Multiple performance indicators as standard to assess and quantify the ecological condition of a site

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Dissertation submitted in fulfilment of the requirements for the degree *Magister Scientiae* in *Environmental Sciences* at the Potchefstroom Campus of the North-West University

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May 2016

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Acknowledgements

I dedicate this dissertation to my sister, Estelle van Niekerk, for her loyalty, unconditional dedication and technical support that helped me to complete this project.

I would like to thank the following people for their contributions:

My supervisors, Prof. Sarel Cilliers and Prof. Juaneé Cilliers for all the time they invested and their valuable and indispensable input,

My former lecturer at the Life Style College, Bruce Stead, who taught me the basics of ecological design,

Dr. Marie du Toit for technical support with maps,

Dr. Ruth Scheepers for proof-reading,

Ms. Gerda Ehlers for librarian assistance, University if Pretoria, and

Ms Erika Roodt for librarian assistance, North West University

Abstract

Ecological sustainability focuses on the application of ecological principles to justify modifications to the environment to meet the human needs of present and future generations. Sustainability can only be achieved with responsible and reasonable decision-making practices in place to guide anthropogenic modifications of the environment to justify economic wealth and human well-being. The application of sound scientific knowledge is needed to set a standard for the use of natural resources responsibly. The right of every person including the rights of future generations to enjoy an environment, which is not harmful to his or her health and well-being, mandate all decision-makers to protect the environment. In practice, it means that one cannot manage what one cannot measure. Sustainable ecological management is possible only through measuring the ecological condition of a site. A need exists to report to be transparent about the successes of recovery. Ecological monitoring is suggested before and after development of a site, irrespective of the scale and impacts of development. This study proposes an index as standard and instrument for consistent assessment and measurement of the ecological condition of a site. Ecological principles and concepts recognise landscape features and attributes which were applied to list and assess 44 ecological landscape indicators by allocation of a rate and a weight value that is regarded as the basis of this site index. These multiple indicators represent measurable site attributes that capture complex qualitative and quantitative information and can be used as a practical standard method of benchmarking. Reliable scientific data are proposed to be used for integrated standard audit reports to determine and address environmental risk. A site was randomly selected to test the index and to compile a management report based on sound scientific data. The numeric score calculated by the index confirms that the assessment value differs from the ecological value communicated by the developer.

***Key terms**: standard; monitoring; indicators; ecological value, biodiversity and ecosystem services; site condition; multi performance indicators.*

Uittreksel

Ekologiese volhoubaarheid berus op die toepassing van ekologiese beginsels om ontwikkeling te regverdig vir huidige en toekomtige generasies. Volhoubaarheid is slegs moontlik indien daar verantwoordelike en redelike bestuurspraktyke bestaan om antropogeniese versteurings vir ekonomiese voorspoed en menslike gesondheid te regeverdig. 'n Standaard vir die verantwoordelike gebruik van natuurlike hulpbronne is nodig deur die toepassing van suiwer wetenskaplike kennis. Die reg van alle mense asook die reg van toekomstige generasies om die natuur te ervaar en te geniet, moet gerespekteer en inaggeneem word deur besluitnemers. In praktyk sal dit slegs moontlik wees indien daar 'n maatstaf bestaan om volhoudbare bestuur te meet en te beoordeel. Ekologiese bestuur is slegs moonlik deur die meting van die ekologiese toestand van 'n terrein. Daar is 'n behoefte aan verslaggewing om die suksesse van ekologiese herstel openbaar te maak. Ekologiese monitering word voorgestel voor en na die ontwikkeling van 'n terrein en ook ongeag die skaal of impak van ontwikkeling. Hierdie studie stel 'n indeks voor as 'n standaard en instrument om op 'n eenvormige wyse die ekologiese toestand van 'n terrein te bepaal. Ekologiese beginsels is vervat in landskapskenmerke en – eienskappe. Die indeks is toegepas om 44 ekologiese landskap indikatore te beoordeel deur twee gewigswaardes toe te ken wat dan as die basis van die terrein indeks beskou word. Hierdie meervoudige indikatore is 'n voorstelling van die meetbare komplekse kwantitatiewe en kwalitatiewe ekologiese terrein-eienskappe wat gebruik kan word as 'n praktiese standaard-metode om as 'n maatstaf te dien. Betroubare wetenskaplike data word voorgestel om gebruik te word as 'n standaard vir oudit verslae om omgewingsrisiko aan te spreek. 'n Terrein vir toetsing van die indeks is lukraak gekies en 'n bestuursverslag is saamgestel wat berus het op suiwer wetenskaplike data. Die numeriese uitslag wat behaal is deur die indeks het bevestig dat die wetenskaplike bepaalde ekologiese waarde verskil van die gekommunikeerde waarde deur die ontwikkelaar.

***Sleutelwoorde**: standaard; monitering; indikatore, ekologiese waarde, biodiversiteit en ekosisteemdienste; ekologiese toestand; veelvuldige prestasie omgewing.*

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List of Abbreviations

BES	Biodiversity and Ecosystem Services
CABE	Commission for Architecture and the Built Environment
CoT	City of Tshwane
ERR	Ecological Recovery Response
EIM	Ecological Index Method
EMPr	Environmental Programme
EIC	Ecology in Cities
EOC-E	Ecology of Cities as Ecosystems
EOC-S	Ecology of Cities as Socioeconomic Structures
GDACE	Gauteng Department of Agriculture, Conservation and Environment
LUCC	Land-use and Land Cover Change
MEA	Millennium Ecosystem Assessment
NRC	National Research Council
PES	Present Ecological State
SER	Society for Ecological Restoration
SOE	State of the Environment
SRR	State of the Rivers Report
SS	Sustainability Science
TEEB	The Economics of Ecosystems and Biodiversity
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development

Chapter 1: Introduction

> ***Today the richness and power of ecological principles can no longer be ignored by designers or society. Serious study of ecology has become a sine qua non for effective designs and solutions (Forman, 2013).***

1.1 Problem statement

Measurements of society's well-being focus predominately on market price to indicate economic value and ignore nature's value as economic capital. The value of Biodiversity and Ecosystem Services (BES), delivered free of charge, is not calculated, with the result that third-party effects of private exchange, the so-called externalities, are ignored unless they are declared illegal (TEEB, 2010).

Urbanisation causes land degradation, which has a direct link with land cover change and holds serious risks for business sustainability, although it can also create significant opportunities for combating biodiversity loss and ecosystem degradation (TEEB, 2010). It has become essential for business to identify nature's invisible flows through the economy and to invest in the ecological condition of land. Sustainable land management requires sound ecological data that are accurate, transparent and available to all stakeholders, not only to make informed investment decisions, but also to develop better policies for land-use and to reverse changes through prevention, mitigation, recovery or restoration of degraded land (Kellner, 2009). Ecological recovery and restoration are actions in response to land that has been degraded, damaged, destroyed or transformed by human activities; this includes the ecological health, integrity and sustainability of the land (SER, 2004; Kellner, 2009).

1.2 Literature review

It is projected that approximately 66% of the world's population will be living in cities by the end of 2050 (United Nations, 2014). Cities are dynamic and experience continuous internal change but the expectation is that as much as 60% of the built environment will be new or replaced by the year 2050 (Ahern *et al.,* 2014). Urbanisation creates local challenges to the environment in the form of human activities that modify climate, water resources, human health and land uses. These modifications gradually change the ecological value and reduce the ecological integrity and health of the regional and global landscape (Wu, 2008). The environmental problems brought about by urbanisation emphasise the fact that cities are ecologically unsustainable and are therefore unable to maintain the earth as a healthy ecosystem (Müller *et al.,* 2010). The manner in which humans alter and reshape the landscape by destroying natural vegetation, replacing natural structures with artificial ones and by changing landscape composition, structure and function, causes land degradation and results in the reduction and loss of biological diversity and economic productivity (Wu & Hobbs, 2007). Human activities in cities are responsible for land changes, reduced landscape functions and new habitat patterns with less natural biodiversity and more exotic species that result in monocultures and biodiversity loss (Odum, 1997).

The challenge that is facing urban planners and ecologists lies not in putting a stop to urbanisation and development, but rather in designing, planning and managing resilient cities. For cities to be resilient, consideration must be given to environmental sustainability as an innovative norm that creates unity between present and future generations by maintaining the balance between development and nature (Wu, 2010, Chen & Wu, 2009). This dynamic balance is required, not only during periods of extreme modification, but also in times of less significant change (Chen & Wu, 2010). The aim to create more sustainable cities is not to prevent change but to maintain resilience and ecological processes; to adjust, through renewal and reorganisation, to a new norm with continued ecosystem service supply (Pickett, *et al.,* 2013). The environmental crisis is perceived as a design crisis in the management of ecosystems since the recovery of ecological processes that follows disturbances is not yet fully understood or taken into consideration (Wu & Wu, 2013). Environmental degradation takes place because of a lack of or the misuse of practical ecological knowledge in design actions and management (Wu & Wu, 2013). The relationship between landscapes, ecosystem services and human well-being requires a new approach to sustainable urban land use that continues the delivery of ecosystem services (Cilliers *et al.,* 2014). Such an approach highlights the importance of building a connection on common ground to enable the interaction between science, nature and society (Cilliers *et al.,* 2014).

Resilience is a reflection of the capacity of a socioecological system to respond to disturbances by absorption and reorganisation, while retaining its identity. Identity refers to landscape dynamics and signifies landscape function, structure and feedbacks (Walker & Salt, 2012). According to Walker and Salt (2012), the identity of the system will lead to one of the following:

(i) The current state of a system can adapt and build resilience

(ii) The altered circumstances can transform it into a different state with reduced resilience

(iii) The identity can be totally lost in the formation of a new, degraded system.

Modern ecological research has found that nature is not in a stable state, but rather in constant flux (Wu & Wu, 2013). This unstable condition, referred to as hierarchical patch dynamics (Wu &

Wu, 2013), highlights the fact that disturbance is an important and integral part of ecosystems and landscapes on all levels (Turner *et al.*, 2001). Furthermore, natural disturbances such as fire or grazing are even requirements for maintaining community structure and ecosystem functions (White, 1979; Turner *et al*., 2001). Socio-ecological disturbances are human-induced disturbances and a result of development, which changes the dynamics of ecosystem functioning forever. Patch dynamics has not been fully incorporated, valued or understood in the theory and practice of design science (Pickett *et al.,* 2004); as a consequence, resilience is not entirely understood as a framework for the design and management of urban systems intended to achieve urban sustainability (Pickett, *et al.,* 2013).

According to the Millennium Ecosystem Assessment (MEA) Report, nature provides a range of benefits, known as biodiversity and ecosystem services that contribute to urban sustainability (UN, 2005). Cities depend on a healthy environment for continuous ecosystem service provisioning. Although these life-supporting services are free to society, their economic value and contribution to social well-being are unfortunately not always appreciated (UN, 2005). The availability of these ecosystem services can be translated into natural capital since they have considerable economic value (Wu & Wu, 2013). Urban development is therefore not only responsible for a significant loss in biodiversity and ecosystem services, but it also affects a city's cross-scale resilience by the destruction of ecosystems (Cummings, 2011).

The MEA has defined four categories of ecosystem services. Services that affect people directly include: (i) provisioning (e.g. timber, food, medicines); (ii) regulating (e.g. climate, water, soil and disease regulation); and (iii) cultural services (e.g. aesthetic value, education, recreation and sense of place or spiritual services) (UN, 2005). The fourth category comprises support services to maintain the abovementioned services and to deliver services such as primary production, nutrient cycling and pollination. Ecosystem services are closely interlinked and involve various aspects of the same biological processes (primary production, photosynthesis, nutrient services, recycling and water cycling) (UN, 2005).

The services delivered by ecosystems are sometimes available far beyond the physical boundaries of where the services are needed (Lovell & Johnston, 2009a). The existence of ecosystems makes it imperative for urban designers to apply an ecological understanding in their practice to protect their ecosystem services. Larson *et al.* (2013) observe that the term "restoration", used in the historical literature, is currently interpreted as "design". It is only recently that responsible planners and managers have realised that natural ecosystems provide similar but more sustainable additional services to hard-engineering constructions (Odum, 1962; Karr, 1996; Mitch & Jørgensen, 2004; Palmer *et al*., 2014).

It is important that the design of the urban planning process be restructured to allow input from ecologists at critical points, in order to address the lack of ecological data and information available to urban planners and designers (Felson, 2013). The role of ecologists in translating scientific knowledge into design applications becomes increasingly important as the pressure on the environment increases (Felson, 2013). Ahern *et al*. (2014) believe that ecosystem service recognition needs to be incorporated into urban planning and design. The Economics of Ecosystems and Biodiversity (TEEB, 2010), a global initiative, draws attention to the global economic benefits of biodiversity. It recognises that particular problems demand specific management and that adaptations need to be made to calculate the environmental cost of the impact of climate change. For instance, human intervention is required to maintain ecosystem services and to support the filtration and infiltration of water in the face of the effects of climate change on the provision of clean water (TEEB, 2010).

An ecological design approach advocates the use of specialist ecologists to advise managers on the effectiveness of their designs in terms of approved goals and objectives, services and trade-offs. Through the initiation of an interdisciplinary “dialogue” between engineering advantages and ecosystem services, design can be optimised (Larson *et al.,* 2013). Ecologists should be the leaders of any process to integrate ecological design and urban planning to ensure sustainable development (Pickett & Cadenasso, 2008). Sustainable development is a dynamic process and not an absolute end (Pickett *et al.,* 2013). Sense of place is associated with design as a social phenomenon and therefore it cannot be assumed as deriving from the environment. It has almost no association with sustainability; rather, it is an appreciation based on the understanding of the ecological and cultural characteristics of a place with a willingness to care for and protect a place and its future (Picket *et al*., 2013). Ecologists should inform design by outlining ecological principles to reconnect ecosystems and to provide places for connections to occur.

In practice, a foundation for sustainability entails natural resources, for example to link the vegetation of a site directly or indirectly to its closest natural surroundings, to establish green corridors and to create functional landscapes that maintain biodiversity (Pickett & Cadenasso, 2008). Urbanisation causes land transformation and fragmentation, which is the main factor in the loss of biodiversity and ecosystem services on all spatial levels (Müller *et al*., 2010). Urban planning and design cannot therefore not be done in isolation, indicating that a disturbance at local level should be linked to the cumulative impact of development on the environment at regional level to promote and secure sustainable development (DEAT, 2005). Biodiversity needs to be protected, despite development, and even the smallest units of fragmented habitat have the potential to contribute to sustainability (Gosh, 2010).

It has become increasingly important to monitor and audit the impacts of urban design on sustainable development by designing green audit or assessment tools that ensure ecologically sound and environmentally responsible built environments by connecting research, policy and practice (Gosh, 2010). Ecological risk assessments focus on sustainable land management and are used by ecologists and ecosystem managers to recover, restore and reverse land degradation by measuring the success of recovery efforts (Kellner, 2009). Evaluation of land condition assumes that a reference condition is an ideal site condition for an area and can be used as a benchmark that represents the natural ecological composition, structure and function for different ecotypes (Kellner, 2009). The reference site is more complex, has greater diversity and functionality than the project site, and is not necessarily a realistic end-goal in the short term for a recovery attempt. A good ecological condition, at worst, deviates slightly from the reference condition (EU, 2000). Change in condition or health is measured mainly through stability, resilience and resistance, defined as the ecosystem's ability to maintain or regain structural and functional attributes and to maintain a given trajectory for recovery in the face of stress and disturbance (Kellner, 2009).

According to TEEB (2010), there is currently no monitoring standard at company level to measure the performance of small fragmented units belonging to companies and to disclose the state of biodiversity and ecosystem services at all levels. This is probably why corporate sustainability reporting on biodiversity is mainly narrative in nature with indicators that focus on management systems, rather than the measurement of performance (TEEB, 2010) There is thus a need to design tools that can identify and manage impacts at local level by targeting performance monitoring (TEEB, 2010).

A concerted effort is required to improve ecological performance reporting according to greed upon requirements for setting such a standard (SANS, 2011). This standard should apply not only to organisations, but also to all landowners and land-users so that responsible owners can be held accountable for the ecological conditions of their properties. This includes protection of the environment and prevention of pollution on all levels (SANS, 2011).

1.3 Demarcation of the study

This study was the identification of multiple performance indicators of ecological condition in order to manage the human impact on land cover and species composition that supports and maintains biodiversity and ecosystem functionality. As method, the index applies scientific principles to set a standard that is useful, cost-effective and constitutes a consistent measuring tool that monitors and evaluates the ecological condition of a site. Assessments can be made at various life stages namely before, during or after a development. This is not a tool that should be applied by inexperienced or uninformed assessors. The objectivity of an assessor is always a concern if no detailed monitoring is undertaken to account for the results. Rating is however regarded as scientifically accepted process. Detailed direct monitoring of the ecological condition, such as vegetation composition, water quality, air quality and precise soil content is not the aim of this project as it focuses on the interpretation of the condition through the holistic assessment of specific ecological landscape indicators by an experienced and responsible assessor.

The testing of the assessment tool by only one assessor may be a limitation as this prevents the comparison and confirmation of results from different assessors. Use of the tool in future will address the repeatability for the sake of objectivity by comparing different site conditions in practice. As this was not the aim of this study, only broad metric guidelines were provided for ecological indicators. Broad metrics were given as an attempt to be objective and to repeat the assessment consistently using different assessors. It is suggested that landscape metrics should be evaluated as consistent guidelines to ensure future objectivity regarding assessment results.

1.4 Definitions of key concepts

Index	A formula that expresses the ratio between one quantity and another (in this study it is the ratio of ecological condition to human impacts).
Criterion	A standard or principle by which the ecological condition is judged.
Ecological approach	An approach to the management of natural resources that considers the relationships among all organisms, including man and his environment
Ecological evaluation	The determination of the value of the functions of an ecosystem, in monetary or other terms, to guide the planning and management of nature conservation
Ecological integrity (reference condition)	The ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitat of the region (Karr & Dudley, 1981)
Ecological quality and condition	The quality of an ecosystem in terms of the biophysical, physical and chemical conditions of environmental integrity; the state of the dynamics of a place, site, area or region reflects the change in biological, geochemical and physical attributes and processes, e.g. vegetation, water, soil and air, as quality of the physical action or movement.

	(Adapted from Walker & Salt, 2012).
Ecological indicator	Characteristics of the environment that can be measured and that indicate the present state of ecological resources.
Indigenous species	In relation to a specific area, a species that occurs naturally, or has historically occurred, in a free state in nature within that specific area, but excluding any species introduced in that area as a result of human activity (CoT, 2005).
Natural area	An area existing in or produced by nature, not artificial or imitated, where vegetation is usually dominant, where little human intervention has taken place and which it is not intensively utilised by humans.
Succession	The natural process by which communities of plant and animal species are replaced by others, usually more complex, over time as a mature ecosystem develops.
Primary succession	Plant succession that begins on bare ground (Walker, 2011)
Secondary succession	A plant succession following the interruption of the normal or primary succession (Walker, 2011)
State of system	Indicates the value of the state variables that constitute a system; for example, if a rangeland system is defined by the amounts of grass, shrubs and livestock, then the state space is the three-dimensional space of all possible combinations of the amounts of these three variables. The dynamics of the system are reflected as its movement through this space (Walker & Salt, 2012).
Response diversity	Within a functional group, different capacities exist to respond to different kinds of disturbances, and the range of different response types available is referred to as response diversity; it is this aspect of diversity that is critical to a system's resilience (Walker & Salt, 2012). (i) Socioecological: the ability to recover naturally after change through hidden natural processes (ii) Socioeconomic: the ability to restore destroyed ecosystem structure, functions and soils after changes by human activities

Recover	Dynamics of natural processes that cause movement to return to a natural condition
Best practice action	A best practice action to mimic nature to create a new ecosystem structure with multiple ecological functions to adapt to anthropogenic changes

1.5 Aims and objectives

The main aim of the study was to develop a scientific tool to assess the ecological condition of a site, to quantify the result as the ecological value in terms of the reference condition, to set a standard for ecological condition and to compare the ecological values of different sites according to the degree of human impacts.

The goal of the tool was to produce realistic, fair and cost-effective information based on ecological landscape principles. Although the data were collected subjectively, the aim was to establish a standard to rate the ecological indicators that provide an objective audit, in an effort to bridge the gap between the current, alleged ecological state of a site after change and the actual ecological value.

The specific objectives of the study were to:

(i) Link and list biodiversity and ecosystem services with a list of site attributes and processes to define the impact of human activities on a site

(ii) Set and list landscape goals and objectives as landscape goals and ecological indicators or characteristics of the ecological condition of a site

(iii) Formulate the reference condition of a site in order to classify the present ecological state of a site and to rate the indicators individually

(iv) Formulate broad landscape metrics as guidelines to assess indicators individually

(v) Compile a field evaluation sheet to be completed by an assessor during a field survey; to use this as the basic structure of the index and to rate and weight the indicators in order to calculate the present state of the site

(vi) Interpret the ecological data in terms of their ecological value and to make general recommendations for informed decision-making and communication to stakeholders of the recovery success of the project

1.6 Methodology

1.6.1 Background on ecological monitoring as the foundation for ecological risk management

The similarity between biological systems and an economy is apparent when the health of a biological system and the health of an economy are monitored respectively through biological monitoring or investors (Karr & Chu, 1997). Biological monitoring aims to detect change in living systems, caused not by natural disturbances but by humans. Such monitoring does not entail all the dimensions of natural variation, but focuses on tracking, evaluating and communicating conditions of biological systems and the impact of human activities (Karr & Chu, 1997). Biological monitoring identifies ecological risks important to human health and well-being, which are more obvious threats than the ecological wealth of natural resources (Karr & Chu, 1997).

Multiple-metric indices of biological condition are similar to economic indices that integrate multiple measures or metrics. According to Karr & Chu (1997), characteristics of the indicators of indices are:

(i) Indicators of biological condition on many levels of biological organisation

(ii) Ideal metrics should reflect specific and predictable responses of organisms to human activities

(iii) Relatively easy to measure and interpret

(iv) Increase or decrease predictably as human influence increases

(v) Sensitive to a range of biological stresses and not simply narrow indicators of commonly produced or threatened or endangered status

(vi) It is most important that the biological attributes that are chosen as metrics are able to differentiate variation caused by humans from the background “noise” of natural variability

(vii) Focus should be on human impact

Karr & Chu (1997) found that the development of effective multiple biological indices involves the following activities:

(i) The classification of environments that define homogenous sets within or across regions (e.g. large or small streams, warm water or cold water streams)

(ii) The selection of measurable attributes that provide reliable and relevant signals about biological effects of human activities

(iii) The development of sample protocols and designs that ensure that biological attributes are measured accurately and precisely

(iv) The definition of analytical procedures to extract and understand relevant patterns in data

(v) The communication of results to citizens and policymakers in all concerned communities in order to contribute to environmental policymaking

1.6.2 Defining the elements of an index of ecological condition

The basic terminology and principles of the Ecological Index Method (EIM), an evaluation technique developed by Vorster in 1982 to assess range conditions in South Africa, were used to compile an index to express the ecological performance and value of a site after human activities (Du Toit, 1995). The concepts used by Vorster (1982) for range management to design the EIM have been adopted in this study to design an Index to measure the ecological condition of a site. The adopted concepts are defined in *Table 1-1*.

Table 1-1: The concepts of the ecological index method adopted from Vorster (1982) to create a structure for the study index

Ecological Index Method (Vorster, 1982)	Study Index (adapted from Vorster, 1982)
Range condition of a natural area affected by human activities	Ecological condition of a project-site affected by human activities classified as natural or transformed
Degree of change from the reference condition	Degree of change from the reference condition
Ecological status of grass species and their grazing value	Ecological status of indictors of ecological condition as the ecological value of a site
Ecological classes (ecological status categories) for grass species recorded in the survey Decreaser Increaser	Ecological classes (ecological status categories) for site vegetation and soil recorded in survey Degraded to recover naturally through self-organisation Damaged to recover Destroyed / transformed to restore
Modification of the above classes that takes grass productivity, palatability and forbs into account High grazing value Moderate grazing value Low grazing value	Modification of the above classes that takes human impact on ecological value into account as a deviation from the natural condition Good value to recover (secondary succession) Moderate value to recover (primary succession) Poor value to recover (reconstruction)

Range condition score (weighting of ecological classes) Decreaser Increaser Bare ground	Ecological condition score (weighting of ecological classes) Insufficient and negative trend Acceptable Good Outstanding
Range condition score as percentage of the value of the reference site	Ecological condition score as percentage of the value of the reference site
Range condition index of: Above 80% Good 60–80% Moderate 40–59% Poor Less than 40% Degraded	Ecological condition index of: Above 80% Good Above 60–80% Moderate Less than 60% Poor

1.6.3 Other Indices

Over the years many quantitative indices have been developed by ecologists to describe species diversity e.g. species richness and evenness (Molles, 1999). The Shannon-Weiner index is an example of a commonly applied measure of species diversity (Molles, 1999).

Another index is the Singapore Index or Index for Biodiversity that was an outcome of the 9th Conference of Parties (COP) to the Convention on Biodiversity to recognise the role of cities as a self-assessment tool to measure biodiversity in cities. A need was identified to give recognition to the role of cities and local authorities and their national biodiversity strategies and action plans to promote cooperation of governments on sub-national levels (CBD, 2012).

Indices are frequently used in the Republic South Africa to comply with the National Water Act (NWA) of 1998 for the protection, use, development, conservation, management and control of water resources, which is guided by sustainability and equity. The obligation to protect the biological integrity of water resources is supported by the State of the Rivers Report to gather information regarding the ecological state of rivers (water quality, quantity and reliability) for the management of this national asset (WRC, 2001). Biological indices classify rivers applying various ecological indices such as fish, riparian vegetation and habitat integrity (WRC, 2001).

1.6.4 Major methodological steps taken to develop an index

The following illustrates the methodology that was followed in this study to assess ecological condition:

(i) A literature study was conducted to understand and build on interrelated research. The aim was to identify the impact of human activities on the ecological condition of a landscape in order to formulate planning, design and management actions to recover and restore the environmental impact

(ii) The elements of the index were evaluated for statistical correctness (Department of Statistics, North West University)

(iii) An index containing 44 ecological indicators was compiled and tested in practice to value the ecological condition of a randomly selected site by the interpretation of the results, and to make recommendations

1.6.5 Overview and content of chapters

This study includes eight chapters.

Chapter 1: Introduction

Economic value is not the only factor that proves a society's well-being and sustainable development. Although the development of cities modifies and degrades the environment, making them unsustainable, the challenge is not to build cities, but to build cities that consist of units of ecological value that contribute to a greater or lesser extent to the functioning of the ecological processes of the greater landscape. Green audit tools are essential to developing sustainable land management practices in response to changing complex, ecological and socioeconomic environments and to producing sound scientific data to disclose and report on corporate social and environmental responsibility.

Chapter 2: Literature study: Resilience in urban ecology and urban design

This chapter introduces the role of resilience and design in urban environments. Two historical approaches that have evolved in urban ecological science are discussed, namely the ecosystem concept in landscape ecology that defines landscape structure, pattern, processes and dynamics; and the essence of landscape design and ecology as instruments to support ecological sustainability and ecological processes in order to recover and restore disturbed landscapes. The aim of this chapter is to highlight the differences and commonalities in the approaches taken by designers and ecologists to the creation of ecological and economic value in urban landscapes.

Chapter 3: A standard for ecological condition

This chapter reviews the criteria used by Palmer *et al*. (2005) to measure ecologically successful river restoration. These criteria were adopted in order to set a standard by applying ecological landscape principles to an assessment of the ecological condition of a site that had been disturbed by human activities. These criteria are identified and discussed as realistic goals or end-state goals, formulated in accordance with a reference condition as a realistic future end-goal state. Recovery success is defined as an improved ecological state and is reflected in a move away from a degraded condition towards an ecologically dynamic end-state that guides the process of recovery or restoration. Classification of the ecological condition of a site is described from the ecological response to the present state to guide the process of recovery.

Chapter 4: Identification of multiple indicators to assess and quantify ecological condition

The ecological condition of a site is characterised as a complex concept that reflects attributes and management of a particular site such as biodiversity, soil, water, air, governance and well-being. In this chapter, ecological landscape goals and objectives are identified and listed as ecological indictors for ecological condition. Ecological landscape elements are then included in a framework in order to integrate biodiversity and ecosystem service objectives with ecological indicators as instruments to support and maintain these processes. Guidelines for rating the ecological state of individual indicators in terms of the reference condition of a location are also discussed and broad metrics are identified for the consistent assessment of sites.

Chapter 5: A protocol to assess the ecological condition of a site

In chapter 5, an evaluation sheet as protocol tool to assist in the assessment of the ecological condition of a site is discussed. The sheet lists the indicators for evaluation, provides space for the assessor to award a rate and weight value to rate indicators individually and to convert collected qualitative ecological data into quantitative data. The final value of the indicator scores is given as the ecological value achieved using a yardstick for realistic end-state goals, which are set at the start of the recovery process.

Chapter 6: Process of data and compilation of a status report

This chapter discusses the selection of a site as a case study for assessment. This project site was ecologically sensitive since it was situated in a protected area adjacent to an urban watercourse. The chapter describes how the index was tested as a tool for the measurement of ecological condition and value. Ecological data were collected by the assessor and were interpreted to assess the impact of human activities on the site.

Chapter 7: Conclusion

The final chapter concludes the dissertation. It makes recommendations and identifies areas for future research.

Chapter 2: Literature Study - Resilience in urban ecology and urban design

2.1 Introduction

Cities are constantly changing, mainly as the result of the impact of human activity. It has been predicted that 60% of current built environments will be new or replaced by the year 2050 (Ahern *et al*., 2014). The primary design of cities focuses on human needs, in order to deliver cost-effective services and to increase human health and well-being. Unfortunately, urban development has negative anthropogenic environmental effects on the local climate, water resources, the health of inhabitants and land-uses, with further cumulative impacts visible at regional and global level (Wu, 2008). Humans and their habits not only influence natural ecosystems but also dominate all other ecosystems (Grimm *et al.,* 2008).

Humans have been influencing the environment for thousands of years. They have been responsible for the extinction of many species through the introduction of agricultural activities that have had devastating results for the environment, including deforestation, soil erosion, disease and regional degradation of vegetation over time (Grimm *et al.,* 2008). Traditionally, human influence on the environment was not evaluated, observed or understood in terms of the ecological impact on the natural or urban environment (Karr, 1996). Urban ecology provides a platform from which to integrate theory and methods of both natural and social sciences in investigating the patterns and processes of cities and in explaining the role of human design on the quality of ecosystem services (Wu, 2008).

2.2 The concept of urban in urban ecology

Urban ecology is a broad term and implies the study of the interactions between the biotic and abiotic aspects of the urban environment, and encompasses the study of the natural environment (Sukopp, 1998; Cilliers & Siebert, 2012). Cilliers & Siebert (2012) found this definition too generic and selected Marzluff's (2001) definition as the most appropriate since it includes human aspects. Marzluff *et al.* (2001) describe urban ecology as an understanding of the coexistence of humans and ecological processes in human-dominated systems, assisted by the efforts of society to become more sustainable. Cilliers & Siebert (2012) suggest that the concept of transdisciplinary should be included to integrate the efforts of non-academic participants and academic researchers in developing new knowledge and theories to address changes and challenges. Urban ecology relates too, to a variety of conditions such as population density, type of land cover and cultural practices occurring in urban areas, recognised as cities, suburbs, exurbs and natural wilder lands (Pickett *et al*., 1997; Farinha-Marques *et al*., 2011).

Urbanisation represents multidimensional processes caused by a change in human population and land cover which replaces natural areas with synthetic/constructed structures, leading to homogenisation and fragmentation that poses a real threat to global biodiversity and environmental degradation (McKinney, 2006; Olden *et al*., 2006; Müller *et al*., 2010, Elmqvist *et al*., 2013). The conversion of land threatens to destroy the entire landscape since urbanisation has an ecological and social factor and is responsible for the reconstruction of a new land cover, causing changes in urban ecosystem functioning (Pickett *et al*., 1997; McIntyre *et al*., 2000).

Urban environments consist of various ecosystem components such as biological, social, physical and built elements. These vary in terms of composition, social institutional norms, soil, water, topography, air and structures (Pickett & Grove, 2009). Urban ecosystems may be artificially reconstructed or natural; the main difference between these two systems is the dominance of humans and the power of their prevailing activities to disturb (McIntyre *et al*., 2000; Pickett *et al*., 2013). Cities have elements of designed and managed ecosystems that cause unique environmental impacts. These should be managed by implementing an ecological landscape approach that focuses on the integration of urban design and ecology (Felson & Pickett, 2005).

Urban design describes landscapes, ecosystems and patches as "*places where people have reshaped the spatial and functional heterogeneity of ecosystems for the benefit of themselves – and sometimes nature*" (Musacchio, 2009). All landscapes that are intensively used and managed (including protected) by people in urban, suburban or rural environments are regarded as designed landscapes. Designed and changed landscapes are novel urban ecosystems with new end-state goals that affect the long-term ecosystem dynamics, with significant changes to the natural species pool. This can lead to the extinction of local species and the introduction of foreign alien biotic elements (Kowarik, 2011). Urban changes affect communities of species and ecosystem functioning of urban climate, hydrology and soils with a further change in associated feedback loops (Alberti, 2005; Kowarik, 2011). Urban biodiversity echoes human culture in its dynamics, ecology and value (Farinha-Marques *et al*., 2011).

The UK's Commission for Architecture and the Built Environment (CABE) describes urban design as a subdivision of urban planning with a role in connecting people and places, movement and urban forms, nature and the built fabric and the processes for ensuring successful villages, towns and cities (CABE, 2000). Urban design is the art of creating places through the design of buildings, spaces and landscape. It is key to sustainable development in a practical and informed way, using natural resources for social progress (CABE, 2000).

Urban ecology is regarded as the ecology of the city and it builds a bridge that links this ecology and urban design. Urban design focuses on linking individual sites with their larger social and ecological contexts and giving recognition to the dynamism of buildings and the landscape. Functional connectivity between sites is contrary to the view of constructing permanent monuments (Pickett *et al*., 2013)

2.3 Historical and modern perspectives of urban ecology

Ecologists first studied urban sites as analogous to places outside cities, lacking a holistic perspective through which to consider ecology as part of the urban fabric. Yet, urban ecology has no single theory (Pickett *et al*., 2013). The definition provided by Pickett *et al.* (2013) describes ecology as "*the study of interactions of organisms with one another, with the environment, and which also includes the transformation of matter, energy, and information that are mediated by organisms. Ecology originates and always returns to the physiological, genetic and behaviour aspects of organisms and does not only include individual organisms or groups of organisms, but also include the larger landscapes and ecosystems of which they are part*". This definition emphasises ecosystems as basic units in ecology.

Landscape changes caused by human alterations of the urban environment have major regional and global environmental impacts (Wu, 2008). A study of urban ecology is required in order to provide answers to the self-organising relationship between spatial-patterns and the corresponding ecological processes within ecosystems in urban areas (Grimm *et al*., 2008; Wu, 2008).

Urban ecology has three distinctive historical perspectives. These have evolved from the following research emphases, namely (a) the ecology in cities (EIC), (b) the ecology of cities as ecosystems (EOC-E), and (c) the ecology of cities as socioeconomic structures (EOC-S) (Wu, 2008). These three approaches regard ecology as knowledge of nature within cities (Grimm *et al*., 2000). The EIC follows a biological perspective and views cities as severely disturbed ecosystems, while the EOS-S follows a socioecological approach with little interdisciplinary crossover between natural and social sciences (Wu, 2008).

The EOS-S perspective views cities as socioeconomic systems designed for human welfare, but unfortunately tends to underplay the importance of biodiversity and ecosystem services and lack cross-disciplinary interactions between the natural and social sciences (Forrester, 1969). In the EOC-E tradition, humans are regarded as integral components of urban systems and this has encouraged interdisciplinary and problem-solving research (Wu, 2008).

Three perspectives in the EOC-E approach are as follows, according to Wu (2008):

(i) An urban systems view that focuses mainly on socioeconomic processes and only regards bio-ecological components as one of the factors for consideration

(ii) An integrative urban ecological approach, with a more holistic interpretation of the EIC and EOC, and which is not a bio-ecology or a socioeconomics only view

(iii) Landscape ecology perspectives of urban studies that have emerged as novel ideas that support and consider heterogeneity, scale and patch dynamics

These perspectives view cities as spatially heterogeneous landscapes composed of multiple interacting patches, within and beyond the city limits. Although these three urban ecology perspectives do not cover the full extent of urban sustainability, modern research and practice consider these perspectives to be the most inclusive since they allow the integration of all approaches (Alberti & Marzluff, 2004). Although they are all complementary, an integrated perspective is essential in order to study and develop urban sustainability since humans not only cause destruction to ecosystems, but are also key to create sustainable landscapes through interdisciplinary (integration of two or more disciplines, such as ecology and landscape ecology) and transdisciplinary (crosses many disciplinary boundaries) to create a holistic approach. It applies to research efforts focused on problems that cross the boundaries of two or more disciplines (Fry *et al*., 2007; Wu, 2008; Alberti *et al*., 2003).

An approach that is inclusive of all historic perspectives accepts that cities or urban systems are complex, with integrated social-ecological systems interacting across the city's mosaic pattern. The impact of humans and their design elements on the ecological structures and processes of non-urban sites complicate and disturb natural ecosystems. The challenge to build sustainable cities lies in unifying social and biological knowledge, concerns and approaches and in analysing the extent of interference in natural areas within and outside urban areas. In addition, spatial heterogeneity and the finer scale dynamics of ecosystem relationships are challenged by the imperative to create a new urban pattern with a new patch-mosaic norm that originates at local level and transforms the fluxes of matter and energy of the entire city (Cilliers *et al*., 2014).

2.4 Urban landscape sustainability

Modern ecology integrates former unconnected ecological approaches through a focus shift from landscape pattern to the sustainability of landscape ecosystem processes on any scale (Pickett *et al.,* 2013). Landscape ecology takes an ecological and a landscape view; the ecological vision focuses on fluxes of matter, energy, organisms and information while the landscape view focuses on spatial heterogeneity on any scale (Pickett *et al*., 2013). In urban areas where humans dominate the landscape through their creation of new landscape designs, the success of these designs depends on the way ecology and landscape are fused in a spatial, multifunctional ecosystem that contributes to a dynamic urban green infrastructure (Pickett *et al*., 2013).

The field of landscape ecology acts as an approach through which to integrate the views discussed above. According to Mussacchio (2009), Carl Troll coined the term in the 1930s in an effort to understand the way humans alter and reorder the spatial organisation of ecosystem patterns and processes. Recently, landscape researchers and practitioners have increasingly concentrated on the way people control the environment by focusing on the complex-based urban problems created by humans, including the effects and impacts of urbanisation (Grimm *et al.,* 2008). As a result, modern ecology includes the concerns of urban geographers and urban sociologists in a new kind of science called urban ecology that is practised as ecological design. Urban ecology links modern ecology to urban planning and design in a rapidly urbanising world with the shared goal of sustainability (Pickett *et al.,* 2013).

2.4.1 Urban sustainability as the goal of landscape ecology

In the urbanised world, the discipline of Sustainability Science (SS) provides a basis for an understanding of how social values, behaviours and actions have influenced the structure, function and changes of designed landscapes (Musacchio, 2009). Sustainability is a three-way interaction that links the environment, the socioeconomic aspects of inhabitants and urban design (Pickett *et al.,* 2013). When urban sustainability is the goal, it has the potential to include all these aspects.

In 1987, the World Commission on Environment and Development (WCED) defined sustainability as provision for the needs of present generations without compromising the ability of future generations to meet their needs (WCED, 1987). Sustainability emphasises the likelihood of the indefinite persistence of an existing system of resources without a decline in the resource base or welfare it delivers (Walker & Salt, 2012). The goal of sustainability highlights the problems of instability that urbanisation causes in the environment, such as biodiversity loss, ecosystem degradation, landscape fragmentation and climate change (Wu, 2010).

Ongoing land cover changes caused by urbanisation constitute the primary impact of humans on natural systems (Vitousek, 1994), with a snowball effect on land transformation resulting from the increased rate of urbanisation (Zipperer *et al*., 2000). Sustainable land use planning requires an ecological approach that conserves ecosystems (Zipperer *et al.,* 2000). SS has become an underlying discipline in the sustainability of land use and land cover change (LUCC) (Wu, 2006). In reality, the environmental problems created by urbanisation highlight the fact that cities are unsustainable and underline the need for them to become more sustainable (Wu, 2006). While some experts argue that urbanisation is the key to regional and global sustainability, others regard urban sustainability as an oxymoron (Wu, 2010). Sustainability and resilience are separate ideas with different consequences in urban development (Derissen *et al.,* 2011). Sustainability is a normative concept that derives from a standard relating to behaviour (Derissen *et al*., 2011). It is understood as basic ideas of inter- and intra-generational justice within species, between species and between the present and the future (Derissen *et al*., 2011). Therefore, sustainability focuses on the extent to which humans have misunderstood natural resources as green capital such as wetlands and animal species that should be maintained if future generations are to meet their own needs (Derissen *et al.,* 2011).

Resilience is a descriptive concept, describing the extent of disturbance that can be absorbed before a system changes its structure through a change in variables and processes that control behaviour (Holling & Gunderson, 2002). Resilience is the capacity of a system to keep its initial state, even after a disturbance, and to avoid change (flip) into another state (Walker *et al*., 2004). According to Holling (1973), resilience cannot be quantitatively measured as a system; and a system is therefore qualitatively classified as being resilient or not (Holling, 1973). In other words, resilience is the capacity of an ecosystem to respond to change after disturbance without changing its basic state or identity (Walker *et al*., 2004). Resilience presents a complex and multi-dimensional challenge to urban sustainability planning and design as it depends on a variety of stochastic processes that result in random reactions (Ahern, 2011). In the context of unpredictable disturbance and change, the concept of resilience offers a new perspective and a possible solution to the paradox of sustainability (Ahern, 2011).

The world is rapidly becoming more urbanised with accompanying increased impact on land-use, human welfare, social equity and sustainability (Ahern, 2011). The theory behind resilience thinking provides an understanding of the management of socioecological systems and engages people with the world of dynamic and adaptive systems. People depend on these complex systems, combined in complex ways, to respond to ecosystem change (Holling, 2001; Walker & Salt, 2012). It has become necessary to recognise the adaptive capacity of ecosystems, their ability to respond to change and to maintain resilience in a functional state after change (Ahern, 2011). Urban resilience is the potential of complex ecosystems to combine biodiversity, tight feedbacks, social capital, modularity, acknowledgement of slow variables and thresholds and innovation (Walker *et al*., 2004).

Urban sustainability focuses thus on the integration of landscape ecology with SS, by viewing humans as ecosystem engineers in developing urban sustainability (Wu, 2008). The challenge is to develop a new understanding of the functioning of urban ecological systems and the way they interact with the environment on a local and a global scale, and to include urban sustainability dimensions in the measurement and analysis of urban quality, urban flows and urban patterns (Alberti, 1996).

2.4.2 Green infrastructure value and urban sustainability

Cities are dynamic, self-organising ecosystems. They give new significance to the idea of sustainability in the sense that adapted cities build resilience through design and management of patches with ecological value within a green infrastructure to avoid risk (Ahern, 2011). Adaptive environmental assessment and management challenge the principle of urban sustainability through the post-implementation monitoring of the ecosystem functions they claim to provide (Felson & Pickett, 2005; Kato & Ahern, 2008; Nassauer & Opdam, 2008; Ahern, 2011). Ahern (2011) offers strategies for urban planning and design called green infrastructure planning to avoid risk and to support, maintain and build resilience that comprises multi-functionality, biological and social diversity, redundancy and modularisation, multi-scale networks and connectivity.

Humans change ecosystems and resilience in the ability of systems to absorb shocks through renewal, reorganisation and development (Folke, 2006). The disturbance of resilient socioecological systems creates the opportunity for innovation by relocating ecological design to the design of a sustainable urban green infrastructure (Folke, 2006). Urban planners need to focus on the protection and enhancement of the urban green totality, on valuing green spaces and compensating for the loss of green spaces by identifying and investing in alternative green spaces that is possible to protect (Cilliers, 2010).

2.4.3 Linking urban planning and design through ecology

Ecology links urban planning and design and creates a sustainable relationship between human actions and environmental degradation (Alberti *et al*., 2003). Researchers and practitioners studying designed landscapes should focus more on the sustainability of landscapes and less on the negative connotations of humans as disturbing agents. In this way, they could change to a positive and appreciative approach that enhances the positive design role humans can play (Alberti *et al*., 2003). This attitude is in contrast to the generally popular marketing strategy of “green cities” that highlights the fact that cities are unsustainable when it comes to the maintenance of a healthy, functioning ecosystem (Müller *et al*., 2010). Designed cities can achieve the goal of urban sustainability by following an urban ecological approach by supporting and maintaining a green infrastructure that creates ecological value by building resilience to absorb and avoid future risks (Wu, 2008).

Impacts of urban design on the nature and form of the urban heterogeneity of green infrastructure are important aspects that help to bridge the gap between ecology and urban design and to avoid risk (Pickett *et al*., 2013). New or altered vegetation can contribute to improved ecological services, making the vegetation component of an urban patch an element of ecological function by design (Pickett & Cadenasso, 2008). Urban design is in fact restoration, suggesting that all designs, intentionally ecological or not, can be evaluated according to their contribution to, or detraction from ecological functioning in urban areas; design should enhance ecosystem functioning (Pickett & Cadenasso, 2008). Therefore, intentional landscape changes should aim at improving ecosystem services by integrating ecology and design through ecologically motivated designs (Pickett *et al*., 2013). Urban design has a different approach and goal from that of the scientific approach of ecology, according to Pickett *et al*., (2013), as designers focus mainly on the following:

(i) Social benefit as central

(ii) Creativity as an important component of design

(iii) Providing a different analysis of site history and conditions

(iv) Generating futuristic models as standard activities

(v) Emphasising accuracy, convenience and beauty as central

Urban designers and ecologists share an interest in the heterogeneous spatial context of landscapes as places where flows of matter, energy, organisms and information are important and dynamic (Pickett *et al*., 2013). In the past, the important role that nature and ecosystems played in cities and the effects of cities on almost every ecosystem on earth were greatly underestimated to avoid risk (TEEB, 2010). For this reason, ecosystems and their services must be included in green infrastructure planning in order to address sustainability (TEEB, 2010). Cities consist of a large number of different systems combined in different ways and are constantly changing because of human actions. Urban planners and ecologists need to become more aware of how activities in one segment of the system affect other segments, especially if they intend to redesign and effectively manage these systems. A tradition of system thinking is required in practice to deal with systems of which humans are indisputably a part (Walker & Salt, 2012).

2.4.4 Ecological design as an element of urban sustainability

The mosaic of human and natural patches in cities is the creation of urban design. The standardised design of new developments unfortunately often neglects certain aspects of ecology and does not regard ecology as the main theme of design (Van der Ryn & Stuart, 2007).

According to Van der Ryn & Stuart (2007), ecological design entails the following:

(i) It is vital for urban and site sustainability.

(ii) It is defined as "any form of design that minimises environmental destructive impacts by integrating itself with living processes" (Van der Ryn & Stuart, 2007).

(iii) It recognises the interdependence of all life-systems by integrating the economy with the needs of other species and natural ecosystems through conserving ecological integrity (Shu-Yung *et al.,* 2004).

(iv) It contributes to the effective use of natural resources and the conservation of natural habitats and allows people to engage in livelihoods that provide manufactured products and economic services (Shu-Yung *et al.,* 2004).

Ecological design is defined by Stead (2012) as "*an environmental awareness and an understanding of the climate of different regions, geographical elements, soil types and conditions, animal life and their requirements, plant types, their regions, their hardiness and sun and shade suitability*." He emphasises the symbiotic relationships of all aspects of a particular site to mimic the natural habitat for natural harmony between these elements.

The disturbances caused to ecosystems by human actions need to be mitigated by recovery that support natural selection to connect the area through natural structural elements such as stone, rock, gravel, slate, wood, reeds, sticks and grasses of the surrounding area to support ecosystem services (Stead, 2012).

2.4.5 Cities are sustainable habitats for humans

Urban sustainability embodies the landscape as a whole. The landscape must be taken into consideration when cities are designed and constructed, even beyond city limits (Wu, 2010). A sustainable city strives for a balance between environmental protection, economic development and social well-being (Wu, 2010). The requirements for urban sustainability are:

(i) To minimise the consumption of urban space and resources

(ii) To optimise the urban form to facilitate urban flows that protect ecosystems and human health

(iii) To ensure equal access to resources and services

(iv) To maintain cultural and social integrity (Alberti & Susskind, 1996; Spiekermann & Wegener, 2003; Wu, 2008; Wu, 2010)

Although cities are not ecologically sustainable, they are globally the primary and most efficient and successful habitat for humans (Grimm, 2008). Cities and urban sprawl comprise only 3% of the earth's land surface although they accommodate more than half the world's population (Grimm *et al.,* 2000). It is critical that cities strive for ecological and economic sustainability since they allow lower per capita costs for clean water, electricity, waste collection, sanitation, telecommunication and other essential social services. This offsets the environmental damage they cause. Cities provide the ideal habitat for a concentration of humans and provide intact habitat for other biological species such as birds, small mammals and reptiles (Wu, 2010). Since urban land-use contributes to degradation, it is essential to identify acceptable and sustainable land cover conditions (Karr, 1996). A distinction must be made between urban land cover that is built up and land that has been transformed into new green assets; "green" environments that signify reconstructed landscapes with ecological value supporting the concept of green infrastructure planning and green assets (Schäffler *et al*., 2013).

Transdisciplinary evaluation has become essential in measuring the way human actions influence urban sustainability and ecological integrity, with specific reference to ecological memory. This is the ability of past states or experiences of a community in urban areas to influence its present and future ecological responses to change (Karr, 1996; Folke *et al*., 2003). In such an evaluation, an environmental performance standard is required to measure the impact of human activities. Such a standard should consider the way humans protect the environment from pollution as part of the meeting of their socioeconomic needs (SANS, 2011).

2.4.6 Sustainable urban ecosystems

The environment consists of ecosystems that cover a specific area or volume of the earth and include collections of organisms that interact within a physical environment (Pickett *et al.,* 2013). Ecosystems vary in size and structure with no common spatial scale and provide a quantifiable description of the earth, for instance, the volume or proportion of space occupied by living tissue, dead organic matter stored in the soil, sub-surface storage and key nutrients or toxins in the system (Pickett *et al.,* 1997). Ecologists need to understand which physical environmental processes control and limit the transformation of energy and materials in ecosystems in order to manage changes in a sustainable way (Pickett *et al.,* 1997).

The structure and function of urban ecosystems are affected by inputs from materials (the source), energy and influences far outside their boundaries. Energy and material emphasises the importance of an ecosystem's local and regional boundaries not inhibiting its processes from a distance (Likens, 1992; Pickett *et al*., 1997). Thus, sustainable ecosystem management focuses on the improvement of shared actions between ecological processes and human activities in order to allow sustainable development (Pickett *et al.,* 1997). It became increasingly important to recognise the social relationship of humans with the environment since they are the dominant component, changing ecosystems through their interaction with ecological processes and modifying various patterns and processes (Burch, 1971; Alberti *et al*., 2003; Pickett *et al*., 2013; Cilliers *et al.*, 2014). Humans influence the rules (including natural occurrences) that govern the earth on all scales and levels (Alberti *et al*., 2003).

Cities as ecosystems are the product of many human choices and actions, and biophysical features such as local geomorphology, climate and natural disturbance regimes (Alberti *et al.,* 2003). The choices and actions of humans reflect different patterns of development, land-use and infrastructure density, causing ecosystem processes to change both directly and remotely through land conversion, the use of resources and the generation of emissions and waste (Alberti *et al.,* 2003). Cities have the ability to maintain ecosystems and human functions and this response characterises the resilience of cities, or the degree to which they can tolerate alteration before reorganisation around a new set of structures and processes occurs (Holling, 2001). Mitigation to minimise the destructive impact on ecosystems is directly associated with the productivity of ecological design and the way humans integrate themselves with living processes (Van der Ryn & Stuart, 2007). Ian McHarg (1997) advocated in his "Design with Nature" concept that the ecological systems in natural landscapes should form the basis of decisions regarding the means of human appropriation of land for development.

Ecosystem functions include a variety of processes such as primary production, ecosystem respiration, biochemical transformation, information transfer and material transport that occur within an ecosystem and link its different structural components (Alberti *et al.,* 2003). The boundaries of ecosystems are open and permeable, making it important to know what flows across ecosystem boundaries (Picket *et al.,* 2013).

2.5 Landscape Ecology

Landscape ecology is "*the study of processes occurring across a spatially defined mosaic (landscapes) and the abiotic and biotic responses to those processes"* (Turner, 1989). The concept of landscape describes structure as *"the spatial relationship among distinct elements or structural components of the landscape; function as the interaction among spatial elements, and change – the temporal alterations in the structure and function of landscapes* (Bell *et al.,* 1997). Consequently, landscape ecology is not simply a science, but also an art for studying and influencing the relationship between spatial patterns and ecological processes on multiple scales (Wu & Hobbs, 2007).

While most if not all cities are regarded as having unstable relationships with the natural environment, cities can increase their sustainability, based on the understanding that urbanisation is part of the solution to regional and global sustainability (Wu & Hobbs, 2007). It is clear that sustainability is an important goal for the urban landscape, and therefore also for urban and landscape ecology. Sustainability includes an understanding of the relationship between spatial-temporal patterns of urbanisation and ecological processes (Wu, 2008).

Cities differ in terms of their diversity and the spatial arrangement of landscape elements and they represent different physical, ecological and socioeconomic processes and are designed and managed within and beyond their boundaries (Wu, 2008). Over many years and using different ecological perspectives, ecologists have studied the effects of the spatial patterns of urbanisation on ecological processes (Wu, 2008). The field of landscape ecology as a whole clarifies the relevance and importance for sustainability of landscaping during development (Mussacchio, 2009). Landscape ecology is a complex interdisciplinary science focusing on spatial heterogeneity; that is, a multi-scaled structure composed of a matrix of patches and gradients in space and time (Wu, 2006). The causes, consequences and degree of diversity of natural and cultural systems plays a key role in dealing with the theoretical and practical complexities of landscapes, where heterogeneity provides direction in finding solutions to the problems facing landscape sustainability (Wu, 2006). A landscape ecology focus integrates ecology with the social and economic functioning of the landscape and allows a better understanding of and solution to landscape management and planning problems (Wu, 2006). In landscape ecology, as the integrated science of landscapes, the issues of spatial heterogeneity, pattern-process relationships and scale can be powerful unifying concepts (Wu, 2006).

The focus of landscape ecology is thus on landscape pattern-process relationships, particularly forms, patterns and changes in the landscape (Turner, 1989). Landscape ecology assists managers of land in adopting an adaptive management approach to address and report on uncertainties through a "learning-by-doing" approach. Such an approach formulates management actions that allow for future adaptations (Ahern, 2011). Consequently, unexpected results require the design of alternative methods (Ahern, 2011). Landscape ecology takes a holistic and transdisciplinary approach to landscape studies and involves assessment, history, planning, management, conservation and recovery (Naveh & Lieberman, 1994). Recently, there has been a shift in landscape ecological research, from "plot-based" and "question-driven" to "place-based" and "solution-driven" studies with a transdisciplinary end (Wu, 2006). An urban green infrastructure provides a network of green spaces throughout the entire urban landscape and offers a transdisciplinary management approach in addressing sustainability and the building of resilience to avoid risk.

The emerging concepts of land-use and land cover change (LUCC) (Rindfuss *et al.,* 2005) have particular relevance for landscape ecology. These concepts form a critical component of SS and place a specific focus on the observation and monitoring of LUCC, assessing its impact on ecosystem processes and services, and understanding the mechanisms involved (Wu, 2006).

To conclude, it is essential for landscape ecology to focus on ecology since it is a "heterogeneous science of heterogeneity" (Wu, 2006). Heterogeneity and processes can be designed and artificially reconstructed through human assistance, which includes the removal of obstacles such as burning, and the enhancement of plant communities through the deposition of debris, the building of micro-catchments to capture water and nutrients, measures to develop niche diversity and the placement of perches for frugivorous birds (Clewell & Aronson, 2013).

2.5.1 Landscape structure

Landscape structure is a patch-corridor-matrix concept that explains the spatial pattern arrangement between patches (Forman & Godron 1986; Dramstad *et al*., 1996). Multiple landscape patterns offer one of the greatest opportunities for improving landscape performance (Lovell & Johnston, 2009b). Although a regional pattern for a patch-corridor matrix is not always obvious or continuous in highly fragmented anthropogenic landscapes, it can create a complex relationship between structure and ecosystem function from the level of local perspective (Lovell & Johnston, 2009b). The quality of a landscape matrix improves ecological performance, brought about by the design and maintenance of urban habitats such as heterogeneous parks, cemeteries and corporate/residential gardens (Lovell & Johnston, 2009b).

Human decisions are primarily responsible for changes in urban ecosystems and the creation of an urban matrix through the linkage of patches and corridors to form an urban green infrastructure (Alberti, *et al*., 2003). A green infrastructure is an interconnected set of natural and human designed ecosystems, green spaces and other features created by urbanisation that creates risk through changing landscapes and ecosystem dynamics (Alberti *et al*., 2003).

Alberti *et al*. (2003) believe that the greatest challenge facing ecology is the full and efficient integration of the complexity and global scale impact of human activity with ecological theory. Humans should be integrated with ecosystem science in order to define their impact on ecological processes (Alberti *et al*., 2003). Humans should also use their dominance to increase ecological and anthropogenic stability to manage resilience (Alberti *et al*., 2003). Urban ecosystem conditions should be evaluated in terms of the changing relationship that exists between diversity and stability, along a gradient of human dominance. This will help to clarify when diversity causes stability, and when it simply means unnecessary abundance of ecological roles created by imported invasive aliens (Alberti *et al*., 2003).

Emerging relations between humans and ecological patterns in urban areas must be addressed as urbanisation is multidimensional and highly variable across time and space (Alberti *et al*., 2003). The implications of interactions between social and ecological agents at landscape level have not as yet been explored; these should be investigated in order to influence and manage pattern-process dynamics positively.

2.5.2 Landscape pattern

The term landscape describes an assemblage of ecosystems and smaller landscape units while landscape pattern on the other hand, represents the repetition of recognisable units in space (Clewell & Aronson, 2013). Urban patterns originate from a combination of natural and engineered landscape elements such as vegetation, buildings and pavements (Cadenasso *et al.,* 2013). Human-dominated landscapes have unique biophysical attributes caused by the redistribution of organisms and the fluxes of energy and materials (Alberti *et al.,* 2003).

An urban design strategy that creates heterogenic patterns on all levels will positively affect the entire landscape pattern (Kolasa & Pickett, 1991). Urban design can create heterogenic patches by following the guidelines suggested by Fischer *et al*. (2006) to maintain biodiversity, ecosystem function and resilience through maintaining and creating:

(i) Large, structurally complex patches of indigenous vegetation

(ii) Structural complexity throughout the landscape

(iii) Buffers around sensitive areas

(iv) Corridors or stepping-stones, and

(v) Landscape heterogeneity, which includes the protection of rare and threatened species

The application of these pattern-orientated strategies will result in heterogeneous, productive sites within an arrangement through the landscape of large, structurally complex patches of indigenous vegetation (Fischer *et al*., 2006). Corridors and patched stepping-stones arranged in a matrix format will form a green infrastructure that connects different landscape patches, thereby retaining structural characteristics similar to those of indigenous vegetation (Fischer *et al*., 2006). Urban and natural ecosystems do not deliver the same quality ecosystem services; according to Alberti *et al*. (2003), they differ because urban systems have:

(i) A relatively low stability

(ii) Different dynamics on all temporal and spatial scales

(iii) More non-indigenous species

(iv) A simpler species composition that changes continuously

(v) A unique and more even distribution and absorption of energy (anti-entropic in the extreme)

Human actions directly affect land cover and therefore control biotic diversity, primary production, soil quality, water run-off, heat distribution and pollution (Alberti *et al*., 2003). The species diversity in urban areas consists of indigenous and exotic species and is highest at intermediate levels of urbanisation, but declines as urbanisation intensifies (Alberti *et al*., 2003; Cilliers *et al*., 2010). Land cover patterns change as the composition of the community changes, or where edge species are present, or in transitional zones of vegetation types (Marzluff, 2001). Humans and their designs also modify microclimate and air quality (Oke, 1988; Alberti *et al.,* 2003). The development of urban areas results in the creation of impervious surfaces, which has a direct impact on the geomorphological and hydrological processes that change fluxes of water, nutrients, and sediment (Leopold, 1968; Arnold & Gibbons, 1996; Alberti *et al.,* 2003). The impact that humans have on the environment requires that the decline in ecosystem structures and functions be monitored and managed (Alberti *et al*., 2003). Ecosystems are regarded as intact or whole if they display ecological integrity and health therefore, degraded, damaged, destroyed or transformed ecosystems all represent deviations from the normal or desired state of an undisturbed ecosystem (Clewell & Aronson, 2013).

2.5.3 Landscape processes

Hydrological catchments provide a framework to study landscape processes and integrate the hydrology of water cycling, geomorphic dynamics, soil formation and other processes (Band *et al.,* 2005). The concept of watersheds integrates numerous ecosystems, which interact with each other and display a measure of ecological cohesiveness in a given location (Lee, 1992; Pickett *et al*., 1997; Clewell & Aronson, 2013). Despite drainage patterns that have been modified in urban areas, a type of drainage system always remains when viewed from the course scale catchment perspective. The quality of urban landscape processes discloses the health of urban ecosystems and represents the degree of change caused by urbanisation (Pickett *et al*., 1997).

Fisher *et al.* (2006) suggest specific process-orientated management strategies to improve landscape processes and the quality of a disturbed landscape matrix. Their strategy includes the following aspects:

(i) Maintain key species interactions and functional diversity

(ii) Apply appropriate disturbance regimes

(iii) Control aggressive, overabundant and invasive species

(iv) Minimise threatened ecosystem-specific processes

(v) Maintain species of particular concern

Process-orientated strategies focus on the ability of an ecosystem to withstand external shocks and protect biodiversity and diversity within functional groups (Elmqvist *et al*., 2013). Keystone species are present and abundant and are species that have a disproportionate effect on ecosystem processes. The loss of these species usually results in a range of cascading changes in ecosystem function and resilience (Power *et al*., 1996). Management of species interactions and functional diversity requires maintenance of the important keystone species and identification of their key ecosystem processes (Fischer *et al*., 2006). Landscape changes can favour a number of indigenous or exotic species, allowing them to become abundant; these may affect other species negatively and even bring about the extinction of indigenous species. In order to protect and maintain natural biodiversity and the ecological functioning of the landscape, it is essential to control invasive species (Zavaleta *et al*., 2001).

2.5.4 Landscape dynamics

Landscapes contain patches of distinct habitats and ecologists use patches and patch dynamics to describe and quantify this heterogeneity in landscapes (Pickett *et al*., 2013). Patch dynamics explains the distribution of species, and patch fragmentation attributes such as size, shape and distance from the nearest similar habitat fragment, are important in explaining the landscape functioning of processes such as colonisation and the extinction of species (Pickett *et al*., 2013). Patches differ from one another in terms of hospitality towards organisms, soil nutrient levels, rates of infiltration of rainwater and temperature and land cover. Individual patches represent a combination of physical, chemical and informational conditions (Pickett *et al.,* 2013).

The spatial patterns between patches influence the ecological and social processes and the dynamics of urban ecological systems (Grimm *et al.,* 2000; Pickett *et al.,* 2013). The scale of patch functions varies and different patch configurations have different information and flow paths for resources (Grimm *et al.,* 2000; Pickett *et al.,* 2013). The landscape links river catchment areas of various sizes, and eventually links patches through green corridors to form the urban green infrastructure.

2.5.5 Landscape units

A land unit represents a patch or site; it is a portion of land that constitutes the smallest single landscape unit and is often intensively designed and managed (Chen & Wu, 2009). Landscapes are larger areas that encompass various kinds of natural and artificially made elements such as natural ecosystems and their fragments, gardens, roads, parks, rivers, residential areas and industrial areas (Chen & Wu, 2009). These landscape elements, known as patches and landscapes, are hierarchically structured patch systems with larger units composed of smaller patches (Chen & Wu, 2009).

Ecosystems and patches have open ecological boundaries that affect the greater landscape processes and dynamics directly (Pickett *et al*., 1997). Landscapes and patches are heterogeneous ecosystems and vary because of their diverse landscape patterns and sizes (Pickett *et al*., 1997). The flow of matter, energy, organisms and information to and from a patch is inseparable from the greater landscape and focuses on a bottom-up approach to link patch relationships with the urban green infrastructure.

A landscape unit is described and classified according to the degree of naturalness of the vegetation and soils; that such a classification is made in order to define the ecological condition and to assess the ecological values such as primary production, habitat, source of genes, topography of soils water and air (Bradshaw, 1983; Llausá & Nogué, 2012). Fragmentation of the landscape caused by human activity changes landscape patterns and ecological functions, leading to land degradation and loss of ecological condition and value (Llausá & Nogué, 2012).

2.5.6 Landscape functions identified as biodiversity and ecosystem services

Landscape functions are those biodiversity and ecosystem services (BES) that we receive from the landscape (Lovell & Johnston, 2009b.). Ecosystem service benefits are freely available to humans from natural resources but are unfortunately poorly appreciated (TEEB, 2010). As their true value as a natural asset to reduce risk does not form part of economic decision-making, the health of ecosystems is in decline (Ring *et al.,* 2012). The economic and social well-being of a society relies on the availability and quality of ecosystem services as additional or natural capital (Schäffler *et al*., 2013). Unsustainable urban development causes depletion and loss of biodiversity and ecosystem services (Wu & Wu, 2013) and such losses hold an increasingly physical and economic risk, and could result in damage to a city's cross-scale resilience, implying an ecosystem state shift into an alternative state, or even an irreversibly deteriorated state (TEEB, 2010).

Ecosystem services, delivered by natural and human dominated urban landscapes, have a positive impact on the quality of human health and deliver services far beyond the physical boundaries of where these services are located (Lovell & Johnston, 2009a). Because the urban environment is inevitably disturbed, it is vital that urban designers apply an ecological understanding to protect ecosystem services through their designs (Larson, *et al.,* 2013). "*Design as restoration in practice*" implies that recovery is in fact integral to the design of ecosystems (Larson, *et al.,* 2013). The focus on ecosystem services provides a new way of thinking about ecological design as the design of ecosystems (Van der Ryn & Stuart, 2007).

Responsible planners and managers have begun to recognise that natural ecosystem services are more resilient and sustainable than hard-engineering constructions (Palmer *et al*., 2014) and that efforts to improve landscape ecological performance in cities should include non-traditional methods such as ecological engineering (Lovell & Johnston, 2009a). An ecological approach based on ecological principles enhances ecosystem services through the design of urban sites that provide climate, biological and nutrient regulation, soil retention and aesthetic services.

2.6 Management of the landscape as a socioecological system

According to Ahern *et al*. (2014), adaptive management is a transdisciplinary method to manage constantly changing socioecological ecosystems along experimental design guidelines with the aim of improving and recovering ecosystems. Guidelines for experimentation and management include the use of assessment protocols to monitor progress together with strategies that recognise urban ecosystem services as part of urban development. In practice, an adaptive urban planning and design framework requires pre- and post-monitoring for consistent reporting on the successes of recovery efforts to achieve an ecologically improved condition (Ahern *et al*., 2014). Adaptive management supports innovation and rewards low-risk exposure in combatting environmental impoverishment (Ahern *et al*., 2014).

2.6.1 Goals and objectives of land condition management

A common goal of urban sustainability is only possible through transdisciplinary collaboration between planners and designers in standardising indicators and metrics through the sharing of best practices across cities (Ahern *et al*., 2014). A successful design and recovery effort uses ecological principles and practices to define landscape goals and objectives. These goals and objectives should focus on multiple landscape functions that maintain and support ecological production and cultural functions in the same site (Lovell & Johnston, 2009b).

Lovell & Johnston (2009b) encourage designers and restorers to aim for multiple targeted performance standards such as the following:

(i) Conserve and reduce energy

(ii) Provide food and habitat

(iii) Manage water quality and quantity

(iv) Reduce, re-use and treat waste

(v) Conserve and increase biodiversity

(vi) Meet visual quality expectations

(vii) Provide recreational facilities

2.6.2 Ecological integrity and condition as goal for a performance standard

Karr *et al*. (1986) proposed a direct relationship between stressors and integrity. The concept of ecological integrity is a benchmark for society against which to evaluate landscapes altered by humans. It sets a standard for managing human impacts on the environment (Karr, 1996). Ecological integrity suggests a meaning beyond human health and implies correspondence with some original condition (Karr, 1996). It is the sum of physical, chemical and biological integrity (Karr & Dudley, 1981). The complexity and integrity of a system indicates biological systems that have evolved over time through their ability to persist, showing that they are resilient to normal variation in that environment (Karr, 1996).

An evolutionary foundation ties the concept of ecological integrity to a benchmark that is the yardstick against which society can evaluate sites that were altered by human actions (Karr, 1996). The current ecological integrity or health of a site describes the historic land changes over time and implies the absence of significant human disturbances or alteration (Stoddard, 2006). Thus, ecological integrity as a benchmark to compare or assess human change to the environment is suggested as an expected background condition when evaluating anthropogenic stress. The reference condition is thus an expected background condition with no, or minimal, anthropogenic stress that can be used to quantify change (Kleynhans & Louw, 2007).

On the other hand, ecological health describes the land-use goal for a site affected by urbanisation or agriculture. Ecological health implies that an evolutionary sense cannot be the goal (Karr, 1996) because according to Karr (1996), healthy sites may still not have ecological integrity because of a lack of ecological history, but sites should not be contaminated, contain eroded soils, or contribute to the degradation of a landscape elsewhere.

The risk of land impoverishment is viewed as the probable potential for loss of species or functions from a system (Kleynhans & Louw, 2007). Biological integrity is the ability of a system to generate and maintain adaptive biota during the course of natural evolutionary processes where the loss of biological integrity indicates the loss of diversity and the destruction of processes necessary to generate future diversity and processes (Angermeier & Karr, 1994).

2.6.3 Evaluation of land cover changes to classify ecological condition

The ecological condition describes land cover in terms of its long-term potential to sustain landscape functions such as biodiversity and various ecosystem services (Trollope *et al*., 1990). Ecological condition defines the state of health and stems from the ecological status, resilience to soil erosion and the potential to sustain biodiversity and ecosystem services (Trollope *et al*., 1990).

Recovery projects aim to improve the ecological condition and focus on the return of human-impacted sites to a more natural condition or an unaltered state (Woolsey *et al*., 2007). The success of a recovery project must be evaluated in terms of the introduced landscape changes, project efficiency, optimisation of future management programs and public acceptance (Woolsey *et al*., 2007). Since changes affect the quality of the greater community, it is the responsibility of those who introduce these changes to the landscape to measure the changes, determine emerging trends, plan accordingly and to make adaptations to them (Steyn *et al*., 2003). Ecological recovery attempts to minimise ecological damage by managing disturbances.

2.6.4 Ecological design

Ecological design has the potential to convert the ecological condition of a site to its pre-existing or historic condition (Pickett *et al*., 2013). Ecological design integrates various disciplines in the built environment in the pursuit of sustainability by applying ecological principles to design and that ecological design proposes specific behaviour to minimise energy and material usage, reduce pollution, preserve habitats and promote community health and aesthetic value (Pickett *et al*., 2013).

2.6.5 Recovery of ecological response to become more sustainable

Ecology theory is the application of sound ecology theory to direct recovery efforts regarding ecological structure and functioning of ecosystems as part of the landscape (Bell *et al.,* 1997; Palmer *et al*., 1997). Landscape ecology is the study of ecological processes that take place across spatially defined landscapes and explains the abiotic and biotic responses of these processes, such as disturbances and organismal dispersal (Turner, 1989). Integration of landscape ecology in recovery projects is beneficial to the field of ecology since it provides practical solutions for recovery studies (Bell *et al.,* 1997). Sustainability and resilience studies focus on the evaluation of the integrated success or failure of a recovery project and include a spatial view of the recovery success and the environmental factors that modify and influence the flow of materials through a landscape (Bell *et al.,* 1997).

Bell *et al*. (1997) are of the opinion that landscape ecology strives to be quantitative and predictive and creates an opportunity to apply landscape ecological concepts that assess recovery projects with specific reference to habitat function and fragmentation. Although ecological recovery efforts benefit from applying landscape principles such as patch arrangements, there is still a need to identify landscape metrics in order to compare areas on a large scale (Bell *et al.,* 1997). A landscape ecological approach involves spatial heterogeneity with a variety of ecosystems and landscape structures in order to aid recovery efforts. Such an approach provides guidance in the selection of reference sites, the establishment of project goals and objectives and the definition of the spatial composition and configuration that paves the way for the recovery of flora and fauna (Bell *et al.,* 1997).

Dynamic attributes related to ecosystem structure and function contribute to the recovery of degraded ecosystems and set a standard for recovery of ecosystem function that meets the aim of sustainable recovery (Aronson *et al.,* 1993). The evaluation of a recovery effort should have a large-scale perspective provided by a landscape ecological perspective and therefore landscape principles provide quantitative information for recovery projects on habitat function and fragmentation with the aim of enhancing ecological integrity and health (Bell *et al.,* 1997).

2.6.6 Natural ecosystems as reference condition and standard for ecological recovery

The term ecology is a general concept for a natural system that takes account of the biological, hydrological and geomorphic aspects of an ecosystem and includes the system's dynamic state (Walker & Salt, 2012). Natural systems not only vary in abundance, composition of species and ecosystem functionality, but also in time and space (Walker & Salt, 2012). A dynamic state in ecology is a valid reference system with the expectation that a dynamic ecosystem shows resilience in responding to external disturbances through its potential to bounce back (Palmer *et al*., 2005).

Natural ecosystems vary in terms of geology, climate, vegetation, land-use history and species distribution, with considerable differences in the interpretation of the ecological performance of sites at various locations (Palmer *et al*., 2005). Historical information is used to establish prior ecological conditions for the evaluation of change in the ecological condition of a specific site and thus it is generally acknowledged that the historic condition has changed drastically and irreversibly over time as a result of natural and human disturbances (Palmer *et al*., 2005). In order to establish how degraded a system may be, it is important to know the present ecological state of a site which is the Present Ecological State (PES) and measured against the reference condition, which is the natural condition or an alternative, functioning ecological condition.

2.7 Ecological condition to recover after disturbance

The recovery response of an ecosystem depends on the quality of its remaining attributes, structure end functions to respond, representing the ecological integrity and health of an ecosystem (Clewell & Aronson, 2013). After an ecosystem was disturbed, the biophysical condition would initially recover and thereafter complex ecological processes such as self-organisation, resilience, self-sustainability would evolve (Clewell & Aronson, 2013).

Various recovery actions to manage the ecological condition of a site are discussed in this section. Ecological recovery provides the basis for the development of a site condition assessment tool that is the aim of this study. Three recovery approaches are recognised in improving the ecological condition of a site:

(i) Restoration

(ii) Rehabilitation

(iii) Reconstruction or best practice action

2.7.1 Restoration

The Society for Ecological Restoration (SER) defines restoration as "*the intentional alteration of a site to establish a defined indigenous and historic ecosystem. The goal of this process is to emulate the structure, functioning, diversity, and dynamics of the specified ecosystem."* Restoration is a process that assists recovery of a degraded or damaged ecosystem (SER, 2002). The US National Research Council (NRC) defines restoration as "*the return of an ecosystem to a close approximation of its condition prior to disturbance*" to emulate "a natural functioning self-regulating system that is integrated with the landscape in which it occurs" (Bradshaw, 2002). These two definitions have two different foci, with the SER definition concentrating on the process of restoration and the NRC definition emphasising the end-state, which is difficult to achieve in practice (Ormerod, 2003).

2.7.2 Rehabilitation

Rehabilitation implies human intervention to assist in the spontaneous recovery response of a damaged and blocked ecosystem in order to recover ecosystem productivity as quickly as possible (Aronson *et al*., 1993). The end-goal is an autonomous, self-sustaining ecosystem that recovers through the process of succession (Aronson *et al*., 1993).

2.7.2.1 Difference between restoration and rehabilitation

Covich *et al.* (2004) regard river restoration as assisting the recovery of ecological integrity in a degraded watershed system by the re-establishment of processes necessary to support the natural ecosystem of the watershed. A distinction between restoration and rehabilitation is clear in the technical and social constraints that often prevent “full” restoration of ecosystem structure and function, as rehabilitation focuses on the sources of system degradation, the re-establishment of processes and the replacement of elements, rather than treating symptoms to achieve a particular condition or static end-state (Covich *et al.,* 2004).

2.7.3 Reconstruction as best practice action

Best practice action, artificial reconstruction and remediation are general terms used to describe the recovery actions that deal with destructed land cover of a site (Bradshaw, 1983). Reconstruction requires human intervention by design to steer recovery caused by a new land-use with no relationship to its previous ecosystem structure or function (Bradshaw, 1983). The new site requires permanent human managerial input (Clewell & Aronson, 2013). In addition to human management, the land will require additional support such as energy, water and fertilisers (Aronson *et al*., 1993). Artificial reconstruction (Bradshaw, 1983) is a best practice action that allows a disturbed site to recover under novel conditions, although it indicates degradation and loss of complexity (Tuvendal & Elmqvist, 2012).

2.7.4 Reference condition for benchmarking

The reference condition is a standard of comparison and evaluation that compares the present ecological state with a historical condition, even if this is arbitrary (Stoddard *et al.,* 2006). The present ecological condition describes the original structure and functionality of an indigenous historic ecosystem and is indicative of the absence of significant human disturbance or alteration (Stoddard *et al.,* 2006). The concept of naturalness in recovering ecosystems to a close approximation of their original natural, self-sustaining and pre-disturbance conditions is constantly emphasised as the primary goal of restoration for naturalness emphasises the loss of species diversity as an indicator of human impact (NRC, 1992).

The reference condition reveals the degradation of the present ecological state which is the result of land-use by landowners and local inhabitants and provides a standard, yardstick, benchmark or point of reference that explains the present ecological state and its degradation (Stoddard *et al.,* 2006).

2.7.5 Natural ecological units as reference conditions

The characteristics of the vegetation of a site refer to "*the degree to which the present vegetation differs from a benchmark representing the average characteristics of a mature and apparently long-undisturbed stand of the same vegetation community*" (Parkes *et al*., 2003). The goal of a benchmark is to provide a consistent and logical reference point for "*naturalness*". The benchmark is set to reflect vegetation conditions before major ecosystem changes caused by significant human disturbances, to define the loss of quality and to direct recovery (Parkes *et al.,* 2003). The aim of the benchmark is not to return the vegetation to a former pristine or undisturbed state, but rather to gain a consistent site view of the historic habitat of former original species, including people (Parkes *et al*., 2003). In South Africa, the *Vegetation types of South Africa, Lesotho and Swaziland*, compiled by Mucina & Rutherford (2006), is used to describe and guide a regional benchmark.

The urban pattern of a site reflects vegetation cover, buildings and surfaces. Vegetation plays a vital role in the structure, function and dynamics of an urban ecosystem and contributes directly to the quality and quantity of ecosystem services and ecological functions of the urban green infrastructure that avoid risk (Pickett & Cadenasso, 2008). Urban design has a direct impact on the vegetation dynamics of a site, which generally decrease along the urban gradient from natural to artificial reconstruction (Pickett & Cadenasso, 2008).

Socioecological systems in urban environments are constantly changing as a result of human activities, indicating that a reference condition is guided by the condition of biological integrity and implies that an end-goal state is sometimes more realistic under severely disturbed conditions (Stoddard *et al*., 2006). Therefore, end-goal states can be historic, least disturbed, minimally disturbed or the best attainable condition and are referred to as requiring restoration, rehabilitation or a best practice action (Stoddard *et al*., 2006).

2.7.6 Ecological state and condition of natural ecosystems

The vegetation of natural ecosystems is primarily evaluated to ascertain the degree of modification by comparing the state of health of a given area with the state of health of a known standard or reference condition as the ideal condition to define the ecological state (Du Toit, 1995). The ecological condition of vegetation goes through various stages, culminating in a stage for primary production that leads to further improved soil fertility, a higher water infiltration rate and increased dry-matter production resulting from the availability of more water for plants (Du Toit, 1995). Such favourable conditions lead to improved species composition, improvement in the density of vegetation and ultimately improved carrying capacity (Du Toit, 1995).

2.7.7 Classification of the state and condition of socioecological ecosystems

Socioecological ecosystems in urban areas experience a combination of stresses and disturbances that cause structural and functional changes. It has become important to understand how these ecosystems change and what limits their performance (Pickett *et al*., 1997). The integration of social and ecological science focuses on ecological design to restore and recover ecosystems to a "best practice" state for urban systems and the degree of change from the natural ecological state defines the ecological response to recover the ecosystem structure and functions and to enhance ecological yield. The structure and function of an ecosystem determines the ecological condition, which can be classified as good, moderate or poor according to the ecological response to recover and enhance ecological yield to mitigate anthropogenic impacts. The following ecological responses have been identified to classify ecological response to recover the ecological condition of a site. The different ecological responses are based on the classifications of Vorster (1982) and Kleynhans & Louw (2007) namely:

(i) **Good**: slight modification with little or no discernible change in ecological condition

(ii) **Moderate**: moderate to considerable modification of ecological condition

(iii) **Poor**: extreme and severe modification of ecological condition

Classification of ecological condition to define ecological response to recover or restore is set out in *Table 2-1* to define ecological response to disturbance.

Table 2-1: Classification of ecological condition to define ecological response to recover (Vorster, 1982)

Ecological classification of condition	Ecosystem structure and function (Bradshaw, 1983)	Response available to recover (Bradshaw, 1983)	Reference condition or end-goal state
Good	Natural or nearly undisturbed ecosystem Ecological integrity and health	Secondary succession (recover / restoration)	Natural
Moderate	Natural soils with/without natural vegetation and	Primary succession (recover / restoration)	Natural

	presence of seed bank Some type of natural skeleton or structure		
Poor	Soils and vegetation destroyed	Best practise action / reconstruction	Artificial reconstruction
Very poor and degraded	Continuous deterioration of soils	Best practise action / reconstruction	Artificial reconstruction

The classification of the ecological condition of a project site is indispensable and is the first step in a pre- or post-ecological assessment to set realistic goals to recover anthropogenic disturbances. A index score that expresses an ecological condition with a value of above 80% is classified as good, 60–80% as moderate, between 40–59% as poor and less than 40% as very poor and degraded (Vorster, 1982; Kleynhans & Louw, 2007).

2.7.8 Summary

Multiple, diverse and interactive patches make up the spatially heterogeneous landscapes of cities. Ecological conditions and the value of patches vary as a result of design and recovery responses brought about by human activities. Urban ecology provides a scientific basis for integrated research to study urban patterns, processes and functions of ecosystems on multiple scales and has given increasing recognition to the importance of the relationship between urban spatial-patterns and ecological processes in achieving urban sustainability. The recovery of patches is the response to mitigate human impact on the environment and should be assessed by a standard pre- and post-evaluation to ensure that patches contribute to the dynamics of an urban infrastructure. In the following chapter, the criteria used to set a standard for ecological performance and to measure ecological value to determine risk are identified.

Spatial heterogeneity is an entry point to manage economic risk and from which to integrate social and ecological sciences in an urban environment (Grimm *et al*., 2000). Cities and ecosystems constantly expand and change; the how and why of changes in patterns places the focus on patch and landscape dynamics over time (Grimm *et al*., 2000).

Chapter 3: A standard for ecological condition

3.1 Introduction

In this chapter, criteria that constitute a standard based on principles to judge the ecological condition of a patch or site are identified and discussed. The ecological status reveals successful design and/or recovery of urban sites or can be expressed as the state of health of natural areas. The landscape ecological concepts discussed in *Chapter 2* (sections. 2.5.1 to 2.5.6) provide a background to what sustainable ecological condition entails. Ecological design and recovery aim to return ecological condition to a healthy state where there is ecological integrity; in certain cases, recovery to a pristine condition is only attainable over ecological time and indicates long-term ecological processes (Karr, 1996).

The following criteria, adapted from Palmer *et al*. (2005), are proposed to initiate a standard for ecological condition by which to measure the success of the design and recovery of project sites:

(i) Create a guiding image of the ecological condition that envisages a future dynamic end-state that is an improvement on, or maintenance of the current state

(ii) Plan and design to create an improved ecological condition that considers a patch as a fragment linked to the greater landscape

(iii) Improve the present ecological condition, making it more dynamic and responsive (adaptive and resilient) or maintain it

(iv) Take precautions to avoid any permanent damage to a patch and its surroundings

(v) Make an ecological assessment to determine the recovery success of the project, to management a site and to communicate this success

Although humans and their activities depend on biodiversity and ecosystems for the services that nature provides, human activities are still the main contributor to land and ecosystem degradation. The degradation of ecosystems presents a serious risk to the performance of the environment and should be prevented by avoiding the pollution of fresh water as a scarce resource and by encouraging businesses to provide products and services that have little impact on the environment (Hanson *et al*., 2012).

Furthermore, there is as yet no quantifiable or approved standard for land resource management that defines successful recovery of ecological condition and therefore, calls for the development of a methodology that consists of concise, measurable, robust and defensible landscape indicators that value ecological condition as natural capital (Ahern *et al*., 2014). Standard criteria should be identified to form a benchmark for judging the ecological condition and recovery success of site projects (Stoddard *et al*., 2006; MEA, 2005; NRC, 1992).

3.2 Criteria to evaluate ecological condition

The criteria to measure restoration success for rivers, suggested by Palmer *et al.* (2005), has been widely accepted as a base for advanced scientific research (Wohl *et al*., 2005; Gillian *et al*., 2005; Jansson *et al*., 2005). Successful recovery requires ecological time to return the site to its previous historic and undisturbed ecological condition, even though recovery to such a condition is usually not possible in the near future (Palmer *et al*., 2005). Recovery success implies an improved ecological state that contributes to increased landscape functioning (Clewell & Aronson, 2013). The recovery aim for all project sites should be to increase biodiversity and ecosystem services at local and landscape level (Palmer *et al*., 2005).

An overview of the recovery criteria to measure recovery success as provided by Palmer *et al.* (2005) is discussed below, with the aim of proposing a standard to appraise ecological condition and to assess recovery success.

3.2.1 A dynamic end-state goal guiding recovery image

The first step in improving ecological condition is to articulate a guiding image for recovery by visualising a future desired state as goal. A guiding image relates to a pre-existing, healthy and dynamic state of a reference condition as an end-state but, unfortunately, over time many changes are made that alter the present land cover, hydrology and climate and distort the guiding image (Palmer *et al*., 2005). Consequently, a guiding image could mean a desired or acceptable condition, implying some level of human disturbance and a lack of ecological integrity and health (Clewell & Aronson, 2013).

Ecological response to recover, i.e. resilience is lost as a result of human activities such as the removal of pristine vegetation, the loss of the seed bank, the construction of buildings that cause obstructions and create different microclimates, the installation of impervious surfaces and the introduction of exotic species (Palmer *et al*., 2005). Available realistic ecological response has become important to define realistic end-state goals to guide recovery in order to improve the condition, rather than to choose the natural condition as the end-goal state. A newly desired condition will be a dynamic ecological end-state achievable within a given regional context, vegetation unit or biome (Middleton, 1999; Choi, 2004; Suding *et al*., 2004; Palmer *et al*., 2005). A realistic reference condition would then be not a historic condition with no or minimal anthropogenic stresses, but an improved future desired state.

Alternatively, in areas where information on the historic condition is lacking or where realistic end-state goals differ greatly from a previous historic condition, recovery goals and objectives are formulated according to available information from a neighbouring, undisturbed or previously recovered site (Rheinhardt *et al*., 1999; Palmer *et al*., 2005). The dynamics and ecological integrity of the larger region contribute and assist in the recovery success of ecologically disturbed fragments through the ecological value added by enhancing diverse indigenous species (Holling & Meffe, 1996; Hughes, 1994; Pickett *et al*., 1997).

The primary objective of ecological recovery is to conserve biodiversity, ecosystem structure, functions and dynamics. Recovery can take the form of restoration or rehabilitation and depends on the degree of degradation at the start to guide the recovery action (Aronson *et al*., 1993). The guiding image describes the potential structure, ecological functioning and dynamics of the desired condition as a fragment within a given location and is unique to every project (Palmer *et al*., 2005). The landscape position of a site-project is viewed as a local fragment, but when viewed from a different geographic scale it becomes part of the larger landscape (Walker & Salt, 2012). The proposed guiding image has dynamic features and is not a static condition to be reached in the near future; rather, it is a move away from the present negative trend towards a progressive recovery trajectory that creates opportunities for reorganisation of biota (Pickett & White, 1985). Social values influence and guide recovery through people's perspectives on, and tolerance for, damage done to the environment (Carreiro & Zipperer, 2011).

Lovell & Johnston (2009b) have suggested a landscape design approach to create multifunctional landscapes that improve the ecological condition of the landscape and which are achieved by linking different sites through their designs to integrate ecological, cultural and production functions within the greater landscape. Such an approach requires an understanding of landscape functions or ecosystem services in order to enhance the entire urban ecosystem (Lovell & Johnston, 2009b).

3.2.2 Area-specific project planning and design for the larger landscape

Many factors determine successful recovery of a project site since it is a fragment of the greater landscape because of its spatial position that determines the recovery response to improve its condition (Palmer *et al.*, 2005). The spatial position of a site in relation to the landscape provides an opportunity to measure and monitor multifunctional performance and according to Lovell & Johnston (2009b), the ecological condition improves when the diversity and dynamics of the landscape increases when:

(i) Heterogeneity is enhanced and increases

(ii) Indigenous vegetation is re-established

(iii) Alien invasive species are removed

(iv) Habitats are enlarged

(v) Soil fertility is improved

(vi) Water use is reduced

(vii) Biota movement is increased throughout a site

Heterogeneity, connectivity and biodiversity are indicators of ecosystem functionality and their prevalence is an indication of good condition (Lovell & Johnston, 2009b). Ecological condition is a complex concept and therefore it is impractical and almost impossible to monitor the detail of every impact (WRC, 2001).

3.2.3 Ecological response to recover

Resilience is an important and complicated component of recovery response and for this reason, indicators are used as smaller components of ecological condition in order to discuss and explain its meaning and because resilience cannot be measured directly (Walker & Salt, 2012). Ecological condition is considered to be good when the recovery takes place through self-organisation and by becoming more self-sustaining, which is in contrast to a condition that requires on-going human intervention to prevent decline (Parkes *et al*., 2003). However, since ecological condition is a multifaceted concept, it is broken down into indicators that define and describe design and recovery elements as instruments to measure and manage the symptoms and risks arising from a specific ecological condition (WRC, 2001). Parkes *et al*. (2003) support the use of indicators as tools to measure ecological performance and recommend their development for assessments in the future.

Indicators are used, ideally in a quantitative manner, as specific measurements to monitor and assess ecological condition when large amounts of complex and detailed information are captured in a simple, understandable and manageable format (WRC, 2001). Not all indicators in a site are in the same ecological state, however, and some may be more degraded than others, with less response to recover (Palmer *et al*., 2005). Indicator metrics are indicator-specific and their recovery ratios vary, with some recovering sooner after a disturbance such as erosion; some, such as biodiversity loss, may take decades to recover (Palmer *et al*., 2005). Indicators are satisfactory when they measure and describe stress and disturbance and, where necessary, they indicate when to stop development and when to acknowledge that conservation would be a better choice than development (Palmer *et al*., 2005). An ecologically sound recovery response should always be the best management choice, even where conservation has failed and crucial ecological services are declining (Dobson *et al*., 1997; Ormerod, 2003; Palmer *et al*., 2005).

An ecological condition recovery is successful for a project when the end-state objectives have been achieved, the desired ecological condition has been attained and when the desired condition always considers the structure and function of the land cover of an ecosystem (Palmer *et al*., 2005). Palmer *et al*. (2005) categorise landscape indicators to measure recovery success according to two adaptive indicator characteristics that strive to:

(i) Move away from a degraded state, which is the improvement of habitat relative to a pre-disturbed ecological condition

(ii) Attain some desired ecological condition, which places the habitat condition closer to, or returns it to an unmodified condition that matches the reference site

The ecological condition improves when moving towards the end-state goal identified as the guiding image and with the acknowledgement that the image is not a single end point in an end-state. Recovery response is an adaptive process along a predefined trajectory towards the goal of achieving broader ecological and societal objectives aimed at improving ecological condition (Palmer *et al.,* 2005). In general, larger undisturbed patches are more responsive, being dynamic and adaptive as a result of their potential for being self-sustaining and resilient that enhances the recovery process and smaller disturbed patches have larger edge-to-interior ratios and require additional human assistance to recover and control external impacts such as invasive alien species (Palmer *et al*., 2005). Recovery success aims at an ecological condition with indigenous plant communities and natural recovery responses, which might be a long-term objective and not always an immediate reality (Carreiro & Zipperer, 2011).

3.2.4 A precautionary approach to preventing environmental harm

In 1948 Aldo Leopold was a leader in the field of ecological recovery and recognised prevention as the first recovery response rule in his philosophy “to do no harm” to the environment. He promoted sound management practices in a moral and aesthetic sense to encourage the protection of species and areas of significance (Ormerod, 2003). According to Chen and Wu (2009), Leopold advocated new land ethics to promote “a state of harmony between man and land”. He was the first to recognise integrity from a biological and ecological perspective, even though he failed to explain what he meant by this (Cairns, 1977). He promoted the protection of ecological integrity, stability, biological communities, community structures and functional characteristics of a particular locality (Noss, 1990).

Adaptive ecosystems are not static and are characterised by changes of demography, biotic interactions, nutrient and energy dynamics and meta-population processes as expected in the natural habitat of a region that has ecological integrity (Angermeier & Karr, 1994; Frey, 1975; Karr & Dudley, 1981; Karr *et al*., 1986). Thus, *ecological integrity* refers to complex ecosystems with indigenous species able to change and adapt over time. It implies that human activities have an effect on the abundance of species and that ecological integrity must be protected in urban areas through the presence of undisturbed areas that indicate good ecological condition (Karr, 1996).

Ecological health is a different concept and refers to well-being, vitality and prosperity with healthy resilient organisms that ensure healthy functional performance (Karr, 1996). Good health suggests an ecological condition that has natural recovery responses and requires limited human assistance, such as the control of fires or the deposition of debris to slow water flow (Karr, 1996). Ecological health describes the end-state objectives identified for an ecological condition however, it does not necessarily protect ecological integrity in an evolutionary sense since the end-goal objectives might not be the state of a previous historical condition (Karr, 1996). According to Karr (1996), a healthy ecological condition presents a state that DOES NOT:

(i) Cause land degradation on the site or any neighbouring sites

(ii) Contribute to soil erosion

(iii) Reduce productivity

(iv) Deplete groundwater

(v) Pollute

The biological condition gradient model proposed by Stoddard *et al.* (2006) explains the stress of human activities on the structure and function of the ecological condition of a site. The ecological condition of a site is shown along a gradient. *Figure 3-1* explains the gradient of stress as degraded, damaged or destroyed to imply that the natural condition is not always a realistic end-state goal. The end goal state of each site is indicated in the green blocks. The reference condition shows three altered site structures and functions as degraded, damaged or destroyed.

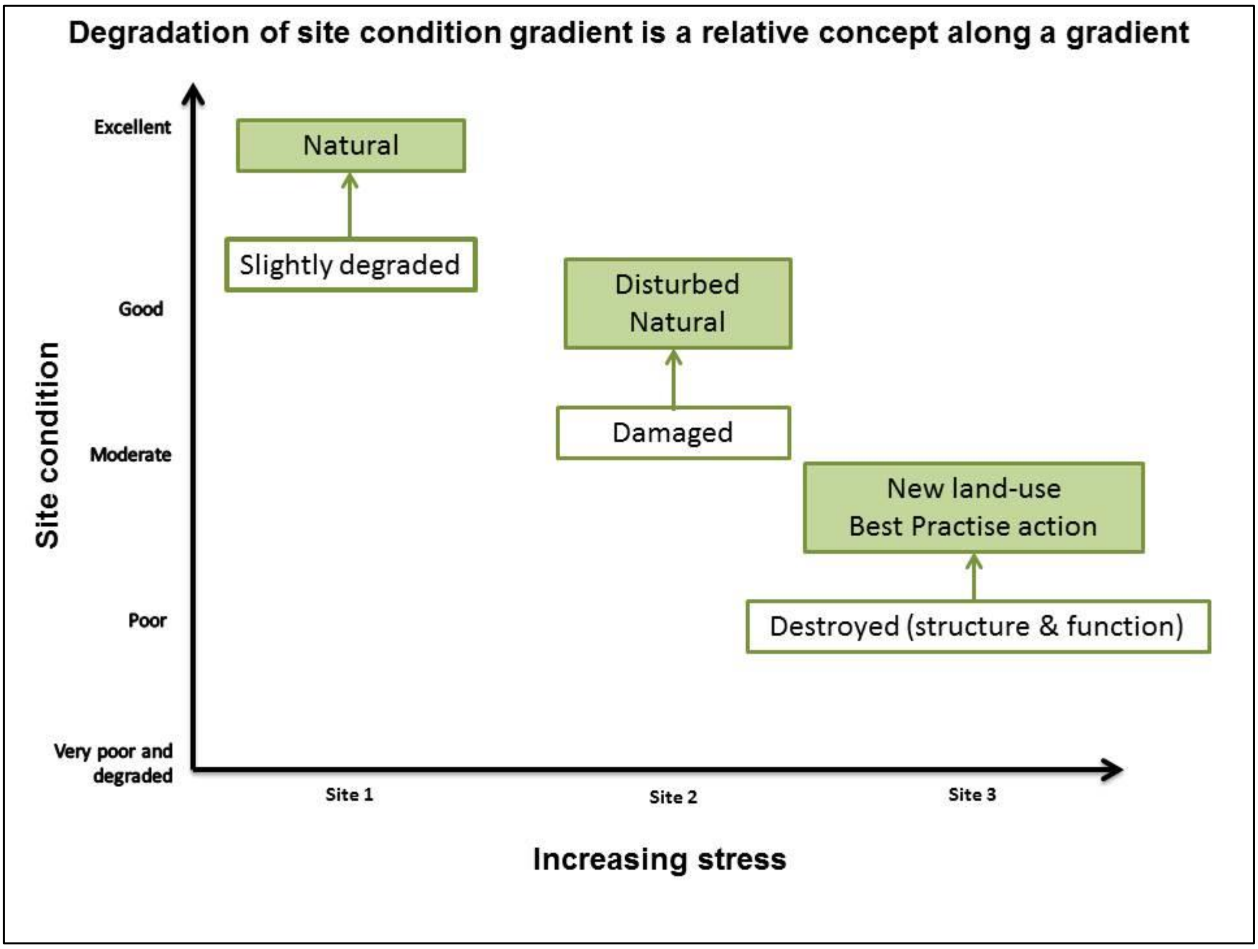

Figure 3-1: Site condition gradient of stress as adapted from Stoddard *et al.* 2006

3.2.5 Assessment of ecological condition to communicate recovery success

The identification of site project objectives at the beginning of a recovery project is essential in measuring recovery success to mitigate human impacts after completion of the project and to improve the ecological condition in future (Dahm *et al*., 1995). A standardised protocol is required to adjust the concept of sustainable ecological condition in order to set a standard to collect and store sound scientific information in a database for reporting (Lovell & Johnston, 2003b).

Sustainable management reports should include recommendations for the improvement of the sites's ecological condition if they are to be meaningful and should provide a guide for the sustainable management of recovery in future (Palmer *et al*., 2005). Even though site assessments are a critical component of recovery projects, recovery success does not require that all project goals are always met and although a universal assessment tool to measure and manage the ecological condition of sites is still lacking, such a tool needs to be developed. A tool to assess the ecological condition will be used to measure recovery success and to manage the environmental performance of a site according to an acknowledged sustainability standard (Palmer *et al*., 2005). Ecological data is fundamental to the site design and recovery in order to classify and identify the ecological condition as natural or artificially reconstructed in the context of the degree of modification. Although planning and design objectives for ecosystem recovery are fundamentally a social decision, it is important to emphasis that ecological recovery success as suggested in the site condition assessment is indicative of the performance success of achieved ecological goals (Palmer *et al*., 2005).

3.3 Ecological response to guide realistic recovery end-goals

Ecological response comprises mostly hidden actions of self-organisation and resilience on a site and guides the recovery plan and design by interpreting the structure and function of the vegetation and soil (Bradshaw, 1983; Holling, 1996; Palmer *et al*., 2005; Walker & Salt, 2012). The structure and function of vegetation and soils identify realistic recovery actions to assist and set realistic end-goals as guidelines for the recovery process and entail the following aspects:

(i) Use the available ecological response to classify the existing vegetation and soil or state as one of three categories, namely natural, near-natural or a new land-use with novel condition

(ii) Use these categories to define the action as recovery which can be an act of restoration, rehabilitation or artificial reconstruction / best practice) (Bradshaw, 1992; Walker & Salt, 2012)

(iii) Determine the reference condition or end-goal state as one of three states, namely historic natural condition, near-natural condition or transformed condition that requires reconstruction, which is novel condition that mimics nature (Karr, 1996; Palmer *et al*., 2005)

(iv) The ecological response hidden in vegetation and soil classifies recovery actions as natural, through primary or secondary succession, or ecological design as best practice action to mimicry nature (Bradshaw, 1992; Holling, 1996; Walker & Salt, 2012)

(v) Realistic recovery goal objectives should be clearly identified as a future end-goal state (Palmer *et al*., 2005)

Realistic recovery end-goals are set out in *Table 3-1* to manage ecological response to recover.

Table 3-1: Classification of the structure and function of vegetation and soil to describe recovery

Vegetation identity (structure and function) (Holling, 1996; Karr, 1996; Walker & Salt, 2012)	**Ecological / vegetation condition (Holling, 1996; Karr, 1996; Walker & Salt, 2012)**	**Manage ecological response with hidden recovery actions as end-state objective (resilience and self-organisation) (Bradshaw, 1983)**	**Reference condition or end-goal state (Bradshaw, 1983)**
Natural (original structure)	Slightly degraded	*Restoration* Secondary succession Sustain spontaneous natural ecosystem recovery	To recover to a pristine condition
Disturbed natural (skeleton of original structure and function)	Damaged	*Rehabilitation* Primary succession Assist spontaneous recovery Recover damaged or blocked ecosystem functions	To recover to a near-natural condition
New land-use (less than 10% of original vegetation structure)	Transformed land-cover and soil	*Ecological design or design by nature* *Reconstruction* *Best practice action (BPA)* Artificial reconstruction to create a new novel ecological condition Mimic structure and function of a natural historic ecosystem Increase biodiversity and improve function efficiency	To create ecosystem structure and function as a novel condition to mimic nature / natural condition

Anthropogenic disturbances have a severe impact on the ecological condition of a site, especially during the implementation phase. This leads to further (interim) degradation; responsible recovery therefore implies that the ecological condition is placed on a trajectory to improve after completion of a project (Palmer *et al*., 2005). A degraded and transformed ecological condition needs ecological design as a best practice action that mimicry nature as a response in order to recover the biodiversity and ecosystem function efficiency, and to avoid further degradation such as sedimentation of the hydrologic infrastructure of the larger landscape (Bradshaw, 1983; Grimm *et al*., 2000). Furthermore, an allowable or “acceptable state” for ecological condition portrays the cultural values of a society and finally results in the quality of socioeconomic decision-making and urban functioning on various temporal and spatial scales (Carreiro & Zipperer, 2011).

3.4 Summary

Criteria for measuring recovery success were discussed in this chapter. These criteria provide an ecological perspective from which to turn formerly hard engineering solutions into an ecologically based recovery response (Palmer *et al*., 2005). A standard protocol should be developed to assess the ecological condition of a site, not only to determine which recovery goals have been met after human intervention, but also to ensure objective assessment and comparable reporting (Palmer *et al*., 2005).

Chapter 4: Identification of multiple indicators to assess and quantify ecological condition

4.1 Introduction

The aim of this chapter is to identify multiple indicators that reflect changes to a site caused by humans. A biological index identifies indicators that describe an ecological condition as actions that can be measured to provide informed data as an essential foundation to determine risk and to manage end-states on different ecological levels (Karr & Chu, 1997). The measured end-states of the indicators and the ecological value of the assessment indicate the biodiversity and ecosystem services that a society seeks to protect (Karr & Chu, 1997). In this study, these indicators were identified by integrating the goals and objectives of two interrelated disciplines, landscape planning and design and landscape ecology, into multiple indicators to assess the ecological condition of a site and to link ecological performance with landscape attributes.

4.2 Goals to assess and quantify the ecological condition of a site

Three management goals recognised by Tainton (1999) for the management of range condition were used to formulate recovery goals to manage the ecological condition of a site as a deviation from a reference condition. These were sometimes achievable only through ecological (geological) time. Management goals identified by Tainton (1999) are:

(i) Evaluate ecological condition of a site relative to its ecological condition potential, with consideration of the historic vegetation type, to guide managers in decision-making to establish the appropriate recovery response

(ii) Evaluate the suitability of current management practices, including management of change over time, in order to plan how to adapt to these changes

(iii) Identify and describe vegetation cover and quantify site condition to respond to human impacts

4.3 Index method to assess site condition

Landscape ecological indicators describe factors and processes that are relevant to sustainable site management in practice and that should be monitored (SER, 2002). Such indicators are instruments to manage landscape goals and objectives that support biodiversity and ecosystem services (SER, 2002). The present ecological status of the site in this study was evaluated by the index, which comprises:

(i) Standard ecological indicators that describe ecological condition and are individually evaluated by the assessor to quantify human impact

(ii) A landscape ecological metric for each indicator as a broad guideline for scientific correctness and objective assessment by different assessors

(iii) Reference condition as the ideal and realistic condition for benchmarking the present condition of an indicator

(iv) An ecological condition score as a percentage to classify the ecological condition as good, moderate or poor or degraded

The Ecological Landscape Framework (ELF) was the result of linking ecological and landscape ecological concepts to identify socioecological indicators to manage landscape goals and objectives to justify the impact of human activities on the ecological condition of a site (Llausás & Nogué, 2012). The index integrates multiple indicators to assess ecological condition and to identify change caused by human activities (Karr & Chu, 1997). Socioecological indicators were identified by linking the following concepts in the framework:

(i) Ecological condition attributes to manage ecosystems

(ii) Landscape ecological concepts

(iii) Landscape goals and objectives on different levels

(iv) Biodiversity and ecosystem services goals and objectives

(v) Landscape goals and objectives

The different socioecological concepts are discussed in the sections below.

4.3.1 Ecological condition attributes to manage ecosystems

Ecosystems are communities where the biotic (living) and abiotic components (air, water and soil) interact and they are linked through nutrient cycles and energy flows (Dale *et al*., 2000). Urban ecosystems are fragmented by human activities and differ greatly in size, causing a decrease of functionality and dynamics within a larger ecosystem (Leitǎo & Ahern, 2002). Components of the ecological condition of a project site are illustrated schematically in *Figure 4-1* below and listed thereafter.

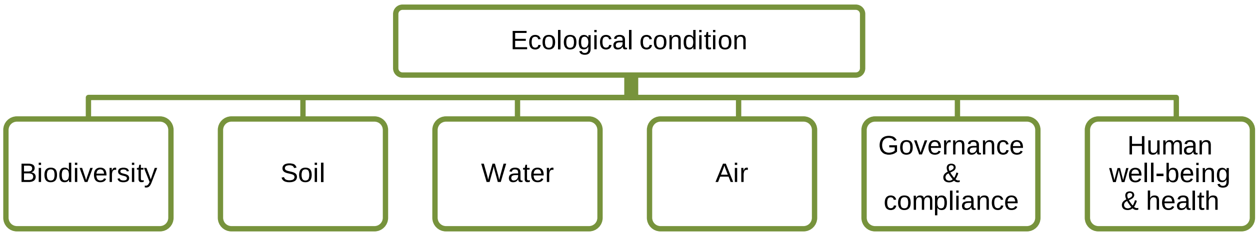

Figure 4-1: Components of ecological condition (Source: Author)

Ecological condition is described and defined by the following ecosystem attributes drawn from various scientific studies:

(i) Biodiversity (Leitão & Ahern, 2002; Fischer *et al*., 2006; Wu, 2008; Ahern 2011; Pickett *et al*., 2013)

(ii) Soil (McHarg 1981; Tainton, 1999; Karr, 1996; Pickett *et al*., 2013)

(iii) Water (Tainton, 1999; Leitão & Ahern, 2002; Alberti 2005; Pickett *et al*, 2013)

(iv) Air and energy (McHarg 1981; Alberti 1996; Wu 2008; Stoffberg *et al*., 2010; Pickett *et al*., 2013)

(v) Governance and mitigation (risk avoidance) strategies (Leitão & Ahern, 2002; TEEB, 2010)

(vi) Human health and well-being (Leitão & Ahern, 2002; TEEB, 2010)

4.3.2 Landscape ecological concepts

The field of landscape ecology deals with the interrelationship between urban landscape patterns and socioeconomic processes that pose risks to ecology of various scale and encourage place-based research to develop urban sustainability (Wu, 2008). Landscape transformation creates opportunities for integrated landscape design and management to improve the quality of a landscape matrix by promoting spatial heterogeneity and multiple ecosystem services (Lovell & Johnston, 2009b). Multi-functionality is a strategy to enable sustainable landscapes dominated by humans to provide ecosystem services (Lovell & Johnston, 2009b).

Leitão & Ahern (2002) developed a conceptual framework of landscape ecological concepts and metrics for application in sustainable landscape planning. The following landscape ecological attributes and management processes drawn from the work of Leitão and Ahern (2002) are used in this study as the foundation for linking different landscape ecological aspects within a framework (see Table 5.2):

(i) Landscape structure

(ii) Landscape processes and functionality

(iii) Landscape changes

(iv) Landscape stability

(v) Water cycling and movement

(vi) Energy capturing

(vii) Monitoring as precautionary action

(viii) Human health and well-being

4.3.3 Landscape goals and objectives on different levels

Landscapes are intentionally designed to enhance ecological performance; it is thus important to assess and monitor the success of recovery in meeting these goals (Lovell & Johnston, 2009b). In the urban context where land cover has been destroyed, recovery not only aims to reconstruct a novel ecological condition but also to enhance ecosystems to recover healthier ecosystem functioning such as storm water management, sediment retention, biodiversity increase and carbon cycling enhancement (Palmer *et al*., 2014).

It is necessary to quantify ecological condition at the local and landscape level in order to monitor mitigation strategies with recovery objectives to mitigate disturbances. This study identified the following integrated goals, originating from landscape ecology and ecology, in recovering ecological condition:

(i) Maintain ecological integrity and health (Karr, 1996; Holling & Meffe, 1996; Leitǎo & Ahern; 2002; Stoddard *et al*., 2006; Shu-Yung *et al*., 2004; Clewell & Aronson, 2013)

(ii) Protect indigenous vegetation (Power *et al*., 1996; Alberti *et al*., 2003; Zavaleta *et al*., 2001; Leitǎo & Ahern, 2002; Fischer *et al*., 2006; Elmqvist *et al*., 2013)

(iii) Adapt to changes through heterogeneity, self-regulation, resilience and redundancy (NRC, 1992; Bell *et al*., 1997; Leitǎo & Ahern, 2002; Shu-Yung *et al*., 2004; Tuvendal & Elmqvist, 2012; Walker & Salt, 2012)

(iv) Maintain landscape connectivity (Leităo & Ahern, 2002; Alberti *et al*., 2003; Palmer *et al*., 2005; Fischer *et al*., 2006; Ahern, 2011)

(v) Secure the ecological functioning of processes (e.g. pollination, seed dispersal, entropic levels, succession, life cycles (Bell *et al*., 1997; Leităo & Ahern, 2002; Wu 2008; Alberti *et al*., 2003; Wu 2010; Ahern, 2011)

(vi) Recover and reconstruct habitat diversity (Karr, 1996; Leităo & Ahern, 2002; Lovell & Johnston, 2009b; Alberti *et al*., 2003; Pickett *et al*., 2013)

(vii) Store and protect gene pool (Karr, 1996; Grimm *et al*., 2000; Leităo & Ahern, 2002; Pickett *et al*., 2013)

(viii) Maximise use of water resources (Leopold, 1968; Leităo & Ahern, 2002; Pickett *et al*., 2013, Palmer *et al*., 2014; Ahern *et al*., 2014)

(ix) Protect soil and prevent soil contamination (Arnold & Gibbons, 1996; Leităo & Ahern, 2002; Alberti *et al.*, 2003; Palmer *et al*., 2005)

(x) Protect water and improve water quality (Leităo & Ahern, 2002; Band *et al*., 2005; Lovell & Johnston, 2009b; Pickett *et al*., 1997; Alberti *et al*, 2003; Clewell & Aronson, 2013)

(xi) Maximise use of rainwater (Leopold, 1968; Alberti *et al*, 2003; Pickett *et al*., 2013; Clewell & Aronson, 2013)

(xii) Inhibit evaporation (Karr, 1996; Leităo & Ahern, 2002; Pickett *et al*., 2013; Palmer *et al*., 2014)

(xiii) Protect and maximise land cover's absorption of energy (Leităo & Ahern, 2002; Wu 2008; Lovell & Johnston, 2009a; Pickett *et al*., 2013)

(xiv) Protect and improve air quality (Leităo & Ahern, 2002; Lovell & Johnston, 2009b; Alberti *et al*., 2003; Wu, 2008; Pickett *et al*., 2013)

(xv) Regulate climate (Ole, 1988; Lovell & Johnston, 2009a; Wu, 2008; Alberti *et al*, 2003; Pickett *et al*., 2013)

(xvi) Prevent damage (Leopold, 1968; Karr, 1996; Leităo & Ahern, 2002; Pickett *et al*., 2013; Alberti *et al*., 2004)

(xvii) Create a sense of place (Chen & Wu, 2009; Lovell & Johnston, 2009a; Lovell & Johnston, 2009b)

4.3.4 Biodiversity and ecosystem services goals and objectives

Ecosystem services comprise the material and nonmaterial benefits that humans derive from ecosystems and therefore ecosystem goals are identified in order to protect natural resources that deliver these services (UN, 2005). Planning for the design of sustainable project sites should aim to sustain and protect natural resources by supporting and maintaining ecosystem services (UN, 2005). The goals of the ecosystem are to provide, regulate, support and maintain services that should be protected as natural resources and green capital which has economic value (UN, 2005). A list of biodiversity and ecosystem objectives is reflected in *Table 4.1*.

Table 4-1: A schematic outline of goals and objectives for biodiversity and ecosystem services (BES)

Biodiversity and ecosystem services goals and objectives*	
Goal	**Objective**
Provide	Food Raw materials Fresh water
Regulate	Local climate Air quality Carbon sequestration and storage Moderation of extreme events Waste-water treatment Erosion control Maintenance of soil fertility Pollination Biological control
Support	Habitat for species Maintenance of genetic diversity
Cultural behaviour	Recreation Mental and physical health Tourism Aesthetic appreciation Inspiration for culture, art and design

* Adapted from The Economics of Ecosystems and Biodiversity (UN, 2005)

4.3.5 Landscape goals and objectives

Multiple indicators are instruments to describe and measure complex concepts such as ecological condition, which are individually assessed to calculate the overall ecological condition of a specific site (Parkes *et al*., 2003). The state of the indicators is individually evaluated to measure human impact in a quantitative manner that provides scientific data also for informed decision-making where large amounts of detailed information on ecological conditions are captured in a simple format (WRC, 2001). Indicators are assessed guided by specific metrics to generate in the long-term, meaningful, sound scientific information on ecosystem functionality and ecological integrity (Woolsey *et al*., 2007). Landscape indicators provide a basis to interpret pattern-process relationships by characterising landscape functioning, human activities and impacts influencing ecological condition (Leităo & Ahern, 2002).

It can be challenging to select the most suitable indicators for an index as a standard to define ecological condition. The landscape objectives should be clearly defined at the start of a project if they are to be used for benchmarking against the reference condition or recovery end-state goals (Woolsey *et al.,* 2007). The purpose of indicator identification in this study was to generate direct and practical information that would also be accurate and clear. The study identified 44 ecological indicators indicative of nine landscape goals representing ecological condition. The intention of landscape goals and objectives is to improve ecological performance through practical assessments and monitoring. *Table 4-2* below lists the landscape goals and objectives as ecological indicators for evaluation and monitoring of landscape and ecological performance.

Table 4-2: Landscape goals and objectives

Landscape goals	Landscape objectives (Leităo & Ahern, 2002), also known as ecological indicators
Heterogeneity of land cover	1. Diversity of tree species 2. Diversity of shrub species 3. Diversity of ground cover species 4. Site pattern – vertical 5. Site pattern – composition and configuration
Habitat diversity	6. Habitat for food 7. Habitat for water provisioning 8. Habitat as wetland 9. Habitat as open areas 10. Habitat for shelter 11. Habitat as forest floor 12. Habitat for recreation 13. Movement routes

Landscape dynamics	14. Decomposition process 15. Internal ecosystems linkage 16. Natural disturbance dynamics 17. Wildlife 18. Exotic predation
Landscape changes	19. Landscape matrix dynamics 20. Fragmentation of the landscape 21. Movement of species 22. Microclimate adaptations to change 23. Land degradation 24. Heterogeneity
Soil stability	25. Indigenous vegetation cover 26. Source of genetic diversity 27. Soil porosity 28. Slope management to prevent erosion 29 Topsoil richness 30. Prevention of soil pollution
Fresh water	31. Water quality 32. Water quality discharge from site 33. Harvesting of rainwater 34. Water conservation 35. Surface quality 36. Canopy cover 37. Water management
Capture and radiation of energy	38. Land cover absorption 39. Avoidance of heat islands 40. Carbon storage and sequestration
Governance and mitigation	41. Endorsement of greater environmental responsibility 42. Precautionary measures
Human health and well being	43. Naturalness and integrity 44. Innovation

4.4 Indicator rating: awarding a rate and a weight value

The ecological condition of indicators is evaluated through standard measurements and metrics that are broadly identified as guidelines to quantify the overall change of landscape patterns and functions caused by human activities (Uuemaa *et al*., 2012).

4.4.1 Ecosystem attributes to rate indicators

Holling (1996) identified two contrasting features with which to describe ecosystem stability and the potential of an ecosystem to lose resilience before changing to an irreversible state (Holling, 1986). A shift within an ecosystem reduces ecosystem variability and causes the loss of ecosystem structure and functionality, resulting in a decline in resilience and in the ability of an ecosystem to absorb disturbances. The two features identified by Holling (1996) to cause a shift are:

(i) ***Ecological resilience*** to maintain the existence of ecosystem function (functional)

(ii) ***Design resilience*** to maintain the efficiency of ecosystem function (response to recover)

This study applied these two features to rate the ecological indicators of the index in order to measure the effect of human disturbance on the ecological condition, according to the reference condition that is required for comparison and includes some measure of biological or ecological impact (Rykiel, 1985). The reference condition states an optimal condition or pre-existing state with no or minimal anthropogenic stress (Rykiel, 1985). Human intervention can assist ecological recovery by creating site stability; for this reason, ecological condition is assessed by using easy to measure and interpret indicators that express the degree of degradation (Angermeier & Karr, 1994). Human intervention is an intentional action taken to recover ecological condition and to assist a self-sustaining system to return to a state as similar as possible to the indigenous biota, although this is not always possible (Angermeier & Karr, 1994). Ecological and design resilience hold different consequences for evaluating, understanding and managing change (Holling, 1996).

4.4.2 Indicator rating and weighting

The concepts of ecological and design resilience are used in this study to allocate a rate and weight value to an indicator. An indicator condition value is the score assigned to the indicator by an assessor during a field survey. The assessor uses ecological and design judgement to award this rate and weight value (Holling, 1996; Picket *et al*., 2013).

The two judgements for an indicator are:

(i) Rate is an *ecological judgement* to categorise indicator modification in terms of the health and functioning of biodiversity and ecosystem functions as a deviation from the reference condition.

The following rating points are allocated in terms of the degree of modification from the natural, undisturbed structure:

1 = Extreme modification of ecological response from reference condition with less than 10% vegetation or no natural (vegetation) structure and function (Walker & Salt, 2012)

2 = Moderate modification of ecological response from reference condition with a basic vegetation (community) structure or function (Bradshaw, 1983)

3 = Slight modification or no discernible change of ecological response from reference condition, with only a neglected intricate structure or function (Kleynhans & Louw, 2007)

(ii) Weight is a *design* and therefore *social judgement* used to categorise indicator modification in terms of ecosystem function efficiency as a result of human intervention, management and landscape design (Pickett *et al*., 2013). The weight is rated against the end-goal state to determine the design success for recovering of ecosystem functioning.

The following rating points are allocated to represent ecological condition according to landscape modification due to current management practises:

1 = Landscape extremely modified and drastic intervention required to revert the negative trend (degradation) of the already destroyed ecosystem function efficiency and to create a new ecosystem structure, i.e. initiate artificial recovery response (Bradshaw, 1983; Holling 1996)

2 = Landscape severely modified and acceptable intervention required with artificial restoration of the destroyed ecosystem functions by supporting the new structure to encourage artificial recovery response in order to reach the end-state goal, i.e. artificial response (Bradshaw, 1983)

3 = Landscape modified and active action to assist self-organisation recovery of the damaged ecosystem's function efficiency in order to recover to the reference condition, i.e. assisted natural recovery response (Clewell & Aronson, 2013)

4= Outstanding intervention that enhances spontaneous natural recovery by removing obstacles and securing ecosystem function efficiency as in the reference condition (Clewell & Aronson, 2013)

Guidelines to assist with ecological and social judgements for indicator rating and weighting are summarised in *Table 4-3*.

Table 4-3: Guidelines for assessors in evaluating indicators

Value	Indicator state (deviation from reference condition)	Description of the recovery response of an indicator
Rate	**Modification of structure and function**	**Present structure and function (response available to recover)**
1	Extremely and severely modified	Reconstruct vegetation and soils – less than 10% of the original vegetation structure (Walker & Salt, 2012)
2	Moderate modification	Modified vegetation with basic functional community structure (Bradshaw, 1983)
3	Slight modification and relatively unaffected state	Recovery trend towards reference condition (Clewell & Aronson, 2013)
Weight	**Design / manage success to sustain structure and function**	**Description of indicator design or management efficiency to support and maintain function**
1	Landscape extremely modified (Very poor state)	Loss and / or decline of ecosystem function Create an new structure and function
2	Landscape severely modified (Extremely modified state)	Artificially reconstruct only a basic skeleton to artificially recover functionality of the ecosystem
3	Landscape modified but natural structure (Good state)	Spontaneous self-organisation (primary succession) with human assistance to remove obstacles to increase the recovery time
4	Near-natural landscape (Excellent state)	Spontaneous self-organisation (secondary succession) with human assistance to remove obstacles to prevent degradation

4.5 Rating of indicators as standard

Indicator values are semi-quantitative or qualitative, depending on the nature of the indicator. For example, “habitat for food”, indicator number 6 in *Table 4.2*, measures the availability of habitat diversity indirectly according to the availability, variety and quality of food as a deviation from the end-state goals set as reference condition. Although it is possible to qualitatively monitor water quality, this study only looks at the visual aspects such as the response of the biota, algae, water colour, etc. In this study, the indicators were grouped according to landscape goals to provide structure to the indicators in the index and to simplify various aspects for stakeholders with little or no ecological knowledge. A before and after project evaluation is advisable in order to set goals at the beginning of the project and to inform managers of the ecological condition after recovery (Fischer *et al*., 2006). A standardised rating system contributes to a consistent and objective allocation of indicator values and is identified as 1, 2, or 3 for a rate value and 1, 2, 3 or 4 for a weight value.

4.6 Summary

This chapter identified the components of an index to assess and quantify the ecological condition of a project site. This information was used to compile an index as a field survey sheet, as discussed in the following chapter.

Chapter 5: A protocol to assess the ecological condition of a site

5.1 Introduction

This chapter describes how an evaluation sheet for field surveys was generated in order to establish a standard protocol for the assessment of ecological condition. A standard protocol allows for the comparison of sites according to an acceptable scientific standard. This assessment sheet is intended to be applicable to all site types, irrespective of size or location.

5.2 Evaluation sheet

The basic structure of a standard evaluation sheet is depicted in *Figure 5-1*.

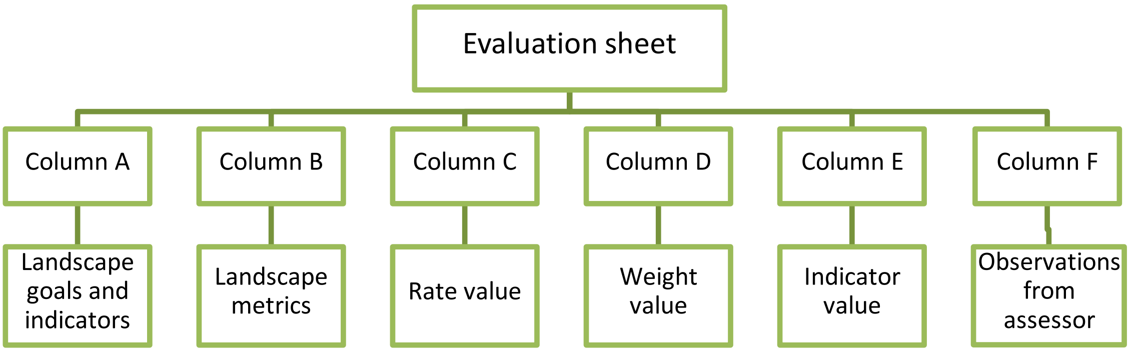

Figure 5-1: Basic structure of the evaluation sheet (Source: Author)

The evaluation sheet guides an assessor through the standard evaluation process to calculate ecological condition as a numeric value through which to express ecological condition as ecological value. The column headers on the sheet allow assessors to follow a similar procedure:

(i) Column A: Landscape goals and indicators

(ii) Column B: Landscape metrics

(iii) Column C-1: Rate value

(iv) Column C-2: Weight value

(v) Column C-3: Indicator value (total = rate multiplied by weight)

(vi) Column D: Observations of assessor to support the assigned indicator value

The evaluation sheet guides the assessor in an evaluation of the state of the 44 landscape ecological indicators according to the proposed landscape metrics provided on the survey sheet (see *Table 5.1* below). The assessor should be a professional ecologist, sufficiently knowledgeable to describe and identify pristine vegetation. The assessor's rate and weight values should be clearly supported for the sake of consistency and future management purposes. The final score of the index expresses the ecological condition of the site as a percentage. *Figure 5-2* gives a schematic outline of the steps to be followed in evaluating indicators and calculating index values.

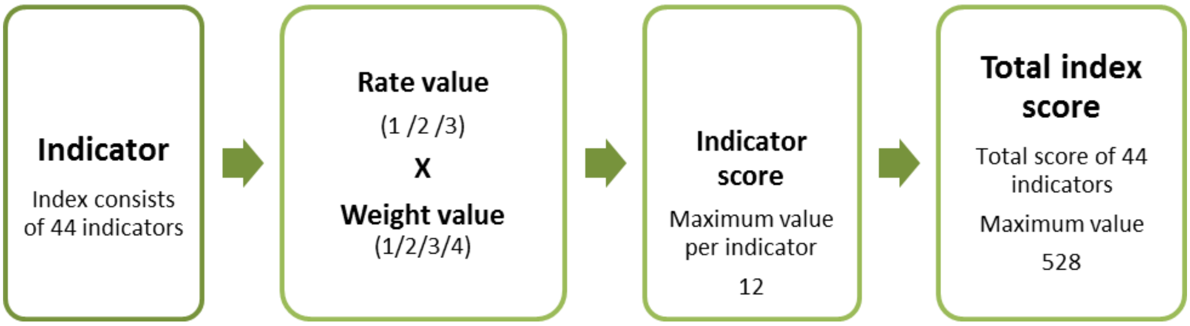

Figure 5-2: Calculation of the ecological value of an indicator (Source: Author)

The protocol to assess the ecological condition of a site is included in the format of an evaluation sheet (*Table 5-1*). The table is used to calculate the numerical score (index value) that is derived for a particular site applying the rating and weighting judgements at a specific time.

Table 5-1: Field survey sheet

Column A **Landscape objectives and ecological indicators**	Column B **Landscape metrics** ***(IMPORTANT: Focus on design goals set as end-state)***	Column C Rating			Column D **Observations made by assessor to support indicator score**
		C1: Rate	**C2: Weight**	**C3: Total**	
(i) Heterogeneity of land cover					
1. Diversity of tree species	% indigenous, % cover, alien invasive threat				
2. Diversity of shrub species	% indigenous, % cover, alien invasive threat				
3. Diversity of ground species cover	% indigenous, % cover, alien invasive threat				
4. Site composition – vertical pattern	Proportion, richness, evenness or dominance and diversity				
5. Landscape composition and configuration	Arrangements of parts and functioning of processes Prevention of habitat fragmentation				
(ii) Habitat diversity					
6. Habitat for food	Presence, variety and quality				
7. Habitat for water provisioning	Presence, variety and quality				
8. Habitat as wetland	Presence, variety, quality and infiltration				
9. Habitat as open areas	Presence, variety and quality				
10. Habitat for shelter	Presence, variety and quality				
11. Habitat as forest floor	Presence, variety and quality				

12. Habitat for recreation	Presence, variety and quality				
13. Movement routes	Presence, variety and quality				
(iii) Landscape dynamics					
14. Decomposition process	Presence, variety and quality				
15. Internal ecosystem linkage	Presence, variety and quality				
16. Natural disturbance dynamics	Presence, variety and quality				
17 Wildlife	Presence, variety and quality				
18. Exotic predation	Presence, variety and quality				
(iv) Landscape changes					
19. Landscape matrix dynamics	Cover change, unit size and connectivity				
20. Fragmentation	Cover change, unit size and connectivity				
21. Movement of species	Cover change, unit size and connectivity				
22. Microclimate adaptations to change	Adaptation to new climate conditions				
23. Land impoverishment of site	Cover change, unit size and connectivity				
24. Heterogeneity	Design success				
(v) Soil stability					
25. Indigenous vegetation cover	Vegetation cover and % cover				
26. Sustained genetic diversity	Seed bank presence				
27. Soil porosity	Soil porosity				
28. Slope management to prevent erosion	Soil surface roughness				
29. Topsoil richness	Prevent erosion				

30. Avoid soil pollution	Precautionary approach				
(vi) Fresh water					
31. Water quality	Water quality of run-off and waste				
32. Water quality discharge from site	Water quality of run-off and waste water				
33. Harvesting of rainwater	Harvesting or ground water				
34. Water conservation	Impoundments and reservoirs				
35. Surface quality	Increased infiltration quality (uneven, pervious, organic component)				
36. Canopy cover	Reduce water run-off speed and heat absorption				
37. Water management	Reduce consumption / use of grey water / seasonal adjustment. Design of irrigation system				
(vii) Capturing and radiation of energy					
38. Land cover absorption	Absorption of heat by vegetation to prevent heat island creation				
39. Avoid heat islands	Air circulation efficiency and heat absorption for energy use and use of natural light				
40. Carbon storage and sequestration	Biomass, air quality and carbon storage by plants				
(viii) Governance and mitigation					
41. Endorse greater environmental responsibility	Accountability, responsibility, transparency and fairness Pro-active or reactive or no strategy				
42. Precautionary actions	Budget				

	Development and diffusion of environmental technologies				
(ix) Human health and well-being					
43. Naturalness	Spiritual experience and sense of place				
44. Innovation	Inspiration: culture, art and design				

Total Index value is defined by: $f(x) = x * y$

Where: x = rate

y = weight

5.3 A conceptual integrated landscape and ecological framework

A conceptual framework integrates different concepts in an index that calculates ecological value. The concept of ecology of cities necessitates an understanding of how the aggregated parts function within a watershed that integrates imperative landscape concepts identified as:

(i) Sites attributes

(ii) Landscape ecological attributes

(iii) Landscape goals

(iv) Biodiversity and ecosystem services objectives

(v) Landscape indicator goals and ecological indicators

Table 5-2 provides a conceptual landscape ecological framework for inter-disciplinary integration of ecology and landscape ecology to contribute to Sustainability Science (SS).

Table 5-2: A conceptual integrated landscape and ecological framework

Site attributes	Landscape ecological attributes	Landscape goals	Biodiversity and ecosystem services goals and objectives	Ecological goals and indicators
Biodiversity	Landscape structure (composition and configuration) Landscape processes and functionality Landscape changes	Maintain ecological integrity and health Protect indigenous vegetation Adapt to changes (through heterogeneity, self-regulation, resilience and redundancy) Maintain landscape connectivity Secure the ecological functioning of processes (e.g. pollination, seed dispersal, entropic levels, succession, life cycles) Create and maintain habitat diversity	***Provisioning***: Food Raw materials Fresh water Medical resources ***Regulating***: Local climate Air quality regulation Carbon sequestration and storage Moderation of extreme events Waste-water treatment Erosion control Maintenance of soil fertility Pollination Biological control (pest regulation) ***Supporting:*** Habitat for species Maintenance of genetic diversity ***Cultural***: Recreation and health	***(i) Heterogeneity of land cover*** 1. Diversity of tree species 2. Diversity of shrub species 3. Diversity of ground species cover 4. Site pattern – vertical 5. Site pattern – composition and configuration ***(ii) Habitat diversity*** 6. Habitat for food 7. Habitat for water provisioning 8. Habitat as wetland 9. Habitat as open areas 10. Habitat for shelter 11. Habitat as forest floor 12. Habitat for recreation 13. Movement routes ***(iii) Site dynamics*** 14. Decomposition process 15. Internal ecosystem linkage 16. Natural disturbance dynamics 17. Wildlife 18. Exotic predation

Site attributes	Landscape ecological attributes	Landscape goals	Biodiversity and ecosystem services goals and objectives	Ecological goals and indicators
				(iv) Landscape changes 19. Landscape matrix dynamics 20. Fragmentation 21. Movement 22. Microclimate adaptations to change 23. Land impoverishment of site 24. Heterogeneity
Soil	Landscape stability	Store and protect gene pool Maximise use of water resources Improve soil quality (prevent contamination)	***Provisioning*:** Vegetation cover Primary production productivity Store and protect seed bank ***Regulating*:** Local climate Air quality regulation Waste-water treatment Erosion control Maintenance of soil fertility Pollination ***Supporting*:** Habitat Maintenance of genetic diversity Erosion control	***(v) Soil stability*** 25. Indigenous vegetation cover 26. Sustain genetic diversity 27. Soil porosity 28. Slope management to prevent erosion 29. Topsoil richness 30. Prevent and avoid soil pollution
Water	Water cycling	Protect and improve water quality Maximum use of rainwater	***Provisioning*:** Fresh water	***(vi) Freshwater*** 31. Water quality

Site attributes	Landscape ecological attributes	Landscape goals	Biodiversity and ecosystem services goals and objectives	Ecological goals and indicators
		Prevent evaporation	***Regulating***: Local climate Water purification ***Supporting:*** Nutrient cycling	32. Water quality discharge from site 33. Harvesting of rainwater 34. Water conservation 35. Surface quality 36. Canopy cover 37. Water management
Air	Capture energy	Protect and maximise land cover absorption of energy Protect and improve air quality Regulate climate	***Provisioning:*** Fresh air (photosynthesis) ***Regulate:*** Climate Air quality regulation (including photosynthesis)	***(vii) Capturing of energy*** 38. Land cover absorption and radiation 39. Avoid heat islands 40. Carbon storage and sequestration
Governance and risk mitigation	Precautionary approach	Prevent damage	***Regulating*****:** Moderation of (extreme) events	***(viii) Good governance and mitigation*** 41. Endorse greater environmental responsibility 42. Precautionary actions
Human health and well-being	Human health and well-being	Create a sense of place	***Cultural:*** Mental and physical health (Recreation, tourism, aesthetic appreciation, spiritual experience) Sense of place (Inspiration for culture, art and design)	***(ix) Human health and well-being*** 43. Naturalness 44. Innovation

5.4 Summary

In this chapter, a description of the compilation of an evaluation sheet was provided. This sheet provides an index as an instrument to measure ecological condition as a tool in setting standards for human decision-making when managing urban ecosystems. The greatest obstacle in the way of acceptance of this index as a quantifiable scientific tool is consistent objective rating of the indicators by assessors. Broad indicator guidelines, provided as a general guide to the assessor, were given as metrics for uniformity. The index was tested on a project site in the Pretoria area, City of Tshwane, Gauteng Province, Republic of South Africa. *Chapter 6* discusses the collection and processing of data to report on the state of the ecological condition after human activities.

Chapter 6: Data collation and status report

6.1 Introduction

This chapter explains how a project site was assessed to test the application of the index in generating ecological data to compile a management report. The project site was recently disturbed and the site was rehabilitated as part of the mitigation plan. The ecological condition was measured after the recovery action by applying the index and a score of 13% was achieved. According to *Table 2.7.7* the ecological condition of the site after the recovery attempt was poor and imitates extreme and the severe modification of the ecological condition. The recovery effort was discussed in *Chapter 6* as the measured condition and do not support the view that the restoration had been successful.

6.2 Report on the recovery success of the Moreleta Outfall Sewer (MOS) project site in the Faerie Glen Nature Reserve

6.2.1 Methodology used to compile the report

Goal of field survey	To test the index in practice as a standard for sustainability
Aim	To calculate the ecological condition of the site
Method	Using the index as assessment tool Collecting data by rating 44 ecological indicators Calculating ecological condition score
Results	Interpreting results
Discussion	Practical actions taken to recover ecological functionality

6.2.2 Background to the MOS project

The goal of the MOS project was to upgrade the urban infrastructure of the municipal outfall sewer, and included the rehabilitation of the reconstruction footprint after the developer had completed the project (CoTN, 2012). *Table 6-1* illustrates the MOS-project activities.

Table 6-1: Activities of the Moreleta Outfall Sewer (MOS) project (CoT, 2012)

Project details	Activities
Goal of project	Installation of additional infrastructure services for present and future needs of the residents of the eastern suburbs of the City of Tshwane, Pretoria
Location	Moreleta Spruit in the Faerie Glen Nature Reserve, City of Tshwane Municipality, South Africa
Project Client	Water and Sanitation Division, City of Tshwane Municipality
Engineering Consultant	Private company
Environmental Authorisation (EA) Water Use Licence issued	Approved on 20 February 2007, Project Reference Number: Gauteng 002/05-06/0402 24 February 2010, Licence Number 27/2/2/A123/1/4
Reconstruction period	From September 2009 to February 2014
Environmental goal identified by developer	Environmental Management Plan (EMP) for reconstruction and rehabilitation

6.2.3 The project site

A portion of the MOS project falls within the boundaries of the Faerie Glen Nature Reserve, a protected area situated in the municipality of the City of Tshwane, Gauteng Province, Republic of South Africa. The site is part of a ridge surrounded by residential suburbs. The reserve covers an area of 120 hectares and includes a watercourse with floodplains and a variety of geological formations and soil types give rise to a great diversity of plant communities (CoT, 2005).

The section of the MOS project that falls within the bounds of the Faerie Glen Nature Reserve was assessed on 22 April 2014. The site comprises a horizontal strip of land of 1 384 meters long, 55 meters at the widest point and covers a surface area of 4.3 hectares that runs parallel to the Moreleta watercourse. The site is situated mainly on the southern side of the watercourse, but also covers a portion on the northern side, therefore straddling the watercourse. The western border coordinates of the site are 25°46'23.4"S 28°17'28.9"E. The site has a history of disturbances from two previously installed outfall sewers. The duration of the total project was four years and five months; the commencement date was in September

2009, and the project was completed in February 2014. The most destructive time of construction in the Faerie Glen Nature Reserve took place around November 2012.

A view of the site in the Faerie Glen Nature Reserve is shown in *Figure 6.1* on 5 November 2012 after the original land cover was removed, showing the visual impact of the removal of vegetation of the site.

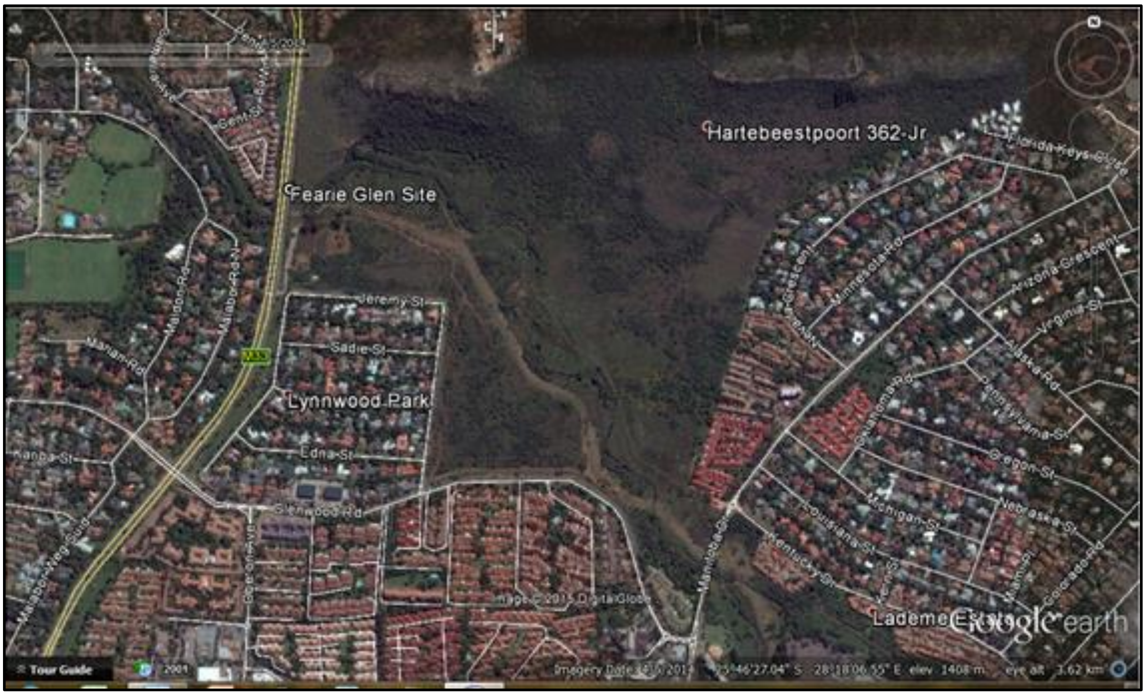

Figure 6-1: A view of the Faerie Glen site on 5 November 2012 perceived to be the time of maximum disturbance. (Source: Google Earth, 2013)

6.2.4 Biophysical description of the site and vegetation

According to the vegetation map of South Africa, two “groups” of vegetation can be used to describe the vegetation types in the reserve (Mucina & Rutherford, 2006). The vegetation unit of the site was identified in this study as Marikana Thornveld, which falls within the Savannah biome; the vegetation is described as open *Vachellia karroo* woodland with shrubs that are denser along drainage lines (Mucina & Rutherford, 2006). The vegetation and soil characterising of the two groups defines the reference condition of the site and acts as the benchmark against which to measure the impact the project had had on the ecological condition of the site at the time of the assessment.

The climate is characterised by summer rainfall, dry winters, a mean annual precipitation (MAP) of between 600–700mm, frost during the winter months and maximum and minimum temperatures that fluctuate between 32.8°C and -1.0°C, respectively (Mucina & Rutherford, 2006).

The geology consists of mafic intrusive rocks of the Rustenburg Layered Suite of the Bushveld Igneous Complex, which underlies the geology of the area with soils, and rocks that include gabbro, norite, pyroxenite and anorthosite (Mucina & Rutherford, 2006). The shales and quartzites of the Pretoria Group of the Transvaal Supergroup contribute to the geological profile of the area, with soils mainly vertic melanic clays with some dystrophic or mesotrophic plinth catenas and some freely drained, deep soils (Mucina & Rutherford, 2006).

6.2.5 Reference condition of the site

The reference condition of a site is a standard of comparison used as a yardstick to assess the present ecological condition against a historical condition, and could be considered arbitrary (Stoddard *et al.*, 2006). The reference condition reveals the impact of human activities on the ecological condition according to a specific standard (Stoddard *et al.*, 2006). The intention is not to regard this reference as an absolute end-goal state or to return the site to a former pristine or undisturbed state, but rather to describe the historic habitat of former indigenous species, including humans (Parkes *et al*., 2003).

6.2.6 Description of the appropriate recovery process

The structure and function of the vegetation and soil determine the site's ecological response to natural recovery. Before the project site was developed, the vegetation and soil were classified as natural and degraded; after reconstruction and at the start of the recovery process the ecological response was classified as natural and partially damaged (*Table 3.1*). The ecological response of the project site was established by the presence of a natural seed bank and relatively minor excavations required by the installation of the pipeline. A near-natural condition was set as end-goal state for recovery.

6.2.7 Field survey sheet completed by the assessor

The compiler of the index, the researcher, assessed the project site. *Table 6-3* gives the completed field survey sheet by the assessor when rating the individual indicators and calculating the total index value of 13 %.

Table 6-2: Field evaluation sheet completed by the assessor

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
1. Heterogeneity of land cover **Design objective: To minimise human intervention and to support only the (natural) primary succession process and to activate the seed bank**					
1. Diversity of tree species	% Indigenous, % cover, alien invasive threat	1	1	1	Land cover was removed but not all organic material was replaced. Seed bank was not activated as an ecological response. Nursery trees were planted, which is expensive and unnecessary. The seed bank was polluted.
2. Diversity of shrub species	% Indigenous, % cover, alien invasive threat	1	1	1	Land cover was removed but not all organic material was replaced. Seed bank was not activated as an ecological response. Nursery trees were planted, which is expensive and unnecessary. The seed bank was polluted.
3. Diversity of ground species cover	% Indigenous, % cover, alien invasive threat	1	1	1	Land cover was removed but not all organic material was replaced. Seed bank was not activated as an ecological response; artificial seeding containing an exotic species, *Eragrostis teff* (van Oudtshoorn, 1992), took place instead.
4. Site composition	Land cover, quality, proportion, richness, evenness or dominance	1	1	1	Bare and poor soils are an indication of soil impoverishment. Ecological response to recover was ignored and seedlings from the seed bank were destroyed. Nursery trees were planted; this is considered a fruitless expenditure as seeds from the seed bank have started to germinate spontaneously.

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
5. Site composition and configuration	Arrangement of elements in a particular form, figure, or combination	1	1	1	Nursery plants were introduced unnecessarily, instead of assisting the spontaneous germination of the seed bank, which is better adapted to local conditions. Additional watering, instead of tree planting, would have assisted spontaneous recovery.
2. Habitat diversity **Design objective: To recover and create habitats**					
6. Habitat for food	Presence, variety and quality	1	1	1	The artificial recovery method used left a less diverse and dynamic site. Spontaneous natural recovery was not considered.
7. Habitat for water provisioning	Presence, variety and quality	1	1	1	The aggressively dominant monotonous grass species, *Pennisetum clandestinum* (van Oudtshoorn, 1992) was planted to stabilise the river reduces the ecological response and dynamics that allow water habitats to develop.
8. Habitat as wetland	Presence, variety, quality and infiltration	1	1	1	River banks are eroding and an aggressive, monotonous grass species was planted that hampers the primary succession stage of wetland vegetation.
9. Habitat as open areas	Presence, variety and quality	2	2	4	Ecological integrity of open areas has been adversely affected by exotic grass species. The exotic grass species has contributed to the speedy recovery of the bare areas in the short term, but will have a negative impact on the integrity of the area in the long term.
10. Habitat for shelter	Presence, variety and quality	1	1	1	Most rocks and all organic materials were removed instead of reusing tree trunks to provide shelter and resting places.

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
11. Habitat as "forest" floor	Presence, variety and quality	1	1	1	All organic material was removed, causing soil impoverishment.
12. Habitat for recreation	Presence, variety and quality	1	2	2	A short-term, visually pleasing site was created, ignoring the activation of ecological processes to improve integrity. Presence of alien plant species threatens biodiversity and ecological functions.
13. Movement routes	Presence, variety and quality	1	1	1	No temporary paths for visitors were made, resulting in soil erosion. Visitors have behaved irresponsibly because they were left with no alternative paths.
3. Landscape dynamics **Design goal: To create, support and maintain multi-functionality and activate seed bank germination**					
14. Decomposition process	Presence, variety and quality	1	1	1	All organic material was removed from the site; this destroyed the decomposition process that could have improved the condition of the soil.
15. Internal ecosystem linkage	Presence, variety and quality	1	1	1	Ecological processes were critically modified on the site.
16. Natural disturbance dynamics	Presence, variety and quality	1	2	2	Dynamics on the site are supported by the ecological response available from the indigenous species of the natural area surrounding the site. The presence of alien plants adjacent to and on the site itself counteracts the recovery process.
17 Wildlife	Presence, variety and quality	2	2	4	Present because of the occurrence in the surrounding natural areas.
18. Exotic predation	Presence, variety and quality	1	1	1	Affected by dogs being allowed to roam freely without proper control from owners visiting the reserve.

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
4. Landscape changes **Design goal: To reduce impact of changes on all scales and to support and maintain multi-functionality**					
19. Landscape matrix dynamics	Cover change, unit size and connectivity	1	1	1	Loss of biodiversity as a result of unsuccessful riverbank recovery. Erosion has caused sedimentation that has polluted the water and destroyed diversity. Disturbance of soil has improved ecological conditions for alien weed infestations. Loss of indigenous species has caused a loss of ecosystem diversity and functionality.
20. Fragmentation	Cover change, unit size and connectivity	1	1	1	The site is a strip within a natural area and varies between 55m in width. This should have enhanced recovery rate, but unfortunately alien weed infestations are present and inefficiently managed, causing ecological disturbance.
21. Movement of all species (corridor)	Cover change, unit size and connectivity	1	2	2	Organic material (rocks and tree trunks) were removed, disturbing the multi-functionality of the site. There is inadequate protection for the safe movement of small biota as a result of poor configuration.
22. Microclimate adaptation to change	Adaptation to new conditions	1	2	2	Genetic loss of indigenous species constitutes a huge ecological loss in time. Soils are sparsely covered by vegetation and are bare and dry, causing higher surface temperatures in summer and lower temperatures in winter.
23. Land impoverishment of site	Cover change, unit size and connectivity	1	1	1	The presence of alien weeds indicated poor management on the part of the contractor. Soils are organically poor with a continuous degrading trend.

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
24. Heterogeneity	Design success	1	1	1	Seed bank has been disturbed and spontaneous ecological recovery destroyed.
5. Soil stability **Design goal: To activate soil processes and seed bank germination to increase presence of biota**					
25. Indigenous vegetation cover	Vegetation cover and %cover	1	1	1	An exotic grass species was seeded without proper ecological foresight. These aggressive invader grass species have severely destabilised the riverbanks. Continuous loss of biodiversity as a result of mechanical interruption of the site.
26. Sustain genetic diversity	Seed bank presence	1	1	1	Genetic potential has been overlooked and destroyed by mechanical interruption. There is a significant loss of historic species and genes.
27. Soil porosity	Soil porosity	1	1	1	Chemical fertilisers were used in a protected area. Soil compacted roads were not recovered. Increased run-off of rainwater from compacted roads has caused erosion.
28. Slope management to prevent erosion	Soil surface roughness	1	1	1	Riverbanks and beds were dramatically modified without the correct stabilisation and restoration; this has had an ongoing, devastating impact on the ecological condition. Soils were disturbed (by mechanical processes) against the contour lines.
29. Topsoil richness	Prevent erosion	1	1	1	Percentage cover of soil has decreased because all organic materials have been removed. Chemical fertiliser has polluted the natural area with long-term ecological implications. Erosion has occurred.
30. Prevent soil	Precautionary	1	1	1	According to the complaints registered, soils were directly contaminated by oil spills,

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
pollution	approach				polluted water was released directly into river course, alien plants and seeds were present, and alien plants were not removed before development began.
6. Fresh water **Design goal: To conserve and improve water quality and prevent pollution of water**					
31. Water quality	Quality of water run-off and waste	1	1	1	Degraded as a result of inadequate protection against sedimentation during construction and recovery, spread of seeds of alien plant species and the exotic monoculture species used to stabilise riverbanks. Complaints have been received of polluted water being pumped directly into the watercourse.
32. Quality of water discharged from site	Quality of run-off and waste water	1	1	1	Pollution caused by chemicals (herbicides), alien plant seed infestation and sedimentation. Degrading trend and continuous pollution as a result of erosion of poor soil surfaces.
33. Harvesting of rainwater	Harvesting or ground water	1	1	1	Poor erosion control measures have caused increased rainwater flow because no attempt has been made to increase water infiltration or to slow down water run-off. Compacted soils and flat surface areas disturb water infiltration.
34. Water conservation	Impoundments and reservoirs	1	1	1	Little or no attention has been given to conservation aspects. Compacted roads have become water channels, causing erosion.
35. Surface quality	Increased infiltration quality (uneven, impervious, organic component)	1	1	1	Poor and compacted surface, which further disturbs the area.

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
36. Canopy cover	Reduce water run-off speed and heat absorption	1	3	3	Bare land was ineffectively recovered because the natural recovery dynamics were seriously degraded by the introduction of an exotic grass species. This has had a negative effect on the ecological integrity of the site that is situated in a protected area
37. Water management	Reduce consumption / reuse grey water / seasonal adjustment Design of irrigation system	2	2	4	Vegetation germinated from the genetic pool would be better adapted to local water needs than the nursery plants that have been introduced.
7. Capture and radiation of energy **Design goal: To capture heat and prevent loss of energy**					
38. Land cover absorption	Absorption of heat by vegetation to prevent creation of heat islands	2	2	4	Heat radiation has resulted from the removal of all organic material that caused sparse land cover.
39. Avoidance of heat islands	Air circulation efficiency and heat absorption for energy use and use of natural light	2	1	2	All organic material was removed and not replaced, causing poor soil with reduced capacity to absorb water and heat that causes radiation.

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
40. Carbon storage and sequestration	Biomass, air quality and carbon storage by plants	2	2	4	All organic material was removed and not replaced, causing poor soils with reduced carbon sequestration capacity.
8. Governance and mitigation **Design goal: To ensure responsible, accountable, fair and transparent management**					
41. Good governance	Accountability, responsibility, transparent and fair Pro-active or reactive or no strategy	2	2	4	Public requests to provide site reports were ignored. A reactive recovery strategy was followed, indicating a lack of transparency and cooperation with local stakeholders. A request by the community for assistance in recycling stones from the site was a positive act, creating retaining walls and supporting local tribal customs.
42. Precautionary	Budget Development and diffusion of environmental technologies	1	1	1	Proper precautions were not taken: Failure by developer to recognise the site as ecologically sensitive and presence within a protected area Presence of alien plants Use of an invasive grass to stabilise riverbanks Removal of organic material Pollution of soil and water quality Loss of biodiversity and functionality
9. Human health and well-being **Design goal: To support, maintain and preserve ecological integrity and health**					

Landscape objectives and ecological indicators	Landscape metrics	Rate (1/2/3)	Weight (1/2/3/4)	Total score (RxW)	Observations made by assessor to support indicator score
43. Naturalness	Spiritual experience and sense of place	2	2	4	There is a loss of ecological integrity. Only short-term recovery success was visible, leaving the recovery process in a negative trend.
44. Innovation	Inspiration: cultural, art and design	1	2	2	Stones were recycled in accordance with the customs of local indigenous people.
Total score of the ecological condition of the site (Max = 528)				73/ 528 13 %	Recovery success to recover ecological response in a near-natural area to sustain biodiversity and ecosystem services.

6.3 Scientific analysis of the recovery effort

The ecological condition of the site was rated as 13% and judged as poor (*Table 2-1*) owing to extreme and severe modification to the ecological condition (Kleynhans & Louw, 2007). Poor ecological condition of a site within a natural area holds an ecological and reputational risk for the developer and the landowner. This report highlights the challenges facing management if the present ecological condition is to be improved and if further degradation of the environment is to be avoided. A scientific analysis of the recovery effort is given as a report in *Table 6-2*.

Table 6-3: Scientific analysis of the recovery effort to sustain biodiversity and ecosystem functionality

Human impacts to be recovered	Management options
Local level	
Loss of biodiversity	Ongoing assisted human intervention is required to enhance the recovery process on the site by replacing the removed vegetation: To enhance recovery response and dynamics To create "safe sites" in order to establish and nurture juvenile populations from the seed bank for spontaneous organisation of vegetation communities To create habitats for decomposers to resume the decomposition process Monthly control of alien invasive plants is necessary in the site's surrounding areas, especially during spring and summer, to avoid further infestation of the site. Such infestations pose a serious threat to transformation of the ecological condition of the region. Control of aliens for two to three years only (target set in the EMP) is not adequate owing to the favourable climatic conditions (almost sub-tropical) for the establishment of weeds in the region. The removal of alien vegetation from disturbed sites in sensitive areas should be an ongoing process if it is to be effective. Permanent, seasonal employment should be created to control aliens as part of the developer's social responsibility. The use of excessive herbicides to control weeds is not recommended in sensitive areas such as river courses; manual removal is proposed as the best practice action and this would also create jobs and contribute to the social resilience of the area by making an effort to address the unemployment crises in developing countries. Instead of removing rocks, several rocky areas should be created to assist in the recovery of habitat diversity, structure and configuration.
Loss of soil fertility	Add organic material or return local materials that have been removed, e.g. tree branches for structure and rocks to improve water retention, aerate soil, assist in seedling germination, slow water flow rate, and increase water retention and biota presence. Recover erosion damage on site, river slopes and riverbanks by creating favourable conditions as habitat for biota and in support of ecological processes.

	Return excess rocks to be used as fill material in dongas, to create habitats and to stabilise riverbanks.
Alien plant control and management	Follow a proactive management plan to prevent alien plants from spreading locally and regionally. Alien plants should be removed before any seeds have been produced; if not, the potential for infestation will remain and increase after completion of the contract.
Protect genes of seed bank	Allow and nourish local seed development rather than introducing foreign nursery plants.
Stabilisation of riverbanks	Unstable riverbanks should be stabilised by permanent structures, such as gabions, to support ecological processes.
Good governance and mitigation	More committed corporate responsibility is required to reduce risk to the environment. The custodian of the area should show greater accountability and responsibility.
Human health and well-being	More consideration should be given to the social needs of the community that has been affected by the project.
Landscape level	
Manageable regional impacts identify as:	Control of alien plant infestation to avoid the threat of ecological transformation is a priority. The spread of alien invasive plant seeds along the river course poses a serious threat and could degrade the integrity of the river ecosystems, cause a loss of biodiversity and ecosystems, and have an impact on other ecosystem services such as: Provisioning: Loss of diversity (suppression of indigenous species) Pollution of fresh water (sedimentation from land cover loss brought about by alien infestation) Land degradation caused by poor organic content arising from the removal of organic material hampers the decomposition process (firewood). Regulating: Air pollution should be controlled to avoid water pollution (dust suppression). Land should be covered (by vegetation or mulch) to avoid heat islands. Avoid/recover compacted areas to avoid soil erosion (reuse locally available materials as obstacles to reduce water flow, e.g. stones, vegetation and tree stumps to spread out run-off). Remove or treat waste water to avoid river pollution. Reusing and adding organic material avoids soil impoverishment. Supporting: Reuse <u>all or most</u> organic and other materials to recover habitat loss. Nurture and support ecological response from seed bank to recover. Do not bring foreign genes into a protected area. Cultural services: Educate and create an awareness of the indigenous vegetation and biota in a site. Minimise inconvenience to locals by observing alternative social needs

	during period of disruption. Open communication channels to address the concerns of stakeholders.

6.4 Summary

Although the judgement of the ecological condition of a site is partially subjective and not easily determined owing to the many different aspects and features involved, ecological data can be collected scientifically to manage and sustain biodiversity and ecosystem services. The importance of reliable ecological information based on ecological principles has become a sine qua non for effective designs and solutions and can no longer be ignored by designers or society (Forman, 2013).

Chapter 7: Conclusion

We all have a responsibility to learn how to live and develop sustainably in a world of finite resources (Tutu, 2009).

7.1 Introduction

The likelihood of the indefinite presence of resources depends on the ecological integrity, health and welfare of existing resources. The continuous dynamic modifications made by urbanisation to the environment, such as biodiversity loss, ecosystem degradation, landscape fragmentation and climate change, constitute the primary impact of humans on natural systems and on the Earth, which is the vernacular home or indigenous habitat of all living biota. The cumulative effect of human impacts on land transformation is the result of an increased rate of urbanisation.

In an urbanised world, the discipline of Sustainability Science (SS) focuses on resilience, providing a basis for understanding human values, behaviours and actions. This science highlights the problems of instability caused to the environment by urbanisation and the imperative to address the sustainability of land-use and land cover change. The truth is that cities are unsustainable without appropriate management; we should strive to make them more sustainable through better ecological practices. Sustainability is a normative concept; land is changed through a process of ecological and social justification to alter the landscape in a sustainable way.

Resilience is an entity's capacity to respond to change after a disturbance, without changing its basic state or identity (Walker & Salt, 2012). This represents a complex and multi-dimensional challenge to urban sustainability, demanding planning and design that create patterns and various stochastic processes that result in unpredictable and random reactions. In the context of unpredictable disturbances and change, Ahern (2011) believes that the concept of resilience offers a new perspective and a possible solution to the paradox of sustainability. The theory of resilience provides an understanding of the management of socio-ecological systems and engages people in a world of dynamic and adaptive systems; we depend on complex systems that are combined in particular ways when responding to ecosystem change. The focus of this study was on the recognition of the adaptive capacity of ecosystems, their ability to respond to change and their ability to maintain resilience in an ecologically functional state after change.

7.2 Evaluation of meeting goals and objectives

In this study, the field of urban sustainability was investigated by integrating ecology and landscape planning and design within the field of Sustainability Science (SS) by focusing on resilience. An index was developed to measure ecological sustainability by the identification and monitoring of multiple indicators of urban quality, urban flows and urban patterns (Alberti 1996). Even though site assessments are a critical component of recovery projects, recovery success does not require that all project goals be always met. The study suggests a universal assessment tool to measure and manage the ecological condition of sites as departure point to bridge the gap between different study fields. Recovery success needs to be measured to manage environmental performance and to acknowledge a sustainability standard.

The literature review illustrated indisputably that a multidisciplinary application and linkage of landscape design and sound ecological principles are the key elements in enhancing resilience and managing the sustainability of ecological condition. Ecological condition is described in this study in terms of the recovery potential of a site, which might vary from natural to significant modification, as long as the end-goal state is clearly defined relative to a realistic reference condition. The study recommended the measurement of the degree of sustainability of a recovery attempt through the monitoring of the driver of change and the adaptation in response to change.

Ecological condition is a complex concept and can be measured only indirectly through selected indicators. This allows the monitoring and management of the anthropogenic impacts to provide an indication of heterogeneity, connectivity and biodiversity of ecosystem functionality (Lovell & Johnston, 2009b). In this study, resilience was identified as a complex concept that explains the recovery of ecological condition; indicators were used as small components and instruments to measure and manage the symptoms and risks arising from ecological condition.

This proposed ecological index uses indicators in a quantitative manner in order to capture large amounts of complex and detailed information in a simple, understandable and manageable format. The data on the various indicators do not have to be in the same ecological state, and some indicators at the same site might be more degraded than others, with weaker responses to recovery. Indicators (*Table 5-1*) proved to be satisfactory management instruments to measure and describe stresses and disturbances, guiding the user in the process of making decisions between development and conservation. An ecologically sound recovery response should always be the first management choice, even when conservation has failed and crucial ecosystem services are declining (Dobson *et al*., 1997).

The primary objective of the study was to create an index to guide land-use and land cover in practice and to recover land to conserve biodiversity, ecosystem structure, function and dynamics as fragments of a greater landscape within a given location. The recovery success of the ecological condition of a site is defined in terms of two adaptive characteristics that strive to:

(i) Move away from a degraded state

(ii) Attain some desired ecological condition

The ecological response to guide the planner and designer in recovery of ecological condition is revealed in self-organisation and resilience (*Table 2-1*) by interpreting the structure and function of the vegetation and soil. The structure and function of vegetation and soil identify realistic recovery actions (*Table 3-1*) that assist in the setting of realistic end-goals as guidelines in the recovery process.

Ecological response of vegetation and soils is explained as:

(i) The state of the vegetation or soil as ecologically natural, near-natural or as a new land-use that should be designed to recover over time through an act of restoration, rehabilitation or reconstruction

(ii) An end-goal state that may be a natural, near-natural or transformed condition that requires reconstruction

(iii) Different categories of ecological response actions described as primary or secondary succession and artificial reconstruction

(iv) The future end-goal state objective for recovery should be realistic

The important factors in understanding the complexity of the ecological condition of a site were found to be (i) landscape heterogeneity and connectivity, (ii) restoration of resilience to support ecosystem services and (iii) ecological implications of urban design.

The ecological condition of a site can be described according to its attributes and management processes and set out in par. 3.3.1 as (i) biodiversity, (ii) soil, (iii) water, (iv) air and energy, (v) governance and mitigation and (vi) human health and well-being. Site attributes are monitored through evaluation of the extent to which the goals and objectives of biodiversity have been achieved, and identified and discusses as integrity, health and functioning of ecosystem services. The management processes are typically determined by the extent to which ecosystem support exists, inter alia, to provide food and habitat, regulate run-off, to pollinate and regulate climate, in other words providing various ecosystem services (multi-functionality).

In this study the reference condition of a site was defined for benchmarking by the relative and present ecological condition of the site before recovery, as the resilience potential to recover the vegetation to the original structure and the functionality of an indigenous historic ecosystem where significant human disturbance or alterations are absent. The structure and function of an ecosystem determines the ecological condition and can be classified as good, moderate or poor according to the ecological response to recover or reconstruct ecological yield to mitigate anthropogenic impacts.

Landscape ecological attributes and management processes considered when reporting on ecosystem function efficiency included (i) landscape structure, (ii) landscape processes and functionality, (iii) landscape changes, (iv) landscape dynamics, (v) water cycling and movement, (vi) energy capture, (vi) monitoring as precautionary action and (vii) human well-being. Landscape goals were broken down according to their objectives, such as trees/shrub/ground cover species diversity, site patterns, habitat for various objectives and many more.

Forty-four (44) ecological indicators were listed (*Table 5-1*) to integrate, assess and quantify ecological condition within an index as a measurement of ecological sustainability and in order to inform reasonable decisions on disturbance of the environment. The identification of indicators was guided by basic landscape goals and objectives that sustain biodiversity and ecosystem services. These concepts were integrated into a conceptual landscape ecological framework (*Table 5-2*) to guide landscape planning and design in focusing on resilience while responding to human impact.

Individual indicators were assessed by well-defined guidelines for purposes of an objective judgement by:

An *ecological judgement* rating indicator modification as:

1. Extremely or severely modified

2. Moderately or slightly modified

3. Relatively unaffected state

A *social judgement* of the design of the current site condition that weighs human intervention and modification of indicators against their impact on ecosystem function efficiency as;

1. Landscape extremely modified: drastic intervention is required to reverse the negative trend or degradation
2. Landscape severely modified: moderate intervention is required to artificially reconstruct destroyed ecosystem functions
3. Landscape moderately modified: the required action is to assist self-organisation recovery of the damaged ecosystem
4. Landscape requires extreme intervention to enhance spontaneous natural recovery, such as the removal of obstacles and the securing of ecosystem function efficiency

A management plan for resilience and sustainability should be derived according to local and regional landscape goals, taking into account the biodiversity and ecosystem goals and objectives of providing sustainable ecosystem management. Management should focus on the improvement of mutual actions between ecological processes and human actions to allow sustainable development and to lead to the integration of landscape goals and objectives as ecological indicators.

In this study, indicators were identified by integrating the goals and objectives of two interrelated disciplines, landscape planning and design and landscape ecology, into multiple indicators that were also linked to general site and landscape attributes (Pickett *et al*., 1997).

A disturbed urban site that a contractor had undertaken to rehabilitate was selected to test the index, to collect sound scientific data and to compile a status report (Paragraph 6.2) to scientifically manage and recover future site disturbances. The concept of resilience was further emphasised by focusing on ecological performance as a recovery success. The reference condition of this site was defined as a benchmark to judge the ecological performance of indicators according to the degree of disturbance of an indicator. A new perspective was lent to the setting of a universal standard for design goals, with the aim of moving away from “green-washing” that depend on non-existing recovery successes.

The goal of the index was to create a practical, scientifically sound and cost-effective standard against which to assess the present ecological condition of a site in order to promote honest, realistic and reasonable auditing of the disturbance and recovery.

7.3 Recommendations and the way forward

7.3.1 The future of the index in practice

It is recommended that the proposed index be applied in the field of ecological monitoring by as many qualified and experienced ecologists as possible. The index is focused on the response of vegetation in order to describe human impacts as the main indicator in explaining ecological condition. Therefore, sound scientific knowledge of the natural and climatic conditions is essential when the index is used as a measuring instrument in practice. In addition, an understanding of how and why the landscape was changed or degraded is important, for instance the effects of a sewerage spill, the blocking of a canal, the removal of organic material, and so on. The index should be applied preferably in diverse landscapes to form an understanding of possible priorities in different landscapes (hilly, flat, arid, humid), differing magnitude of impacts (totally or partially transformed) and also in urban, suburban and semi-natural areas and natural areas to determine the impact of the region versus local landscape and ecosystems.

The researcher was the developer and sole tester of this index. At this stage, the index constitutes a prototype but it has the potential to contribute in future to fair and responsible auditing of the ecological condition of a site. It would be of great value if support and official recognition for the index were obtained. Critique and comments from fellow ecologists and the improvement of the index through workshops and feedback would be of great value and could lead to the further refinement and adjustment of the methodology. This would improve the tool and increase its value in preserving biodiversity, sustainability and resilience. This tool is most specific in providing reasons for degradation and it guides management interactions to improve the ecosystem. Some of the methods proposed are not pure engineering but the advantage of the index is that in some instances, a simple approach is what is required to remove obstacles and allow nature to take over in a spontaneous recovery process that uses the natural seedbank and other locally available resources such as rocks.

Future use of this tool could address the objectivity of the index and its repeatability by comparing different site conditions in practice. It was not the intention of this study to present the metrics for the evaluation of landscape ecological indicators. Broad guideline metrics were provided only in an attempt to improve objectivity. For this reason, landscape metrics will have to be clearly defined to ensure future objectivity of the assessment of results.

The inter-relationships between biotic and abiotic factors in the biophysical environment is not yet fully understood and therefore the outcome of the application need to be re-evaluated and after a certain period, should be carefully monitored to determine whether the desired improvement has been achieved. This outcome should also be re-assessed to improve our knowledge and to adjust the index. It is not possible to provide a fully objective method of assessing the state of an ecosystem. Nature and its complexities will probably never be fully understood and therefore some compromise will always be required when assessing the ecological state of an ecosystem. This does not mean that nothing can be done to improve resilience and therefore sustainability; the application of this proposed index may pave the way for an improvement in our understanding of ecology. Data is valuable even for applications that are not obvious and should be captured, stored in a central database and made available for future ecological studies of an area or region. A databank will also aid in the protection of the integrity of researchers if others disagree with their findings.

The aim of this study was to develop a management tool to scientifically and numerically assess and measure the present ecological state of a site relative to the end-goal state of the reference condition. The tool is an index and has the potential to contribute to a definite standard for auditing the ecological condition and determining the ecological value of a site prior to or after development. One of the main aims of this index was to provide a practical, cost-effective tool that could be universally applied to improve the integrity of corporate reporting.

7.3.2 Suggestions for further research

Resilience and the dynamics that exist within a plant community should be defined in terms of the resilience and dynamics within a society, in order to improve intellectual knowledge on social welfare as a response to poverty.

7.3.3 Concluding remarks

In the Millennium Development Goals Report 2015 (UN, 2015), Ban Ki-Moon, Secretary-General of the United Nations, specifies the need to address the root causes of sustainable development and to integrate economic, social and ecological dimensions. The study of ecological principles explains human interventions that affects ecological integrity and health and by extension, the quality of the environment. By focusing on ecological principles through the application of scientifically sound knowledge, sustainability is highlighted in order to reverse the loss of environmental resources. A management focus on biodiversity and ecosystem services provides a practical approach to work towards sustainable socioeconomic development that creates green capital. This could result in a significant reduction in the rate of loss of biodiversity.

The protection and maintenance of biodiversity and ecosystem services in developed areas indicates that ecological condition should always aims to protect ecologically integrity. The cumulative impact of areas that has varied grades of ecologically integrity, although might be ecologically healthy, such as nature reserves, parks, wetlands, educational campuses, business premises, open parking areas, railway reserves, verges of roads, suburban gardens, open sites and green roofs, sustains the integrity of the environment. Land cover that has ecological integrity creates green capital that contributes to the protection of biodiversity and ecosystem services, not only in terms of visible land cover, but also in terms of the genes of species that are confined as ecological knowledge through their adaptations over millennia to survive disturbances. Ecological design is a powerful instrument as a best practice action and response to ecosystem change, to create a new ecological condition, which ideally mimics the structure and functions of a natural historic ecosystem by applying ecological principles to improve the multifunctionality of urban sites. Resilience in ecology and urban design links theory and practice for sustainable cities (Pickett *et al.,* 2013).

The protection of the ecological integrity of indigenous biota supports the power and richness of ecological principles, which can no longer be ignored by reasonable people when making sound judgements on sustainability. Although disturbances divide the wholeness of the ecological state of the earth and influence human welfare and well-being, ecological principles have become the sine qua non in effective design and solutions.

In conclusion, the environment reveals the power of energy as three basic ecological principles: (i) the capture of energy by materials (primary production), (ii) the consumption of energy and matter, and (iii) the decomposition of energy and matter in recycling processes.

All responsible citizens should strive to find a way to allow development in a world of finite resources while living responsibly (Tutu, 2009). The Constitution of South Africa protects ecological sustainability; the duty to care for the environment is an imperative to all South Africans, which have a duty not to pollute or cause ecological degradation, to promote conservation and to secure ecologically sustainable development in order to justify economic and social development (Constitution of South Africa, 1996).

Dr. Anton Rupert a respected South African businessperson and conservationist, considered humans as custodians of the Earth that should use ecological principles as innovative energy for sustainable land management, and not rely on more legislature and administration to control landowners (Marx, 1986). Ecological power should be bound by the custodian of property owners to manage their land sustainable by protecting ecological and social integrity.

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