/11/2019		7	2			0	0																											
SOU-RU-3	W	-34,037843	18,415211	14/11/2019		9	2			0	0																											
SOU-RU-3	Y	-34,037843	18,415211	14/11/2019		4	3			0	0																											
SOU-RU-3	B	-34,037843	18,415211	14/11/2019		2	2			2	1																								2			
SOU-SU-1	w	-34,016561	18,439518	14/11/2019	1	10	10			20	2											16									4							
SOU-SU-1	B	-34,016561	18,439518	14/11/2019		1	4			4	1											4																
SOU-SU-1	W	-34,016561	18,439518	14/11/2019	1	6	4	1		4	2								3												1							
SOU-SU-1	Y	-34,016561	18,439518	14/11/2019		5	8			223	3							2	212												9							
SOU-SU-2	Y	-34,017305	18,447538	14/11/2019		5	3			31	2											26									5							
SOU-SU-2	B	-34,017305	18,447538	14/11/2019		4	4			0	0																											
SOU-SU-3	W	-34,02521	18,439912	14/11/2019		3	8	1		6	1																				6							
SOU-SU-3	B	-34,02521	18,439912	14/11/2019		1	3			1	1								1																			
SOU-SU-3	y	-34,02521	18,439912	14/11/2019	2	1	1															2									1							
SOU-UR-2	b	-34,00275	18,47656	14/11/2019			2																															
SOU-UR-2	W	-34,00275	18,47656	14/11/2019	1	3	2																															
SOU-UR-2	Y	-34,00275	18,47656	14/11/2019			2											2		1																		
SOU-UR-3	W	-33,987869	18,464503	14/11/2019		23	7	1										2				2																
SOU-UR-3	Y	-33,987869	18,464503	14/11/2019	2	40	6	1														7																
SOU-UR-3	B	-33,987869	18,464503	14/11/2019		2	2	2																														
Total					**236**	**937**	**1157**	**48**		**6380**		**50**	**115**	**2**	**6**	**112**	**8**	**2517**	**307**	**305**	**1**	**742**	**201**	**2**	**6**	**47**	**0**	**393**	**24**	**0**	**704**	**0**	**0**	**4**	**847**	**0**	**0**	**4**