UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

Enhancing resilience between people and nature in urban landscapes

by

Alexis Schäffler
Student number: 14944758

Thesis presented in partial fulfilment of the requirements for the degree Master of Philosophy (Sustainable Development Management and Planning) at the University of Stellenbosch
90 Credits

Supervisor: Professor Mark Swilling

School of Public Leadership

1 February 2011

Declaration

By submitting this thesis, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

February 2011.

Abstract

The particular global context that is fundamentally altering the world is one in which the combined resource requirements of cities are unprecedented. This thesis communicates the thoughts, ideas and research observations on contemporary urbanisation dynamics through a synthesis of various perspectives. This conceptual fusion, as an attempt to provide a holistic overview of contemporary urban dynamics, forms the basis for developing a framework from which the multiple dimensions of cities can be addressed. This theoretical framework, which includes empirical analyses on the state of cities, is then applied to Johannesburg as a case study for deepening the understanding of urban dynamics and to assess implementation of the theoretical framework in reality.

Despite being guided by the general aims of investigating current urban growth trends and the conceptual frameworks with which urban systems could be better understood, the complexity of the task at hand defied a static and linear research process. The ideas that emerged through the research journey, as opposed to a process, were synthesised using a literature review from which the framework of managing complex social-ecological systems was developed. Central to this framework is the metaphor of resilience, which through the idea of systemic adaptability, prioritises the need for both social and ecological opportunity to be enhanced. This is critical in the face of cross-cutting global challenges and in terms of cities as archetypical complex social-ecological systems.

In reviewing literature on contemporary urbanisation dynamics, it was found that the socio-economic, spatial and ecological tensions characterising developing country cities, require strategies to enhance urban resilience rooted in local social and ecological capabilities that differ from developed nations' contexts. These practical concerns were the catalyst for suggesting green infrastructure as a framework in which the joint social and ecological values of green assets are valued equally. This in line with the logic of enhancing a system's overall systemic adaptability. The theoretical frameworks included in the literature review, therefore, emerged through the weaving back and forth of thoughts, debates and practical concerns about creating resilience between people and nature in the urban landscapes of developing countries

The methodological implications of a green infrastructure framework resulted in the need to determine the total economic value of ecosystem services, as the benefits that society accrues through ecosystem functioning. Valuing both the social and ecological benefits of such ecosystem derivatives, not only relates to the concept of mutual resilience building, but makes the economic case for investment in natural assets. Through experience with this methodology, it emerged that

valuation exercises of ecosystem services require primary research that connects physical data on ecosystem functioning to tangible economic values. In the chosen case study, however, this original research is yet to take place and methodologies for valuing Johannesburg’s green assets had to unfold based on data availability. The development of a methodology within a methodology is a major feature of this paper, which is guided by the logic that for overall systemic resilience to be sustained, investment in natural assets needs to explicitly account for the total economic values of ecosystem services.

The conclusions suggest that Johannesburg is nevertheless in a unique position to capitalise on the concept of green infrastructure, from which social and ecological opportunity can be mutually enhanced. In a paradoxical way, the city’s tree-planting boom that resulted in the construction of the world’s largest urban forest in natural savannah grassland, has created inventories of ecological and social resilience that represent the multifunctional value of green assets, if valued explicitly. Recognition of these values shows that ecological assets extend beyond publicly delineated open space and that Johannesburg’s culture of greening is potentially playing a significant role in sustaining the resilience between its people and nature.

However, until the detailed base research is conducted on the connections between Johannesburg’s green assets and their associated social and ecological dividends, these assets remain potential inventories of resilience whose values are yet to be fully determined. The recommendations of this thesis are therefore largely to strengthen the research and data bases on Johannesburg’s green assets. Original research is needed so that precise valuation exercises of Johannesburg’s ecosystem services can take place. This research is also the foundation from which a more robust and empirically sound case can be made for motivating investment in Johannesburg’s strategically unique green infrastructure, in the context of social-ecological challenges and the global movement towards green economies, jobs and cities.

Opsomming

Die spesifieke globale konteks wat die wêreld ten diepste verander, is ’n konteks waarin die gekombineerde behoeftes van stede ongekend is. Deur ’n samevatting van verskeie perspektiewe bied hierdie tesis gedagtes, idees en navorsingswaarnemings oor die hedendaagse stadsdinamika. Hierdie samevoeging van konsepte, as ’n poging om ’n holistiese oorsig van hedendaagse stadsdinamika te bied, vorm die grondslag vir die ontwikkeling van ’n raamwerk van waaruit die veelvuldige dimensies van stede benader kan word. Hierdie teoretiese raamwerk, wat empiriese analises van die stand van stede insluit, word dan toegepas op Johannesburg as ’n gevallestudie om die stadsdinamika beter te verstaan en die gebruik van die teoretiese raamwerk in die praktyk te evalueer.

Die gedagtes wat uit die navorsing voortgespruit het, word saamgevat deur ’n oorsig te gee van literatuur waaruit die raamwerk vir die bestuur van komplekse sosio-ekologiese sisteme ontwikkel is. Die kern van hierdie raamwerk is die metafoor van weerstandsvermoë (“resilience”) wat, deur die gebruik van die konsep sistemiese aanpasbaarheid, die behoefte aan sowel meer sosiale as ekologiese geleenthede as die belangrikste prioriteite identifiseer. Dit is deurslaggewend in die lig van deursnee- globale uitdagings en in terme van stede as argetipiese komplekse sosio-ekologiese sisteme.

In die oorsig van literatuur oor die hedendaagse stadsdinamika is daar gevind dat die sosio-ekonomiese, ruimtelike en ekologiese spanning wat stede in ontwikkelende lande kenmerk, strategieë vereis wat stadsweerstand, wat uit plaaslike sosiale en ekologiese vermoëns spruit, sal verhoog. Hierdie praktiese kwessies was die katalisator om ’n groen infrastruktuur voor te stel as die raamwerk waarbinne die gesamentlike sosiale en ekologiese waardes van groen bates ewe veel waarde dra, wat in pas is met die logiese gedagte om ’n sisteem se algehele sistemiese aanpasbaarheid te verhoog. Die teoretiese raamwerk wat ingesluit is in die literatuur wat bestudeer is, het dus na vore gekom deur die uitruil van gedagtes, debatte en praktiese benaderings tot hoe weerstandigheid geskep kan word tussen mens en natuur in die stedelike landskappe van ontwikkelende lande.

Die metodologiese implikasies van ’n groen infrastruktuur-raamwerk het dit noodsaaklik gemaak om die totale ekonomiese waarde van ekosisteemdienste, as die voordele wat die samelewing deur ekosisteme ontvang, te bepaal. Die belangrikste navorsing om letterlike inligting oor Johannesburg se ekosisteemdienste aan tasbare ekonomiese waardes te verbind, moet egter nog gedoen word, en metodologieë om die stad se groen bates te evalueer moet ontwikkel word afhangende van die

beskikbaarheid van inligting. Die ontwikkeling van ’n metodologie binne ’n metodologie is ’n belangrike kenmerk van hierdie tesis, wat gelei word deur die logiese gedagte dat belegging in natuurlike bates baie duidelik die totale ekonomiese waarde van ekosisteemdienste moet bepaal as algehele sistemiese weerstandsvermoë gehandhaaf wil word.

Die gevolgtrekkings dui daarop dat Johannesburg nietemin in ’n unieke posisie is om finansiële voordeel uit die konsep van ’n groen infrastruktuur te trek. Op ’n teenstrydige manier het die stad se grootskaalse poging om bome aan te plant, wat gelei het tot die wêreld se grootste stedelike woud in ’n natuurlike grasvlakte, inligting gebied oor ekologiese en sosiale weerstandigheid, en dit verteenwoordig die multifunksionele waarde van groen bates as daar uitdruklik waarde daaraan geheg word. ’n Erkenning van hierdie waarde wys dat ekologiese bates verder strek as ’n openbare afgebakende oop ruimte en dat Johannesburg se groen kultuur moontlik ’n deurslaggewende rol speel om die weerstandsvermoë tussen sy mense en die natuur volhoubaar te maak.

Voordat noukeurige grondnavorsing oor die verband tussen Johannesburg se groen bates en hulle gepaardgaande sosiale en ekologiese voordele egter nie uitgevoer is nie, bly hierdie bates potensiële beskrywings van weerstandsvermoë waarvan die waarde nog nie ten volle bepaal is nie. Die aanbevelings van hierdie tesis is daarom hoofsaaklik dat navorsing voortgesit word, en dat die kennisgrondslag van Johannesburg se groen bates verbreed word sodat ’n presiese evaluering van ekosisteemdienste gedoen kan word as die grondslag van sterker en empiries gestaafde redes om in die stad se groen infrastruktuur te belê.

Acknowledgements

I would like to thank my supervisor, Professor Mark Swilling, for guiding me to see the connections in this research journey. Without your insight and opinions, none of this work would have been possible. Most of all, thank you for your patience.

I would like to thank everyone at the Sustainability Institute, who were part of a turning point in my life and Eve Anneke for one day saying to me “Don’t waste your energy”. I am incredibly privileged and grateful to experience the wisdom of the Sustainability Institute, in all its forms.

To everyone at the Gauteng City Region Observatory who helped me better understand Johannesburg’s complex dynamics. Thank you for your time and investing in the ideas of this thesis.

To my friends, who although I scarcely saw them during this year, were as close to me as ever. Thank you for waiting for this journey of mine to end. Your support when I felt uncertain helped me take the steps forward even when I couldn’t see the road ahead. You are an inspirational group of men and women.

To Matthew, thank you for listening to me when all I spoke about was this thesis. Thank you for keeping me calm and centred, and for being there when all I needed was a hug. You never failed to be patient and understanding, always encouraging me to carry on.

And to Anthony, Christine and Vincent. I am eternally grateful for all your different opinions about how to undertake this journey. Thank you for allowing me the opportunity to pursue my academic endeavours. Thank you for understanding my ups and downs. The laughter and tears I shared with you all were so important – I know I didn’t go through this on my own.

Table of Contents

List of Acronyms and Abbreviations

ADM	Acid Mine Drainage
AQMP	Air Quality Management Plan
CBD	Central Business District
CDE	Centre for Development and Enterprise
CER	Certified Emissions Reductions
CoJ	City of Johannesburg
CO_2	Carbon Dioxide
EGS	Ecosystem Goods and Services
EPWP	Expanded Public Works Programme
EUA	European Union Emissions
FSE	Federation for a Sustainable Environment
FTFA	Food and Trees for Africa
GCRO	Gauteng City Region Observatory
GDS	Growth and Development Strategy
GER	Green Economy Report
GPG	Gauteng Provincial Government
GDP	Gross Domestic Product
GJMC	Greater Johannesburg Metropolitan Council
GVA	Gross Value Added
HDI	Human Development Index
IDP	Integrated Development Plan
IERM	Institute of Environment and Recreation Management
IHDP	International Human Dimensions Programme on Global Environmental Change
ILO	International Labour Organisation
IPSA	Interior Plantscapers Association
IPPS	International Plant Propagators' Society

IUCN	International Union for Conservation of Nature and Natural Resources
JCP	Johannesburg City Parks
LIA	Landscape Irrigation Association of South Africa
LMA	Lawnmower Association of South Africa
JMOSS	Johannesburg Metropolitan Open Space System
JPLS	Johannesburg Poverty and livelihoods Study
MEA	Millennium Ecosystem Assessment
RTG	Rocking the Gardens
SACN	South African Cities Network
SA	South Africa
SAFGA	South African Flower Growers Association
SALI	South African Landscapers Institute
SANA	South African Nursery Association
SDF	Spatial Development Framework
SAGIC	South African Green Industries Council
SOER	State of the Environment Report
StatsSA	Statistics South Africa
TEV	Total Economic Value
UGF	Urban Green File
UNEP	United Nations Environment Programme
UN Habitat	United Nations Human Settlement Programme

List of Figures

List of Tables

Chapter One: Introduction

1.1 Background

Studies of contemporary urban growth trends reveal the consensus that the world's future is an urban future. Evidence also shows that high rates of urbanisation are occurring in developing countries – rates that are mainly absorbed by smaller urban areas instead of megacities (Davis, 2004: 5: 7). These cities therefore embody a paradox of offering potential social progress on the one hand, but are possibly less equipped to deliver such progress on the other (Davis, 2004: 7). Cities concentrate poverty and environmental degradation due to an increased demand for natural resources resulting from accelerated urban population growth (Martine *et al,* 2008: 1). Growing urban appetites for food, fuel and infrastructure, place enormous pressure on the regenerative ability of urban ecosystems, with ripple effects on ecosystems far beyond the urban centre. Running parallel to this ecological crisis is an economic crisis, reflected in the number of unemployed people in developing countries, which is expected to rise in 2010 by between 18 and 51 million people over 2007 levels (ILO in Swilling & Fischer-Kowalski, 2010: 10).

Conversely, cities offer potential advantages of social and economic advancement due to economies of scale and the political will and mobilisation encompassed by high concentrations of people (Satterthwaite, 2006: 6). Cities have the opportunity to be potential sites of mobilisation and innovation and provide the organisational setting for future socio-economic, technical and ecological change (Satterthwaite, 2006: 6). As Hodson & Marvin (2010: 299) state, cities are often simultaneously represented as being significant contributors to climate change, victims of climate change; and as key sites of innovative response. It is amidst these insights that various response strategies to climate change and resource constraints have been developed (Hodson *et al,* 2010: 300). Additionally, the interconnected nature of contemporary global problems has resulted in the consensus that strategic options for addressing resource pressures, must be met with a search for more equitable and just strategies that address the needs of all communities (Hodson *et al,* 2010: 299-300). This reflects the consensus that:

> " ...global warming, climate change, ecosystem breakdown, and resource depletion, as part of the ecological crisis facing the international community, are occurring in conjunction with a global economic crisis, poverty and rapid urbanisation without investment in sustainable infrastructure" (Swilling *et al,* 2010: 10).

In response to the ecological challenges faced and posed by cities, a growing body of work reveals that urban green spaces can offset many of the ecological burdens experienced in and beyond urban areas. Examples from around the world show that urban green spaces provide a range of ecosystem services, as the benefits people obtain from ecosystems, and can therefore serve as response options to urban ecological challenges (MEA, 2005: 1-3). For instance, urban forests contain relatively high levels of biodiversity, contribute to air purification and mitigate storm water flow, whereas city parks and gardens have recreational, psychological and health benefits (Alvey, 2006: 196; Ward *et al,* 2010: 49). The intersection between research on urban green spaces and studies of ecosystem services, is leading many researchers to promote the inclusion of green spaces, as inventories of ecosystem services, in urban planning (Cilliers *et al*, 2004: 5;, James *et al,* 2009: 66).

Urban green spaces can therefore be potential sources of addressing the increasing loss of local ecosystem services in cities. However, evidence shows that many green areas in cities have become isolated or disconnected from the wider environment, resulting in either net losses in biodiversity or only benefitting minority communities (Borgström *et al*, 2006). As Barthel *et al* (2005) state, protecting green spaces in isolation will fail to sustain the capacity of the urban ecosystem to generate services. Furthermore, an overview of urban research reveals that the contribution of urban green spaces to the entire urban system, including socio-economic benefits, is not always prioritised or understood. In the context of interconnected urban challenges, the full ecological, social and economic contribution of urban green spaces in a systemic context, therefore, needs to be assessed. This is also important if an integrated city is to be formed where collaboration is prioritised between city aspects that have not previously had much to do with each other (Scott, 2010: 1).

Where the potential for urban green space to contribute to ecosystem service provision remains untapped, or where urban green spaces are not integrated into mainstream planning, a more robust case is needed to include these spaces in planning agendas. This thesis investigates "green infrastructure" as a possible way to revitalise the case for including green spaces in urban planning. Green infrastructure has been introduced as a way to upgrade cities' ecological assets, such as urban green space, as coherent planning entities (Sandström in Tzoulas *et al,* 2007: 169). The proposal is to accord green infrastructure the same status as traditional structures, such as buildings and highways or "grey" infrastructure, drainage and sanitation systems or "blue" infrastructure" and schools, prisons or "red" infrastructure (Sandström, 2002: 380; Walmsley, 2006: 257; Yeang, 2008: 128). Focusing only on traditional infrastructure services does not recognise a city's natural or ecological values and functions, and integrate them with other important economic and cultural objectives (Eugster, 2003: 8-9). The implication of prioritising green infrastructure is that the ecosystem services, provided by urban green spaces, can be treated on an equal basis with other urban services such as transport networks or electricity provision and funded, managed and implemented as such (Ernstson, 2008: 37).

The argument for green infrastructure as a response option to urban challenges, also raises a critique against emerging strategies attempting to address the twin issues of ecological and economic security. A majority of these strategies are underpinned by the view that urban infrastructure is crucial when coming to terms with the challenge of building more 'sustainable cities' (Swilling & Annecke, forthcoming). However, these strategies view urban infrastructure as the "critical" networks of energy, water, waste, and transport systems, which users of cities depend on for bringing in resources, bodies, information and energy into the city (Hodson & Marvin, 2010: 3; Swilling *et al,* forthcoming). In responding to the unsustainable use of infrastructure systems, emerging solutions developed by cities predominately focus on reworking traditional urban infrastructures by as evident in examples of new mobility systems, energy efficiency, water and sanitation systems, renewable energy production and waste management (Hodson *et al,* 2010: 3). Despite the potential of restructuring "critical" infrastructure systems to offset growing urban appetites, focusing only on "grey" and "blue" networks, overlooks the opportunities provided by a city's ecological assets such as urban green spaces, community gardens and urban forests.

Green infrastructure is underpinned by a systemic logic in that it links ecological capacity and social opportunities of an area and prioritises connectivity in the way it is implemented and managed (Yeang, 2008: 128; Mell, 2008: 71). Green infrastructure can therefore represent a multi-scale response to unsustainable urban growth, which speaks the language of environmentalists and development planners alike. The need for cross-scale adaptation strategies is based on seeing cities as "complex, multi-scalar social-ecological systems" (Walker, Holling, Carpenter & Kinzig, 2004). This insight is rooted in resilience thinking, which relates to the ability of a desired complex adaptive system to absorb disturbance and reorganise itself, i.e. the capacity of a system to self-organise (Folke *et al,* 2004: 558). Resilience thinking argues that the adaptability of social and ecological processes needs to be enhanced in tandem, requiring social-ecological systems, such as cities, to monitor, evaluate and respond to change at multiple scales (Barthel, 2008: 13; Ernstson, 2008: 143). The resilience metaphor has also been adopted by strategists arguing for the restructuring of traditional infrastructure systems, as part of creating more resilient infrastructure and more self-reliant urbanism (Hodson *et al,* 2010: 3-5). Although these infrastructure reconfigurations are necessary in the transition to more resilient cities, incorporating green infrastructure in these reconfigurations is a more systemic approach to creating more resilient urban infrastructure.

The City of Johannesburg, South Africa, is the specific urban system in which ecosystem service provision will be analysed in this study. With an average population growth of 4.1% per year, accommodating Johannesburg's growing population is increasingly a challenge where some 33% of the city's residents are housed in less than adequate accommodation (CoJ, 2003: 14; StatsSA, 2007: 7). Rapid urbanisation, catering for rising basic needs such as job creation, shelter, food and water provision, and waste assimilation, coupled with unsustainable resource use is placing enormous pressure on the generation of ecosystem services in Johannesburg (CoJ, 2003: 37). Consequently, there are threats to air and water quality, waste levels and a functioning sanitation system – burdens which are often borne disproportionately by the more vulnerable residents of Johannesburg (CoJ, 2003).

While the city of Johannesburg is facing cross-cutting social-ecological constraints, such as water and air pollution and poverty, it is also endowed with a major physical asset, namely the world's largest urban forest, which stands at over ten million trees (CoJ IDP 2010/11: 16). This urban forest is a unique ecological asset, complemented by large garden services and nursery sectors. This thesis chooses the ecological and green assets of the city as examples of how green infrastructure can potentially enhance the desired resilience of an urban social-ecological system. Planning for a green supply chain, based on the formalisation of an ecosystem goods and services sector, is a potential source of green job opportunities and green economy for Johannesburg whilst also facilitating the provision of ecosystem services. This supply chain includes the commercial practices involved in the maintenance, service and trade needs of Johannesburg's trees, parks and green assets, thereby formalizing the business case for investment in Johannesburg's green infrastructure service providers. The contribution of green infrastructure to Johannesburg's desired resilience is therefore assessed in a systemic context focusing on the sustainability of the entire urban system.

1.2 Motivation for the approach adopted in this thesis

Amidst unprecedented urbanisation in developing countries, the role of cities in determining the capacity of ecosystems to sustain societal development is increasingly being recognised (Folke, Colding & Berkes, forthcoming). This recognition, which is rooted in a social-ecological systems approach to understanding cities, depicts cities as closely coupled human-nature systems, whose institutional adaptability to environmental feedbacks is a critical determinant for enhancing ecosystem resilience and the sustained provision of ecosystem services (du Plessis, 2008). The role of ecosystem services in enhancing the robustness and adaptability of cities, in the face of change or disturbance, also highlights the importance of incorporating social-ecological resilience as a key dimension of urban sustainability transitions. Applying social-ecological systems analysis, and in particular, the metaphor of social-ecological resilience, to understanding cities is therefore a necessary conceptual shift to forge links between the natural and social sciences, and to prioritise the dependence of social wellbeing on the sustainable provision of ecosystem services (Scoones, 1999: 479).

Equally important to understanding cities as social-ecological systems, is exploring insights on how to practically implement urban sustainability transitions and realise the enhancement of social-ecological resilience in developing country cities. Sustainability transitions literature focuses on reducing the socio-economic material and energy flows in cities through redesigning their related infrastructures, which is crucial for reducing urban metabolisms and improving resource efficiency (Weisz & Steinberger, 2010: 1; Brunner, 2007: 11). Despite the work on material flow analysis, however, ecosystem services as infrastructure services themselves, and their role in wider development processes, remains largely overlooked in transitions literature which focuses on socio-technical adjustments. To address this concern, it is necessary to revitalise ecosystem services as coherent planning entities, that are a formally included infrastructure category in sustainability transitions (Sandström in Tzoulas *et al,* 2007).

A green infrastructure framework is explored as a possible link between the attempt to enhance social-ecological resilience on the one hand, and the emerging work on implementing sustainability transitions on the other. Jansson & Polasky (2010) explain the need to make this connection: "Despite the obvious connections between ecosystem services and well-being, it has proven difficult to translate the importance of maintaining the flow of ecosystem services into tangible and credible estimates of the value of these services". The implication is a more robust argument for ecosystem services, as infrastructure services in themselves, and the need to explore possible ways of accurately valuing the benefits flowing from ecological assets. This is based on the emphasis within the social-ecological system discourse on society's capacity to respond to environmental change through new types of policy responses, which requires a level of ecological knowledge and recognition of the value of ecosystem services, to enhance and invest in such services (Folke, Colding & Berkes, forthcoming).

1.3 Refining the research questions

Stake (1995: 20) explains that "the researcher's greatest contribution perhaps is in working with the research questions until they are just right". At the outset of my research process, I had various topics that I saw necessary to explore and whose interaction warranted further detailed enquiry and refinement. My initial inspiration was an interest in urban sustainability, an overarching theme that developed from my previous academic work on sustainable development. Central to contemporary urban sustainability are developing country cities, as increasingly relevant contexts in the face of the second urbanisation wave. I felt the particular spatial, socio-economic and ecological changes induced by the second urbanisation wave are urgent research topics for investigating urban sustainability transitions.

With urban sustainability as my overarching theme, it also became clear to me that research, policy and everyday activity needs to engage with "the interface between human society and the natural environment" (Burns, Audouin, Weaver, 2006: 380). I was consequently inspired to advance my understanding of human-environment systems and contribute to the development of more integrated knowledge base to inform decision-making regarding contemporary challenges (Burns *et al,* 2006: 379). The understanding of cities as closely linked human-environment interactions, has been redefined by systems thinking as the need to develop a framework for understanding joint 'social-ecological systems' to replace the reductionist, one-dimensional view that "resources can be treated as discrete entities in isolation from the rest of the ecosystem and social system" (Berkes & Folke, forthcoming).

After establishing the importance of taking into account social-ecological interactions when thinking about future urban development, a number of topics emerged as central for investigation. On a theoretical level, I became aware of the discourse on resilience thinking, initially developed by C.S Holling (1973), which prioritises concepts such as adaptive management, cross-scale interactions and adaptive co-management[1]. Furthermore, upon further enquiry into literature on the second urbanisation wave, a critical finding was that the growing demands of cities to feed, fuel and sustain their growing populations are occurring because cities' local green spaces, and the services they provide, are being traded off for development pressures. During this process, I updated the focus of my literature review and identified an opportunity for linking the *conceptual work* on social-ecological systems and emerging literature on *implementing sustainability transitions* through the concept of *ecosystem services.* This theme particularly emphasises the relationship between how ecosystem services are managed by society and the extent to which such services are accurately valued as contributing to wider development and infrastructure transitions.

[1] To capture the phenomenon of cross-scale interactions, resilience theorists have developed the term panarchy that explains the multi-scalar nature of social-ecological system dynamics (Holling, Gunderson & Peterson in Holling *et al*, 2002: 74). Adaptive management is suggested as an appropriate management approach for dealing with these complex dynamics, through prioritising adaptation to changing conditions (Folke *et al,* 2005: 444). Adaptive co-management is put forward as a collaborative management approach to connect institutional adaptation at different scales (Olsson *et al,* 2007).

Through investigating the state of knowledge on the above interactions, obstacles were faced in terms of detailed literature on enhancing social-ecological resilience in developing country cities. An overwhelming majority of work on this theme focuses on European or Northern American contexts, which posed challenges for suggesting frameworks for supporting ecosystem service provision in developing countries. Re-assessing this challenge, however, spurred on an attempt to connect the idea of social-ecological resilience to the practical realities of developing country contexts. I was intrigued by the body of literature, Benedict & McMahon (2002: 12), Walmsley (2006; 252) & Sandström (2002: 373), that has at its core the idea of 'green infrastructure', which focuses on the multifunctional benefits of ecological assets and green space. Although this has been viewed as a resurgence of earlier work focusing on ecological design and strategic landscape planning, such as that of Ian McHarg and Brian Hacking, the conceptual reach and *de facto* implications of green infrastructure in practice have been identified as untapped research opportunities, particularly in developing countries (Kambites & Owen, 2006: 483).

I used these research gaps as opportunities for exploring an additional research theme, the possibility of investigating an *appropriate framework* for *accurately valuing of set of ecosystem services* in urban developing country contexts. My decision to investigate valuation frameworks was inspired at a global level by the report, *The Economics of Ecosystems and Biodiversity* that revives earlier work on ecological economics by showing a compelling cost-benefit case for public investment in ecological infrastructure (TEEB, 2009: 1). I found this logic well-suited to my argument, and I adjusted my research to incorporate the idea of total economic valuation, as a possible method to demonstrate the feasibility of 'green infrastructure' as a strategic planning framework with which to elevate ecosystem services to traditional infrastructure categories included in sustainability transitions. I knew that translating the accurate valuation of ecological assets into a financial argument is the critical challenge for policy-makers, and was inspired to use the *Methodology to value the natural and environmental resources of the City of Cape Town* by Martin de Wit *et al* (2009), to emphasise the economic value of ecosystem services to municipalities and the role of society in accurately value these services.

I maintained a focus on the pragmatic concerns of developing country contexts, as challenged by the lack of "adequately developed knowledge infrastructure to drive the kinds of innovations that are required to both withstand the global ecological-economic crisis and take advantage of the crisis" (Swilling, 2010). The wider development and economic roles of ecosystem services, beyond their inherent ecological benefits, as extending into practice the conceptual developments of social-ecological resilience and transitions literature, represented what I sought to investigate in the

Johannesburg case study. My decision to focus on the value-added contribution of Johannesburg's green systems, as significant ecosystem service providers, also stemmed from my personal interaction with Johannesburg's culture of greening to which I have been sensitised from childhood. I have grown up constantly linked to Johannesburg's green systems - from experiencing the day-to-day operations of a retail garden nursery, the knowledge and daily work of horticulturalists, the process and ideas behind landscaping, and interaction with many gardeners of all backgrounds. I have also seen how green supply chains, gardens and gardeners, have developed around green space, as potential sources of social-ecological resilience, if valued explicitly. In addition to the challenges I faced on acquiring primary datasets on Johannesburg's green assets, I therefore knew that my case study required an analysis beyond what was publicly delineated or conserved.

1.4 Primary issue statement

The purpose of this thesis is to demonstrate the significance of the roles that ecosystem services play in building the resilience of urban landscapes, with special reference to the planning of, investment in, and maintenance of, so-called 'green infrastructure'. A case study of Johannesburg is used because this is a city that faces many sustainability challenges, but also has key ecological assets, which can be valued fairly accurately in ecological, social and economic terms.

1.5 Research questions

This thesis explores the aforementioned issue statement through an investigation based on a number of preliminary research questions. The research questions that informed the research process were not known upfront at the start of my research, they were the result of linking the schools of thoughts and themes that emerged during the search process.

(i) How can the core analytical insights emerging from the scholarship on social-ecological systems analysis be applied to the study developing country cities?

(ii) Is it possible to derive from this scholarship an appropriate framework for the accurate valuation of a set of ecosystem services in urban developing country contexts?

(iii) What does Johannesburg's forest and its associated green spaces mean to their public custodians, and have these custodians in any way valued the services provided by the city's ecological assets, or developed a method of valuing the socio-economic benefits of investing in ecosystem services?

(iv) Given the lack of specific research on valuing Johannesburg's ecological assets, what possible set of methods would be feasible to understand and value the services flowing from the city's forest and green spaces?

(v) How can Johannesburg's urban forest and green spaces be valued beyond the public sector domain and what set of methods can be applied for this purpose?

1.6 Research design

A key issue in academic research is the type of study undertaken in order to provide acceptable answers to the research problem or questions, as explained by Mouton (2001: 49). This is otherwise known as the type of research design to be followed, which is elaborated upon by Bryman (2008: 31):

"A *research design* provides a framework for the collection and analysis of data. A choice of research design reflects decisions about the priority being given to a range of dimensions of the research process."

The research design can therefore be understood as guiding the execution of a research method and data analysis, and chosen as the study that will best meet the research questions (Bryman, 2008: 698; 30; Mouton, 2001: 55). To carry out the research objectives outlined in Section 1.5, two broad research design types were employed as maps of how the research was intended to be executed. A literature review was chosen to provide a context to the research questions and clarify concepts, through a comprehensive review of non-empirical research, as well as of secondary material analysing real-world dynamics, to establish an understanding of empirical trends associated with the second urbanisation wave. In line with Stake's view (1995: xi), a case study was undertaken to capture the particularity and complexity of a single case and build an understanding of its activities. Although the case study aimed to demonstrate the significance of ecosystem services in enhancing a urban social-ecological resilience, through a valuation methodology, it also added to my existing understanding, proliferating rather than narrowing the methodological findings developed in the literature review (Stake, 1978: 6).

1.7 Literature review methodology

1.7.1 Literature review approach and purpose

Mouton (2001: 179) defines a literature review as a study that "provide[s] an overview in a certain discipline through an analysis of trends and debates". Bryman (2008: 81) elaborates on the purpose of exploring existing literature, which should identify the following issues:

- What is already known about this area?
- What concepts and theories are relevant to this area?
- What research methods and research strategies have been employed in studying this area?
- Are there any significant controversies?
- Are there any inconsistencies in findings relating to this area?
- Are there any unanswered research questions in this area?

Following the recommendations of Bryman (2008: 81), I used the research gaps and obstacles identified in section 1.3 as analytical opportunities. A literature review was therefore chosen as an appropriate format to build an understanding of the themes and issues surrounding contemporary urban sustainability transitions and as a context for answering the research questions. A review of both empirical and non-empirical research was chosen in order to adopt a holistic systems approach to understanding the interlinkages between worldly phenomena, as informed by the primary issue I was addressing, namely urban social-ecological linkages (Gallopin, 2003: 22; Clark, 2007**:** 1737).

The purpose of the literature review is to establish a sound theoretical understanding and overview of existing scholarship on social-ecological systems analysis, in relation to the second urbanisation wave. To this end, core analytical insights were extracted from the relevant scholarship and applied to the study of developing country cities, answering research question (i). With the motivation of connecting theoretical understandings to the practical realities of developing countries, the literature review also sought to establish a possible framework with which to value the ecological assets in urban developing country contexts, answering research question (ii). This was achieved through a review of the emerging scholarship on sustainability transitions and frameworks with which such transitions can be implemented. The literature review therefore aims to clarify the language of, and make connections between, social-ecological systems analysis, ecosystem services, resilience thinking, green infrastructure and total economic valuation.

To the extent that the literature review sought to understand what is observed as a complex world of increasingly urban social and ecological interactions, which is the general observation informing the work, the approach to the literature review exhibited a relationship between theory and research that is inductive, where theory is the *outcome* of research (Bryman, 2008: 11; original italics). As Bryman (2008: 11) notes, with an inductive stance, generalizable inferences are drawn out of observations, which are social-ecological systems, characterised by multiple non-linear feedback loops that, in turn, required appropriate theories for conceptual understanding. However, Bryman (2008: 9-11) further explains that “the inductive process is likely to entail a modicum of deduction” where, on the basis of what is known about a particular domain and of theoretical considerations in relation to that domain, a hypothesis is deduced that is then subject to empirical scrutiny.

Elaborating on the inclusion of deductivism in an inductive research approach, Bryman (2008: 11-12) explains that a weaving back and forth between data and theory is generally known as an iterative approach. An iterative research strategy happens when, once theoretical reflection on data has been carried out, the researcher may want to collect further data to establish the conditions in which a theory will or will not hold (Bryman, 2008: 11-12).

Therefore, although the literature review formed the initial exploratory phase of the research methodology, it was very much an ongoing process. Bryman (2008: 99) elaborates: "[t]he literature review is often viewed as a distinct phase in the research process, but in fact it is often an ongoing component of the research project". I found it useful to adopt this iterative, or recursive approach since my data collection and analysis proceeded in tandem, repeatedly referring back to each other (Bryman, 2008: 541). This resulted in an evolving analysis of literature that was constantly reviewed and updated as I came across new insights and debates.

1.7.2 Literature review search process

Although the search process for literature review, as the chosen format for communicating observations on existing literature, was informed by the research questions identified in section 1.3, I also needed to contextualise these questions in the first place. I therefore conducted extensive bibliographic searches through profiling online databases, electronic journal articles, books and published theses as well as international reports and conferences available through the JS Gericke Library at Stellenbosch University. During my Bachelor of Philosophy, I had also completed a mini-dissertation entitled *Reviewing the emergence of the notion of a sustainable city: key features of an unsustainable city and interventions needed for cities to become more sustainable,* as part of a Sustainable Cities module. I used the scholarship profiled in this work as a preliminary literature review whose themes I used as initial inputs into my library searches.

As I came across new insights and publications, I expanded the key themes according to which I searched for scholarship. I was interested in the conceptual transition beyond reductionist theoretical frameworks that separate human and environment systems, as well as empirical trends associated with the second urbanisation wave such as ecosystem services in developing country cities. I therefore structured my literature search according to school of thought, theory or definition as well as by research themes and constructs as suggested by Mouton (2001: 92-93). I searched scholarship according to the interaction of schools of thought and research themes, as summarised in Table 1:

School of thought	Themes
Sustainable development	The second urbanisation wave
Urban sustainability	Urban growth trends
	Unequal urban systems
	Urban design and spatial patterns
	Urban planning biases
	Reducing urban ecological footprints
	Urban green space
	Sustainability transitions
	Developing country sustainability
Social-ecological systems analysis	Ecosystem services
	Resilience
	Complex adaptive systems
	Adaptive capacity
	Adaptive co-management
	Cross-scale interactions & feedbacks
Green infrastructure	Strategic land-use planning
	Multifunctionality
	Infrastructure categories
Ecological economics	Total economic valuation
	Valuation methodology & techniques

Table 1 Literature search inputs

The theoretical and practical insights extracted in the literature review process in-turn provided the criteria for the formation of research questions (iii), (iv) and (v). Although the methodology of answering these questions is structured by the valuation framework developed De Wit et al (2009), I knew that an understanding of Johannesburg as a system, and its ecological assets, was necessary for the locating the research questions. To address this need, I therefore embarked on a Johannesburg-specific literature review that aimed to deepen my knowledge of the city's contextual background and state of ecological assets. As background to valuating the city's ecosystem services, the following themes, elaborated upon in section 3.2, emerged as key considerations for contextualising Johannesburg as an urbanising system:

- The gold mining boom
- The tree-planting boom

- Economic restructuring
- A sprawling, de-centred city
- Losses to green space

Reviewing the literature on Johannesburg's social-ecological state, also revealed that very little academic scholarship had undertaken an analysis of the city's entire basket of ecosystem services or an economic valuation thereof. This was a constructive undertaking since the lack of detailed valuation of Johannesburg's green spaces was a good indication of the methodological reach necessary for the case study. Instead of deterring me from applying De Wit's valuation framework, I included as a research question the state of knowledge on Johannesburg's ecosystem services, as an opportunity to address the sparse academic work on the city's ecosystem service providers and as departure point for the case study valuation exercise.

1.8 Case study methodology

1.8.1 Case study approach and purpose

One of the core themes emerging from the literature review was the importance of valuing a set of ecosystem services in developing country cities, and the valuation framework developed by De Wit *et al* surfaced as an appropriate means to link in practice the idea of social-ecological resilience building and sustainability transitions in developing country cities. The six step methodology proposed by De Wit *et al* was therefore chosen to execute and structure the case study, thereby answering research questions (iii), (v) and (vi). Johannesburg was chosen for the case because, although it is a city that faces many sustainability challenges, it also has key ecological assets, which if accurately valued in ecological, social and economic terms, can enhance the ability of policy to respond to social-ecological vulnerability. The purpose of the exercise was therefore an application of the six generic steps to prepare a *valuation case study* on ecosystem goods and services in Johannesburg, following Wit *et al's* methodology (2009: vi). The unit of analysis was defined using the municipal borders of the Johannesburg, an area of approximately 164 458 hectares, whilst acknowledging that ecosystem boundaries are permeable and do not strictly confirm to administrative borders (JMOSS, 2002: 17; Ernstson, 2008: 119).To estimate the value of ecosystem services in Johannesburg, the case study was therefore broken down into six methodological steps:

1. Assess the relative importance of different natural assets for the generation of EGS
2. Estimate the importance of EGS to users/beneficiaries
3. Establish the links between EGS and development objectives
4. Assess the ability of the City to influence the value of EGS through management
5. Assess the ability of ecosystems to yield a sustainable flow of EGS and prioritise according to risks.
6. Apply valuation techniques to selected case studies.

1.8.2 Data collection methodology

To execute the methodology, empirical data was sourced through a mixture of secondary data analysis, Geographic Information System (GIS) mapping exercises, semi-structured interviews, pilot case samples, collection of primary data as well as a number of empirical observations and field visits to the city's green spaces (Mouton, 2001: 157: Bryman, 2008: 589). However, the Johannesburg literature review, undertaken to provide contextual background to the case study had included a degree of qualitative and quantitative data on the city's green assets, which proved useful for estimating the relative importance of natural assets for generating ecosystem goods and services. For this first step of the methodology, a content analysis of existing research was therefore undertaken to analyse what had already been published pertaining to ecosystem services providers in Johannesburg (Mouton, 2001: 157; 165). The content analysed included government publications, such as the Johannesburg State of Environment Reports of 2003 and 2008, historical studies of the Witwatersrand's tree-planting boom and socio-political commentaries of Johannesburg's greening culture. Apart from a limited degree of quantitative data documented in government reports, however, the existing data on Johannesburg's green assets was mainly qualitative secondary data, that dealt with Johannesburg's ecological assets as representations of the city's unequal past, rather than as units of analysis in their own right.

I therefore refined my analysis using De Wit *et al's* recommendation of necessarily limiting the study to the ecosystem services that are directly or indirectly linked to the particular social-ecological vulnerabilities facing Johannesburg. Secondary data analysis was employed for this purpose, which involved reanalysing existing research on the sustainability challenges experienced in the city through consulting official government documents, budgets and annual reports, state of environment reports, media items in the press and peer-reviewed academic articles (Mouton, 2001: 164). Although this data analysis revealed that a detailed study of the specific set of ecosystem services provided in Johannesburg is lacking, the services typically provided by the kinds of green systems in Johannesburg found were profiled according to existing international ecosystem service literature (Mouton, 2001: 164).

Estimating the importance of ecosystem goods and services to beneficiaries, the second methodological step, followed the three-tiered user categorisation suggested by De Wit *et al* (2009). I identified stakeholders within categories of 'residents', 'key commercial interests' and 'public bodies' who benefit from the prioritised ecosystem services. As suggested by the methodology, the means to linking ecosystem goods and services to development objectives is a content analysis of a city's Integrated Development Plan (IDP), which every South African municipality is required to produce to map short, medium to long-term strategies (CoJ, 2010). The six core development principles, as outlined in the City of Johannesburg 2010/2011 IDP, were identified and matched to the prioritised ecosystem services.

A secondary data analysis was further conducted to assess the city's ability to influence the value of ecosystem goods and services and to assess the ability of ecosystems to yield a sustainable flow of goods and services, methodology steps 4 and 5 respectively. In addition to secondary data sourced from government documents and media articles, data was collected through mapping exercises with the GIS department at Johannesburg City Parks (JCP), as the official conserving and greening agent of the city. I established relationships with two GIS specialists at JCP, whose GIS databases were profiled for empirical data on the city's ecological assets, after which spatial mapping of various GIS layers took place. The maps produced in this process by JCP included distribution of trees within the metropolitan municipal boundary (figure 5), percentage tree cover per municipal ward boundary (figure 6) and aerial photographs, showing examples of suburbs according to socio-economic status (figures 8 and 9), and an aerial view of peripheral suburban development (figure 10).

A series of semi-structured interviews were held with two GIS specialists at JCP in order to build an understanding of the GIS mapping process used in latter stages of the methodology. Bryman (2008: 196) explains that a semi structured interview is a "context in which the interviewer has a series of questions that are in the general form of an interview schedule but is able to vary the sequence of questions". Semi-structured interviews also allow the interviewer some latitude to ask further questions in response to what are seen as significant replies" (Bryman, 2008: 196). The interviews revealed that the JCP GIS databases were incomplete, lacking data for public open spaces and ecological networks due to zoning irregularities and for Johannesburg's tree distribution, since an official city-wide tree count is yet to be completed. To gain insight into mapping issues in the Johannesburg, such as illegal land zoning, poor ecological inventories and the progress of JCP projects, an interview was held with a registered GIS practitioner at the Gauteng City Region Observatory (GCRO) a unit providing research advice to government on issues in the city region (Storie, 2010).

Semi-structured interviews were also held with a variety of relevant participants throughout the case study data collection process. The interviews held are summarised in Table 2:

DATE	**PERSON**	**TOPIC**
11 August 2010	Mr. Reese Clements (CFO, JCP)	Employment and financial statistics of JCP

18 August 2010	Mikki Roxmouth (SALI)	Economic contribution of SAGIC
20 August	Kay Montgomery (Life is a Garden)	Economic contribution of SAGIC
23 August 2010	Wayne Stewart (SANA vice president: marketing)	Economic contribution of SAGIC
26 August 2010	Professor Di Goodwin (SAGIC board member)	Economic contribution of SAGIC and biodiversity contribution of urban ecosystem services
3 September 2010	Bernadette Vollmer (SALI)	Ecological landscape planning
15 September	Florian Kroll (Siyakhana Food project)	Urban agriculture and provisioning ecosystem services
17 September 2010 29 September 2010 30 September 2010 1 October 2010	Professor Coert Geldenhuys	Ecosystem services of trees Carbon Stock estimates

Table 2 Summary of interviews held

The valuation phase of the methodology involved a process of matching the prioritised ecosystem services to appropriate valuation techniques, identified in Table 2. Valuation exercises were carried out for ecosystem services on which existing data was available in accordance to the specified valuation type. For instance, a secondary data analysis was conducted of the replacement and disaster management costs of ill-functioning regulating ecosystem services in Johannesburg, such as water filtration and purification. However, apart from a limited degree of quantitative data documented in government reports and media items, the existing primary data on Johannesburg's green assets was mainly qualitative, posing problems for estimating total economic valuations. Broadening De Wit *et al's* tools, new primary data emerged from quantitative valuation studies of the specific regulating and cultural ecosystem services in Johannesburg:

Valuation of regulation services: economic productivity and attractiveness – Estimating the carbon stock of Johannesburg's urban forest

With the aid Professor Coert Geldenhuys, a forest ecologist from Stellenbosch University, a pilot case study was undertaken to estimate the carbon stock of Johannesburg's urban forest. Since this calculation has not been carried out for Johannesburg, Professor Geldenhuys assisted me in developing a methodology to carry out a carbon stock calculation on a pilot-study scale that could be extrapolated to city-level. The process involved various field visits to Emmerentia Park to demarcate a $50x50m^2$ area, representative of an urban tree stand, in which the necessary primary data were measured. Primary data measured for each tree included calculating the diameter at breast height, stem lengths and estimating the percentage branch volume of the total tree volume. This numerical data was inputted into the carbon stock methodology developed by Professor Geldenhuys whom I visited several times to ensure my calculations were correct. The final step in this pilot study was to correlate the total carbon stock of Johannesburg area to carbon prices at the time of writing. Table 7 includes the "methodology to estimate the carbon stock of Johannesburg's urban forest", which is explained in detail in Chapter Three. Primary data figures can be found in Table 16.

Valuation of cultural services: Economic contribution of the green supply chain to Johannesburg and individual sectors

The aim of including SAGIC in the case study is to estimate the contribution of Johannesburg's green industries in economic terms. The initial data collection process involved a survey research in which data is to be completed by self-completion questionnaires on the part of the participant (Bryman, 2008: 699). The survey was sent to the SAGIC's administrative division on the 16th of August 2010 as an electronic mail attachments for distribution to individual members. The survey included the following questions:

16 March SAGIC survey:
1. The number of people employed in your organisation 2. The average salaries of your employees 3. The race composition of your employees 4. The annual turnover or revenue of your organisation. Approximate figures are fine. 5. The stock value of your organisation 6. The percentage of your stock that is "green" or soft (such as plants, flowers etc) vs. The percentage of stock that is "hard" such as pebbles, concrete goods etc. 7. The percentage of your stock that is indigenous and/or water wise vs. The percentage of your stock that is exotic and/or water intensive 8. A profile of your customer market or customer composition by race, age and gender 9. The composition of your supply chain in terms of type of suppliers and location or geography of your suppliers.

Table 3 Questions included in the SAGIC survey

The aim of this survey exercise was to collect a body of quantitative and quantifiable primary data in connection with the variables related to the economic contribution of SAGIC (Bryman, 1008: 699) However, the response rate to the surveys was lacklustre and a significant number of participants would not divulge the key data required, and were particularly unwilling to release information pertaining to annual turnover, employee numbers and average employee take-home salary. I interviewed several members of SAGIC to establish whether the contribution of Johannesburg's green industries had been calculated in quantified in either employment or annual revenue terms. The following responses were recorded: "The information you are looking for does not exist" (Montgomery, 2010) "You will find nothing" (Goodwin, 2010) and "Those are statistics we actually don't collect, but should" (Stewart, 2010).

To address the lack of industry data, I contacted the financial departments at two SAGIC-registered organisations, the South African Nurseryman's' Association (SANA) and the South African Landscaping Institute (SALI). Through sourcing numerical data pertaining to their respective membership fee categories, I was able to estimate a total range of earnings along a minimum-maximum continuum for a segment of the study population (Bryman, 2008: 168). A non-probability sample was used for this calculation since access to SANA and SALI datasets influenced the selection of sample units, which were therefore not selected randomly (Bryman, 2008: 696). The methodology that was developed specifically to calculate the total range of economic contribution for SANA and SALI is explained in Table 10, and the respective datasets found in Tables 8, 9, 11 and 12.

A pilot case sample was also used to indicate a feasible valuation technique for estimating the employment contribution of Johannesburg's green supply chain. The methodology, explained in Table 14, was applied to a non-probability sample, since the data made available to me from the Geographic Department at StatsSA pertained to a specific suburb in Johannesburg, Greenside, which was therefore used as the sample unit. Piloting the valuation technique in such a sample has value in that the chosen research methodology, applied in Table 15, is demonstrated as a potentially feasible tool to illustrate the value of garden employment at city-level (Bryman, 2008: 247).

Valuation techniques were therefore developed to overcome the primary data constraints pertaining to Johannesburg's ecosystem services. To this extent, the case study emerged as a methodological study which is defined by Mouton (2001: 173) as a study "aimed at developing new methods of data collection and sometimes also validating a newly developed instrument through a pilot study". This included analysing ecological assets beyond what is publicly delineated or conserved, and revealed layers of social and ecological resilience that appear hidden from traditional ecological economic valuations. The value streams encompassed by green supply chains, gardens, trees and gardeners of all types, potentially play a significant role in sustaining Johannesburg's social-ecological resilience, if valued explicitly.

It is nevertheless acknowledged that primary research is needed to determine the exact economic contribution of Johannesburg's ecosystem services, which at the time of writing, are not valued in tangible terms. If valued explicitly and conceptualised as infrastructure or an industry service, green assets position Johannesburg uniquely in a future where the catalysts for green economies and jobs are already underway. Although applications of an ecological valuation exercise will therefore be subject to unfolding methodologies, it is also necessary to recognise the limits of replicating models due to the ever-changing nature of social-ecological interactions and their associated data. Total economic valuation concepts are still a critical step forward towards investing in the infrastructure services of green assets through explicit recognition of their value streams and total economic value. As De Wit et. al. (in De Wit *et al,* 2009: 239) have summarised for ecosystem valuation methodologies:

> "...it is not expected that the research will feed directly into decision-making (i.e. instrumental utilisation). The research may be used as an instrument of persuasion (i.e. mobilisation of support) to invest in natural assets, and it is hoped that in the medium- to longer-term it has a wider influence on policy paradigms and beliefs. The focus of this study, and the focus of this chapter, is thus deliberately on the argument itself, as well as the transmission and cognition of the argument (De Wit in De Wit *et al,* 2009: 239*).*

1.9 Significance of the study

The academic pursuit of a holistic framework with which to understand cities is gaining momentum, prompting a rethinking of the relationship between cities' social and ecological components and challenging the assumption of a "human-free" ecosystem paradigm in particular (Chapin *et al*, 2009: 2410; Alberti *et al,* 2003: 1173). The integrated consideration of the social and ecological, as prioritised by social-ecological system analysis, focuses on the impacts of increasing urban and human-dominated activity on the generation of ecosystem services. This perspective focuses on the adverse affects of unsustainable resource management on the capacity of institutions to adapt to changes in ecological processes, the feedbacks of which are often not incorporated into policy decisions. Running parallel to the accumulating work on social-ecological systems, is an emerging literature on sustainability transitions, which focuses on reducing the socio-economic material and energy flows in cities through redesigning their related infrastructures (Weisz & Steinberger, 2010: 1).

While the reassessment of the way we use and respond to resources, and insights into reducing urban metabolisms, through redesigning the infrastructure that conduct resource flows, are critical in the transition towards more sustainable cities, ecosystem services as infrastructure services in themselves, and their role in wider social development, remain largely overlooked (Brunner, 2007:

11). There appears to be a lack of attention given to the infrastructure networks of green spaces and ecological networks, as planning entities in themselves, institutionalised in policy-making agendas and valued in terms of the critical services they provide. This paper shows that 'green infrastructure' is a possible framework to revitalise ecosystem services in urban policy agendas and upgrade developing country cities' ecological assets as coherent planning entities (Sandström in Tzoulas *et al,* 2007). It will be shown that green infrastructure provides a potential link between the conceptual developments of social-ecological systems thinking and the prioritised infrastructure entities to be included in urban sustainability transitions

Through an in-depth case study of Johannesburg's urban forest and associated green spaces, this study will show that these ecological assets have benefits beyond their inherent ecological values, and therefore can be understood, managed and valued on par with traditional infrastructure assets. The study indicates that if assessed more accurately, Johannesburg's ecological assets accrue significant economic benefits to its custodians, who therefore have a sound financial argument for enhancing and investing in the city's ecosystem services. Furthermore, since in-depth assessments of the ecological, social and economic benefits of Johannesburg's ecological networks are sparse, the study highlights the need, and lays the foundation for, further detailed valuation exercises of the city's green infrastructure.

1.10 Clarification of concepts

The following are key terms and concepts used in this research paper which deserve clarification:

<u>Social-ecological system:</u> A social-ecological system is "an integrated system of ecosystems and human society with reciprocal feedbacks and interdependence. The concept emphasizes the humans-in-nature perspective" (Folke *et al,* 2010).

<u>Resilience:</u> Resilience is defined as the ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance (Resilience Alliance, 2007: 1).

<u>Adaptability:</u> Adaptability or adaptive capacity is the capacity of a social-ecological system, including their human and ecological components, to respond to, create and shape variability and change in the state of the system and influence resilience (Folke *et al,* 2010, Chapin *et al,* 2009: 241).

<u>Adaptive co-management:</u> Adaptive co-management is a process by which institutional arrangements and ecological knowledge are tested and revised in a dynamic, ongoing, self-organized process of learning-by-doing (Folke *et al* in Olsson, Folke & Berkes, 2004: 75).

Complexity: Complexity, as methodological approach or philosophical tradition, sees *complex* systems as constituted "through a large number of dynamic, nonlinear interactions", i.e. that "the behavior of complex systems is constituted through relationships". Complex systems have emergent properties that cannot be predicted "merely by analyzing the components of a system" (Cilliers, 2000: 41).

Sustainability: Sustainability is use of the environment and resources to meet the needs of the present without compromising the ability of future generations to meet their needs (Chapin *et al,* 2009: 241; World Commission on Environment and Development (WCED), 1987). Furthermore, as defined by Swilling (2004), sustainable development is "…planning in ways that allow for a balance between growth, equity and sustainability, rather than just a balance between growth and equity" (Swilling, 2004).

Ecosystem services: Ecosystem services are the benefits that society derives from ecosystems and the ecological functions that help sustain and improve human life (Chapin *et al,* 2009: 241, Daily *et al*: 1997). Ecosystem services are generally classified into four categories: namely provisioning services, regulating services, supporting services, and cultural services (Kremen & Ostfeld, 2005: 540).

Green infrastructure: Green infrastructure is seen as a "new framework that provides a strategic approach to land conservation" where ecological assets are seen as community necessities that need to be upgraded and managed as traditional infrastructure utilities (Benedict et al, 2002: 3). In practice, and in addition to being a strategic framework, green infrastructure is a "network of open space, woodlands, wildlife habitat, parks and other natural areas that sustain clean air, water and natural resources and enriches quality of life" (Benedict et al, 2002: 3).

Green industry: The green industry can be understood as the supply chain of private and other non-public entities involved in commercial practice pertaining to the ecosystem goods and services provided by green assets. The green industry in South Africa, however, has been formally organised into the South African Green Industries Council (SAGIC), the umbrella body representing the consumer green industry in the country (Life is a garden, 2010). Landscaping businesses, garden services, irrigation companies, propagators and growers, wholesale and retail nurseries are some of types of commercial industries represented by SAGIC.

1.11 Thesis outline

Figure 1 shows the outline of the thesis and the manner in which the research begins, as broadly structured by the two research design types, and how it unfolded during the research journey. Chapter One establishes the context for the study, the relevance of the research themes and describes the conceptual and methodological developments that take place in more detail throughout the thesis.

Chapter Two is the literature review, which is comprised of three sections. Firstly, the conceptual framework informing the study is explored and the idea regarding social-ecological systems develops as a departure point from which to approach urban dynamics. These dynamics are then rooted in their contemporary context, by describing current urban growth trends in developing countries as the focal system of the research. Thereafter, it is discovered that for social-ecological systems to maintain their ability to adapt and respond to change in the face of unprecedented urbanisation, a more robust case for urban ecological resilience is required. Developing this revitalised approach is the focus of the final section of Chapter Two, which profiles green infrastructure as a framework to enhance the resilience between people and nature in urban landscapes. The methodological implications of green infrastructure are outlined using a framework for valuing natural assets.

Through a case study literature review, Chapter Three investigates Johannesburg as an urbanising system facing cross-cutting challenges. The purpose of this review is to render the analysis of urban growth trends more real and specific. This case study chapter also applies the methodology implied by a green infrastructure framework to value Johannesburg's ecological assets. Due to the obstacles faced in executing the valuation exercise, Chapter Three further includes the development of specific methodologies within the broader total economic framework methodology.

Chapter Four provides a concluding summary of the experience of understanding urban systems and the transition to social-ecological resilience. Based on this experience, and particularly through the encounters with Johannesburg's green assets and knowledge surrounding these assets, recommendations are made as opportunities for future research.

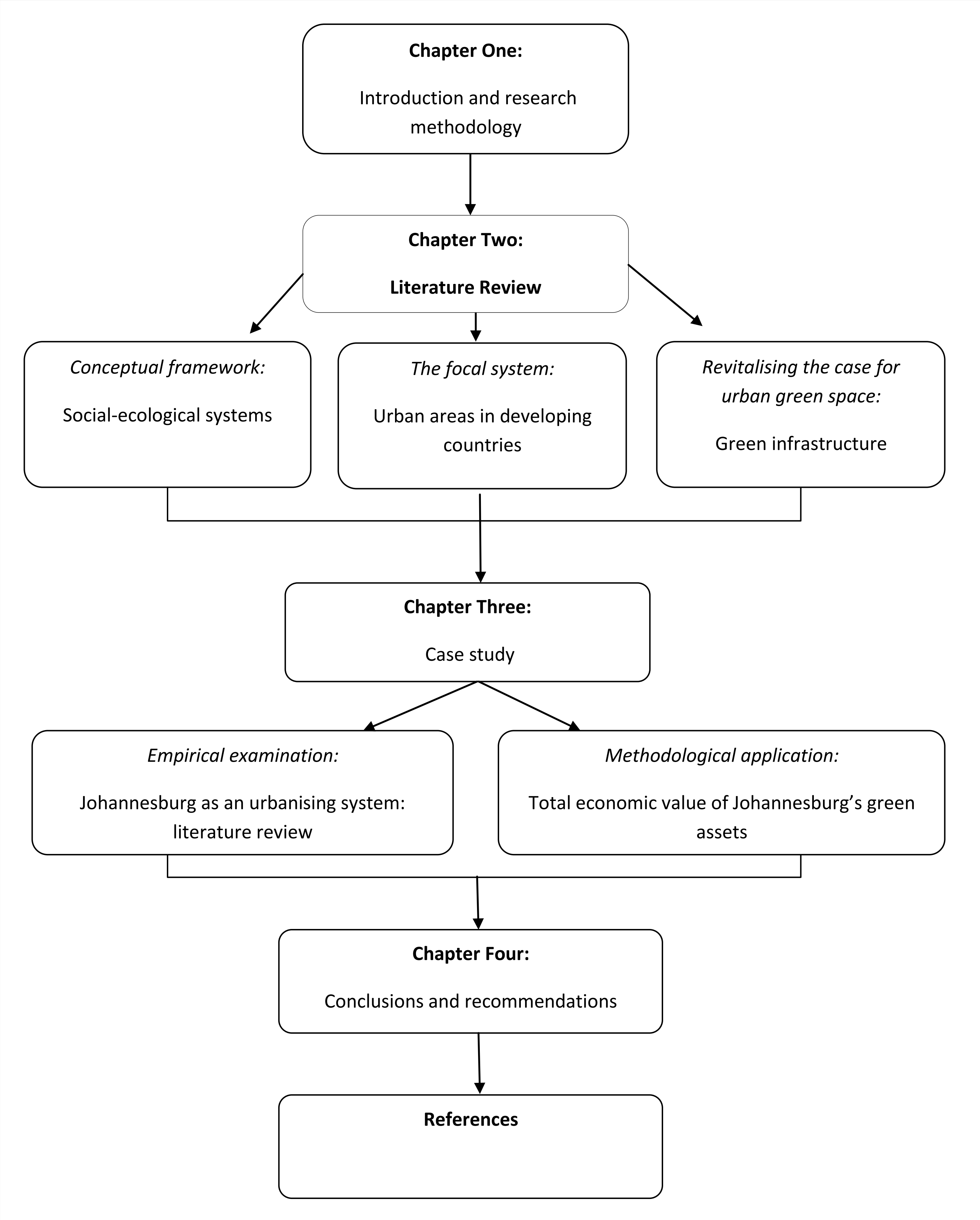

Figure 1 Thesis outline

Chapter Two: Literature Review

2.1 Introduction

The literature review aims to understand what is observed as an increasingly urban world made up of complex social and ecological interactions. A conceptual framework is developed for this purpose, through profiling the relationship between the continued provision of ecosystem service and social well-being. The concept of resilience emerges as a metaphor to enhance this relationship based on the idea of adaptive management. The second urbanisation wave, as fundamentally altering social-ecological resilience, is then profiled according to what are seen to be the major themes teased out of a multidimensional complex urban future. The connections between social and ecological resilience within urban areas surface through an appreciation of the urban green space as a potential source to address the erosion of cities' adaptability. A review of urban green space reveals the need for a revitalised approach to urban planning that values green assets on a par with traditional infrastructure services. Green infrastructure is explored as a framework that potentially enables green assets to be valued, managed and implemented in the same way as conventional infrastructure. Tracking the conceptual developments of this chapter demonstrates an economic case for investment in natural assets to enhance the resilience of both ecological and social systems.

2.2 Conceptual framework: social-ecological systems

The Millennium Ecosystem Assessment (MEA) (2003: 3) defines an ecosystem as a dynamic complex of plant, animal and micro organism communities and the nonliving environment, that interact as a functional unit. The crucial role of healthy and resilient natural ecosystems is captured by the MEA (2003: 1):

> "The composition of the atmosphere and the soil, the cycling of elements through air and waterways, and many other ecological assets are all the result of living processes – and all are maintained and replenished by living ecosystems."

The MEA's statement refers to some of the services provided by natural processes in the ecosystem. Four categories are identified by the MEA (2003: 3): *provisioning services* such as food and water; *regulating services* such as regulation of floods, drought, land degradation and waste; *supporting services* such as soil fermentation and nutrient cycling; and *cultural services* such as recreational, spiritual and religious and non-material benefits. Ecosystem services can be seen as the delivery, provision, protection or maintenance of goods and benefits that humans obtain from ecosystem functions (Tzoulas *et al*, 2007: 170).

The quality and quantity of ecosystem services available to humans is influenced by biodiversity, which is the variability among all living organisms (MEA, 2005: 8). It includes diversity within ecosystems in terms of habitats, species and genes and is one of the most important indicators of ecosystem health (Tzoulas *et al,* 2007: 170). Biodiversity ensures that the ecosystem's natural processes can continue to provide the range of life-supporting services necessary to sustain life. Furthermore, species-rich heterogeneous habitats are considered to be more resilient than homogenous habitats (Tzoulas *et al,* 2007: 170). The resilience of the natural environment is crucial insofar as the services provided through natural ecosystems sustain and fulfil human life (MEA, 2005: 53). Ecosystem services therefore have the potential to contribute to quality of life, sustainable development and can buffer societies against environmental shocks and disturbances (MEA, 2003: 1).

However, ecosystems are situated in social contexts and cannot be preserved in isolation. The natural environment is part of a conjoined social-ecological system, where natural ecosystem processes provide services to social systems, which, in turn, influence the generation and distribution of ecosystem services. Although society's capacity to adapt to change and respond to external shocks is dependent on a resilient natural environment and sustainable flows of ecosystem services, humans and their institutions determine the nature of these flows. Consequently, the generation and distribution of ecosystem services becomes a central concern of human decision-making (Ernstson, 2008: 37). The concept of ecosystem services is therefore a way to describe the relationships between social and ecological processes, which together form what are increasingly termed "social-ecological systems". Since neither ecological nor social systems can be analysed or managed in isolation, the resilience of a social-ecological system needs to be understood systemically.

The major contribution of social-ecological system analysis has been to stress the integrated nature of humans *in* nature and that the conceptual boundary between social and ecological systems is artificial due to the reciprocal feedback loops between social and ecological processes (Folke *et al,* 2005: 443). This idea is an extension of the insight, such as that communicated in the MEA, that humans are an integral part of ecosystems, which therefore comprise of social and ecological interactions (MEA, 2003: 3). Acknowledging that people affect and respond to ecosystem processes, and often in nonlinear ways, is an attempt to bring together two broad threads of literature on ecosystems (Chapin *et al*, 2009: 242). The first is rooted in ecology and the natural sciences, which focus on ecological sustainability as the basis for biodiversity conservation (Chapin *et al*, 2009: 242).

The second comes from geography and political ecology, which address socio-economic sustainability and human well-being as functions of ecosystem health (Chapin *et al*, 2009: 242).

Integrating natural science analysis with social theory, involves recognising that human interventions can increase some ecosystem services, often at the expense of others, which, in turn, feed back into the combined social-ecological system (MEA, 2005). For instance, as a result of intense human use, many ecosystem services are degrading, and enhancing the providers of these services is becoming a critical concern for ecosystem management (Barthel *et al*, 2010). This thinking is rooted in resilience theory, an area of research that sees humans as part of joint social-ecological systems, in which changes in either social or ecological dynamics reverberate throughout the system (Folke *et al,* 2004). As Folke *et al* (2004: 567) explain, "undesired shifts" in ecosystem caused by human activity therefore increase the entire system's vulnerability to shocks, compromising the adaptability of both ecological and social communities.

2.3 The concept of resilience

Rooted in systems thinking, resilience theory was a system developed by ecologists to explain the nonlinear[2] dynamics of complex adaptive systems (Walker & Salt, 2006: xiv). Research shows social-ecological systems have powerful reciprocal feedback loops and act as complex adaptive systems that operate at multiple scales of space and time (Folke *et al,* 2004: 443; Gundersun, Allen & Holling, 2010: xix). Ecosystems are viewed as complex adaptive systems characterised by historical dependency, nonlinear dynamics and feedbacks, threshold effects and limited predictability (Levin in Folke *et al,* 2004: 559). Resilience theory approaches complex adaptive systems by identifying three core features of the world: a) humans are part of linked human-nature systems, i.e. we are part of social-ecological systems, b) social-ecological systems are complex adaptive systems and, c) resilience determines the sustainability of these systems (Walker *et al,* 2006; xiv).

The concept of resilience has many definitions, but it is used here to describe "the ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance" (Resilience Alliance, 2007: 1). Resilience therefore relates to the ability of a desired social-ecological system to "absorb disturbance and reorgani[s]e", i.e. the capacity for self-organisation (Folke *et al,* 2004: 558). This definition builds on the work of C.S Holling, the founder of resilience thinking. Holling introduced the notion of "resilience" to describe three aspects of ecosystem change (in Gunderson *et al*, 2010: xv).The first is the persistence of

[2] Nonlinear dynamics refer to the unpredictable and discontinuous characteristics of social-ecological systems where the feedback affects of chance within the system are uncertain.

relationships within a system and the ability of systems to absorb changes and still persist. The second is the occurrence of multiple states, which challenges the assumption of a single equilibrium and global stability – a perspective based on accelerating ecological change currently experienced globally as a result of intensified human activity. These two insights led Holling to define resilience as the amount of disturbance a system could take before it shifted into an alternative configuration, affecting a system's "function, structure, identity and feedbacks" (Ernstson, 2008: 36). The third idea developed by Holling was the "surprising and discontinuous nature of change", which links to complex systems having nonlinear and cross-scale dynamics that are constantly changing (Gunderson *et al,* 2010: xv).

Decreasing resilience makes systems increasingly sensitive to smaller and smaller external forces that can trigger shifts in social-ecological system states (Gundersun *et al*, 2010). When ecosystems are transformed into less desirable states, the generation of ecosystem services may adversely affected (Gundersun *et al*, 2010). Similarly, when social processes shift into less desirable regimes, the provision of desirable socio-economic opportunities may be less widespread. A recurring theme in resilience theory is that undesirable states may also be extremely resilient, becoming "undesired" traps that impede movement towards more desirable socio-ecological configurations (Gundersun & Folke, 2005; Gundersun *et al,* 2010: Folke *et al,* 2004; 574).

The extended definition of resilience used in this thesis is based on the insight that in complex social-ecological systems, societal learning and ecological adaptation are linked by multiple feedback loops. This explicitly recognises the interconnectedness of social-ecological systems and the potential for adaptation at various institutional levels. In complex adaptive systems, resilience therefore reflects the degree to which a system "is capable of self-organisation" and build capacity for "learning and adaptation" at multiple scales (Folke *et al,* 2004; 558). The notion of strengthening a social-ecological system's adaptive capacity relates to the ability of a desired system to renew itself after an intense disturbance. Conceptually, this allows us to question how humans can "sustain and enhance the capacity of social-ecological systems to improve the management of essential ecosystem services" as well as the provision of socio-economic opportunities (Barthel *et al*, 2010: 1). This explicitly considers how social-ecological systems create synergies between different system processes to respond and adapt to environmental change.

The resilience metaphor therefore provides a foundation for approaching the management of system regime shifts and promoting the case for addressing perverse, but resilient, system states. Applied to the current global context, work on social-ecological resilience sees humans as the predominant drivers of ecological organisation, and therefore of social-ecological regime shifts

(Gundersun *et al,* 2010: 12). Folke *et al* (2004: 558) elaborate, stating that humans are challenging "the capacity of desired ecosystem states to cope with events and disturbances". However, the concept of resilience also creates space for reversing this trend by emphasising that humans have the capacity to manage ecological and social systems in a manner that can build or enhance desirable resilience (Gunderson *et al,* 2010: 12). It therefore is an opportunity for investigating social responses and adaptation approaches to undesired ecosystem states. The central question is how human-induced changes can contribute to positive feedback loops between humans, their institutions and the natural environment and increase the desired resilience of the entire social-ecological system. As Walker *et al* (2006) explain:

> "... [human actions and] their capacity to manage resilience with intent determines whether they can successfully avoid crossing into an undesirable system regime or succeed in crossing into a desirable one".

2.4 Adaptive management

The defining contribution of resilience theory is the approach to managing complex adaptive systems called "adaptive management", as an integrated and appropriate way to deal with ecosystem complexity (Folke *et al,* 2005: 444). Extending social-ecological system analysis into thinking about adaptation is important insofar as many social-ecological studies have focused mainly on the dynamic human-nature interactions within urban landscapes, but less on the actual management of such systems (Ernstson, 2008: 20). Swyngedouw & Heynen (2003: 899) elaborate, noting that little attention has generally been paid to the process of social-ecological *change.* Exploring the human capacity to enhance desirable system states is important in attempting to reverse the negative impacts of human intervention on the ecosystem and in addressing the social, ecological, spatial and temporal injustices facing the world today.

Folke *et al* (2004: 574) explain that humans are part of the trajectory and stability of the ecosystem and determine their own paths through the management thereof. This creates space for identifying sources of resilience in society that contribute to ecosystem service provision and more equal socio-economic opportunity (Barthel *et al,* 2010: 1).The underlying logic is explained by Folke *et al* (2005: 444) who note that a social-ecological system with high adaptability, is one where the actors have the capacity to reorganise the system towards a desired state after a disturbance is experienced. Walker *et al* (2006) elaborate, explaining that because humans dominate social-ecological systems, the adaptability of such systems is mainly a function of the behaviour of the individuals and groups managing them.

2.4.1 Across scales and across disciplines

Adaptive management attempts to address or match cross-scale dynamics of social-ecological systems by integrating different approaches of analysis, i.e. it is an interdisciplinary management framework (Gundersun *et al,* 2010: xx). This involves integrating a diverse range of disciplinary approaches, decision-making processes and social coordination techniques, into a governance framework often termed “adaptive governance” (Folke *et al*, 2005: 444; Gundersun *et al,* 2010: xx). The impetus of this integrated approach comes from the recognition that it is important to monitor, evaluate and respond at multiple scales of a social-ecological system when managing for resilience (Barthel, 2008: 13; Ernstson, 2008: 143). This is because the adaptive capacity of complex systems strongly depends on influences and dynamics at scales above and below (Peterson in Folke *et al,* 2004: 558). The logic behind a wider, integrated approach to adaptive management is therefore cross-organisational adaptation rather than isolated pockets of good governance.

The call for cross-scale adaptation is also linked to the dynamics of ecosystems and other complex adaptive systems, which are taking place under extremely variable environments. We have greater uncertainty about how ecosystems, of which we are part, will respond to inevitable increases in levels of human use (Steffen *et al* in Folke *et al,* 2004: 558). These dynamics are problematic for management as our data and predictive ability of cross-scale dynamics is limited (Gunderson & Allen in Gunderson *et al*, 2010: xx). Adaptive management acknowledges this challenge of restoring the regenerative and self-healing ability of social-ecological systems, in a context where resilience is eroded at multiple scales. As such, it is an approach which confronts the various sources of complexity in systems, including ecological, economic, social, political and organisational (Gundersun & Allen in Gundersun *et al,* 2010: xx). Adaptive management approaches the interactions between different system components through bringing together disciplinary approaches to enhance a diversity of responses in the face of uncertainty (Gundersun *et al* in Gundersun *et al,* 2010: xx; Olsson *et al,* 2007). Adaptive governance is therefore the framework for managing complex ecosystems, where the social context applies adaptive management through multiple ways of knowing and integrated policy-making (Gundersun *et al,* 2010: xxi)

The motivation for interdisciplinary management and bringing together diverse forms of knowledge and experience is also based on critiques of partial learning. As Folke *et al* (2005: 442) note, often the response to ecosystem management focuses on single issues or resources and disregard interactions across scales. In complex adaptive systems, isolated management or planning is likely to erode the capacity of ecosystems to sustain both social and economic well-being (Folke *et al,* 2005: 442). As Folke *et al* (2004: 433) explain, addressing only the social dimension of resource management without understanding ecosystem dynamics, or focusing only on the ecological side as the basis for decision-making, will not result in sustainable outcomes, but rather on too narrow conclusions. Moving beyond approaches that focus on individual components of social-ecological systems is necessary, if broad scale adaptation is to be achieved where positive feedback loops between system processes boost the overall system's desired resilience.

2.4.2 Co-adaptation

At the heart of adaptive management for resilient social-ecological systems is, therefore co-adaptation, where all components of a system are involved in resilience-building. Co-adaptation aims to enhance the ability of management systems to respond to feedbacks from the environment by emphasizing feedback learning (Berkes & Folke, forthcoming). The capacity to respond to environmental feedbacks is seen with the aim of increasing the likelihood of sustaining species diversity, decreasing long-term management costs and facilitating learning and shaping policy (Berkes et al, forthcoming). It therefore argues for planning to represent the multiple scales at which system processes operate and the inter-linkages between contemporary global challenges (Barthel *et al,* 2010). This rests on the hypothesis that enhancing social and ecological resilience in tandem, rather than in isolation, is more likely to boost transformations from undesirable system states (Folke *et al,* 2004). This can be seen as mutual resilience building where a simultaneous focus on social and ecological resilience extends the contribution of ecosystem services into wider development processes.

With a view to creating a systemic argument for ecosystem service provision, co-adaptive management provides a crucial connection between ecological, social and economic resilience. It offers the much needed bridge between socio-economic goals and ecological restoration, which are not exclusive agendas but form the connection between sustainability and development. It is therefore a management framework that allows for identifying the potential of ecosystem services to contribute to poverty eradication and development, that is decoupled from *material* economic growth (Swilling *et al* 2010: 11). The resilience metaphor is therefore a way to understand desired system states by conveying a multi-objective reality and focusing on potential synergies within and across systems (Folke *et al,* 2005: 448).

Mutual resilience building of social and ecological systems offers a theoretical platform from which to address systemic global issues. This involves moving away from the vicious cycle created by human domination over ecosystems, to restoring the ability of ecosystems to provide services and create positive relationships and learning between people and nature at multiple scales. Adaptive management of ecological, social and economic processes, therefore, makes the systemic argument for addressing erosion of resilience in social-ecological systems as a whole. This conceptual framework sees the benefits of improving ecological resilience extending beyond the natural environment and into socio-economic systems using the logic of cross-scale adaptation. As the Resilience Alliance (2007: 1) states:

> "Solutions that address individual problems as they arise may be successful in the short term, but they may also set into motion feedbacks that later come into play. Likewise, piecemeal interventions do not prepare a system for dealing with ongoing change and future shocks".

2.5 The focal system: urban areas in developing countries

The United Nations State of the World Cities report of 2008/9 confirmed that half of humanity is now living in cities, with three million people added per week to cities of the developing world (UN Habitat, 2008/9). The high rates of urbanisation in developing countries will mainly be absorbed by smaller urban areas instead of megacities and are concentrated in Asia and Africa (Davis, 2004: 7). Asia is predicted to host 63% of the world's population by 2050 and Africa is said to have the highest rate of urban population change so that by 2050 half of the continent's population will be urban (UN Habitat, 2008/9). The ability of urban systems in developing countries to manage desired social-ecological resilience is a system focus that cannot be understated (Gunderson *et al,* 2010: 433).

The dynamics, variables and trajectories of the new urban age increasingly influence global social-ecological resilience and are urgent research priorities and form the focus of this chapter (Gunderson *et al,* 2010: 433). The concept of mutual social-ecological adaptability will be explored in terms of the resilience of the urban systems generally, as well as the resilience of desirable system states within specific cities (Resilience Alliance, 2007: 10). The pertinent themes of current urban growth trends will therefore be outlined, with a particular focus on how these dynamics play out in developing country contexts.

2.6 The second urbanisation wave

Pieterse (2008: 16) explains that contemporary urban growth trends are part of a second wave of urbanisation, compared to a first wave during 1750 and 1950 in Europe and North America. The second wave is occurring in a particular context in history, associated with a form of globalisation rooted in "economic liberalization...and linked to a geographical realignment of production, consumption and sites of power" (Bealll, 2002: 42). The second urbanisation wave is particularly occurring in the developing countries of Africa, Asia and Latin America who have experienced rising urban populations over relatively short time periods (Pieterse, 2008: 18). Martine *et al* (2008: 10) reveal that the main driver of the scale of this urban growth is no longer urban-rural migration, but natural population increase. The significance of these increases is that the processes underpinning this wave of urbanisation have produced significant shifts in production and consumption, affecting socio-economic processes, such as encouraging "weaker economies to cut costs through lowering prices and wages, which was invariably accompanied by ...deteriorating working conditions and [other] social cost[s]" (Beall, 2002: 43). Furthermore, urbanisation is both a social phenomenon and a physical transformation of landscapes through intense use of ecological processes around the globe, which are together critical components underpinning the global urban age (IHDP, 2005: 8).

The second wave of urbanisation is the reality that is fundamentally transforming the future of our world. Hodson & Marvin (2010b: 300) state that urbanisation totally dominates the huge metalogistical systems made up of resource flows, energy, water, waste foods, as well as flows of people and goods that make up the contemporary world. These complex dynamics have led research on global urban change to view urbanisation as multi-dimensional and highly variable across time and space (Alberti *et al,* 2003: 1173). This is also related to the nature of cities, which have been cited as the quintessential example of complex adaptive systems (Batty *et al* in Resilience Alliance, 2007: 9) As Swyngedouw *et al* (2003: 899) explain, the myriad transformation and metabolisms that support and maintain urban life, always combine physical and social processes as infinitely connected (Swyngedouw *et al*, 2003: 899). Urban practices are therefore manifestations of interactions between different ecological, social, economic and infrastructural processes, that also differ according to scale and locality.

Furthermore, cities "reproduce within their territory the interactions among socio-economic, geopolitical, and environmental processes at local, regional, and global scales" (IHDP, 2005: 10). Cities also affect ecological and social systems at multiple geographic and temporal scales, rendering urban landscapes extreme among social-ecological systems (Ernstson, 2008: 16). Cities therefore particularly challenge the assumption of a "human free" ecosystem paradigm as well as approaches advocated by the natural and social sciences in their separate domains (Alberti *et al*, 2003: 1173-1174). Separately, the natural and social sciences cannot explain how complex urban landscapes, in which social and natural factors work simultaneously at different scales, emerge and evolve (Alberti *et al,* 2003: 1174). Although the complexity of urban landscapes cannot be overstated, there are certain trends that can be teased out of the multiple feedback loops and dynamics between urban processes (Pickett, Cadenasso & Grove, 2004: 378). Based on an overview of the second urbanisation wave, the following dynamics are generally apparent in cities and should be represented in planning for mutual resilience building in cities:

2.6.1 Growing urban appetites

The second wave of urbanisation is a context in which cities are fundamentally transforming the nature of consumption and distribution of natural resources (Swilling, 2004). Cities have become centres of economic and industrial activity, drawing on resources at global scales through trading routes, impacting ecosystems far beyond urban centres (Ernstson, 2008: 16). The combined requirements of urban systems and unprecedented demand ecosystem services, brought about by city growth, are unsustainable in the long run (Swilling, 2004; MEA*,* 2005: 817). This is because intense resource extraction demanded by cities to fuel, feed and sustain growing urban populations, destroys the regenerative ability of the biosphere. As a result, increasing threats exist to the quality of air, quality and availability of water, waste-processing and recycling systems and many other ecosystem services upon which human well-being is dependent (MEA*,* 2005: 805).

In terms of ecosystem services, urban areas are primary sites of consumption and draw on ecosystems far away from the centre of urban activity for provisioning, regulation, supporting and cultural services (MEA, 2005: 797). Growing cities therefore strain both urban and rural ecosystems, the latter of which are increasingly drawn on to support growing urban appetites for water, food and energy and waste throughputs. A conservative estimate mentioned by Kennedy, Cuddihy & Engel-Yan (2007: 45) is that the equivalent areas of ecosystems required for sustaining cities are typically one or two orders of magnitude greater than the areas of cities themselves.

The MEA (2005: 805) explains that net flow of ecosystem services is invariably into, rather than out of, urban systems. These flows are increasing substantially due to rapid urban population growth, and the ecological footprints of cities are growing at alarming rates (MEA*,* 2005: 805; SACN, 2009). Because of the enormous impact of urban landscapes beyond urban boundaries, the spatial influence of cities is felt at local, regional and global scales. The multi-scalar nature of the growing ecological footprints, means that the burden is often on ecosystems far removed from the city itself (MEA, 2005: 806; 816). Urban development therefore harms ecosystems in surrounding regions when products and amenities are imported by urban residents, who draw on ecosystem services from other parts of the planet (MEA 2005: 806).

Intense dependence on resource networks beyond the physical boundaries of the city, also undermines sustainable flows of ecosystem services to urban populations. In a similar way that globalisation affects socio-economic groups in uneven ways, the above ecological burdens are also borne disproportionately. The most vulnerable are often the poor, who face risks when ecosystem services are lacking, or the quality of provision is sub-standard. This disproportionate burden is often due to having less economic or political influence and consequently, insufficient access to alternative response options. In particular, the importation of services is something that vulnerable groups cannot afford, as imported or alternative ecosystem services are often more expensive than those available locally. The vicious cycle that ensues makes poorer income groups dependent on local ecosystem services, the availability and quality of which are often lower than their imported counterparts.

As Holling *et al* (in Gundersun & Holling, 2002: 3) state, "[t]hese examples signal that stresses on the planet have achieved a new level because of the intensity and scale of human activities". The disproportionate burden borne by vulnerable societies and far away ecosystems as a result of growing urban appetites for resources, puts ecosystem service provision at the centre of an integrated approach to urban planning. This involves prioritising the distribution of ecosystem services in order to address the overlapping and uneven manifestations of urbanisation (Ernstson, 2008). The long-term effects of contemporary urbanisation are another scale at which urban ecological trends become political. The MEA (2005: 806) explains that current urban activities impose burdens on distant people and future generations, by reducing future access to ecosystem services. Temporal justice issues are therefore a central concern relating to the urban impacts on future generation and distribution of ecosystem services (MEA, 2005: 806).

Growing urban appetites for resources and ecosystem services are therefore altering the ability of functioning ecosystems to absorb and adapt to change (Folke *et al,* 2004: 575). As a result, the self-repairing and regenerative capacity of ecosystems can no longer be taken for granted and threats exist to the desired resilience of ecological systems, beyond the geographic and temporal boundaries of contemporary urban centres (Folke *et al,* 2004: 558). This indicates that ecological burdens have multiplier affects, with feedbacks into other ecosystems, so that city footprints imprint themselves locally and globally. Furthermore, under the changed ecological conditions of urbanisation, cities' ability to ensure their longer term economic and material reproduction will be dependent on their capability to guarantee their ecological security (Hodson *et al,* 2010b: 302).

2.6.2 Urbanisation-without-growth

The second urbanisation wave has also induced particular changes and a unique restructuring of the economic and technological spheres of cities (Pieterse, 2008: 17-18). The nature of contemporary globalisation has rendered economic growth and development highly dependent on service sectors that are largely knowledge-intensive (Pieterse, 2008: 17). Global production and consumption processes of these types therefore pose challenges for many developing countries without the capacity to invest in and manage a knowledge-based economy. Davis (2004: 9) elaborates, explaining that in many developing countries, the new urban order has been decoupled from industrialisation and development, resulting in "urbanisation-without-growth". Without adequate investment in infrastructure or the capacity to do so, developing countries are insufficiently positioned to develop strategic solutions to global ecological and economic change. This trend has given rise to stark divisions, where the urban poor are often spatially segregated from economic enclaves (Pieterse, 2008: 17). Davis' (2004: 9) exploration of urban slums shows that only some regions, such as the newly industrialised countries, have been able to effectively integrate themselves into the information age.

Within cities, major urban infrastructure networks have also been 'opened up' to the private sector, resulting in the infrastructure sector comprising an important competitive financial market (Graham & Marvin, 2001: 13-14). Graham *et al* (2001: 15) explain that new forms of infrastructure are selective and often bypass less favoured areas, mirroring to the trends of the knowledge economy. This 'unbundling' of urban infrastructure has been termed the splintering of network infrastructure due to its associated uneven and fragmented service provision (Graham *et al*, 2001: 14). As a result, infrastructure provision in cities has created isolated pockets of development and opportunity correlated to urban spatial trends (Pieterse, 2009). Urban infrastructure provision has therefore begun to mirror the unevenness of the knowledge economy, so that developing country cities face the dual challenges of uneven access to both economic and infrastructure development.

Related to the nature of infrastructure provision in the second urbanisation wave is the growth of informal settlements, which is another example of uneven spatial patterns in cities today. Informal or slum settlements are often located on steep slopes, along floodplains or adjacent toxic industrial or transport facilities (MEA, 2005: 150-151). The physical location of informal housing in marginal areas such as floodplains and hill slopes, coupled with the concentrations of people in urban slums, means that ecosystem services such as floods and landslides are felt more intensely by vulnerable groups. The spatial settings of urban activity, determined by socio-economic processes, therefore exacerbate many of the repercussions of ecosystem degradation. Consequently, these groups are unprotected from risks associated with ecosystem service disasters such as floods, and their lack of capacity to cope with the consequences of uneven spatial settings, reveals that ecological burdens in urban areas are not evenly distributed (MEA*,* 2005: 153). Isolation from economic activity exacerbates these ecological burdens, which are often linked to socio-economic biases existent in spatial planning where as a result of privatised infrastructure markets, comprehensive urban planning is often eroded in favour project-based infrastructure investments (Pieterse, 2008; 26).

That many rapidly growing developing country cities have not reached the same growth in socio-economic opportunity as developed countries, shows that the second urbanisation wave is occurring simultaneously with other problems of our time. The fact that most unemployment rates will be absorbed by cities in developing countries requires that the socio-economic roles of ecosystem services in the wider development process are factored into urban resilience strategies (Swilling: 2007). This is not to detract from ecological crises but to illustrate how these problems are culminating in a polycrisis – a situation "where there is no one, single big problem – only a series of overlapping, interconnected problems..." (Morin in McGregor, 2009). This view is also advocated by systems thinking, which notes that the more we study the problems of our time, the more we come to realise that they are systemic problems that cannot be understood in isolation (Capra in Jackson, 2003: 3).

The potential of urban response options to enhance the mutual resilience building of economic, social and ecological dimensions of urban systems in developing countries, therefore, needs to be examined. This underpins a systemic argument for ecosystem service provision in social-ecological systems. As Dalby in Hodson *et al* (2010: 299-300) states: "All cities face the critical challenge of how to ensure that they can guarantee their long-term ecological *and* economic survival in a context of human-made global ecological change". However, the potential for cities to be inventories of social-ecological change needs to be assessed in relation to the capacity of developing country cities to adapt to change, in the face of resource and infrastructure constraints. As Hodson *et al* (2010: 302) explain, significant differences exist in the capability of cities to respond effectively to sustainability challenges such as energy security and climate change (Hodson *et al,* 2010: 302).

2.6.3 The urban tension

Urban areas in developing countries play paradoxical roles in world futures. These cities offer potential social progress on the one hand, but are possibly less equipped to deliver such progress (Davis, 2004: 7). In one respect, cities "often concentrate poverty and environmental degradation" (Martine *et* al, 2008: 1). This relates to unprecedented urban appetites for natural resources and ecosystem services and demand for infrastructure and service provision due to rapid urban population growth. Since the setting of urbanisation is in smaller urban areas in developing countries, infrastructure and service provision often lag behind urbanisation, posing problems for increasingly strained urban systems (Davis, 2004: 16). As the IHDP (2005: 11) notes, cities in developing countries often have fewer resources to cope with the complex infrastructural, social and environmental issues associated with urbanisation.

With the least resources to cope with expansion and multiple service pressures, developing countries play a paradoxical role in the transition to desired urban systems (Swilling, 2004). This is because cities also provide potential advantages of social and economic advancement, due to economies of scale, as well as being the organisational setting for future socio-economic, technical and ecological change (Satterthwaite, 2006: 6). As Scott & Webb in Scott (2010: 1) explain, the density of populations, buildings, economies of scale, and atmosphere of innovation potentially make cities the social-ecological systems where many of the solutions for a more sustainable world could intersect. The MEA (2005: 817) elaborates, stating that urban structures themselves provide opportunities to lighten the load on the Earth's ecosystems. This thinking is part of a growing body of work on how urbanisation and urban transformation can be redirected to harness cities as generators of innovation and solutions for desired system states of sustainability (Resilience Alliance, 2007: 9). Consequently, the second urbanisation wave provides opportunities to mitigate many urban-related problems and enhance mutual resilience building in cities (IHDP, 2005: 12).

Work on urban resilience is therefore increasingly focusing on the "urban problem" versus "urban opportunity" where developing country cities offer opportunities for sustainability but present many challenges such as poverty, pollution and disease (Resilience Alliance, 2007: 7). The resilience of the global social-ecological system is, therefore, dependent on the capacity of complex urban processes, and particularly in developing countries, to absorb disturbances that result from cross-scale dynamics (Gunderson *et al,* 2010: 433). The urban tension in developing countries could leave global social-ecological systems more vulnerable to changes and create undesired system states; or buffer disturbances and accelerate recovery and renewal, thus enhancing desired system states (Gunderson, 2010: 434). Burdett (2010: 10) elaborates on the paradoxical role embodied by contemporary cities:

> "Like human bodies, over time, cities concentrate problems – congestion, consumption, pollution, violence and inequality. But because they bring people together, they have the capacity to innovate and adapt."

2.6.4 Spatial dimensions

The second wave of urbanisation has created issues for human well-being and social, ecological and temporal justice. However, it is clear that these issues are underpinned by distinct spatial dimensions (MEA, 2005: 806). The use of space within cities is a research area receiving increasing attention in work on urban resilience. As Alberti & Susskind (in Alberti *et al,* 2003: 1172) explain, the spatial organisation of a city and its infrastructure affect the resources needed to support the city's human activities and thus the city's level of environmental pressure on the regional and global environment. Furthermore, the capacity of a city to provide ecosystem services is dependent on the spatial configuration of its ecosystems, which cannot be taken for granted (Andersson, 2006). Urban responses to resilience building should therefore consider how spatial changes and infrastructure trends, running parallel to socio-economic restructuring and growing urban appetites, are influencing the adaptive capacity of urban social-ecological systems.

Zhang in Andersson (2006) explains that in terms of shape, rather than process, urbanisation results in an environment that is compositionally more heterogeneous, geometrically more complex and ecologically more fragmented. As a result, cities may represent the most complex mosaic of multiple land uses and the roles of spatial heterogeneity and spatial scale are critical in understanding the sustainability of urban form (Andersson: 2006). The nature of the second wave of urbanisation, that it has overlapping and uneven manifestations, therefore calls for a planning approach and framework that cuts across the different scales and spaces affected by city growth. Ernstson (2008: 16-17) elaborates, stating that:

> "It is therefore crucial to address what constitutes the living environment of these human habitats in which local and regional ecosystems, together with the built environment of houses, plazas and public space form important parts".

A growing body of work shows that the cities' growing and unfair ecological burdens often occurs because ecosystem services and natural green space *in* cities has been traded-off for other land use types (Tratalos *et al,* 2007: 308-209; Colding, 2007: 46; Tzoulas *et al,* 2007: 168). Despite the numerous pressures associated with urbanisation, such as rising demands for resources and infrastructure capacity, many examples show that urban land-use changes have compensated for growing urban populations, demands and appetites (Pieterse, 2008: 17-20; CoJ, 2003: 77). As the MEA (2005: 805) explains, in many peri-urban areas and regions surrounding cities, both arable and non-arable land is increasingly being built over, to provide for commercial, industrial and residential purposes for rapidly growing cities. Sandström (2002: 373) elaborates on the spatiality of urbanisation, explaining that rapid growth of urban populations has increased the amount of land exploited for roads and buildings, at the expense of parks and other green spaces in cities.

As land in cities is converted into built-up areas to accommodate more and more urbanites, the local capacity of urban ecosystems to provide services for urban populations is undermined (MEA, 2005: 809, Bryant, 2006: 27). This is because pressure to develop urban green spaces for alternative land use-uses erodes the local ecological resilience of urban systems, with adverse affects on the system's overall adaptive capacity (Andersson, Barthel & Ahrné*,* 2007: 1267). Consequently, cities become increasingly dependent on far away ecosystems because their local capacity to provide critical life-supporting services is lost (MEA, 2005: 809). This has been accompanied by the recognition that actors in urban systems are often disconnected from scales, societies and ecological processes that do not constitute their immediate local environment. In contexts of urban sprawl, physical disconnects have been created between humans and nature, as well as mental or cultural distances from the life-supporting services provided by the ecosystem. In these instances, resilience theorists argue to diversify mental monocultures (Barthel, 2004: 10). Reinvestment in – and generation of – ecological knowledge, is part of mobilising institutional adaptability to environmental change.

The use of land in cities is therefore a way in which to analyse the multiple scales at which urban growth manifests. The spatial manifestations of urbanisation and associated urban land use patterns, therefore, influence the quality of, and access to, ecosystem service provision in cities, with ripple effects at scales beyond the urban centre. This is the context in which the role of urban green spaces in addressing a loss of urban ecosystem resilience, is being recognised (Ernstson *et al,* 2008: 130). The call is increasingly made for more robust preservation and maintenance of green spaces in urban environments, if the criteria of liveable cities are to be met and if the resilience of urban ecosystems is to be improved (Ward *et al* 2010: 49, MEA, 2005: 809). This is because urban green spaces are crucial local suppliers of ecosystem services to cities and may serve as local sources of urban resilience, that can reduce dependence on imported ecosystem services in the face of rapidly rising ecological footprints. Some of the locally generated ecosystem services provided by urban ecological assets such as parks and forests, include air filtering, micro-climate regulation, noise reduction, rainwater drainage, waste assimilation and recreational values (Bolund & Hunhammer, 1999: 295).

For efficiency reasons and on ethical and educational grounds, it therefore makes sense for cities to generate ecosystem services locally, as explained by Bolund *et al* (1999: 300). As such, the contribution of urban green space to ecological resilience is only one dimension of urban resilience building. As urban landscapes are as much ecological as they are social and economic, planning that is single-minded about the use of urban green space, be it exclusively for ecological or social benefits, is counterintuitive for social-ecological system resilience. Responding to the range of scales created by new urban forms and to bridge the ecological and economic needs of an urban system, requires considering the system-wide opportunities that ecosystem services and urban green spaces provide to social-ecological systems (Hodson & Marvin, 2010: 300; Swilling, 2007).

Acknowledging the various roles of green space in cities is also a response to evidence that spatial scale is generally underdeveloped and seldom explicitly included in approaches to sustainability transitions (Hodson *et al,* 2010: 4). Assessing the potential of urban green space as potential sources of social-ecological resilience is an attempt to address the limited focus of land use planning on the landscape-linkages of natural assets and economic performance (McDonald *et al,* 2005: 7; Landscape Institute, 2009: 1). An overview of urban research reveals that the neglect of urban processes' spatial dynamics is due to the fractured approach to planning, which has created a divide between socio-economic agendas and ecological sustainability. Although efforts have been made to develop multi-level perspectives on urban transitions, there is still uncertainty regarding how cities "fit" in which multi-level transitions in which the multiple scales and processes are prioritised (Hodson *et al,* 2010b: 4-5). The conceptualisation of urban space and associated planning priorities are, therefore, important considerations in addressing the barriers to, and opportunities for, more sustainable spatial form in cities.

2.6.5 Urban planning priorities

In terms of their production, the spatial dimensions of cities are functions of a wide range of management practices and the multiple scales at which decision-making occurs have been cited as contributing to the heterogeneity of urban space (Andersson, 2006). The interactions between social, economic and institutional decision-making trends, therefore, affect the development and distribution of green spaces in cities and urban capacity to provide ecosystem services. Research shows that many urban management processes, in attempting to solve problems affecting the city, have failed to understand the interconnected nature of urban processes and challenges (UN-Habitat, 2008: 2). Policy debates are often poorly informed, partly due to ignorance of the processes involved, and partly because they are driven by vested interests which, in turn, affect the priorities of urban planning agendas (MEA, 2005: 810-811). Where ecosystem services have been included in urban planning, they have often been treated as separate or isolated from socio-economic development planning (MEA*,* 2005: 818). This neglects the roles that green space and ecosystem services can play in development that is decoupled from resource use (Swilling *et al,* 2010: 11).

2.6.5.1 Planning biases

Disregard for sustainable resource use has multiple causes, but is largely linked to the dominant economic framework that guides market signals. Under this system, market signals do not fully reflect social and environmental externalities, resulting in distorted pricing of natural resources and a lack of incentive to encourage the restoration thereof. As explained in the MEA (2003: 6), market mechanisms are such that markets have historically not existed for ecosystem services or where they do exist, the institutional environment champions economic growth over conservation of the natural resource base. Additionally, mainstream economics views the ecosystem as a subset of the economy, where no constraints to economic growth are imposed by ecological limits (Williams & McNeill in U21Global, 2005: 9). As a result of this view, resource limits are often ignored in key policy documents despite the dependence of development on ecological sustainability (Williams *et al* in U21Global, 2005: 9; Swilling: 2010).

Running parallel to the trend of distorted market frameworks is, the intersection of capital investment with urban planning (Gandy, 2004: 360). In urban systems, spatial planning is influenced by infrastructure investments that often by-pass less favourable locations. Gandy (2004: 372) explains that these relationships are creating market-driven conceptions of urban infrastructure, widening inequalities in urban service provision and increasingly fractured urban spaces. This reveals that inadequate informal planning may contribute to unsustainable urban form, resulting in the ring-fencing of service provision where areas not attractive to investors – i.e. not profitable – are underprovided for. Furthermore, certain land use types and spatial patterns, such as urban agriculture or green areas, are often traded-off for economic, commercial, industrial or residential concerns. This is confirmed by Brown (2008: 210) who states that there is often insufficient land to accommodate both sprawl-like development, associated with rapid urbanisation, and green spaces that positively affect human wellbeing.

Ecosystem services and their distribution are, therefore, influenced by the direction of capital investment and the degree to which they are publicly or privately managed (Ernstson, 2008: 35). Engaging with the interplay between space and capital, shows that local patterns of urban ecosystems, such as green and blue spaces, are moderated by political land use struggles (Ernstson; 2008: 34). Social-ecological analysis reveals that the choice of how to use green areas is often a matter of taste and culturally constructed values, which are often dominated by those with higher economic, cultural and social capital (Bourdieu in Ernstson, 2008: 19). Numerous studies show that access to urban green space is rarely uniformly distributed as wealthy income groups are able to afford to move to areas with better environmental offering (McConnachie & Shackleton, 2010: 244; Barbosa *et al,* 2007: 192). Furthermore, the greater housing density in slum settlements translates into significantly lower areas of public green space per household, as poorer residents in developed countries do not have sufficient areas of private space in their homesteads (McConnachie *et al,* 2010: 247).

2.6.5.2 A conceptual crossfire

Land use tensions are also evident, in that pro-poor development agendas often argue for more economically equitable planning priorities versus the conservation approaches of environmental conservation disciplines. Although the boundary between socio-economic progress and ecological sustainability is artificial as human well-being is dependent on ecosystem health, there is nevertheless a divide between different social and ecological agendas. Oleyar *et al* (2008: 289) explain, research and management of urban areas are typically geared toward a single purpose. Quinlan & Scogings (2004: 6) give insight on the roots of the tension between social and ecological planning priorities:

> "What causes misunderstanding is not the novelty of another discipline's caveats, but the implications of incorporating them into one's own discipline. In other words, scientists are grappling not only with changes to the form and practice of environmental research, but also with underlying questions about how those changes will affect their own disciplines."

Failure to embrace the full range of issues and stakeholders in cities, whether ecological or social communities, results in exclusive agenda-setting. Although environmental conservation or social development are in their own capacity not undesirable, planning with a single goal in mind, be it biodiversity or conservation or the enhancement of a city's social fabric, will not sustain systemic resilience (Oleyar, 2008: 290). Single-scale analysis generally manifests itself in the form of environmental concerns viewed as obstacles to growth and development (De Wit *et al,* 2009: 12). As a result, what are seen as purely socio-economic issues – such as poverty and job creation – receive primary attention in planning agendas which, in turn, overlook the socio-economic opportunities that ecosystem services in their desirable states offer. As Swilling (2007) explains, many pro-poor development arguments neglect the role that ecosystem services and natural resources can play in the wider development arguments and also at the expense of critical life-supporting services. As a result of the cross-fire between "green" and "brown" sustainability agendas, ecosystems are not seen as economic assets that can potentially provide economic opportunities (Miththapala in IUCN, 2008: 21).

The inclusion of green space urban planning has been negatively affected by failure to acknowledge the mutual benefits that ecosystem services can potentially supply to both ecological and social systems (Sandström *et al,* 2006: 45; Swillling, 2007). The problematic communication between the natural and social sciences has resulted in the concept of urban green space treated one-dimensionally – that it is something *nice* to have instead of providing both ecological and social-ecological opportunities (Sandström *et al,* 2006: 45; Van der Ryn & Cowan in Walmsley, 2006: 45). The following statement is an example of this one-dimensional view:

> "Expenditures on open spaces and greenways are too often viewed as a luxury, subordinated to more pressing socioeconomic concerns and typically the first items to be eliminated from municipal budgets." (Miller, 2005: 431)

Furthermore, where urban green spaces are protected, they are often luxury ecological assets that only the wealthy have access to, leading to the fragmentation of open space and green areas in urbanising cities (Benedict & McMahon, 2002: 14). In developing countries, this creates isolated pockets of "green" development and exacerbates the uneven access to opportunity already felt by vulnerable urban citizens. Developing countries, as the context of rapid urbanisation, are therefore facing a dual threat of increasing pressure to develop urban land for residential, commercial or industrial purposes at the expense of green areas and a future of fragmented urban green space. Both threats erode developing countries' local capacity to provide ecosystem services, which is aggravated by the absence of coherent policy frameworks with guidelines on the protection and maintenance of green open spaces.

The misguided tension between socio-economic agendas and conservation approaches of the natural sciences, coupled with the interconnected contemporary challenges call for planning approaches that are systemic in focus. As Capra (1996: 3) explains, transformation for sustainability and enhancing social-ecological resilience requires an appreciation of the systemic and interconnected nature of contemporary systems. The tensions between the social and natural sciences is most likely conceptual in that the language of each discipline does not necessarily allow for studying humans in nature and seeing the boundary between social and ecological worlds as artificial. This boundary has nevertheless encroached on planning priorities, with increasing calls for upgrading the importance assigned to urban green space, preferably as a coherent planning entity (Sandström, 2002: 380). Elevating urban green space in planning also offers an opportunity to deepen the understanding of mutual resilience building and enhance the adaptive capacity of both social and ecological urban systems.

2.7 Developing a methodological framework: Revitalising the case for urban green spaces

In response to the historical neglect among planners of ecosystem service provision, there has been a re-examination of the way cities are planned, and particularly to the role of green spaces in urban resilience-building (MEA, 2005: 820). Rapid urbanisation has also stimulated an upgrading of interest in urban green space, and the ways in which this space can benefit cities have become key issues in urban planning (Sandström, 2002: 373). However, the inclusion of green space planning and ecosystem service provision in decision-making agendas is by no means widespread. This is part of a broader trend within the practice of sustainable development where environmental concerns are seldom sufficiently integrated with economic sectors and decision-making (Sneddon, Howarth & Norgaard*,* 2006: 256). Disregard for the benefits that urban green spaces can provide to both social and ecological systems overlooks the multifunctional role that urban ecosystem services can play in urban systems. Oleyar (2008: 290) notes that research has often been single-minded in its approach to valuing natural amenities, despite the fact that when research efforts are viewed collectively, the multiple functions of such amenities become clear.

To elevate ecosystem service provision in cities to a more prominent position in planning, a more robust case therefore needs to be made for including urban green spaces in planning agendas. A revitalisation of the current approach to urban green spaces is also needed if isolated pockets of green areas in cities and unequal access to ecosystem services are to be addressed. This section explores a more systemic approach to urban green spaces in order to assess the potential of ecosystem services to contribute to broader system resilience rather than exclusively to social or ecological functions (Barthel, 2010: 1). Revitalised urban green space and ecosystem service planning therefore includes multi-functional assessment, which is an important response to the multiple and interconnected nature of contemporary urban challenges. In other words, this chapter's focus is on how urban green areas can be acknowledged as sites of social-ecological interaction that can nurture ecological knowledge, value creation processes and human agency to improve both urban ecological and social processes (Ernstson, 2008).

2.8 Green infrastructure

An approach that is gaining increasing attention with the view of appreciating the multifunctional benefits of ecosystem services is the concept of green infrastructure (Tzoulas *et al,* 2007: 169; Pickett *et al,* 2008: 9; Stucki & Smith, 2010; de Groot *et al,* 2010: 3; City of New York, 2010: 1). The term infrastructure is defined as the substance or underlying foundation, especially the basic installations and facilities on which the continuance and growth of a community depends (Webster's *New World Dictionary* in Walmsely, 2006: 253; 257). Walmsely (2006: 257) explains that most people associate infrastructure with roads, sewers, and utility lines (the "grey infrastructure") or hospitals, schools and prisons (the "social infrastructure") which are collectively seen as "built infrastructure". Conventional urban engineering infrastructure is planned, built and maintained as a system of interconnected parts whereas most conservation programmes protect individual parks or isolated natural amenities (Yeang, 2008: 131; Benedict *et al,* 2002: 16). Mounting arguments are therefore being made for viewing the ecological assets of a social-ecological system as "green infrastructure" or eco-infrastructure that parallels the "grey" human-made infrastructure of roads, drainage systems and utilities (Yeang, 2008: 128).

Green infrastructure is becoming commonly increasingly used by planners to refer to among other things, green roofs, green open space, community gardens and urban forests (Benedict *et al*, 2002: 12; Dunn, 2010: 47-48). Despite its diverse application and different contextual meanings, there is consensus that green infrastructure is underpinned by a systemic logic in that it is seen to deliver both social and environmental services (Wolf in Kollin, 2003: 1). In line with this view, Kambites & Owen (2006: 484) define green infrastructure as encompassing "connected networks of multifunctional, predominately unbuilt, space that supports both ecological and social activities and processes". As a result, green infrastructure can be seen as an interconnected network of green space that conserves natural ecosystem values and functions, and provides associated benefits to human populations (Benedict *et al,* 2002: 12).

Green infrastructure is therefore an interconnected framework of both conservation and development prospects that can be used by ecologists and land use planners alike (Kambites *et al,* 2006: 484; McDonald *et al,* 2005: 7-9). By focusing on the multifunctional system of urban green space, green infrastructure serves as a bridge between a system's ecological and social capacity (Sandström, 2002: 380; Söderman & Saarela, 2010: 129). Linkages and connectivity are viewed as overriding characteristics of green infrastructure and render it an increasingly appropriate approach to mutual resilience building in urban landscapes faced with system-wide challenges (Kambites *et al,* 2006: 490). The connectivity between social and ecological function, as one of the linkage levels encompassed by green infrastructure, is underpinned by the logic of "mutual advantage" (Kambites *et al,* 2006: 490). This logic, which views conservation values, land development, growth management and the built environment on par with each other, is why green infrastructure differs from conventional open space planning. It means that the linkages between ecological and social functions should be included explicitly in green infrastructure planning (Kambites *et al,* 2006: 490). Green space systems revitalised as "green infrastructure" are therefore to be designed as built infrastructure is, to link elements into a system that functions as a whole rather than as separate, unrelated parts (Benedict *et al,* 2002: 15). This includes planning for multi-functionality of the ecological, social and economic benefits, functions and values of ecological assets (Benedict *et al,* 2002: 15).

By pre-identifying ecologically significant lands and suitable development areas, green infrastructure establishes a new connectivity between a system's landscape and its built form (Yeang, 2008: 128; Benedict *et al,* 2002: 13). The green infrastructure approach therefore sees spatial connectivity as the nexus between ecological and social function. Using this approach as a framework for shaping urban form extends in strategies in terms of space, beyond administrative boundaries (Kambites *et al,* 2006: 484). In doing so, green infrastructure rehabilitates the ecological connectivity of the immediate environment and turns human intervention in a landscape from a negative into a positive (Yeang, 2008: 128). This landscape-scale focus also distinguishes green infrastructure from conventional conservation planning by providing solutions for increasing land fragmentation that incorporate land uses for both ecological needs, such as biodiversity enhancement, and human purposes, such as working or recreational landscapes (McDonald *et al,* 2005: 7). The Landscape Institute (2009: 4) explains that although the connectivity between ecological and social functions takes many forms, the physical connections make the most impact by unlocking the range of opportunities provided by natural assets.

The social connectivity of green infrastructure is nevertheless important in planning for green infrastructure as ecological assets function at different scales in terms of stakeholder need and administrative jurisdiction. As Kambites *et al* (2006: 490) explain, various stakeholders have different needs, which may coincide or be in conflict, and the connectivity between different users needs to be prioritised (Kambites *et al,* 2006: 490). Furthermore, as nature and ecosystems do not recognise administrative boundaries, green infrastructure needs to be connected across different government levels and incorporated across multiple scales (Benedict *et al,* 2002: 15; Kambites *et al,* 2006: 490) At a strategic level, administrative connectivity requires the embedding of policy at multiple governance levels so that green infrastructure is strategically similar to traditional built infrastructure (Landscape Institute, 2009: 8; Benedict *et al,* 2002: 15). Benedict *et al* (2002: 15) explain that green space systems therefore need to be rolled out across multiple jurisdictions and incorporate green space elements at each level of government.

Affording green infrastructure the same status as other physical urban structures such as buildings and highways is an increasingly common research and planning priority (Sandström, 2002: 380). As a coherent planning entity, green infrastructure should be planned, managed and implemented publicly as roads and other "grey" infrastructure or schools and other "social" infrastructure are (Walmsley, 2006: 257; Benedict *et al,* 2002: 15). Green infrastructure should also be financed in the same way as traditional infrastructure is, as a primary public investment, funded upfront with other essential services rather than with surplus government funds (Walmsley, 2006: 257; Benedict *et al,* 2002: 17). Van der Ryn & Cowen (in Walmsley, 2006: 247) elaborate on the conceptual basis of green infrastructure: "[t]he name "green infrastructure" implies something that we *must have* instead of green space that is something *nice to have*". Seen in this way, green infrastructure is a critical public investment that is embedded in statutory planning process (Benedict *et al,* 2002: 17; Kambites *et al,* 2006: 490). As Wolf (2004: 33) states:

> "A city would never build a road, water or electrical system piece by piece, with no advanced planning or coordination. Green infrastructure is the idea that nature in cities should be administered in an integrated way, just as grey infrastructure systems have been."

2.9 Revitalising the case for infrastructure reconfigurations

The defining contribution of a green infrastructure approach is seeing infrastructural assets as the ecological and natural assets that provide multiple social, environmental and economic functions (Landscape Institute, 2009: 4). As the Landscape Institute (2009: 4) explains, green infrastructure strategically prioritises the provision of ecosystem services and aims to enhance a system's ecological assets. In doing so, green infrastructure responds directly to the increasing pressure to develop land into built environments at the expense of green open spaces. Green infrastructure's assets, as inherently spatial and multi-scalar, may also advance the case for and implementation of resilient infrastructure at multiple scales and governance if incorporated into "critical" infrastructure categories. The following statement gives insight on the idea of integrating ecological infrastructure with other built and social asset investment:

> "Vegetation is part of the region's infrastructure, woven into a complex network of power lines, roads, aqueducts, and sewers that together help to sustain human health and quality of life. Yet, little is known about how this green infrastructure creates benefits and costs for people. (Rowntree, Nowak & McPherson in McPherson, Rowntree & Rowntree, 1994: 1)

2.9.1 Greening infrastructure systems versus green systems

Green infrastructure's direct response to the widespread erosion of ecological resilience introduces a critique of emerging research on sustainability transitions. A recurring theme of such research is to suggest reconfigurations of the infrastructure that control the material and energy flows of cities (Weisz & Steinberger, 2010: 2). This is based on consensus that metalogistical systems in cities, - intensive international airline networks, massive logistical transport systems and enormous energy and water networks – are shaping global planetary ecologies through resource depletion, carbon production and pollution (Hodson & Marvin; 2010a: 300-310). Emerging responses to the metalogistical domination of cities include refitting new energy infrastructure structures, laying down new ICT systems, road pricing control measures, and introducing decentralised renewable energy technologies (Hodson & Marvin, 2009: 516). Strategists advocating these transformations argue that more resilient urban infrastructure systems, as traditionally defined, can internalise resource requirements and boost the self-reliance of cities (Hodson *et al,* 2010: 2).

The emerging literature on technological transitions situates technical networks in relation to wider socio-political-economic structures (Hodson *et al,* 2010b: 3; Guy *et al,* 2001: 27). These socio-technical-regimes have become the focus of much transition literature in sustainability science by portraying a network-focused image sensitive to political, cultural, economic and physical interconnections (Smith, Stirling & Berkhout*,* 2005: 1491; Guy *et al,* 2001: 27). This image sees cities as assemblies of physical and cultural networks where changes to technical infrastructure co-evolve with social functions and social interests (Guy *et al,* 2001: 27-29; Hodson *et al,* 2010b: 3). According to this multi-level approach, reconfigured technical infrastructure needs to be strategically linked to the multiple scales at which cities operate and the multiple governance levels that shape infrastructure provision (Hodson *et al,* 2009: 517; Hodson *et al,* 2010b: 6).

Although urban infrastructure transformations are undoubtedly important in addressing the congested metabolism of many cities, focusing purely on traditional utilities in socio-technical transitions overlooks the potential sources of infrastructural change that ecological assets themselves provide. In explaining socio-technical regimes in relation to transformation for sustainability, Smith *et al* (2005: 1491) focus on the wider, linked processes that green the systems of social and technological practice. The implicit assumption is that "red" or social and "grey" or built infrastructures need to be greened to enhance a socio-technical regime's adaptive capacity (Smith *et al,* 2005: 1492). In contrast, focusing on green systems themselves, as infrastructure styles, may actually lessen the reliance of society on man-made infrastructure and its associated energy and water requirements Benedict *et al* (2002: 17) state that the strategic placement of green infrastructure may reduce the need for grey infrastructure due to the systemic benefits that properly managed ecological assets can have for a region's ecosystem and economy.

Without explicit inclusion of green systems themselves in urban infrastructure categories, technological reconfigurations remain one-dimensional as the sources of regime change available. As Miththapala in IUCN (2008: 21-22), explains, conventional definitions of infrastructure and the investment in this infrastructure, ignores one of its most productive components – natural ecosystems. Miththapala in IUCN (2008: 22) elaborates:

> "Few people would deny that infrastructure— the facilities, services and equipment needed for society to function— lies at the heart of economic development and poverty reduction. So it is hardly surprising that development investments, national spending and overseas aid have always focused heavily on it."

When natural assets are viewed as separate entities or afterthoughts in land use planning, the symbiosis between natural assets, local environmental and economic performance is overlooked (Landscape Institute, 2009: 1). Therefore, despite progress made in expanding work on transitions and system innovations, the technological dominance of emerging sustainability solutions does not accommodate the green infrastructure that we are intimately connected to in everyday life (Geels & Schot, 2007: 399-400). The erosion of resilience of this green infrastructure is the core challenge of many ecological urban problems, where the capacity of local ecosystems to adapt is increasingly undermined. Seen in this light, enhancing ecological resilience by valuing ecological assets as "critical" infrastructure responds directly to the call for more resilient urban infrastructure in existing transition literature.

2.9.2 Embedding infrastructure capabilities in local contexts

Furthermore, incorporating the ecological support structures that function as nature's infrastructure in "critical" infrastructure categories may assist in connecting an area's infrastructural capabilities to its local context (Yeang, 2008: 128). Embedding technological possibilities in a region's local context is an area of difficulty increasingly cited in emerging socio-technical transitions literature (Hodson *et al,* 2009: 516). Hodson *et al* (2010b: 4) state that within the field of socio-technical transitions, spatial scale generally remains implicit or underdeveloped in multi-level analysis. The limited focus on spatial scale, aside from national level, has resulted in uncertainty about where transitions occur, including the spaces and places of transitions in local contexts (Hodson *et al,* 2010b: 4). To rectify the limited attention given to spatial scale, existing transition research suggests that intermediary bodies such as research and technology institutions can facilitate the flow of knowledge between different users and scales (Hodson *et al,* 2009: 516).

Green infrastructure explicitly sees an area's infrastructural possibilities as the connectivity between local ecological functions and socio-economic needs. Since green infrastructure is a systemic framework that connects conservation and development opportunities, it provides this landscape-scale focus needed to understand the shaping of urban form (McDonald *et al,* 2005: 7). The explicit inclusion of spatial connectivity in green infrastructure frameworks therefore responds to the difficulties that existing technological transition research faces in conceptualising the role of pace and regions in urban transitions. The connectivity between different users; government levels; social and ecological functions; and physical landscapes embedded in green infrastructure has the potential to restore, enhance and create intermediaries through a green supply chain of ecological and social flows. This supply chain has, at its core, the flow of ecological knowledge between different actors and the feeding of knowledge at different management organisations and scales seen as the functions of intermediaries by existing transition literature (Folke *et al,* 2005; Hodson *et al,* 2009: 521-522).

Connecting response options to the country contexts is crucial in ensuring appropriate sustainability transitions. Research assessing the success of technology transfers reveals that developing countries face challenges to the transfer of technologies, and particularly of sustainable technologies such as renewable energy provision (Brent *et al*, 2008; 1). Mabuza, Brent & Mapako (2007; 237) attribute the unsuccessful transfer of technology in developing regions such as Africa to the lack of a sustainable method of distribution, servicing and improving technology. The technological predominance of socio-technical transitions may therefore be a luxury found in developed countries and something developing economies are poorly equipped to finance and implement. The overwhelming number of European case studies demonstrating technological solutions for material and energy flow management cited in socio-technical transition literature is one case in point (Hodson *et al,* 2010; Hodson *et al,* 2009).

Part of embedding transition abilities in developing country contexts is the need to create inclusive cities in these countries where poverty, income inequality, marginalization and various forms of exclusion have created an urban divide that reduces social and economic opportunity for vulnerable groups (UN Habitat 2010). Responding to these challenges in an ecologically sustainable way has led to the urgent priority of creating decent work in a sustainable, low-carbon world, but particularly in developing countries (UNEP, 2008; 3). This logic is aligned to growing recognition that economic policy needs to respond to the severity of the ecological crisis and has provided the impetus for green economy and green job initiatives (Swilling, 2010). A green economy is defined by UNEP (GER, 2010: 5) as:

> "...an economy that results in improved human well-being and reduced inequalities over the long term, while not exposing future generations to significant environmental risks and ecological scarcities."

Valuing green infrastructure such as urban parks, urban forests and community gardens, has the potential to offer "green" collar jobs that provide a pathway out of poverty for marginalised groups that also enhance ecological resilience (UNEP, 2008: 289). The double dividend of addressing the twin challenges of ecological and social wellbeing by enhancing ecological infrastructure and society's adaptive capacity renders green infrastructure an appropriate framework for implementing the idea of a green economy. Investing in economic sectors that build on or enhance the earth's natural capital or reduce ecological scarcities or environmental risks forms the foundation of this green economy (UNEP, 2010: 4). However, in many developing countries, low skilled work forms a large part of the employment sector and the skills gap between available workers and green technology industries has been cited as an employment challenge (UNEP, 2008: 25). The type of employment opportunities offered by green infrastructure industries facilitating ecosystem service provision such as the planting and maintenance of urban gardens, forests and parks, provide the low-skilled employment opportunities needed to match the skills base in developing countries.

However, bridging the developing country skills gap by growing manufacturing and research and development industries is nevertheless crucial in creating more opportunities that enable more equitable socio-economic realities in the long term. Green infrastructure offers the prospect of addressing the skills deficit in two areas. Firstly, if ecological assets such as regional parks are to be perceived on a par with traditional public utilities such as housing provision, green infrastructure potentially creates a new type of service or expands the reach of the public service sector. Through government-driven public service jobs, green infrastructure offers enormous opportunity for those countries that previously had difficulty in finding their place in the "old" economy due to unequal access of skills, resources or opportunities (UNEP, 2008: 25-26).

Economic investment in ecological assets also requires higher skilled job and academic training for professionals such as horticulturalists and ecologists. In doing so, green infrastructure entails secondary and tertiary sector employment opportunities, which expands the reach and range of a country's skills base. As the UNEP Green Jobs Report (2008: 38) states, green collar jobs extend from private business to government offices and to academia and support a variety of educational backgrounds. However, in developing countries, where barriers exist to the successful transfer of technological innovation, the diversity of both the ecological assets and employment opportunities encompassed in a green infrastructure approach is potentially a more just approach to green economy transitions.

The creation of green jobs in the face of intersecting ecological and development challenges can also boost a city's global competitiveness. Recent studies show that a rising number of "green movements", in an attempt to "out-green" each other, have cities that are creating their own localised sustainability solutions (Karlenzig, 2010: 8). For cities wanting to compete globally, the economic imperative is then to make the transition from energy intensive and ecologically unsustainable urban forms, which have become unattractive for economic investment. This is confirmed by Ward & Schäffler (2008; 5) who note the trend internationally is towards decoupling and greener economies. Karlenzig (2010: 9) elaborates,

> "Growing a green economy will be a fundamental facet of urban resilience. Key areas of future job growth are in green building and landscaping, water-conservation technologies, low-carbon materials design, advanced low-carbon transportation, green information and communications technologies, and smart-grid development."

The social-ecological system, as legitimised by a green infrastructure framework, may therefore be an appropriate way of envisioning urban sustainability transitions in developing countries where development challenges coincide with losses of ecological resilience and where the provision of decent and sustainable jobs is an urgent planning priority. Green infrastructure planning can also facilitate those cities who want to be cities of the future, in ecological and economic investment terms. It is a type of planning that enhances the resilience of both economic and ecological systems, which is an unprecedented opportunity in the face of rapidly eroding ecological resources, development challenges such as poverty and inequality as well as the worst financial crisis since the Great Depression that crippled economies and their investment ratings (Karlenzig, 2020: 15). A green infrastructure approach draws attention to the type of infrastructure transitions cities invest in. Although sustainability response options focusing on "grey" infrastructure such as public transport systems, high density urban form and renewable energy technologies are important, investment in green assets directly addresses loss of ecologic resilience. The type of infrastructure investments made from a sustainability transition perspective can be the crucial link between social and ecological systems at multiple levels – through reconnecting people and nature, improving diversity of all life forms and responding to development imperatives in a green and ecological manner.

2.10 The real value of ecosystem services

At the core of a green infrastructure planning approach, is an economic rationale for investing in and maintaining the natural assets of social-ecological systems in addition to the ecological motivations commonly advocated by the natural sciences (De Wit *et al,* 2009: 258). Despite the direct link between ecosystem health and human well-being, less investment in ecological infrastructure has broader economic implications that extend beyond the non-performance of natural assets (Miththapala in IUCN, 2008: 22; De Wit *et al,* 2008: 3; De Wit in De Wit *et al,* 2009: 2). The financial and economic logic for addressing further loss of ecological resilience is based on real value accounting of ecosystem goods and services (De Wit in De Wit *et al,* 2009: 2).

Real value accounting is an area of research and a method of valuation that has developed alongside the critique of traditional economic accounting systems which have hidden the costs of economic development that destroys habitats and impairs ecosystem services (Daily *et al,* 1997). However, critiques of traditional economic decision-making have themselves struggled to explicitly clarify the link between ecosystem goods and services and socio-economic development (De Wit *et al,* 2009: 8) De Wit (in De Wit *et al,* 2009: 2) gives insight here:

> "The argument that the natural environment needs to be preserved for its own sake may have raised awareness and educated people on the importance of the natural environment, but have not provided a convincing financial rationale to invest in natural assets."

The short-term bias of mainstream economic decision-making is a familiar point of critique in literature exploring the value of ecosystem services, as captured by markets and policy decisions, in relation to economic services or manufactured capital (Constanza *et al,* 1997: 253). However, valuing natural assets purely for their ecological value overlooks the fact that these assets function in conjoined social-ecological systems accruing benefits beyond their intrinsic value. Without acknowledging the value of services that flow from ecosystem processes to humans, our official government decision-making systems have little economic reason to invest in natural assets as a type of infrastructure. As a result, the services provided by ecological infrastructure or natural assets receive insufficient priority in budget allocations, on both expenditure and revenue sides (De Wit *et al*, 2008: 2). Miththapala in IUCN (2008: 22) gives insight on the implications of separating ecological infrastructure from economic development and poverty reduction:

> "If ecosystems are recognized as assets which yield many of the services required for the economy and society to function properly, the human, social and financial capital that is required to sustain them (and which they, in turn, sustain) also needs to be allocated."

When natural assets are overlooked in municipal accounts, they are treated as free services that flow to society, as in the case of other services such as utilities which receive the majority of investment and funding (De Wit *et al,* 2009: 2; Miththapala in IUCN, 2008: 22). However, as De Wit *et al* (2009: 2) explain, the natural factories that produce these services also need proper ongoing maintenance and in the case of damage, repair as is the case for traditionally-maintained infrastructure assets. Aside from these expenditure implications, insufficient inclusion of natural assets in municipal budget allocations overlooks the revenue-generation potential and broader economic contribution of ecosystem services. As a result, "balance sheets rarely tally up the economic benefits that ecosystem services provide, or recognise that there is a tangible return to investing in their conservation" (Miththapala in IUCN, 2008: 22).

This exacerbates the persistent problem of ecosystem undervaluation in development planning, which fails to appreciate the value-adding potential of resilient green infrastructure base (Miththapala in IUCN, 2008: 22). To avoid further loss of resilience and factor into development planning the economic contribution of ecological assets such as urban green spaces, attention is increasingly on integrated valuation frameworks. De Wit *et al* (2009: 9) explain that an integrated valuation framework:

> "...considers the services that ecosystems provide, the impact these goods and services have on economic systems such as crops, water, livestock and energy and how this relates to Total Economic Value".

Following the work of Martin de Wit *et al,* Total Economic Value (TEV) is a framework "used to value both market and non-market benefits, as well as values derived from future use, along with values totally unrelated to future consumption" (De Wit *et al,* 2009: 7). The implication of valuing ecosystems in an integrated manner, in the same way as traditional infrastructure is valued, is that investment to maintain natural assets and enhance the value of the flows from these assets becomes an economically rational decision for municipalities (De Wit *et al,* 2009: 3). In other words, by calculating the total economic value of natural assets, a focused economic argument can be made for the investment, maintenance and expansion of ecosystem services, which are, in turn upgraded to the category of "green infrastructure" (De Wit *et al,* 2010: slide presentation). Improving the incentive structure of the beneficiaries of ecosystem services to invest in natural assets is important for internalising green infrastructure in economic accounting procedures and government policies that affect the functioning of ecosystems (De Groot *et al*, 2010: 3; 13).

Every social-ecological system is endowed with its own set of ecosystem services that constitute the main services types in that system. This involves assessing the relative importance of different natural assets for the generation of ecosystem goods and services in a specific system (De Wit *et al* in De Wit *et al,* 2009: 66). Similarly, the channels through which ecosystem services contribute to economic needs to be prioritised in relation to the specific set of beneficiaries and development challenges in a particular economy. For natural assets, such as green infrastructure, to be contextually relevant, the impact of ecosystem services on key development challenges is a critical part of total economic valuation (De Wit *et al* in De Wit *et al,* 2009: 69). In terms of valuation, this means estimating the importance of ecosystem goods and services to users or beneficiaries and establishing the links between ecosystems services and development objectives (De Wit *et al* in De Wit *et al,* 2009: 66; 68).

As socially mediated, ecological processes need to be valued in relation to the institutions mandated to manage certain environmental functions. De Wit *et al* (in De Wit *et al,* 2009: 69-70) explain that the ownership status of ecosystem goods and services may be under municipal control or be shared with other institutions. Awareness of the management differentials of ecosystem services has implications for motivating an economic case for green infrastructure investments as well as whose mandate it is to do so. In terms of methodology, this means assessing municipal ability to influence the value of ecosystem goods and services through management (De Wit *et al* in De Wit *et al,* 2009: 69).

However, one caveat to valuing the ecosystem service types is that, as a result of human activity and associated land use change, ecosystem services of a particular area may be artificially constructed services that are valuable to society, but undermine the naturally occurring ecological assets endemic to a particular area. For this purpose, the desired system state of a social-ecological system needs to be analysed in relation to naturally occurring ecological processes. This implies acknowledging that the ability of natural assets to provide sustained flows of ecosystem services may be undermined, or that the environments in which these services naturally occur may be vulnerable to undesired change or risk (De Wit *et al* in De Wit *et al,* 2009: 70). The implication for valuation is ranking according to risks faced where those natural assets whose adaptive capacity is being seriously eroded, and that have a higher impact if their resilience is undermined, need to be given priority in assessment (De Wit *et al* in De Wit *et al,* 2009: 70).

The valuation techniques chosen to assess the overall ecological and economic contribution of specific ecosystem services depends on the availability of data for a given context (De Wit *et al* in De Wit *et al,* 2009: 72). Valuation techniques are also contingent on the context being studied in that valuation criteria need to make local sense and convey information that is meaningful for the stakeholders involved in order to influence decision-making agendas. Based on the discussion of total economic value, De Wit *et al* (in De Wit *et al,* 2009: 65) propose the following six-step methodology to value the total contribution of ecosystem goods and services:

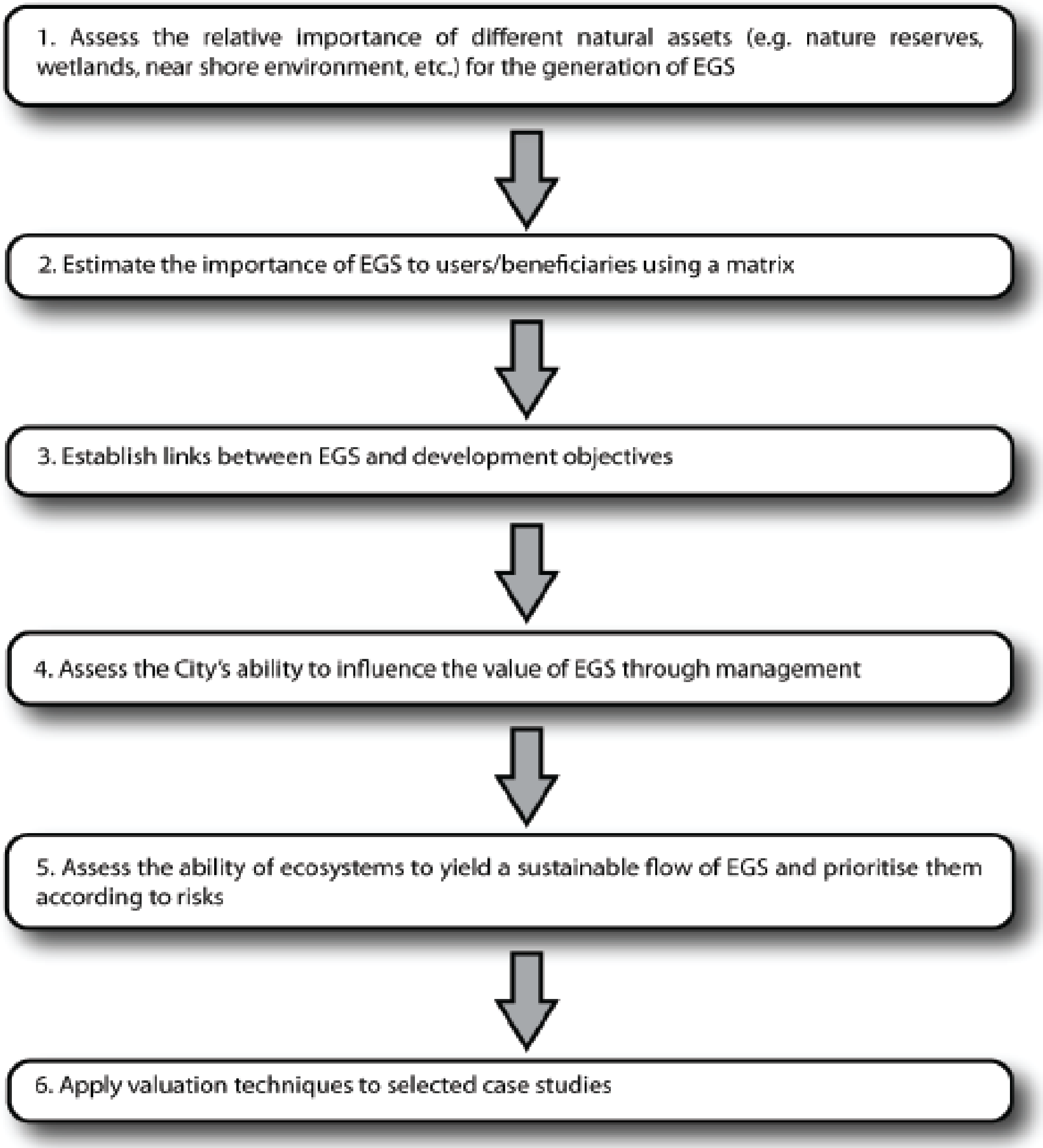

Figure 2 The Six Step Valuation Methodology of Ecosystem Gods and Services EGS in De Wit et al, 2009: 65

2.11 Concluding thoughts: The literature review journey

The resilience of social-ecological systems is fundamentally being altered by the second wave of urbanisation where developing countries are the main location of future urbanisation. However, developing countries are faced with particular challenges in terms of their ability to invest in the infrastructure needed to meet unprecedented urban growth levels. The resultant urban tension is one where developing country cities face cross-cutting ecological and socio-economic challenges, but as urban centres, are potential sites of transformation for sustainability. Based on social-ecological system analysis, transformation for sustainability needs to improve the adaptive capacity of social and ecological systems simultaneously. Response options that focus exclusively on either social or ecological systems are unlikely to sustain an overall system's resilience.

The distinct spatial dimensions of contemporary urbanisation trends necessitate awareness of the use of land in cities and the changing nature of land patterns, as a result of increasingly pressurised urban systems. Despite the complex nature of space and how it is formed, there is a major role for urban green spaces in transformation for urban sustainability. This is based on the erosion of local ecosystem resilience in cities as a result of green areas being traded off for commercial, industrial and residential purposes. Market distortions and short-term investment decisions have contributed to this erosion, as has the idea that socio-economic challenges are separate to, and more important than, ecological resilience. This miscommunication between development priorities requires that ecological assets, which in the case of cities are generally urban green spaces, are treated on a par with other social and economic investments.

The green infrastructure approach to valuing ecological assets is suggested for the revitalisation of urban green space as a coherent planning entity that is planned, budgeted and implemented in the same way as other infrastructure assets. Green infrastructure responds to social-ecological system analysis by prioritising the multifunctional nature of ecological assets, which therefore have socio-economic as well as ecological benefits. Furthermore, by pre-identifying ecologically suitable lands in a given area, the green infrastructure approach provides the landscape-scale focus that has been overlooked in much contemporary sustainability transition literature. This spatial link responds directly to the loss of ecological resilience affecting urban centres today and embeds infrastructure in a country's local ecological context, thereby advancing the case for infrastructure configurations. Developing countries seek to benefit from such an approach as investment in a green supply chain not only provides low skilled employment opportunities, but offers an opportunity to bridge skills gaps, in turn enhancing knowledge networks and boosting a city's global competitiveness.

At the heart of a green infrastructure approach is valuing ecological assets in terms of their ecological and economic benefits. This is important to influence decision-making systems and investment decisions by making explicit the services that society derives from ecosystems in social-ecological systems. To demonstrate the idea of total economic valuation, the six-step methodology proposed by De Wit *et al* in De Wit *et al* (2009) will be applied to a case study in Chapter Three. The following sections will analyse the City of Johannesburg as a social-ecological system, where ecological processes have been fundamentally altered by human activity and ecological challenges occur alongside socio-economic problems. Thereafter the main ecological assets will be assessed in terms of their ecological and socio-economic benefits to value the green infrastructure base of the city.

Chapter Three: Case study

3.1 Urbanisation and ecosystem services in Johannesburg

The idea of green infrastructure has been proposed as a response option to the multiple challenges facing cities where, for overall resilience to be sustained, the adaptability of both social and ecological systems needs to be enhanced. This conceptual framework includes a theoretical methodology where the total economic value of ecosystem services, as provided by natural assets, needs to be prioritised in planning and investment decisions. To make this conceptualisation real, however, the argument put forward in Chapter One will be applied to Johannesburg as a city facing multiple social and ecological challenges as a result of urbanisation. On the other hand, the construction of various green systems and the sparking of an industry and green supply chain are case studies of infrastructure styles based on ecological assets, if explicitly valued.

Johannesburg as a case study therefore offers the chance to unpack the complex dynamics of the second urbanisation wave. It is a city with significant development challenges including lacklustre employment growth due to the dominance of tertiary economic activity, which is exacerbated by population growth occurring much faster than job creation. Yet Johannesburg's status as having the capacity to innovate, adapt and invest in economic opportunity is legendary, contributing most to South Africa's economy in terms of GDP, while covering the smallest land surface in the country. This paradoxical identity, where hawkers, day labourers and others sell a variety of consumable items at robots in order to make a living, is underpinned by a history of spatial exclusion inherited from apartheid legacies and in Johannesburg, unemployment and socio-economic disparity is vividly apparent. Spatial injustices are paralleled by a rapidly sprawling landscape, resulting in an increasingly built-up form to compensate for growing urban appetites for roads, cars, food and houses. Within a private car-dominated transport system and a trend towards car-based enclaves from which certain socio-economic groups are excluded, there are elements to Johannesburg's spatial form that perpetuate the loss of social and ecological resilience.

It is therefore unsurprising that a large portion of writing on Johannesburg focuses on its contested and unequal past (Crankshaw, 2008; Bond, 2007; Nuttal & Mbeme, 2008). However, despite the unsustainable features of Johannesburg's urban growth, government documents extensively publicize the city as the world's largest urban forest. Although there appears to be no verifiable statistic on the exact number of trees in Johannesburg, an overview of relevant literature and documents estimate that the forest stands at approximately ten million trees (CoJ SOER, 2008: 100; CoJ, 2004). If it is accepted that Johannesburg is the site of a ten million-strong forest, the city's trees are significant for a number of ecological and socio-economic reasons and uniquely position Johannesburg as a potential site of transformation for sustainability.

In assessing the relative importance of Johannesburg's natural assets, the urban forest is significant in terms of its scale and geographic reach. However, the forest has been subject to significant criticism in that its artificial construction in naturally occurring grassland, has created hydrological pressures in a region without a large navigable water body, and the dominance of introduced species is potentially detrimental to other ecological processes. Furthermore, much like the rest of Johannesburg's physical landscape, the urban forest has not been evenly distributed and its application has been in the predominately white, wealthy northern suburbs. Despite these issues, at the current stage of Johannesburg's development, there are ecosystem services provided naturally by the vast tree canopy that, in a rapidly urbanising and built-up urban system, offers much needed green respite. These services represent the complexity of Johannesburg's greenery in that the mining boom that provided the initial impetus for a largely non-indigenous forest, has also created an urban system where carbon storage and sequestration, nutrient recycling, water filtration, natural cooling, and the provision of habitat for other species, are some of the ecosystem services offsetting threats to ecological resilience.

However, Johannesburg-specific information on the ecosystem services provided by the estimated ten million trees and associated green spaces, is largely non-existent. Based on interaction with relevant work and in accordance with the findings of Stoffberg *et al* (2010: 9), little research has been done on urban forests and urban green spaces and there appears to be a general lack of information on urban tree species in general. It is also apparent that where detailed analyses have been conducted on the economic benefits of urban greening, these studies are specific to European and Northern American contexts, or are otherwise based on rural Southern African ecological systems. The lack of data on urban forest functions and their tangible economic values, could be reasons for the disregard of Johannesburg's green features as urban infrastructure services that accrue tangible values to the city if valued explicitly (Jim *et al,* 2008: 674).

If the necessary research is conducted to connect detailed information on Johannesburg's ecological systems to quantifiable economic values, the joint social and ecological benefits of the ecosystem services provided by the city's green systems can be assessed. This is because although the evolution of Johannesburg's ecological reality is constructed in many ways and has followed a similar pattern to the city's unequal socio-spatial history, it has also included an economy and culture of greening that potentially forms a much overlooked infrastructure base. Since this infrastructure comprises green assets, Johannesburg has the potential to enhance the resilience of its ecological and social systems through the tangible benefits of 'free' ecosystem services, as well as the feedback loop represented by a green supply chain. Acknowledging the wider socio-economic roles of the urban forest and the social systems that have accompanied its development, creates the space for Johannesburg to respond and enhance the benefits that are already planted in the city.

This chapter therefore analyses Johannesburg's urban forest as a prominent ecological feature, which together with parks, gardens and other green areas can collectively be referred to "urban green systems", despite being largely introduced systems (James *et al,* 2009: 66; Koningnendijk, 2005: 9). Johannesburg also includes other natural assets that provide ecosystem services and form ecological networks, such as aquatic areas and wetlands. An appreciation of these natural assets within the city is important insofar as achieving a landscape scale focus, as well as understanding that social-ecological values of ecosystem services extend beyond publicly delineated space to other green networks. However, due to the lack of detailed context-specific data, some of the values of Johannesburg's ecosystem services provided by trees and green spaces, are based on reasonable assumptions and other values have been derived from similar studies conducted in other contexts. This is a research gap that needs to be addressed in future studies so that original data is available to build a more in-depth inventory of the world's largest urban forest, which is a claim that also needs to be investigated. For the purposes of this study, however, the ten million trees will be taken as a reasonable assumption that is yet to be refuted in public statements. In addition, accurate data on the range of ecosystem services on offer in Johannesburg is also unavailable and primary research is needed to connect these dividends to tangible economic values through detailed valuation exercises.

An overview of Johannesburg's experience as a city is crucial to understanding the social-ecological context that renders its greening and forestry important sources of urban resilience in the face of cross-cutting challenges. Thereafter the green infrastructure systems operating in Johannesburg are outlined in terms of their social-ecological values. However, due to the lack of data to link physical information of Johannesburg's green infrastructure with economic value, many of the empirical requirements of the methodology for valuing natural assets, as described in chapter one, were impossible to fulfil in detail. Although this is acknowledged as a weakness of the case study application, which hampered the implementation of the research strategy, the case study is therefore also seen as a stepping stone for further research. This is in terms of the development of a possible conceptual framework with which to execute detailed analyses of the multiple values of Johannesburg's green systems and green infrastructure valuation work specific to the city. To this degree, the data limitations had the unintended result of the case study journey developing a methodology for future research. Connecting detailed ecological information to tangible monetary values is nevertheless a research task for future analysis, in order for Johannesburg to enhance its social-ecological resilience through green infrastructure assets.

3.2 Johannesburg as an urbanising system: literature review

> "For many people, Johannesburg has become the imagined spectre of our urban future. Global anxieties about catastrophic urban explosion, social fracture, environmental degradation, escalating crime and violence, as well as rampant consumerism alongside grinding poverty, are projected onto a city the fate of which has implications and resonance way beyond its borders." (Beall, Crankshaw & Parnell, 2002: 3)

Beall *et al's* commentary on the extent and complexity of Johannesburg's challenges reveal the multi-faceted attack being carried out on people and nature in Johannesburg (Bond, 2007: 11). The many levels of this attack render the city a quintessential complex social-ecological system, which culminates in spatial, racial, gendered, ecological and class contradictions (Bond, 2007: 2). As a result, there are numerous intersecting processes that influence Johannesburg's system state and future ability to adapt to undesirable circumstances. However, the trend that traverses all Johannesburg's social-ecological features is that, unlike the now atypical cities of the industrialized Northern hemisphere but in common with many cities of the South, Johannesburg's population is expanding (Beall *et al,* 2000: 121). The most recent official data, released in March 2008, estimate Johannesburg's population at 3.8 million, which is a 20.6% change from 3.2 million in 2002 (CoJ IDP, 2010/11: 12). Van Huyssteen *et al* (2009: 179) further state that amongst the 4.3 million people in all the city regions in South Africa, the population of the City of Johannesburg alone increased by 1.25 million people between 1996 and 2007.

Official population statistics estimate Johannesburg's population at close to 3.9 million and a household count at just over 1 million, making Johannesburg the largest city in South Africa and translates into an average of 2003 persons per square kilometre (StatSA, 2007: 7; CoJ SDF, 2007/8: 2; SACN, 2006: 5). This is based on the municipal boundaries identified by the CoJ, which encompasses an area of approximately 164 458 hectares (JMOSS, 2002: 17) However, other documents reveal that Johannesburg's population varies between 4.3 million to 4.6 million people, which if true, means that the projected population growth for 2025 has already been exceeded (Theunissen in Urban Green File (UGF), 2010: 21). However, at a regional scale, together with the cities of Tshwane and Ekurhuleni, with populations of 2.3 million and 2.7 million respectively, and other smaller urban areas, Johannesburg forms part of the Gauteng City-Region, which is South Africa's smallest, but most densely populated with approximately ten million people (StatsSA, 2007: 7; Wray in GCRO; 2010: 39).

The rapid process of Johannesburg's urbanisation is characteristic of low- and middle-income countries of the twenty first century, as the trend which is replacing the slow and gradual demographic transition that characterised industrialised countries (Beall, Guha-Khasnobis & Kanburg, 2010: 197). Johannesburg displays many of the features associated with the second urbanisation wave and in line with findings on contemporary urbanising systems; dynamics play out in unpredictable ways in this complex urban system. One such example is that Johannesburg's anomalistic physical existence is coupled with a potentially significant ecological asset, confirming that urban dynamics are products of multiple overlapping and complex trends. Before the relevant ecological assets relevant can be identified and valued, Johannesburg's unique metamorphosis as a city within the second urbanisation wave and the trends that have formed the contextual background to this complex reality and its challenges need to be appreciated.

3.2.1 Contextual background

It is generally recognised that the choice of the site of Johannesburg in 1886, and the initial urban expansion, has much to do with the discovery of gold and the geographical locations of where gold was first found (Beavon, 2004: 4). The gold-bearing reef, to which Johannesburg owes its existence, was formed as a result of biological processes and tectonic movements (Turton *et al,* 2006: 313). These movements, coupled with sedimentary cycles, occurred approximately 3000 million years ago and exposed a gold-bearing reef to the surface of where Johannesburg is now located (Beavon, 2004: 4; Werdmüller in Turton *et al* & Turton *et al,* 2006: 314-315). This made the discovery of gold a relatively easy one, and significantly shaped South African's future and particularly, Johannesburg's identity as the 'City of Gold' or 'iGoli' in IsiZulu (Werdmüller in Turton *et al,* 2006: 314-315; Bond, 2007: 2).

The tectonic movements, which involved the collision of two large masses of rock, also lead to a period of orogeny or mountain building that created a major watershed in Southern Africa called the Witwatersrand ridge (Beavon, 2004: 3). Translated into English, Witwatersrand means "Ridge of White Waters", which took its name from the myriad of small springs that cascade across the region's geographical complex before starting their journey as rivers down to the sea thousands of kilometres away (Turton *et al,* 2006: 316). At a high altitude of approximately 6000 feet above sea level, all rain falling to the south of the Witwatersrand forms part of the Vaal/Orange Primary Catchment area and ultimately into the Atlantic Ocean, whereas all rainwater falling to the north is part of the Crocodile Marico Secondary Catchment, and ultimately flows east into the Indian Ocean (CoJ SOER, 2008: 150). At this high altitude, potable water has to be pumped to Johannesburg from the Lesotho Highlands Water Project and any disruption to this water supply would have critical impacts on the city's water supply (Turton *et al,* 2006: 316; CoJ Water, 2010: Theunissen in UGF, 2010; 19). As an important headwater for major river basins, changes to water quality and stresses on water availability in the Witwatersrand also impacts many stakeholders downstream (Turton *et al,* 2006; 316).

Johannesburg is therefore unique on both global and local levels, in that it is one of the few major cities of the world that does not lie on a river, a lake, or seafront, and therefore lacks many of the fundamental factors usually associated with city development (Turton *et al,* 2006: 313-316). This is because metropolitan development, a trajectory that in the West took years to unfold, was compressed in Johannesburg in under a century, yet without the fundamental features usually associated with urban growth (Mbembe *et al* in Nuttal *et al,* 2008: 18).

3.2.1.1 The gold-mining boom

Johannesburg's initial urban expansion has roots in the gold-mining boom during the 1880s and as a result, Johannesburg's experience of urbanisation is very particular due to its origins in gold production, which depended on a highly unequal migrant labour system and the demand of primary commodities elsewhere in the world (Beall *et al* (2002: 3).Various commentaries therefore note that the sole reason for Johannesburg's creation was the pursuit of material wealth, rather than the appropriateness of its location for long term human development (Turton *et al,* 2006: 316, Mbembe *et al* in Nuttal *et al,* 2008: 18). This period, where the fuel for rapid growth was gold, and Johannesburg as a primary commodity-based economy, has become known as the period of racial Fordism, which lasted roughly from the end of World War II to the onset of the oil crisis in the mid 1970s (Beavon, 2004: 6; Beall *et al,* 2002: 33).

The foundations that mining set in place for Johannesburg cannot be overstated. Despite significant economic restructuring, banks, finance houses, mining company headquarters and an established CBD lined the streets of the "City of Gold" within the first ten years of its existence (Chipkin in Bremner, 2000: 185; Bond, 2007: 6). What has been described as originally a dusty, dirty mining camp was rapidly transformed into one of the largest urban centres in Africa, with population numbers eclipsing that of much older cities in the region (Beavon, 2004: 6). Beavon (2004: 7) further explains that within a matter of decades, Johannesburg expanded northwards, but fairly evenly in other directions, assuming metropolitan proportions throughout the twentieth century.

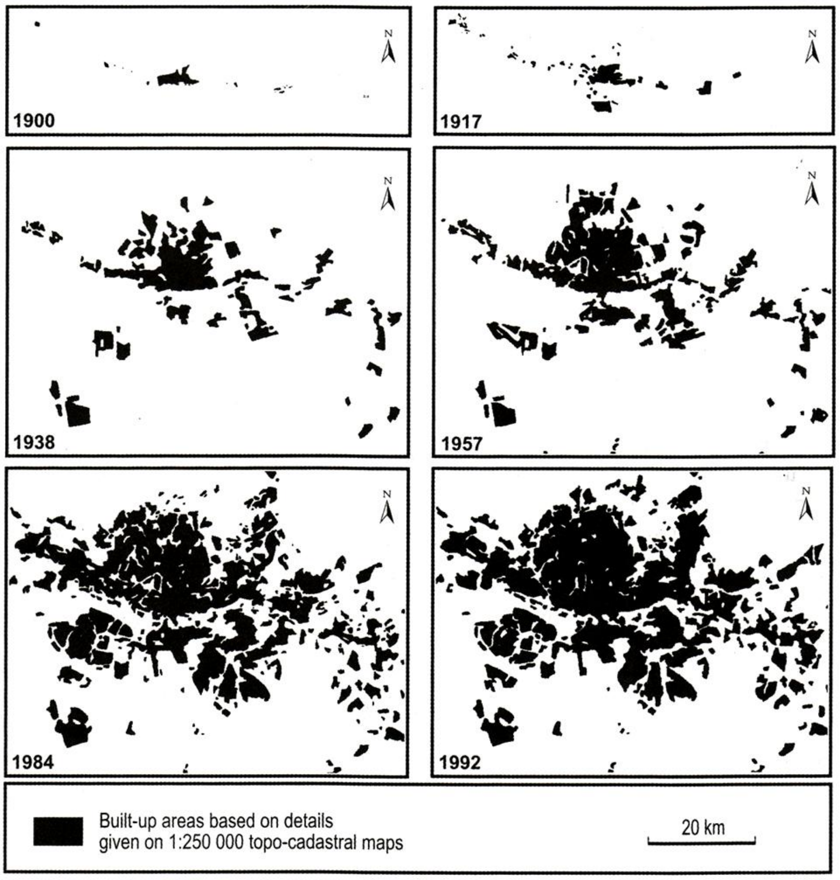

Figure 3 "Aerial growth of Johannesburg and the Central Witwatersrand" (in Beavon, 2004: 7)

Although gold mining provided the initial attraction for Johannesburg's growing urban population, this growth occurs during a time when the South African apartheid state was at its most interventionist, and developed strategic industries through protectionist trade policies such as tariff barriers on imported goods (Beall *et al*, 2002: 35). It is therefore unsurprising that despite successive waves of booms and slumps of gold mining, this period was generally a prosperous phase for Johannesburg and South Africa as a whole, with a massive influx of foreign capital into the country and relatively high rates of employment growth (Beall *et al*, 2002: 33; Tomlinson *et al* in Tomlinson *et al,* 2003: 5). Johannesburg's good labour absorptive capacity during the mining boom was also a result of the state's interventionist role in labour market policies, where apartheid regulation governed the employment and housing of Blacks, who were restricted to cheap working-class labour in a system of mass production (Crankshaw, 2008: 1695).

On the other hand, mass consumption was reserved for the White middle and skilled working class (Crankshaw, 2008: 1695). The protection of White workers from competition for wages and jobs during the period of racial Fordism represents the apartheid government's aim to prevent the growth of a Black middle class in Johannesburg (Crankshaw, 2008: 1695; Beall *et al,* 2002: 36). Therefore, despite distinct racial distributions of these opportunities as a result of apartheid policies, in the early periods of Johannesburg's history, mining and factories absorbed thousands of low-skilled, mainly African, work seekers (CoJ GDS, 2006: 28). The gold mining boom was therefore the trigger for Johannesburg's initial urban expansion and economic growth, which depended on commodities in demand elsewhere, as well as Johannesburg's original attraction for as a destination city for people seeking opportunity and livelihoods (Murray, 2004: 141).

Analysing the spatial dimensions of Johannesburg's Racial Fordism, shows that mining establishments and upcoming manufacturing and secondary industrial activity were located on the south side of the city's central business district, in a strip running along an east-west axis (Crankshaw, 2008;: 1695). Spatial divisions during this period of Racial Fordism occurred along racial lines to construct an urban space economy exclusively for Whites, as revealed by Chipkin:

> "The notion of the apartheid city was not simply a shorthand to describe racial segregation as it manifested itself spatially. Rather, the term spoke to an urban political economy that reproduced wealthy white cities while simultaneously underdeveloping black areas" (Chipkin, 2005: 91).

It is as a result of spatial segregation along racial lines during this period that the early expansion of Johannesburg's physical boundaries can be seen as a growing racial landscape (Tomlinson *et al* in Tomlinson *et al,* 2003: 5). As explained by Tomlinson *et al* (in Tomlinson *et al,* 2003: 5), workers that had initially lived close to sites of production in working class suburbs such as Jeppe or Fordsburg, or in mining compounds, were gradually segregated and relocated. Furthermore, Beavon (2004: 147) explains that after 1948, all Black people were increasingly confined to the south-west of Johannesburg, now known as Soweto, and supplemented by the townships of Lenasia and Eldorado Park, reserved for Indian and Coloured people respectively. During the mining boom, this spatial segregation was legitimised by influx-control laws, which denied urban residential and employment rights to Africans, as well as by the forcible eviction of non-whites to peripheral urban areas (Posel in Beall *et al,* 2002: 36; Beavon, 2004). Coupled with other measures, these spatial segregation polices resulted in the whole of the City of Johannesburg proclaimed as white in 1933 (Tomlinson *et al* in Tomlinson *et al,* 2003: 5).

3.2.1.2 The tree-planting boom

The significance of Johannesburg's mining past also provided the impetus for the construction of the largest urban forest in the world, which has been said to have grown to ten million trees (Co SOER, 2008: 100). During the Gold Rush, the intense mining activity and mine dumps that dominated Johannesburg's landscape increased the already-high dust levels of the Highveld climate (Turton *et* *al,* 2006: 319). In an attempt to settle the dust, trees were planted with the creation of parks for recreational purposes (Turton *et al,* 2006: 319). The demand for trees was also generated by the need for mine timbers and poles to support the shafts and mining excavations that fuelled the rapidly expanding gold rush town (Turton *et al,* 2006: 319; Davie, 2002). Christopher (1982: 116) elaborates, noting that the initial impetus for forestry in South Africa as a whole, evolved in the 1890s as a result of the interior urban markets and the demand for pit props from the mining industry.

For logistical reasons, the forestry plantations were located close to urban markets and particularly around the Witwatersrand (Christopher, 1982: 117). The trees preferred for supporting mining activity were Australian Eucalyptus, familiarly known as Blue Gum, chosen for their short growing period of 8-12 years, which brought the quickest commercial return and their tall, branchless appearance made them ideal for use as poles in propping up mine shafts (Christopher, 1982: 117; Mawson, 2004). Experiments and tests were also conducted on other varieties, such as Black Wattles and Jacarandas, to test their suitability for mine props, resulting in the introduction of non-indigenous trees being planted en masse in areas such as Saxonwold, Parktown, Craighall and Fairlands to be used as underground mine timber (CoJ SOER, 2008: 29; 83; Mawson, 2004; Davie, 2002). Thus, the tree-planting boom and varieties chosen for the forest's construction were initially based on commercial incentive, which, in turn, depended on the length of growing time of a particular variety (Christopher, 1982: 116).

However, Davie (2002) explains that the massive tree-planting scheme that accompanied the mining boom, also gave preference to street trees and trees that the colonials were familiar with, such as oaks, London planes and pepper trees. Research by Stewart e*t al* (2009: 150) investigates this trend where in many southern hemisphere colonial cities, the land was cleared of native vegetation and urban planning principles were imported onto these urban landscapes. The authors explain that European settlers applied to these diverse lands exactly the same principles of urban design, land use practice, landscape and planting design principles, as well as the tried and tested species that they employed in Europe (Ignatieva and Stewart, in Stewart *et al,* 2009: 150). The artificial engineering of Johannesburg's trees during the city's colonial beginnings can therefore explain the occurrence of an urban forest in natural grassland, as well as the dominance of introduced trees in the city.

Mawson (2004) and Davie (2002) elaborate, stating that it was not until the mining boom that tree-planting begun in Johannesburg, which is naturally savannah grassland, characterised by rocky outcrop and scattered shrubs, but no trees. The natural vegetation that is found in the Witwatersrand catchment area is mixed grassland zone, dominated by indigenous grasses such as *Loudetia simplex* or common rust grass, *Themeda trianda* or red grass and *Trachypogon spicatus* or giant spear grass (CoJ SOER, 2008: 82). The "Highveld" region, which is intersected by the Witwatersrand watershed, therefore takes its name from the high altitude of this naturally occurring savannah grassland (Turton *et al,* 2006: 314-16). Other vegetative structures that are naturally found in the Highveld include pure grassland, bush grassland, mixed grassland and temperate mountain bushveld and wetland areas (CoJ SOER, 2008: 82).

However, natural Northern Highveld forests are also found in the Witwatersrand area and are classified under the Northern Afrotemperate Group (Von Maltitz *et al*, 2002; 33). The indigenous trees that are found in these forests include *Acacia caffra* or common hook thorn and *Rhus leptodictya* or Karee (CoJ SOER Report, 2003: 82). Von Maltitz *et al* (2002: 32) explain that the Northern Highveld forests are the most "biogeographically eroded" as they contain a very small portion of typical Afrotemperate elements and are fragmented indigenous forests that have retreated and lost much of their original character. Indigenous Northern Highveld forests therefore occur in patches and the known forests of this type in Johannesburg include Melville ridge and the Witwatersrand National Botanical Garden (Von Maltitiz *et al,* 2002: 100-101). The fragmentation of the indigenous forests in the Witwatersrand region is part of a wider trend, where increasing anthropogenic activity as a result of urbanisation has significantly altered the state of natural vegetation occurring in the "Highveld" area.

The suburban development that accompanied the rapidly expanding gold rush town is also representative of the artificial tree-planting boom, as revealed by suburbs named as "Forest Town, Parkview and Park Town" (Davie in Turton *et al,* 2006: 319). Matshikiza (in Nuttal *et al,* 2008: 221) elaborates on the extent of the tree-planting boom and its associated green spaces: "They say that Johannesburg has the most extensive greenbelts of any city in the world – grassy parks with swimming pools and Jacaranda trees". However, the areas where greenbelts have been applied are located in the northern quadrant of the city and historically home to the residences of wealthy mining magnates (Parktown & Westcliff Heritage Trust, 2010). As a result, on satellite images, the northern parts of Johannesburg resemble a rain forest, whereas the south is relatively treeless and bare (JHB City Parks, 2008/09; 10). The tree planting backlog in the south and other previously disadvantaged areas is representative of a wider apartheid trend where the ecology of so-called "non-white" areas was largely neglected (CoJ JCP, 2008/9: 10; CoJ JCP, 2010). Bond (2007: 9) and Poulsen (2010: 22) depict this trend:

> "From the air, the pleasing bright green quilt of well-watered English-style gardens and thick alien trees that shade traditionally white - now slightly desegregated - suburbs, is pocked with ubiquitous sky-blue swimming pools." (Bond, 2007: 9).

> "A journey through Johannesburg traverses extreme models of housing and urban neighbourhoods. From enormous houses with vast landscaped gardens in tree lined avenues, to shacks sitting shoulder to shoulder separated by muddy paths". (Poulsen, 2010: 22)

The city's ecological disparity, coupled with the importation of foreign landscape principles, has therefore created many constructed ecological systems within Johannesburg. The uneven erection of the ten million strong, largely introduced, urban forest is a visible example of this constructed physical reality (CoJ, 2004). Therefore, not only is the forest incongruent in terms of the natural landscape, but its erection has been along race and class lines, due to the spatial framing of race and the fixing of social forms in space during Racial Fordism and, more broadly, during apartheid (Mbembe *et al* in Nuttal *et al,* 2008: 20). This uneven application can be seen as part of a constructed urban form where ecological systems have been erected, much like the rest of the city's built environment, according to socio-spatial divisions. Mbembe *et al* (in Nuttal *et al,* 2008: 18) give a critical view on the planting of Johannesburg's forest:

> "Compensating for the lack of advantages of a striking natural setting, the city planted the biggest manmade forest in the world and, through its built environment, laboured to create a sense of splendour and sensory stimuli" (Mbembe *et al* in Nuttal *et al,* 2008: 18).

It is therefore critical to recognise the roles that colonial city-building and Johannesburg's poisoned identity as the archetypal apartheid city have played in the construction and distribution of the city's ecological assets (Sudjic, 2007: 1). Johannesburg's constructed aesthetic is also evident in other aspects of its built environment where European, American and international architectural influences were preferred to any real engagement with local conditions and climate (Gaule, 2005: 2336-2336; Bremner, 2000: 186). It is for these reasons that Johannesburg's physical reality has been described as constructed, designed and even imaginary (Mbembe in Nuttal *et al,* 2008: 38-64; Murray, 2004: 142). However, it is amidst Johannesburg's subsequent experience of socio-economic and spatial restructuring, that the urban forest, green spaces and its constructed green aesthetic receive a new imperative. This is because the socio-economic and spatial trends that have shaped Johannesburg's metamorphosis as a city have also created cross-cutting challenges that threaten the city's social and ecological resilience. In this current context, the initial construction of ecological systems for mining and aesthetic purposes, now offer functions and benefits that counteract some of the challenges of contemporary Johannesburg, if explicitly accounted for. Johannesburg's physical context has indeed been fundamentally altered by the application of predominately introduced green spaces and trees coupled with an unequal spatial form, yet this constructed physical reality has had the unintended consequence of potentially being a source of social-ecological resilience in the city's current context.

3.2.2 Economic restructuring

In his commentary on the city, Rogerson (2004: 15) states that Johannesburg is often likened to the New York of Africa, "dominating the continent in terms of the scale and sophistication of its stock market, financial services, corporate vibrancy, media and culture". Rogerson's statement refers to the period of deindustrialisation and subsequent rise in service sectors and tertiary economic activity. This has been termed the post-Fordist era of Johannesburg's socio-economic profile, which roughly covers the period from the mid-1970s to the present (Beall *et al,* 2002: 33). The restructuring of Johannesburg's economy broadly includes a decline in mining activity and associated employment; a rise and subsequent decline in manufacturing; and an increasingly dominant service-sector (Crankshaw, 2008: 1695).The Centre for Development and Enterprise (CDE) elaborates:

> "Although Johannesburg is still often described as 'iGoli – city of gold', by 1970 employment in the primary sector, which includes mining, had fallen to 35 958, while that in the secondary sector and tertiary sectors stood at 652 459." (2002: 3)

The shift from the reliance upon primary commodities, industry and manufacturing and declines in employment in these sectors is contrasted by a steady growth in employment of the tertiary sector (Murray, 2004: 142; Beall *et al,* 2002: 33). Elaborating on this process, Rogerson (2004: 15) states that in contrast to the weak employment trends in primary and secondary sectors, "employment in the tertiary sector has escalated rapidly since 1980 due to the burgeoning growth of the financial services, insurance, real estate and business services economy". Johannesburg's experience of economic restructuring is therefore not unlike other global trends within developing countries, where a large degree of excluded workers in rapidly growing cities are unable to compete in knowledge-intensive sectors.

The haemorrhage of jobs in the mining and manufacturing sectors is therefore the result of a massive deindustrialisation process where Johannesburg's tertiary sector is increasingly dominant (Murray, 2004: 142). Due to the decline of employment in the manufacturing sector from the 1980s onwards, Johannesburg has experienced a slower overall rate of employment growth (Beall *et al,* 2002: 33). Beall *et al* (2000: 110) summarise the system-wide effects of Johannesburg's Post-Fordist socio-economic profile:

> "High unemployment and a declining manufacturing sector in Johannesburg have reduced the demand for unskilled and, to some extent, semi-skilled, labour, resulting in lower wages for those in unskilled work and 29 per cent unemployment in Gauteng province as a whole." (Beall *et al,* 2000: 110)

Therefore, despite the significance of primary commodities in Johannesburg's initial expansion, mining was a relatively short-lived sector of the city's economy, and was surpassed in economic contribution terms by manufacturing in the 1980s, after which goldmines were largely exhausted and employment here was in decline (Beall *et al,* 2002: 35; Crankshaw, 2008: 1695). Beall *et al* (2000: 109) explain that this is reflective of a wider South African trend of declines in employment in the major primary and secondary sectors, such as agriculture, manufacturing and mining, whereas increases have been felt in the tertiary sectors of services and finance. These changes also represent South Africa's reintegration into the global economy based on secondary and tertiary markets and competitive advantages in knowledge and information networks (Tomlinson *et al,* 2003: 15).

The South African inequality legacy has, however, meant that the decline in demand for unskilled and semi skilled jobs has played a role in deepening inequality in Johannesburg (Beall *et al,* 2002: 39). The deep skills mismatch inherited from earlier periods has created a socio-economic profile where unskilled workers, almost entirely filled by poorly educated Africans, are unable to compete in tertiary sectors (Beall *et al,* 2002: 39). As a result, Johannesburg sits in a dual reality of being "South Africa's quintessential professional, private sector city", yet because only the well-educated now have prospects for accessing this knowledge economy, it is also a city where the dream of full employment is unlikely to come true (Rogerson, 2004: 15; CoJ GDS, 2006: 28).

If not already accentuated by Johannesburg's aspirations to continue to "lead as South Africa's primary business city", as stated in the city's vision, the growing number of people migrating to the city presents a further challenge for rising unemployment (CoJ IDP, 2010/11: 12). The slow economic growth rate in Johannesburg since 1980 has been accompanied by a fast rate of population growth, of which Africans constitute 74% (Beall *et al,* 2000: 110; Crankshaw, 2008: 1707). Van Huyssteen *et al* (2009: 180) note that between 1996 and 2007, the biggest percentage of Black population growth occurred in the City of Johannesburg, which constituted 14% of all population growth in the country. Bond (2007: 10) gives details of the extent to which employment growth lags behind population growth, stating that due to migration into the city, the annual growth of Johannesburg residents has been 4.2 % yet, with job creation of less than 3% at the time of writing. Beall *et al* (2002: 33) elaborate, stating that in the face of a growing population, during the period of Post-Fordism, Johannesburg, and the country as a whole, experienced slower economic growth.

Although its economic characteristics have changed, Johannesburg is therefore still a magnet for people from across the country as well internationally; yet its attraction is not met with the same success for everyone (Beall *et al,* 2000: 121). Nowhere is this more apparent than in the growth of

Johannesburg's informal economic sector and day labourers, which is linked to the structural changes in the city's economy as well as the mismatch between employment and population growth (Tomlinson *et al* in Tomlinson *et al,* 2003: 16; Harmse, Blaauw & Schenk, 2009: 363). Rogerson (2004: 15) attributes the growth of the informal economy to the failure of the formal economy to generate sufficient employment for expanding numbers of work seekers, including the influx of new migrants from South Africa and Sub-Saharan Africa. This aspect of Johannesburg's urbanisation is in line with a broader South African trend where urbanisation, cross-border migration of nationals and immigration of non-nationals are concentrated around nodes of regional trade and production (Landau, 2007: 63-64).

Cross-border migration is related to the dynamic ties between rural and urban areas in South Africa and although the phenomenon of cross-border migration potentially renders the flow of people into the city less permanent, the oscillating movement between rural and urban areas may be exacerbating the challenge of sustaining employment growth within a single urban centre (CoJ GDS, 2006: 23; Beall, Guha-Khasnobis & Ravi Kanbur, 2010: 200). Therefore, the explosion of urban population growth, coupled with the predominance of informality in labour, is indicative of urbanisation and urban migration occurring with enormous development challenges where less skilled workers are unable to compete in the global market economy and where jobs in other sectors are already under threat (Beall *et al,* 2010: 188).

Therefore, as mentioned in the Johannesburg Poverty and Livelihoods study (JPLS), whilst achieving the highest score on the Human Development Index (HDI) in comparison with six other South African cities, there are real inequalities in the Johannesburg (JLPS, 2008: 4). Half of Johannesburg's households earn below the national minimum of R1600 per month and almost 20% of its inhabitants are not accommodated in formal housing (City of Johannesburg in JLPS, 2008: 4). Studies have also shown that the city features in the top 20 list of national concentrations of households without access to piped water with similar findings for electricity provision (van Huyssteen et al, 2009: 189). The effects of Johannesburg's unequal socio-economic reality are also clear in that 39% of households in the city are the recipient of one or more of the seven types of social grants in South Africa (JPLS, 2008: 17). These trends are paralleled by the fact that Johannesburg generates 40% of South Africa's Gross Value Added (GVA) and along with the rest of Gauteng, has some of the highest levels of Research and Development investment; greater pools of highly skilled workers and superior scientific and technological output compared to the rest of the country (van Huyssteen et al, 2009: 184).

3.2.3 A sprawling, de-centred city

Arku (2009: 254) explains that along with population growth rates that are higher than those in developed regions, African cities have experienced rapid spatial expansion. Arku (2009: 253) goes on to state that this current urban development pattern is dominated by unlimited outward extension, low-density residential developments and haphazard spatial patterns. Johannesburg has had a similar experience, where due to uncontrolled urban sprawl, industrial restructuring has resulted in the spatial dispersal, fragmentation and decentralisation of manufacturing, commercial and residential activity (Murray, 2004: 141-145). The out-migration of commercial, residential and industrial activity from the inner city, is related to tertiary sector businesses favouring locations on the "edge" cities of northern suburb neighbourhoods such as Rosebank, Sandton and Midrand (Murray, 2004: 142; Crankshaw, 2008: 1697). This trend represents the particular spatial form of Johannesburg's deindustrialisation, where the peripheral nature of urbanisation has led to the splintering of activity away from the urban core and de-densification of the built environment (Crankshaw, 2008: 1697; Murray, 2004: 143; CoJ GDS, 2006: 38). As a result, there has been a decentralisation of core economic activity and its outflow from the inner city to other areas in Gauteng has created a de-centred city increasingly losing people to other urban areas beyond the inner city (Czeglédy in Tomlinson *et al,* 2003: 23-28; CoJ GDS, 2006: 19).

The splintering of Johannesburg's urban activity is, therefore, representative of the second urbanisation wave, where developing country cities have experienced extensive growth and development, but also where growth has pushed the urban frontier further away from the traditional urban core (Murray, 2004: 143). Furthermore, as is typical of other South African trends, Johannesburg's sprawling landscape overlaps with socio-economic disparity. This is because although racial desegregation has somewhat eroded racial polarisation, with Africans representing 74% of the population and in sheer numbers representing the middle class, the occupational income profile of Johannesburg's neighbourhoods has not changed significantly (Crankshaw, 2008: 1707). Tomlinson *et al* (in Tomlinson et al, 2003: 13) describe Johannesburg's residential form as becoming increasingly balkanised, differing according to low-income people living in the south of the inner city, the inner-city population, or the generally high-income population in the north. The city's socio-economic restructuring towards an increasingly tertiary oriented development path has, therefore, not only excluded the majority of low skilled workers, but reshaped the landscape of the metropolitan region where the urbanisation of suburbia has diverted capital investment from the inner city to historically wealthy suburbs (Gaule, 2005; Murray, 2004: 141-142). Crankshaw (2008: 1697) summarises the changing geography of Post-Fordist Johannesburg:

> "..the northern neighbourhoods have become the effective new city centre with the lion's share of the growth of new office and retail developments while the old city centre has borne the brunt of the decline of the manufacturing sector." (Crankshaw, 2008: 1697).

The role that commercial incentives and municipal housing grants play in this socio-spatial matrix and in broader property development cannot be overestimated. Murray (2004; 142) notes that in addition to suburban urbanisation, there is a proliferation of subsidised housing initiatives on peripheral locations away from economic and social opportunities. Bond (2007: 8) elaborates, stating that small housing grants force developers to seek out ever cheaper land on the city's distant periphery, which has resulted in many low income black residents actually being further away from job opportunities than during apartheid times. As a result, areas of extreme neglect are therefore often geographically congruent with neighbourhoods in which the population is most adversely affected by the changing occupational and employment opportunities in the city (Beall *et al,* 2000: 116).

Therefore, in addition to the ever-increasing need for development, Johannesburg is dealing with the challenge of burgeoning informal settlements on its fringes (SACN, 2008: 78). However, there are also polynucleated clusters of office complexes, shopping malls and leisure activities along the urbanised periphery, which have therefore become insular islands and car-based enclaves at the expense of publicly accessible spaces (Murray, 2004: 145-146). These clusters of mixed commercial and residential development projects, increasingly taking place on the urban fringe, reinforce spatial segregation by separating social groups by visual boundaries, three metre high walls, security gates and check-points, and growing commuter distances to economic opportunities (Murray, 2004: 146; Bond, 2007: 7). The overlapping of informal settlements with insular pockets of suburban development are testimonies to Johannesburg's growing, yet contradictory growing landscape. This fragmented urban expansion has meant the re-emergence of Johannesburg as a cosmopolitan city, yet only for a small segment of its population, resulting in many exclusive living and employment opportunities (Simone in Nuttal *et al*, 2008: 72).

3.2.4 Losses to green space

Amidst increasing physical expansion of Johannesburg's impervious surfaces, the city's stock of natural capital is being threatened and, in turn, the services that flow from local natural assets. Approximately 74% of Johannesburg' natural vegetation has been lost due to pressure from human settlements and other commercial activity, and this encroachment has been cited as one of the major factors threatening natural open spaces (SACN, 2008: 79; CoJ SOER, 2008: 134). Finding the physical spaces and capacity to sustain increasing human activity amidst rampant low-density sprawl has therefore resulted in a significant amount of land use change at the expense of the city's natural spaces (Beavon, 2004: 241; Murray, 2004: 145; CoJ SOER, 2008: 100). The loss of open space due to such development pressures threatens the stock of natural assets capital from which ecosystem services necessary to sustain the city's population flow (De Wit *et al,* 2009: 14).

Residential settlements, which increased by 1.37% between 2004 and 2007, are a significant component of Johannesburg's changing landscape and built-form. Accommodating housing has been cited as a major cause of decreases in Johannesburg's open spaces (CoJ SOER, 2008: 103). Although housing is a necessary provision for a growing population, the nature and type of investment in this infrastructure presents a worrying picture on two accounts. Firstly, low density residential form, which constitutes the majority of new housing developments on the outskirts of the city, decreases stocks of natural assets though widespread conversion of land into hard surfaces (CoJ SOER, 2008: 107). Secondly, natural habitat loss is particularly acute in informal settlements where low-quality, unplanned and under-serviced infrastructures undermine formal open space management plans, placing additional pressure on natural environments (CoJ SOER 2008: 108; 149; SACN, 2008: 78). Johannesburg's SOER notes that because influx into the city remains unmanaged, the growth in informal settlements compounds the need to provide housing in a fast, as well as sustainable, manner (CoJ SOER, 2008: 108).

Not only are informal settlements poorly integrated into nodes of economic opportunity, but their rapid and informal nature of development is further pressurising Johannesburg's ecological resilience (De Groot *et al,* 2010b: 22). The rapid establishment of informal settlements, as indicative of the challenge of providing housing in Johannesburg, also represents Johannesburg's socio-political context, where there is a distinct trend of politically popular infrastructure investments receiving higher priority in planning agendas. This is largely linked to the historical ties of Johannesburg's social movements to anti-neoliberal activist work, that results in housing and traditional infrastructures of water, electricity and sanitation forming part of politically popular planning agendas, against which the city's ecological assets effectively have to compete (Bond, 2007: 17; Beall *et al,* 2000: 116). It is against this backdrop that Johannesburg is seen as a non-starter in the realm of environmental issues as summarised by Beall *et al* (2000: 836):

> "... an overwhelming preoccupation with issues of social justice has meant a rather slow start to the campaign for environmental justice. In Johannesburg, therefore, it is the questions of how to extend basic services to the historically disadvantaged populations and how to pay and charge for services

across the city, that have most concentrated the minds of participants in urban governance in the post-apartheid period." (Beall *et al,* 2000; 836)

However, running parallel to the loss of open space to accommodate for increasing numbers of urbanites is that Johannesburg's green aesthetic and affinity with trees has been carried forward in this urbanising system. Although the benefits of this largely introduced ecological system have been critiqued as potentially detrimental to other ecosystem services and are indeed underpinned by socio-spatial disparity, these values need to be assessed relative to other alternatives in the context of cross-cutting social and ecological pressures. This culture of greening has also been incorporated at various levels of urban activity, indicating that although the conversion of public open space poses threats to ecosystem functioning, inventories of ecological resilience exist in addition to formally conserved and delineated public open space.

3.3 Assessment of the relative importance of different natural assets for the generation of ecosystem goods and services (EGS)

In keeping with the methodology developed by De Wit *et al* (2009: 10), it is necessary to prioritise ecosystem services, flowing from ecological assets, with the highest relative importance for valuation. This is also related to the numerous ecosystem services that exist in a social-ecological system, making it necessary to identify those services relevant as target areas for investment in ecological assets (De Wit *et al,* 2009: 19). For this discussion, the relevant ecosystem services are those provided by Johannesburg's 'urban green systems', which will be used to collectively refer to trees, parks, gardens and other green areas such as golf courses, that are managed either publicly or privately in the city (James *et al,* 2009: 66; Koningnendijk, 2005: 93). The choice for valuing those services offered by the city's green spaces and trees, is that Johannesburg's constructed green systems have benefits beyond the inherent value of ecosystem services, and as such, are representative of the multifunctional role of ecological systems.

This is because the ecosystem services naturally provided by green spaces and trees, render Johannesburg's constructed green systems potential sources of ecological resilience amidst threats to ecosystem functioning. The construction of the urban forest has also had the unintended consequence of sparking a green industry and value chain through which jobs; revenue and knowledge flow and are continually re-invested into Johannesburg's major ecological asset. These industry benefits are sources of social resilience in terms of their real economic values, and deserve attention amidst Johannesburg's unemployment socio-economic and unemployment concerns.

These ecosystem services, as social-ecological dividends accruing from Johannesburg's green assets, therefore present the case for green infrastructure and in a paradoxical twist, the artificial and uneven application of the urban forest has created potential sources of ecological adaptability, that also accrue indirect economic benefits by providing employment and income generation for a city experiencing significant development challenges. Murray (2006: 53) captures these unconventional forms of agency prompting an environmental consciousness in South Africa:

> "In the not-necessarily ecological space of South African gardening, however, other models have exerted their influence upon indigeneity, primarily the design and planting by contemporary practitioners of naturalistic, wild, and grassland gardens, a repertoire given visual reference in coffee-table books, television programmes, garden shows and decor magazines." (Murray, 2006: 53)

It is important to note, however, that numerous natural assets do exist in Johannesburg, including the terrestrial ecosystems of grasslands and ridges, aquatic ecosystem wetlands and rivers, and open spaces such as non-built public or private green areas, including parks, nature reserves, gardens and cemeteries as major natural assets in (CoJ SOER, 2008: 126; CoJ SOER, 2003: 81). Appreciating these assets is important as Johannesburg's ecological system operates as a whole of intersecting parts. Prioritising those ecosystem services flowing from Johannesburg's green spaces, trees and green supply chain, does not replace the importance of investing in naturally occurring ecological assets, but advances the case for such investment through the explicit recognition of the joint social-ecological values of the city's constructed green systems as green infrastructure. For purposes of clarity, therefore, and because of the introduced nature of systems such as the urban forest and private gardens, the terms 'ecological' or 'green' assets will be used to refer to the 'ecological' or 'green' systems prioritised in this application.

Ecological systems providing ecosystem goods and services						
Terrestrial ecosystems						*Aquatic ecosystems*
Urban Forest and trees (ecological asset)	Grasslands	Ridges	Public open spaces e.g. Municipal parks, public gardens & cemeteries (ecological asset)	Nature reserves	Private open spaces e.g. golf courses, private gardens (ecological asset)	Water courses e.g. wetlands & rivers

Table 4 Ecological systems providing ecosystem goods and services

To establish the relative importance of dividends flowing from Johannesburg's green systems, the ecosystem services generally provided by urban green space were profiled to achieve a comprehensive understanding of their contribution to ecological resilience. In relation to urban tree cover, Sander, Polasky & Haight (2010: 1646) summarise the wide range of benefits naturally provided by trees in urban areas:

> "protection against soil erosion, provision of habitat for wildlife, local air quality improvements, reductions in the urban heat island effect, energy savings through building shading and insulation, carbon sequestration, and reductions in storm water runoff." (Sander *et al,* 2010: 1646).

Many of the ecosystem services offered by urban forests can be extrapolated to urban green space broadly, which include: "air and water purification, wind and noise filtering, microclimate stabilisation, mitigation of storm water flow, erosion control, habitat provision, and water table enhancement" together with natural hazard regulation and pollination services (Ward *et al,* 2010: 49; MEA, 2005: 57-58). The critical supporting, regulation and provisioning ecosystem services performed naturally by urban green spaces and trees, in turn offer cultural ecosystem services through social, health and psychological benefits. Contact with nature, direct physical health benefits and creating spaces for social interaction are generally recognised as the cultural ecosystem services of green space (James *et al,* 2009: 65). At a general level, there are numerous ecosystem services naturally provided by green space and forests in cities that accrue to local urban systems as well as having globally beneficial dividends. However, focusing exclusively on Johannesburg, the following ecosystem service categories offered by its urban green spaces are priorities for investment based on their contribution to reducing pressures on the city's current state of social-ecological resilience:

3.3.1 Regulating services

3.3.1.1 Water flow regulation

The mitigation of storm water flow by urban green spaces is a critical regulation function in an urban environment such as Johannesburg, where low-density development has increased the percentage of impervious surfaces (Ward, Parker & Shackleton, 2010: 49; Murray, 2004: 145; CoJ SOER, 2008: 166). When the permeability of urban surfaces is reduced, the natural water filtration ability of green spaces is undermined, decreasing the flow of water that seeps into the ground, which increases storm water volumes and flood peaks during storms (Picket *et al,* 2008: 9; Bond, 1999: 50). Tree canopies contribute to reduced storm water runoff, through intercepting rain and reducing the amount of water falling on hard surfaces that is normally removed by storm water drainage systems (McPherson in McPherson *et al,* 1994: 110; Wolf, 1998).

Furthermore, McPherson (in McPherson *et al,* 1994: 129) reveals findings that more runoff is avoided by street trees than by trees at other sites, because the canopies of these trees intercept rainfall over mostly paved surfaces, which is highly relevant for Johannesburg with a significant amount of street trees. Xiao (in Kirnbauer *et al*, 2009: 3-4) elaborates stating that through intercepting storm water, the canopy of an urban forest reduces runoff volumes "with the potential to reduce flooding hazard, surface runoff pollution loads and the costs associated with storm water management and treatment". With regard to stabilising water tables, riparian forest vegetation can stabilise streams and act as filters for the seepage of water from the adjacent landscape, and may contribute to the rehabilitation of rivers such as the Juksei, which has been largely transformed by urban activity (Geldenhuys, 2008: CoJ SEOR, 2008: 153).

Reductions in peak storm water runoff and water retention are also performed by other green spaces, through the filtering functions of vegetation and soil biota, which, if planned systematically, can function as drainage networks to buffer surface water in cities (De Groot *et al,* 2002: 398; Sander *et al,* 2010: 1655; Pickett & Cadenasso, 2008: 10; Bryant, 2006: 29). The contribution of green space to stabilising water tables through water filtration, reduction in storm water runoff and flood attenuation, are further priority services for Johannesburg's hydrological reality of water supply challenges (Ward *et al,* 2010: 49; Turton *et al,* 2006: 314). The ability of green space to reduce peak storm water flows and increase the flood attenuation capacity of urban areas, also serves as a disaster management service for an impermeable region prone to flooding.

3.3.1.2 Water purification

Another hydrological-related service provided by green spaces is the removal of pollutants from water bodies (Wolf & Blahna, 2010). Pollution filtration and water purification ensures maintenance of water quality, which is critical in Johannesburg where heavily polluted and acid water are fast becoming realities for the economic heartland of South Africa (Keet in Saving Water SA, 2010 (Chiabai, 2010: 2; 15; Benedict *et al,* 2002: 14). Acid mine drainage (or AMD) is globally understood to occur through the weathering of sulphide minerals, which together with saline wastewater disposal, is contaminating shallow unconfined aquifers in the South African goldfields (Weiersbye, 2007a: 14; Weiersbye *et al,* n.d: 239).

The occurrence of AMD in Johannesburg is generally attributed to the cyanide-containing solution necessary for dissolving gold, and requires the addition of lime to regulate the pH balance of the solution (Naiker *et al,* 2003: 30). During mining operations, this solution was separated for further processing, while the mine tailings were pumped to large "slimes dumps" and to disposal sites south of Johannesburg (Naicker *et al,* 2003: 30). When tailings or slime dumps are undisturbed, as applicable to Johannesburg's abandoned mine operations, they are exposed to oxygenated rainwater that causes the oxidation of sulphides in the mine tailings (Naicker *et al,* 2003: 30). The result is that after the termination of mine operations, acidified water percolates through the dumps, which then fills the cavities of old mine shafts, enters the groundwater regime beneath dumps and infiltrates wider ecological systems (Naicker *et al,* 2003: 30; Mail & Guardian, 2010).

The dual occurrence of AMD on the one hand, and the largely introduced urban forest, on the other, is one of the contradictions of Johannesburg's landscape. This is because although the urban forest has been criticised for inducing hydrological pressures, there are certain types of plants that are tolerant to toxic conditions, with the ability to degrade, transform, sequester, immobilise or otherwise render pollutants harmless, as explained by Weiersbye (2007b). These functions broadly fall under the process of phytoremediation, which is the use of plants, algae, soil micro organisms and even non-living biomass to improve the quality of a substrate (Glick in Weiersbye, 2007a: 13). Weiersbye *et al* (n.d: 239) note that "[s)ince phreatophytes obtain most of their water requirements from groundwater, contaminants could become accumulated in the rooting-zone via transpiration, or even above ground in foliage".

Furthermore, as Weiersbye (2007b) notes, as shrubs and trees generally absorb larger amounts of pollutants than grassy vegetation, they act as pollutant 'sinks', whereas grassy vegetation allows infiltration of water and pollutants to leach to groundwater. These water purification and substrate rehabilitation functions are ecosystem services that could become further mechanisms for the cleansing of AMD, showing that the hydrological affects of the urban forest are more complex than previously thought – depending on vegetation and species types (Weiersbye *et al,* n.d: 239). Water purification, however, is a primary service offered by Johannesburg's wetlands. Although the ecosystem services of aquatic ecosystems is not the strict focus of this study, wetlands in certain catchments in Johannesburg, such as those dominated by vast reed beds, have proven to be imperative in natural water purification (CoJ SOER, 2008: 160). This is because wetlands serve as sinks for pollution, trapping polluting metals in sediments and peatlands, and research has revealed the major role of wetlands in trapping some of the main constituents of AMD (McCarthy & Venter in

Tutu, McCarthy & Cukrowska, 2008: 3668; 3682). The extent of the crucial role that wetlands play in addition to the pollutant filtering abilities of tree and other vegetation categorised as phreatophytes, cannot be ignored in analysing water purification services in Johannesburg.

3.3.1.3 Climate regulation

The role that urban forests and green spaces play in climate regulation at various scales is another ecosystem service gaining increasing attention amidst concerns about microclimate stabilisation and heat-island affect on the one hand, and the accumulation of pollutants in the atmosphere at a more global level, on the other. Through the shading of hard surfaces and thereby the interception of solar radiation, as well as through evapotranspirative cooling, tree canopies cool areas and lower urban temperatures (Bowler, *et al,* 2010: 147; McPherson *et al,* 1997: 54). McPherson *et al* (1997: 53-54) elaborate on the natural air conditioning services provided by trees in cities, stating that urban forests can cool urban areas and conserve energy requirements by shading buildings and other heat-absorbing surface. These microclimate stabilisation functions are important services in the context of urban heat island effect, which is the difference in temperatures between rural and urban areas (Bowler *et al,* 2010: 147). In Johannesburg, studies show a mean urban-rural temperature difference of 11˚C and that the city's urban heat island affect is increasing due to the growing number of hard, heat-absorbing surfaces (Goldreich, 2006: 248; CoJ SOER, 2003: Tyson, du Toit, Fuggle, 1972: 533). Other microclimate regulation functions include the buffering of wind speed and the retaining of heat during winter (Geldenhuys, 2010).

The moderation of urban climates by trees also occurs through air quality regulation, which vegetation naturally performs by removing air pollutants, resulting in significant air quality improvements for urban areas (McPherson *et al,* 1997: 53). Johannesburg is in a unique position to have a vast numbers of pollutant-absorbing canopies that filter dust particles and pollutants from the air (De Groot, Wilson & Boumans, 2002: 396; Weiersbye, 2007). This is critical in a city where in addition to traffic-induced air pollution and domestic burning of low-grade coal and wood, landfill and waste incineration emissions as well as the use of coal and diesel fuels by industry are having adverse atmospheric impacts locally and globally (CoJ SOER, 2003: 41-43; 181). This pollutant filtering serves to enhance air quality, and through the removal of carbon-related pollutants and emissions, the urban forest performs an essential and relevant ecosystem service in the context of global climate change. This is specifically related to the ability of forests to reduce atmospheric Carbon Dioxide (CO_2) because trees naturally sequester CO_2 and store carbon in their biomass (Chiabai *et al,* 2010: 3; Trexler in McHale, McPherson & Burke, 2007: 50). Creedy & Wurzbacher

(2001: 71) elaborate on this process, explaining that "carbon sequestration, as a result of photosynthesis, involves the uptake and conversion of atmospheric CO_2 into cellulose and other organic compounds, such as wood."

Due to the threat of projected climate change, there is growing interest in the ability of forests to sequester atmospheric CO_2 derived from fossil fuel combustion and the ability of urban forests to act as "carbon sinks" (Lal, 2005: 243; Stoffberg *et al,* 2010: 9). Furthermore, as Weiersbye (2007b) states, "the contribution of the stems and leaves of plants above ground to carbon sequestration may be significant, but the contribution of the roots and organic compounds in the soils is even more so". Therefore, the scale and sheer size of Johannesburg's urban forest, and its above and below ground carbon stores, is a potentially critical carbon sink and a highly relevant ecosystem service in contemporary climate dynamics. This relevance is also important in terms of the movement towards emissions trading and carbon market, potentially positioning Johannesburg as an attractive economic investment and carbon offset instrument (McHale *et al,* 2007: 49-50).

3.3.2 Cultural services

The overall aesthetic, social and psychological values of urban green space are significant sources of social enhancement to cityscapes (Ward *et al,* 2010: 54). Travelling around Johannesburg during lunch times during working days, it is common to see many people out of their work spaces, in parks, lying or sitting on grass or other green areas on sidewalks or under trees. Parks are also a common site for activities such as church meetings, dog walking or soccer practice as well as for major events and concerts such as the "Rocking the Gardens" at Emmerentia Park, which tallied over 5000 visitors in two days (RTG, 2009). However, these services appear to be racially and socio-economically bound, with many parks in or adjacent to non-white suburbs being the temporary sleeping place of homeless people, while parks in close proximity to predominately white suburbs are the location of choice for many white dog-walkers. The sight of black domestic workers meeting socially on grass or green patches outside their employees houses during lunch times, is also indicative of differing socio-economic profiles, yet whether it is for a recreational break under the vast canopy of a London Plane tree, or for religious meetings, such services are nevertheless important for mental and social well-being.

Green systems in Johannesburg also create jobs and employment and serve to enhance industry and economic activity, which are 'cultural' ecosystem services representing the role of green assets in the city's wider development process. On the one hand, the use of ecosystem services flowing from Johannesburg green space for employment occurs through the public entity Johannesburg City Parks

(JCP), a section 21, non-profit company, whose mandate it is to "provide and manage the parks, designated open spaces, environmental conservation services and cemeteries for and on behalf of the City of Johannesburg" (CoJ JCP, 2008/9: 4). As the conserving and greening agent of Johannesburg, JCP embarked on the 200 000 tree planting campaign for "Greening Soweto", the objective of which is to turn the biggest predominately black township in South Africa into an urban forest, and the "Xtreme Park Makeover" where JCP set a world record in 2007 by creating the first park in just 24 hours (JCP, 2010; CoJ JCP, 2008/9: 40.

Through the labour required for the roll out and maintenance of projects and upkeep of ecological assets, JCP contributes to job creation, which is boosted by its alignment with South Africa's Expanded Public Works Programme (EPWP), which in 2010 created an additional 2088 jobs for Johannesburg (Clements, 2010). JCP has also embarked on an environmental sector learnership programme with the view to developing environmental skills such as horticulture. This is an example of the educational services provided by green systems that can facilitate skills development in ecologically-oriented knowledge sectors (JCP, 2010). JCP has also created its own external services division, which serves as a marketing and revenue generation department through approaching other state organisations to take over the greening of their buildings or open spaces in return of a fee (Clements, 2010). To a degree, therefore the 'urban forest brand' contributes to revenue generation through use in publications, advertising and marketing media, which are also awareness-raising services. Furthermore, in a context where investors are increasingly incorporating low carbon targets into their decisions, rendering high carbon economies increasingly unattractive for investment, Johannesburg's urban greening brand is a potentially lucrative economic asset if the relevant ecosystem services are valued accordingly (Ward *et al*, 2008: 7).

On the other hand, the use of green systems in Johannesburg's supply chain together form a 'green industry' that contributes significant jobs and finances to the national economy through employment and sales, as explained by Hoy (2009: 52). Davie (2002) elaborates, stating that the construction of the urban forest and the application of green spaces to the city's landscape, were accompanied by a boom in garden services, landscaping businesses and nurseries (Davie, 2002). The umbrella organisation that represents the consumer green industry in South Africa is the South African Green Industries Council (SAGIC) which includes The South African Landscapers Institute (SALI), The Landscape Irrigation Association of South Africa (LIA), The Lawnmower Association of South Africa (LMA), The South African Arboricultural Association, The Interior Plantscapers Association (IPSA), The South African Flower Growers Association (SAFGA), The Institute of

Environment and Recreation Management (IERM), The South African Nursery Association (SANA), and the International Plant Propagators' Society (IPPS) (Life is a Garden, 2010).

This supply chain of retail nurseries, landscaping services, wholesale growers and other organisations provide services to both private individuals and commercial interests, who maintain a significant portion of Johannesburg's green infrastructure base, whilst contributing to green industry development. Related to these commercial activities is the enhancement of property values through visually appealing gardens as well as those gardens in which large trees are not high in monetary value, but provide a visual buffer to the outside world. Furthermore, the act of "gardening", which can be a purely aesthetic service as well as having intrinsic or spiritual value for the gardener, are also cultural ecosystem services encompassed at the heart of this greening culture. Private individual and organisations therefore play a major role in the provision of Johannesburg's ecosystem services through investing in green spaces and rendering the green aesthetic is also an source of job and revenue creation for the city.

Furthermore, Johannesburg's culture of greening has been incorporated by non-profit entities or social enterprises that have carried forward the city's tree-planting legacy in the roll out of various greening projects. Initiatives such as Food and Trees for Africa (FTFA), a section 21 company operating in Johannesburg, as well as nationally, play a critical role in facilitating urban greening projects through social entrepreneurship which involves combining innovation, opportunity and resourcefulness to transform social systems and provide services for marginalised groups of society in either a for-profit or non-for-profit way (Schwab Foundation, 2006; 1). In a hybrid model of social entrepreneurship, FTFA either receives funding or 'donations' of trees and vegetable seedlings at a reduced cost from various members of the private green industry such as nurseries or wholesale growers (FTFA, 2010).

Social enterprise projects that use greening as their modus operandi to promote social change are therefore additional sources of job creation, either directly through employment in a social enterprise such as FTFA, or indirectly through the beneficiaries of permaculture projects that promote teaching people to feed themselves through urban agriculture, which can, in turn, be a revenue source for local communities and enhance skills development (FTFA, 2010). A further example of the carrying forward of the tree-planting culture that is receiving a new imperative in the context of current ecological challenges is the trend towards events productions and concerts such as "Rocking the Gardens" to offset the carbon emissions generated through the holding of such an event (RTG, 2010). The mission statement of the Rocking the Gardens event was to plant the equivalent number of trees in carbon terms that the event produced in emissions, showing again the benefits of the 'urban forest' brand. In this case it was utilised by the events industry in terms of the concert venue itself, the creation of jobs during tree-planting activities and the sparking on of interest in other industries and professions required to conduct carbon-related calculations.

3.3.3 Provisioning services

The supply of food by urban green spaces is a critical provisioning service in a city where there is a downward trend in primary agricultural activity, due to demands placed on land as a result of other development pressures (CoJ SOER, 2008: 111). The permaculture initiatives of FTFA and other non-profit companies have led to the establishment of programmes such as the Siyakhana Food Project, that shows how urban green space can contribute to food provision and food security. Through the conversion of a section of the Bezuidenhout Park, donated by JCP, the Siyakhana Food Project has enabled the local production of food and the cultivation of herbs for medicinal healing, while creating jobs in the process (Kroll, 2010). The ability of green spaces to provide food is also being incorporated into Johannesburg's private gardens, where there is a growing demand for landscaping companies and horticulturalists to incorporate vegetable gardens in their designs. A food garden in the upmarket suburb of Westcliffe was recently valued at R50 000, revealing a potential new trend in addition to the traditional demand for ornamental services provided in Johannesburg's gardens by decorative plants, flowers and trees that could enhance the status of the green industry (Schäffler's Landscaping, 2010).

Forest ecologist, Professor Coert Geldenhuys (2007), states that the use of bark for traditional medicine, and the concomitant phenomenon of bark traders, is commonly observed as one of the provisioning services of trees in rural areas of South Africa, despite the illegality thereof. Although bark traders and bark harvesting are not well documented in urban areas, Geldenhuys (2010) notes that the medicinal use of tree bark, roots and leaves in Johannesburg, is likely to become a major market in the context of rural to urban migration, where new urbanites may bring with them the practice of bark harvesting from rural areas into Johannesburg, in an attempt to find substitutes for pharmaceutical medicines. This is in a context where the capital value for timber used in herbal medicine industry is significant and for some Southern African forests has been estimated at $40 000 per ha (Geldenhuys in Aronson *et al*, 2007).

Bark is therefore just one of the products provided by trees for human consumption. Another is the use of forest timber for fuelwood in domestic households, yet the exact sources of Johannesburg's fuelwood are uncertain and it is generally the case in urban South Africa that coal and wood converted into charcoal is transported into, rather than produced, in urban areas (Scholes & Scholes, 1998: 424). To this extent, the urban use of timber-derived products appears to differ from that in rural areas where the clearing of wood for building material, fuelwood and household goods, as well as large-scale timber operations and other timber products are some of the multiple products provided by of trees (Geldenhuys in Poker, Stein & Walker, 1998). For the Johannesburg context, therefore, timber-derived products are not identified as immediate priorities relative to the other ecosystem services provided by trees.

3.3.4 Supporting services

Although De Wit *et al* (2009) state that supporting services, as the basis for all other ecosystem services, are seldom valued separately, Johannesburg's green systems naturally contribute to soil formation and photosynthesis through the planting and gardening activities of many of the actors involved in the green supply chain, as well as in non-private organisations. Furthermore, the littering of leaves by trees, is a natural composting service that facilitates the building up of organic material and enhances the nutrient status of the site (Geldenhuys, 2010). Nutrient cycling improves the nutrient levels at the micro-scales of gardens, parks and other green spaces, in-turn supporting ecosystem functioning on a broader scale.

Although introduced, forest species are often criticised as "alien invaders", research shows that certain alien plants play nursing roles through the shading services of their canopies, thus providing suitable environment for shade tolerant indigenous trees, and facilitating the recovery of natural forest systems, such as the indigenous Northern Highveld Forest, (Geldenhuys, 2010; Geldenhuys in Poker *et al*, 1998). Furthermore, trees and vegetation provide habitats for other species, including fauna and flora of various sizes and avian and terrestrial creatures, which potentially enhances the biodiversity of an urban area. Forested urban areas are major attractions for many bird species, who seek out patches of greenery, dense lines of vegetation and green belts for food and shelter (Trendler & Hes, 2000: 13). Trendler *et al* (2000: 9) go on to highlight the importance of South Africa's urban gardens in attracting bird life and if gardens are designed for a variety of habitats, including open areas and canopy habitats, they attract diverse bird species in addition to species richness. Barthel *et al* (2010: 3-5) elaborates, stating that the heterogeneity of urban gardens generally increases the diversity of bird species, which is enhanced by garden features such as bird baths and nesting boxes coupled with bee boxes. The provision of habitats for birds further supports pest regulation as another ecosystem services (Barthel *et al,* 2010: 9).

3.4 Estimates of the importance of EGS to users or beneficiaries

In their methodology, De Wit *et al* (2009: 66) explain that the value of ecosystem goods and services is "determined by people's active and passive use thereof" and as such, these users or beneficiaries need to be considered in terms of how they rank such services. However, the on-site data needed to meet this methodological requirement was not possible to capture, due to resource and time constraints that inhibited field surveys in Johannesburg. To establish which ecosystem functions flowing from Johannesburg's green spaces were relevant to city users, those beneficiaries directly involved in, and affected by, the functioning of the above-mentioned ecosystem services were profiled using the three categories of residents, key commercial groups and public bodies given by De Wit *et al* (2009: 35-36).

The following users are seen to be important for the "residents" category

- Residents living in informal settlements without significant green spaces, to indicate high levels of dependency in terms of threats to ecological resilience such as flash floods, as mentioned by De Wit *et al* (2009, 18)
- Residents living in formal housing with immediate access to significant green spaces
- Property owners
- Employees in the green supply chain
- Employees in section 21 companies involved in greening aspects
- Cultural, recreational and religious groups
- Sports groups
- Gardeners and 'food' gardeners
- Local communities benefitting from social enterprise projects
- Educational groups
- Bark harvesters and users of timber-derived products

Falling under the category of "key commercial interests", the following users benefit from Johannesburg's urban green spaces:

- Mining companies
- The real estate industry in terms of property values enhanced by aesthetically superior gardens
- The private green supply chain
- Events companies
- Social enterprises (profit or non-profit, section 21 companies)

- Spin-off industries who incorporate elements of greening into their operations

Key public bodies that benefit from the relevant EGS:

- Public departments responsible for recovering disaster management costs
- Public departments responsible for public health costs
- Public departments responsible for water treatment and purification processes
- Public conservation and greening departments (Johannesburg City Parks is relevant here, although certain parts of the city's green spaces are managed by provincial and even national environmental departments)
- The Expanded Public Works Programme
- Department of Economic Development

3.5 Links between EGS and development objectives

The ecosystem services provided by Johannesburg's green system, therefore, benefit a wide range of users, revealing a network of value streams that extend beyond the intrinsic value of ecological functions. The relevance of these value streams in terms of the wider development process, is evident in an overview of Johannesburg's socio-economic profile as a city facing pressures to provide economic inclusiveness and employment creation. However, as suggested by the methodology of De Wit *et al* (2009: 26), the connection between the relevant ecosystem services and development objectives can be assessed through the broad guidance of a city's Integrated Development Plan (IDP), as a strategic guide to a city's vision for development. According to the City of Johannesburg's five year IDP (2010/2011: 12), the six core development principles have been identified:

- Proactive absorption of the poor
- Balanced and shared growth
- Facilitated social mobility and reduced inequality
- Settlement restructuring
- Sustainability and environmental justice
- Innovative governance solutions.

The provision of jobs and employment creation through Johannesburg's green supply chain, and public and non-profit bodies involved in greening, has clear links to absorption of the poor, balanced and shared growth, and the facilitation of social mobility and reduced inequality. These strategic objectives reveal the broader development benefits of Johannesburg's green systems reconceptualised as 'green infrastructure'. Industries such as garden services and maintenance, which are based on the upkeep of ecological assets, represent the labour absorption potential of formalizing a green infrastructure sector. Furthermore, green infrastructure solutions have economic multipliers since the "leverage achieved by investing in natural assets is higher compared to the leverage from investing in other traditional economic services (De Wit *et al,* 2009: 3). This multiplier also occurs through green infrastructure interventions that potentially reduce the need for costly investments in traditional grey infrastructure. For instance, reassessing what infrastructure categories are included in responses to Johannesburg's acid mine drainage and flash flooding, green infrastructure may be critical mitigation and adaptation interventions with significant financial benefits. Investing in these natural assets therefore frees up financial resources and revenue that can be redirected for other development objectives such as job creation. This value-adding potential represents the economic and fiscal opportunities that arise from seeing natural assets as infrastructure service providers.

In addition to risk mitigation services, that put pressure on Johannesburg's fiscus, natural infrastructure services provided by Johannesburg's green assets also play a role in reducing the disproportionate experiences of environmental risks and hazards. This is related to the vulnerability of low-income groups to interruptions in the flow of ecosystem services. For instance, those areas declared disaster areas in terms of the Disaster Management Act (Act 57, 2002) after Johannesburg's flash floods were generally informal settlements, located in low-lying areas and characterised by poor housing quality and infrastructure services (Madumo in CoJ, 2009). Therefore, the loss of ecosystem resilience affecting services such water flow regulation, disproportionately affects those physically vulnerable to floods in informal settlements, without sufficient green spaces to improve flood attenuation nor the financial resources to respond to such shocks. To this extent, improved access to and investment in green infrastructure services facilitates more equitable socio-spatial experiences, and is indirectly linked to the ability of lower income groups to realise upward mobility. These issues indicate the value of investing in Johannesburg's green assets, to promote sustainability and environmental justice on both an ecological and social perspective in terms of the shared access to more sustainable living options for current and future generations.

Furthermore, although settlement restructuring is not directly associated with ecosystem services flowing from Johannesburg's green spaces, reconceptualising these spaces as green infrastructure potentially allows for more sustainable urban form where green, and living spaces, provide "free" ecosystem infrastructure services. This is a critical consideration given Johannesburg's sprawling landscape of hardscaped surfaces and where "conserving green spaces" is as a key IDP intervention (CoJ idp, 2010: 17). Furthermore, as De Wit *et al* (2009: 36) point out, the ecosystem services or dividends flowing from green sapces are costly to artificially provide when their resilience is eroded.

Johannesburg's green supply chain, public and social enterprises, through incorporating greening into their core operations, are responding to the unique opportunities that currently exist for cities to "lead the greening of the global economy" (UNEP GER, 2011: 454). The innovations involved in incorporating green assets as central features of sustainability transitions create positive spinoffs in terms of reinventing Johannesburg's identity as a world class Africa city. The 'value streams' created by Johannesburg's green systems, represent examples of innovative governance solutions to ecological challenges and broader social projects in integrated development planning agendas.

3.6 Assessment of the City's ability to influence the value of EGS through management

As the official conserving and greening agent of the city, Johannesburg City Parks (JCP) is responsible for the active management of the city's ecological assets, which together with ongoing projects include (CoJ JCP, 2008/9: 4):

Area of Management	Quantity
Number of parks and arterials	2 343
Area of developed parks and arterials	6 603,3 hectares
Area of undeveloped parks	3 591,1 hectares
Nature reserves	1 202,6 hectares
Street verges	7 500 hectares
Street trees	1,3 – 1,6 million
Number of cemeteries	35
Area of cemeteries	904 hectares
Number of crematoria	2
Number of nurseries	2
Water surfaces	174 hectares
Bird sanctuaries	366,4 hectares
Trails and river trails	107km
Environmental & education centres	6
Size of fleet	306 Vehicles; 127 Trailers

Table 5 Natural assets managed by JCP

However, various management difficulties present themselves if the stated quantities of JCP's various assets are scrutinised and the longevity of major JCP projects are assessed. One striking example is that in the 2008/9 report, between 1,3 and 1,6 million street trees have been identified in addition to the 2,5 million trees that have been inventoried in public parks, cemeteries, nature reserves and conservation areas (CoJ JCP, 2008/9: 4; CoJ JCP, 2010). However, in discussions with the spokesperson of JCP, 6 million publicly mandated trees are thought to exist out of the ten million trees in Johannesburg (Moodley, 2010). Moodley (2010) also reveals that the ten million tree figure is not supported by hard evidence and apart from aerial grid-based views of Johannesburg; there is no official or accurate tree census to confirm how many trees actually exist in the city. Moodley (2010) states that the ten million trees is a 'guesstimate' number that presents problems for JCP, further commenting that from a public department perspective, "it is impossible to manage what you can't measure". One member of the JCP Geographic Information Systems department, for instance, stated that the information on the city's tree database is highly inaccurate since the last mapping exercise conducted by JCP recorded only 240 000 of the much publicised ten million tree figure (CoJ JCP, 2010).

The oft-quoted statement of "with more than ten million trees, the City of Johannesburg looks like a rain forest on satellite pictures" is therefore yet to be proven, resulting in challenges in terms of the mapping and capturing of the city's trees, which, in turn, impacts on the tree maintenance programme (CoJ JCP, 2010). What this data challenge does reveal, however, is that a significant proportion of the trees in Johannesburg are managed privately. Approximately three to four million trees are estimated to grow in private gardens through the city's suburbs (Moodley, 2010; CoJ JCP, 2010). Although the number of trees at the private tree and garden level is not statically proven, a spatial analysis of Johannesburg's tree distribution is indicative of the overwhelming concentration of trees in suburbs and private gardens. Figures 5, 6, 7 and 8 are visual representations of this trend, which also shows the disparity that still characterises Johannesburg's green landscape, as a challenge to the city's ability to influence the shared value of ecosystem services.

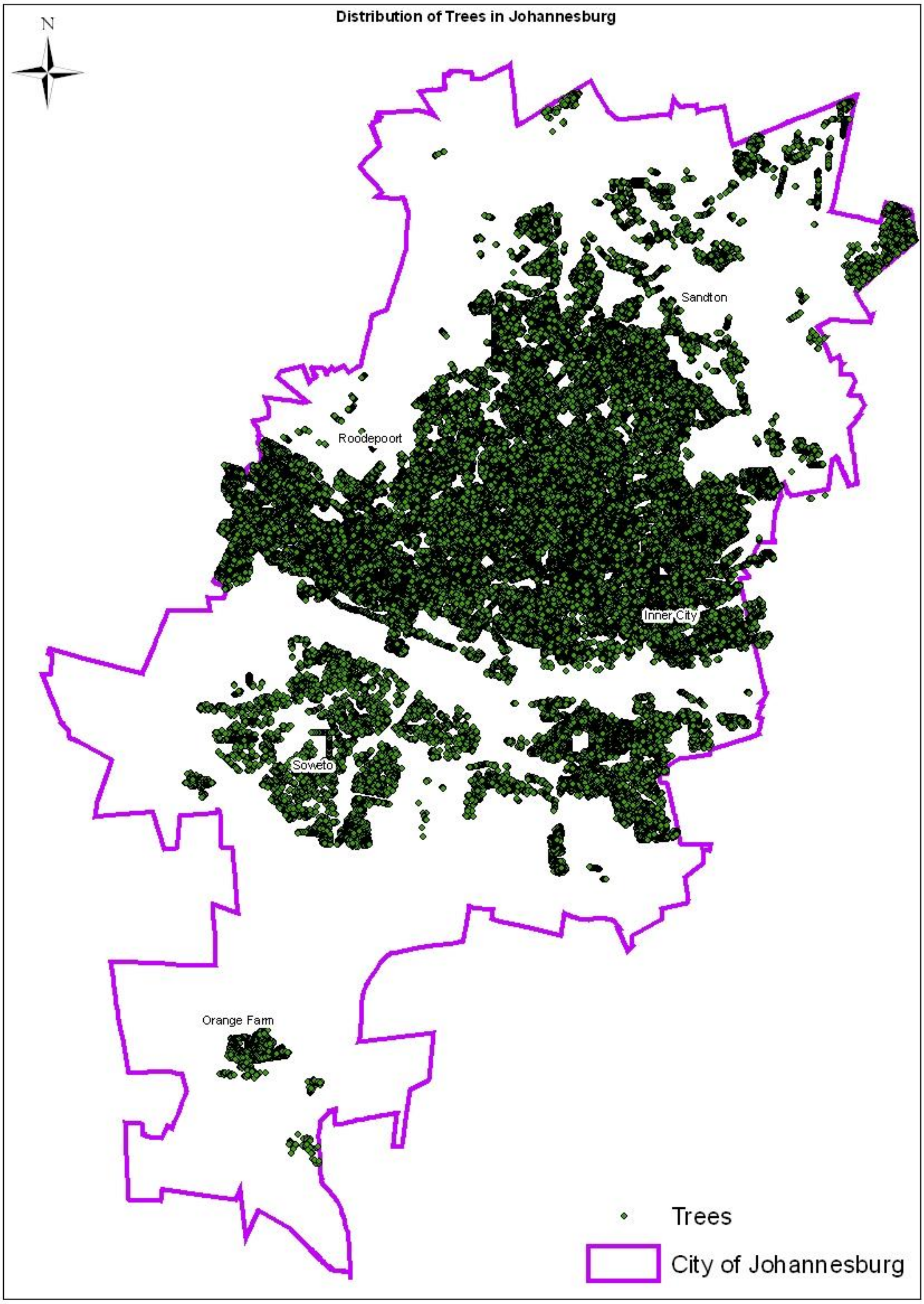

Figure 4 "Distribution of trees in Johannesburg" (CoJ JCP, 2010)

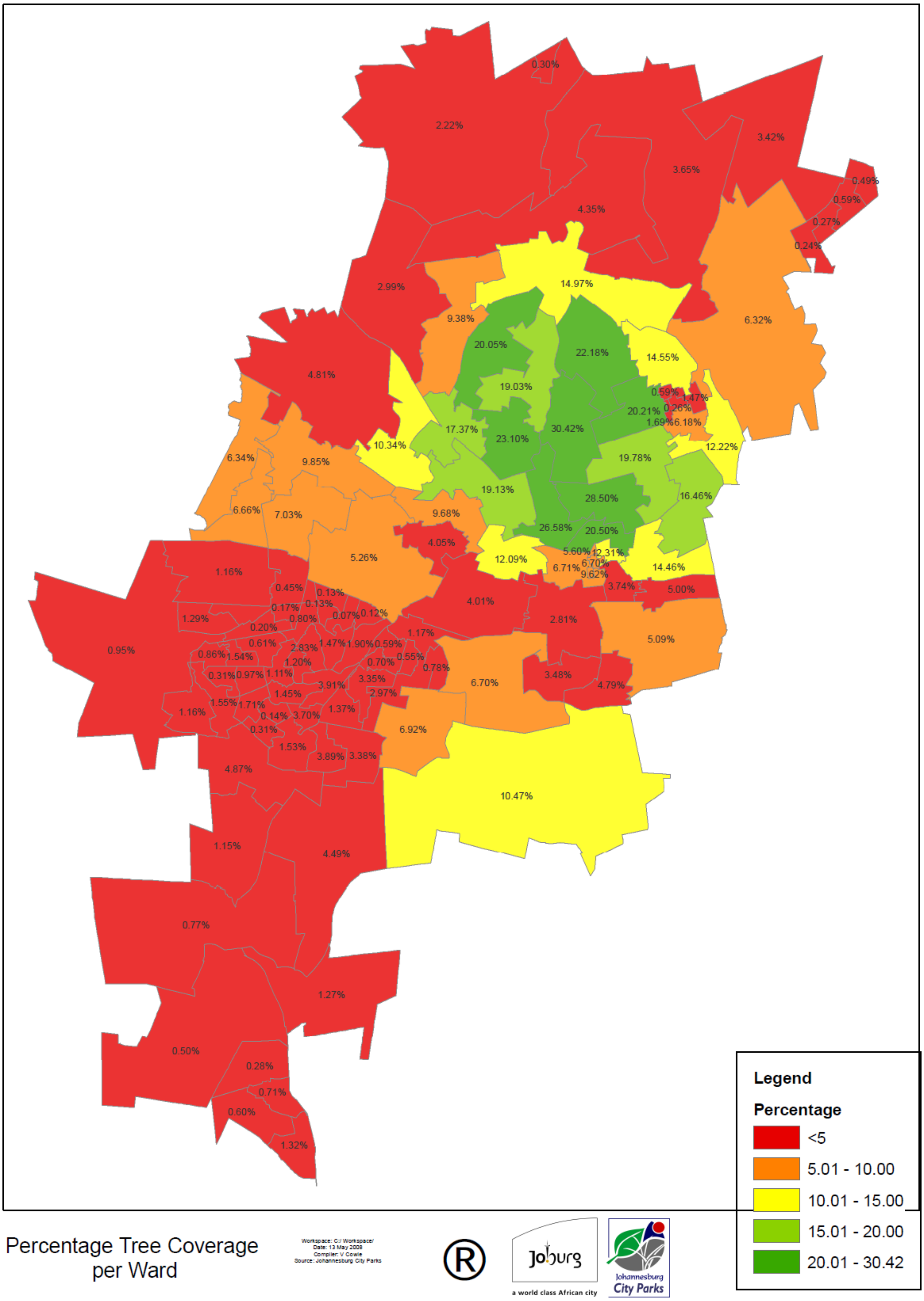

Figure 5 "Percentage tree cover per ward" (CoJ JCP, 2010)

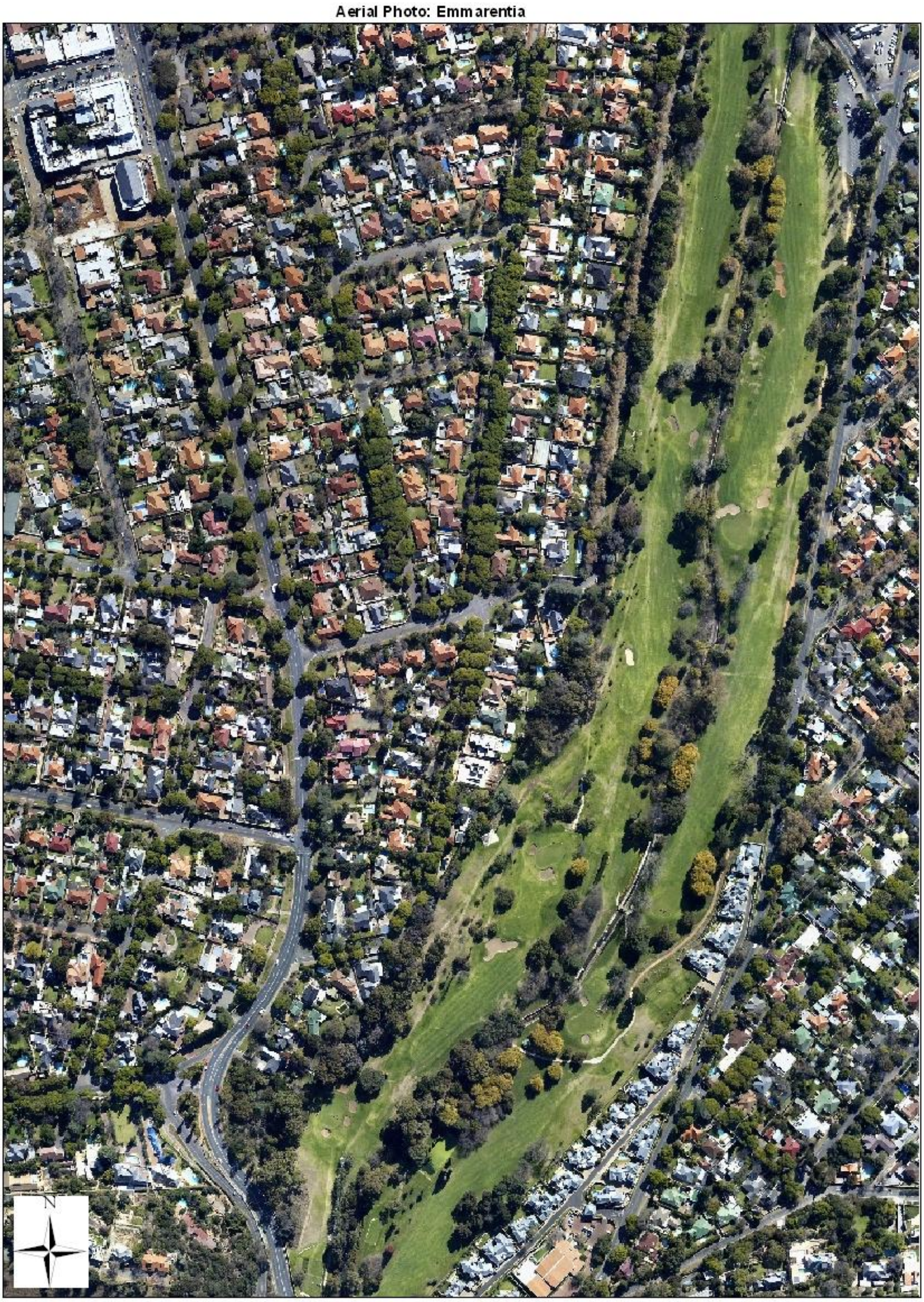

Figure 6 "Aerial photograph of Emmerentia' (CoJ JCP, 2010)

Aerial Photo: Orange Farm

Figure 7 "Aerial photograph of Orange Farm" (CoJ JCP, 2010)

Many individual gardeners or households in Johannesburg ensure that their gardens are well-maintained, through investing in sources of green management such as employing gardeners, garden services, seeking landscaping advice and visiting retail garden centres. The role of the supply chain and related flows of knowledge and financial resources that supports these green investments is, therefore, a factor in maintaining the status of green assets. Johannesburg's green industry is linked to the demand for, and interest in, green aesthetics by private households and corporate bodies, who factor garden and landscaping design, garden services and nursery retail services into their decision-making and consumption criteria. However, the South African nursery and growers sectors have been severely affected by the economic climate since the 2008 financial crisis with many nurseries and suppliers subsequently closing down (Erasmus, 2010). The South African Nursery Association recorded that 39 members resigned from May 2009 and a further 14 from September 2009, and additional members have been suspended due to unpaid membership fees, although these latter figures were not divulged by SANA (Appel 2010). However, these effects are also seasonally-bound, as is the nature of green industries that depend on seasons for planting and growing times, and many nurseries and suppliers terminated operations during winter or the off-season, only reopening in spring and on-season (Erasmus, 2010). The management of Johannesburg's green assets is nevertheless influenced by the functioning, or non-functioning of the green supply chain and its resource inputs.

At a public level, there appear to be further uncertainties regarding the management of parks and other public green assets and open spaces. On the one hand, the roll out of greening projects and rehabilitation programmes of natural assets has gained momentum, particularly in the build up to the 2010 Soccer World Cup. For instance, two of the major projects implemented in 2010 by JCP, namely Greening Soweto and the rehabilitation and greening of Klipspruit, have been declared 2010 World Cup Legacy projects (JCP, 2010). Although it is understandable that JCP is capitalising on the momentum building up to the international soccer event, the fact that the bulk of the Greening Soweto project took place in winter, when the Highveld frosts hits the hardest, and particularly in Soweto, has resulted in many of the trees not surviving the cold (JCP unnamed sources, 2010). This reveals that ambitious greening projects aimed at receiving good media-coverage are potential quick-fixes that waste valuable tree saplings, falling within the maximum range of 200 000 trees, that could be otherwise nurtured to full growth. A further example is the Cosmo City development, a R3.5 billion Greenfield project where 305 ha has been allocated to "nature areas" and a massive tree-planting scheme has been underway in the "new green suburb" (CoJ, 2009, 2010). However, during interviews with various members of JCP, it appears that the Cosmo City trees planted have not been properly maintained and although there is a focus on indigenous trees, which have a higher rate of survival, most have died due to community negligence (CoJ 2009; JCP unnamed sources 2010).

Figure 8 "Aerial photograph of Cosmo City" (CoJ JCP, 2010)

Although indeed underpinned by socio-spatial inequities, private green spaces such as gardens and trees in gardens, play a crucial role in the management of Johannesburg's green assets and influencing the status of urban green systems. However, there is one caveat to assessing the City's ability to maintain the flow of ecosystem services from green assets in their present state. This is that green systems take time to grow and most of the well-maintained green assets are in historically well-endowed green areas, where tree species can be between 60 to 100 years old (CoJ, 2010). Individual perceptions of investment in these green assets, have also benefitted from this rich green history as well as the immediacy of contact with greenery in general. This is another influence on green asset management, revealing differences in the perceptions of, and commitment to, the type of physical infrastructure between the general northern-southern suburb divide. The different political agendas voiced at local government level, are also relevant in this context, where in the south for instance, land issues are priority issues in the context of growing demands for housing development (Beall *et al,* 2000: 836). In contrast, despite the imprint of commercial interests and the historical prevalence of alien vegetation, in the north there is a greater concern with resource management, protecting natural assets such as ridges and koppies and ecological features of Johannesburg's landscape (Beall *et al,* 2000: 836).

However, in her analysis of the idea of gardening in South Africa, Murray (2006: 52) comments on the environments inherited from apartheid, "which made 'home and garden' the entitlement of white South Africans, while reproducing generations of black people in relation to the land premised on labour mirgrancy and domestic/garden work". Murray (2006: 56) looks forward, noting the political and economic opportunities associated with democracy, which have brought new experiential possibilities for black South Africans, especially those who have the capital and leisure to afford a middle-class lifestyle. To this degree, Murray (2006: 56) states that "for black South Africans now resident in previously white 'garden suburbs', being at home might entail the need to become familiar with domestic plant and design knowledges that were once the privilege of the oppressor". Murray (2006: 56) then explains that, in South Africa, such garden knowledge was previously only permitted to black people through the menial labour of 'the garden boy', who were therefore sources of knowledge transfers. Johannesburg's socio-economic dynamics, therefore, present themselves through the culture of gardening, that embodies different experiences of greening in a South African context, and influence the management of green assets which are subject to changing social framings and contexts.

The ability of Johannesburg as a city to manage the ecosystem services provided by its green systems is, therefore, subject to many complexities and challenges. The lack of data on one of the city's largest ecological systems, the urban forest, significantly undermines maintenance of public trees as well as the ability of public entities to make well-informed decisions for further enhancement of these assets. There also appear to be deficiencies in ecological expertise, or rather a short-term focus on green projects that need to be nurtured and maintained over time. Divergent environmental perspectives are a further layer in the social-ecological landscape of Johannesburg in which social perceptions interact to form a discontinuous fabric of urban space (Mbembe in Nuttal *et al,* 2008: 64). The overwhelming concentration of trees in private areas nevertheless, points to a value stream between private individuals and organisations that reinvest human and financial capital in greening their immediate surroundings. Socio-economic circumstances thus continue to play a role in the management of green assets, as is clear in the adverse affects of economic conditions on green investments, although this trend may highlight the fact that green surroundings are perceived as luxury surroundings rather than as having critical social-ecological values.

3.7 Assessment of the ability of ecosystems to yield a sustainable flow of EGS

The ability of Johannesburg's green systems to sustainably provide their services is, therefore, influenced by socio-political dynamics and investments in ecological assets. On the contrary, the ecological risks to ecosystem service provision in this context are linked to demands of Johannesburg's growing population as well as the city's socio-economic and spatial profile. Furthermore, many of the risks to the ecosystem services mentioned in section 3.1 are also the basis for prioritising such services. As such, there are joint spatial and socio-economic influences that impact on the resilience of ecological systems, both locally and globally, albeit with different consequences. Depending on how these influences play out, there are impacts on ecosystem service provision that potentially decrease the risk threshold of many ecological systems, undermining their flows of dividends and often with disproportionate affects on poorer groups.

One of the most pertinent ecological risks is to water flows as well as the quality of these flows. The flood attenuation capacity of Johannesburg's open spaces, that in their natural state absorb storm water run-off, is being severely affected by the encroachment of riparian zones by hard surfaces (CoJ SER, 2008: 166; GJMC, 2000). The increased velocity and turbulence of flooding waters unable to be filtered through permeable surfaces washes away aquatic organisms and the loss of aquatic and wetland resilience impacts on riparian vegetation as well as soil intactness that support wider "green corridors" (CoJ SOER, 2008: 166).

In addition to water flow pressures, diminished water quality still poses a significant risk to the health of Johannesburg's ecosystems. Acid mine drainage has led various sources to predict an impending water crisis with catastrophic consequences and Johannesburg as an "acid water time bomb" (Mail & Guardian, 2010; Van der Merwe in Mining Weekly, 2010). As Keet (in Saving Water SA, 2010) explains, "[t]he acid mine water is currently about 600 metres below the city's surface, but rising at a rate of 0.6 and 0.9 metres a day". There are critical impacts on supporting ecosystem services and studies into the soil conditions of slimes dumps east of Johannesburg, that show that the topsoil is heavily acidified and contaminated by heavy metals, which severely affects aquatic life and if leached into groundwater, will result in long term pollution (Naicker *et al,* 2003: 40; Rosner & Van Schalkwyk in Naicker *et al,* 2003: 30).

Although water quality is likely to be one of the greatest threats to ecological resilience in Johannesburg, other adverse ecological impacts cumulatively combine to decrease ecosystem thresholds and their ability to bounce back from external pressures at both micro and global climate scales. Air quality risks, induced by various spatial and socio-economic activities, are one such threat that despite being a less visible impact, affects multiple life forms. Increasing vehicle tailpipe emissions, domestic burning of low-grade cool and wood, high concentrations of pollutants induced from industrial and waste incineration operations, as well as toxic dust from unrehabilitated mine dumps accumulate to exacerbate an already visibly apparent smog-laden skyline (CoJ SOER, 2003: 38-41; CoJ SOER 2008: 19; Letshwiti, Stanway & Mokonyama, 2003; AQMP, 2003: 9; CSR, 2005; Bond, 2007: 5; Beall, Crankshaw & Parnel, 2000: 853). This is also in a context where temperatures in Johannesburg are to increase by 2.3˚C in the near future, due to the increase in hardscaped surfaces, that together with pollutants induced from socio-economic activity, may have adverse feedback affects on general ecosystem functioning (Theunissen in UGF, 2010: 16; 21).

There are also risks to the stock of ecological assets in Johannesburg due to low-density sprawl that is increasing built-form on the one hand, and informal settlements on the other. Official documents note that the availability of natural habitat and intact vegetation in Johannesburg, upon which animals depend, is diminishing due to low-density development (CoJ SOER, 2008: 126; 149). These documents explain that the trading off of green spaces such as ridges, natural vegetation and habitats, rivers and wetlands, as a result of urban development and associated urban activity, leads to biodiversity losses and increased vulnerability of natural areas (CoJ SOER, 2008: 108; 149; 150). However, although publicly zoned open space may be threatened, there is a tenuous link between low-density sprawl and risks to the stock of natural assets. This is because the culture of greening has been carried by forward by private individuals and various branches of section 21 companies into new housing and property developments. Figure 9 shows the suburb of Northgate, the archetypical example of a new polynucleated suburb on the peri-urban edge, yet well-endowed with trees and green spaces relative to residential and hardscaped land uses. The incorporation of green landscapes into new developments potentially offset the risks posed to Johannesburg's natural capital stock, which extends beyond officially conserved open space. It is nevertheless important to highlight the risk to ecosystem function of urban development that inhibits or excludes green systems.

Aerial Photo: Northgate

Figure 9 "Aerial photograph of Northgate" (CoJ JCP, 2010)

3.8 Applying valuation techniques

In the Johannesburg Metropolitan Open Space System report (JMOSS, 2002), an introductory statement mentions that the massive economic implications of conserving natural habitats...

> "...call for the urgent evaluation of the services rendered by [Johannesburg's] remaining open spaces, the raising of public awareness of these services and the development of appropriate management strategies" (JMOSS, 2002).

The JMOSS report then gives a broad overview of the "ecosystem services provided by open space", where open space is used as a general category rather than referring to the specific services accruing to Johannesburg (JMOSS, 2002: 10-11). An outline is given of some of the economic values of ecosystem services, such as the monetary benefits of plants in mitigating air pollution, yet these values are based on research conducted in other contexts and are not specific to Johannesburg (JMOSS, 2002: 11-12). Since the publication of JMOSS, it appears that the broader economic benefit of Johannesburg's ecological assets is a study waiting to be undertaken. There is, however, an ongoing project, through the South African National Biodiversity Programme (SANBI), of valuing the ecosystem services provided by the grasslands, which have an estimated worth of US$1.2 billion based on hydrological services and the worth of the cattle and sheep grazing in the grassland biomes (SANBI, 2008). Beyond the grasslands valuation, there is no in-depth analysis of the tangible economic values of Johannesburg's ecosystem services, which are not limited to natural assets and public open spaces, but include services provided by the urban forest and the feedback loops of other green systems and supply chains.

Without accounting for the total economic values of the ecosystem services provided by Johannesburg's green landscape and systems, the effect that Johannesburg's greening has had on ecological and supply chain activity remains largely overlooked. The ecosystem services provided directly and indirectly by Johannesburg's green spaces, therefore, need to be valued in relation to the affects of urbanisation on the city's ability to withstand adverse ecological and social shocks. De Wit *et al* (2009: 29) state that the availability of data and the selection of an appropriate valuation are crucial considerations in this final step of the methodology. Given the limited original and detailed research on the value of ecosystem services in Johannesburg, data availability proved to be a major obstacle in valuing the relevant green systems and hampered the research strategy significantly. Despite these difficulties, a tabulated profile of the valuation possibilities that links valuation techniques to prioritised ecosystem services, was conducted in accordance with the suggestions of De Wit *et al* (2009: 37). Table 6 presents the results of this exercise for Johannesburg.

Valuation of the dividends flowing from Johannesburg's green systems was, therefore, carried out where possible in terms of the data availability for the optimal valuation techniques identified.

	Ecosystem services	Valuation techniques
Regulation	Water flow regulation (stormwater and runoff regulation)	Replacement costs, preventative costs, disaster management costs and costs of ecosystem failure. Substitute costs. Healthcare costs. Productivity costs. Carbon price. Economic attractiveness
	Natural hazard and disaster regulation (floods, etc)	
	Water purification	
	Climate regulation (pollutant and carbon neutrality at both micro and macro scales, heat island effect)	
Cultural	Aesthetic, mental and psychological values	Hedonic pricing and choice value experiments. Employment and revenue of green supply chain and other revenue-generating greening initiatives. Economic attractiveness.
	Recreation, sport and religious use	
	Job and employment creation	
	Economic and industry enhancement	
	Education & skills development	
	Awareness raising	
	Livelihood enhancement	
	Sparking new industries	
Provisioning	Food provision and food security	Substitute costs/costs of alternatives. Hedonic pricing and choice value experiments.
	Ornamental services	
	Bark harvesting	
Supporting	Soil formation	Not valued separately, according to methodology.
	Photosynthesis	
	Natural composting & nutrient cycling	
	Biodiversity and habitats (broader ecosystem support)	
	Nursing and recovery of indigenous vegetation	

Table 6 Matching EGS to valuation techniques in Johannesburg

3.8.1 Valuation of regulation services

3.8.1.1 Replacement and disaster management costs

During the February 2009 floods, that hit areas along the Klipspruit River after a thunderstorm, more than 300 families were left homeless, two people died and three others went missing (Mungishi in CoJ, 2009; Madumo in CoJ, 2009). Coupled with the wrecking of houses, the extreme damage to infrastructure required storm water drainage to be reconstructed and roads resurfaced (Madumo in CoJ, 2009). These disaster response options are estimated to cost the City approximately R350 million, a cost that does not include the fatalities caused by decreased flood attenuation (Madumo in CoJ, 2009). Lekotjojo & Evan (2009) also state that due to the strain induced by impervious surfaces, malfunctioning storm water infrastructure is costing the City millions of Rands to artificially mitigate. In light of the resultant strain on Johannesburg's existing storm water infrastructure, the city's green spaces and trees perform critical roles in absorbing and reducing storm water runoff, as disaster mitigation responses to flash flooding (Konijnendijk, Gauthier & Van Veehuzen, 2004: 1).

The February 2009 flash floods, as one example of the affects of the non-performance of water flow regulation, indicate the importance of natural disaster mitigation services in Johannesburg, as well as the dire implications of uncontrolled low-density sprawl, through increased impermeable surfaces on catchment management in the city (Theunissen, in UGF, 2010: 17; CoJ SER, 2008: 166). Investments in green spaces that facilitate flood attenuation and stormwater absorption may, therefore, save Johannesburg significant amounts in terms of infrastructure costs. The appropriate valuation for water flow regulation, therefore, includes the costs of disaster management as well as the costs of replacing existing stormwater infrastructure. Although it is not a city-wide value, the R300 million in disaster costs incurred due to one flash , is indicative of the significant magnitude of such costs accumulating over time.

Replacement cost techniques are also relevant for valuing the water purification services naturally provided by ecological systems. One case in point is Grootgeluk mine, owned by Aurora, that has been receiving a R5 million subsidy from the government every month until recently for water treatment (Newmarch, 2010). Some analysts predict that it costs R2.5 million a month to pump 25Ml of water and further estimate that R200 million is needed urgently in the next 17 months for a water rehabilitation programme at the time of writing (Hartley, 2010; FSE, 2010). Since many people in Johannesburg depend on borehole water for drinking, irrigating their plants and crops and for other domestic use, significant health care costs may be incurred as a result of acid-water-induced illness (FSE, 2010). The costs of dealing with acid mine drainage through water treatment therefore pose significant budgetary challenges to the City as do the substitute costs incurred by households

(Newmarch, 2010). The cost of providing the same level of water quality artificially therefore represents the significance of 'free' water quality for Johannesburg, yet a detailed valuation exercise of these substitute costs is yet be conducted (De Wit *et al,* 2009: 39).

Although the phytoremediation services of Johannesburg's urban forest have not been analysed in detail, a study conducted on the effect of contaminated groundwater on tree species and sub-soil strata in the Free State showed that one of the most water-sapping species, Eucalyptus, had the highest concentrations of contaminated elements in its foliage, bark and wood as well as in the litter layer and topsoil below its canopies (Weiersbye *et al,* n.d: 239). If detailed analysis is available to assess the relationships between contaminated mine water and the phytoremediation services of Johannesburg's trees, their constructed application may prove a valuable mechanism to clean polluted substrata (Weiersbye, 2007b). This research is also important insofar as the pollutant-cleansing functions of the urban forest poses a risk to vegetation and soils, risks that need to be assessed in relation to trees being a "potential sink for inorganic pollutants that could prevent AMD from moving into groundwater" (Weiersbye *et al,* n.d: 239). An area for future ecosystem valuation is investigating the possibility that the high water use of many of the water-sapping trees, such as Eucalyptus, has prevented a far worse situation than that is currently being experienced. In other words, the leakage of acidified water into Johannesburg's water table may have been to a greater extent if many of the introduced tree species had not been introduced in the first place.

3.8.1.2 Economic productivity and attractiveness

In terms of decreased air quality, there are also significant health impacts and health costs associated with pollution-related illness (AQMP, 2003: 4; CoJ SOER, 2008: 183). This translates into direct economic costs due to losses in worker productivity as well as secondary impacts such as loss of investment, tourism and reduced economic attractiveness for Johannesburg as an investment destination (CoJ SOER, 2008; 183). However, as "we enter an era where carbon and other emissions from production processes will make products less attractive and less competitive globally", the urban forest is a unique carbon sink that enhances Johannesburg's economic attractiveness (Banks *et al,* 2008: 7). The absence of an official tree census meant that primary data on the biomass of the urban forest was unavailable, which did not allow for an accurate analysis of the amount of carbon that has accumulated over time in the forest as carbon stock. An attempt was nevertheless made to determine an approximate carbon value encompassed by the urban forest. This exercise was conducted with the assistance of Professor C. Geldenhuys, a forest ecologist from the Department of Forest and Wood Science at Stellenbosch University.

Geldenhuys has published extensively for on the topic of reconceptualising the value of trees as an investment in ecosystem services (Cambridge Resilience Forum, 2010). In particular, Geldenhuys & Berliner's (2010: 6) report, *Estimation of the Carbon Sequestration Potential of the Natural Forests of the Wild Coast,* commissioned for the Eastern Cape Parks' Wild Coast Project, develops a formula to calculate the estimated amount of carbon held by the current stock of standing Wild Coast forests (Geldenhuys *et al*, 2010: 6). Although the report, is applied to the Port St. Johns and Manubi forests along the Wild Coasts, the carbon stock formulas are useful methodological guides for the Johannesburg valuation exercise (Geldenhuys *et al,* 2010: 11). This is because Geldenhuys *et al* generate primary data, used by official government documents, for above-ground biomass calculations (Geldenhuys *et al,* 2010). As Geldenhuys (2010) explains, Johannesburg's city trees are similar to woodland trees so that approximately 50% of the tree volume is held in the branches, necessitating a focus on above-ground biomass carbon storage. Using the Eastern Cape Project as a general guide, the valuation exercise for Johannesburg's urban forest is therefore executed through collaboration with Professor Geldenhuys whose professional experience in the area of forest ecosystem services is utilized to develop a methodology specific to Johannesburg's forest type. As shown in Table 7, a carbon stock formula is adjusted for a woodland area such as Johannesburg using a sample site multiplied by the number of trees estimated to occur in the city (Geldenhuys, 2010).

Methodology to estimate the carbon stock of Johannesburg's urban forest:	
Stage	**Description**
1.	Choose a 50x50m area in within the City of Johannesburg's municipal boundaries with a mixture of trees and open spaces to be representative of urban tree distribution
2.	Calculate the diameter at breast height (DBH in cm)
3.	Calculate the stem length to main branches (m)
4.	Estimate the percentage (%) of the branch volume as a proportion of the total tree volume = B (e.g. 70% =0.7)
5.	Calculate the Basel Area = π*DBH*DBH*/40000
6.	Calculate the stem volume =BA*stem length*0.7
7.	Calculate the total tree volume = Stem volume/(1-B)
8.	Calculate biomass = tree volume *0.7
9.	Calculate volume per ha = biomass/0.25 (metric tonnes per ha)
10.	Calculate biomass per ha = volume per ha*0.7
11.	Calculate carbon stock = biomass per ha*0.5 (metric tons per ha)
12.	Calculate carbon stock of entire CoJ area = carbon stock per ha*total CoJ ha (164 458 ha)

Table 7 "Methodology to estimate the carbon stock of Johannesburg's urban forest" (Geldenhuys, 2010)

However, various assumptions were made due to the lack of primary research on Johannesburg's urban forest. A $50x50m^2$ was chosen to represent a typical tree stand in Johannesburg including open areas and trees of different sizes and varieties. This area was used to assume a value of the carbon stock of an area that could then be extrapolated to the city level in terms of the total 164 458 ha of the City of Johannesburg (JMOSS, 2002: 17). Caveats to this analysis are that biomass calculations depend on the specific gravity of each tree and therefore vary per tree species as does the biomass per hectare in Johannesburg since each plot has different landscape characteristics. Above-ground calculations were also only conducted as it was impossible to do detailed research on the biomass stored below-ground in the available time and with the available resources. As a result, the analysis excluded carbon stored below ground and excluded the contribution of roots and organic compounds in soils which can be more significant than that of the stems and leaves of plants (Weiersbye, 2007b). Reasonable assumptions were made, however, to achieve a rough indication of the Johannesburg's carbon storage through timber biomass.

Table 16 in the Appendix shows that the chosen area stores an estimated 32.2 metric tons of carbon per hectare. Extrapolated to the city level, this translates into a carbon stock of 5, 3 million metric tons of carbon that has accumulated as a result of the construction of Johannesburg's urban forest. Based on a market related carbon price at the time of writing of € 15.42, in terms of the European Union Emissions (EUA) market, Johannesburg's carbon storage is potentially valued at €82 269 015 (Cantor CO_2, 2010). Furthermore, the spot price of Certified Emissions Reductions (CER) at the writing time is €13.86, which equates to €73 469 622 (Cantor CO_2, 2010). These two values converted into Rands based on exchange rates at the time of writing are respectively R785 828 663 and R701 868 194. These values are the fixed stocked values of carbon, otherwise known as the growing stock, based on the amount of carbon that has accumulated in the forest over time (Geldenhuys, 2010). If primary data had been available on the annual growth rate of the trees, the carbon sequestered through the forest per annum could be calculated, which could provide information on the carbon value accrued annually in monetary terms.

Such carbon calculation exercises are therefore part of valuing a currently latent market – the carbon stock and sequestration services provided by Johannesburg's urban forest. Once real values are attached to these services, carbon stock and sequestration can become a market that is part of the formal economy, through which trade and spending flow. The potential therefore exists to create a "Johannesburg Carbon Exchange" based on the monetary value of carbon, which in-turn has economic spinoffs for both the public fiscus and market-related trade activity. For instance, the increased spending that flows from trading in carbon is a potential injection into the City of

Johannesburg' tax base, from which other public projects and investments can be financed. This tax injection, as well as the employment created through formalising a carbon market, represents the potential multiplier benefits of the urban forest's ecosystem services. Furthermore, because these services already flow from the trees, such a carbon exchange project does not require the budgetary financing that would be necessary for initial start-up. This positions Johannesburg as a carbon exchange centre and highlights the importance of assigning a tangible value to the carbon stock and sequestration services naturally provided by the forest.

The carbon trade industry could become an important source of revenue for municipal urban forestry expansion and other greening projects in Johannesburg, with a secondary benefit of investment attracted to the city (Stoffberg *et al,* 2010: 10). However, the priority given to carbon sequestration in terms of carbon trading is based on the functioning of global carbon markets, which have been highly criticised for allowing market actors to buy "the right to pollute", thereby transforming pollution from a social evil into a neutral commodity (Harvard Law Review, 2010: 2068-2069). Carbon and pollutant neutrality should nevertheless be a ubiquitous goal for South Africa, on both environmental justice and economic attractiveness levels, and the carbon removal and storage functions performed by an estimated ten million strong forest are critical services to this extent (Weiersbye, 2007b).

3.8.2 Valuation of cultural services

3.8.2.1 Enhanced well-being

Although the psychological, mental and recreational use of Johannesburg's green systems are worthy of valuation, the techniques required to establish these values are beyond the scope of this study. The goal of future research can therefore be to conduct choice and hedonic valuation exercises such as willingness-to-pay for ecosystem services. To this extent, the data and records from JCP, nature and tourism organisations, as well the records of organised recreation groups, can be accessed, as suggested by De Wit *et al* (2009: 17). Detailed consultations with relevant user groups should also be conducted to assess participants' experiences with Johannesburg's green assets.

3.8.2.2 Economic contribution to Johannesburg and individual sectors

For this analysis, valuation of the cultural ecosystem services is therefore necessarily limited to the economic contribution of the green supply chain and other revenue- and employment-generating streams involved in greening. This valuation is also prioritised in order to reveal the economic opportunities that exist from green infrastructure activities if we reconceptualise what are defined as business-as-usual jobs and value streams. However, an overview of research and communication with the green industry reveals an absence of accurate published information regarding the economic size and value of South Africa's and in turn, Johannesburg's private green industry (Hoy, 2009: 54). The knowledge gaps in the green industry of Johannesburg and South Africa as a whole are contrasted to that applicable to other parts of the world such as the United States of America and Australia where information on the contribution of the "garden" market is publicly available (Hoy, 2009: 52-53). The obstacles faced in terms of available primary research for this specific valuation exercise included:

- Detailed analysis of Johannesburg, as well as South Africa's, green supply chain is yet to take place.
- The data and levy records of members in the green supply chain that were accessed did not contain the primary information required to calculate the total economic contribution of the green industry in Johannesburg. As such, the study had to be limited to organisations falling under SAGIC from which data could be extracted. These included the South African Nursery Association (SANA) and the South African Landscaping Institute (SALI). However, these two organisations are directly involved in supplying green systems at a retail level on the one hand, and at a service level on the other, and are major role-players in connecting the various points of the green supply chain to the public.
- There are organisations operating independently of the South African Green Industries Council (SAGIC) that perform the same activities as registered SAGIC members. Although these members contribute to the green supply chain and possibly significantly so, as independent 'green' industry members they were excluded from the study. Although this places a limit on the valuation exercise, original research on independent actors in the green supply chain has not been conducted thus rendering it impossible to include them based on current available information.
- When analysing the SAGIC green supply chain in Johannesburg, members based in other Gauteng metropolitan regions need to be included as many relevant organisations are based throughout the province although they do operate in Johannesburg. This is also the reason why SANA and SALI only categorise their datasets according to Gauteng membership as a whole.
- Field research as many members of the green supply chain were reluctant to divulge the information necessary to calculate the contribution of Johannesburg's methodology. This

hampered the initial research strategy in which relevant members were asked to volunteer: i) their annual revenue figures, ii) number of employees, iii) geographical location and iv) costs of services offered such as garden services or design.

However, through consultation with SAGIC, it was established that membership for SALI and SANA is categorised according to four divisions depending on revenue earnings. The SALI and SANA membership fee categorisations are included in Tables 8 and 9 respectively:

Category	Annual Turnover	Total membership fee
Principal		
1.	0 - R500 000	R3 800
2.	R500 000 - R1.5 Million	R8 000
3.	R1.5 – R5 Million	R9 300
4.	R5 Million plus	R10 300

Table 8 SALI 2010/2011 Membership Fee Breakdown (SALI, 2010)

Category	Annual Turnover	Total membership fee
Principal		Not divulged
1.	0 – R640 000	Not divulged
2.	R650 000 – R2 Million	Not divulged
3.	R2 – R6.5 Million	Not divulged
4.	R6.5 Million plus	Not divulged
b) Full additional members		R1 484
c) Branch member		R1 777

Table 9 SANA 2010/2011 Membership Fee Breakdown (SANA, 2010)

To achieve a reasonable estimate of the worth of the Johannesburg-Gauteng green industry, it was established that if the membership numbers per category were extracted, a total range of each category's revenue earnings could be calculated according to a minimum-maximum continuum. In consultation with the administrative divisions of SALI and SANA respectively, the total numbers of members in each category were revealed, allowing for a calculation of the "total range of economic contribution" to be established. The methodology for this calculation is explained in Table 10.

To calculate total range of economic contribution: Step a) Calculate the membership numbers per category Step b) Multiply the total members per category by the minimum revenue allowed for that category Step c) Multiply the total members per category by the maximum revenue allowed for that category Step d) Calculate the total "minimum range of economic contribution" Step e) Calculate the total "maximum range of economic contribution" *Note: When calculating the "maximum range of economic contribution", there is no ceiling limit for the highest category earners. The minimum revenue of the highest earning category is used as a conservative estimate since these members could be earning anything above this limit. Therefore, the total "maximum range of economic contribution" could be much higher than estimated.*

Table 10 Calculating total range of economic contribution

The results of the valuation exercise indicate that the total minimum range of economic contribution that Johannesburg-Gauteng SALI and SANA members feed to the economy is R20 000 000.00 and R387 850 000, respectively. The total maximum range of economic contribution for SALI and SANA is R77, 000, 000.00 and R775, 850, 000.00, respectively. These values and the supporting data are included in Table 8 and 9. It is acknowledged that these values are only estimates, but based on an indication of what each category's members earn; it is assumed that an indication of what the industry is worth can be derived. It is also recognized the range between the minimum and maximum economic contributions leaves room for a large degree of error. Furthermore, the most recent SALI membership numbers received from the organisation's administrative unit are 2004 figures, which are likely to have changed subsequently but this data is not available. However, since these categories and data are employed by the relevant organisations, the given ranges are taken to indicate roughly what their associated industries contribute to the broader economy in terms of revenue.

SALI DATASETS (latest 2004)				
Category	Range	Numbers per category	Range total contribution	
			Min	Max
0	0 - R500 000	25	-	12 500 000
1	R500 000 - R1.5 Million	13	6 500 000	19 500 000
2	R1.5 – R5 Million	9	13 500 000	45 000 000
3	R5 Million plus	0		
Total		47	**20 000 000**	**77 000 000**

Table 11 SALI Datasets showing the total range of economic contribution for the Johannesburg-Gauteng members

SANA DATASETES (2010/2011)				
Category	Range	Numbers per category	Range total contribution	
			Min	Max
0	0-R650 000	59	-	38 350 000
1	R650 000 - R 2m	99	64 350 000	198 000 000
2	R2m to R6.5 m	48	96 000 000	312 000 000
3	R 6.5 m +	35	227 500 000	227 500 000
Total		241	**387 850 000**	**775 850 000**

Table 12 SANA Datasets showing the total range of economic contribution for the Johannesburg-Gauteng members

Focusing on SALI and SANI as two micro-scale examples of the economic contribution of the green supply chain only allows for a birds-eye view of what the entire green industry is worth. The role of numerous other organisations that contribute to green systems through different points in the supply chain needs to be analysed for a more robust investigation of the Johannesburg-Gauteng green infrastructure base. These points include among others, those organisations responsible for propagating plants, procuring fauna and flora, irrigating landscaped sites, the suppliers of outdoor landscaping equipment and products, those who promote arboriculture practices, interior landscaping associations and flower growers (Life is a Garden, 2010). The valuation exercise conducted on the economic contribution of Johannesburg's green supply chain is therefore incomplete, and the total industry worth cannot be fully concluded. Recording a similar experience during his interaction with the green Industry in the broader Gauteng region, Hoy (2009: 99) states:

> “Within the Green Industry, members do not have the funds, time or inclination, to spend hours at a time in focus groups, working through questionnaires, and as a result, any other method of sampling (other than disproportionate stratification) would not allow for selected representatives from the SAGIC subset, to represent and decide on the member’s interests. This was evident by the fact that the researcher had to make numerous efforts to contact the SAGIC body, before any response at all was obtained and even at that stage, the response was considered as very poor. Hence, disproportionate stratification allowed the researcher to use only selected (volunteer/co-opted) members of the SAGIC subset in focus groups.” (Hoy, 2009: 99).

Research of the monetary flows from the entire SAGIC body to the rest of the economy is required before further accurate economic value can be determined. This requires the cooperation of SAGIC members who, in the initial valuation strategy of stakeholder interviews and questionnaires, were either unable to contribute information due to resource constraints, or unwilling to divulge such information where they could. The green industry is positioned uniquely in a context where investments in natural assets and catalysts for green economies are already underway. SAGIC therefore stands to benefit commercially from this movement if it capitalises on the momentum around green economies and industries, harnessing its green identity as a platform for green infrastructure development.

However, it is possible that the demands for green services in Johannesburg are related to the high inputs required by highly manicured lawns, hedges and gardens of the wealthy northern suburbs. The ecological sustainability of this system itself needs to be assessed in terms of the extent to which Johannesburg’s green system and its supply chain in particular, rely on artificial chemical inputs, fossil-fuel dependent machinery and unrecycled water for irrigation. The excessive use of artificial nutrients and pesticides that are never used entirely efficiently by the receiving plants accumulates as run-off from the intensive nutrient-overloading of inorganic inputs (Conway & McNeely in Pretty *et al,* 1995: 130; McNeely *et al,* 2001; 7). Pesticides also accelerate soil erosion and artificial nitrogen and phosphorous pathogens create water and nutrient pollution affecting habitats and ecological systems far beyond the domestic garden scale (Ashton, 2008: Magdoff, 2007: 109-110; (Pagiola *et al*, 1998: 38). These are ecological concerns that need to be subject to detailed analysis.

3.8.2.3 Employment in the green supply chain

The employment in gardens, as opposed to the indirect employment created by the need for gardens, is another facet of the experience of gardening in Johannesburg. Domestic garden work is a green system that provides jobs for many individuals, although this type of work also embodies the mismatches between socio-economic opportunities. Furthermore, despite the continuation of domestic garden employment as well as the changed political framing of ‘garden boy’ to domestic garden work, racial desegregation and economic restructuring have altered the labour dynamics encompassed by the domestic garden supply chain. This is captured by Murray (2006: 56):

> "Now, for contemporary middle-class black South Africans, arrival in the suburbs might best be entertained neither through personal mastery nor the 'garden boy,' but through outsourcing to professional garden services."

Various dynamics are therefore at play in valuing employment creation of Johannesburg's green supply chain. In many circumstances, people tend to their own gardens as a recreational and personal opportunity to get in touch with nature and relieve stress of the city. However, the physical labour required in lifting heavy bags of compost, moving concrete pots, digging, bending and 'living on your knees' is physically straining, particularly for older individuals (Coetzee in Murray, 2006: 46). In many cases the physical requirements, and time constraints of busy urban living, often deter people from garden work, and the maintenance of a garden in Johannesburg in such circumstances is therefore facilitated by either a gardener employed by the household or the out-sourcing to a garden services team or maintenance company.

Although vast landscaped gardens indicate Johannesburg's socio-economic parallels, their existence has sparked an employment chain for an otherwise excluded workforce. However, Andersson (2006; 394) shows that a large percentage of gardeners in Johannesburg are not South African, but migrants from neighbouring countries that have created access to a specific labour market – that for gardeners and domestic workers. In valuing the economic contribution of Johannesburg's green industry, garden employment as a labour sector and garden services as an industry created around the need for such employment are therefore two important components for analysis. Furthermore, the phenomenon of housing complexes and town-house developments has created an industry of corporate garden service teams that deal only with large-scale residential or office-park developments. If valued explicitly, these value streams, sparked as a result of the maintenance requirements of green space, are potentially important sources of employment. Additionally, the extent to which garden work absorbs 'unskilled' workers is tenuous since much of the ecological knowledge and understanding of how a garden works as a system is highly valuable from a green infrastructure perspective as an opportunity for informal skills transfer.

The major problem encountered in assessing the total employment contribution of domestic garden work was that the only study conducted on garden-related employment is at a Gauteng-scale and refers to 'gardeners, horticultural and nursery growers' and farm owners and skilled farm workers without a specific breakdown thereof (StatsSA, 2010). Table 10 includes these results, showing that

4 569 people are employed in these occupations overall, which appears to be a very conservative figure since 513 Zimbabweans alone are estimated to be employed in domestic garden work in Johannesburg (IDRC, 2010). What this does reveal, however, is that a significant number of domestic gardeners are unaccounted for by official data capturing exercises, and this is possibly due to the predominance of non-South African garden employees. Andersson (2006: 389) gives insight here, noting the "stereotypical images among white employers of Malawians being trustworthy, disciplined and reliable workers – nowadays evidenced by personnel advertisements in Johannesburg newspapers".

Quarterly Labour Force Survey (2nd Quarter 2010)	
Raw numbers	
Variables in layers	
Province, Gauteng	
Occupation	Gardeners, horticultural and nursery growers (farm owners and skilled farm workers)
Frequency	4 569

Table 13 Quarterly Labour Force Survey (StatsSA, 2010)

Although an economic valuation exercise of those employed in domestic garden work is a labour force study on its own, an attempt was made to estimate a relevant employment value. The exercise faced similar difficulties in terms of garden service companies unwilling to divulge information, which rendered the extraction of information through interviews largely ineffective. This problem was exacerbated by the fact that the majority of garden services profiled required specific site visits to assess the degree and type of maintenance needed and people required for such work. Despite enquiring for a quote for "a medium-size-garden that needed weekly maintenance", most companies' response was that the requirements depend entirely on the site and the state of the garden. The valuation exercise of those employed in domestic gardens was also faced with the difficulty of double-counting since many SANA and SALI members offer garden services as part of their operations. A further problem was caused by the fact that in times of financial difficulty, many green supply chain members such as landscapers will offer garden services as a supplementary source of income if required. To this extent, there is a large degree of variation in the employment contribution of domestic garden work as is evident in the employment of temporary workers or 'casuals' employed by garden services during 'busy' seasons. Since there is no accurate figure on the number of garden services and garden employment in Johannesburg, an alternative strategy is suggested for future research to estimate these employment values, as shown in Table 15.

To estimate the value of garden employment:
Step a) Identify a low-density residential area.* Step b) Consult the 2001 census of household dwelling types per suburb in South Africa from StatsSA. ** Step c) Based on the number of low-density 'formal' dwelling types in a given suburb, and the assumption that the majority of these have gardens that require maintenance; estimate the number of households either employing a gardener or a garden service company. Step d) If "x" households employ a gardener: i) Multiply "x" households by the average wage of the gardener per day ii) Multiply (i) by 8 hours (assumed working hours in a day) iii) Multiply (iii) by 245 days (assumed working days per year based on working 5 days a week and 15 days leave a year) = total annual wage of gardeners per area If "x" households employ a garden service company: i) Multiply "x" households by the monthly fee of garden services ii) Multiple (ii) by 12 months = total annual revenue of one garden service company **Note: Low density residential areas are assumed to include some form of 'green space' such as a garden that requires maintenance for its continued existence. This is based on the findings of the CoJ Spatial Development Framework (2007; 16), which states that Johannesburg's residential dwellings vary from 10 du/ha in golf, equestrian or country estates to 40-70 du/ha in townhouse and cluster developments. Whether households actually do invest in garden maintenance is unconfirmed.* ***The 2001 census is the most recent available database on dwelling types per area in South Africa.*

Table 14 Estimating the value of garden employment in Johannesburg

This valuation technique is necessarily limited by the assumption that either a gardener or a garden service is used for the maintenance of a garden, as opposed to a combination of both types of garden maintenance. In reality, this combination is likely and further base research is necessary to extract exactly what kind of maintenance activity takes place in Johannesburg's gardens. Table 16 illustrates the potential value of garden employment in Johannesburg from available data for the specific area in consultation with the Geographic Department of StatsSA. Such an example needs to be extrapolated to city-scale to achieve an overall value of garden employment in Johannesburg.

To estimate the value of garden employment:
a) Chosen low-density residential area: Greenside (StatsSA, 2001) b) Greenside has 1 483 dwelling units per ha (StatsSA, 2001) c) If 60% of Greenside households use garden employees, approximately 889 households employ either a gardener or a garden service. d) If gardeners are employed at an average wage of R120.00 per day based on the recommendations of a local landscaping company: i) 889 x 120 (wage per day) = R106 680.00 ii) 106 680 x 8 (hours per day) = R853 440.00 iii) 853 440 x 245 (days per year) = **R209 092 800.00** (total annual wage of gardeners per area as calculated above) If garden service companies are used at an average fee of R1800.00 per month based on the quote of a local garden service: i) 889 x 1800 (monthly garden service fee) = R1 600 200.00 ii) 1 600 200 x 12 = **R192 024 00.00** (total annual revenue of one garden service company as calculated above)

Table 15 An example to illustrate the estimation of the value of garden employment in Johannesburg

3.9 Concluding thoughts: Valuation case study

In an attempt to answer the question of whether Johannesburg's ecological assets have been formally valued, a discrepancy emerges between what these assets mean in factual terms and the value assigned to them by public sector custodians. The gap analysis conducted to estimate the value of a set of ecosystem services in Johannesburg results in a moderated version of the total economic valuation methodology developed by De Wit *et al* (2009). Although the ecosystem services categories and associated valuation techniques included in De Wit *et al*'s framework are used as general guides, alternative methods are explored to demonstrate possible ways of understanding and valuing the joint social and ecological benefits of Johannesburg's green assets.

In line with the original methodology, the chosen valuation techniques are related to those ecosystem services that emerge as priorities for investment based on Johannesburg's specific social-ecological vulnerabilities. Matching water flow regulation and water purification to disaster and replacement costs is critical in the face of flash flooding and the decanting of acid mine water. On the other hand, the extent to which Johannesburg's economic productivity and attractiveness are enhanced by services flowing from green assets is a vital consideration for elevating the employment, revenue and wider development contribution of such assets into decision-making agendas. Furthermore, the priority given to the prioritised ecosystem services is necessarily linked to the nature of Johannesburg's urbanisation and development, where trends such as low density sprawl, the city's mining history – albeit with paradoxical implications – and a process of disparate economic restructuring give precedence to the social-ecological dividends flowing from flood regulation, phytoremediation and the economic role of the city's green supply chain.

Expanding the methodology for valuing the interest accruing to Johannesburg from its ecological assets gives insight into the ability of the city to sustainably ecosystem services. The management of ecosystem services in Johannesburg is undermined by the porous understanding of the set of local ecosystem services on the one hand, and the lack of accurate valuations assigned to these services on the other. Through this recognition, however, non-public sector custodians and cultures of greening, such as Johannesburg's green industry and value chain, emerge as sources of social-ecological resilience that exist in addition to official public sector custodians. The sustainable flow of Johannesburg's ecosystem services is also threatened by the very social-ecological vulnerabilities that render such services as priorities for investment. Ecosystem threats such as losses to green space, biased policy agendas and critical water challenges undermine the existence of functioning, resilient and adaptable green infrastructure providers whose services therefore require better economic and policy strategies (Kremen *et al,* 2005: 546).

The valuation techniques used in this case study are possible ways of rethinking what constitutes traditional infrastructure services to incentivise, mainstream and invest in the more sustainable use thereof. Expanding the methodology suggested by De Wit *et al* (2009) therefore allows for reconceptualising ecological assets as providers of municipal and economic development services to addressing the porous public understanding of the ways in which ecosystem services anchor jobs, financial and municipal resources. If valued explicitly, the multiple functions offered as 'free' services to Johannesburg by its green systems, can be prioritised to motivate further investment in such systems as infrastructure service providers.

Johannesburg has the potential to capitalise on its green assets as sources of social-ecological resilience, which could position the city attractively as a 'green economy' of the future. Such movements are already underway, both globally and locally. At a global level, the UNEP-led Green Economy Initiative was launched in 2008 and the supporting Green Economy Report is to be launched in 2010 (UNEP, 2010: 3; 8). Locally, the Gauteng Province has released a "Developmental Green Economy for Gauteng" strategy and the "Green Strategic Programme for the Gauteng Province", in which Johannesburg needs to play a crucial role (Spencer *et al*, 2010: GPG, 2010). How

Johannesburg harnesses its ecological assets to play a leadership role, as well as create economic activities of significance is crucial for the future of the city. If the steps taken to invest in ecosystem services are overlooked, an opportunity will be missed to enhance both the flow of ecosystem services and socio-economic opportunity, as multiplier affects of green infrastructure.

Chapter Four: Conclusion and research implications

The consensus that the world is facing an increasingly urban future, in which the combined social and ecological demands of cities are unprecedented, provided the initial context and theme to be investigated by this thesis. However, the analysis of current urban growth trends and cities in particular, made me aware of theoretical frameworks, debates and methodological concerns that were not envisaged at the outset of the research. The weaving together of these conceptual and practical concerns, which interact in close relation to each other in this thesis, mirrors the complexity of social-ecological systems themselves. On reflection, therefore, the research is itself an unfolding methodology of how to conceptually and practically address the multiple and non-linear dimensions of complex systems.

4.1 Concluding reflections of literature review

In reviewing key literature on the second wave of urbanisation, it emerged that a holistic approach to conceptualising cities and sustainability transitions is critical in terms of the multiple, embedded features of urban forms and the interconnected nature of contemporary global challenges. In developing this understanding, social-ecological systems analysis developed as an appropriate framework from which to understand multi-dimensional realities. Applied to the current context, this analysis pivoted on threats to ecosystem service provision, which is increasingly an urban and human-induced situation; the need for social-ecological change and active management; and the cross-scale focus required for co-adaptation of both social and ecological processes. This is a synthesis of conceptual developments using the resilience theory, which is increasingly gaining recognition as a platform for addressing systemic global issues.

It emerged from the literature review that the resilience of social-ecological systems is being fundamentally altered by current urbanisation dynamics where developing countries are the main focus of future urban growth. Building on the threats to ecosystem services, a growing body of work is prioritising the role of urban green space as an source of local ecological resilience in the context where cities increasingly depend on far away ecosystems for enhancing their adaptive capacity. However, the necessary inclusion of developing country contexts within the analysis meant that the research had to be sensitive to the particular challenges such regions face in terms of their ability to invest in the infrastructure required to meet the demands of increasing urbanites.

Faced with these practical realities, the review was impelled to consider the type of infrastructure investments that could potentially enhance both ecological and social opportunity in a way that was appropriate to developing country contexts. Working through various ideas, green infrastructure developed as a framework to revitalise the case for urban green space in planning and investment decisions. It was shown that if valued on par with other infrastructure utilities, ecological assets not only enhance the flow of ecosystem services necessary for human well-being, but contribute to employment creation and boost the economic attractiveness of a city in the context of green economies and job markets. This implies that ecological assets are valued in terms of their total economic benefits, or real value, in order to assign a tangible financial value to ecosystem services. The methodological framework reviewed in this regard showed that beyond the inherent value of ecosystem services, the contribution of such services to wider development processes needs to be made explicit for a sound financial case of investment in natural assets.

4.2 Concluding reflections of case study

It is worth reflecting on the study of Johannesburg as an urbanising system and application of the idea of green infrastructure using the following statement by McPherson *et al* (2005: 411): "[t]he urban forest is, in part, an artificial construction, and street and park trees are its most cultivated component". The authors go on to state that despite the constructed nature of forests in cities, city trees are increasingly viewed as optimal strategies to respond to the multiple challenges facing cities (McPherson *et al,* 2005: 411). Acknowledging that the urban forest is one type of green space asset, McPherson *et al's* insights capture the possibility that, despite threats to Johannesburg's ecological resilience, urban green space and cultures of greening can be sources of social-ecological resilience. Therefore, although Johannesburg is characterised by an unsustainable spatial form, mismatched economic reality and threats to ecosystem services induced by socio-economic activity, the tree-planting and greening cultures have been carried forward at multiple levels of urban interaction. In a somewhat paradoxical way, the city's constructed green systems are potential sources of mutual resilience in a system facing combined pressures to ecological and social adaptability. These overlapping trends are testimonies to the heterogeneous and contradictory form of contemporary cities as well as to the role of urban green space in enhancing local capacity to respond to external shocks.

4.3 Methodological implications

Although a research strategy was developed for the purpose of motivating future investment in ecological assets and associated value streams, much of the key Johannesburg-specific data required to fulfil the methodological requirements was lacking. Despite this obstacle, opportunities emerged for valuing Johannesburg's green systems beyond their inherent ecological benefits. Availability of secondary data allowed for an analysis for an estimation of the costs of regulating services not functioning at their optimum. Using replacement cost techniques indicates the feasibility of internalising 'free' regulating services into municipal budgeting processes and highlights the need for greater public understanding of the links between ecosystem and human welfare (Palmer *et al,* 2004: 1251).

The lack of quantitative data for estimating the benefits of Johannesburg's cultural ecosystem services stimulated experimentation with new techniques for estimating the city's carbon stock and the economic contribution encompassed by the green supply chain. For instance, to overcome primary data constraints in terms of carbon values, the collaboration with renowned forest ecologist Professor Coert Geldnhuys resulted in a modification of existing carbon sequestration formulas for a specific Johannesburg site. Extrapolating this sample study of above-ground biomass to a city-level, the carbon stored in Johannesburg's forest can be converted into R785 828 663, using the market related carbon price at the time of writing. New valuation techniques for cultural ecosystem services also emerged through an interpretation of market data and membership fees pertaining to SANA and SALI, as sample valuations of the range of revenue contribution for SAGIC. Using data collated from StatsSA, employment in the green supply chain can also be estimated through a sample valuation study based on the assumption that low-density dwellings in Johannesburg require garden maintenance in the form of a garden service company or garden employee.

The moderated methodology is therefore a response to the data constraints experienced in attempting to explicitly value the role of Johannesburg's green systems as potential infrastructure service providers. Filling this data gap is one of the critical steps in investing in the city's ecosystem services since the physical, on-site research needs to be connected to real economic values for the concept of 'green infrastructure' to be implemented. This empirical link needs to be the focus of future research for an accurate conclusion of the value of Johannesburg's green assets to be reached and to provide a more robust case for investment in the city's green infrastructure.

4.4 Implications for further research

The case study therefore shows that although the ecosystem service provided by Johannesburg's green systems have potentially significant economic values, for robust economic valuations to be carried out primary research is required for concrete conclusions are to be reached. The priorities for future work therefore include:

1. With regard to the urban forest, investment in a tree census is a critical primary research area required for detailed evaluation of the goods and services that flow as dividends from

the forest. The spokesperson of Johannesburg City Parks (Moodley, 2010) confirms the need for an accurate tree count, stating that "a tree census is ideal for academic research institutions to conduct a detailed academic study of our trees". There are multiple beneficiaries that seek to benefit from such an exercise, form a tree management and record keeping level to the actual verification of how many trees Johannesburg has within its municipal boundaries. This could be lucrative in terms of branding for the city and sparking a new economic industry based on the forest's associated ecosystem services.

2. A detailed study is needed of the status of ecosystem service provision in Johannesburg. This requires primary data on Johannesburg's ecological assets in their entirety, extending beyond public open spaces, to assess the ecological health of those assets that provide what have been identified as critical ecosystem services in this paper.
3. In-depth participatory research needs to take place with a focus on stakeholder consultations to estimate the priority given to ecosystem services by individuals, commercial interests and public bodies.
4. Due to the lack of base research on Johannesburg's green industry, as embodied by SAGIC, future studies need to analyse the industry's contribution in revenue and employment terms to the Johannesburg economy. SAGIC has an opportunity to reposition itself as more than a green industry, but also as a green infrastructure industry sustaining wider development and ecological processes. Independent green industry workers, including gardeners employed in domestic contexts, need to be included in this analysis.

Viewing ecological assets as an infrastructure type enables the formal inclusion of ecosystem service provision in wider development processes. Johannesburg not only demonstrates the potential of such a green infrastructure development path, but is appropriately positioned to invest in this type of infrastructure as a key urban strategy for securing economic attractiveness and the flow of ecosystem services critical to the city's ability to adapt to change. In recognising these multiple benefits, it is a missed opportunity for Johannesburg if investment in ecological assets is not prioritised and such assets are not valued explicitly as infrastructure services.

References

1. Alberti, M., Marzluff, J.M., Shulenberger, E., Bradley, G., Ryan, C., & Zumbrunnen. 2003. Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. *Bioscience,* 53 (12): pp 1169-1179, December.
2. Alvey, A. 2006. Promoting and preserving biodiversity in the urban forest. *Urban Forestry & Urban Greening,* 5: pp 195-201.
3. Andersson, J.A. 2006. Informal Moves, Informal Markets: International Migrants and Traders from Mzimba District, Malawi . *African Affairs*, 105 (420): pp 375–397. [Online]. Available: http://afraf.oxfordjournals.org.ez.sun.ac.za/content/105/420/375.full.pdf+html [15 October 2010].
4. Andersson, E., Barthel, S., & Ahrné, K. 2007. Measuring Social-Ecological Dynamics Behind the Generations of Ecosystem Services. *Ecological Applications,* 17 (5): pp 1267-1278. Ecological Society of America.
5. Appel, W. 2010. Interview with membership and bursary administrator at SANA on 13 October 2010. Johannesburg [Telephonic conversation].
6. Arku, G. 2009. Rapidly Growing African Cities Need to Adopt Smart Growth Policies to Solve Urban Development Concerns. *Urban Forum,* 2: pp 253-270, February 5.
7. Barbosa, O., Tratalos, J.A., Armsworth, P.R., Davies, R.G., Fuller, R.A., Johnson, P., & Gaston, K.J. 2007. Who benefits from access to green space? A case study from Sheffield, UK. *Landscape & Urban Planning,* 83: pp 187-195.
8. Barthel, S. 2004. Sustaining urban ecosystem services with local stewards participation in Stockholm (Sweden): pp 1-18, December 7. Sweden: Stockholm University.
9. Barthel, S., Colding, J., Elmqvist, T., Folke, C. 2005. History and Local Management of a Biodiversity-rich, Urban, Cultural Landscape. *Ecology & Society.*
10. Barthel, S. 2008. *Recalling Urban Nature – linking city people to ecosystem services.* Sweden: Stockholm University. (Dissertation). [Online]. Available: http://www.stockholmresilience.org/download/18.6b38234911d6cedb12580009510/barthelphd.pdf [14 April 2010].
11. Barthel S., Folke, F., & Colding, J. 2010. Social-ecological memory in urban gardens – Retaining the capacity for management of ecosystem services. *Global Environment Change.*
12. Beall, J. 2002. Globalization and Social Exclusion. *Environment and Urbanization,* 14 (1): pp 41-51, April.

13. Beall, J., Crankshaw, O. & Parnell, S. 2000. Local government, poverty reduction and inequality in Johannesburg. *Environment and Urbanization,* 12 (1): pp 107-122, April.

14. Beall, J., Crankshaw, O. & Parnell, S. 2002. *Uniting a divided City: Governance and Social Exclusion in Johannesburg.* London: Earthscan.

15. Beall, J., Guha-Khasnobis, B. & Kanbur, R. 2010. Introduction: African Development in an Urban World: Beyond the Tipping Point. *Urban Forum,* 21: pp 187-204, May 29.

16. Beavon, K. 2004. *Johannesburg: The Making and Shaping of the City.* Leiden, The Netherlands: University of South Africa & Koninklijke Brill.

17. Benedict, M.A., & McMahon, E.T. 2002. Green Infrastructure: Smart Conservation for the 31st Century. *Renewable Resources Journal,* 20 (3): pp 12-17, Autumn.

18. Berkes, F. & Folke, C. forthcoming. *Linking social and ecological systems for resilience and sustainability*, chapter 1.

19. Bolund, p., & Hunhammar, S. 1999. Ecosystem services in urban areas. *Ecological Economics,* 29: pp 293-301.

20. Bond, P. 1999. Basic infrastructure for socio-economic development, environmental protection and geographical desegregation: South Africa's unmet challenge in *Geoforum,* 30: pp 43-59. [Online]. Available: http://www.sciencedirect.com.ez.sun.ac.za/science?_ob=MImg&_imagekey=B6V68-3XG1X76-4-1&_cdi=5808&_user=613892&_pii=S0016718598000311&_origin=search&_zone=rslt_list_item&_coverDate=02/28/1999&_sk=999699998&wchp=dGLzVlb-zSkWb&md5=e55bce6ea3134150023c59128191a6d8&ie=/sdarticle.pdf [31 July 2010].

21. Bond, P. 2007. The Heart of Global Apartheid: 'Joburg'*. Paper presented at the Centre de Cultura Contemporània de Barcelona*. KwaZulul-Natal: Centre for Civil Society, pp: 2-23, September.

22. Borgström, S, T., Elmqvist, T., Angelstam, P., Alfsen-Norodom., C. 2006. Scale Mismatches in Management of Urban Landscapes. *Ecology & Society,* 11 (2): pp 16.

23. Borraine, A. 2004. The State of the Cities Report 2004 and implications for city development strategies. *Presentation to Cities Alliance Public Policy Forum, Durban, November 1- 3 2004.* Durban: South African Cites Network.

24. Bowler, D.E., Buyung-Ali, L., Knight, T.M., & Pullin, A.S. 2010 Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape & Urban Planning,* 97: pp 147-155.

25. Bremner, L. 2000. Reinventing the Johannesburg inner city. *Cities,* 17 (3): pp 193-2000.

26. Brent, A.C. & Kruger, W. J.L. 2008. Systems analyses and the sustainable transfer of renewable energy technologies: A focus on remote areas of Africa in *Renewable Energy* (2008), pp 1-8.

27. Brown, L. 2008. *Plan 3.0.* London: WW Norton & Company. Chapter 10: 'Designing Cities for People', pp 192-212.

28. Bryant, M.M. 2006. Urban Landscape conservation and the role of ecological greenways at local and metropolitan scales. *Landscape and Urban Planning*, 76: pp 23-44.

29. Burdett, R. 2010. Heart of the city in *The Financial Times: The Future of Cities.* Part One: p 10, April 7.

30. Burns, M., Audouin, M., & Weaver, A. 2006. Advancing sustainability science in South Africa. *South African Journal of Science,* 102: pp 379-384, September/October.

31. Capra, F. 1996. Deep Ecology – A New Paradigm in *The Web of Life: a new scientific understanding of living systems.* New York: Anchor Books.

32. Cambridge Resilience Forum. 2010. *How do we reconceptualise the value of trees as an investment in ecosystem services?* Presentation at Sappi. Braamfontein. October 12.

33. Cantor CO_2. 2010. *Thursday, 14 October, 2010.* [Online]. Available: http://www.cantorco2e.com/myCantorCO2e/CERs/ [14 October 2010].

34. Cartwright, A. P. 1973. Johannesburg in *Pride of South Africa,* vol 7. South Africa: Purnell .

35. Centre for Development and Enterprise (CDE). 2002. *Johannesburg Africa's World City – A challenge to action: Executive Summary,* October. Parktown: CDE.

36. Chapin III, F.S., *et al.* 2009. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution,* 23 (4): pp 241-249, November 16.

37. Chiabia. A., Travisi, C., Markandya, A., Ding, H., & Nunes, P. 2010. Economic Assessment of Forest Ecosystem Services Losses: Cost of Policy Inaction. *Basque Centre for Climate Change,* September 13. [Online]. Available: http://ideas.repec.org/p/bcc/wpaper/2010-13.html [10 October 2010]

38. Chipkin, I. 2005. The Political Stakes of Academic Research: Perspectives on Johannesburg. *African Studies Review,* 48 (2): pp 87-109, September.

39. Christopher, A, J. 1982. *South Africa.* World's landscapes series. London: Longman.

40. Cilliers, P. 1998. Complexity and Postmodernism: understanding complex systems. London: Routledge.

41. Cilliers, P. 2000. "What can we learn from a theory of complexity?" *Emergence*, 2(1): pp.23-33, January.

42. Cilliers, S.S., Müller, N. & Drewes, E. 2004. Overview on urban nature conservation: situation in the western-grassland biome of South Africa. *Urban Forestry & Urban Greening,* 3: pp 49-62, April 7.

43. City of Johannesburg. 2003. State of the Environment Report. [Online]. Available: http://www.joburg-archive.co.za/2003/budget/idp/annex3.pdf [13 June 2010].

44. City of Johannesburg. 2006. *Growth and Development Strategy: Long Term Strategic Perspective,* Chapter 2. [Online]. Available: http://www.joburg-archive.co.za/2006/pdfs/gds_book/chapter2.pdf [24 August 2010].

45. City of Johannesburg. 2007. *An overview of Joburg's vehicular emissions measurements and control methods.* [Online]. Available: http://www.joburg-archive.co.za/2007/pdfs/air_quality/vehicle_emission_measurements2007.pdf [4 October 2010].

46. City of Johannesburg. 2007-2008. *Spatial Development Framework.* [Online]. Available: http://www.joburg.org.za/index.php?option=com_content&task=view&id=502&Itemid=129 [3 September 2010].

47. City of Johannesburg: Johannesburg City Parks. 2008. *Diepkloof gets its extreme park.* [Online].Available: http://www.jhbcityparks.com/index.php?option=com_content&task=view&id=20&Itemid=36 [6 September 2010].

48. City of Johannesburg: Johannesburg City Parks. 2008/9. *Annual Report 2008/9* [Online]. Available: http://www.jhbcityparks.com/pdfs/annual_report089.pdf [6 June 2010].

49. City of Johannesburg. 2009. *Flood victims get some relief.* May 19. [Online]. Available: http://www.joburg.org.za/index.php?option=com_content&task=view&id=3846&Itemid=20 [2 October 2010].

50. City of Johannesburg. 2009. *Soweto is mopped up after floods.* March 4. [Online]. Available: http://www.joburg.org.za/index.php?option=com_content&task=view&id=3563&Itemid=22 [2 October 2010].

51. City of Johannesburg. 2010. *The Seven Regions.* [Online]. Available: http://www.joburg.org.za/regions [4 September 2010].

52. City of Johannesburg. 2010/2011. *Integrated Development Plan: Strategic overview and key integrated development plan interventions,* Chapter 2. [Online]. Available: http://www.joburg-archive.co.za/2010/pdfs/idp2010/idp/ch2_idp.pdf [31 August 2010]

53. City of Johannesburg. 2010. *Flora Mokgohloa: making Jozi greener.* [Online]. Available: http://www.joburg.org.za/index.php?option=com_content&task=view&id=972&Itemid=131 [4 October 2010].

54. City of Johannesburg. 2010. *City of Johannesburg State of Energy Report.* [Online]. Available: http://www.uemp.org.za/uemp_docs/01_Johannesburg_State_of_Energy_Report_Phillip.pdf [4 October 2010].

55. City of Johannesburg: Johannesburg City Parks. 2010. *Major Projects.* [Online]. Available: http://www.jhbcityparks.com/index.php?option=com_content&task=view&id=111&Itemid=58#greening [12 October 2010].

56. City of Johannesburg: Johannesburg City Parks. 2010. *Greening Soweto.* [Online]. Available: http://www.jhbcityparks.com/index2.php?option=com_content&do_pdf=1&id=114 [12 October 2010].

57. City of Johannesburg: Johannesburg City Parks. 2010. *Learner's complete City Parks' training.* [Online].Available: http://www.jhbcityparks.com/index.php?option=com_content&task=view&id=543&Itemid=56 [12 October 2010].

58. City of Johannesburg: Johannesburg City Parks. 2010. *The city that's a rain forest.* [Online]. Available: http://www.jhbcityparks.com/index2.php?option=com_content&do_pdf=1&id=14 [13 October 2010].

59. City of Johannesburg: Johannesburg City Parks. 2010. *Maintaining Joburg's Green Crown.*[Online].Available: http://www.jhbcityparks.com/index.php?option=com_content&task=blogsection&id=8&Itemid=31 [6 September 2010].

60. City of Johannesburg: Johannesburg City Parks GIS Department. 2010. [Personal communication]. [31 August 2010].

61. City of Johannesburg: Johannesburg City Parks Financial Departments. 2010 [Personal Communication with Clements, R., Chief Financial Officer]. [11 August 2010].

62. City of Johannesburg: Johannesburg City Parks. 2010. *Distribution of Trees in Johannesburg.* Personal interaction with GIS Department.

63. City of Johannesburg: Johannesburg City Parks. 2010. *Percentage Tree Cover per Ward.* [Online]. Available: http://www.jhbcityparks.com/pdfs/treecoverage_per_ward.pdf [6 September 2010]

64. City of Johannesburg. Johannesburg City Parks. 2010. *Custodians of Johannesburg's Green Heritage: Who we are.* [Online]. Available:

http://www.jhbcityparks.com/index.php?option=com_content&task=blogsection&id=4&Itemid=27 [6 August 2010],

65. City of Johannesburg. 2010. *Cosmo City is a thriving Suburb.* [Online]. Available: http://www.joburg.org.za/content/view/2089/168/ [6 September 2010]

66. City of Johannesburg. 2010. *More Trees planted in Cosmo City.* [Online]. Available:http://www.joburg.org.za/index.php?option=com_content&task=view&id=3550&Itemid=21 [6 September 2010]

67. City of Johannesburg. 2010. Johannesburg City Parks. *Greening Initiatives in the context of the Open Space Framework within the City of Johannesburg.* [Online]. Available: http://www.jhbcityparks.com/pdfs/open_spaces/greening_initiatives.pdf [6 September 2010]

68. City of Johannesburg. 2010. Johannesburg City Parks. *Xtreme Park Makeover.* [Online].Available:http://www.jhbcityparks.com/index.php?option=com_content&task=view&id=113&Itemid=31 [6 June 2010].

69. City of Johannesburg. 2002. *Johannesburg Metropolitan Open Space System*. Pretoria: Strategic Environmental Focus, October.

70. City of Johannesburg. 2003. *Air Quality Management Plan for the City of Johannesburg (AQMP).* [Online]. Available: http://www.joburg- archive.co.za/2006/pdfs/jhbair_quality.pdf [4 October 2010].

71. City of New York. *NYC Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways.*

72. Clark, W. 2007. Sustainability Science: A room of its own. T*he National Academy of Sciences USA,* 104 (5): 1737-1738. February 6.

73. Colding, J. 2007. 'Ecological land-use complementation' for building resilience in urban ecosystems. *Landscape & Urban Planning,* 81: pp 46-55, November 28.

74. Constanza, R., *et al.* 1997. The value of the world's ecosystem services and natural capital. *Nature,* 385: pp 253-260, May 15. London: The Copyright Licensing Agency Limited.

75. Crankshaw, O. 2008. Race, Space and the Post-Fordist Spatial Order of Johannesburg. *Urban Studies,* 45 (8): pp 1692-1711. July 2008,

76. Creedy, J., & Wurzbacher, A.D. 2001. The economic value of a forested catchment with timber, water and carbon sequestration benefits. *Ecological Economics,* 38: pp 71-83.

77. CSR: The responsible business experts. 2005. *EcoCity: Johannesburg, South Africa.* [Online]. Available: http://www.article13.com/A13_ContentList.asp?strAction=GetPublication&PNID=1120 [31 July 2010].

78. Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder, L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D., & Woodwell, G.M. 1997. *Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems.*
79. Davis, M. 2004. Planet of Slums. *New Left Review,* 25: pp 5-34, March-April.
80. De Groot, R.S., Wilson, M.A., Boumans, R.M.J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services in *Ecological Economics,* 41: pp 393-408.
81. De Groot, R., *et al.* 2010. The economics of valuing ecosystem services and biodiversity in *The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations,* Chapter 5, March.
82. De Groot, R., *et al.* 2010b. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation in *The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations,* Chapter 1, March.
83. De Wit Sustainable Options, Jaymat Enviro Solutions & City of Cape Town. 2008. *Why investing in natural assets makes financial sense for the municipality of Cape Town: A summary for decision makers,* pp 1-7. Cape Town. Unboxed Publishing Company.
84. De Wit, M., van Zyl, H., Crookes, D., Blignaut, J., Jayiya, T., Goiset, V., Mahumani, B. 2009. *Investing in Natural Assets: A business case for the environment in the City of Cape Town,* September 18. Brakenfell: Natural Value Joint Venture.
85. De Wit, M., Jayiya, T., van Zyl, H., Blignaut, J., & Crookes, D. 2009. *Methodology to value the natural and environmental resources of the City of Cape Town.* Report prepared for the Environmental Resource Management Department, City of Cape Town, May 29.
86. De Wit Sustainable Options. 2010. *Investing in Natural Assets: A business case for the environment in the City of Cape Town.* Presentation to Urban Ecology CityLab, UCT, July 28.
87. Devey, R., Skinner, C., & Valodia, I. 2003. Informal Economy Employment Data In South Africa: A Critical Analysis in *TIPS and DPRU Forum, 2003, The Challenge of Growth and Poverty: The South African Economy Since Democracy*, Indaba Hotel, Johannesburg, 8-10 September. [Online]. Available: http://www.inclusivecities.org/pdfs/devey%20skinner%20valodia%20Informal%20Economy%20employment%20data%20in%20ZA.pdf [13 October 2010].
88. Dunn, A. D. 2010. Siting Green Infrastructure: Legal and Policy Solutions to Alleviate Urban Poverty and Promote Healthy Communities. *Environmental Affairs,* 37: pp 41-66.
89. Du Plessis, C. 2008. Understanding cities as social-ecological systems. *Wolrd Sustainable Building Conference.* SB'08. Melbourne, Australia, 21-25 September.

90. Eisenhardt, K. M. 1989. Building Theories from Case Study Research. *The Academy of Management Review,* 12 (4): 532-550, October.

91. Erasmus, P. 2010. Interview with nursery manager on 13 October 2010. Johannesburg. [Telephonic conversation].

92. Ernstson, H. 2008. *In Rhizomia: Actors, Networks and Resilience in Urban Landscapes.* Stockholm: Stockholm University. (Doctor of Philosophy). [Microfiche].

93. Eugster, G. 2003. Washington: City in the Woods. *Prepared for the Joint Ventures Conference: Partners in Stewardship,* Los Angeles, CA, Draft, pp 1-28, December 11.

94. Federation for a Sustainable Environment (FSE). 2010. *Latest acid mine drainage crisis calls for a constructive response from civil society,* January 20. [Online]. Available: http://www.fse.org.za/index.php?option=com_content&view=article&id=254:-latest-acid-mine-drainage-crisis-calls-for-a-constructive-response-from-civil-society-&catid=1&Itemid=55 [5 October 2010].

95. Flyvbjerg, B. 2006. Five misunderstandings about case study research. *Qualitative inquiry,* 12 (2): 219-245, April.

96. Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chaping, T. & Rockström. 2010. Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecology and Society,* 15 (4): 20. [Online]. Available: http://www.ecologyandsociety.org/vol15/iss4/art20/ [10 January 2011].

97. Folke, C., Hahn, T., Olssson, P., & Norberg, J. 2005. Adaptive Governance of Social-Ecological Systems. *Annual Review Environment & Resources,* 30: pp 441-473, July 25.

98. Folke C., Colding, J. & Berkes, F. forthcoming. Building resilience and adaptive capacity in social-ecological systems, chapters 1 and 14.

99. Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling, C.S. 2005. Regime Shift, Resilience, and Biodiversity in Ecosystem Management. *Annual Review Environment & Resources,* 35: pp 557-581, August 5.

100. Folke, C., Carpenter, S., Elmqvist, Gunderson, L., Holling, C.S., Walker, B. 2002. Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. *Ambio,* 31 (5): 437-440, August.

101. Food and Trees for Africa (FTFA). 2010. *Our History.* [Online]. Available: http://www.trees.co.za/index.php?option=com_content&view=article&id=84&Itemid=71 [27 October 2010].

102. Gandy, M. 2004. Rethinking urban metabolism: Water, space and the modern city. *City,* 8 (3): pp 363-379, December.

103. Gaule, S. 2005. Alternating Currents of Power: From Colonial to Post-apartheid Spatial Patterns in Newtown, Johannesburg. *Urban Studies,* 42 (13): pp 2335-2361, December.

104. Gauteng Provincial Government (GPG). 2010. *Terms of Reference to develop a consolidated Green Strategic Programme for the Gauteng Province.* Johannesburg: Gauteng City Region Observatory, p; 1-4.

105. Geels, F.W., & Schot, J. 2007. Typology of sociotechnical transition pathways. *Research Policy,* 36: pp 399-417.

106. Geldenhuys, C.J. 1998. Requirements for improved and sustainable use of forest biodiversity: examples of multiple use of forests in South Africa, in Poker, J., Stein, I. & Werder, U. (eds). *Proceedings Forum Biodiversity - Treasures in the World's Forests*, Alfred Toepfer Akademie für Naturschutz, Schneverdingen, Germany. *Paper presented at Forum: Biodiversity – Treasures in the World's Forests*, 3-7 July, pp. 72-82, Schneverdingen, Germany.

107. Geldenhuys, C.J. 2007. Restoring natural forests to make medicinal bark harvesting sustainable in South Africa in Aronson, J., Milton, S.J., Blignaut, J.N. (eds). *Restoring natural capital: science, business, and practice.* Island Press, pp 170-178, Chapter 20.

108. Geldenhuys, C.J. 2008. *Rehabilitation of Forest-related Stream bank vegetation within winelands in the Western Cape.* University of Stellenbosch: Department of Forest & Wood Science, University of Stellenbosch & Pretoria: Forestwood cc, June.

109. Geldenhuys, C. J. 2010. [Personal communication]. 17 September 2010.

110. Geldenhuys, C.J. & Berliner, D. 2010. Estimation of the carbon sequestration potential of the natural forests of the Wild Coast. Eastern Cape Park's Wild Coast Project. Report no FW-02/10, FORESTWOOD cc, Pretoria, pp: 1 – 29, April.

111. Goldreich, R. 1992. Urban Climate Studies in Johannesburg, a sub-tropical city located on a ridge – a review. *Atmospheric Environment,* 26B (3): pp 407-420. [Online]. Available: http://www.sciencedirect.com.ez.sun.ac.za/science?_ob=MImg&_imagekey=B757F-48BCXKW-23 1&_cdi=12897&_user=613892&_pii=095712729290016L&_origin=search&_zone=rslt_list_item&_coverDate=09/30/1992&_sk=999739996&wchp=dGLbVzz-zSkzS&md5=710fbef6e084215abaceb5d009c0dfc2&ie=/sdarticle.pdf [28 September 2010].

112. Goldreich, Y. 2006. Ground and top of canopy layer urban heat island partitioning on an airborne image. *Remote Sensing of Environment,* 104: pp 247-255. [Online]. Available: http://www.sciencedirect.com.ez.sun.ac.za/science?_ob=MImg&_imagekey=B6V6V-4KNKC0V-1-N&_cdi=5824&_user=613892&_pii=S0034425706001866&_origin=browse&_zone=rslt_list_it

em&_coverDate=09/30/2006&_sk=998959997&wchp=dGLbVlW-zSkzV&md5=2d56debd695bb4bf8aad69b1ed20a7d0&ie=/sdarticle.pdf [28 September 2010]

113. Graham, S. and Marvin, S. 2001. *Splintering Urbanism. Bridging the Green and Brown Agendas.* London: Routledge. Chapter 1: 'Introduction', pp 1-36.

114. Greater Johannesburg Metropolitan Council. 2000. *Impacts on Soil.* March 16. [Online]. Available: http://www.ceroi.net/reports/johannesburg/csoe/html/nonjava/Soil/impact.htm [2 October].

115. Greater Johannesburg Metropolitan Council. 2000. *Driving Forces Relating to Soil.* [Online]. Available: http://www.ceroi.net/reports/johannesburg/csoe/html/nonjava/Soil/driving.htm [3 September 2010].

116. Guy, S. & Marvin, S. 2001. Urban Environmental Flows: Towards a New Way of Seeing in Guy, S., Marvin, S. and Marvin, T. (eds). *Urban Infrastructure in Transition: Networks, Buildings, Plans.* London: Earthscan, pp 22-37.

117. Gunderson, L.H., & Holling, C.S. (eds). 2002. *Panarchy: Understanding Transformations in Human and Natural Systems.* USA: Island Press.

118. Gunderson, L.H., & Folke, C. 2005. Editorial: Resilience – Now More than Ever in *Ecology & Society,* 10 (2): pp 22. [Online]. Available: http://www.ecologyandsociety.org/vol10/iss2/art22 [11 May 2010].

119. Gunderson, L.H., Allen., C.R., & Holling (eds). C.S. 2010. *Foundations of Ecological Resilience.* Washington: Island Press.

120. Harmse, A., Blaauw, P., & Schenk, R. 2009. Day Labourers, Unemployment and Socio-economic Development in South Africa. *Urban Forum,* 20: pp 363-377.

121. Hartley, W. 2010. Acid mine water 'needs rapid response'. *Business Day,* September 7. [Online]. Available: http://www.businessday.co.za/articles/Content.aspx?id=120231 [5 October 2010].

122. Harvard Law Review Association. 2010. Uncommon goods: On environmental virtues and voluntary carbon offsets. *Harvard Law Review*, 123: pp 2064-2087, June 1. [Online]. Available: http://web.ebscohost.com.ez.sun.ac.za/ehost/pdfviewer/pdfviewer?vid=1&hid=106&sid=ddfe12f1-3342-482e-ba2f-f9205b7cd90b%40sessionmgr113 [11 October 2010].

123. Hetz, T. 2005. The Effect of Minimum Wages on the Employment and Earnings of South Africa's Domestic Service Workers. *Department of Economics Working Paper Series,* No. 2005-

04. Washington DC: American University. [Online]. Available: http://www1.american.edu/cas/econ/workingpapers/2005-04.pdf [14 October 2010].

124. Heynes, P. 2008. Complexity Theory and Evaluation in Public Management. *Public Management Review,* 10 (3): pp 401-419.

125. Hodson, M., & Marvin, S. 2009. Cities mediating technological transitions: understanding visions, intermediation and consequences. *Technology Analysis & Strategic Management,* 21 (4): pp 514-534, May.

126. Hodson, M., & Marvin, S. 2010. Can cities shape socio-technical transitions and how would we know if they were? *Research Policy:* pp 1-9.

127. Hodson, M. & Marvin, S. 2010b. Urbanism in the anthropocene: Ecological Urbanism or premium ecological enclaves. *City,* 14 (3): pp 299-313, June 4.

128. Hoy, L. H. 2009. *A proactive water supply shortage response plan focusing on the Green Industry in the Rand Water supply area*. University of South Africa. [Masters Thesis]. January.

129. International Development Research Centre. 2010. *Zimbabwe in Johannesburg.* [Online]. Available: http://www.idrc.ca/cp/ev-158064-201-1-DO_TOPIC.html [15 October 2010].

130. International Human Dimensions Programme on Global Environmental Change (IHDP). 2005. *Science Plan: Urbanization and Global Environmental Change.* Report no. 15. Germany: IHDP.

131. International Union for Conservation of Nature and Natural Resources (IUCN). 2008. A world without biodiversity? In *The Magazine of World Conservation,* 39 (1), January. Switzerland: The World Conservation Union.

132. Jackson, M. C. 2003. *Systems Thinking: Creative Holism for Managers.* Chichester: John Wiley & Sons Ltd.

133. James, P., Tzoulas, K., Adams, M.D., *et al.* 2009. Towards an integrated understanding of green space in the European built environment. *Urban Forestry & Urban Greening,* 8: pp 65-75.

134. Jansson, A. & Polasky, S. 2010. Quantifying Biodiversity for Building Resilience for Food Security in Urban Landscapes: Getting Down to Business, Ecology & Society, 15 (3): 20.

135. Jim, C.Y. & Chen, W.Y. 2008. Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). *Journal of Environmental Management,* 88: pp 665-767.

136. Johannesburg Poverty and Livelihoods study (JPLS). 2008. Centre of Social Development in Africa, University of Johannesburg. [Online]. Available: http://www.ncr.org.za/pdfs/Research_Reports/Livelihoods%20study.pdf [27 October 2010].

137. Kambites, C., & Owen, S. 2006. Renewed prospects for green infrastructure planning in the UK. *Planning Practice and Research,* 21 (94): pp 483-396

138. Karlenzig, W. 2010. The Death of Sprawl Designing Urban Resilience for the Twenty-First-Century Resource and Climate Crises in *The Post Carbon Reader Series: Managing the 21st Century's Sustainability Crises,* Heinberg, R. & Lerch, D. (eds). Healdsburg, CA: Watershed Media.

139. Kennedy C., Cuddihy, J., & Engel-Yen. 2008. The Changing Metabolism of Cites. *Journal of Industrial Ecology,* 11 (2): pp 43-.59.

140. Kirnbauer, M.C., Kenney, W.A., Churchill, C.J., & Baetz, B.W. 2009. A prototype decision support system for sustainable urban tree planting programmes. *Urban Forestry & Urban Greening,* 8: pp 3-19.

141. Konijnendijk, C., Gauthier, M., van Veenhuizen, R. 2004. Trees and Cities – Growing together. *Urban Agriculture Magazine,* 13: pp 1-5, December.

142. Konijnendijk, C.C., Ricard, R. M., Kenney, A. & Randrup, T.B. 2005. Defining urban forestry – A comparative perspective of North America and Europe in *Urban Forestry & Urban Greening,* 4: pp 93–103.

143. Kremen, C. & Ostfeld, R.S. 2005. A call to ecologists: measuring, analyzing, and amanaging ecosystem services. *Frontiers in Ecology and the Environment,* 3 (10); 540-548.

144. Kroll, F. 2010. [Personal communication with Siyakhana Food Project manager]. [15 September 2010].

145. Lal, R. 2005. Forest soils and carbon sequestration. *Forest Ecology and Management,* vol 220: pp 242-258. [Online]. Available: http://www.sciencedirect.com.ez.sun.ac.za/science?_ob=MImg&_imagekey=B6T6X-4H99917-1-5&_cdi=5042&_user=613892&_pii=S0378112705004834&_origin=search&_zone=rslt_list_item&_coverDate=12/10/2005&_sk=997799998&wchp=dGLzVzb-zSkWA&md5=0b9dedb0c181a190f1efe48797a433d7&ie=/sdarticle.pdf [11 October 2010].

146. Landscape Institute. 2009. *Green infrastructure; connected and multifunctional landscapes,* April. London: The Landscape Institute.

147. Landau, L.B. 2007. Distribution and development? Immigration, urbanisation and sustainable livelihoods in Johannesburg. *Development Southern Africa,* 24: pp 61-76.

148. Leedy, P. D. & Ormrod, J. E. 2001. *Practical Research: Planning and design* (7th ed). New Jersey: Pearson Educational International and Prentice Hall

149. Leiman, A., Standish, B., Boting, A., Van Zyl, H. 2007. Reducing the healthcare costs of urban air pollution: The South African experience. *Journal of Environmental Management,* 84: pp 27-37. [Online] Available: http://www.sciencedirect.com.ez.sun.ac.za/science?_ob=MImg&_imagekey=B6WJ7-

_4KPX914-2-2&_cdi=6871&_user=613892&_pii=S0301479706001629&_origin=search&_zone=rslt_list_item&_coverDate=07/31/2007&_sk=999159998&wchp=dGLzVlz-zSkWb&md5=2a797d070ad4fd89d1c3227e52e9cdd1&ie=/sdarticle.pdf [28 September 2010].

150. Lekotjolo, N., & Evans, S. 2009. Gauteng flood plans ready. *Times Live,* January 13. [Online]. Available: http://www.timeslive.co.za/thetimes/article31438.ece [28 September 2010].

151. Letshwiti, V., Stanway, R.A., & Mokonyama, M. 2003. Strategic Overview and analysis of vehicle ownership trends in South Africa with an emphasis on light passenger vehicles in *Proceedings of the 22nd Southern African Transport Conference (SATC2003), Pretoria,* 14-16th July. [Online]. Available: https://www.up.ac.za/dspace/bitstream/2263/7448/1/Letshwiti_Strategic(2003).pdf [4 October 2010].

152. Life is a garden. 2010. *SAGIC (South African Green Industries Council.* [Online]. Available: http://lifeisagarden.co.za/website/index.php [7 August 2010].

153. Lipietz, B. 2008. Building a Vision for the Post-Apartheid City: What Role for Participation in Johannesburg's City Development Strategy? *International Journal of Urban and Regional Research,* 32 (1): pp 135-163, March.

154. Mawson, N. 2004. *Johannesburg's Rich Tree Heritage.* [Online]. Available: http://www.engineeringnews.co.za/article/johannesburgs-rich-tree-heritage-2004-09-03 [13 October 2010].

155. Mabuza, L.O.K., Brent, A.C. & Mapako, M. 2007. The transfer of energy technologies in a developing country context – Towards improved practice from past successes and failures in *Proceedings of the Word Academy of Science, Engineering and Technology,* 22: pp 237-241.

156. Mail & Guardian, 2010. *Johannesburg on acidic water time bomb*. 21 July. [Online]. Available: http://www.mg.co.za/article/2010-07-21-johannesburg-on-acidic-water-time-bomb [31 July 2010].

157. Martine, G., McGranahan, G. Montgomery, M. & Fernandez-Castilla, R. 2008. Introduction, in Martine, G., McGranahan, G. Montgomery, M. & Fernandez-Castilla, R. (eds). *The New Global Frontier: Urbanization, Poverty and the Environment in the 21st Century*, pp 1-16. London: Earthscan.

158. McConnachie, M.M., & Shackleton, C.M. 2010. Public green space inequality in small town in South Africa. *Habitat International,* 34: pp 244-248.

159. McDonald, L.A., Allen III, W.L., Benedict, M.A., & O'Conner, K. 2005. Green Infrastructure Plan Evaluations Frameworks. *Journal of Conservation Planning,* 1: pp 6-25.

160. McGregor, S.L.T. 2009. Integral Leadership's Potential to Position Poverty Within Transdisciplinarity in *Integral Leadership Review,* IX (2), March. [Online]. Available: http://www.integralleadershipreview.com/archives/2009-03/2009-03-article-mcgregor.php [15 July 2009].

161. McHale, M.R., McPherson, E.G., & Burke, I.C. 2007. The potential of urban tree plantings to be cost effective in carbon credit markets. *Urban Forestry & Urban Greening,* 6: pp 49-60. [Online].
Available:
http://www.sciencedirect.com.ez.sun.ac.za/science?_ob=MImg&_imagekey=B7GJD-4MVDVMM-1-1&_cdi=20204&_user=613892&_pii=S1618866707000118&_origin=search&_zone=rslt_list_item&_coverDate=02/20/2007&_sk=999939998&wchp=dGLzVlz-zSkzV&md5=e3f236e1b550332261d9273d40644a21&ie=/sdarticle.pdf [11 October 2010].

162. McPherson, E.G. Rowntree, D.J., & Rowntree, R.A. (eds). 1994. *Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project.* Gen.Tech.Rep.NE-186. PA: U.S. Department of Agriculture, Forest Services, Northern Forest Experiment Station: pp 1-201.

163. McPherson, E.G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., & Rowntree, D.J. 1997. Quantifying urban forest structure, function and value: the Chicago Urban Forest Climate Project. *Urban Ecosystems,* 1: pp 49-61. Chapman & Hall.

164. McPherson, G., Simpson, J.R., Peper, P.J., Maco, S.E., & Xiao, Q. 2005. Municipal Forest Benefits and Costs in Five US Cities. *Journal of Forestry,* 103 (8): pp 411-416, December.

165. Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and Human Wellbeing: Biodiversity Synthesis.* Washington DC: World Resources Institute.

166. Mell, I, C. 2008. Green Infrastructure: concepts and planning. *Forum,* 8: pp 69-80, June. Newcastle University.

167. Miller, J. 2005. Biodiversity conservation and the extinction of experience. *Trends in Ecology and Evolution,* 20 (8): pp 430-434, August.

168. Moodley, J. 2010. Interview with spokesperson of Johannesburg City Parks on 12 October 2010. Johannesburg. [Telephonic interview].

169. Murray, M.J. 2004. The Spatial Dynamics of Postmodern Urbanism; Social Polarisation and Fragmentation in São Paulo and Johannesburg. *Journal of Contemporary African Studies*, 22 (2): 139-164, May.

170. Murray, .S.A. 2006. The Idea of Gardening: Plants, Bewilderment, and Indigenous Identity in South Africa. *English in Africa,* 33 (2): pp 45-66, October.

171. Naicker, K., Cukrowska, E., & McCarthy, T.S. 2003. Acid mine drainage arising from gold mining activity in Johannesburg, South Africa and environs. *Environmental Pollution,* 122: pp 29-40.

172. Newmarch, J. 2010. Rising toxic debt fuels urgent debate. *Business Day,* August 11. [Online]. Available: http://www.businessday.co.za/Articles/Content.aspx?id=117604 [5 October 2010].

173. Nowak, D. J. & Walton, J.T. 2005. Projected Urban Growth (2000-2050) and Its Estimated Impact on the US Forest Resource. *Journal of Forestry,* Dec 2005; 103, 8: pp 383-389.

174. Noy, C. 2008. Sampling Knowledge: The Hermeneutics of Snowball Sampling in Qualitative Research. *International Journal of Social Research Methodology,* 11 (4): pp 327-344, October: [Online]. Available: http://web.ebscohost.com.ez.sun.ac.za/ehost/pdfviewer/pdfviewer?vid=1&hid=15&sid=b34237cd-3b36-4937-94b8-ec549e10a8ae%40sessionmgr10 [23 October 2010].

175. Nuttal, S. & Mbembe. A. (eds). 2008. *Johannesburg: The Elusive Metropolis.* Johannesburg: Wits University Press.

176. Oleyar, M.D., Greve, A.I, Withey, J., Bjorn, A.M. 2008. An integrated approach to evaluating urban forest functionality. *Urban Ecosystem,* 11: pp 289-308, July 16.

177. Olsson, P., Folke, C., Galaz, V., Hahn, T., & Schultz. 2007. Enhancing the Fit through Adaptive Co-management: Creating and Maintaining Bridging Functions for Matching Scales in the Kristianstads Vattemrike Biosphere Reserve, Sweden. *Ecology & Society,* 12 (1): pp 28. [Online]. Available: http://www.ecologyandsociety.org/vol12/iss1/art28 [11 May 2010].

178. Olsson, P., Folke, C. & Berkes, F. 2004. Adaptive Comanagement for Building Resilience in Social-Ecological Systems. *Environmental Management,* 34 (1): 75-90.

179. Palmer, M., *et al.* 2004. Ecology for a Crowded Planet. *Science,* 304: pp 1251-1252, May 28.

180. Parktown & Westcliff heritage Trust. 2010. *Welcome to the Parktown Heritage and Westcliff Heritage Trust.* [Online]. Available: http://www.parktownheritage.co.za/ [2 August 2010].

181. Phelps, R., & Hase, S. 2002. Complexity and action research; exploring the theoretical and methodological connections. *Educational Action Research,* 10 (3): pp 507 -524. London: Routledge.

182. Pickett, S.T.A., & Cadenasso, M.L. 2008. Linking ecological and built components of urban mosaics: an open cycle of ecological design in *Journal of Ecology,* 96: pp 8-12.

183. Pickett, S.T.A., Cadenasso, M.L., & Grove, J.M. 2004. Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landscape and urban planning,* 69: pp 369-384.

184. Pieterse, E. 2008. *City Futures: Confronting the Crisis of Urban Development.* South Africa: UCT Press.

185. Pieterse, E. 2009. *Sustainable Cities: Planning in Cape Town.* Class discussion (Sustainable Cities). Stellenbosch: Sustainability Institute, University of Stellenbosch.

186. Poulsen, L. 2010. A Room in the City: Strategies for Accessing Affordable Accommodation. *Urban Forum,* 21: pp 21-36, February 9.

187. Quinlan, T., & Scogings, P. 2004. Why bio-physical and social scientists can speak the same language when addressing Sustainable Development. *Environmental Science & Policy,* pp 1-10.

188. Republic of South Africa. 2002. *Disaster Management Act, No 57 of 2002.* Cape Town; Government Gazette. [Online]. Available: http://www.francesbaard.gov.za/documents/related%20legislation/Disaster%20Management%20Act,%202002.pdf [27 February 2011].

189. Resilience Alliance. 2007. *Assessing and managing resilience in social-ecological systems: A practitioner's workbook,* Version 1.0, June.

190. Rocking the Gardens. 2010. *Welcome to Rocking the Gardens 2010.* [Online]. Available: http://rockingthegardens.com/2009/05/27/welcome-note/ [14 October 2010].

191. Rogerson, C.M. 2004. Towards the World-Class African City: Planning local economic development in Johannesburg. *Africa Insight,* 34 (4): pp 12-21, December.

192. Sander, H., Polasky, S., & Haught, R.G. 2010. The value of urban tree cover: A hedonic property price model in Ramsey and Dakota NCounties, Minnesota, USA. *Ecological Economics,* 69: pp 1646-1656.

193. Sandström, U. G. 2002. Green Infrastructure Planning in Sweden. *Planning Practice & Research,* 17 (4): pp 373-385.

194. Sandström, U. G., Angelstam, P., & Khakee, A. 2006. Urban comprehensive planning – identifying barriers for the maintenance of functional habitat networks. *Landscape and Urban Planning,* 75: pp 43-57.

195. Satterthwaite, D. 1999. The Key Issues and the Works Included: Overview and Key Findings in Satterthwaite, D. (ed). *The Earthscan Reader in Sustainable Cities.* London: Earthscan, pp 3-21

196. Saving Water SA. 2010. *Johannesburg CBD threatened by rising acidic water.* [Online]. Available: http://www.savingwater.co.za/2010/07/21/19/jhb-threatened-by-acidic-water/ [31 July 2010].

197. Schäfflers Landscaping. 2010. [Personal communication]. [29 September 2010].

198. Scholes, R.J., & Scholes, M.C. 1998. Natural and human-related sources of ozone-forming trace gases in southern Africa. *South African Journal of Science,* 94: pp 422-425, September. [Online]. Available: http://researchspace.csir.co.za/dspace/bitstream/10204/774/1/scholes_1998.pdf [12 October 2010].

199. Schwab Foundation. 2006. Fostering social entrepreneurship. *Presented at the World Economic Forum*, Davos, January.

200. Scott, M., (ed). 2010. Building the 21st Century City. *Raconteur on Smart Cities*. The Times: Raconteur Media, June 1.

201. Scoones, I. 1999. New Ecology and the Social Sciences; What Prospects for a Fruitful Engagement? *Annual Review of Anthropology,* 28: 479-507

202. Sneddon, C., Howarth, R.B., & Norgaard, R.B. 2006. Sustainable development in a post-Brundtland world. *Ecological Economics,* 57: pp 253-268.

203. Smith, A., Stirling, A., & Berkhout, F. 2005. The governance of sustainable socio-technical transitions. *Research Policy,* 34: pp 1491-1510.

204. Söderman, T., & Saarela, S.R. 2010. Biodiversity in strategic environmental assessment (SEA) of municipal spatial plans in Finland. *Impact Assessment and Project Appraisal,* 28 (2): pp 117-133. June.

205. South African Cities Network. 2006. *State of the Cities Report 2006.* [Online]. Available: http://www.sacities.net/2006/pdfs/cities_2006.pdf [3 September 2010].

206. South African Cities Network. 2008. *Sustainable Cities 2008.* [Online]. Available: http://www.sacities.net/2009/pdfs/sustainable_cities2008.pdf [1 October 2010].

207. South African Cities Network. 2009. *Sustainable Cities 2009.* [Online]. Available: http://www.sacities.net/2009/pdfs/sustainable_cities2009.pdf [23 July 2010].

208. Gauteng Provincial Government.. 2003. *State of the Environment Report: Air Quality*. [Online]. Available:

http://www.environment.gov.za/soer/reports/gauteng/Chapter%207%20Air%20Quality.pdf [5 October 2010].

209. South African Landscape Institute (SALI). 2010. *Notes to the SALI Gauteng Application for Membership.* [Received through email communication]. [15 October 2010].

210. South African National Biodiversity Institute. 2008. *National Grasslands Biodiversity Programme.* [Online]. Available: http://www.undp.org/gef/documents/writeups_doc/bio/SAGrasslands.doc [9 October 2010].

211. South African Nursery Association (SANA). 2010. Membership Fee Breakdown. [Received through email communication]. [17 October 2010].

212. South African Nursery Association (SANA). 2010. *Partnerships and Affiliations.* [Online]. Available: http://www.sana.co.za/Industry/ [16 August 2010].

213. Statistics South Africa. 2001. *Census 2001.* Pretoria: Statistics South Africa.

214. Statistics South Africa. 2001. *Census 2001: Household Dwelling Type.* Geographic Department. [Electronically received through email communication]. [16 October 2010].

215. Statistics South Africa. 2007. *Community Survey.* Pretoria: Statistics South Africa

216. Statistics South Africa. 2010. *Quarterly Labour Force Survey (2nd Quarter 2010).* Geographic Department. [Electronically received through email communication]. [16 October 2010].

217. Spencer, F., Swilling, M., Everatt, D., Muller, M., Schelschenk, J., du Toit, J., Meyer, R. & Pierce, W. 2010. A strategy for a developmental green economy for Gauteng: Preliminary Report, DRAFT. *Report prepared for the Gauteng Province Department of Economic Development.*

218. Stake, R. E. 1995. *The Art of Case Study Research.* USA: Sage Publications.

219. Stake, R.E. The Case Study Method in Social Inquiry. *Educational Researcher,* 7 (2): 5-8, February.

220. Stewarta, G.H., Meurkc, C.D., Ignatievaa, M.E., Buckleya, H.L., Magueurd, A., Casea, B.S., Hudsona, M., Parker, M. 2009. Floristics, biodiversity and conservation values of urban residential and public woodlands, Christchurch: Urban Biotopes of Aotearoa New Zealand (URBANZ) II. *Urban Forestry & Urban Greening*, 8, pp 149-162.

221. Stoffberg, G.H., van Rooyen, M.W., Van der Linde, M.J., Groeneveld, H.T. 2010. Carbon sequestration estimates of indigenous street trees in the City of Tshwane, South Africa. *Urban Forestry & Urban Greening,* 9: pp 9-14.

222. Stucki, V. & Smith, M. 2010. Integrated Approaches to Natural Resources Management in Practice: The Catalyzing Role of National Adaptation Programmes for Action. *Ambio,* September 15.

223. Sudjic, D. 2007. Editorial in *Urban Age,* Bulletin 5, Winter. Cities Programme for London School of Economics and Alfred Herrhausen Society, the International Forum of Deutsche Bank. [Online]. Available: http://www.urban-age.net/0_downloads/UABulletin5JHB.pdf [3 September 2010].

224. Swilling, M. 2004. 'Rethinking the Sustainability of the South African City'. *Development Update,* 5 (1): pp 215-242.

225. Swilling, M. 2007. South African Cities in the Second Decade of Democracy: Emerging Conceptual and Policy Spaces for a New Urban Agenda. *Paper presented at the International Colloquium: Urban Challenges in Brazil and South Africa*, Rio de Janeiro, 10-13 September.

226. Swilling, M. & Fischer-Kowalski (eds). 2010. 'Decoupling and Sustainable Resource Management: Scoping the Challenges'. *Decoupling Working Group.* UNEP: International Panel for Sustainable Resource Management. Version: 4. March.

227. Swilling, M. & Southall, R. (eds). 2010. Growth, Resource Use and Decoupling: Towards a 'Green New Deal' for South Africa. *Paper accepted for publication in 2010 of the New South African Review*. Johannesburg: Wits University Press.

228. Swilling, M. & Anneke, E**.** (forthcoming) *Just Transitions: Explorations of Sustainability in an Unfair World*. Chapter 5. Cape Town: Juta.

229. Swyngedouw, E. & Heynen, N.C. 2003. Urban Political Ecology, Justice and the Politics of Scale. *Antipode*: pp 898- 918. Oxford: Blackwell Publishing.

230. Thaiutsaa, B., Puangchita, L., Kjelgrenb, R. & Arunpraparut, W. 2008. Urban green space, street tree and heritage large tree assessment in Bangkok, Thailand. *Urban Forestry & Urban Greening,* 7: pp 219-229.

231. Theunissen, N. 2010. City Visit: Flood Warning in Garner, G. (ed). *Urban Green File,* 15 (1), p 16-22, April.

232. Thomas, G. 2010. Doing case study: Abduction Not Induction, Phronesis Not Theory. *Qualitative Inquiry,* 16 (7): pp 575-582

233. Tomlinson, R., Beauregard, R.A., Bremner, L., & Mangcu, X. 2003. Section 1: Reorganizing Space. *In* Tomlinson, R., Beauregard, R.A., Bremner, L., & Mangcu, X. (eds). *Emerging Johannesburg: Perspectives on the Post-Apartheid City.* New York: Routledge.

234. Tratalos, J., Fuller, R.A., Warren, P.H., Davies, R.G. & Gaston, K.J. 2007. Urban form, biodiversity potential and ecosystem services. *Landscape and Urban Planning,* 83: pp 308-317.

235. Trendler, R., & Hes, L. 2000. *Attracting Birds to your garden in Southern Africa.* Cape Town: New Holland Publishing.

236. Turton, A., Schultz, C., Buckle, H., Kgomongoe, M., Malungani, T. & Drackner, M. 2006. Gold Scorched Earth and Water: The Hydropolitics of Johannesburg. *Water Resources Development,* 22 (2): pp 213-335, June.

237. Tutu, H., McCarthy, T.S., & Cukrowska, E. 2008. The chemical characteristics of acid mine drainage with particular references to sources, distribution and remediation: The Witwatersrand Basin, South Africa as a case study. *Applied Geochemistry,* 23: pp 3666-3684.

238. Tyson, P.D., du Toit, W.J.F., & Fuggle, R.F. 1972. Temperature Structure Above Cites: Review and Preliminary Findings from the Johannesburg Urban Heat Island Project. *Atmospheric Environment,* 6: pp 533-542, 14 March. [Online]. Available: http://www.sciencedirect.com.ez.sun.ac.za/science?_ob=MImg&_imagekey=B757C-48CG0KX-C4-1&_cdi=12895&_user=613892&_pii=0004698172900704&_origin=search&_zone=rslt_list_item&_coverDate=08/31/1972&_sk=999939991&wchp=dGLbVzzzSkzS&md5=32696ec386093d42651e2bef4cb970cb&ie=/sdarticle.pdf [28 September 2010].

239. Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Ka´zmierczak, A., Niemela, J., James, P. 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape & Urban Planning,* 81: pp 167-178, March 5.

240. UN-Habitat. 2008. *State of the World's Cities Report 2008/2009: Harmonious Cities.* London: Earthscan, pp x-xvi.

241. UN Habitat. 2010/2011. *State of the World's Cities 2010/2011: Bridging the Urban Divide.* Nairobi: UN Human Settlements Programme Habitat Press, March 18.

242. United Nations Environment Programme (UNEP). 2008. *Green Jobs: Towards decent work in a sustainable, low-carbon world.* Washington DC: Worldwatch Institute, September.

243. United Nations Environment Programme (UNEP). 2010. *Green Economy Report: A Preview.* Switzlerland: United Nations Environment Programme, Division of Technology, Industry and Economics.

244. United Nations Environment Programme (UNEP). 2011. *Green Economy Report – Cities: Investing in energy and resource efficiency.* [Online]. Available:

http://www.unep.org/greeneconomy/Portals/88/documents/ger/GER_12_Cities.pdf [27 February 2011].

245. Van der Merwe, C. 2010. Acid Mine Drainage an 'impending crisis' – Aveng. *Mining Weekly,* February 15. [Online]. Available: http://www.miningweekly.com/article/acid-mine-drainage-an-impending-crisis-says-aveng-ceo-2010-02-15 [31 July 2010].

246. Von Maltitz, G., Mucina, L., Geldenhuys, C.J., Lawes, M.J., Eeley, H., Aidie, H., Vink, D., Fleming, G. & Bailey, C. 2003. Classification system for South African Indigenous Forests. *An objective classification for the Department of Water Affairs and Forestry Unpublished report,* No. ENV-P-C 2003-017, Environmentek, CSIR, Pretoria. 275 pp.

247. Walker & Salt, 2006. *Resilience thinking: sustaining ecosystems and people in a changing world.* Washington DC: Island Press.

248. Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. 2006. A Handful of Heuristics and Some Propositions for Understanding Resilience in Socio-Ecological Systems in *Ecology & Society,* 11 (13). [Online]. Available: http://www.ecologyandsociety.org/vol11/iss1/art13 [11 May 2010].

249. Walker, B., Holling, C.S., Carpenter, S.R. & Kinzig, A. 2004. Perspective: Resilience, Adaptability and Transformability in Social–ecological Systems in *Ecology and Society,* 9 (2): 5. [Online]. Available: http://www.ecologyandsociety.org/vol9/iss2/art5 [22 July 2010].

250. Walmsley, A. 2006. Greenways: multiplying and diversifying in the 21st Century. *Landscape & Urban Planning,* 76: pp 252-290, May 31.

251. Ward, S. & Schäffler, J. 2008. "Gauteng 2034 development strategy: Energy trend paper" in *Gauteng 2055 development strategy: Gauteng Department of Economic Development,* October.

252. Ward, C.D., Parker, C.M., & Shackleton, C.M. 2010. The use and appreciation of botanical gardens as urban green spaces in South Africa. *Urban Forestry & Urban Greening,* 9: pp 49-55.

253. Weiersbye, I Cukrowska, E.M., Margalit, N., Feingersh, T., Revivo, G., Braun, O., Stark, R., & Zut, Y. N.d. *Acid Mine drainage and phreatophyte vegetation: Biogeochemical cycling of pollutants by phreatophyte vegetation on acid mine drainage: Implications for Land Use Planning.* Abstract. [Online]. Available: http://forestry.daff.gov.za/webapp/ResourceCentre/Documents/Reports/4273___Day2_session3_item3.pdf [5 October 2010].

254. Weiersbye, I. 2007a. Global Review and Cost Comparison of Conventional and Phyto-Technologies for Mine Closure. *Mine Closure, Plenary Report.* Santiago.

255. Weiersbye, I. 2007. Phytotechnologies – user-friendly technologies for environmental damage control. *Eagle Bulletin.* Johannesburg: University of the Witwatersrand.

256. Weisz, H., & Steinberger, J.K. 2010. Reducing energy and material flows in cities. *Current Opinion in Environmental Sustainability,* 2 (3): pp 185-192.

257. Williams, J.B., & McNeil, J.M. 2005. Neoclassical Economics and the Case for and Economic Analysis based on Sustainable Development in *U21 Global,* March. [Online]. Available: http://www.u21global.edu.sg/PartnerAdmin/ViewContent?module=DOCUMENTLIBRARY&oid=14094 [25 October 2010].

258. Wolf, K. 1998. *Urban Forest Values: Economic Benefits of Trees in Cities.* Fact Sheet no. 29: November. University of Washington.

259. Wolf, K. 2003. Ergonomics of the City: Green Infrastructure and Social Benefits in Kollin, C., (ed). *Engineering Green: Proceedings of the 11th National Urban Forest Conference,* Washington D.C: American Forests.

260. Wolf, K. 2004. Economics and Public Value of Urban Forests in *Urban Agriculture Magazine,* 13: pp 31-33. Special Issue on Urban and Periurban Forestry. [Online]. Available: http://www.cfr.washington.edu/research.envmind/Policy/Urban_Ag.pdf [2 June].

261. Wolf, K., & Blana, D. 2010. *Urban ecosystem services: Seattle Urban Forest.* Seattle: June 4.

262. Wolrd Comission on Envrionmetn and Development. 1987. *Our common future.* Oxford University Press.

263. Wray, C. 2010. Working Towards a Successful Gauteng City-Region. *Gauteng City Region Observatory (GCRO),* January/February. PositionIT.

264. Wysham, D. 2008. Carbon Market Fundamentalism. *Multinational Monitor,* pp 23-26, November/December.[Online].Available:http://web.ebscohost.com.ez.sun.ac.za/ehost/pdfviewer/pdfviewer?vid=1&hid=9&sid=67b9db49-3921-4f31-9f40-fa28c2c6415f%40sessionmgr4 [11 October 2010].

265. Yeang, K. 2008. Ecomasterplanning. *Yeang's Eco-Files*: pp 128-131. John Wiley & Sons Ltd.

Appendix

Please see overleaf.

Carbon estimates for Johannesburg												
Tree	DBH	Stem length = Height to main branches (metres)	Total height	B = % Branch volume as a proportion of total tree	BA Basel area = PI*DBH*DBH/40000	Stem volume = BA* stem length*0.7	Total tree volume = Stem volume /(1- B)	Biomass = tree volume * 0.7	Volume per ha (Metric tonnes per ha) = biomass/ 0.25	Biomass per ha = volume per ha*0.7	Carbon stock (metric tonnes per ha) = biomass per ha*0.5	Carbon stock (metric tons) of entire CoJ area = carbon stock per ha * total CoJ ha (164 458)
1	51.5	3	11.5	0.7	0.208391	0.4376	1.4587	1.02112				
2	45.2	2	6.5	0.45	0.160525	0.2247	0.4086	0.28603				
3	62.3	3.1	12	0.6	0.304959	0.6618	1.6544	1.15808				
4	25	2	5.5	0.4	0.049107	0.0688	0.1146	0.08021				
5	39.5	1.2	5.5	0.35	0.122591	0.103	0.1584	0.1109				
6	31	2	8	0.4	0.075507	0.1057	0.1762	0.12333				
7	37.5	1.75	7.5	0.3	0.110491	0.1354	0.1934	0.13535				
8	5	1.7	6	0.4	0.001964	0.0023	0.0039	0.00273				
9	4.1	1.7	6	0.4	0.001321	0.0016	0.0026	0.00183				
10	7.4	1.7	6	0.4	0.004303	0.0051	0.0085	0.00597				
11	18	2.5	8	0.2	0.025457	0.0446	0.0557	0.03898				
12	21.2	1.8	12	0.6	0.035313	0.0445	0.1112	0.07787				
13	20.1	1.7	10	0.5	0.031744	0.0378	0.0755	0.05288				
14	18	1.8	10	0.5	0.025457	0.0321	0.0642	0.04491				
15	14.4	2.6	10	0.4	0.016293	0.0297	0.0494	0.03459				
16	18.7	2.4	10	0.5	0.027476	0.0462	0.0923	0.06462				
17	29.1	1.6	10	0.5	0.066535	0.0745	0.149	0.10433				
18	9.4	2.3	7.5	0.45	0.006943	0.0112	0.0203	0.01423				
19	34.3	2.6	14	0.5	0.092439	0.1682	0.3365	0.23553				
20	74	3.1	1.9	0.85	0.430257	0.9337	6.2244	4.35707				
21	68.7	3	19	0.85	0.370833	0.7787	5.1917	3.63416				
22	17.8	3	10.5	0.75	0.024895	0.0523	0.2091	0.14638				
23	30.9	2	10.5	0.7	0.075021	0.105	0.3501	0.24507				
24	16.8	1.7	10.5	0.8	0.022176	0.0264	0.1319	0.09236				
25	17.2	2.1	10.5	0.7	0.023245	0.0342	0.1139	0.07973				
26	18.7	2.4	10.5	0.6	0.027476	0.0462	0.1154	0.08078				

27	18	3	5	0.45	0.025457	0.0535	0.0972	0.06804				
28	43	2.8	11.5	0.6	0.145279	0.2847	0.7119	0.49831				
29	53.4	2.2	11.5	0.65	0.224051	0.345	0.9858	0.69008				
30	21	2.2	13	0.5	0.03465	0.0534	0.1067	0.07471				
31	24.9	16	7	0.75	0.048715	0.5456	2.1824	1.5277				
32	20.1	2.4	10	0.4	0.031744	0.0533	0.0889	0.06222				
33	24.9	1.8	10	0.45	0.048715	0.0614	0.1116	0.07812				
34	16.4	3.5	12	0.45	0.021133	0.0518	0.0941	0.0659				
35	22.6	1.7	12	0.4	0.040131	0.0478	0.0796	0.05572				
36	26.7	1.5	12	0.4	0.056013	0.0588	0.098	0.06862				
37	11.6	2.1	9	0.5	0.010573	0.0155	0.0311	0.02176				
38	14.5	1.7	9	0.45	0.01652	0.0197	0.0357	0.02502				
39	69.5	1.4	15.5	0.6	0.37952	0.3719	0.9298	0.65088				
Total								**16.1161**	**64.4643**	**45.125**	**32.23217**	**5 300 838.596**
												(5,3 million metric tons carbon)

Table 16 Carbon stock estimates of Johannesburg's urban forest