Seeing the wood for the trees: an evaluation of the Buffelsdraai Landfill Community Reforestation Project

by

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Grassland Science, School of Life Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by the National Research Foundation (NRF), eThekwini Municipality and the Wildlands Conservation Trust.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Signed: Prof. Kevin Kirkman

Date: 3 December 2015

DECLARATION 1: PLAGIARISM

I, Kathryn Elizabeth Roy (Student number: 213573257), declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

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DECLARATION 2: PUBLICATIONS

My role in each presentation is indicated.

Chapter 3

Roy, K.E., Kirkman, K.P., Adie, H., Douwes, E. & Roberts, D. 2015. Planting for ecological resilience: will Durban's Buffelsdraai Reforestation Project also reach its anticipated biodiversity targets? Sixth World Conference on Ecological Restoration, Manchester, United Kingdom, 25-28 August (Oral presentation).

Terblanche, K.E., Kirkman, K.P., Adie, H., Douwes, E. & Roberts, D. 2014. Seeing the wood for the trees: taking stock of Durban's reforestation project. KZN Sandstone Sourveld and Reforestation Research Year-End Research Symposium, Durban, 25 November (Guest speaker).

Terblanche, K.E., Kirkman, K.P., Adie, H., Douwes, E. & Roberts, D. 2014. Functional forest or green desert: is Durban's flagship reforestation project meeting stated targets? Conference on Ecological and Ecosystem Restoration, New Orleans, LA USA, 28 July-1 August, (Oral presentation).

Terblanche, K.E., Kirkman, K.P., Adie, H., Douwes, E. & Roberts, D. 2013. Functional forest or green desert: is Durban's flagship reforestation project meeting stated targets? EKZNW Symposium of Contemporary Conservation Practice, Howick, 4-8 November (Keynote oral presentation).

I collected the data, carried out all the statistics, prepared and delivered the presentations.

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Signed: Kathryn Elizabeth Roy

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ABSTRACT

Cities, and African cities in particular, will need a suite of relevant tools and approaches to deal with the varied climate change-related threats that these cities will likely endure in the future. African cities will be most affected due to the challenges of underdevelopment and resource shortages and, therefore, must address the climate change challenge in a way that ensures meaningful developmental co-benefits and overall cost-effectiveness. Local level actions, such as ecosystem-based adaptation (EBA), and community-based adaptation (CBA), are both effective forms of adaptation for African cities. The City of Durban (eThekwini Municipality, South Africa), has embarked on a novel approach that combines both these tools, the community ecosystem-based adaptation (CEBA) concept, of which the Buffelsdraai Landfill Community Reforestation Project (BLCRP) is a powerful example. The BLCRP is restoring indigenous forest in the buffer zone surrounding the Buffelsdraai Regional Landfill Site. The project aims to sequester a proportion of CO_2 emissions generated locally during the 2010 FIFA World Cup™, whilst also uplifting local impoverished communities and building functional ecological infrastructure. The need to build the resilience of the city to climate change, in the face of increased uncertainty and risk, is considered urgent by planners. Building functional ecological infrastructure, which includes indigenous forest ecosystems, can help bolster this resilience. Early detection in restoration projects, such as the BLCRP, can allow problems to be identified and rectified through adaptive management in the early stages of restoration. This approach will affect the success and cost effectiveness of the restoration project. The BLCRP is currently in the establishment phase, a time when enrichment planting is best evaluated. This study examines the extent to which the composition, measures of diversity, and functional traits of planted species at restoration sites, are comparable with a local forest reference site. After three to five years, restored sites show low similarity with the reference forest due to different species composition and low species diversity and richness. Functional richness is significantly lower in two of the Buffelsdraai sites. Additionally, few bird-dispersed species were planted at Buffelsdraai and the restoration sites are infested with invasive alien plants compared with the reference ecosystem site. Furthermore, planted tree densities at the restoration site were considerably lower than figures recommended for restoration projects. Given these findings, the BLCRP is unlikely to meet long-term goals. To address these project shortfalls, I propose a higher planting density and a rigorous process to select tree species for planting. This includes implementing the framework species method at Buffelsdraai, which has proven successful in various countries. The framework species method encompasses the planting of mixtures of early and late successional species to capture the site, establish a multi-layered canopy, modify the microclimate and diminish weed growth in the years immediately after plantings. Species planted will also attract animals that will further disperse seeds into the planted area. A desktop assessment of forty-eight tree species helped determine which species would be suitable for field-testing and for eventual planting as framework species at Buffelsdraai. These included tree species common to the vegetation type found at the reference ecosystem site. A total of 18 species were considered unacceptable and removed, leaving 30 species as candidates for future testing. Best performing species were *Celtis africana, Ekebergia capensis, Ficus natalensis, Bridelia micrantha* and *Croton sylvaticus* due to their ability to attract wildlife, grow fast and tall and remain resilient to climate change. Worst performing species were *Eugenia natalitia*, *Dalbergia obovata, Millettia grandis, Allophylus natalensis* and *Baphia racemosa*, all of which were rejected from further testing. Future steps, such as nursery- and field-testing of candidate species, are recommended. The framework species method can be integrated with the current restoration method at Buffelsdraai. These recommendations will enhance biodiversity, increase canopy closure and reduce site management costs. Critically, appropriate and continuous monitoring is required to initiate appropriate management responses.

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Term	Abbreviation
17th Conference of the Parties and 7th Meeting of the Parties	COP 17 CMP 7
Buffelsdraai Landfill Community Reforestation Project	BLCRP
Buffelsdraai Regional Landfill Site	BRLS
Community ecosystem-based adaptation	CEBA
Community-based adaptation	CBA
Durban Adaptation Charter	DAC
Durban Metropolitan Open Space System	D'MOSS
Durban Solid Waste	DSW
Ecosystem-based adaptation	EBA
Environmental Planning and Climate Protection Department	EPCPD
Global Climate Change Models	GCM
Greenhouse gases	GHG
Indigenous Trees for Life'	ITFL
International Panel on Climate Change	IPCC
International Union for Conservation of Nature	IUCN
Invasive Alien Plants	IAPs
Kenneth Stainbank Nature Reserve	KS
Municipal Climate Protection Programme	MCPP
Non-metric multidimensional scaling	NMDS
Non-profit organisation	NPO
Organisation for Economic Co-operation and Development	OECD
Specific leaf area	SLA
University of KwaZulu-Natal	UKZN
Wildlands Conservation Trust	WCT

CHAPTER 1: INTRODUCTION

"The extent of human-induced change and damage to Earth's ecosystems renders ecosystem repair an essential part of our future survival strategy" (Hobbs and Harris 2001).

The recent increased use of carbon-offset projects, for mitigation of CO_2 emissions (Galatowitsch 2009, Diederichs and Roberts 2015), has resulted in the need to better understand the options available, the tools for implementation, and ways to capture and share information about such undertakings. Planting of trees is one such mitigation approach that if implemented through ecosystem restoration mechanisms, offers additional benefits such as biodiversity protection and increased ecosystem services. A greater number of benefits, including critical long-term sustainability, arise when involving local communities. In comparison, mitigation through monocultures or plantations has enormous negative impacts on biodiversity, and provides little or no cultural and subsistence resources for local communities (Alexander et al. 2011). The growing number of tree planting projects has provided many opportunities to boost the science of restoration ecology (Galatowitsch 2009). Ongoing monitoring is important to determine whether projects are on a trajectory to meet their goals and to ascertain whether adaptive management is required. Monitoring also enables us to share knowledge and expertise gained (Mansourian and Dudley 2005).

1.1 Ecological restoration in a changing climate

Ecological restoration, the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society for Ecological Restoration International Science and Policy Working Group 2004), is a key tool in meeting conservation goals (Holl and Aide 2011, Hobbs et al. 2011). With urban areas expanding and open spaces dwindling, protecting only the pristine wildlands in rural areas is no longer adequate for meeting conservation goals (Holl and Aide 2011). The restoration of city green spaces and degraded abandoned land becomes crucial, not only to protect biodiversity and hence improve ecosystem services, but also to improve urban life (e.g. reduced city temperatures, increased health benefits, improved public health) and increase adaptation to climate change (e.g. reduced run-off and chance of floods, increased water infiltration) (Gill et al. 1998, Grimm et al. 2008). Restoration interventions are becoming increasingly common all over the world (Holl and Aide 2011, Hobbs et al. 2011). However, scientists recognise a paradox emerging in restoration ecology. Anticipated climate changes may render restoration back to historic systems difficult or impossible (Hobbs et al. 2006, Choi 2007). The conventional historical template that has guided restoration practices may no longer be useful or relevant (Harris et al. 2006). Simultaneously, climatic changes could render future environmental conditions of an area unknown therefore basing restoration plans on perceived future conditions is difficult (Hobbs et al. 2011, Higgs et al. 2014). Climate change is likely to impact on the practice and outcome of restoration projects due to unexpected changes to biophysical conditions such as temperature and rainfall, which alter processes such as growth and reproduction (Harris et al. 2006). Interestingly, the act of restoration can also impact on climate change, through the increase of vegetated surfaces and the sequestration of carbon (Harris et al. 2006). Restoration also fits into the suite of adaptation measures to ameliorate the effects of climate change. The principal objective for ecosystem restoration should be to focus on building ecosystem resilience to future change (Harris et al. 2006, Mawdsley et al. 2009a).

The eThekwini Municipality refers to the Buffelsdraai Landfill Community Reforestation Project (BLCRP) as a 'reforestation' project in its title (EPCPD 2011a), however it is widely described as a restoration project as there are no proven records that forests covered this area originally. In essence, the BLCRP is rehabilitating degraded land. Rehabilitation is the process of re-establishing the productivity and a portion of the species originally present. Over a period, the protective function and ecosystem services of the original ecosystems may be re-established. Alternatively, restoration aims to re-establish the structure, productivity and species diversity of the original ecosystem and over time, ecological processes and functions will match those of the original ecosystem (Lamb and Gilmour 2003). Therefore, the difference between rehabilitation and restoration is that that rehabilitation does not aim to reach the same levels of species diversity and does not expect the ecosystem to return to its exact previous state, as does restoration. Most restoration activities essentially fall within the definition of rehabilitation as restoration to an exact previous state is not seen as probable (Lamb and Gilmour 2003, Choi 2007). However, to remain consistent with the eThekwini Municipality terminology, the term restoration will be used for the remainder of this dissertation.

1.2 The Buffelsdraai Community Reforestation Project

This dissertation will be focussed on the Buffelsdraai Community Reforestation Project (BLCRP), which is being driven by the eThekwini Municipality (local government for the City of Durban), specifically the Environmental Planning and Climate Protection Department (EPCPD). The project was born from the Municipal Climate Protection Programme (MCPP), whose primary goal is on institutionalising climate change considerations into all facets of the Municipality's day to day work (Roberts 2008). The BLCRP is discussed fully in the sections following.

1.3 The search for a carbon offset site in eThekwini Municipality

The "greening" of the 2010 FIFA World Cup™, held in South Africa, provided an opportunity for ecological restoration to play a role in offsetting carbon emissions generated through hosting the event. Normally, event-greening programmes concentrate on mitigation measures; however, local authority priorities in Durban prompted the establishment of projects having adaptation benefits alongside the mitigation benefits. Ecological restoration through tree planting is seen as a "win-win-win" (Roberts et al. 2011) approach that aids in reducing biodiversity loss, improving carbon sequestration and enhancing the supply of ecosystem services. The Buffelsdraai Landfill Site was one of three possible sites selected, through the MCPP, for forest restoration projects within the eThekwini Municipal Area out of a potential 25. The Buffelsdraai Landfill Site was selected because: 1) it is a municipally-owned site thus easy to get access to, 2) it was one of the largest sites therefore providing ample space for carbon sequestration through tree planting, 3) it is in a priority area for conservation and 4) it is in a rural part of eThekwini where jobs are scarce and thus job creation would be beneficial. Furthermore, a restoration project within the buffer zone of the Buffelsdraai Landfill Site was considered beneficial to the Durban Solid Waste (DSW) department as the landfill site Record of Decision required that a nature conservancy be established in the buffer zone. Therefore, the BLCRP satisfied the nature conservancy objectives of the DSW (N. Diederichs-Mander 2015, pers. comm., 12 November)[1].

[1] Nicci Diederichs-Mander: Managing Director of Futureworks; Nicci@futureworks.co.za

1.4 The Buffelsdraai Landfill Site

The Buffelsdraai Landfill site is a regional waste landfill that is situated between the towns of iNanda and Verulam, approximately 25 km north of Durban in the province of KwaZulu-Natal, South Africa (Figure 1.1). The site is owned and managed by the DSW department of the eThekwini Municipality. The landfill began operating in 2006, serving the area north of the Umgeni River to Tongaat. It is expected to remain in operation for the next 75 years (EPCPD 2011a).

According to the Health Act, 1977 (act 63 of 1977) in South Africa, all landfill sites require a buffer zone between the active landfill, where the waste is dumped, and the communities living adjacent to the landfill. This buffer zone ensures that these communities are shielded from impacts arising from the landfill operations such as noise and air pollution. In the case of Buffelsdraai, the active landfill is 116.2 ha in extent and is fenced off from the 787 ha buffer zone. Over 7000 trees were planted along this fence, to prevent fire and to screen the views and odours from the landfill. Durban Solid Waste has a strong environmental policy, which includes the rescue, relocation and rehabilitation of any plants impacted on by the construction of the landfill. This environmental ethic of DSW resulted in motivation for a nature conservancy to be established on the landfill and its buffer zone. The BLCRP was created in the landfill buffer zone, with the objective of, establishing a functioning, diverse, indigenous forest (EPCPD 2011a).

The landfill site buffer zone was historically, and almost exclusively, farmed for sugarcane. However, some extant, forested riverine areas and patches of grassland occur, with the result that only 520 ha of the buffer zone requires active reforestation. Many of the untransformed areas are infested with invasive alien plants (IAPs) and regular control measures are required.

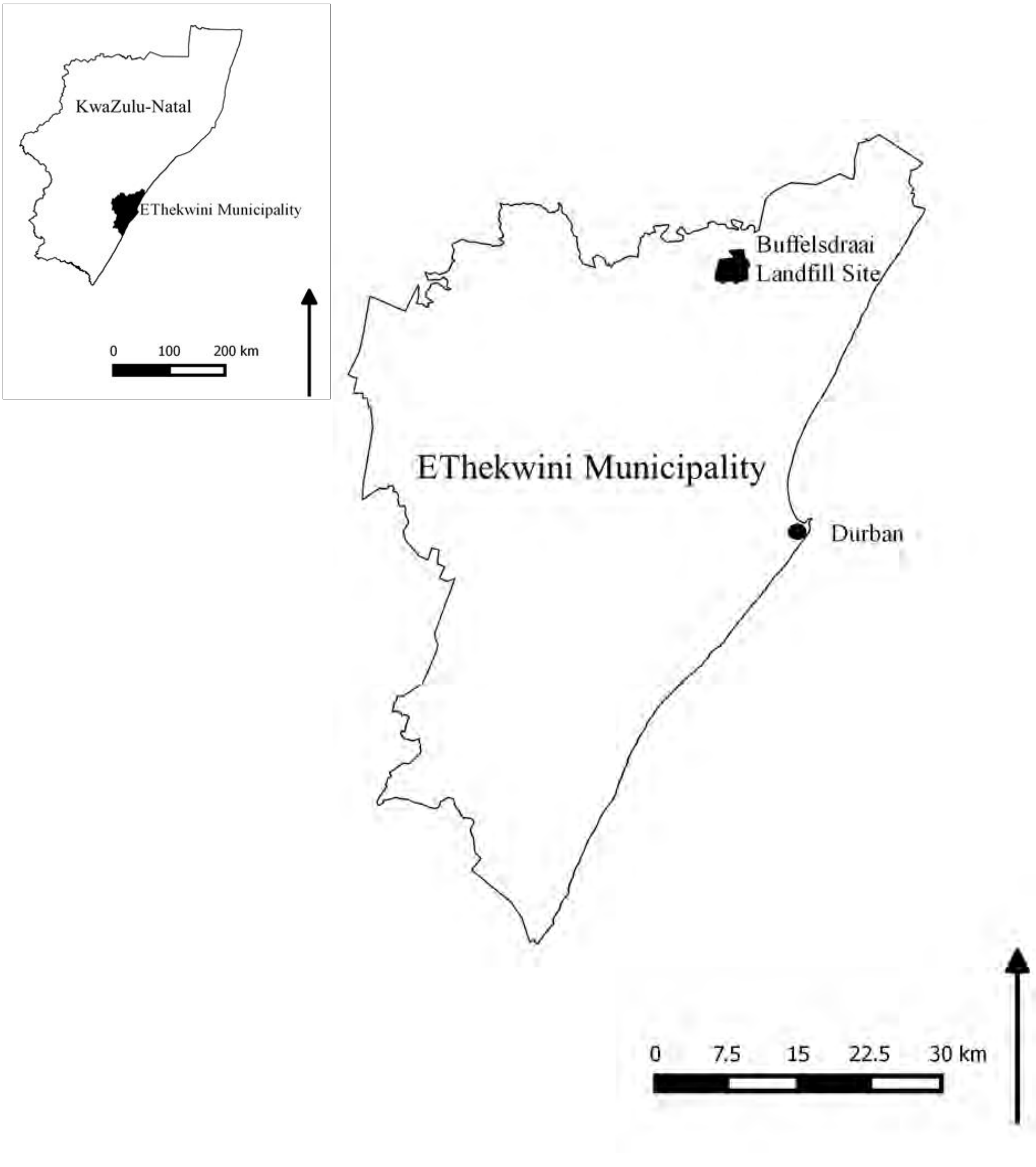


Figure 1.1 The location of Buffelsdraai Landfill Community Reforestation Project within the eThekwini Municipal Area

1.4.1 Climate/weather

Verulam is the nearest town to the Buffelsdraai Regional Landfill Site. Mean annual temperatures range from 5.8 °C to 28.9 °C in July and 17.3 °C to 32.6 °C in January. The mean annual precipitation is 766 mm and most rainfall occurs from December to March (EPCPD 2011a).

1.4.2 Geology

Dwyka Tillite dominates the study area. Soils vary greatly and range from poorly drained Glenrosa soil forms to well drained Hutton soil forms. The topography of the study area is also highly variable, ranging from 200 m to 325 m above sea level. The area encompasses the large Black Mhlasini stream that flows across the northern parts of the study area and the White Mhlasini River that flows along the southern boundary (EPCPD 2011a).

1.4.3 Vegetation type

The broad vegetation type existing in the area belongs to the KwaZulu-Natal Coastal Belt and is classified as Endangered (Mucina and Rutherford 2006). Ezemvelo KZN Wildlife (government organisation tasked with maintaining wilderness areas and public nature reserves in KwaZulu-Natal) subdivided this vegetation type into smaller scale vegetation sub-types. The study area is demarcated as North Coast Grassland (Scott-Shaw and Escott 2011). KwaZulu-Natal Sandstone Sourveld occurs to the west and North Coast bushland occurs just to the north of the study site (Scott-Shaw and Escott 2011). Little of the historical vegetation type exists in the study area as it was replaced with sugar cane. Along the south-facing slopes, small, isolated forest patches occur but mainly riparian forest exist in many of the drainage lines. These patches however, are restricted in their distribution (EPCPD 2011a).

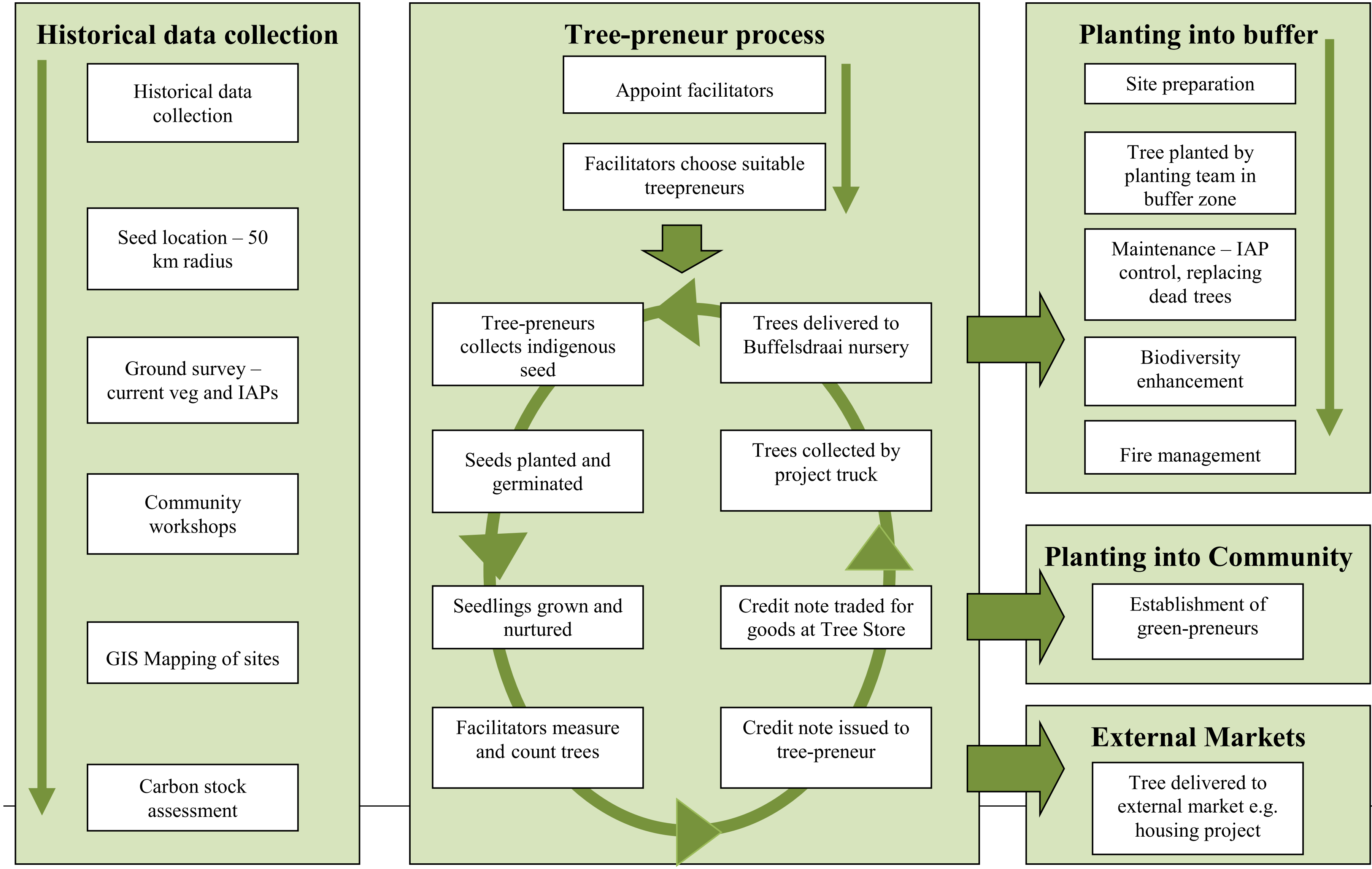
1.5 The adoption of an Ecosystem-based adaptation (EBA) approach at Buffelsdraai

Prior to the launch of the BLCRP, the site was farmed intensively for over 100 years, likely depleting all viable indigenous seed populations in the soil. Only small patches of intact forest occur, which are unlikely to provide sufficient seed source for natural regeneration at the restoration site. Consequently, active restoration, which included planting indigenous trees into the buffer zone, was the preferred land rehabilitation/restoration method. The EPCPD also acknowledged the need to uplift local communities and involve them in the process of reforestation (Roberts and O'Donoghue 2013). The EPCPD therefore encouraged seed harvesting from intact forest as the basis of the process. Community seed harvesting is considered as having the potential to foster greater community participation in reforestation programmes thereby achieving better socioeconomic, ecological and cultural integration (Brancalion et al. 2012). Community involvement also has the potential to uplift the local community through employment opportunities. The process of restoration (Figure 1.2) was therefore based on the Wildlands Conservation Trust's (WCT) 'Indigenous Trees for Life' (ITFL) concept (Douwes et al. 2015). The ITFL concept involves the development of numerous 'tree-preneurs': local community members who grow trees that are traded to the project in exchange for goods and services (e.g. building materials, food, bicycles, driving lessons, school fees). The local community is also hired to dig holes, plant trees, clear IAPs, fight wildfires and cut fire breaks. An active restoration approach could allow for a more species rich secondary forest, uplift local communities and improve carbon sequestration through planting of trees that are known to sequester large amounts of carbon

Wildlands Conservation Trust (WCT) was appointed by eThekwini Municipality to implement the tree-preneur process. WCT employs local community members as facilitators for the Buffelsdraai project. WCT, on behalf of the EPCPD, educate community facilitators to locate, identify and propagate indigenous tree seeds. The role of the facilitator is then to teach 'tree-preneurs' seed collection and propagation techniques. Tree-preneurs collect the seeds within a 50 km radius of the BLCRP site to prevent genetic contamination and propagate these seeds in their home gardens. Once the seedlings are at a certain height (30 cm) the facilitators visit each tree-preneur and count and measure the trees for collection. Thereafter, the tree-preneurs are issued with credit notes that can be redeemed at participating stores for goods or services to the value of the credit note. These goods include food, clothing, bicycles or building materials. Services include paying for school fees or driving lessons. The small trees are collected from the community and transported to the nursery at the Buffelsdraai landfill site where they are hardened off to prepare them for planting into the landfill buffer zone. At the start of the rainy season, the project employs community members to dig holes and to plant these trees into the buffer zone. The planting team ensures that mixes of species are planted and that trees are randomly placed within the demarcated planting block. Seedlings are at least 30 cm in height when they are planted to ensure that they are large enough to compete and survive in the harsh conditions outside of the nursery. A permanent maintenance team is active at the restoration site to replace dead trees, control IAP species and to undertake fire protection measures.

Through tree planting, this project aims to sequester carbon, enhance biodiversity and alleviate poverty within communities living adjacent to the landfill site. Central to this aim is securing ecosystem services (e.g. improvement of water quality, creation of biodiversity refuges, sediment control, river flow regulation, flood mitigation, improved visual amenity and fire risk reduction). These ecosystem services will aid in short-term resilience to harmful weather patterns such as flooding, whilst improving the long-term climate change adaptation benefits (Douwes et al. 2015). Incorporating this community ecosystem-based adaptation (CEBA) concept ensures prioritisation of both biodiversity enhancement and community engagement, and the stated target to attain levels of biodiversity with that of a local reference forest site (Douwes et al. 2015).

Figure 1.2 The Buffelsdraai Landfill Community Reforestation Process adapted from the Wildlands Conservation Trust



The objectives of the restoration of Buffelsdraai pertinent to this study are as follows (EPCPD 2011a):

- To restore forest habitats that are strategic from a biodiversity protection and management perspective. The Buffelsdraai landfill site buffer zone is regarded as strategic as it is one of the few large open spaces left in the northern parts of eThekwini Municipality and it is therefore appropriate to protect the area from the future spread of urban development.
- To assist the municipality in offsetting the climate change impact of hosting the 2010 FIFA World Cup™. The reforestation of the area will lead to the long-term sequestration of atmospheric carbon in biomass and soils.

With projects such as this, early detection of problems that may arise in the restoration process through monitoring and evaluation, are vital, especially in a changing climate. Early detection allows the implementing agency to mitigate unforeseen negative effects brought about through the restoration process before they manifest long-term (Choi 2007). The aim of the BLCRP is to create natural forest of a similar composition and structure to a nearby reference site. Given the high levels of flammable methane that will be produced by the landfill site, and the perceived fire risk associated with any proximal grasslands, it was considered inappropriate to rehabilitate the buffer zone with grassland (R. Winn 2014, pers. comm. 10 December)[2].

Realistically, the BLCRP will not contain all the species that would be found in intact forest, nor will it have the same structure as one. However, management can steer the restoration site on a trajectory that will allow it to end up similar to the reference site over time. This highlights the importance of monitoring and evaluating progress to keep a project on track, especially early on.

1.6 Aims and objectives

The main aim of this dissertation is to examine the restoration process at the BLCRP and to assess whether the process will achieve the stated goal of representing an indigenous coastal forest. The objectives are as follows:

[2] Richard Winn: Environmental Asset Manager, Durban Solid Waste; Richardwinn@worldonline.co.za

- Place the BLCRP in the current climate change adaptation literature and provide a rationale for its initiation;
- Examine measures of diversity, structure and function at the active restoration sites at Buffelsdraai;
- Compare these findings with a reference ecosystem site to determine whether the project is on a trajectory to meet the project goals; and
- Compile a set of candidate framework species for enrichment planting at the site.

1.7 Outline of dissertation structure

Chapters are written as discrete units to facilitate publication. Thus, each chapter contains its own literature review, materials and methods, results, discussion, and conclusions, resulting in some repetition among chapters.

The different components of this dissertation are organised into five chapters as follows:

Chapter 2 couches the BLCRP in the current climate change adaptation literature and provides a rationale for its origin. The chapter discusses the vulnerabilities of African cities related to urbanisation and climate change and that adaptation is a preferred method for coping, specifically ecosystem-based adaptation. This chapter will help frame the need for restoration in the new (inevitable) urban world, and in doing so, highlight the relevance of this project.

Chapter 3 examines the current restoration methodology to determine if it is on a trajectory to meet project goals. In this chapter, species richness, species diversity, stem density, species composition, and functional diversity are examined and compared to a reference site.

Chapter 4 develops a candidate framework species list that would be suitable for forest restoration at the Buffelsdraai Landfill Site and other coastal reforestation projects in the Durban area.

The final chapter, Chapter 5, integrates the work and provides conclusions and documentation of the contributions of this research. Research recommendations are included.

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CHAPTER 2: CLIMATE CHANGE ADAPTATION IN AFRICA: THE RATIONALE BEHIND DURBAN'S BUFFELSDRAAI COMMUNITY REFORESTATION PROJECT (PAPER 1)

2.1 Abstract

Cities, and African cities in particular, will need a suite of relevant tools and approaches to deal with the varied climate change related threats that they will face in the years to come. Given the challenges of underdevelopment and a shortage of resources, Africa must address the climate change challenge in a way that ensures meaningful developmental co-benefits and overall cost-effectiveness. Local level actions, such as ecosystem-based adaptation (EBA), and community-based adaptation (CBA), are both effective forms of adaptation for African cities. The City of Durban (eThekwini Municipality, South Africa), has embarked on a novel approach that combines both these tools. This community ecosystem-based adaptation (CEBA) approach, of which the Buffelsdraai Landfill Community Reforestation Project is a powerful example, is now integral to Durban's climate change adaptation work stream. Importantly, Durban has also invested heavily in promoting and developing transnational initiatives/networks, which feeds the knowledge gained at local level, back into national and international processes. This has ensured that knowledge generated in cities can inform and alter global thinking.

Keywords: *Climate change adaptation; ecosystem-based adaptation; urbanisation*

2.2 Introduction

Climate change impacts and the effects of increased global urbanisation are "converging in dangerous ways" that could ultimately result in unparalleled destructive impacts (UN Habitat 2011). Cities with large populations and extensive infrastructure are important contributors to climate change, but are simultaneously heavily affected by it (Heinrichs et al. 2013). This vulnerability to climate change has led cities to adopt certain adaptation measures as a way to cope with the unavoidable climatic change related impacts (Carmin et al. 2009). While there are many negative impacts, some positive opportunities do exist. Because cities are centres of wealth and power, they have great potential to direct future, more sustainable developments on earth (Satterthwaite et al.

2007, Revi and Rosenzweig 2013). Additionally, policy makers in cities can use the opportunities to change human behaviour related to climate change. Although high population densities in cities result in increased vulnerability, they also have the ability to alter behaviour at a city-wide scale. Through changes in patterns of consumption, production and societal relations, adaptation to the negative impacts of climate change can be encouraged, and human contributions to climate change can be mitigated (Kamal-Chaoui and Robert 2009). Furthermore, cities can use climate change as an opportunity to be more competitive (Kamal-Chaoui and Robert 2009).

The scale and urgency of climate change means that cities need to develop strategies to mitigate and adapt to climate change urgently (Hamin and Gurran 2009, UN Habitat 2011, Revi and Rosenzweig 2013). Addressing vulnerabilities earlier will help cities to adapt and then reap future benefits. Meanwhile delaying action could result in higher costs in the future, combined with a limitation of future adaptation options or emission reductions (Kamal-Chaoui and Robert 2009). Durban (eThekwini Municipality, South Africa), is one city that has embraced the challenge of planning for climate change and is considered to be an early adapter (Carmin et al. 2009). In this regard, Durban's Municipal Climate Protection Programme (MCPP), implemented in a phased approach, helped to guide initial thinking (Roberts and O'Donoghue 2013). A city-wide climate change adaptation and mitigation strategy was developed, through an inclusive and participatory process (Roberts 2008). Although similar is some ways to the climate change programmes of other large cities in the world (that integrate vulnerability assessments and focused response strategies at the local level), Durban's MCPP has a large emphasis on adaptation to climate change as opposed to a purely mitigation-based approach (Roberts 2010, Roberts and O'Donoghue 2013). One of the fundamental reasons for this is that adaptation options have the ability to address a number of development issues. These development co-benefits are vital in Durban, if post-apartheid development gains are to be retained (Roberts 2010). The Durban adaptation work stream was initiated in 2006, and includes municipal-, community- and ecosystem-based adaptation components. These focussed on projects that embrace a "no-regrets" approach, considered beneficial under multiple climate change scenarios (Roberts and O'Donoghue 2013).

African cities have a role to play in developing and testing novel approaches to managing climate change, through adoption of meaningful mitigation and adaptation strategies. In this regard, Durban is considered a leader, as it has already developed local level actions that benefit local communities and the environment. Of note was the establishment of the Durban Adaptation Charter (DAC) during the 17^{th} Conference of the Parties and 7^{th} Meeting of the Parties (COP 17 CMP 7) for the United Nations Conference of Climate Change. Prior to COP 17 CMP 7, the Environmental Planning and Climate Protection Department (EPCPD) of the eThekwini Municipality aimed to ensure effective implementation of the DAC through continued work with members of the partnership along with new international partners. Through local thinking, the EPCPD has acted globally by influencing the priority assigned to the importance of urban adaptation (Roberts and O'Donoghue 2013). Many of the lessons learnt in Durban have been showcased nationally and internationally (Carmin et al. 2009, Archer et al. 2014) even though it is often assumed that local governments will only have limited international influence (Roberts and O'Donoghue 2013). EThekwini Municipality played a lead role in the establishment of the DAC, which demonstrates the potential that a local government can have in shaping and influencing global debate and action on climate change. The ideas developed and shared, including between and among other DAC partners, has resulted in a growing body of knowledge that has already influenced policy changes at global level (Roberts and O'Donoghue 2013) .

2.3 Climate change and its impacts

Anthropogenic climate change, which refers to an increase in the emissions of greenhouse gases (GHG) that are associated with human activities (IPCC 2007), is now acknowledged as reality by most scientists (Adger et al. 2005, Solomon et al. 2009, Heinrichs et al. 2013). Climate change is now seen as this century's foremost global challenge (Hamin and Gurran 2009), with the result that an International Panel on Climate Change (IPCC) has been established. The IPCC seeks to determine the environmental and socioeconomic impacts of climate change on the world, through use of insights gleaned from current climate change science. Through endorsement of the IPCC reports, governments acknowledge the authority of the scientific content (IPCC 2015).

According to the IPCC, climate change impacts are believed to manifest in four ways, namely: gradual changes in mean climatic conditions; greater seasonal and inter-annual variability; more extreme events; and, rapid climate changes producing disastrous ecosystem shifts (Tompkins and Adger 2004, IPCC 2013). These different manifestations of climate change will have varying effects on societies, including increased vulnerability in some sectors, juxtaposed with improved opportunities in others (Tompkins and Adger 2004). Globally, direct climate change impacts include, (but are not limited to those presented in Table 2.1) increases in extreme rainfall events, increased droughts, sea level rise, permafrost melt, loss of glaciers and snowpack, Arctic sea ice retreat and increased intensity of hurricanes (Solomon et al. 2009, IPCC 2013). All of these could yield disastrous effects, though as will be shown later, it is unlikely that all these impacts will occur in all areas, and certainly not simultaneously.

Table 2.1 Impacts associated with climate change

Impacts	**Likelihood of further changes later this century** (IPCC 2013)	**Resulting impacts**	**Risks already present in Durban unrelated to climate change**
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	“Very likely over most of the mid-latitude land masses and over wet tropical regions” (IPCC 2013)	Human health, infrastructure, sanitation	Yes
Increases in intensity and/or duration of drought	“Likely (medium confidence) on a regional to global scale” (IPCC 2013)	Agriculture, food security, human health, air quality, water quality, biodiversity	Yes
Increased incidence and/or magnitude of extreme high sea level	“Very likely” (IPCC 2013)	Infrastructure, coastal ecosystems	Yes
Increases in intense tropical cyclone activity	“More likely than not in the Western North Pacific and North Atlantic.” (IPCC 2013)	Infrastructure, human health	No
Permafrost melt	Already occurring	Infrastructure, positive feedback to climate change	No
Sea ice retreat	Already occurring	Biodiversity, positive feedback to climate change	No

The fifth assessment report of the IPCC's Working Group I highlights the fact that warming of the earth's climate system is unequivocal (IPCC 2013). The report provides evidence to show that the concentrations of GHGs have increased, the atmosphere and oceans have warmed, amounts of snow and ice have reduced, sea level has risen and oceans have become more acidic (IPCC 2013). These changes affect not only people, but also biodiversity and built infrastructure. The extent of these impacts is likely to increase as CO_2 levels increase and average global temperatures rise. Current predictions estimate that average global temperatures will increase between 1.0 °C and 2.5 °C (IPCC 2013). The extent of both physical and psychological illnesses in humans, alterations in plants' and animals' growing/breeding seasons and living ranges (see Table 2.2 for more biological ramifications) is likely to grow, as is the damage to infrastructure that is vulnerable to sea level rise, flooding, and extreme temperatures (Gill et al. 1998).

Table 2.2 Global climate change impacts on biodiversity (table has been adapted from EPA (2015) unless an alternative reference is provided), although not comprehensive.

Type of impacts	**Possible outcomes of impacts**	**Examples**
Changes in the Timing of Seasonal Life-Cycle Events	Climate affects stages of species' life cycles (e.g. migration, blooming, mating). Due to climate change the timing of these events has been altered leading to timing mismatches in migration, breeding, and food availability. Survival rates decline if migrant species arrive at their specified location earlier or later than food sources are present.	Warmer springs on the East Coast of the US have resulted in 28 species of migratory birds nesting earlier, and in California, 16 out of 23 butterfly species are arriving earlier.
Range Shifts	As temperatures increase, the habitat ranges of various species are moving poleward in latitude and/or upward in	In the Cape Floristic Region, only 5% of the Proteaceae species (modelled with a bioclimatic model)

	elevation. For certain species, this results in a reduction in range, movement into less hospitable habitats or increased inter-species competition.	are projected to retain more than two thirds of their current range (Midgley et al. 2002).
Food Web Interactions	The interrelated nature of food webs means that if climate change impacts on a particular species, this could in turn affect a wide range of other species.	Reduction in sea ice due to climate change results in decreased Arctic ice algae. These algae are eaten by zooplankton, which are in turn eaten by Arctic cod which are fed on by seals. Seals are eaten by polar bears. Hence, reduction in sea ice and therefore, ice algae can contribute to reduced polar bear populations.
Threshold Effects	Climate change could cause a threshold, or "tipping point," to be passed which is irreversible.	Rising ocean temperatures increase ocean acidity resulting in increased coral bleaching and die-offs. Chronically stressed coral reefs are less likely to recover.
Pathogens, Parasites, and Disease	Shifts in climatic and ecological conditions could spread pathogens, parasites, and diseases, to areas not found before, with potentially serious effects on human health, agriculture, and fisheries.	An increase in Climate suitability for malaria as a result of climate change is increasing the population risk for infection (Caminade et al. 2014).
Extinction Risks	Climate change, combined with land use change and pollution, are major contributors to species extinction.	In a recent study, it has been suggested that the sixth mass extinction is already underway (Ceballos et al. 2015).

2.4 Mitigation or Adaptation?

In light of the evidence (some of which is presented above), anthropogenic climate change is now a certainty. The IPCC (IPCC 2013) has concluded that the response by humanity should be to shift to correcting this by acting against the causes of climate change (Hamin and Gurran 2009). Currently, two key responses to climate change namely mitigation and adaptation (Table 2.3), are touted as being effective if used simultaneously (Hamin and Gurran 2009).

Table 2.3 Mitigation and adaptation definitions (Adger et al. 2005)

	Mitigation	**Adaptation**
Definition	The reduction of GHGs in the atmosphere.	The adjustment in behaviour to optimise on the benefits, and reduce the negative impacts of climate change.
Measures	Mitigation means implementing policies to reduce GHG emissions and enhance sinks.	Adaptation occurs in physical, ecological, and human systems. It involves changes in social and environmental processes, along with perception of risk, and the associated practices that will reduce that risk. It also involves exploring new opportunities to manage with the altered environment.
Examples	Switching to low-carbon energy sources, such as renewable energy.	Improving water use efficiency and building additional water storage capacity.

The Organisation for Economic Co-operation and Development (OECD) urge that we need to immediately mitigate climate change through reducing GHGs in the earth's atmosphere (OECD 2008). However, to achieve emission reductions that are able to stall the cycle of global warming, it will be necessary for a wide variety of policy instruments to be deployed and it will require action from all countries (OECD 2008). Hamin and Gurran (2009) explain that there is general agreement, although strong differences do persist, on the steps that should be taken to decrease GHGs at local, national and international scales. To date, however, efforts to mitigate against climate change have been either poorly informed, inappropriate or non-existent and GHGs have not been reduced to a level that will prevent unavoidable changes in the world's climate (Hamin and Gurran 2009). While those authors consider this to be unfortunate, there are a myriad of reasons for this poor response, such as a lack of international collective action, failure of the largest GHG-emitting countries to ratify the Kyoto Protocol, and the lack of significant national emissions cuts through systems such as carbon trading, to name a few (Harris 2007). Without substantial changes in countries policies, GHG emissions will continue to escalate thereby perpetuating associated climate change (OECD 2008, Hunt and Watkiss 2011). As a result, the simultaneous use of adaptation and mitigation measures, has emerged as a suggested approach, for countries and cities, to help combat the effects of climate change (Hamin and Gurran 2009). It is anticipated that adaptation can empower those that use this approach, be they individuals, cities, or countries. Adaptation does not necessitate the involvement of other countries or players (as is necessary with emissions reductions). Such adapters are empowered to cope with, and have more resilience against, the impacts that climate change may bring (Table 2.1). This is important because climate change is expected to create novel challenges for governments, communities and people (Amundsen et al. 2010). Climate change will have less of an impact on those with better coping strategies and careful adaptation planning.

2.5 Urbanisation and the nature of cities

Roberts and O'Donoghue (2013) describe it as the perfect storm – the combination of climate change and rapid urbanisation with population growth and development deficits. In this century, urbanisation and climate change are now the driving forces of change, and both are interacting in negatively and positively reinforcing ways (D. Roberts 2014, pers. comm. 25 April)[3]. This leads to increased vulnerability of people and biodiversity within cities around the world, particularly in Africa (Roberts and O'Donoghue 2013), as will be discussed further below. New and innovative ways to help these cities adapt are necessary, although such adaptation in urbanized environments is viewed as a complex challenge (Archer et al. 2014).

2.5.1 Global change and the growth of urban areas

The global urban population has dramatically increased since 1900, when 13% of the global population was dwelling in urban areas. Just over a 100 years later, more than half the world's population is living in cities (Grimm et al. 2008, UNEP 2011, Revi and Rosenzweig 2013). Should this urbanisation trend continue, a further three billion people will reside in urban areas by 2050, increasing the urban population to two-thirds

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of the world's population (Revi and Rosenzweig 2013). Cities are also growing to unprecedented sizes with the majority of megacities (cities with more than 10 million people) occurring in developing countries (Grimm et al. 2008).

2.5.2 Urban biodiversity and ecosystems

Biodiversity, the variety of life, which is vital for the sustenance of the human race, is also severely threatened by the impacts of climate change, and ongoing biodiversity losses will likely add to the perfect storm described above. Not only is biodiversity threatened by climate change, with effects such as transformed distributions, species extinctions, and the decoupling of co-evolved relationships (Mawdsley et al. 2009b), but also by habitat loss through urbanisation. In urban areas, hardened surfaces replace open spaces, and the ecosystem services that those spaces supply are either diminished or eliminated. Within cities, biogeochemical cycles are altered, which can have regional and global effects. These include the urban heat island effect and impacts on hydrogeologic cycles (e.g. increased run-off and decreased infiltration) that ultimately have severe consequences for biodiversity (Gill et al. 1998, Grimm et al. 2008, Alberti 2010, Sushinsky et al. 2013), including altered diversity and abundance of fauna and flora (Shochat et al. 2006). Such biophysical changes are chiefly attributed to the transformation of vegetated areas, which provide evaporative cooling, shading, rainwater interception, storage and infiltration functions, to impervious built surfaces (Gill et al. 1998). Biodiversity loss could prove to be a major threat to human well-being (Díaz et al. 2006) and this point is key in the argument for adaptation to climate change. It follows that, should the earth's extant ecological systems be protected and managed, some measure of resilience to the impacts of climate change might be gained. This is currently anticipated to be through the ongoing supply of ecosystem goods and services to urban populations. Resilience of ecological systems means that the system can withstand external stresses, and over time return to its previous state. This resilience is dependent on the biodiversity of that system - the diversity of species, genetic variability and regional pool of species and ecosystems (Thompson et al. 2009).

2.5.3 Cities and climate change

Heinrichs et al. (2013) refer to cities as both the 'culprits' and 'victims' of climate change. Cities produce most of the CO_2, other GHGs, and reduce natural land cover that would normally act as a carbon sink, replacing it with hardened surfaces thereby accelerating climate change (Grimm et al. 2008). Cities are also victims of climate change due to their huge populations and reduced ecosystem services. This combination leaves them vulnerable to risks, such as heat stress, air and water pollution, landslides, flooding, drought, increased aridity and water scarcity, all of which are exacerbated by climate change (IPCC 2013, Revi et al. 2014). Due to a vast number of cities being situated on coastlines, these issues are further compounded by rises in sea level, storm surges and coastal flooding. These risks have extensive detrimental impacts on the health, assets and livelihood of city residents and on the local and national ecosystems and economies (IPCC 2013, Revi et al. 2014).

Although all cities will be affected by climate change, current predictions suggest the most severe impacts will be felt in urban areas in developing countries (Thomas et al. 2007, Carmin et al. 2012, Roberts and O'Donoghue 2013), such as Africa, Asia and Latin America (Downing et al. 1997, Satterthwaite et al. 2007, Revi and Rosenzweig 2013, Roberts and O'Donoghue 2013, Heinrichs et al. 2013). Poverty, poor living conditions and lack of infrastructure (Table 2.4) are some of the challenges cities in the global south already face (Revi and Rosenzweig 2013, Roberts and O'Donoghue 2013). Combined with the high density of people in these areas, the added risk that climate change could bring means that adaptation in these urban environments is urgent (Sanchez-Rodriguez 2009).

2.5.4 Vulnerability of African cities

African cities in particular are typified by their informal nature, fast population growth, shortages of human and financial capital which leads to development shortfalls, increasing inequality, poor governance, high levels of poverty, growing biodiversity loss and deteriorating environmental conditions (Table 2.4) (Roberts and O'Donoghue 2013). The largely informal and often decrepit state of urban areas, together with the impacts of climate change, has been described by Roberts and O'Donoghue (2013) as the 'perfect storm'. The IPCC (2013) also highlights how the rapid urbanisation that is so characteristic of African countries has resulted in rapid growth of informal, urban communities. This informality has left such communities extremely vulnerable, especially those situated in areas at risk from the extreme weather events that will be associated with increased climate change (Revi et al. 2014).

Importantly, many of the predicted climate related risks e.g. droughts, floods, temperature extremes are not new to Africa or African cities. At the city level, while it is anticipated that climate change may exacerbate some of these risks, it is difficult to predict which risks will be most problematic, or where/when they will surface. This is due to the unreliability and inadequacy of outputs gleaned from the downscaling of current global climate change models (GCMs) (Wilby et al. 1999, Prudhomme et al. 2002). GCM outputs are at a larger scale and a lower resolution than what would be needed at the local scale (Di Luca et al. 2015). As such, regions/cities should undertake region/city specific risk assessments. It is unlikely that a region or city will experience all the risks listed in Table 2.1, but as part of adaptation planning and disaster risk management for these areas, such a list is deemed necessary. The likelihood and possible impacts and damage that may result if a given risk were to materialise, should be assessed. This is regardless of whether a risk is new, and directly related to climate change, or if climate change has merely exacerbated the impacts of an existing or previously encountered risk. Ultimately, if communities are empowered to deal with generic risks they may be more adaptive to any additional challenges brought about by or associated with climate change.

Added to the complexity of issues in African cities, is a general high reliance by people on natural resources and biodiversity (Billé et al. 2012, Roberts and O'Donoghue 2013), which will be heavily depleted through urbanisation and climate change. The conversion of open space to concrete surfaces and degradation of surrounding natural areas, combined with climate change and the shifting of survivable habitat, invasion of invasive alien plants (IAPs), will have far-reaching and disastrous impacts for biodiversity and for individuals relying on these ecosystem services (Grimm et al. 2008, Roberts and O'Donoghue 2013).

Table 2.4 Definitions of terms related to poverty

Term	**Definition**
Poverty	"Poverty is associated with the undermining of a range of key human attributes, including health. The poor are exposed to greater personal and environmental health risks, they are less well nourished, have less information and are less able to access health care; they thus have a

	higher risk of illness and disability. Conversely, illness can reduce household savings, lower learning ability, reduce productivity, and lead to a diminished quality of life, thereby perpetuating or even increasing poverty" (WHO 2015) "Poverty is often defined in absolute terms of low income – less than US $2 a day" (WHO 2015)
Poor living conditions	Poor living conditions are characterised by high levels of crime, overcrowding and lack of access to sanitation, running water, electricity and garbage removal.
Development short falls	Lack of infrastructure such as clinics, hospitals, schools, housing, piped water and other government facilities typify development short falls.
Inequality	"The existence of unequal opportunities and rewards for different social positions or statuses within a group or society"
Poor governance	"Bad governance is associated with corruption, distortion of government budgets, inequitable growth, social exclusion, lack of trust in authorities" (World Bank 2015)

2.6 Adaptation as an option for African cities

Human populations and infrastructure in African urban areas are anticipated to suffer significantly as a result of climate change-induced disasters (e.g. Table 2.1). This is due to several factors:

- Dependence on agriculture (UN Habitat 2011), specifically rain-fed agriculture (Dixon et al. 2003);
- High reliance on natural resources by many urban dwelling African people (Adger et al. 2003, Roberts and O'Donoghue 2013);
- Rapid expansion of urban areas, including the expansion of informal settlements, some of which are linked to climate change-induced migrations (Satterthwaite et al. 2007, UN Habitat 2011);
- Expansion of carbon-based energy production systems (such as coal burning stations in SA), as these are still seen as cheaper than other renewable and nuclear energy sources (UN Habitat 2011);

- Lack of financial resources required to provide suitable infrastructure and other protection and/or disaster management measures to deal with natural disasters associated with climate change (Satterthwaite et al. 2007, Conway 2009);
- Large development deficits (UN Habitat 2011), such as those which occur in South Africa due to segregation laws enforced under the Apartheid Regime (Roberts and O'Donoghue 2013); and
- Poor planning coupled with policies which focus on aspirations of living carbon intensive lifestyles (Mudombi 2013).

Even if global agreements that seek to reduce GHGs are implemented, the time lags required to stabilise and/or reduce the effects of anthropogenic emissions are insufficient (Hamin and Gurran 2009). Recent research (Adger et al. 2005) indicates that people, and the cities they live in, have no choice but to adapt to climate change.

2.6.1 Ecosystem-based adaptation (EBA)

Because Africa is still relatively rich in biodiversity, as compared to many developed nations, ecosystem-based adaptation (EBA) is considered a cost effective means to bolster adaptation to climate change in the region (Roberts et al. 2011). EBA is defined as *"...the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. Ecosystem-based adaptation uses the range of opportunities for the sustainable management, conservation and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change. Ecosystem-based adaptation is most appropriately integrated into broader adaptation and development strategies."*(Secretariat of the Convention on Biological Diversity 2009)

The EBA concept arose from an increased awareness and understanding of ecosystem services and their role in supporting human societies, through a diverse range of provisioning, regulating and supporting services. There is growing consensus in the literature that climate change response strategies should include biodiversity and ecosystem elements (Hulme 2005, Roberts et al. 2011). EBA and related activities address this requirement through a range of relevant interventions. These include the establishment and management of protected areas to safeguard the continued delivery of ecosystem goods and services and prioritisation of sustainable water resource management where for example, riverine vegetation is restored and protected in order to regulate floods and provide water storage (Colls et al. 2009). Such activities build on the recognition that healthy ecosystems can play a big role in climate change adaptation through the ongoing provision of natural resources, raw materials, food, water, habitat, and shelter.

EBA strategies can also have many other benefits, including the following:

- Enhanced climate change mitigation through carbon sequestration and the increase of carbon stores (Colls et al. 2009, Roberts et al. 2011, Revi et al. 2014);
- Aiding biodiversity conservation through the protection, restoration and management of particular ecosystems (Colls et al. 2009);
- Bolstering food security, reducing risk to disasters and aiding in sustainable water management (Colls et al. 2009);
- Buffering humans and cities against natural disasters (Roberts and O'Donoghue 2013);
- Low maintenance costs whilst simultaneously delivering more effective benefits as compared with hard engineering measures (Roberts and O'Donoghue 2013); and
- Readily available to poorly resourced communities (Colls et al. 2009).

Given that many African cities are severely under-resourced, and their inhabitants heavily reliant on natural resources (Roberts and O'Donoghue 2013), EBA is an option that should be prioritised. Indeed, EBA could prove to be the main coping strategy for African cities (Roberts et al. 2011).

Lessons learnt from a study conducted by the International Union for Conservation of Nature (IUCN) (Colls et al. 2009) indicate that local communities involved in these initiatives appear to be more successful. As such, a proactive reduction of non-climate stresses, that degrade ecosystem condition and result in less resilient ecosystems, will further boost successes and should be prioritised. Additionally, the broad involvement of partners other than local community members is essential for a cooperative approach, and for securing funding for projects. Adaptive management approaches should be prioritized, together with ongoing knowledge transfer and capacity building, so as to facilitate meaningful adoption of the various activities and measures required. Such an approach will ensure improved local knowledge, in addition to an understanding and awareness of the impacts of climate change (Colls et al. 2009).

2.6.2 Community-based adaptation (CBA)

Community-based adaptation (CBA) "identifies, assists, and implements community-based development activities that strengthen the capacity of local people to adapt to living in a riskier and less predictable climate" (Ayers and Forsyth 2009). It addresses local development concerns, that would render humans vulnerable to impacts resulting from climate change (Ayers and Forsyth 2009). CBA seeks to engage the poor and vulnerable, and is considered ideal for peri-urban and rural areas with high levels of poverty (Archer et al. 2014). Given the high unemployment rate in many African cities, involving communities in this type of adaptation can assist communities to help themselves become more resilient (Archer et al. 2014).

CBA differs from EBA mainly in that it does not focus on the restoration of ecosystems. Community adaptations include raising houses on stilts or creating floating food gardens in areas prone to flooding to reduce/prevent inundation during the monsoon season in Bangladesh (Ayers and Forsyth 2009). CBA also revolves around communities making their own decisions as opposed to having decisions imposed on them by governments or institutions (Satterthwaite et al. 2007), which is not always the case with EBA. Archer et al. (2014) noted that in Durban "a single approach to adaptation is insufficient", CBA should be incorporated into a wider toolbox that can be applied at the local governance level (Archer et al. 2014), as is the case with EBA.

2.6.3 Adaptation vs resilience

In their fifth assessment report, the IPCC's WG II (Revi et al. 2014) found that EBA is a vital component in helping cities become resilient (Revi et al. 2014). Because EBA provides mitigation co-benefits, it is seen as a "powerful, resource-efficient means to address climate change and to realize sustainable development goals" (Revi et al. 2014). Given the challenges African cities face, such as high vulnerability, low adaptability and a higher risk of negative impacts than developed countries (Roberts et al. 2011), these cities need an opportunity to escape from the status quo. EBA can be that mechanism for escape (Roberts et al. 2011). EBA offers an opportunity for a "bouncing forward" approach that is cost effective and leads to African cities "leap-frogging" to more "climate-smart" states (Roberts et al. 2011). In most of the resilience literature, the term "bouncing back" is referred to, which is a *return* to a previous state (Thompson et al. 2009, Harrington et al. 2010). The notion of returning to a previous state is now seen as inappropriate. Indeed, it is now recognised that the current economic and development approach lies at the very root of most of the observed risk, vulnerability and unsustainability, and is driving the depletion of ecosystems (Roberts et al. 2011). Resilience can be unhelpful if a system is in a negative state and that system may be too resilient to the required positive changes (Standish et al. 2014). The notion of bouncing forward challenges the existing global development view and calls for novel approaches that are focussed on sustainability and an adaptive green economy (Roberts et al. 2011). It is a notion where cities should not just want to cope, but rather thrive – using innovative means, creative approaches and also taking risks (Roberts et al. 2011).

2.6.4 Climate change and other 'planetary boundaries'

Rockström et al. (2009) proposed nine planetary boundaries within which the human population can operate safely. Transgressing these boundaries means that there could be irreversible consequences. "*Planetary boundaries define, as it were, the boundaries of the "planetary playing field" for humanity if we want to be sure of avoiding major human-induced environmental change on a global scale*" (Rockström et al. 2009). Climate change is described as one of these planetary boundaries, along with ocean acidification, biogeochemical nitrogen and phosphorus cycles, stratospheric ozone, land system change, global freshwater use, and as mentioned previously, the rate of biological diversity loss. Should a planetary boundary be transgressed, dangerous circumstances could arise as a result of the triggering of sudden, non-linear environmental change by crossing specific thresholds.

Given that current biodiversity loss is estimated to be as high as the previous five mass extinctions on earth (Ceballos et al. 2015), this high rate of biodiversity loss has already transgressed its 'safe' planetary boundary, as determined by Rockström et al. (2009). This high loss of biodiversity is considered to have already heralded a sixth global mass extinction (Ceballos et al. 2015). As discussed above, one of the co-benefits of EBA is the conservation of biodiversity (Colls et al. 2009, Roberts et al. 2011), and as such, the need reduce the rate at which biodiversity is lost is apparent. Rockström et al. (2009) also indicated that the climate change planetary boundary has been transgressed. This provides a strong reason to promote EBA as it addresses both the biodiversity loss and climate change concerns. Assisting communities to adapt, promoting global climate change mitigation measures, and improving management and restoration of biodiversity should all be considered as priorities.

2.7 The importance of addressing climate change at local level

The global nature of climate change has led to the understanding that international reductions in GHG emissions, and adaptation policies that boost community resilience, are useful (Gupta 2007). However, high-level international agreements and protocols often lack clear guidelines, because climate change science is relatively young. As such, policies developed at local or city level have been suggested to be more relevant and also more effective (Satterthwaite et al. 2007, Bulkeley 2010). The following reasons are the basis for this conclusion:

- At the local level, people are motivated to find solutions for their own problems (Gupta 2007, Revi and Rosenzweig 2013);
- At the local level, there is more knowledge of the local pressures and problems. This leads to the development of more appropriate measures for local risk management (Gupta 2007, Hunt and Watkiss 2011, Revi and Rosenzweig 2013);
- The potential for change lies in cities' high concentration of economic activity, innovation, quick reacting local government, potential for social transformation and densification and increased levels of infrastructure (Revi and Rosenzweig 2013);
- Local scale analysis will more likely coincide with local administrative boundaries, thereby facilitating decisions at a more applicable level of governance (Hunt and Watkiss 2011);
- City-scale assessments are appropriate as the risks of impacts associated with climate change (Table 2.1) are either exclusive to, or exacerbated in urban areas (Hunt and Watkiss 2011); and

- To be effective, adaptation needs to be integrated into local frameworks, policies and investments (Revi et al. 2014).

Although local level adaptation is seen as important (Gupta 2007, Revi and Rosenzweig 2013, Revi et al. 2014) , there are hindrances to action at this level (Figure 2.1). The hindrances are grouped under four main elements regarding problems that adaptation at the local level faces. These four elements are related to issues with government politics (local through to national), institutional challenges, lack of capacity within local government and the complications that arise when using external funding, which is common in local level adaptation. However, if such challenges can be overcome the level of adaptation is expected to be high. Gupta (2007) discusses that climate change is a 'glocal' issue, which operates at different levels of government, local, national and international and that there needs to be a division of responsibility between the actors (Gupta 2007). Local level action, although a preferable form of adaptation, is therefore not sufficient as a stand-alone initiative (Gupta 2007).

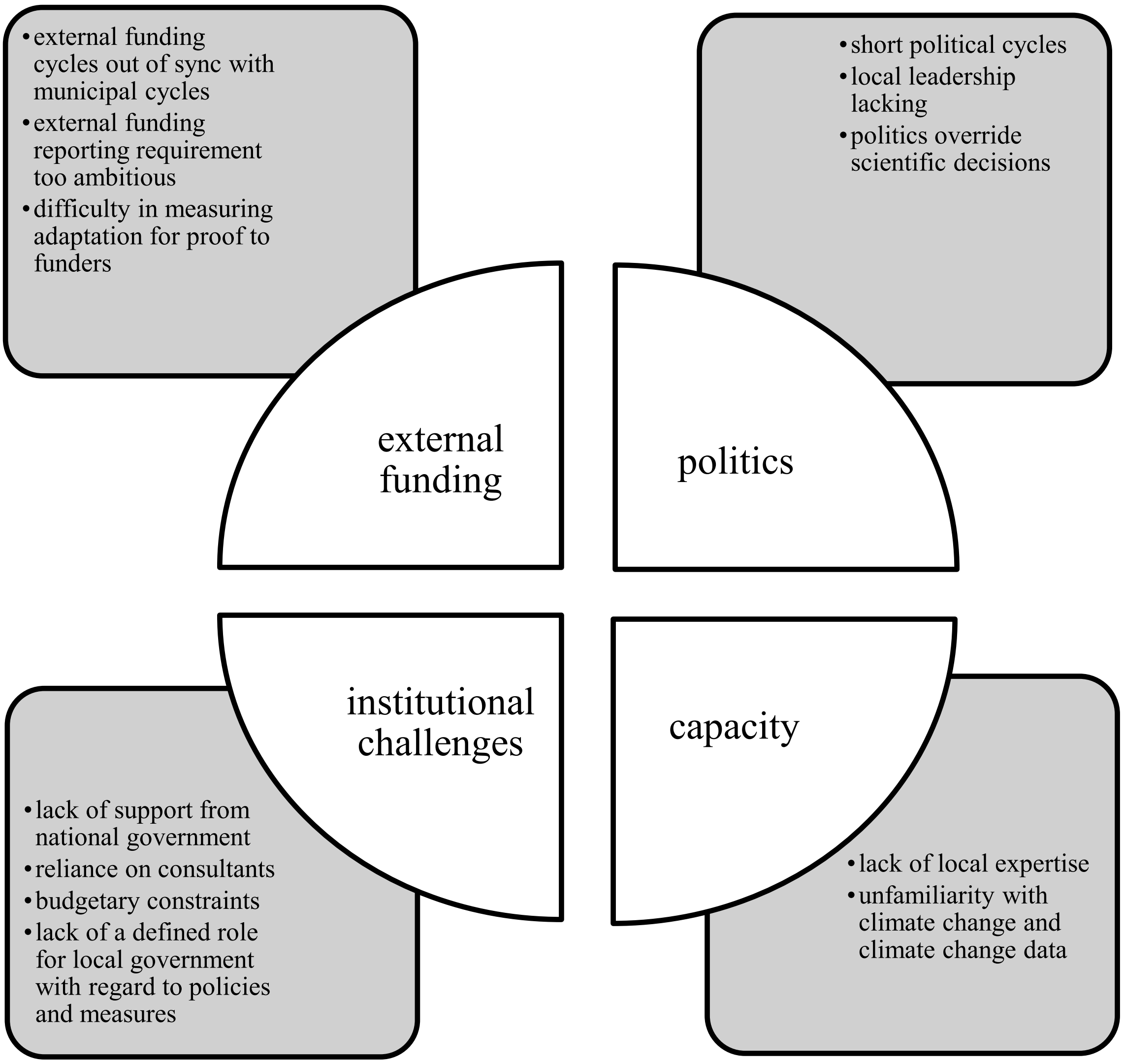

Figure 2.1 Hindrances to adaptation at the local. Adapted from Amundsen et al. (2010), Carmin et al. (2013) and Revi et al. (2014).

2.7.1 The interface between local and global scale implementation of EBA

While it may be recognised that Africa is particularly vulnerable to climate change (Dixon et al. 2003, Roberts et al. 2011), and that EBA is one means to help African cities adapt to climate change, many implementation challenges remain. City-level policies and actions are not stand-alone initiatives, as they are usually closely aligned with national and international policies, plans, legislation or agreements. The key issue with climate change related policies and plans, is that a broadly accepted and endorsed international agreement is still lacking. The result is that cities across the globe have not, in any meaningful way, been able to easily align the mitigation or adaptation approaches adopted, either with other cities, or with national and international actions (Betsill and Bulkeley 2006, Bulkeley 2010). However, despite these challenges, some adaptation policies in various cities appear to have had success (Durban, South Africa and Quito, Ecuador (Carmin et al. 2009)). As such, it is clear that cities and local government should play a stronger role in adaptation planning at a local scale, and this idea has recently gained some popularity (Roberts 2010, Cartwright et al. 2013).

Given the lack of alignment, it may be difficult for city-level policies and actions to be shared with the rest of the world. However, because of the power and influence that large cities hold, one proposal is that transnational initiatives be used as a vehicle, so that local level knowledge and experience can be used to influence global scale actions (Bulkeley 2010). Such transnational initiatives/networks provide the political space and often the resources for meaningful adaptation approaches (Bulkeley 2010). Adaptation in this instance is often depicted as a linear model (Figure 2.2), where global directives inform adaptation at the local level, and then are only made relevant at that scale (D. Roberts 2014, pers. comm. 25 April). Ideally, adaptation should form part of a feedback loop (Figure 2.3). This would ensure that knowledge gained is fed back into the system, to inform global knowledge and directives. Transnational initiatives could provide the vehicle that stimulates consolidation of this information back into a more holistic adaptation system (D. Roberts 2014, pers. comm. 25 April). Because of ongoing doubt in the success of current international climate change negotiations, a growing number of still independent networks, which seek to address climate change, have emerged (Bulkeley 2010). ICLEI – Local Governments for Sustainability, is one example of a transnational initiative already operating in the climate governance sphere. ICLEI is a global association, of cities and local governments that is committed to sustainable development. This movement promotes action at a local level to improve global sustainability (ICLEI 2014). The formation of these types of networks is important as it signals that local governments are coming together in new ways around patterns of governance and that they recognise their importance in the global arena (ICLEI 2014).

The Durban Adaptation Charter (DAC) is another transnational network that brings together local governments (DAC 2014) with a focus on adaptation. The Durban

Adaptation Charter was arguably the most significant outcome of a convention of city leaders held concurrently with the COP 17 CMP 7 in Durban, South Africa in December 2011. The charter commits local governments to taking action against climate change at a local level. Specifically in a manner that allows their communities to adapt to associated climate change risks as a means to reduce their vulnerability. Durban's local government played a lead role in the DAC and through the DAC, it has been able to elevate the importance of urban adaptation globally. By 2015, there were 1082 signatories representing local governments from over 40 countries (DAC 2014). This demonstrates the potential that local governments have in shaping and influencing the global debate on climate change.

Transnational Networks such ICLEI and the DAC help cities overcome specific barriers. They also promote and can assist with access to resources and expertise, funding opportunities and the ability of cities to either disseminate, or learn from, good practices (Bulkeley 2010). In this way, cities are able to use their knowledge and lessons learned to influence and feed back into global directives with expertise about local level adaptation. Cities have now been empowered to inform and revolutionise global thinking (D. Roberts 2014, pers. comm. 25 April)[3].

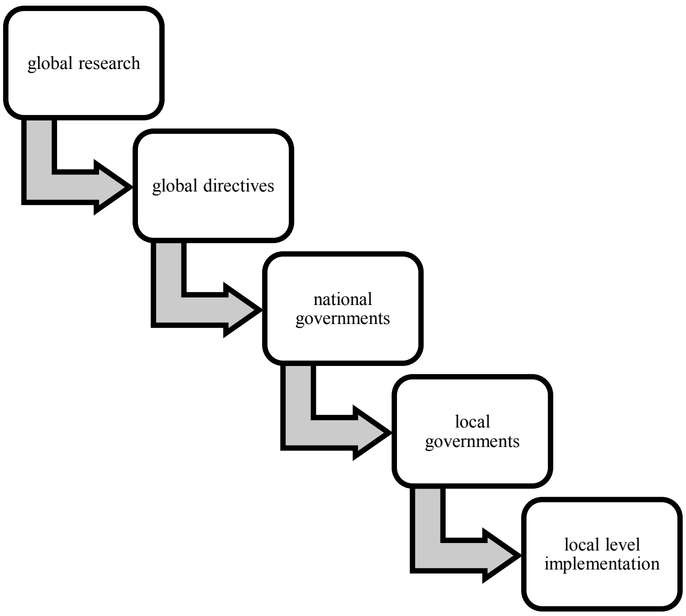

Figure 2.2 The established, top-down linear flow of knowledge and strategies, which has driven the various responses to climate change.

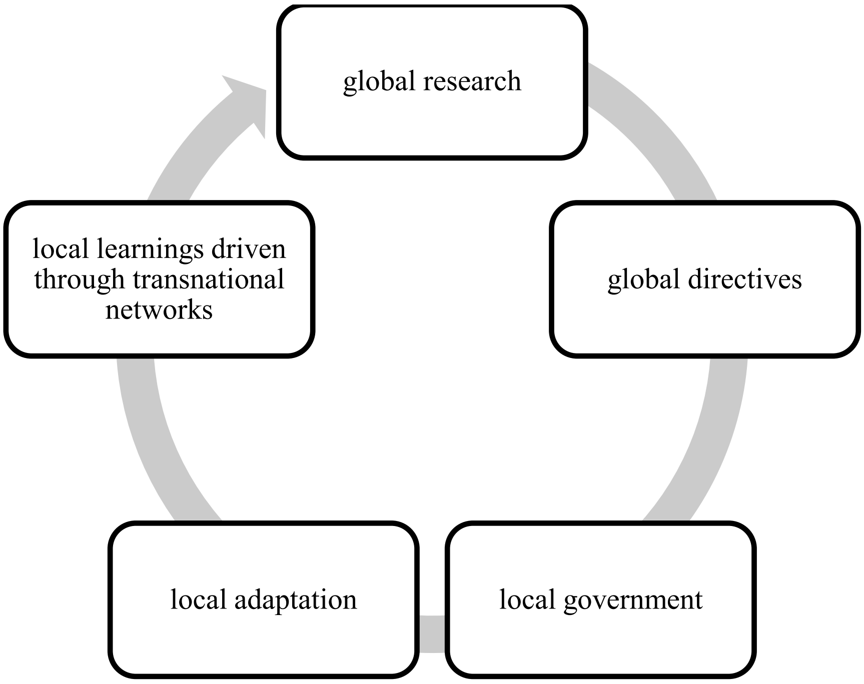

Figure 2.3 The ideal flow of adaptation knowledge is circular, with local learnings and knowledge being fed back into global research and policy.

2.8 Durban's approach to adaptation

Durban, situated on the east coast of South Africa, in the heart of the Maputo-Pondoland-Albany global biodiversity hotspot, contains four of South Africa's eight biomes, seven vegetation types and over 2000 indigenous plant taxa. It is South Africa's 3rd largest city, with a population of around 3.5 million people and is governed as part of the 2,297 km^2 eThekwini Municipality (Stats SA 2011). Unemployment is high (30-39%) and education levels are low, with only 37% of the population over the age of 20 having completed high school (Stats SA 2011). Substantial development deficits exist due to a lack of resources (human and financial), poverty, rising inequality, poor governance and increasing levels of informality (Roberts and O'Donoghue 2013). Droughts, floods, and storm damage occur regularly, and sea level rise is a threat due to the coastal locality. Habitat transformation and environmental degradation have already resulted in high levels of biodiversity loss. A large and already vulnerable local community also rely heavily on ecosystem services generated by natural areas, for survival.

Roberts and O'Donoghue (2013) state that Durban's natural ecosystem services are "*essential to ensuring Durban's long-term sustainability and meeting the basic needs of the poor and vulnerable. The free ecosystem services provided by the city's open space system were valued at US$ 387.5 million per annum in 2003, when the system was substantially smaller than it is today*." Importantly, these ecosystem services are considered a critical means for climate change adaptation. As such, EBA is a vital tool in Durban's climate change adaptation plan. The main reason for the EBA work in Durban is based on the idea that protecting indigenous biodiversity and the related ecosystem services will in turn increase the adaptive range of the city (Roberts and O'Donoghue 2013).

2.8.1 Durban Community Ecosystem-Based Adaptation Initiative

In 2011, Durban hosted COP 17, simultaneously launching the Durban Community Ecosystem-Based Adaptation (CEBA) Initiative. CEBA emphasises the link between communities and the ecosystems on which they rely. This involves the restoration of natural ecosystems, by the impoverished communities that rely on them, and ensures cleaner and greener neighbourhoods that are less reliant on services from the local municipality. Furthermore, the approach has catalysed a new sector for Durban's green economy. Local community members are involved in invasive alien plant control, propagation and planting of indigenous trees, riparian bank restoration, collection of recyclable materials and litter removal. All these include opportunities for skills development and associated training (Roberts and O'Donoghue 2013). Many of these activities take place on land that forms part of the Durban Metropolitan Open Space System (D'MOSS). D'MOSS is a system of open spaces, (74 000 ha of land and water) that includes areas of high biodiversity value linked together in a viable network of open spaces. Their ecosystem benefits aside, D'MOSS, along with other tracts of untransformed land, are a platform for CEBA, and play a vital role in Durban's transformation to a green economy.

The CEBA model has three elements: the upliftment of impoverished communities through establishment of green jobs; the restoration of ecosystems; and the forging of partnerships between the public, private and NGO sectors. The Durban CEBA initiative therefore merges EBA and CBA whereby vulnerable communities are engaged and uplifted through ecosystem restoration. This in turn ensures greater resilience, through income generated and improved ecosystem services, to a wide range of risks including those associated with climate change (Table 2.1). The approach draws on the strengths of both EBA and CBA, ensuring that ecosystem services are protected, adaptive capacity to climate change is bolstered, and at least some carbon emissions are mitigated (Roberts and O'Donoghue 2013). The involvement of the NGOs and private sector has allowed for greater flexibility and has ensured that innovative approaches are not stifled or overly restricted by red tape and government bureaucracy.

2.8.1.1 Buffelsdraai

The focus of this dissertation investigation is on a local level, CEBA project in Durban, namely the Buffelsdraai Community Reforestation Project. The project has had much international recognition, and despite being a local government initiative, has already influenced policy and practice in cities around the world, specifically through transnational networks. The knowledge-sharing approach adopted aims to promote good practices/outcomes and knowledge gained with a global audience (Chapter 1).

2.9 Conclusions

Adaptation to climate change is a vital tool that cities can adopt as a means to cope with the unavoidable impacts of climatic changes. It should be implemented as a complementary approach, together with mitigation efforts. African cities in particular will benefit from the approach, given their high reliance on natural resources and ecosystem services for their livelihoods, and their high vulnerability to climate changes. Importantly, adaptation does not necessitate global action as does mitigation. It instead gives power to the adapting city, allowing for improved local adaptive capacity without the need for global agreements. Adaptation at the local level is a powerful and efficient tool due to rapid results made possible by local people with knowledge of relevant local barriers and issues. Specifically, the protection of biodiversity is key to this approach where the combination of ecosystems management and community development can ensure enhanced ecosystem service provision to those same communities and others. The BLCRP is a powerful example of CEBA in practice.

2.10 Acknowledgements

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CHAPTER 3: FUNCTIONAL FOREST OR GREEN DESERT: IS DURBAN'S FLAGSHIP REFORESTATION PROJECT MEETING STATED TARGETS? (PAPER 2)

3.1 Abstract

The City of Durban (South Africa) is restoring indigenous forest and woodland ecosystems in the buffer zone surrounding the Buffelsdraai Regional Landfill Site. The Buffelsdraai Landfill Community Reforestation Project (BLCRP) initially aimed to offset a proportion of CO_2 emissions generated locally in the Greater Durban area during the 2010 FIFA World Cup™. However, the climate change adaptation focus of the project is now receiving greater attention than the required carbon mitigation function. The need to improve the resilience of the city to climate change, in the face of increased uncertainty and risk, is considered urgent by planners. Building functional ecological infrastructure, which includes indigenous forest ecosystems, can help bolster such resilience. Early detection of issues that arise in restoration projects such as this can ensure that problems are identified and quickly rectified through adaptive management in the early stages of restoration. This will ultimately affect the success and cost effectiveness of the restoration project. The BLCRP is currently in the establishment phase, when enrichment planting is best evaluated. This paper examines the extent to which tree species composition, measures of diversity, and functional traits of planted species at restoration sites, are comparable with a local forest reference site. After three to five years, restored sites show low similarity with the reference forest due to different species composition and low diversity. Thirty-seven tree species were recorded in the reference ecosystem, while restored sites averaged 24 species. Functional richness was significantly lower in two of the Buffelsdraai sites. Additionally, few bird-dispersed species were planted at Buffelsdraai and the restoration sites are infested with invasive alien plants present compared with the reference ecosystem site. Furthermore, planted tree densities at the restoration site were considerably lower than figures recommended for restoration projects. However, the composition of planted trees is likely to be resilient to climatic changes due to the prevalence of generalist species. Given these findings, the BLCRP is unlikely to meet some of the stated long-term goals. It is recommended that the planting density be increased to ~2500 trees per hectare and that the number of bird-dispersed species be

increased. It is further recommended that forest tree species similar to that occurring in local forests be planted to enhance carbon sequestration and increase species diversity. These recommendations will ensure enhanced biodiversity and increased canopy closure. Critically, appropriate and continuous monitoring is required to initiate appropriate management responses.

Keywords: *restoration ecology; functional diversity; climate change resilience; early detection*

3.2 Introduction

Recent conservation efforts around the globe have transformed from preserving 'pristine' or 'intact' ecosystems to that of restoring degraded ecosystems (Hobbs and Harris 2001). One of the biggest challenges to restoration projects is that degraded systems often respond unpredictably to management efforts, resulting in inconsistent and unexpected outcomes (Suding et al. 2004). Additionally, many restoration projects are not followed up with long-term monitoring because funding beyond the inception phase is not secured (Sayer et al. 2004). The intersection of these two challenges means that unexpected and undesirable outcomes from restoration projects may go unnoticed and therefore unmanaged. Furthermore, it takes many decades before there can be a realistic evaluation of 'success' or performance towards the desired condition due to the time it takes for restoration to occur (Kanowski et al. 2010). This timeframe is generally too far down the line from initial restoration efforts to alter issues detrimental to the project. Monitoring that detects outcomes of restoration activities that deviate from project objectives within the first few years of project inception is required to implement corrective measures.

3.2.1 Early detection for success

Early warning systems allow for the identification of barriers or challenges in the beginning stages of restoration. Importantly, the original composition of restoration plantings will have a large effect on the functioning, composition and structure of the end point of restoration (Rodrigues et al. 2011). Early detection allows problems to be identified and rectified through adaptive management in the early stages of restoration, which ultimately will affect the success and cost effectiveness of the project (Mansourian and Dudley 2005).

Few case studies in the literature exist regarding early detection monitoring of restoration projects. Isolated case studies highlight the importance of monitoring for adaptive management and achieving of project goals. Monitoring and the associated adaptive management identify whether corrective action is necessary to shift the project towards its goals. Additionally, money wasted on unsuccessful restoration is saved. For example, monitoring initiated by a lawsuit investigating the widening of a freeway impacting on marsh on San Diego Bay identified pollinator limitation as critical and highlighted the importance of neighbouring upland sites to support ground-nesting bees. These findings and the subsequent adaptive management met the requirements of two threatened bird species (Zedler et al. 2012). Early monitoring of a reforestation project in the French Alps initiated in 1860 may have prevented the early seral plant assemblages that continue to dominate the site after 150 years (Vallauri et al. 2002). Effective monitoring and evaluation should not be considered an afterthought but rather as an integral component of project implementation (Vallauri et al. 2005). Measuring restoration progress identifies restoration shortfalls that require corrective action and contributes towards securing sufficient funding and resources, important aspects for the long-term success of restoration projects (Vallauri et al. 2005, Kanowski et al. 2010).

3.2.2 Restoration resilience for success

In the face of climate change, managers should not only be monitoring and applying adaptive management but also ensuring these systems are resilient to climate change. Climate change alters biophysical patterns such as rainfall, temperature and soil conditions, thereby significantly affecting the outcomes of restoration (Harris et al. 2006). Resilient ecosystems are necessary to buffer the impacts of climate change and thus continue to provide ecosystem services. Ecosystems are made more stable and resilient when they comprise important functional groups that contain a number of ecologically significant species, each with differing responses to environmental factors (Walker 1995). Increasing species diversity increases the likelihood that this redundancy and associated ecosystem resilience will occur (Peterson et al. 1998).

3.2.3 Assessing the Buffelsdraai Community Reforestation Programme

The City of Durban (eThekwini Municipality, South Africa), embarked on a novel Community Ecosystem-Based Adaptation (CEBA; Diederichs and Roberts 2015) approach as part of a project initially established to offset a portion of CO_2 emissions generated during the 2010 FIFA World Cup™. Referred to as the Buffelsdraai Landfill Community Reforestation Project (BLCRP), the project was expanded to include the CEBA concept to ensure prioritisation of both biodiversity enhancement and local community engagement. The target of the project (aside from carbon sequestration and poverty alleviation) related to this dissertation is to achieve levels of biodiversity comparable with that of a local reference forest site. This goal is to be achieved by creating an indigenous forest by planting over half a million indigenous tree seedlings into the buffer zone of the Buffelsdraai landfill site. The planting programme is based on the 'Indigenous Trees for Life' (ITFL) concept designed by the Wildlands Conservation Trust, a non-profit organisation (NPO). Impoverished local community members collect indigenous tree seeds, grow them at their homes and then exchange the seedlings for goods and services such as food and school fees (http://www.wildlands.co.za).

The BLCRP is currently in the establishment phase, a time when enrichment planting (planting with the purpose of increasing density and species richness) is best evaluated (Kanowski and Catterall 2007). Weaknesses in project design and implementation are best identified within the first few years of inception to reduce the probability of escalating costs later. In this chapter, I evaluate the tree species used and the seedling planting procedure at Buffelsdraai. I examine species diversity, composition, key plant functional traits of planted species at the restoration site, and compare these measures with the reference ecosystem.

3.3 Materials and methods

3.3.1 Research area

The study site is located within the ~ 800 ha buffer zone surrounding the Buffelsdraai Regional Landfill Site (BRLS), 12 km from the coast and 25 km north of Durban, in KwaZulu-Natal province (Figure 3.1). Historically, the land at BRLS was cultivated with sugar cane. Since the establishment of the BLCRP, a phased tree planting programme, initiated in November 2009, has gradually ensured replacement of sugar cane with indigenous trees. Planting of trees is undertaken by the Wildlands Conservation Trust on behalf of the Environmental Planning and Climate Protection Department (EPCPD) of the eThekwini Municipality. I surveyed three active restoration sites that correspond with project planting blocks. Sites B1, B2 and B3 were planted with trees in 2009, 2010 and 2011, respectively. Mean annual temperatures range from 5.8 °C to 28.9 °C in July and 17.3 °C to 32.6 °C in January. The mean annual precipitation is 766 mm and most rainfall occurs from December to March (EPCPD 2011a).

The EPCPD selected the forest at the Kenneth Stainbank Nature Reserve (KS), located in Yellowwood Park, a suburb 13 km south of Durban (Figure 3.1) as the reference ecosystem for the restoration programme at BLCRP. The site was chosen for several reasons. First, parts of KS were once planted with sugarcane and it has since restored to coastal forest thereby providing a benchmark of species richness and diversity that is attainable for Buffelsdraai, through restoration. KS is a good example of a restored coastal forest, which is the desired vegetation type at Buffelsdraai; second KS is located within 50 km (~35 km) of the restoration site, a distance considered important by the EPCPD to represent genetic fidelity (Douwes et al. 2015) and both are within 15 km of the coast with similar climates. Third, KS is a forest, and the development of a forest vegetation type will satisfy carbon sequestration objectives (NASA 2010), a key component of BLCRP goals. Finally, the forest patches in the Buffelsdraai area are in steep valleys and riverine areas that were not cultivated and thus not representative of the broader lowland coastal forest.

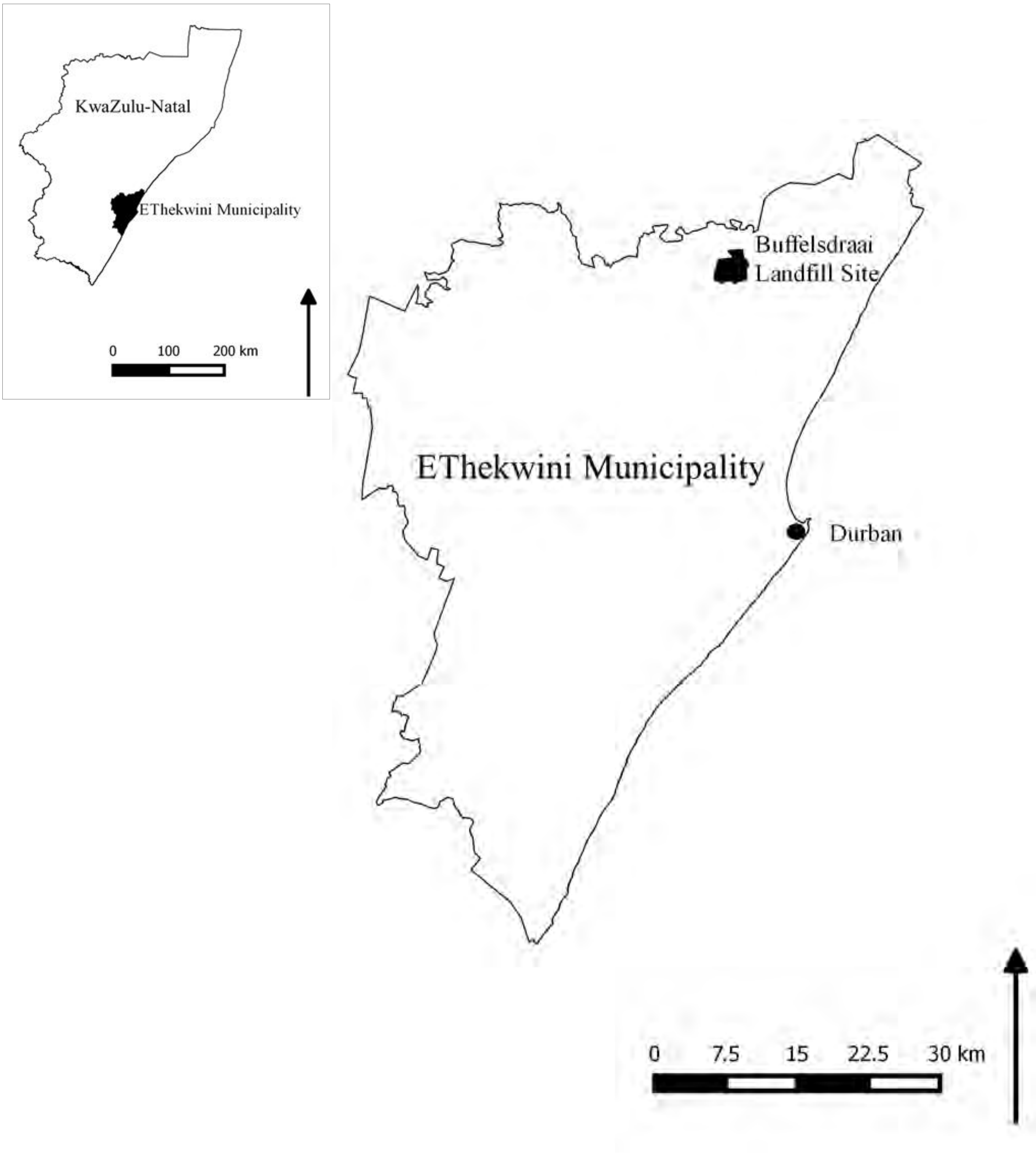

Figure 3.1 Location of the restoration site and reference site within the eThekwini Municipal Area.

3.3.2 Restoration site surveys

I examined the species richness, diversity and composition of three sites at Buffelsdraai and compared these indices with mature forest at KS, the desired condition for restoration activities at Buffelsdraai. I used a 200 m^2 circular plot (radius = 7.98 m). To avoid bias in plot selection (Coomes et al. 2002), I determined the locality of plots before sampling by overlaying a 40 m × 40 m grid over each study site in a geographic information system using ArcMap 10.1 (ESRI 2012). Grid centre points identified sampling points. Twenty plots at each site were randomly selected and were located in the field by GPS. All planted tree seedlings within the 200 m^2 circular plots were identified to species and recorded. I estimated the percentage of vegetation cover visually. The incidence of invasive alien plants (IAP) was estimated by recording the number of individuals in four 1 m^2 subplots positioned at each cardinal point of the plot boundary. Field surveys were conducted in March and April of 2013. Field surveys at KS were undertaken in September 2013 and followed the methodology used at Buffelsdraai. Trees with a diameter at breast height (1.3 m above ground level) (dbh) >10 cm were identified to species in 20 randomly selected plots. Tree height and dbh were recorded.

3.3.3 Functional diversity

The following functional traits reflecting key ecological processes (Díaz and Cabido 2001) were measured: seed mass, specific leaf area, wood density (continuous traits), seed dispersal, and resprouting ability (categorical traits). I used the 10 most dominant species at each site for the continuous traits as they accounted for 70-95% of the frequency and basal area (horizontal surface area of a stem at 1.3 m above ground level) at Buffelsdraai and Kenneth Stainbank respectively. Dominant species were identified using a derivation of the Mueller-Dombois and Ellenberg (1974) method for KS. Size was not factored into the equation because only seedlings were recorded at Buffelsdraai.

The 10 dominant species at Buffelsdraai site and KS were calculated using Importance Values (Mueller-Dombois and Ellenberg 1974):

$$IV = (RD + RDo + RF)$$

IV is the importance value, RD is the relative density (the percentage of individuals of one species of the total number of individuals for all species), RDo is the relative dominance (the total basal cover of one species as a percentage of the total basal cover of all species) and RF is the relative frequency (the percentage of all surveyed plots occupied by a particular species).

Specific leaf area (SLA), which is positively related to relative growth rate across species and negatively to leaf longevity (Poorter and Remkes 1990, Pérez-Harguindeguy et al. 2013), was determined using the method in Pérez-Harguindeguy et al. (2013). I collected five fully expanded leaves in sunlight from five individual trees of each species. Whole twig sections were collected and stored in a cooler box to prevent desiccation prior to processing. Leaves (including the petiole) were scanned, and their area calculated using ImageJ (Abramoff et al. 2004). Leaves were oven dried at 70 °C for 72 h before weighing. SLA was calculated as the ratio of leaf area to dry mass (Pérez-Harguindeguy et al. 2013).

Seed mass is related to seedling survival (Moles and Westoby 2004, Pérez-Harguindeguy et al. 2013). Large seeded species compensate for lower seed numbers by improved survival during seedling establishment through larger amounts of reserves within the seed (Moles and Westoby 2004). Seeds of the 10 most important species at Buffelsdraai site and KS were collected, dried and weighed. Seeds selected for measurement were in the late development stage. An online database (Plant Resources of Tropical Africa, www.prota4u.info) was used to supplement these data.

Wood density is an important trait due to its role in the stability, carbon gain and growth potential of plants and underlies the trade-off between growth and survival (King et al. 2006, Poorter et al. 2008). Wood density data for the 10 most important species at each site were obtained from published databases (Global Wood Density Database, Zanne et al. (2009); African Wood Density Database, Carsan et al. (2014)). I supplemented these data for outstanding tree species using the protocol in Chave (2005). Wood core samples were collected in the field using a 5.15 mm diameter increment borer (Hagloff, Sweden). Wood cores were taken from 5-10 randomly selected trees of the target species. Cores were taken at breast height (1.3 m) with the peripheral flakes removed but the bark left intact prior to sampling. Core wet volume was the product of the core length and the diameter of the corer. Samples were oven dried at 80 °C for five days. Wood density was reported as basic specific gravity (oven dry mass/green volume; g/cm^3) (Pérez-Harguindeguy et al. 2013). I used a conversion factor of 0.872 (Chave et al. 2006) to correct the 'air-dry wood density' (moisture content of 12%) reported by the African Wood Density Database.

Seed dispersal gives insight into distribution of a species at a local scale. In South Africa's forests, which persist within the grassy, fire-prone matrix, seed dispersal is critical for forest species that are not adapted to fire. Tree species that are dispersed by birds have a higher chance of their seeds arriving at sites safe from fire (bush clumps and forest patches where birds perch) as opposed to species dispersed solely by mammals. Mammals are forced to move between 'safe sites' in the 'matrix' and thus the seeds they ingest are more likely to end up in sites that are hostile to regeneration. Seed dispersal was categorised as being dispersed by birds, mammals only or abiotically.

Tree resprouting capacity indicates species response to disturbance and is a vital persistence strategy for woody species (Bond and Midgley 2001, Poorter et al. 2010, Moreira et al. 2012). Resprouting ability was categorised as a species either being able to resprout after disturbance or not.

Altitudinal distribution and spatial distribution were selected as surrogates for climate tolerance. Species with broad spatial distributions tend to be generalist species that can survive under a wide range of environmental conditions (Fridley et al. 2007). Species that have restricted ranges generally have lower dispersal ability, have small populations and are weaker competitors making them more sensitive to climatic changes (Thuiller et al. 2005). Spatial distribution was categorised into three categories: 1) species endemic to South Africa, 2) species situated throughout southern Africa and 3) species distributed throughout southern and South Africa and into tropical Africa. Altitudinal distribution was categorised into three categories: 1) species restricted to coastal habitats (coast), 2) species found from coastal areas to 1500 m a.s.l. (coast and midlands) and 3) species distributed through a wide range of elevations, from the coast to elevations that exceed 1500 m a.s.l (coast, midlands and Drakensberg).

A local identification guide (Boon 2010) and an online database (Plant Resources of Tropical Africa, www.prota4u.info) were used to supplement my own knowledge of diaspore dispersal and tree resprouting capacity.

3.3.4 Data analysis

Tree species richness among active restoration sites and the reference ecosystem site were compared using Mao-Tau sample-based rarefaction (100 runs, EstimateS, (Colwell 2013). Sample-based rarefaction controls for stem density and thus enables a direct comparison between sites. I compared species diversity among active restoration sites and the reference ecosystem site using the exponential of Shannon entropy (Jost 2006). The Shannon exponential is measured in units of 'effective number of species' and is thus directly comparable within and between groups. The Morisita-Horn abundance-based similarity index was used to compare species composition among sites. The index is sensitive to abundant species and is resistant to under sampling and species richness because rare species have a negligible effect (Chao et al. 2006). Values closer to zero indicate no overlapping species, whereas values closer to one indicate species occur in the same proportions in both samples and are therefore more similar. Both the Shannon entropy and Morisita–Horn indices were computed using the SPADE programme (Chao and Shen 2010). A non-metric multidimensional scaling (NMDS) based on a Bray–Curtis dissimilarity matrix (PRIMER v6) (Clarke and Gorley 2006) was used to graphically represent differences in plant species composition between sites.

Functional diversity data were tested for normality using Kolmogorov-Smirnov tests in SPSS (SPSS 2012). ANOVAs were then performed for continuous data along with a post hoc Tukey test (seed mass, wood density, SLA) to test for significant differences between sites. Chi Square tests (SPSS 2012) for categorical data were performed to determine whether there was an association between sites and categorical data. Effect size analyses selected for the Chi square tests were Phi and Cramer's V values. Phi was used to measure the strength of association between sites where only two categories were present (resprouting ability) and Cramer's V was used for dispersal mechanism and altitudinal and regional distribution. All tests used the 95% significance level.

Functional richness (Cornwell et al. 2006, Villéger et al. 2008) and functional evenness (Villéger et al. 2008) indices were calculated with the program FDiversity (Di

Rienzo et al. 2010). Functional richness (F_{ric}) measures how much of the niche space is occupied, providing insight into vulnerability to invasion, productivity and the buffering of environmental fluctuations (Villéger et al. 2008). The higher the F_{ric} value, the more functional space is occupied. Functional evenness (F_{eve}) measures the distribution of traits within the occupied trait space. The values for F_{eve} range between zero and one, with higher values indicating an even distribution of traits. Assuming even resource availability, lower functional evenness indicates that some of the niche space is unutilised thereby decreasing the productivity of the site and simultaneously increasing the opportunity for invasion (Mason et al. 2005). The data were standardised (Cornwell et al. 2006, Schleuter et al. 2010).

3.4 Results

3.4.1 Diversity

Thirty-seven species were recorded at KS (Appendix 2) and 35, 20, 28 were found at site B1, B2 and B3, respectively (Appendix 1). Rarefied species richness was highest in the reference ecosystem site compared with the active restoration sites (Table 3.1). Species diversity was considerably higher in the reference ecosystem (21.7) compared with the active restoration sites. Among the restoration sites, B1 had the highest species diversity (17.5) compared to B2 (8) and B3 (11.5) (Table 3.1).

Table 3.1 Rarefied species richness and species diversity (95% CI) recorded at Kenneth Stainbank and Buffelsdraai. The number of species recorded at each site was rarefied to ~215 individuals. Species diversity (95% CI) was measured by the Shannon exponential (Chao and Shen 2010) from active restoration and reference ecosystem sites (SPADE) (Chao and Shen 2010) KS : Kenneth Stainbank; B1, B2 and B3: restoration sites at Buffelsdraai.

Site	Species richness (95% CI)	Shannon Exponential Mean (95% CI)
B1	27.3 (22.6-31.9)	17.5 (15.9-19.1)
B2	18.8 (13.9-23.6)	8 (6.8-9.1)
B3	24.7 (19.6-29.7)	11.5 (10.1-13)
KS	37 (30.9-43.1)	21.7 (18.4-24.9)

KS shared fewer species with the active restoration sites sharing only nine, six and nine species of its 37 species with B1, B2 and B3 respectively (Table 3.2, Figure 3.2). In contrast, the restoration sites at Buffelsdraai were more similar in terms of species composition (Figure 3.2). Among active restoration sites, B1 and B3 shared the most species with 21 common species (Table 3.2, Figure 3.2).

Table 3.2 Pairwise Morisita–Horn comparisons between the active restoration sites at Buffelsdraai and the Kenneth Stainbank reference ecosystem. The 95% confidence interval was calculated using the modified bootstrap percentile method based on 200 replications (Chao and Shen 2010). Estimate means: 1 = most similar, 0 = dissimilar. KS: Kenneth Stainbank; B1, B2 and B3: restoration sites at Buffelsdraai.

Site	Estimate
B1 vs B2	0.5 (0.4-0.6)
B1 vs B3	0.6 (0.5-0.7)
B1 vs KS	0.3 (0.2-0.4)
B2 vs B3	0.9 (0.8-0.9)
B2 vs KS	0.1 (0.02-0.1)
B3 vs KS	0.2 (0.2-0.3)

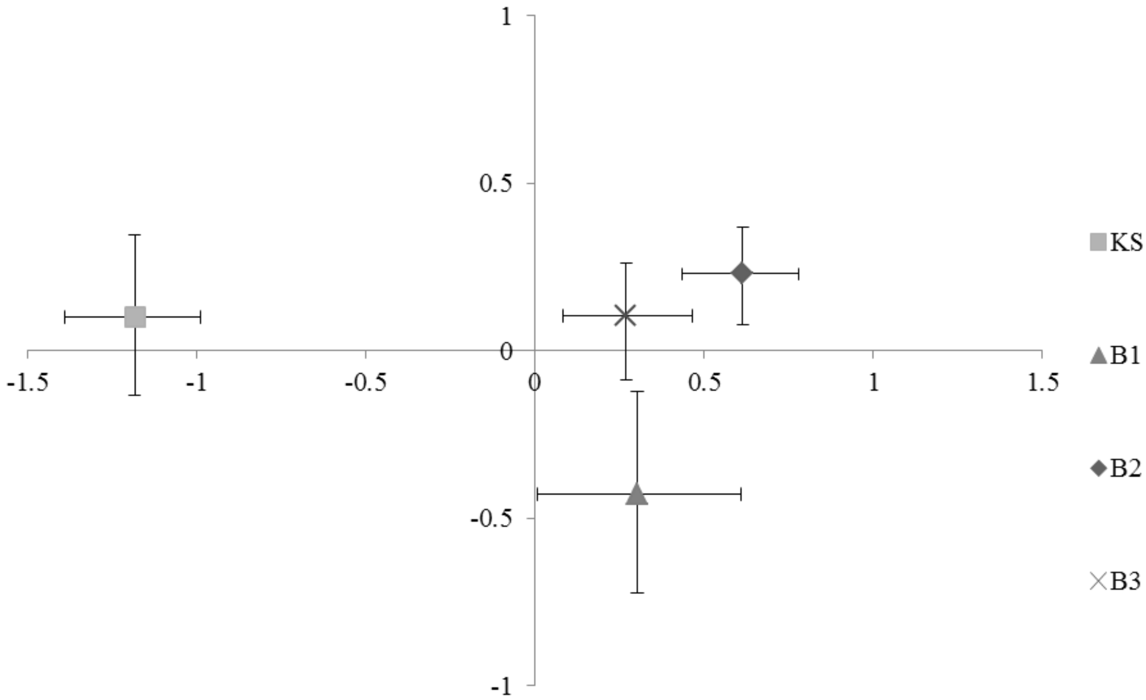

Figure 3.2 NMDS ordination of 80 plots based on Bray–Curtis species similarity coefficients for species composition. Error bars indicate 95% confidence intervals. KS: Kenneth Stainbank; B1, B2 and B3: restoration sites at Buffelsdraai.

3.4.2 Stem density

Seedling planting densities varied from 620 stems/ha in B2 to 972.5 stems/ha in B1 (Table 3.3).

Table 3.3 Stem density (95% CI) of active restoration sites at Buffelsdraai, B1, B2 and B3: restoration sites at Buffelsdraai. Dates shown in brackets indicate the year the sites were planted.

Site	Planting density (stems/ha) (95% CI)
B1(2009)	972.5 (1193.0-752)
B2(2010)	620 (781.1-458.9)
B3(2011)	735 (908.6-561.4)

3.4.3 Functional diversity

Compared to KS, F_{ric} was lower in all the Buffelsdraai sites. There was a significant difference between KS and B2 and B3. F_{eve} did not differ significantly between study sites (Table 3.4).

Table 3.4 Functional richness (95% CI) and Functional evenness (95% CI) at each study site. Indices were calculated using FDiversity (Di Rienzo et al. 2010). KS: Kenneth Stainbank; B1, B2 and B3: restoration sites at Buffelsdraai. Sites that do not have significantly different richness or evenness from other sites are indicated as such with the same letter (A or B).

Sites	Functional Richness	Sig.	Functional Evenness	Sig.
B1	1.35 (1.91-0.79)	A	0.63 (0.75-0.51)	A
B2	0.64 (0.92-0.37)	B	0.53 (0.65-0.40)	A
B3	0.65 (0.94-0.36)	B	0.58 (0.68-0.49)	A
KS	1.98 (2.61-1.35)	A	0.54 (0.68-0.41)	A

There were no significant differences between the Buffelsdraai sites or between the Buffelsdraai sites and KS for wood density, SLA and seed mass (p>0.05) (Figure 3.3).

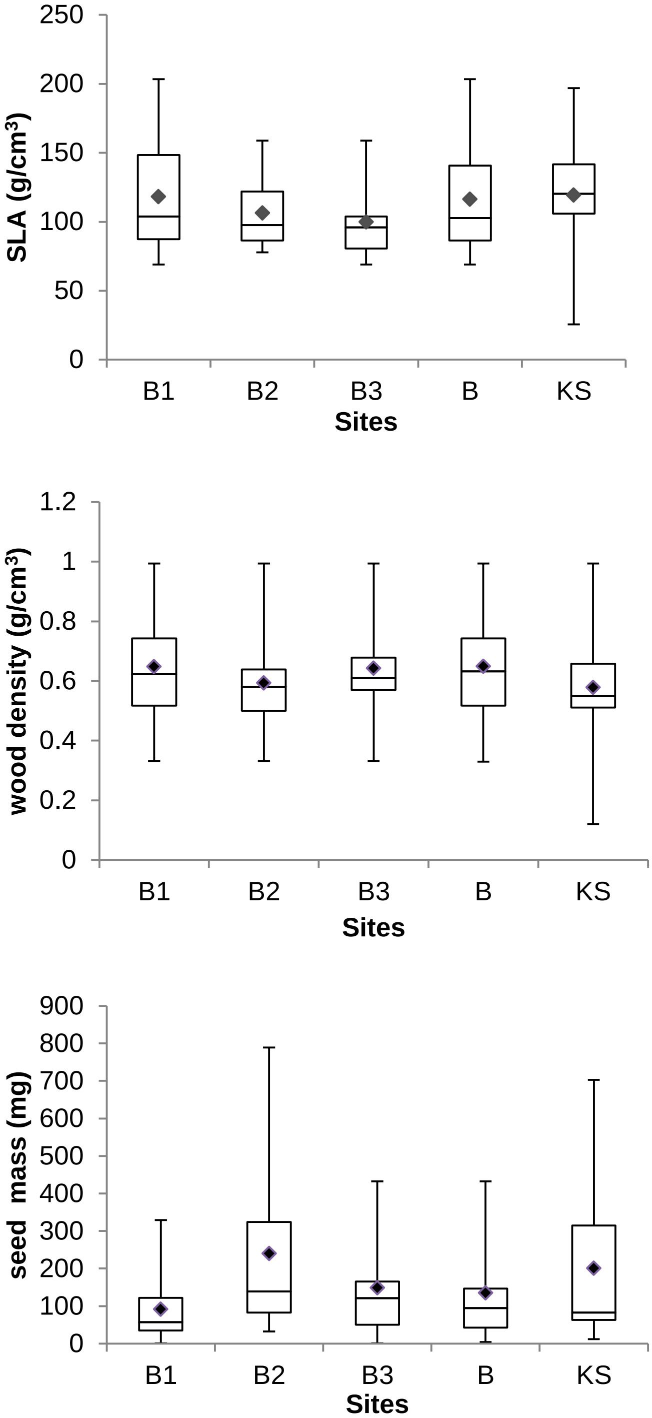

Figure 3.3 Average SLA (top), Wood density (middle) and seed mass (bottom) per site using SPSS (SPSS 2012). KS: Kenneth Stainbank; B1, B2 and B3: restoration sites at Buffelsdraai. 'B' refers to the Buffelsdraai sites combined.

There was a clear difference between the Buffelsdraai and KS sites with regards to dispersal mechanism and resprouting ability, but not with altitude and region (Figure 3.3). These chi square results indicate that when comparing all Buffelsdraai (combined) sites with KS, there is a significant association ($\chi^2 = 12.944$; Cramer's V = 0.4; $p<0.05$) between site and the type of dispersal mechanism used. The tests indicate that there are more bird-dispersed species at KS then would be expected by chance, and less mammalian and abiotic-dispersed species. Conversely, Buffelsdraai had less bird-dispersed species than would be expected but more mammalian and abiotic-dispersed species. Additionally, there is an association ($\chi^2 = 3.879$; phi = 0.219; $p<0.05$) between site and whether a plant is a resprouter or not indicating KS had slightly less resprouter species than would be expected, and Buffelsdraai had slightly more. There was no association between altitude and site ($\chi^2 = 0.110$, $p>0.05$) nor region and site (likelihood ratio 0.38; $p>0.05$) with sites having similar altitude and region categories to expected values. Figure 3.4 illustrates these data in percentages.

Kenneth Stainbank is dominated by bird-dispersed species. In contrast, Buffelsdraai has a high level of mammalian and abiotic-dispersed species (Figure 3.4). Fewer species with the capacity to resprout were recorded in the mature forest at Kenneth Stainbank compared to Buffelsdraai (Figure 3.4). The altitudinal ranges and regional distribution of species is similar between Buffelsdraai and Kenneth Stainbank, both dominated by wide-ranging species found through tropical Africa and with high altitudinal ranges (Figure 3.4).

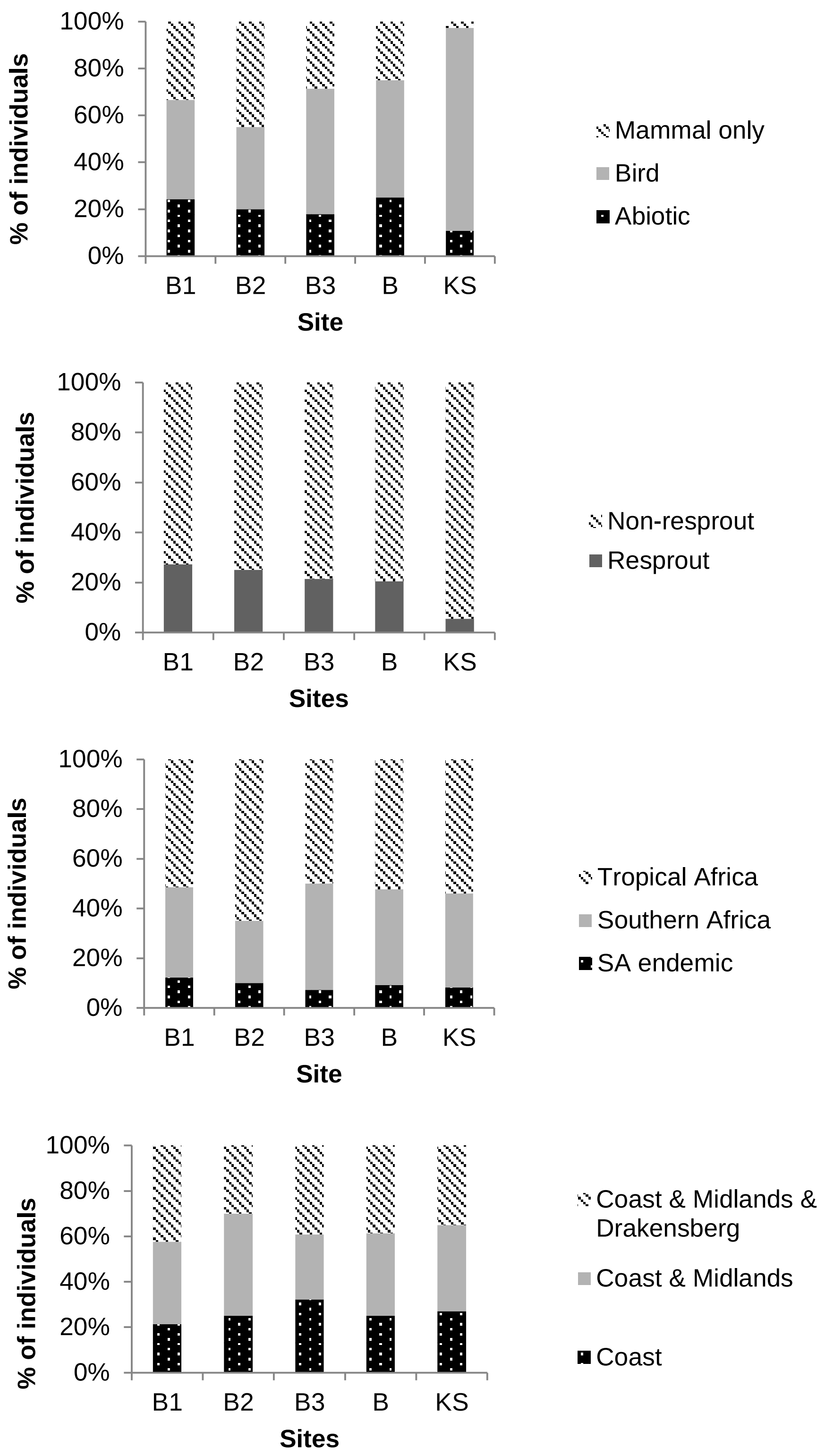

Figure 3.4 Dispersal mechanism (top left), resprouting ability (top right) region (bottom left) and altitude (bottom right) per site using SPSS (SPSS 2012). KS: Kenneth Stainbank; B1, B2 and B3: restoration sites at Buffelsdraai. "B" refers to the Buffelsdraai sites combined.

Between 4.45 (B3) and 7.95 (B2) invasive alien plants were found in the four 1 m^2 subplots on average (Table 3.5), indicating between 19 875 and 11 125 individuals would be present per hectare respectively.

Table 3.5 Mean number of invasive alien plant individuals per hectare (95% CI) using SPSS (SPSS 2012).

	Mean density/ha	95% CI
B1	15 000	(11 129-18 871)
B2	19 875	(12 819-26 931)
B3	11 125	(5 527-16 723)

3.5 Discussion

The BLCRP is a unique reforestation project that aims to increase biodiversity, sequester carbon and uplift adjacent communities, although only the former is addressed in this dissertation. This type of reforestation project is unprecedented in South Africa and is therefore incomparable to any other reforestation project in the country. Perhaps most similar, is the rehabilitation of the mined Richards Bay coastal dunes. Post-mining rehabilitation in this case involves two ways to establish vegetation on mine tailings. The first way involves the establishment of commercial *Casuarina equisetifolia* plantations, and the second involves restoration of indigenous vegetation on the coastal dunes. The restoration of the indigenous vegetation takes place through the addition of fast growing annuals into the topsoil and thereafter, passive restoration takes place through ecological succession followed by gap dynamics. Around 60% of coastal dune forest tree species are still absent after approximately 30 years (Van Aarde and Guldemond 2012). This process differs markedly from restoration at Buffelsdraai, which is based mainly on active restoration whereby tree seedlings of desirable species are planted. The BLCRP process will most likely result in higher species richness, with a composition that is more similar to the desired vegetation type, in a quicker time frame than passive restoration would occur.

3.5.1 Species diversity and richness

The composition and functioning of the initial species assemblage of a restoration project has a long-lasting impact on restoration endpoints (Rodrigues et al. 2011). Thus what a project starts with in terms of composition and function is critically important, emphasising the significance of corrective actions early on in a project lifespan. Results of this study indicate that Buffelsdraai sites have lower species diversity and species richness when compared with the reference site. Additionally, there is a large difference in species composition, with a dominance of pioneer, nitrogen-fixing species at Buffelsdraai. Changes to species richness and diversity, along with composition, will need to be made early on to avoid them having long term influences on the project endpoints. It is, however, important to note that Buffelsdraai is still early on in the successional phase and so it is expected to be missing particular climax and shade tolerant species. Vitally, enrichment planting is planned to occur at Buffelsdraai at a later stage, where additional species will be added, including understory, forb and shrub species. This will improve species richness, diversity and structure.

3.5.2 Functional diversity

Lindenmayer et al. (2015) recently found that restoration practitioners have emphasised the importance of ecological functioning over traditional measures such as richness. Restoration planning has moved away from prioritising taxonomic diversity. Many restoration projects now seek to achieve functional diversity with the goal of creating functioning ecosystems (McGill et al. 2006, Cadotte et al. 2011). High species diversity does appear to translate to greater ‘success’, but it might be due to the increased functional diversity that comes with more species (Rodrigues et al. 2009). Species selection criteria aligned with restoration goals are thus more important than the number of species that are planted.

Significantly higher functional richness in B1 and KS compared to the other two Buffelsdraai sites indicates that B2 and B3 have a higher chance of invasion due to the unfilled trait space, thereby escalating management costs. Selection and planting of species with varying functional traits would be advantageous.

The lack of significant differences for functional evenness at any of the sites indicates that traits are clustered similarly in the trait space among the sites. The values were in the mid region for the index, illustrating that the traits are neither discreetly clustered nor uniformly distributed.

3.5.2.1 Seed mass

Plants with larger seeds have an advantage over smaller seeds, as they can better survive numerous hazards during seedling establishment (Turnbull et al. 1999, Kidson and Westoby 2000). The increased survival of larger seeds was proposed to be a result of larger seeds being able to hold more resources than their smaller-seeded counterparts with the trade-off of fewer seeds being produced. Additionally, the larger amount of resources held by bigger seeds may help with drought tolerance (Gilbert et al. 2001) and thereby improve survival (Palma and Laurance 2015). Although there was no significant difference between seed masses between the sites, the generally lower seed mass and smaller spread of different seed masses at Buffelsdraai possibly means that natural regeneration (resulting from the active restoration plantings) could be diminished. Diminished natural regeneration may be due to the lower survival rate of smaller seeds and their sensitivity to drought conditions, which is a frequent occurrence in the Buffelsdraai area.

3.5.2.2 Wood density

Although Buffelsdraai and KS might differ in species composition, the apparent lack of significant difference between wood densities at these sites could mean that the forests have similar carbon sequestration potentials. This is notable as carbon sequestration is an important goal of the BLCRP, although not investigated fully in this dissertation.

3.5.2.3 Seed dispersal

Seed limitation is a major constraint to restoration of degraded land (Barbosa and Pizo 2006, Orrock et al. 2009, Shoo and Catterall 2013, Palma and Laurance 2015) and has resulted in many novel techniques to increase the flow of propagules to restoration sites, such as direct seeding and the introduction of bird perches (Shoo and Catterall 2013). Fruiting trees present in the matrix attract dispersal vectors such as birds resulting in improved seedling establishment (Galindo-González et al. 2000, Barbosa and Pizo 2006), a mechanism that artificial bird perches simulate (Corlett and Hau 2000). Fundamental to restoration programmes is the use of biota to increase natural regeneration (Elliott et al. 2003), as this helps to reduce management costs and fast-tracks the restoration process.

It has become evident that there is a large difference in the dispersal mechanisms between the restoration and reference sites, with the restoration site having fewer bird-dispersed species. Most of the reference forest trees are bird-dispersed, which creates a positive feedback for natural regeneration. It would be advantageous for there to be more bird-dispersed species introduced at Buffelsdraai to attract birds to the site. These birds can then enhance natural regeneration by introducing seeds from other sources. It is possible that as the current species mix grows at Buffelsdraai, trees could attract birds through perch sites.

3.5.2.4 Resprouting ability

Human impacts and climate change may result in increased fire events within forests, where previously these events would be rare (Kauffman 1991). Although only few resprouting species would traditionally be found in forests of the region, as evidenced in Kenneth Stainbank, there is merit in using these species for restoration purposes in a scenario of the anticipated changes to the local climate. I recommend that resprouting species be placed in high fire risk areas as a buffer to the core forest to protect it from fire. Tall, quick growing species should be grown to create a canopy in order to reduce the risk of fire over the long term (chapter 4).

3.5.3 Resilience

Managing restoration projects in increasingly uncertain times will necessitate a myriad of different approaches. Such approaches will need to focus on improving ecosystem resilience and aiding adaptation of forested ecosystems to the inevitable changes due to climate change and the associated environmental shifts (Millar et al. 2007). Multiple functional groups and species with wide tolerances results in restored vegetation that is more resilient (Zedler 2005). Species with broad spatial distributions tend to be ‘generalist’ species that can survive under a wide range of environmental conditions and have a wide climate tolerance (Thuiller et al. 2005, Fridley et al. 2007), and should therefore be encouraged in restoration plantings to foster resilience to future climate changes. Pywell et al. (2003) showed that generalist species performed better over time in restoration projects than habitat specialists. More than 90% of species at Buffelsdraai have a wide geographical distribution and most species extend beyond the coast indicating that these species may have the capacity to absorb changes in the local climate.

3.5.4 Planting density

High-density plantings generally range between 2,500 and 5000 seedlings (Lamb et al. 2005, Catterall and Kanowski 2010). Plantings at this density overcome a major constraint to restoration activities such as competition with existing grasses, forbs and alien plants which account for high post-planting maintenance costs (Gritt and Nielsen 2011). One of the immediate objectives of reforestation projects is canopy closure, which usually occurs within three to five years (Lamb et al. 2005, Rodrigues et al. 2009). Management costs decline considerably once grass and weeds are shaded by a developed canopy (Elliott et al. 2003, Kanowski et al. 2003, Gritt and Nielsen 2011). Three to five years after planting, the low planting density at Buffelsdraai translates to no canopy closure. Grass and alien plants dominate the restoration sites increasing the risk of fire.

3.6 Recommendations

The goals of the BLCRP project discussed in this dissertation are to attain similar species diversity, richness and functionality to an intact forest; therefore, project management will need to be adapted. To achieve these objectives I recommend the following:

- An increased number of species, higher diversity of species and higher tree planting densities throughout the site. Adopting these recommendations will enhance biodiversity and increase canopy closure, which will reduce management effort and cost invested in IAP removal and fire break management (Gritt and Nielsen 2011);
- A wider representation of bird-dispersed tree species will encourage greater numbers of avian dispersal vectors and result in increased seed dispersal and enhanced natural regeneration (Galindo-González et al. 2000);
- A more focused species selection process (chapter 4). I recommend using the framework species method to select more suitable species for restoration plantings. Framework species are planted to supplement and speed up natural regeneration and boost the recovery of biodiversity (Elliott et al. 2003). The current payment scheme requires adjustment to account for priority species (e.g. higher prices for desirable tree species, such as those that are difficult to grow, those that are bird-dispersed or species that are rare). If seeds of species required

are not found in the surrounding areas, these desirable seeds can be provided to the tree growers; and

- A reduction in tree competition with grasses and IAPs. I recommend a more rigorous IAP removal management system be implemented.

3.7 Conclusions

This study measured and compared the species composition, diversity, richness and functional diversity of a restoration project with that of a local reference forest. The diversity and richness recorded at the restoration site were lower than that of the reference site, while species composition differed markedly. Additionally, functional richness was higher at the reference site compared with two of the Buffelsdraai sites and there was a dominance of IAPs. There was also a general lack of bird-dispersed species. Overall results confirmed that the restored sites were dissimilar to the reference forest. However, the composition of planted trees is likely to be resilient to climatic changes due to the prevalence of generalist species. Given these findings, the BLCRP is unlikely to meet all its long-term goals. I recommend that the planting density be increased to ~2500 trees per hectare to enhance canopy closure and reduce IAP invasion. Similarly, the number of bird-dispersed species should be increased to encourage greater numbers of avian dispersal vectors to foster natural regeneration. I further recommend that tree species more similar to that occurring in local forests be planted to enhance carbon sequestration and to increase species diversity. Appropriate, continuous monitoring through adaptive management is recommended.

3.8 Acknowledgements

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CHAPTER 4: AN ADAPTATION OF THE FRAMEWORK SPECIES METHOD FOR USE IN THE BUFFELSDRAAI REFORESTATION PROJECT AND OTHER COASTAL FOREST RESTORATION PROJECTS IN DURBAN, SOUTH AFRICA (PAPER 3)

4.1 Abstract

The Buffelsdraai Landfill Community Reforestation Project (BLCRP) is restoring indigenous forest in the buffer zone surrounding the Buffelsdraai Regional Landfill Site. The project aims to sequester a proportion of CO_2 emissions generated locally during the 2010 FIFA World Cup™, whilst also uplifting local impoverished communities and building functional ecological infrastructure. A previous study on Buffelsdraai has shown that it requires adaptive management to meet its targets. To address these project shortfalls, I propose a rigorous process to select tree species for planting. I recommend implementing the framework species method at Buffelsdraai, which has proven successful in various countries. The framework species method encompasses the planting of mixtures of early and late successional species to capture the site to establish a multi-layered canopy, attract animals that will further disperse seeds into the planted area, modify the microclimate, and diminish weed growth in the years immediately after plantings. Forty-eight tree species were selected for a desktop assessment to ascertain which species would be suitable for field-testing and for eventual planting as framework species at Buffelsdraai. Species selected for the assessment are common tree species in the vegetation type and species found at the reference ecosystem site. The evaluation used four criteria namely, growth rate, height, ability to attract wildlife and resilience to climate change. Each species was ranked as one of four criteria (excellent, acceptable, marginal and unacceptable) for each category, with unacceptable resulting in a species being rejected. In total 18 species were garnered as unacceptable and removed, leaving 30 species as possibilities for future testing. Best performing species were *Celtis africana, Ekebergia capensis, Ficus natalensis, Bridelia micrantha* and *Croton sylvaticus* through their ability to attract wildlife, grow fast and tall and remain resilient to climate change. Worst performing species were *Eugenia natalitia*, *Dalbergia obovata, Millettia grandis, Allophylus natalensis* and *Baphia racemosa*, all of which were rejected from further testing. Future steps, such as nursery- and field-testing of suggested species, are recommended. The framework species method is not

contradictory to the current restoration method at Buffelsdraai, and I recommend that it be integrated as the initial step in the restoration process.

Keywords: *framework species; restoration; species selection; Buffelsdraai*

4.2 Introduction

Habitat loss and land degradation due to increasing agriculture, urbanisation and plant invasions have highlighted the importance of habitat restoration to secure/enhance ecological processes and hence ecosystem services (Gill et al. 1998, Grimm et al. 2008). Appropriate species selection in ecological restoration plantings is important to restore species richness levels and attain good ecosystem functioning (Pywell et al. 2003, Padilla et al. 2009). Furthermore, it helps to reduce the risk of species failure and decrease the wastage of resources on species that do not perform well (Pywell et al. 2003, Padilla et al. 2009).

The framework species method has proven successful for species selection in wide-scale forest restoration programs in Australia (Goosem and Tucker 2013) and Thailand (Elliott et al. 2003). The method involves planting early successional species to capture degraded sites rapidly by modifying the microclimate, and reducing weed establishment that would usually suppress the growth of indigenous forest species. At the same time, late successional species are planted to establish a multi-layered canopy over the long term. Species that attract animals are planted, as those animals can facilitate further seed dispersal. This in turn enhances natural regeneration throughout the site. Another benefit is that restored sites function as a seed source to restore degraded adjacent sites for long-term forest restoration, as seeds from within the planted area will be distributed outwards. Framework species have various characteristics: 1) high survival and growth rates in degraded sites; 2) crowns that spread and are relatively dense allowing them to shade out herbaceous weeds; 3) the ability to survive fire (either through resistance or recovery); 4) easy to propagate in nurseries; 5) provision of wildlife attracting resources at an early age to promote seed dispersal (Goosem and Tucker 1995, Elliott et al. 2003). Thus, this method provides a framework to select candidate species that meet specific criteria within the above-mentioned categories.

Restoration goals guide the type of species selected. The types of species selected will affect whether restoration projects meet their goals (Urbanska et al. 1997). For example, a restoration project that aims to act as a wildlife refuge requires tree species that provide structure for nesting bird species and appropriate food resources (Society for Ecological Restoration International Science and Policy Working Group 2004). Restoration projects that aim to sequester carbon require trees that have the potential to store large amounts of carbon (Holl and Aide 2011). Consequently, species selection should be based on meeting project goals.

In this chapter, I use the framework species to evaluate and thus recommend certain candidate framework species that will align the Buffelsdraai Landfill Community Reforestation Project (BLCRP) with its goals and aid the restoration process through assisting natural regeneration at Buffelsdraai. The aim of the BLCRP is to establish a functioning, diverse, indigenous forest in the landfill buffer zone to secure ecosystem services and sequester atmospheric carbon (EPCPD 2011b). Kenneth Stainbank Nature Reserve (KS) was selected as a reference site to evaluate performance of the restoration activities at Buffelsdraai. KS in particular was selected because it represents a vegetation type similar to what is desired at Buffelsdraai. KS was formerly under sugar cane but converted to forest through natural regeneration. Therefore, KS is a good model of what is achievable at Buffelsdraai. However, eThekwini Municipality opted for a more proactive approach to avoid the pitfalls associated with natural regeneration (e.g. inappropriate species mixes, reliance on natural seed sources, alien plant invasions, and the longer time taken to regenerate (Mansourian et al. 2005)).

The Wildlands Conservation Trust's 'Indigenous Trees for Life' (ITFL) model was selected because it satisfies eThekwini Municipality's requirement to address development needs through poverty alleviation. Under the ITFL model, local community members collect indigenous tree seeds from the areas surrounding the landfill site, grow them out in their home gardens and then trade established seedlings back to the BLCRP for goods (e.g. food, building materials, bicycles) and services (driving lessons, school fees). The model has worked effectively to date but there is no rigorous species selection process. Consequently, tree species planted at Buffelsdraai are a non-random subset of the regional pool. Species chosen by the tree-growers are easy to germinate, easy to collect, and quick growing (see chapter 3). Three to five years after restoration planting, the diversity of seedlings planted at Buffelsdraai is low, species composition is different with few of the most common local forest tree species included, and there are few bird-dispersed species when compared with the designated reference site. To overcome these planting shortfalls, a rigorous species selection process is required to realign land restoration practices with the restoration goals articulated in the management plan.

The aim of this chapter is to evaluate tree species common to forests in the eThekwini Municipal Area using the framework species method. The goal is to have a subset of candidate species, which satisfy criteria adapted specifically for Buffelsdraai, that then require further assessment using nursery and field trials. I recommend using high performing species as framework species at Buffelsdraai and other possible coastal restoration sites in the Durban area.

4.3 Materials and methods

4.3.1 Research area

The EPCPD selected the forest at the Kenneth Stainbank Nature Reserve (KS), located in Yellowwood Park, a suburb 13 km south of Durban (Figure 4.1) as the reference ecosystem for the restoration programme at BLCRP. The site was chosen for several reasons. First, parts of KS were once planted with sugarcane and it has since restored to coastal forest thereby providing a benchmark of species richness and diversity that is attainable for Buffelsdraai, through restoration. KS is a good example of a restored coastal forest, which is the desired vegetation type at Buffelsdraai; second KS is located within 50 km (~35 km) of the restoration site, a distance considered important by the EPCPD to represent genetic fidelity (Douwes et al. 2015) and both are within 15 km of the coast with similar climates. Third, KS is a forest, and the development of a forest vegetation type will satisfy carbon sequestration objectives (NASA 2010), a key component of BLCRP goals. Finally, the forest patches in the Buffelsdraai area are in steep valleys and riverine areas that were not cultivated and thus not representative of the broader lowland coastal forest.

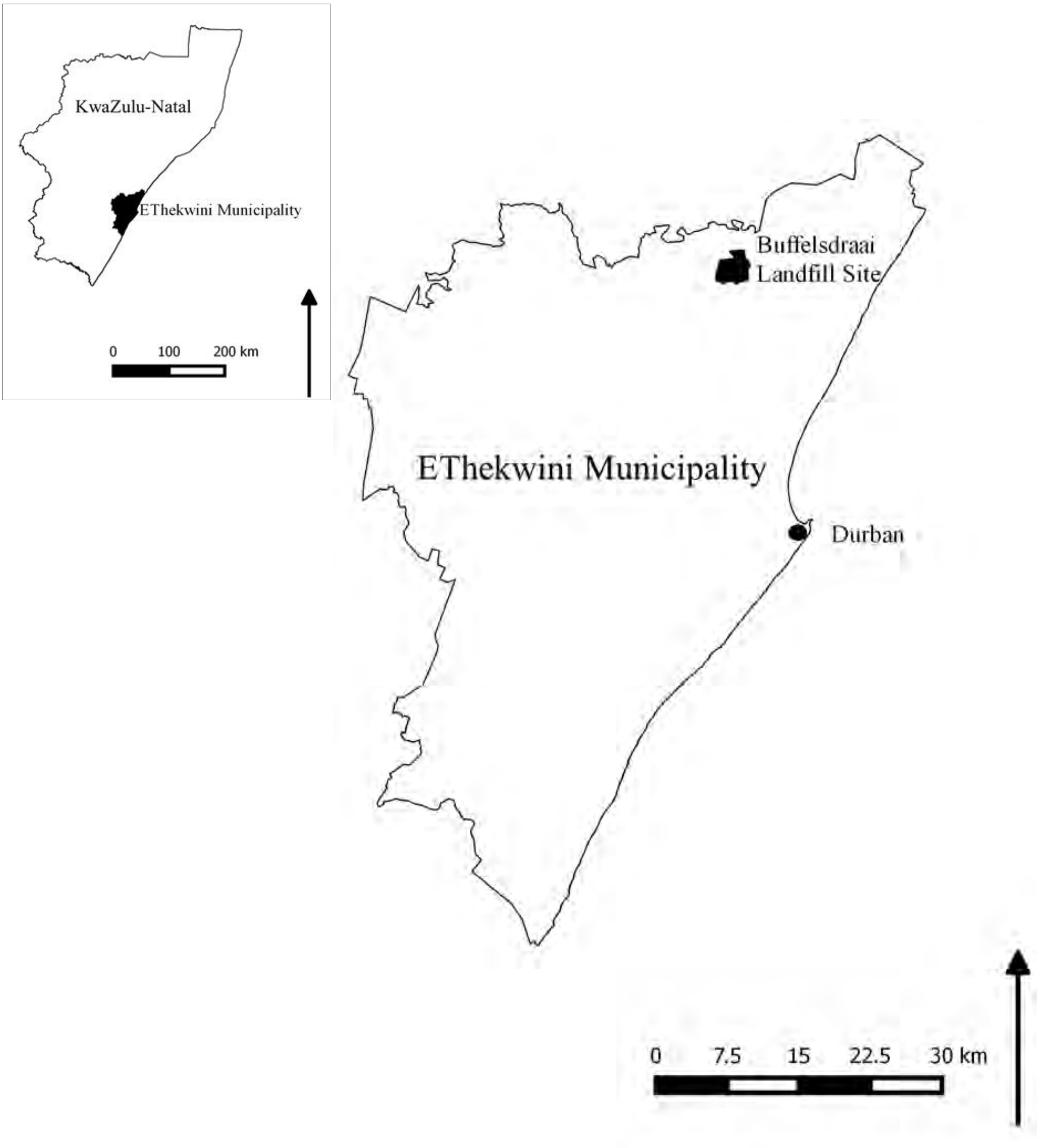

Figure 4.1 Location of the restoration site and reference site within the eThekwini Municipal Area.

4.3.2 Restoration site surveys

I examined the species richness, diversity and composition of forest at KS, the desired condition for restoration activities at Buffelsdraai. Twenty 200 m^2 circular plot (radius = 7.98 m) were set out randomly to avoid bias in plot selection (Coomes et al. 2002). I determined the locality of plots before sampling by overlaying a 40 m × 40 m grid over the study site in a geographic information system using ArcMap 10.1 (ESRI 2012). Grid centre points identified sampling points. Twenty plots were randomly selected and located in the field by GPS. Trees with a diameter at breast height (dbh) >10 cm were identified to species. Tree height and dbh were recorded. Field surveys at KS were undertaken in September 2013.

4.3.3 Framework species

To adapt the framework species method (Goosem and Tucker 1995, Elliott et al. 2003) to satisfy the restoration objectives for Buffelsdraai I omitted tree tolerance mechanisms because the capacity to survive fire was not considered critical due to the existing fire protection measures at Buffelsdraai. Similarly, seedling survival rate was omitted because this aspect requires field evaluation. To align the selection of tree species with project goals, I included surrogate measures for resilience to climate change and the ability to store carbon.

Forty-eight tree species were selected for assessment. The trees were selected based on common tree species in the vegetation type and species found at the reference ecosystem site (Appendix 2). Categories selected were based on Elliott et al. (2003) and adapted to local conditions at Buffelsdraai. Ultimately, categories selected were, 1) attractiveness to wildlife, 2) growth rate, 3) resilience to climate change and 4) carbon storage potential.

4.3.3.1 Attractiveness to wildlife

Attractiveness to wildlife is an important characteristic of framework species as it enhances natural regeneration at the restoration site by attracting dispersal agents (Galindo-González et al. 2000, Barbosa and Pizo 2006). I used seed dispersal as a measure of attractiveness. Species dispersed by birds were considered more desirable because diaspores dispersed by birds (as opposed to solely by mammals), have a greater probability of arriving, and hence establishing, at ‘safe sites’ and therefore a higher chance of germination. Forest dwelling birds avoid the grassy matrix that characterises South African forest landscapes. Diaspores are dispersed directly to forest patches and thus avoid the severe constraints to establishment such as fire and grass competition within grassy areas. In my selection criteria, species dispersed 'abiotically' were deemed unacceptable, 'mammals only' were marginal, 'birds only' and 'both birds and mammals' were categorised as excellent. Species dispersed by mammals were considered because those dispersal agents (e.g. monkeys, various buck species) are found at Buffelsdraai and therefore are able to disperse those seeds. Species dispersed by abiotic means were included if they were well-known nectar producers and would therefore potentially attract seed dispersers.

4.3.3.2 Carbon storage potential

Carbon storage capacity was selected because carbon mitigation is an important project goal. Tree height was selected as a surrogate for carbon storage capacity. Tree height is directly correlated with traits related to carbon storage (Falster and Westoby 2003, Martinez-Cabrera et al. 2011). Tree species with an average height of below 5 m were considered unacceptable and mainly consisted of species categorised as shrubs, climbers and small trees. Species with a height of between 5 m and 10 m were mainly small trees and were categorised as marginal. Acceptable trees ranged between 10 m and 15 m. Trees categorised as excellent were tree species with heights over 15 m and are trees known to be medium to tall.

4.3.3.3 Growth rate

Fast growing individuals are key to creating a closed canopy, a necessary management requirement to suppress weed establishment and growth. Species with growth rates of 40 cm/year and below were considered by the field guides (Johnson and Johnson 1993, Venter and Venter 1996, Boon 2010) to be slow growing and were therefore considered unacceptable in this study. Growth rates of between 70 cm/year and 40 cm/year were referred to as moderate growth in the guides and were therefore categorised as marginal. Growth rates of between 70 cm/year and 100 cm/year were considered as fast and so were categorised at acceptable. Very fast growing species were categorised as excellent and comprised species that had growth rates of 100 cm/year and above.

4.3.3.4 Resilience to climate change

Elevation and geographic distribution were selected as surrogates for climate tolerance. Species distributed over a broad elevation range are likely to have wide environmental tolerances and thus greater buffering capacity to climate change (Le Roux and McGeoch 2008). Thus, species with distributions that extend into tropical Africa were considered excellent, species distributed throughout southern Africa were considered acceptable, whilst species endemic to South Africa were considered unacceptable.

Additionally, species with broad spatial distributions tend to be generalist species that can survive under a wide range of environmental conditions (Thuiller et al. 2005, Fridley et al. 2007). Species with elevations ranging from coastal areas to altitudes exceeding 1500 m a.s.l (mountainous areas in the Drakensberg) were considered excellent. Species categorised as acceptable were species extending from the coast to altitudes up to 1500 m a.s.l (the KZN midlands). Species distributed from the coast and to elevations not exceeding 400 m a.s.l were considered as marginal, whilst species restricted to the coast were considered unacceptable.

Local identification guides (Johnson and Johnson 1993, Venter and Venter 1996, Boon 2010) and online databases (Plant Resources of Tropical Africa, www.prota4u.info; PlantZAfrica, www.pza.sanbi.org) were used to supplement my own knowledge of diaspore dispersal, height, growth rates and distribution.

Once each species' height, seed dispersal mechanism, distribution and growth rate had been assigned a category (excellent, acceptable, marginal, unacceptable), an overall category was assigned to each species so that each species could be ranked. Species with one or more 'unacceptable' categories were rejected.

4.4 Results

4.4.1 Attractiveness to wildlife

Forty-one species were considered excellent attractors of wildlife (Table 4.1). These species' seeds are dispersed by birds or both birds and mammals. Two species' seeds are solely distributed by mammals and thus were assigned the acceptable category. Only four species were considered unacceptable and these are species distributed abiotically.

Although *Brachylaena discolor* is dispersed abiotically, the nectar in the flowers attracts birds and insects and was therefore not rejected.

4.4.2 Carbon storage potential

Seventeen species were considered to have heights that exceed 15 m, thus having a high capacity to store carbon (Table 4.1). Eight species were categorised as acceptable, growing to heights between 10 m and 15 m. Seventeen tree species were marginal and a further six species were disregarded because their reported heights are below 5 m. Such species would not make large a contribution to carbon potential.

4.4.3 Growth rate

Fifteen species were categorised as having excellent growth rates and nine species as acceptable. Fifteen species were considered marginal, whilst nine species were considered unacceptable and rejected from further testing (Table 4.1).

4.4.4 Resilience to climate change

Twenty-six species have distributions that extend into tropical Africa and were therefore considered good generalist species and thus categorised as having excellent regional distribution (Table 4.1). Nineteen species were considered acceptable as they are distributed throughout southern Africa whilst three species were considered unacceptable due to them being endemic to South Africa. Regarding altitudinal distributions, 21 species were categorised as excellent as they are distributed at various elevations, ranging from coastal areas to mountainous areas in the Drakensberg exceeding 1500 m a.s.l (Table 4.1). Nineteen species have ranges extending from the coast to the KZN midlands (not exceeding an altitude of 1500 m a.s.l), whilst five species are restricted to 400 m a.s.l. Three species are restricted to coastal altitudes and were therefore rejected.

According to my selection criteria, 30 tree species were identified as candidate framework species. Overall, 18 tree species were rejected due to slow growth rates, low attractiveness to wildlife or low stature Table 4.1).

Table 4.1 Summary of framework species classifications based on a desktop study (E, excellent; A, acceptable; M, marginal; U, unacceptable and R, rejected)

Species	Seed dispersal	Seed dispersal ranking	Growth Rate (cm/year)	Growth rate ranking	Region	Region ranking	Altitude	Altitude ranking	Height (m)	Height ranking	Overall
Celtis africana	birds	E	200	E	tropical Africa	E	coast- 2100 m a.s.l	E	30	E	E
Ekebergia capensis	both birds & mammals	E	100	E	tropical Africa	E	coast – 1500 m a.s.l	E	10 to 35	E	E
Ficus natalensis	both birds & mammals	E	130	E	tropical Africa	E	coast – 2200 m a.s.l	E	5 to 20	E	E
Bridelia micrantha	birds	E	200	E	tropical Africa	E	coast - Drakensberg	E	7 to 15	A	E
Croton sylvaticus	birds	E	150	E	tropical Africa	E	coast - Midlands	A	21	E	E
Ficus burkei	both birds & mammals	E	90	A	tropical Africa	E	coast - Drakensberg	E	10 to 18	E	E
Rauvolfia caffra	birds	E	150	E	tropical Africa	E	coast – 1400 m a.s.l	A	20	E	E
Afrocarpus falcatus	birds	E	50	M	tropical Africa	E	coast - Drakensberg	E	45	E	E
Albizia adianthifolia	mammals	A	200	E	tropical Africa	E	coast – 1050 m a.s.l	A	10 to 25	E	E
Antidesma venosum	both birds & mammals	E	90	A	tropical Africa	E	coast – 1220 m a.s.l	A	20 to 30	E	E
Rapanea melanophloeos	both birds & mammals	E	50	M	tropical Africa	E	coast - Drakensberg	E	6 to 18	E	E
Trema orientalis	birds	E	200	E	tropical Africa	E	coast - Drakensberg	E	4 to 6	M	E
Trichilia dregeana	both birds & mammals	E	100	E	tropical Africa	E	coast – 1200 m a.s.l	A	10 to 12	A	E
Chaetacme aristata	both birds & mammals	E	70	A	tropical Africa	E	coast – 1450 m a.s.l	A	13	A	A

Species	Seed dispersal	Seed dispersal ranking	Growth Rate (cm/year)	Growth rate ranking	Region	Region ranking	Altitude	Altitude ranking	Height (m)	Height ranking	Overall
Chrysophyllum viridifolium	both birds & mammals	E	70	A	tropical Africa	E	coast – 460 m a.s.l	M	10 to 20	E	A
Commiphora harveyi	both birds & mammals	E	100	E	southern Africa	A	coast - Midlands	A	5 to 15	A	A
Mimusops obovata	both birds & mammals	E	80	A	southern Africa	A	coast - Midlands	A	20	E	A
Searsia chirindensis	birds	E	100	E	southern Africa	A	coast - Drakensberg	E	4 to 10	M	A
Englerophytum natalense	both birds & mammals	E	50	M	tropical Africa	E	coast – 1525 m a.s.l	E	6 to 17	A	A
Syzygium cordatum	both birds & mammals	E	60	M	tropical Africa	E	coast - Midlands	A	8 to 15	A	A
Canthium inerme	birds	E	60	M	southern Africa	A	coast – 2000 m a.s.l	E	4 to 7	M	A
Cryptocarya woodii	birds	E	50	M	southern Africa	A	coast - Drakensberg	E	5 to 10	M	A
Euclea racemosa	birds	E	50	M	southern Africa	A	coast – 1500 m a.s.l	E	6	M	A
Phoenix reclinata	both birds & mammals	E	50	M	tropical Africa	E	coast - Midlands	A	3 to 6	M	A
Protorhus longifolia	both birds & mammals	E	80	A	southern Africa	A	coast - Midlands	A	6 to 10	M	A
Tricalysia lanceolata	birds	E	50	M	southern Africa	A	coast – 2000 m a.s.l	E	3 to 10	M	A
Xylotheca kraussiana	both birds & mammals	E	50	M	southern Africa	A	coast - Transvaal	E	3 to 8	M	A
Brachylaena discolor	abiotic - wind	U	100	E	southern Africa	A	coast - Midlands	A	4 to 10	M	A
Euclea natalensis	both birds & mammals	E	50	M	southern Africa	A	coast – 1200 m a.s.l	A	4 to 10	M	A
Sclerocroton integerrimus	both birds & mammals	E	50	M	southern Africa	A	coast – 460 m a.s.l	M	7.5 to 9	M	A
Podocarpus latifolius	birds	E	30	U	tropical Africa	E	coast - Drakensberg	E	20 to 30	E	R

Species	Seed dispersal	Seed dispersal ranking	Growth Rate (cm/year)	Growth rate ranking	Region	Region ranking	Altitude	Altitude ranking	Height (m)	Height ranking	Overall
Sideroxylon inerme	both birds & mammals	E	40	U	tropical Africa	E	coast - Midlands	A	10 to 18	E	R
Carissa bispinosa	birds	E	30	U	tropical Africa	E	coast - Drakensberg	E	5 to 10	M	R
Cussonia sp.	birds	E	80	A	southern Africa	A	coast - 1640 m a.s.l	E	5	U	R
Ziziphus mucronata	both birds & mammals	E	30	U	tropical Africa	E	coast – 2000 m a.s.l	E	9	M	R
Drypetes arguta	birds	E	30	U	tropical Africa	E	coast – 600 m a.s.l	M	10 to 15	A	R
Drypetes natalensis	mammals	A	30	U	tropical Africa	E	coast – 1500 m a.s.l	E	9	M	R
Strelitzia nicolai	birds	E	100	E	southern Africa	A	coast – 520 m a.s.l	M	4 to 6	U	R
Mimusops caffra	both birds & mammals	E	60	M	southern Africa	A	coast	U	15 to 25	E	R
Anastrabe integerrima	both birds & mammals	E	100	E	SA endemic	U	coast – 1220 m a.s.l	A	3 to 10	M	R
Eugenia capensis	birds	E	40	U	southern Africa	A	coast – 2150 m a.s.l	E	3 to 7	M	R
Olea woodiana	birds	E	40	U	tropical Africa	E	coast	U	17	E	R
Combretum kraussii	abiotic	U	80	A	tropical Africa	E	coast – 1201 m a.s.l	A	15	A	R
Eugenia natalitia	birds	E	40	U	southern Africa	A	coast - Midlands	A	3 to 5	U	R
Dalbergia obovata	abiotic - wind	U	100	E	southern Africa	A	coast - Midlands	A	0.5 to 15	U	R
Millettia grandis	abiotic	U	100	E	SA endemic	U	coast – 600 m a.s.l	M	10 to 20	E	R
Allophylus natalensis	birds	E	50	M	southern Africa	A	coast	U	2 to 5 m	U	R
Baphia racemosa	abiotic	U	50	M	SA endemic	U	coast – 900 m a.s.l	A	3 to 5	U	R

4.5. Discussion

This study assessed 48 candidate framework species for potential use in the reforestation planting at the BLCRP. Examination of a different planting scheme was necessary because it was shown in the previous study (Chapter 3) that the current planting scheme used for BLCRP is not on a trajectory to meet its targets as it is dissimilar to a natural forest reference site. Corrective action was deemed necessary to realign it with project goals. The framework species method was used for this study as it creates a framework for species selection through the evaluation of various criteria.

According to the framework species method and the adjusted criteria used in this study, desirable species for selection are species that are fast growing, attract wildlife, have the potential to store large amounts of carbon and are generalists so they can be resilient to climate changes. Of the 48 tree species screened, I identified 30 candidate framework species. Of the 30 possible candidate species, 13 were ranked as excellent and 17 as acceptable. Best performing species were *Celtis africana, Ekebergia capensis, Ficus natalensis, Bridelia micrantha* and *Croton sylvaticus* as a result of their tall heights, fast growth rates, their ability to attract wildlife (all seeds dispersed by birds and/or birds and mammals) and their wide altitudinal and regional distributions. Eighteen species were rejected from further testing. The worst performing species were *Eugenia natalitia*, *Dalbergia obovata, Millettia grandis, Allophylus natalensis* and *Baphia racemosa*. The rejection was due to a combination of factors such as slow growth rates, lack of ability to attract wildlife, low carbon storage potential and low resilience to climate change.

Few of the species that have currently been planted at Buffelsdraai (Appendix 1) qualify as framework species under the selection criteria used here. Current planted species at Buffelsdraai are dominated by low in stature, abiotic- or mammalian-dispersed species such as various acacia species, *Erythrina lysistemon*, and short scrambling shrubs such as *Dalbergia obovata* and *Tecomaria capensis* (Chapter 3). These types of species do not grow tall and do not create a dense canopy, a necessary requirement to shade out weed growth in the years immediately after planting. The majority do not attract dispersal agents to assist in natural regeneration.

4.5.1 Attractiveness to wildlife

Studies have suggested that enhancing the attractiveness of restoration plantings to birds may increase the dispersal of propagules into a site (McClanahan and Wolfe 1993, Robinson and Handel 1993) and hence highlights its significance to restoration. Importantly, most species were dispersed by either birds or both birds and mammals, which is characteristic of South African forest tree species. Species dispersed by mammals were considered because those dispersal agents (e.g. monkeys, various buck species) are found at Buffelsdraai and therefore are able to disperse those seeds.

The four species rejected were species with abiotic dispersal mechanisms. Combretum kraussii (wind dispersal), Dalbergia obovata (wind dispersal), Millettia grandis (explosive dispersal) and *Baphia racemosa* (wind dispersal). These species do not produce fleshy fruit (Boon 2010) that would attract dispersal vectors to the site. *Brachylaena discolor* was originally rejected due to it having abiotic dispersal mechanisms, however this species is known to attract wildlife through its prolific nectar production (SANBI 2003) and was therefore not rejected. Tree species not dispersed by birds attract dispersal agents by offering nest sites, nectar or through the presence of invertebrates (Reay and Norton 1999).

4.5.2 Carbon storage potential

Carbon storage potential is important to meet carbon sequestration goals at Buffelsdraai. Tall trees store more carbon than shorter trees and were therefore categorised as more important. Unsurprisingly, tall trees that exceed 15 m in height included species such as *Celtis africana, Ekebergia capensis, Afrocarpus falcatus, Croton sylvaticus and Albizia adianthifolia,* all known for their considerable height. Species such as *Dalbergia obovata, Baphia racemosa* and *Eugenia natalitia* were rejected because they failed the minimum size threshold and will therefore have less potential to store large amounts of carbon. Although tree height is important in carbon sequestration, high density planting is also crucial for rapid accumulation of carbon (Kanowski and Catterall 2010) and should be considered when planning the planting schedule at Buffelsdraai.

4.5.3 Growth rate

Nine species had slow growth rates (< 40 cm/year) These species included *Eugenia natalitia, Ziziphus mucronata,* and *Afrocarpus latifolius* (SANBI 2003) which are all known for their slow growth. Fast growing species (>100 cm/year) which would be necessary to create a canopy quickly (Stanturf et al. 2001) included *Celtis africana, Bridelia micrantha, Albizia adianthifolia* and *Trema orientalis*. Therefore, these species would be beneficial species to plant at Buffelsdraai. Studies have shown that canopy closure aids in maintaining a moist microclimate, it suppresses weeds and grasses, and assists in recruitment of late-successional species (Parrotta 1993, Kanowski et al. 2003). It is therefore vital for restoration planting at Buffelsdraai to have species that are fast growing to create canopy closure.

4.5.4 Resilience to climate change

Rapid, on-going global environmental change along with the increased invasion of ecosystems by non-native species has caused a shift in restoration objectives (Hobbs et al. 2011). Restoration planning has changed from a focus on historical fidelity to one where ecosystem function is emphasised to secure ecosystem services in future environments (Society for Ecological Restoration International Science and Policy Working Group 2004, Choi 2007). Recent efforts to address these challenges include focussing restoration on future goals, such as ecosystems that are functional under different climatic change scenarios, rather than historical ideals of what the site was in the past (Choi 2007). Species selection is thus based on species that are able to survive under a wide range of climatic conditions. The South African endemic species *Anastrabe integerrima, Millettia grandis* and *Baphia racemosa* were rejected along with *Olea woodiana*, *Mimusops caffra* and *Allophylus natalensis* due to their narrow coastal ranges (Table 4.1). Pywell et al. (2003) showed that generalist species performed better over time in restoration projects than habitat specialists. Additionally, habitat generalists were seen to respond quicker to climate change than habitat specialists, and also with greater upslope expansion as seen on Marion Island (Le Roux and McGeoch 2008, Walther 2010). Planting species at Buffelsdraai that will be more resilient to climate change will aid in the long-term sustainability of the project. However, some endemic species should be considered for inclusion as a secondary, conservation objective. Restored forest could provide important habitat for endemic and red data species.

4.5.5 Recommendations

The framework species method has provided a list of suitable candidate species for planting at Buffelsdraai. Specific recommendations are as follows:

- The candidate species selected here require nursery and field-testing to evaluate germination and growth rates. Failure to survive under field conditions would be the most important reason to reject a tree species from a planting scheme (Elliott et al. 2003).
- Planting *Afrocarpus* species would increase carbon storage potential substantially; however, these would need to be planted once a canopy is established, as they are slower growing when exposed to sun. *Afrocarpus falcatus* would be favoured over *Afrocarpus latifolius* due to its faster growth rate (SANBI 2003).
- Introducing species, such as *Ficus burkei, Englerophytum natalense,* and *Rapanea melanophloeos,* that would attract a wide range of birds, insects and provide food for monkeys.
- Species that were rejected for slow growth but performed well in other categories, such as *Sideroxylon inerme* and *Ziziphus mucronata,* require further examination. Including a few slow-growing species will diversify the planting mixture and create variation in understorey niches for wildlife (Elliott et al. (2003). Likewise, a few endemic species should be included for conservation purposes.

Planting framework species functions to attract dispersal agents, assist in natural regeneration and provide resilience to climate change. Following the framework species strategy does not preclude planting of other species. Enrichment planting at a later stage is recommended to increase species diversity or contribute further structure and function. Additional species selection criteria (Goosem and Tucker 2013) worth considering for inclusion at Buffelsdraai are:

- select species that form mutualistic relationships with animals;
- plant rare, threatened and locally endemic species to increase their populations; and
- plant poorly dispersed species to facilitate colonisation.

4.6 Conclusions

The framework species method has aided the first step of species selection at Buffelsdraai, and other coastal forest restoration projects in KZN. By creating the framework species method, the authors (Goosem and Tucker 1995) have provided a ‘framework’ on which other restoration ecologists, working with different forest types, can build their restoration projects. The study shows how flexible this method is and that it is possible to adjust it to suit specific project needs. Best performing species have been identified (Table 4.1) through their ability to attract wildlife, grow fast and tall and remain resilient to climate change. Worst performing species have been rejected from further testing. Having this selection process prior to actual nursery and field-testing decreases the cost and effort involved by reducing the number of species that would need to be grown and tested. Additionally, the framework species method is not contradictory to the current planting method at Buffelsdraai. I recommend that it be integrated within the Wildlands Conservation Trust’s ITFL concept, as a primary step, with candidate species listed as the species local community members collect. Should seeds of species not be available to them, I recommend that the management team provide these. The eventual planting of the selection of framework tree species suggested in this study can address many project issues (Chapter 3) namely increasing carbon sequestration potential, increasing bird-dispersed species to assist in natural regeneration, improving composition and increasing species richness and diversity.

4.7 Acknowledgements

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4.8 References

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CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Introduction

The scale and urgency of climate change means that cities need to develop strategies to mitigate and adapt to climate change within defined timeframes. Identifying current vulnerabilities to climate change will help cities to adapt and then reap future benefits. Meanwhile delaying action could result in higher costs in the future, combined with a limitation of future adaptation options or emission reductions. Mitigation projects are on the rise and are aiming to reduce CO_2 emissions, specifically regarding the planting of trees through reforestation, afforestation and forest restoration. However, planting of trees should be implemented through ecosystem restoration mechanisms, as opposed to exotic plantations or monocultures, thus achieving additional benefits such as ecosystem services enhancement and biodiversity conservation. The inclusion of local communities will further aid in adaptation and sustainability through poverty alleviation. The goal of the Buffelsdraai Landfill Community Reforestation Project (BLCRP), a community ecosystem-based adaptation project, is to achieve all of these outcomes through tree planting in the buffer zone of a landfill site. Measuring the performance of restoration practices at the BLCRP is important as a means to evaluate project goals and implement adaptive management where necessary.

5.2 Aims and objectives

The goal of this research was to evaluate the BLCRP. Consequently, the objectives of this study were to, 1) place the BLCRP in the current climate change adaptation literature and provide a rationale for its origin, 2) examine measures of diversity, structure and function at the active restoration sites at Buffelsdraai, 3) compare these findings with a reference ecosystem site to determine whether the project is on a trajectory to meet the project goals and 4) compile a set of candidate framework species that may be used for enrichment planting at the site.

5.3 Conclusions and recommendations

Cities are vulnerable to climate change due to their high concentrations of people, and low levels of ecosystem services. As discussed in Chapter 2, adaptation will be necessary to aid cities in coping with the impacts brought on by unavoidable climatic changes. Not all cities are affected equally by climate change, with African cities being highly vulnerable. They are typified as informal cities with fast population growth, shortages of human and financial capital, development shortfalls, increasing inequality, poor governance, high poverty levels, growing biodiversity loss and worsening environmental conditions. Paradoxically, their inhabitants are heavily reliant on the natural resources for their survival and livelihood. Given the challenges of underdevelopment and a shortage of resources, Africa must address the climate change challenge in a way that ensures meaningful developmental co-benefits and overall cost-effectiveness. Chapter 2 argues that local level adaptation, such as the BLCRP, is a powerful and efficient tool for African cities due to rapid results made possible by local people with knowledge of relevant local barriers and issues. Ecosystem-based adaptation (EBA) and community-based adaptation (CBA) are both effective forms of local level adaptation for African cities. The City of Durban (eThekwini Municipality, South Africa), has embarked on a novel approach that combines both of these tools, the community ecosystem-based adaptation (CEBA) concept, of which the Buffelsdraai Landfill Community Reforestation Project (BLCRP) is a powerful example. CEBA combines ecosystem management and restoration with community development to ensure enhanced ecosystem service provision. Importantly, in the face of a changing climate, ecosystem restoration should also focus on building ecosystem resilience to future change.

To ensure the implemented restoration projects are on a trajectory to meet the stated goals, early detection of trajectories is important to identify shortfalls and implement corrective management. Chapter 3 measured and compared the species composition, diversity, richness and functional diversity with a local reference forest. This dissertation showed that species diversity and species richness were lower than that of the reference site. The composition of trees planted at Buffelsdraai differed substantially from the reference site. Additionally, functional richness was higher at the reference site compared with two of the Buffelsdraai sites. Consequently, the restoration sites were not similar to the reference forest. However, the composition of planted trees is likely to be resilient to climatic changes due to the prevalence of generalist species. Given these findings, the BLCRP is unlikely to meet long-term goals. I recommend that the planting density be increased to ~2500 trees per hectare and that the number of bird-dispersed species be increased. I further recommend that tree species more similar to that occurring in local forests be planted to enhance carbon sequestration and increase species diversity.

To address the project shortfalls identified in chapter 3, I propose a rigorous process to select tree species for planting. The framework species method, discussed in chapter 4, is recommended for aiding in species selection for the BLCRP and other coastal forest restoration projects in the greater Durban area. Through the use of this method, the chapter recommends 30 candidate framework species, which will later be nursery- and field-tested to ascertain germination and growth rates under those conditions. These candidate species have fast growth rates, attract wildlife, have the potential to store large amounts of carbon and remain resilient to climate change. These are desirable attributes to create a canopy that facilitates natural regeneration, modifies the microclimate, and reduces weed establishment. Additionally, a rigorous species selection process prior to actual nursery and field testing will help reduce the cost and effort involved in the project by decreasing the number of species that would need to be grown and tested and reducing plant losses in the project lifetime. The study demonstrates the flexibility of this method as it can be adjusted to suit specific project needs, such as the need to increase carbon in the BLCRP. In chapter 4, I highlight that the framework species method is not contradictory to the current planting method at Buffelsdraai. I thus recommend that the framework species method be used for species selection at Buffelsdraai, and as a primary step in the restoration process whereby selected framework species are required for collection by local tree growers. Should these species not be found by the tree growers, I recommend that these seeds be provided to them. This specific selection of tree species will address many project issues discussed in Chapter 3, through increasing species with high carbon sequestration potential, increasing bird-dispersed species to assist in natural regeneration and increasing species richness, diversity and improving species composition. My recommendations will aid in better species composition and help accelerate the restoration process thus aiding the BLCRP in meeting its goals.

5.4 Future research

There are various topics that could be explored involving the BLCRP, spanning the ecological, social and scientific fields. Due to this broad range of fields, I will only discuss studies directly related to the outcome of this dissertation. Further research could include:

- continual monitoring studies to determine if the BLCRP is on a trajectory to meet its project goals. This will include investigating if the planting density, species diversity and bird-dispersed species are increasing, if the structure is improving and determining whether alien invasion is decreasing with increasing planting density;
- nursery and field testing to evaluate germination and growth rates of candidate framework species. The successful framework species would then be recommended for use in the BLCRP and other coastal forest restoration projects;
- testing the effects of various planting densities on speed of growth and height of trees;
- calculating carbon stores at Buffelsdraai;
- determining if natural regeneration is occurring on site; and
- additional research on the exact ecosystem services being provided by Buffelsdraai.

5.5 Final comments and summary conclusions

The BLCRP requires a few interventions to get it back on a trajectory to meet its goals, as it is currently dissimilar to a local reference site. Recommendations include increasing bird dispersed species, planting density, species diversity and functional richness through the implementation of the framework species method. The BLCRP is a powerful form of adaptation that is empowering locals to cope with climate changes, improving ecosystems, bolstering biodiversity and increasing ecosystem services through local level action that is deemed important in a vulnerable African city. The dissertation highlights that African cities have a role to play in developing and testing novel approaches to managing climate change, through adoption of meaningful mitigation and adaptation strategies and Durban can be considered a leader in this regard.

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Appendix 1: Planted species identified at the Buffelsdraai Landfill Community Reforestation Project

Species
Acacia caffra
Acacia karroo
Acacia natalitia
Acacia nilotica
Acacia robusta
Acacia sieberiana
Agapanthus praecox subsp. orientalis
Albizia adianthifolia var. adianthifolia
Baphia racemosa
Bauhinia tormentosa
Brachylaena discolor
Bridelia micrantha
Chrysanthemoides monilifera
Clerodendrum glabrum
Combretum edwardsii
Croton sylvaticus
Dalbergia armata
Dalbergia obovata
Dichrostachys cinerea
Dombeya rotundifolia
Erythrina lysistemon
Euphorbia tirucalli
Ficus burtt-davyi
Ficus glumosa
Ficus sur
Grewia occidentalis
Harpephyllum caffrum
Heteropyxis natalensis
Kigelia africana
Maytenus peduncularis
Millettia grandis
Protorhus longifolia
Schotia brachypetala
Sclerocarya birrea
Sclerocroton integerrimum
Scolopia zeyheri
Searsia chirindensis
Searsia pentheri
Strelitzia nicolai

Succulent schefflera
Syzygium cordatum
Tabernaemontana ventricosa
Tecomaria capensis subsp. capensis
Trichilia dregeana
Vangueria infausta subsp. infausta
Ziziphus mucronata

Appendix 2: Tree species identified at the Kenneth Stainbank Nature Reserve

Species
Albizia adianthifolia var. adianthifolia
Anastrabe integerrima
Antidesma venosum
Baphia racemosa
Brachylaena discolor
Bridelia micrantha
Canthium inerme
Carissa bispinosa
Celtis africana
Chaetachme aristata
Commiphora harveyi
Croton sylvaticus
Cryptocarya woodii
Dalbergia obovata
Drypetes arguta
Englerophytum natalense
Ficus burkei
Ficus natalensis
Trema orientalis
Millettia grandis
Rauvolfia caffra
Mimusops obovata
Olea woodiana
Eugenia natalitia
Cussonia natalensis
Phoenix reclinata
Podocarpus falcatus
Podocarpus latifolius
Protorhus longifolia
Rapanea melanophloeos
Sclerocroton integerrimum
Searsia chirindensis
Sideroxylon inerme
Strelitzia nicolai
Syzygium cordatum
Tricalysia lanceolata
Xylotheca kraussiana