Urban sustainability and social-ecological systems: Linking civic ecology, nature and ecosystem services for the achievement of the SDGs

by

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Pietermaritzburg.

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As the candidate's supervisor I have approved this thesis for submission.

Signed:  Name: Rob Slotow Date: 07 January 2021

PREFACE

The experimental work described in this thesis was carried out in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof Rob Slotow and Prof Mathieu Rouget.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of work of others it is duly acknowledged in the text.

ABSTRACT

To address global environmental change and ensure well-being, an improved understanding of complex human-environment relationships is needed. It further requires that the role of natural systems and ecosystem services are recognised for their contributions to the Sustainable Development Goals (SDGs), are included in a broad range of development sectors, and are managed and protected appropriately to safeguard those contributions. This PhD contributed to the evolution of the application of sustainability frameworks, from global to local level, by providing local-level evidence from two sources of change, civic / community action and local government actions (eThekwini Municipality). Through the five papers produced in this PhD research, I developed and assessed contributions of civic ecology, research organisation processes, and government planning and management, to global sustainability, using social-ecological systems and ecosystem services theory as a foundation. In Chapters 2, 3 and 4, a mixed methodological approach was used (household surveys, interviews, field observations and impact assessment) to identify the systemic linkages between civic ecology interventions of the Wise Wayz Water Care programme (case study), ecosystem services, SDGs, and human well-being. Chapter 5 analysed virtual vs face-to-face international conferences of the Sustainable and Healthy Food Systems programme (case study) and identified impacts on inclusivity, organisational learning, carbon footprints, barriers and enabling conditions for improved efficiency, and environmental sustainability, of international research collaborations. Chapter 6 used the Durban Research Action Partnership (D'RAP) transdisciplinary science-action collaboration as a case study, to explore the links between social outcomes and ecosystem services from multiple viewpoints, through expert collaboration and engagement for urban planning and sustainability. The main contributions made by this work are: (1) Identification, quantification, and assessment of civic ecology interventions as a tool to improve human well-being, using a social-ecological systems approach; (2) Linking local interventions to global policy outcomes through quantified systems mapping of civic ecology, natural capital, and ecosystem services enhancement, related to the SDGs; (3) Linking ecosystem services to human well-being improvements and policy implementation through transdisciplinary approaches. This thesis provided insights, tools, methods and evidence for local-level actions, yielding national and international sustainability wins.

DECLARATION

I, Rashieda Davids, declare that:

i. The research reported in this thesis, except where otherwise indicated, is my original research.

ii. The thesis has not been submitted for any degree or examination at any other university.

iii. This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

iv. This thesis does not contain other persons writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

   a. Their words have been re-written, but the general information attributed to them has been referenced; Where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

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vi. Where articles / papers comprise this thesis, published or unpublished, these are all works of my own, although, due to their assistance, my supervisor and co-supervisor names appear as co-authors.

vii. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Rashieda Davids
7 January 2020

DECLARATION 1 - PLAGIARISM

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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and / or include research presented in this thesis (include publications in preparation, submitted, *in press* and published and give details of the contributions of each author to the experimental work and writing of each publication).

Publication 1

Civic ecology enhances natural capital,, ecosystem services and well-being of local communities: Evidence from two communities in Durban. South Africa. Rashieda Davids, Mathieu Rouget, Margaret Burger, Kirsten Mahood, Ntswaki Ditlhale, Rob Slotow. *Sustainability* 2021, 13, 1300. https:// doi.org/10.3390/su13031300

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Publication 2

Civic Environmental Management, Ecosystem Services and Social-Ecological System Outcomes: An Impact Assessment. Rashieda Davids, Mathieu Rouget, Margaret Burger, Kirsten Mahood, Ntswaki Ditlhale, Rob Slotow. Under review at the *Journal of Environmental Management*.

Author Contributions: Conceptualisation, R.D.; formal analysis, R.D.; funding acquisition, K.M. and N.D.; investigation, R.D. and M.B.; methodology, R.D. and R.S.; supervision, M.R. and R.S.; visualisation, R.D.; writing—original draft, R.D.; writing—review and editing, M.R., M.B., N.D., K.M., and R.S.

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Publication 4

The environmental impact of research meetings: a mixed-methods case-study from the Sustainable and Healthy Food Systems research programme. Rashieda Davids, Pauline Scheelbeek, Nafiisa Sobratee, Rosemary Green, Barbara Häesler, Tafadzwanashe Mabhaudhi, Suparna Chatterjee, Nikhil Venkateshmurthy, *Georgina Mace (Deceased), Alan Dangour, Rob Slotow. Under review at the *Journal of Cleaner Production*.

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Publication 5

Linking Social Outcomes To Ecosystem Services: A Demand Analysis For Local Strategic Planning Towards Urban Sustainability
Rashieda Davids, Mathieu Rouget, Debra Roberts, Nohkuthula Dubazane, Cameron McLean, Jo-anne Douwes, Patrick O'Farrell, Benis Egoh, Michelle Audouin, Nadia Sitas, Ryan Blanchard, Rob Slotow. [Unpublished work].

Author Contributions: Conceptualisation, R.D. and M.R.; formal analysis, R.D., investigation, R.D.; methodology, R.D., M.R., D.R., N.D., C.M., J.D., P.O., B.E., M.A., N.S., R.B. and R.S. supervision, R.S. and M.R.; visualisation, R.D.; writing—original draft, R.D., writing—review and editing, R.D., D.R., P.O., B.E., M.A., N.S., R.B. and R.S.

Signed:

DEDICATION

First and foremost, all praise and thanks is due to Allah (God) who has perfectly crafted my circumstances: my environment, and my spiritual, mental and physical capabilities to complete this research, and made it possible.

This work is dedicated to:

- *My supportive and loving husband, Fadlu, and children, Shadeed, Mishka and Muhammad Shaldi - I will never forget your sacrifices during my time of working relentlessly to complete this work. I pray that you be equally rewarded for all the benefit that may be derived from this research, for our community, country and the world. Your love, and mine for you, gives me the power to keep striving for a better world.*
- *My parents, who have raised me with willpower and the heart to succeed and who envelop me with love and admiration, and my two other parents (in-laws), who taught through their beautiful ways, that love has no boundaries. My you all be blessed beyond measure.*
- *My dear sisters and friends (of whom became my sisters), thank you, wholeheartedly, for your beautiful support, encouragement and for cheering me on!*
- *My family, grandparents, brothers, nieces and nephews – thank you too, for supporting me.*

This work is for all of us. May you always be inspired to aim for the stars!

I love you all, dearly.

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LIST OF ABBREVIATIONS

AECI	African Explosives and Chemical Industry
D'MOSS:	Durban Metropolitan Open Space System
ES:	Ecosystem Services
HLPE	High Level Panel of Experts on Food Security and Nutrition
IAP:	Invasive alien plant/s
IDP:	Integrated Development Plan
KZN	KwaZulu-Natal
MEA	Millennium Ecosystem Assessment
NCP	Nature's Contributions to People
NDP:	National Development Plan
NGO	Non-Governmental Organisation
NSSD:	National Strategy for Sustainable Development
SDG:	Sustainable Development Goals
SM:	Supplementary Material
SO:	Social outcome
SP	Strategic Priority
UKZN	University of KwaZulu-Natal
UN DESA:	United Nations Department of
VUE:	Visual Understanding Environment
WWWC:	Wise Wayz Water Care Programme

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CHAPTER 1: **INTRODUCTION**

The 2030 Sustainable Development Goals (SDGs) aim to reduce the impact of urban development on life-supporting natural systems, with goals to conserve the environment and to eliminate poverty placed at the core of the agenda (United Nations Development Programme 2016). It is understood that sustainable social and economic development is only possible if it occurs within the limits of the environment, and natural capital and ecosystem services are therefore critical to achieve the SDGs and their associated targets (Rockström and Sukhdev 2017). Future Earth was launched at the Rio+20 United Nations Conference on Sustainable Development in Brazil, as an international initiative on global sustainability research. Future Earth incorporates integrated environmental change research, through collaborations between science and society, aimed at reaching global sustainability through societal transformations (Jiménez-Aceituno et al. 2020; Mauser et al. 2013). The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) provides scientifically credible state-of-the-art assessments to Governments, the private sector and civil society, on biodiversity and nature's contributions to people (ecoystem services) to inform evidence-based policy decisions at all levels (IPBES 2019). The most recent IPBES assessment highlighted that biodiversity and ecosystem services are in rapid decline, and the direct drivers of change (from the greatest impact) are changes in land and sea uses; exploitation of organisms; climate change; pollution; and invasive alien species – all of which are underpinned by values and behaviours of society such as local governance, consumption and production patterns, trade and technological innovations and population dynamics (IPBES 2019).

The magnitude of human activities has pushed us into the epoch of the Anthropocene, and we now risk crossing planetary boundaries that would cause catastrophic and irreversible environmental changes, with consequences for human well-being (Steffen et al. 2015). It is predicted that anthropogenic environmental pressures will intensify in the future, resulting in further environmental degradation, climate change, and pollution, and impacting on the ability of natural capital to provide ecosystem services (IPBES 2019; Steffen et al. 2015; Millennium Ecosystem Assessment (MEA) 2005, McGranahan et al. 2005). Population growth and rapid rates of urbanisation, particularly in the cities of the South, are placing increasing pressure on- and demands for- ecosystems and their services (Steffen et al. 2015; Holden and Otsuka 2014). The growing strain on ecosystem services, is concerning for the well-being of poorer communities, many of whom are directly dependant on ecosystem services for survival (Davenport et al. 2012; Stoian 2005; Shackleton and Shackleton 2004). It is predicted that current trajectories of biodiversity and ecosystem services loss may result in global targets, such as the SDGs, not being met, with progress being undermined for 80% of the targets assessed by IPBES for the Goals related to poverty, hunger, water, health, climate, cities, land

and oceans (SDGs 1, 2, 3, 6, 11, 13, 14, and 15) (IPBES 2019).

These concerns raise the importance for science to better understand the linkages between human progression and environmental limits, for example, through the understanding, and application, of sustainability frameworks (Steffen et al. 2015; Raworth 2012; Rockström 2009). This can, in turn, support government actions that are needed to ensure sustainability (Dearing et al. 2014) and to protect and manage important ecosystems and their services, to safeguard the livelihoods of citizens, particularly the urban poor (Tallis et al. 2008; MEA 2005). Radical changes are needed to achieve sustainablity, through seeking to facilitate major shifts in understanding and actions, across a range of diverse actors, at both organisational and individual levels (McPhearson et al. 2021).

The aim of this PhD is to apply social-ecological systems thinking and ecosystem service theory, to analyse the various roles that both humans and the environment play, towards achieving sustainable human well-being outcomes, using a transdisciplinary approach. This aim does not sit in one specific research or scientific domain, but crosses multiple disciplines, which necessitates an understanding of each of their basic concepts. This Chapter therefore outlines the various frameworks and theoretical concepts that underpin the aim of the PhD Thesis, and provides a description of the applicability of each in undertaking the research.

Sustainability Frameworks

The planetary boundaries framework proposed nine 'safe operating space' global biophysical boundaries that humans should remain within to avoid irreversible or catastrophic environmental change. These are: climate change, biodiversity loss, freshwater use, land use change, ocean acidification, atmospheric aerosol loading, stratospheric ozone depletion, chemical pollution, and biogeochemical (phosphorus and nitrogen) flows (Rockstrom et al. 2009). The revision and update of the planetary boundaries framework by Steffen et al. (2015) resulted in a two-tier boundaries approach, which considered the importance of cross-scale interactions and regional-level heterogeneity of the processes supporting the boundaries. The boundaries of climate change and biogeochemical flows were identified as foundational, whereby crossing these will have cascading effects on the remaining boundaries, and set in motion changes that may leave the planet in an unhospitable state (Steffen et al. 2015).

The planetary boundaries framework has instigated high levels of international interest and has influenced global discourse on sustainability (Cole et al. 2014). However, there are numerous alternative approaches (for example, Running 2012) for describing Earth System functioning, including potentially valuable metrics for quantifying the human imprint on it, that provide ways to assess and quantify interactions among boundaries, which complement the original

approach, and enrich the planetary boundaries concept as it continues to evolve (Steffen et al. 2015).

Building on the Rockström (2009) safe operating space model, a 'safe and just operating space,' was proposed (Raworth 2012), which identified the social foundation as the inner boundary, below which are many dimensions of human deprivation including health care, food security, water and sanitation, income, education, jobs, gender equity, social equity, and resilience (Fig. 1.1). Beyond the environmental ceiling that forms the outer boundary are many dimensions of environmental degradation linked to, for example, climate change, land use change and freshwater use. The donut shaped area defined the environmentally safe and socially just operating space for humanity that lies between the two boundaries. This safe and just space is also defined as the space within which inclusive and sustainable economic development takes place (Raworth 2012).

The planetary boundaries concept was merged with the safe and just space concept to develop a new framework to identify national (Cole et al. 2014) and regional scale (Dearing et al. 2014) safe and just operating spaces for sustainable development. It was argued that the application of the concept at regional level can have an impact on governance and policy-making, and serve as an important symbolic and communication instrument for regional equity and sustainability (Dearing et al. 2014).

While much focus has been given in scientific literature to mapping SDGs at national policy level, less attention has been on understanding how local sustainability initiatives are addressing the SDGs (Jiménez-Aceituno et al. 2020). This PhD contributes to the evolution of the application of sustainability frameworks, from global to local level. It does this by providing local level evidence on actions from two local level sources of change: (1) civic/community action and (2) local government actions (eThekwini Municipality) through establishing linkages between natural capital, ecosystem services, social outcomes, human well-being, and the SDGs (**Chapters 2, 3, 4 and 6**).

Figure 1.1: A safe and just space for humanity: The 11 dimensions of social foundation (Rio+20) and nine planetary boundaries (Rockström 2009) indicating the environmental ceiling (From Raworth 2012)

Social-ecological systems, ecosystem services and human well-being

A central aim of this work is to establish the linkages between natural capital and social outcomes at the local level – towards achieving sustainable development. I do so by taking a social-ecological systems approach, with a lens of natural capital and ecosystem services enhancements.

Natural capital can simply be explained as capital from nature: a stock including all natural resources that support human societies in water, air, sea, above and below-ground (Mace et al. 2015). There is an understanding that natural capital underpins human, economic, societal, and cultural well-being (Costanza et al. 2014), whereby well-being is "*embedded in and rests on a resilient biosphere*" (Folke et al. 2016, p. 41). The nature of human 'health and well-being', happiness, and good-life, have been contemplated for decades, and a variety of

conceptualisations have been proposed, majority of which were from the psychological and health sciences, with four categories featuring most prominently: 'hedonic and eudemonic', 'quality of life', and 'wellness' (Neve and Sachs 1992).

Hedonic conceptualisation of psychological well-being focusses on pleasure, happiness, and life satisfaction (Ryan and Deci 2001), and 'eudemonic,' purports that psychological health is achieved by fulfilling one's true nature, functioning at optimal level or fulfilling your potential (Lent 2004). The third, broader category of well-being is 'quality of life' (Roscoe 2009; Lent 2004), which includes social, physical and psychological well-being. Quality of life is defined by the World Health Organisation as a "*broad range concept affected in a complex way by the persons' physical health, psychological state, level of independence, social relationships and their relationship to salient features of their environment*" (World Health Organization Quality of Life Assessment Group 1998, p. 1570). The fourth definition, 'wellness', emphasises that well-being is more than the absence of illness, its rather a holistic lifestyle that includes numerous components of health and functioning: physical, spiritual, and personalist aspects (Palombi 1992, Roscoe 2009).

In the 1990s, five constituents of well-being emerged from research conducted across 23 countries, where perceptions of good life and bad life were discussed by poor people: material assets, health, security, good social relations, and freedom of choice and action (Narayan et al. 2000). The Millennium Ecosystem Assessment similarly defined human well-being in these five categories as, "*security; an adequate supply of basic materials for livelihood (for example, food, shelter, clothing, energy, etc.); personal freedoms; good social relations; and physical health"* (Neve and Sachs 1992), and linked them to ecosystem services (Fig. 1.2).

Ecosystem services are the benefits that humans derive from nature (MEA 2005). They include regulating services or regulating Nature's Contributions to People (NCP), of climate regulation, water and air purification, flood mitigation, biological regulation, and/or disease control, hazard regulation, and maintenance of biological diversity (genepool protection); cultural or non-material NCP of aesthetic, recreational, cultural, and educational services; provisioning services or material NCP of water supply, food, medicinal resources, building materials and harvesting products (de Groot et al. 2010; Díaz et al. 2018). Ecosystem disservices include nuisances or undesirable effects of natural or human-impacted ecosystems to humans, such as invasive species, biological hazards, pests, storms, floods, and heat waves (Lyytimäki and Sipilä 2009; Döhren and Haase 2015). Despite ecosystem services being crucial for human well-being and survival, many are degraded or used unsustainably (MEA 2005).

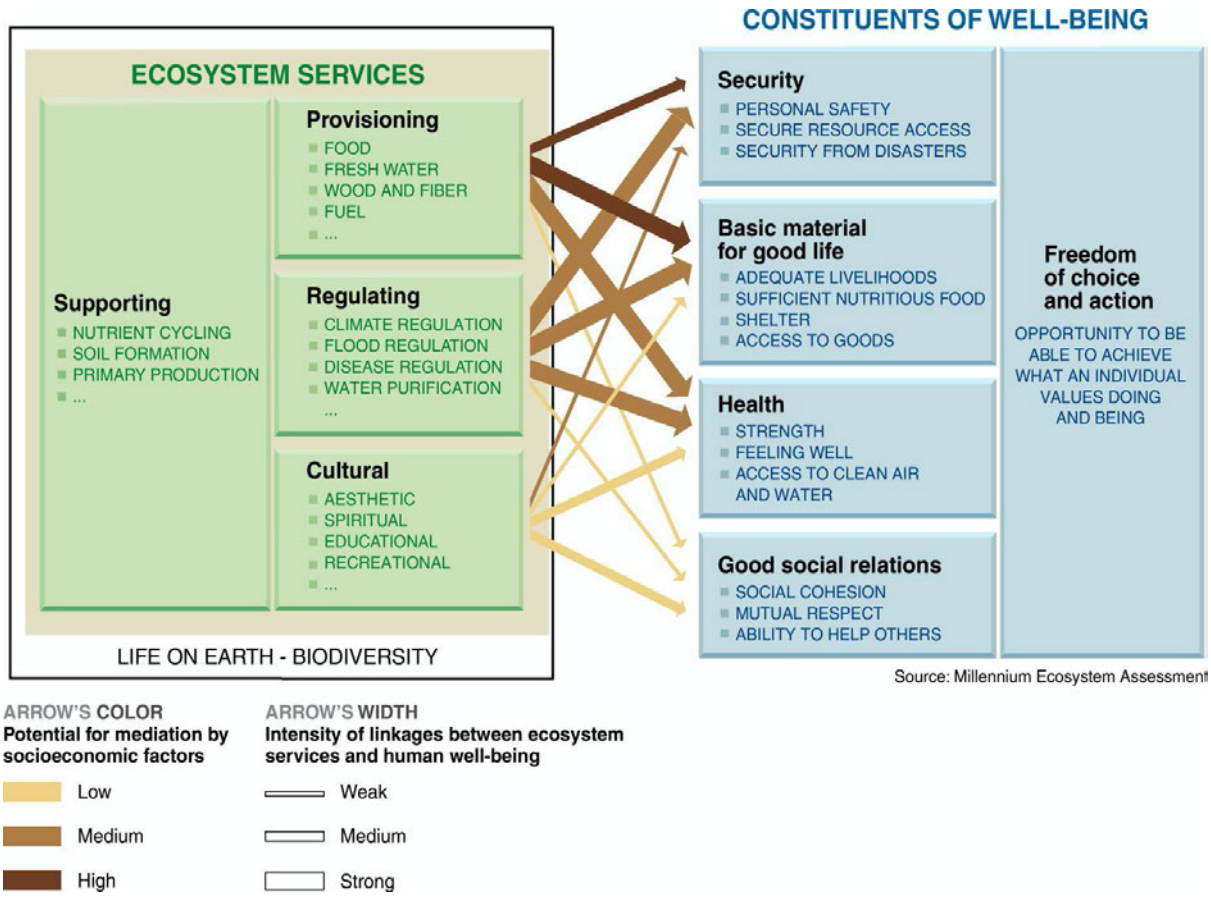

Figure 1.2: The links between ecosystem services and human well-being (from MEA 2005)

Ecosystems and societies are intertwined from local to global scales, forming social-ecological systems (Folke et al. 2016). Interactions occurring across scales in social-ecological systems often result in feedbacks that either benefit system changes or inhibit them (Levin et al. 2013), and influence the capacity of the biosphere to sustain human development (Fischer et al. 2015). Aiming to improve the local environment, for example through environmental management, could yield benefits at multiple scales (Folke et al. 2016).

The concept of social-ecological systems research was originally defined as a framework for the study of intertwined natural and human systems (Berkes and Folke 1998), but has since been used for a diversity of sciences in addition to social and environmental sciences, including medicine, arts, humanities and psychology (Colding and Barthel 2019). A framework for social-ecological research was proposed (Fig 1.3), which put forth a list of 60 variables that could be used for the characterisation and monitoring of social-ecologial systems, with three main components being the social system, the ecological system and the interactions between them, which include: (1) from ecosystem to social system: ecosystem services supply and ecosystem disservice supply; (2) from social system to ecosystem: ecosystem services demand

and human actions on the environment and (3) bidirectionally, the social-ecological coupling between the ecosystem and the social system (Pacheco-Romero et al. 2020).

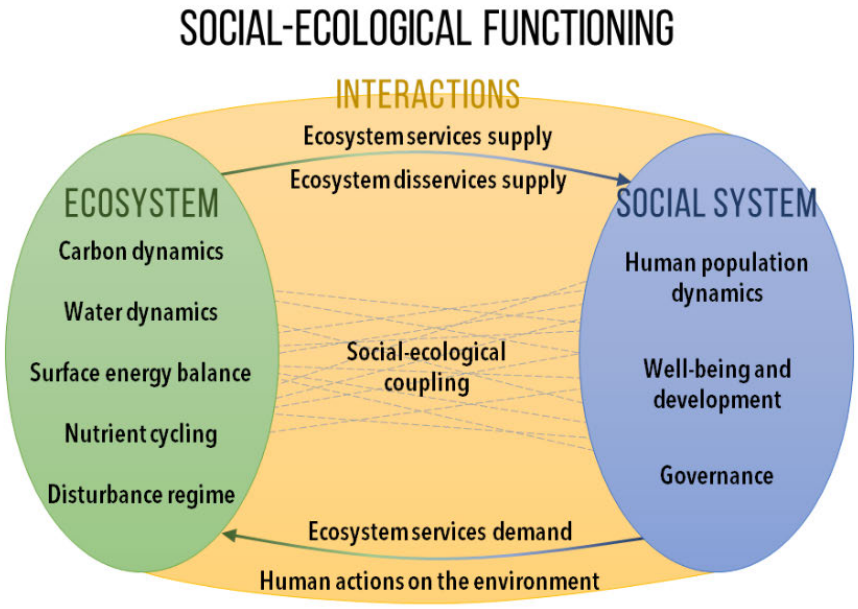

Figure 1.3: Social-ecological System Functioning. Functional charateristics of social-ecological systems: Three main components are the sub-systems 'ecosystem', 'social systems' and the 'interactions' between them. The social-ecological coupling is the interaction that does not flow from 'ecosystem' or 'social system', but is a state dimension of links and feedbacks between them (from Pacheco-Romero et al. 2020)

Numerous definitions have been used in scientific literature to describe social-ecoloigal systems, however, 65% of articles that dealt with social-ecological systems research, failed to provide any definition at all (Colding and Barthel 2019). The lack of a consensus definition for social-ecological systems was identified as a weakness, and there was thus a call for a more precise definition to be developed, which includes 'economics' since the social, ecological and economic 'triad' is inherent in sustainable development (Colding and Barthel 2019). Through this thesis, a variety of social, economic and ecological interplays are explored, which directly responds to this call for deeper integration of the 'triad' to be considered in social-ecological systems.

The following excerpt, from Folke et al. (2016), frames the aim, and purpose, of this thesis:

> *"Humans operate in a legacy of social-ecological interplay, directly or indirectly, consciously or unconsciously, shaping the capacity of the biosphere and our options and opportunities for development. This is a critical observation if sustainability for us humans, future generations included, is of concern. And if human well-being is a central goal of sustainability, its dependence on a resilient biosphere has to be accounted for, a necessity that has become more and more obvious".*

Plural values of ecosystem services

Research in the last decade has advanced the concept of the plural valuation of nature, as it is attributed and valued through different lenses, by diverse actors, from diverse disciplines, religions, races, genders, ethnicities and geographies (Pascual et al. 2017; Rincón-Ruiz et al. 2019; Jacobs et al. 2021). Through valuation, the importance and significance of nature to people's lives is assessed; however, such importance differs between individuals and groups of varying levels of power, given that values are based on the different perspectives or lenses whereby human-nature relations are perceived (Jacobs et al. 2021). The consideration of the plural values of nature is an important aspect towards effective societal decision-making, on the management and use of nature (Jacobs et al. 2021). Plural valuation is proposed a solution to improve decision making through knowledge generation, as it encompasses a science-policy process in which multiple values, as they are attributed to nature by social actors, are assessed (Rincón-Ruiz et al. 2019).

The following vision for plural valuation was formulated, on the basis of the visions and goals of various initiatives and their applications in different contexts (Jacobs et al. 2021):

> *"We imagine a world in which the diversity of values – especially neglected values – and knowledge related to nature and its contributions to quality of life are included in policy, decision-making, governance and practice to achieve a more just and sustainable world. We envision a world in which the participation and representation of all people is realized and nature's contributions to people are distributed equitably within and across generations."*

Practical steps to incorporate plural valuation of nature, as proposed by the literature (Jacobs et al. 2021), have been taken, particularly in Chapters 2 and 6 of this Ph.D: (1) Creating opportunities for nurturing plural values and forming alliances within existing disciplinary silos; (2) Creating innovative methodologies, practices and networks across disciplines, age groups, and professional expertise; (3) Knowledge production and learning through strengthening science-policy-practice dialogues beyond disciplines; (4) Connecting local

communities practices, capacities and concepts of value and integrating neglected voices; and (4) Engaging a broader community through formal and informal with concepts of plural valuation.

The plural valuation of nature is therefore derived from broad and evolving conceptual and methodological approaches, which aim to highlight the diversity of values from diverse stakeholders, which ultimately contributes towards decision making that fosters environmental sustainability and social equity (Zafra-Calvo et al. 2020).

Sustainability governance, social-ecological systems and ecosystem services

At the 2012 United Nations Conference on Sustainable Development, Rio+20, commitments were made by governments to mainstream sustainable development, through integrating, and recognising the linkages between, economic, social and environmental aspects. The 2030 sustainable development agenda aims to address a broad range of development issues, and thus include goals and targets that consider social, economic and environmental (biosphere) considerations (United Nations Development Programme 2016). Natural capital and ecosystem services are foundational in achieving the SDGs, given that sustainable social and economic development is only possible if it occurs within the limits of the environment (Rockström and Sukhdev 2017). Core to the sustainability concept is the consideration of economic and social development being intimately linked to ecosystem functions that supply the 'free' ecosystem services, which are the basis for social and economic development, whereby the loss of ecosystem functions will ultimately impact on future social and economic development (Department of Environmental Affairs (DEA) 2011; Rockström and Sukhdev 2017). Environmental challenges are often associated with anthropogenic way of life and consumption, which impact the other two dimensions of sustainability, whereby the natural environment both impacts- and is impacted by- economic and social dimensions (Silvestre and Tîrcã 2019).

In terms of the National Strategy for Sustainable Development (NSSD), a systems approach to sustainability is applied, providing for the economic system, the socio-political system, and the ecosystem to be embedded within each other, and further integrated through the governance system that provides a legitimate regulatory framework that holds all the other systems together (DEA 2011). Furthermore, the NSSD emphasises the importance of ensuring sustainable development that allows for the aforementioned systems to remain mutually compatible, while the key development challenges are met through specific actions and interventions to eradicate poverty and severe inequalities (Department of Environmental Affairs (DEA) 2011). Specifically towards sustainable cities and communities, SDG 11 requires the protection of natural heritage, the reduction of environmental impacts, and for development planning that is

strengthened though positive economic, social, and environmental links between urban, peri-urban, and rural areas (United Nations 2015). In order to facilitate sustainable development and to achieve the SDGs, it is, therefore, crucial to understand the social-ecological systems that underpin them, and the relationships between natural capital, ecosystem services and social outcomes.

This study aims to address this challenge by considering the social-ecological systems from multiple viewpoints, with a focus on poverty alleviation and enhancement of social outcomes through civic ecology (Chapters 2, 3 and 4), the reduction in environmental impacts from research practices (Chapter 5), and improved development planning for sustainability through transdisciplinary science-action approaches (Chapter 6) (Fig 1.4).

Civic ecology

Civic ecology initiatives aim to provide diverse environmental and socio-economic benefits, through people-centred participatory approaches (Cock and Fig 2000). Civic ecology practices include environmental stewardship actions that enhance natural capital, ecosystem services, and human well-being, in social-ecological landscapes, such as cities (Krasny et al. 2013). Civic ecology practices are increasing, and contributing to global sustainability initiatives; however, their contributions to ecosystem services are rarely measured (Krasny et al. 2013). This research aims to address this gap by quantifying the contributions of civic ecology to ecosystem services (Chapters 2 and 3).

Social-ecological systems, sustainability and transdisciplinary approach

The application of a holistic perspective on social-ecological systems is proposed as a solution to problems involving both people and nature (Carpenter 2002). The recognition by scientists and governments that ecosystems and humans influence each other, whereby humans are negatively impacting ecosystems, and ecosystems influence well-being, has led to large scale interdisciplinary and transdisciplinary collaborations becoming increasingly common (Sakai and Umetsu 2014). Transdisciplinarity has been proposed a solution to the disjunction between science and action, with a host of solutions to address the science-policy nexus being proposed, including joint knowledge production (Hegger and Dieperink 2014), learning organisations, and transdisciplinary research (Lang et al. 2012). The transdisciplinary approach aims to combine research and implementation disciplines in order to move ecosystem service theory into practice (Nahlik et al. 2012), by undertaking cross-cutting research and integrating and synthesising ecological and institutional methods and data, to aid multifaceted decision making (Lawton and Rudd 2013).

A transdisciplinary approach integrates knowledge from different disciplines and non-academic participants with a focus on generating integrated, transformative knowledge and theory among science and society (Jahn et al. 2012). Most scholars have agreed that a transdisciplinary approach is required to deal with problems of sustainability, which are complex and require integrated solutions from a variety of disciplines (Jahn et al. 2012). Figure 1.4 highlights this process with the key steps relating to both team and issue formulation, the creation of new knowledge, and transdisciplinary integration, where results for practice and scientific understanding are produced (Jahn et al. 2012).

Throughout this thesis, the concept of transdisciplinarity has been applied from both the practitioner and scientist perspectives, respectively, by "*working with scientists to improve implementation practices, through more effective problem solving"* (Chapters 2, 3 and 4) while also "*collaborating across disciplines, and with practitioners and policy makers and other stakeholders to address societal problems*" (Chapter 5 and 6), .

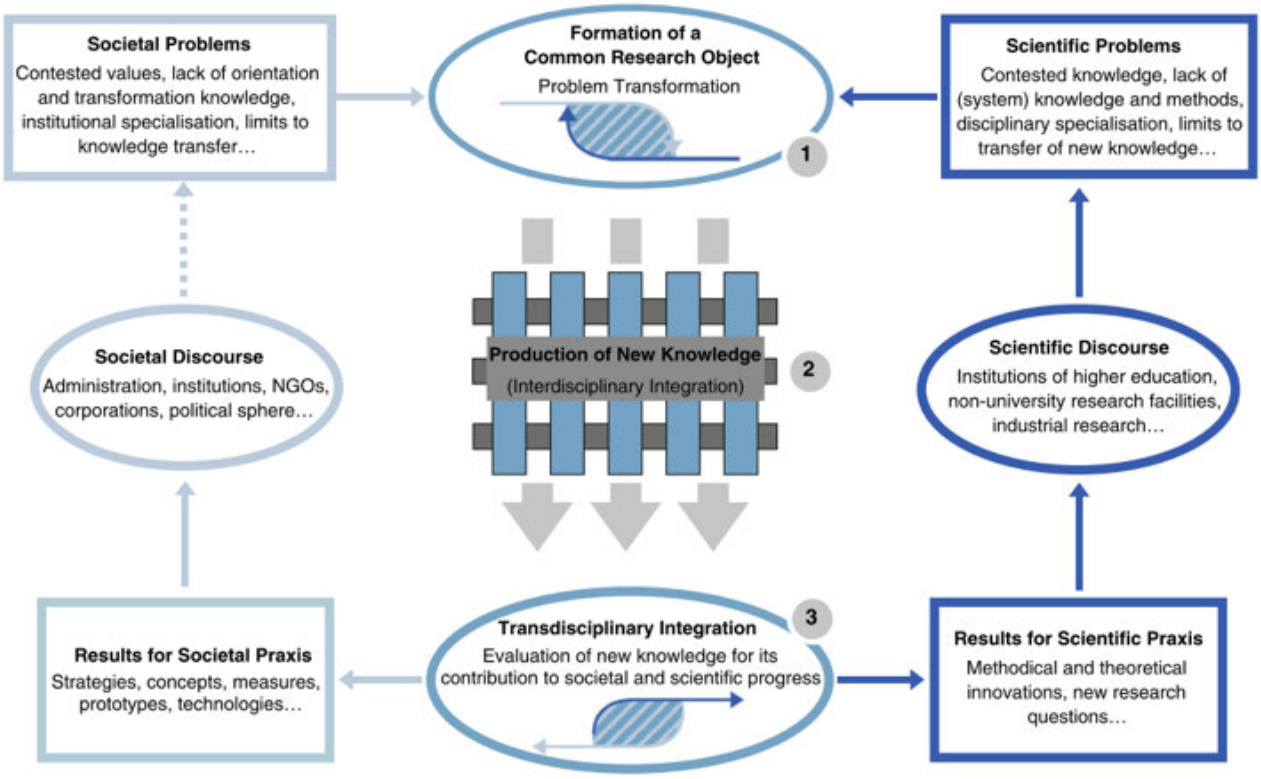

Figure 1.4. A conceptual model of transdisciplinarity (from Jahn et al. 2012)

COVID-19 Pandemic and its effects on social-ecological systems

The outbreak of the coronavirus disease 2019 (COVID-19) pandemic started in Wuhan, China, in December 2019 (El Zowalaty et al. 2020). About a month later, on 30 January 2020, the

World Health Organisation declared COVID-19 as a global emergency, due to the rapid rate of spread and the growing cases of deaths in China and internationally (Saadat et al. 2020). COVID-19 spread to every continent except Antarctica (El Zowalaty et al. 2020).

The mandatory wearing of masks and the use of hand sanitiser, resulted in massive amounts of medical wastes in the environment, while restrictions on travel and millions of people being on 'lockdown' resulted in improvements in air pollution, reduced carbon emissions, reduced water pollution and environmental noise reduction, in certain parts of the world (Saadat et al. 2020, Zambrano-Monserrate et al. 2020).

This PhD study commenced long before onset of the COVID-19 pandemic. However, the considerations of the pandemic in relation to social-ecological systems and ecosystem services are warranted, given that the pandemic did not only cause impacts on human health and deaths, it also resulted in significant global economic and social distress, and both positive and negative environmental impacts (Bashir et al. 2020). Scientists have acknowledged that it is likely that the positive environmental impacts of COVID-19 are temporary, and that alternative means of environmental protection and mitigation of negative environmental impacts are thus needed (El Zowalaty et al. 2020, Zambrano-Monserrate et al. 2020), raising the importance of the social-ecological systems protection and enhancement considerations of this Thesis.

1.1 Study aims and key research questions

The aim of this PhD is to apply social-ecological systems thinking and ecosystem service theory, to analyse the role of the humans and the environment in achieving sustainable human well-being outcomes using a transdisciplinary approach. Transdisciplinary approaches towards sustainability require inputs from a variety of actors. In this thesis, I analyse inputs from (1) local communities; (2) institutional/government actors, and (3) research/academic community (Fig. 1.5). The concept of ecosystem services through the lens of civic ecology is applied, in order to highlight that local actions towards natural capital improvements can make significant national and global policy achievements, through contributing to the SDGs.

The following research questions have been crafted to achieve the objectives of this research:

Chapter 2:

1. What are the various benefits of civic ecology practices to the social-ecological system of disadvantaged communities, particularly with respect to ecosystem services?
    a. What are the values and perceptions held by the beneficiaries (people from the community working as part of the Wise Wayz Water Care (WWWC) civic ecology

programme), and the broader community related to the WWWC civic ecology programme?

b. How do ecosystem services (ES) use and values differ between the beneficiaries and the broader community?

Chapter 2:

2. What are the ecological, socio-economic and health outcomes of the community-based environmental management interventions?
3. What is the significance of the impacts of community-based environmental management interventions on the social-ecological system?
4. How can the significance of the ecological, social and health outcomes associated with different local scale civic management interventions be measured, in a practical way that is accessible to decision-makers?

Chapter 4:

5. How does ownership and access to biodiversity and ES contribute to human well-being?
6. What is the significance of the ecological, social and health outcomes associated with different local scale civic interventions?
   How do different civic interventions contribute to the SDGs?

Chapter 5:

7. How can learning and collaboration in virtual teams assist to enhance inclusivity for marginalised scientists, such as those in the Global South, or emerging researchers who may be constrained by funding; or women?
8. How can international research teams more effectively use virtual collaboration to actively contribute to global sustainability and climate change mitigation efforts?
9. How can systems thinking principles assist to unpack learnings and improve virtual research collaboration processes going forward?

Chapter 6:

10. What are the linkages between natural capital, ES and social outcomes (SO) relative to the city of Durban?
11. What are the most critical ES-SO relationships for Durban, and how can ES-SO relationships be prioritised?

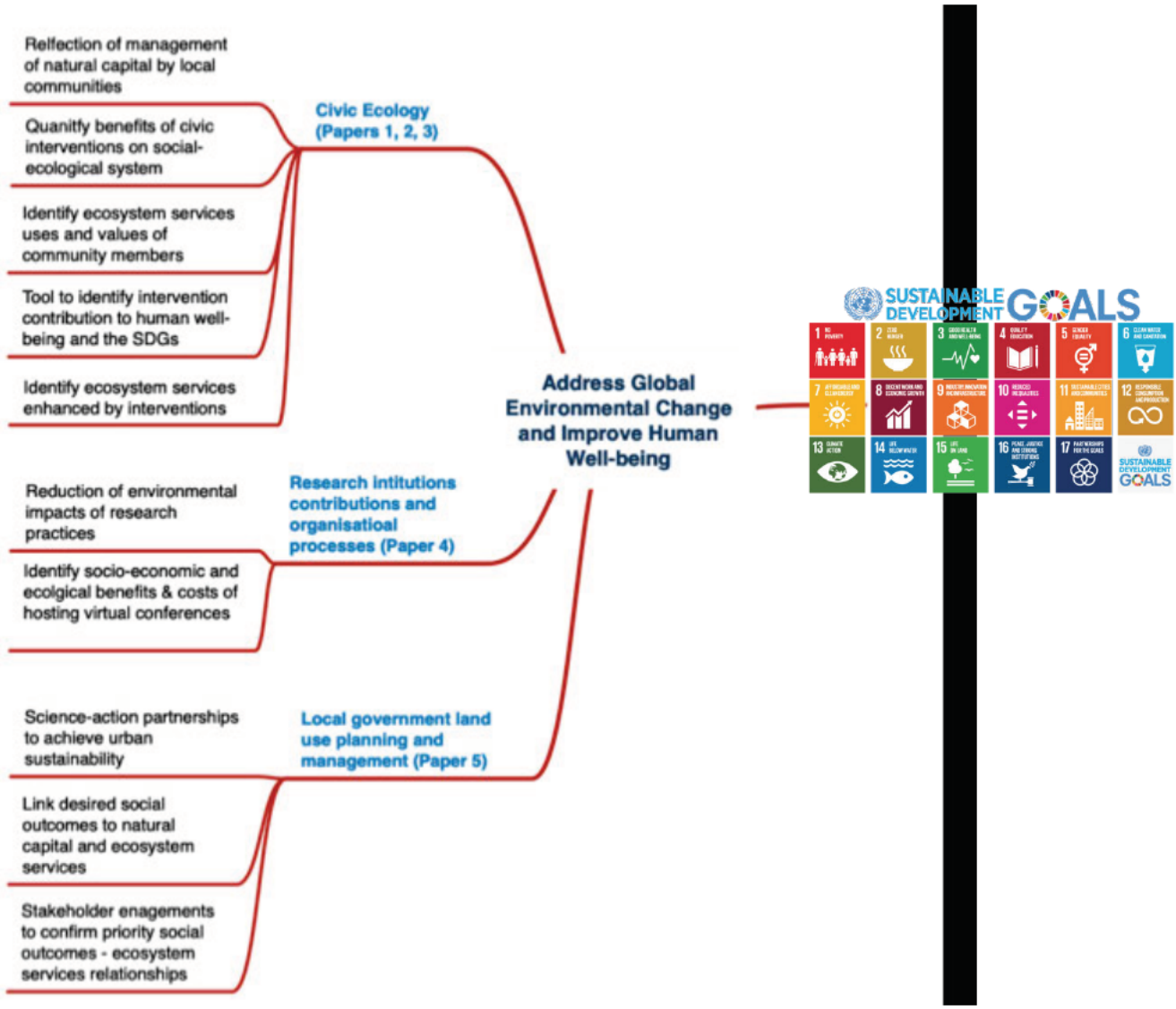

Figure 1.5: Overview of PhD Research Themes: Civic ecology, research institutions and local government contributions to the Sustainable Development Goals, through natural capital and ecosystem services enhancements that aim to address global environmental change and enhance human well-being.

1.2 Methods

This study applied a social-ecological-systems approach. Social-ecological-systems describe an integrated system of humans and nature, within which social and ecological components influence each other in a constantly evolving and interdependent manner (Berkes et al. 2003; Folke 2006; Ostrom 2009). To do this, a mixed methodological approach was employed, including household surveys, interviews, field observations, environmental impact assessment and systems mapping (Table 1.1).

Ethical Approval was granted by the UKZN Humanities and Social Sciences Research Ethics Committee for all research conducted in this thesis. See Table 1.1 for the Ethics Approval reference numbers.

1.2.1 Study area

This research was undertaken in Durban, South Africa. Durban is administered by eThekwini Municipality, the local government authority, is situated in the province of KwaZulu-Natal, South Africa, and is approximately 2291.93 km^2 in extent (1.4% of the province) with a population of 3.55 million (Davids et al. 2016). Durban has a 98 km long coastline that is dissected by the rivers of 18 major water catchments and 16 estuaries. Due to its high levels of plant endemism and habitat loss, the municipality sits within the Maputaland-Pondoland-Albany global biodiversity hotspot (Mittermeier et al. 2005). The study area included urban and peri-urban/rural environments, with approximately two-thirds of the municipal area being rural or semi-rural, where a large proportion of local inhabitants are indigent and directly reliant on ecosystem services for basic needs (Roberts and Donoghue 2013, Sutherland et al. 2016)

Table 1.1: Methods for each Chapter and Associated Ethics Approvals

Chapter	Methods	Ethics Approval from UKZN Humanities and Social Sciences Research Ethics Committee
2	Literature reviews, social-ecological systems analyses, household and beneficiary surveys, stakeholder workshops, interviews ecosystem services assessment, site visits	Ref no: HSS/0035/018D
3	Literature reviews, social-ecological systems analyses, household and beneficiary surveys, stakeholder workshops, interviews, site visits, environmental impact assessment	Ref no: HSS/0035/018D
4	Literature reviews, social-ecological systems analyses and mapping, quantifying intervention contributions to sustainable development goals and human well-being	Ref no: HSS/0035/018D
5	Literature reviews, surveys, carbon emission calculations, SWOT analyses	Ref no: HSS/0844/018CA
6	Literature reviews, workshops, literature reviews, stakeholder engagement, prioritisation processes	Ref no: HSS/1929/016

Social challenges in Durban include: high levels of poverty; unequal basic service delivery; high rates of urbanisation; many densely populated informal settlements; and dual governance arrangements, whereby eThekwini Municipality jointly administers communal land in the rural hinterland in the northwest and southwest areas of the municipality with traditional authorities, the Ingonyama Trust Board, and provincial government (Davids et al. 2016; McLean, et al. 2016; Sutherland et al. 2016). Due to these challenges, socio-economic development priorities have taken preference over environmental and biodiversity concerns, in the past (Roberts 2008).

In the South African context, high per-capita carbon emissions and increasing and severe pressures on the natural resource base have resulted in the degradation of many ecosystems, to the extent that South Africa is considered to be on an unsustainable development path (Department of Environmental Affairs 2011). For Durban, numerous threats to biodiversity and the associated delivery of ecosystem services exist, including habitat destruction and fragmentation, spread of invasive alien species, pollution (eThwkwini Municipality 2012), and climate change (Roberts et al. 2012).

1.3 Research approach

This research was undertaken under the auspices two overarching research programmes being facilitated by the University of KwaZulu-Natal, in partnership with government and research organisations, namely, the Durban Research Action Partnership (D'RAP) and the Sustainable and Healthy Food Systems Project (SHEFS).

1.3.1 D'RAP

The Durban Research Action Partnership (D'RAP) was first initiated between eThekwini Municipality (EM) and the University of KwaZulu-Natal (UKZN) in 2004, and formalised in 2011 (Cockburn et al. 2016). . The aim of D'RAP is to close the research-action gap, through the provision of human capacity, research, and specialist skills from the academic sector, to support local government departments performing various functions in the biodiversity and environmental disciplines in Durban (Roberts et al. 2012; Cockburn et al. 2016). The partnership was developed to advance knowledge in biodiversity conservation and management within the context of global environmental change. Through the partnership, collaborative research is conducted within the eThekwini Municipal Area in a range of disciplines including environmental, biological, social science, governance, and economics. The programme not only aims to generate much-needed knowledge to assist managers in the Municipality in making biodiversity and conservation decisions, but also to build capacity by

employing interns and supporting student research activities at the university. Such novel institutional partnerships are important for generating knowledge and learning, and to address the gap between scientific research, policy development, and management, within a local government setting (Rouget et al. 2016).

1.3.2 SHEFS

The Sustainable and Healthy Food Systems (SHEFS) project is multi-partner research consortium led by the London School of Hygiene and Tropical Hygiene, in partnership with the University of KwaZulu-Natal (UKZN) in South Africa, University College London, the School of Oriental and African Studies, University of London, The Centre for Food Policy at City University of London, The Food Foundation, The Royal Veterinary College, and he Public Health Foundation of India, and the Ashoka Trust For Research In Ecology And The Environment. SHEFS is funded by the Wellcome Trust under their Our Planet Our Health Programme.

The primary aim of SHEFS is to provide policy makers with novel, interdisciplinary research evidence to define future food systems policies that deliver nutritious and healthy foods in a sustainable and equitable manner. The study aims to develop comprehensive and integrated understandings of the links between environment, food systems and health and to develop interdisciplinary approaches to create a shared understanding of policy environments for the co-development of policy options.

1.4 PhD Structure

The PhD is structured in publication format. The following publications are included in this PhD:

CHAPTER 2: *Civic ecology enhances natural capital,, ecosystem services and well-being of local communities: Evidence from two communities in Durban. South Africa.* Rashieda Davids, Mathieu Rouget, Margaret Burger, Kirsten Mahood, Ntswaki Ditlhale, Rob Slotow.. Accepted for publication in MDPI *Sustainability (in press)*.

CHAPTER 3: *Civic Environmental Management, Ecosystem Services and Social-Ecological System Outcomes: An Impact Assessment.* Rashieda Davids, Mathieu Rouget, Margaret Burger, Kirsten Mahood, Ntswaki Ditlhale, Rob Slotow. Under review at the *Journal of Environmental Management*.

CHAPTER 4: *Local Enhancement of Ecosystem Services for Achievement of the SDGs: A Systems Analyses*. Rashieda Davids, Mathieu Rouget, Rob Slotow. Submitted to *Ecosystem Services*.

CHAPTER 5: *The environmental impact of research meetings: a mixed-methods case-study from the Sustainable and Healthy Food Systems research programme.* Rashieda Davids, Pauline Scheelbeek, Nafiisa Sobratee, Rosemary Green, Barbara Häesler, Tafadzwanashe Mabhaudhi, Suparna Chatterjee, Nikhil Venkateshmurthy, *Georgina Mace (Deceased), Alan Dangour, Rob Slotow. Under review at the Journal of Cleaner Production.

CHAPTER 6: *– Linking ecosystem services to desired social outcomes – outcomes from an expert workshop in Durban, South Africa*. Rashieda Davids, Mathieu Rouget, Debra Roberts, Nohkuthula Dubazane, Cameron McLean, Jo-anne Douwes, Patrick O'Farrell, Benis Egoh, Michelle Audouin, Nadia Sitas, Ryan Blanchard, Rob Slotow. [Unpublished work].

CHAPTER 2: CIVIC ECOLOGY UPLIFTS LOW-INCOME COMMUNITIES, IMPROVES ECOSYSTEM SERVICES AND WELL-BEING, AND STRENGTHENS SOCIAL COHESION

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Photo: Folweni Community Credit, Rashieda Davids

Abstract

Ecosystem services enhance well-being and the livelihoods of disadvantaged communities. Civic ecology can enhance social–ecological systems; however, their contributions to ecosystem services are rarely measured. We analysed the outcomes of civic ecology interventions undertaken in Durban, South Africa, as part of the Wise Wayz Water Care programme (the case study). Using mixed methods (household and beneficiary (community members implementing interventions) surveys, interviews, field observations, and workshops), we identified ecosystem service use and values, as well as the benefits of six interventions (solid waste management and removal from aquatic and terrestrial areas, recycling, invasive alien plant control, river water quality monitoring, vegetable production, and community engagement). Ecosystem services were widely used for agriculture, subsistence, and cultural uses. River water was used for crop irrigation, livestock, and recreation. Respondents noted numerous improvements to natural habitats: decrease in invasive alien plants, less pollution, improved condition of wetlands, and increased production of diverse vegetables. Improved habitats were linked to enhanced ecosystem services: clean water, agricultural production, harvesting of wood, and increased cultural and spiritual activities. Key social benefits were increased social cohesion, education, and new business opportunities. We highlight that local communities can leverage natural capital for well-being and encourage policy support of civic ecology initiatives.

Keywords: ecosystem services; environmental management; stewardship; social ecology; social–ecological system; sustainable development

2.1 Introduction

The magnitude of human activities has pushed us into the epoch of the Anthropocene, where we risk crossing planetary boundaries that would cause catastrophic and irreversible environmental changes, with negative consequences for human well-being (Steffen et al. 2015). It is predicted that anthropogenic environmental pressures will intensify in the future, resulting in further environmental degradation, climate change, and pollution, and impacting on the ability of natural capital to provide ecosystem services (McGranahan et al. 2005, MEA 2005, Steffen et al. 2015). Ecosystems and their services, or "nature's contributions to people (NCP)" (Díaz et al. 2018), are essential to support human well-being and development (MEA 2005). It is understood that natural capital underpins social, human, and built capita, and the interaction between these various forms of capital will determine the levels of well-being that humans could achieve in a particular context through, for example, ecosystem services (Costanza et al. 2014). Ecosystems and people are interdependent and intertwined through the concept of social–ecological systems.

Social–ecological systems research looks at the reciprocal interactions between people and nature at various temporal and spatial scales (Fischer et al. 2015). Knowledge of social, ecological, and other components in a system, and on the use and benefit of ecosystem services, is needed in order to derive maximum benefit from interactions in a system. Social–ecological systems provide a basis for understanding the interlinked dynamics of environmental and societal change (Fischer et al. 2015). Since human activities are the major drivers in social–ecological systems, whereby they can either diminish or enhance ecosystem services and well-being (Krasny et al. 2013), societal change would be essential to ensure ecosystem service protection and sustainability (Mauser et al. 2013). To foster societal change towards support for environmental management, we need an understanding of how biodiversity and ecosystem services are perceived by humans. Such perceptions would include the way in which humans observe, value, understand, and interpret biodiversity and ecosystem services (Morales-Reyes et al. 2018).

Demands for ecosystem services are increased with increasing populations in cities (Davids et al. 2018), particularly in cities of the global south, that have added pressures of poverty, and direct dependence on ecosystem services for livelihoods and well-being of the poor (Shackleton 2004, Stoian 2005). Ecosystem services provide the foundation for economic opportunities to empower the disadvantaged (MEA 2005). The disruption of social–ecological linkages can have detrimental effects on communities, particularly when access to ecosystem services are denied (Baird and Leslie 2013), or when ecosystem disservices, such as floods or invasive species, are experienced. This raises the importance of understanding and strengthening social–ecological linkages, while ensuring that ecosystem services are managed

appropriately, particularly in disadvantaged communities.

Civic ecology initiatives, or "community-based conservation", aim to provide diverse environmental and socio-economic benefits through people-centred participatory approaches (Cock and Fig 2000). Civic ecology practices include environmental stewardship actions that enhance natural capital, ecosystem services, and human well-being, in social–ecological landscapes, such as cities (Krasny et al. 2013). While civic ecology practices are increasing and contributing to global sustainability initiatives, their contributions to ecosystem services are rarely measured (Krasny et al. 2013).

In this study, we examined the understanding, use, and values of ecosystems and their services with regards to two low-income local communities, one peri-urban/rural and one urban, where some community members are implementing civic ecology initiatives. As a case study, we used the private sector-funded Wise Wayz Water Care (WWWC) programme, being implemented along the Golokodo and Mbokodweni Rivers, within Durban, South Africa (Fig. 2.1). Using a mixed methods approach (household surveys, interviews, field observations and workshops), we investigated the following questions: (1) What are the values and perceptions held by the beneficiaries (people from the community working as part of the WWWC civic ecology programme), and the broader community, related to the WWWC civic ecology programme? (2) What are the various benefits of civic ecology practices to the social–ecological system of disadvantaged communities, particularly with respect to ecosystem services? (3) How do ecosystem services uses and values differ between the beneficiaries and the broader community? In answering these questions, we explored how increased knowledge of ecosystems through civic ecology practices in social–ecological systems contribute to the protection and increased use and benefit of ecosystem services, both for beneficiaries and other members of disadvantaged communities.

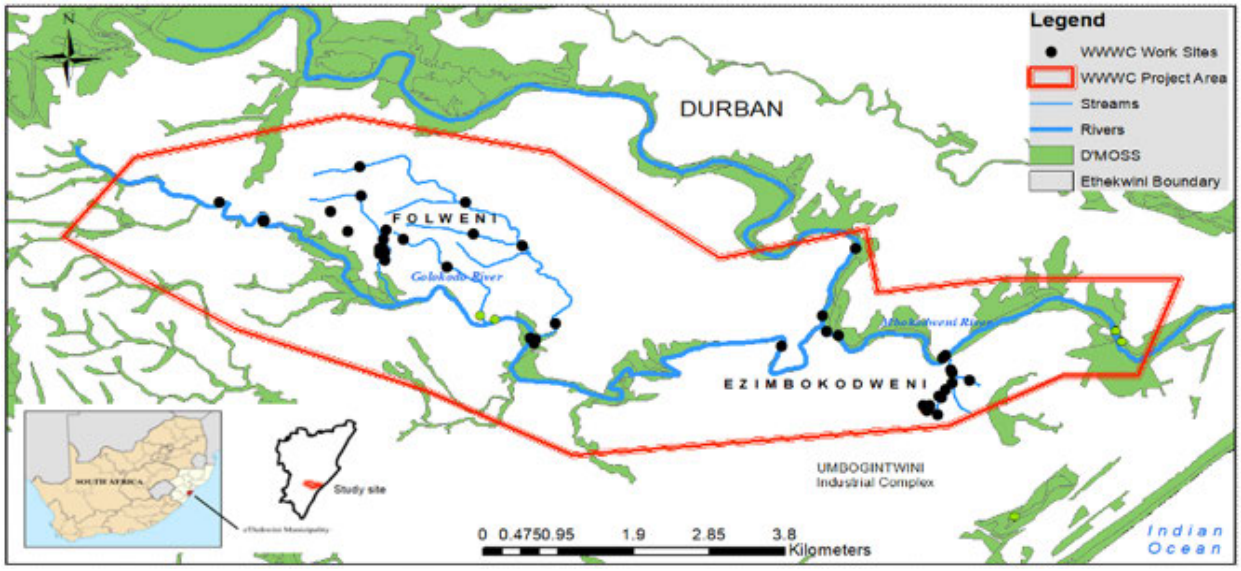


Figure 2.1: Study area: Wise Wayz Water Care Work (WWWC) sites in eThekwini Municipality (Durban), South Africa, indicating the sites within the peri-urban/rural Ezimbodweni and more urban Folweni communities. D'MOSS—Durban Metropolitan Open Space System.

2.2 Materials and Methods

2.2.1 Study Area

2.2.1.1 Socio-Economic Characteristics

The WWWC work area, the study area (Fig. 2.1), is situated in two peri-urban communities, Folweni and Ezimbokodweni, located in Durban, in the province of KwaZulu-Natal, South Africa. Both fall within the eThekwini Metro Municipal boundary. Folweni is more urban and is administered by eThekwini Municipality, while Ezimbokodweni is more peri-urban/rural and is jointly administered by eThekwini Municipality and Ingonyama Trust Board (traditional authority of communally owned rural lands).

The study area is characterised as one of the poorest in Durban, with low education, employment, and income levels. In Folweni, 17% have no source of income and 37% earn less than ZAR 1600 (USD 99.60 @ USD 1/ZAR 16.06) per month, 35% have secondary education, only 6% have higher education, 53% of households have piped water inside the dwelling, 42% have flush toilets connected to a sewer, and 47% of households are headed by females (Department of Statistics South Africa 2020). Similarly, in Ezimbokodweni, 20% have no source of income, a third of the population earn less than ZAR 1600 per month, 30% have completed secondary education, only 2.8% have higher education, 10.7% households have piped water inside the dwelling, 4% have a flush toilet connected to a sewer, and 40% of

households are headed by females (Department of Statistics South Africa 2020).

Sewage infrastructure in the Folweni area is poorly maintained; most of Ezombokodweni utilises informal pit latrines, and is not serviced by waterborne sewer systems, with sewerage being noticed to surcharge into water courses in both areas (Ward 2016). A small number of households in Ezimbokodweni are located within the 1:100 floodplain of the Mbokodweni River. Solid waste is a problem, and smaller streams have become blocked by solid waste, invasive alien plants, and illegal sand mining, resulting in stagnant water that exposes the community to various water borne diseases (GroundTruth 2017). Issues in the broader area, as noted in the Local Area Plan, include sanitation being a major problem (with failing and unhygienic ventilated improved pit latrines), lack of recreational facilities and meeting venues, lack of tertiary educational facilities, and poor/lack of housing facilities (eThekwini Municipality 2017).

2.2.1.2 Bio-Physical Characteristics

The climatic condition of the study area is moderate, situated in a coastal climatic zone, with mean annual temperatures of between 18.5 and 22 °C and a mean annual rainfall ranging between 820 and 1423 mm. The study site is traversed by the Mbokodweni and Golokodo rivers, which fall within the U60E quaternary catchment and the North Eastern Coastal Belt aquatic ecoregion (Kleynhans, Thirion and Moolman 2005). Numerous wetlands and drainage lines are present along the rivers (Fig 2.1). River flows, widths, and depths vary across the study area, and between wet and dry seasons. Sites along the Golokodo River are up to 10m wide and 1m deep, and flows range from slow, to moderate, to fast. River substrates include sand and bedrock. Along the Mbokodweni River, widths and depths range from 3 to 20 m and 0.5 to 2 m, respectively, with moderate to fast flows. The dominant substrate is sand, bedrock, and cobble (GroundTruth 2017).

Results from biological monitoring of Durban's aquatic systems revealed that 71 of the 175 sites are considered to be in a poor state, and only 3 sites are in a near natural state (eThekwini Municipality 2017). Impacts on rivers include illegal spills and discharges, solid waste dumping, sand mining, poor operation of wastewater treatment works, realignment of watercourses, flow reduction, removal of riparian flora, and infestation by invasive alien plants (eThekwini Municipality 2017). The rivers in the study area are similarly classified as being impacted by solid waste pollution, bank and channel modification, and invasive alien plant invasion (GroundTruth 2016, 2017).

All of the sites are found in the KwaZulu-Natal Coastal Belt vegetation type, within the Indian Ocean Coastal Belt Bioregion (Mucina and Rutherford 2006). This vegetation type is classed

as endangered. Vegetation of significance is situated on settled areas, and along riverbanks, characterised by small valley forests and bushes. In the broader study area, vegetation included small patches of grasslands, many of which have been degraded due to settlement and subsistence farming activities (eThekwini Municipality 2018).

The site is traversed by the Durban Metropolitan Open Space System (D'MOSS), and parts of the site are classified as Critical Biodiversity Areas (eThekwini Municipality 2018). D'MOSS is a formal municipal planning policy instrument that identifies a series of interconnected open spaces that incorporate areas of high biodiversity value and natural areas (eThekwini Municipality 2017), with the purpose of protecting the globally significant biodiversity (located within the Maputo-Pondoland Biodiversity Hotspot) and ecosystem services within the city (Roberts and Donoghue 2013; Rouget et al. 2016).

2.2.2 Case Study: Wise Wayz Water Care Programme

The Wise Wayz Water Care (WWWC) programme commenced in 2016 and brought together community members from Folweni and Ezimbokodweni (the "beneficiaries"), who were previously working as separate volunteer groups, mainly performing litter removal along the Mbokodweni and Golokodo river systems. Under WWWC, the beneficiaries are working and learning together, working towards improving the socio-economic and environmental conditions of their communities through the implementation of various environmental management interventions. This work was stimulated by flooding that damaged houses in the lower lying areas during a heavy rainfall event that occurred in 2016. The flooding was exacerbated by solid waste and alien vegetation blockages in the river systems, which resulted in flow and channel blockages that caused localised flooding. The beneficiaries (N = 130) include males (N = 41) and females (N = 87), with various levels of education, ranging from Grade 1 (lowest level of primary education) to Grade 12 (highest level of secondary education), with 1 person having tertiary education.

The WWWC programme is managed by a non-profit organisation, i4WATER, through funding provided by a business operating in the Mbokodweni Catchment, and located in the Umbogintwini Industrial Complex (Fig. 2.1), the African Explosives and Chemical Industry (AECI) Community Education and Development Trust, since 2016. The objectives of the WWWC programme include improving the environmental health of the lower Mbokodweni Catchment (the study area) and supporting sustainable livelihoods of beneficiaries as well as the greater community through training and skills development, alongside small enterprise development. Beneficiary training included invasive alien plant (IAP) identification, removal, and control; poultry and vegetable production (fertilisation, disease, and pest control; irrigation, harvesting, and marketing); environmental and aquatic management and monitoring (for

example, use of water-related citizen science tools, i.e., miniSASS, clarity tube, Escherichia coli (*E. coli)* swab); health and safety training; and community education and engagement.

The beneficiaries of the WWWC programme implemented six environmental management interventions within natural areas in and around Ezombokodweni and Folweni, namely, (1) Solid waste management and removal: removal of waste from aquatic and terrestrial areas; (2) Recycling: waste collection and storage for recycling; (3) Invasive alien plant control: identification and control of invasive alien plants along rivers and streams; (4) Water quality monitoring: monthly biophysical monitoring of river water quality; (5) Community vegetable gardens: vegetable production (two gardens) using permaculture methods; (6) Community engagement: door-to-door community engagement, surveys, and knowledge sharing. Interventions were identified by beneficiaries in response to related challenges faced in the community, and were implemented with support from business funding, within the lower Mbokodweni catchment, at 20 sites, within Folweni (11) and Ezomkodweni (9), along various rivers, tributaries, wetlands, and open areas (Fig 2.1).

Interventions considered in this study were undertaken over a 3-year period from 2016 to 2018. The removal of solid waste from the rivers took place 4 days per week by 45 team members who managed to collect an average of 1.1 tons of solid waste per month. The recycling team collected and separated the recyclable waste from the collected solid waste, which amounted to approximately 0.48 tons of recyclable waste per month. The community engagement and education team, of 44 members, visited homes in their areas 3 times per week to discuss the various socio-economic and environmental issues that the community is facing. The team also provided information and education to the homes they visited on how to address some of the challenges. The invasive alien plant clearing teams worked along 6.8 km of rivers, as well as in wetlands, to remove invasive alien plants. The team cleared 40 ha using mechanical methods. Species cleared included up to 28 species categorised as invasive in South Africa, primarily *Diplocyclos palmatus, Canna indica, Arunda donax, Lantana camara, Melia azerdarach, Tithonia diversifolia*, and *Ricinus communis.* The aquatic monitoring team conducted assessments at 22 sites on a monthly basis, analysed and interpreted the data collected, and used the findings to address the challenges undermining the river health. In the 2 community vegetable gardens, 28 team members worked daily to plant a variety of vegetables and herbs, including spinach, tomatoes, carrots, cabbage, kale, beetroot, and lettuce.

2.2.3 Identifying Values and Perceptions of the WWWC Programme

2.2.3.1 Focus Group Meetings, Workshops, and Interviews

In order to obtain more details on the operational aspects of the interventions, and to ascertain personal perceptions on the programme, we conducted focus group meetings with the WWWC implementers, i4Water, and 1 AECI representative, which involved open discussions of the WWWC programme. We also hosted 2 workshops with 20 and 60 WWWC beneficiaries. During the first workshop, beneficiaries were asked to participate in various individual and group activities in order to (1) identify the positive and negative events or aspects of the WWWC project; (2) identify strengths, weaknesses, opportunities, and threats related to the WWWC programme; and (3) note any changes in the community and biophysical environment that occurred due to the WWWC programme. Personal interviews were held with 9 beneficiaries and 1 coordinator from the programme funding institution in order to obtain greater insight into the WWWC programme, personal experiences, and the manner in which the programme had changed individuals' lives, including contributions to their livelihoods, sense of place, and health.

2.2.3.2 Surveys

We conducted surveys (N = 3) with beneficiary, community, and external stakeholders (including the WWWC funders, AECI, and government stakeholders (eThekwini Municipality), as well as the South African National Biodiversity Institute (SANBI) (Appendix 1), in order to identify individual understanding and perceptions of the WWWC programme and associated benefits to the community and beneficiaries, as well as the environment and ES use, and also to gather data on the social, ecological, and economic attributes of the study area (Nkambule 2017). These surveys also collected socio-economic and health data of participants. Open-ended questions were designed to extract perceptions of the value of the programme to the social–ecological-system of the study area. The three surveys were (1) beneficiaries survey, (2) community survey, and (3) key stakeholder online survey. Beneficiary surveys were conducted in a workshop setting (N = 60), community surveys were conducted at randomly selected households along the Mbokodweni and Golokodo rivers (N = 60), and key stakeholder online surveys were conducted via Survey Monkey (N = 6). The beneficiary and community questionnaires were translated into IsiZulu, and participants were allowed to choose the language of their preference to complete the questionnaires. Informed consent to utilise the outcomes of the study for research purposes was obtained from all participants, as required by the Ethical Approval. Data collected in the surveys were coded using Grounded Theory, whereby the main themes from open ended questions were identified from the data, and not from a preconceived hypothesis (Charmaz 1996). Two of the authors participated in the survey

coding, and engaged in discussions to reach consensus regarding the coded responses, to ensure intercoder reliability (Lombard et al. 2005). Data collected via the surveys were analysed using Statistical Package for Social Sciences (SPSS) 25. This study is limited in that surveys were only conducted after interventions were implemented.

2.2.4 Site Visits

The authors conducted site visits to Folweni, Ezimbokodweni, and selected WWWC work sites to identify the general living conditions of the community in the study areas (housing, water supply, waste management, etc.), and the biophysical condition of the areas where the WWWC interventions were implemented (wetlands and rivers, open spaces, etc.). Direct field observations were made, and photographs were taken for record purposes. We held on-site discussions with i4WATER and beneficiaries from each of the intervention teams. These visits were done to gain a deeper contextual understanding and gather firsthand data on the interventions and their impacts on site.

2.2.5 Social–Ecological System Workshops with Beneficiaries

In order to better understand the social–ecological system of the study area, we hosted the second workshop with WWWC beneficiaries ($N = 60$), who were randomly selected from the list of beneficiaries. We used A0 size maps as the focus of discussions, which showed the locations of WWWC work areas (WWWC programme boundary and locations of management intervention sites, for example, water quality monitoring points, and solid waste removal sites). Maps were drawn using ArcGIS 10.4, showing the WWWC work sites relative to other landscape attributes and ecological habitats, namely, the D'MOSS, including wetlands, rivers, and vegetation habitats. Beneficiaries reflected on the maps and related their experiences in the study area. Key questions that were explored in the workshop related to existing or perceived understandings of (1) opportunities related to social activity, knowledge sharing, and natural resource use (for example, water extraction, livestock grazing, and watering); (2) potential expansion of WWWC work areas; and (3) threats relating to health and safety, such as sources of pollution and illegal dumping of solid waste.

2.2.6 Identifying Ecosystem Services Used and Valued

Ecosystem services were identified from survey responses on the basis of the existing use or demand for that service. Surveys (as described above) were used to collect data on ecosystem service usage by (access), and values of, beneficiaries and community members. The ecosystem services included in the survey were (1) *River water use*: use of natural water from river or stream (for example, for washing clothes or cars, or for general household use); (2) *Natural material harvesting*: gathering natural materials for various uses, for example,

medicinal plants or wood; (3) *Subsistence use*: direct use of natural resources to sustain life, for example, food or water; (4) *Agricultural use*: crop or livestock production; (5) *Cultural practices*: use of natural areas for cultural practices or rituals; and (6) *Recreation and leisure*: use of natural areas for leisure or outdoor activities.

2.3 Results

2.3.1 Perceived Ecological, Health, Safety, and Socio-Economic Benefits from Civic Ecology Interventions

Both the beneficiaries (from survey and workshops) and the broader community (from all household surveys (surevy data was combined for Folweni and Ezimbokodweni)) reported positive changes in the community after civic ecology interventions had been implemented (Fig. 2.2). These were in the observation that the area and stream were cleaner, but also indirect benefits such as improved education and less danger. Beneficiaries also identified the benefit of improved health, including having noticed a decrease in the number of mosquitos in the area due to the improvement in the river water flow.

The benefit that was most noted by community participants and beneficiaries was that the area was cleaner after clearing solid waste pollution from the land and rivers. This work, coupled with the knowledge sharing on the dangers of littering and poor waste management by beneficiaries, has resulted in a reduction of dumping by residents. This cleanliness can be linked to a decrease in the risk of diseases associated with pollution, and reduction in risk of injury to humans and animals (for example, reports that skin rashes no longer occurred after children played in the river, and a reduction in mosquitos), which are considered to be positive health outcomes (Ziraba et al. 2016).

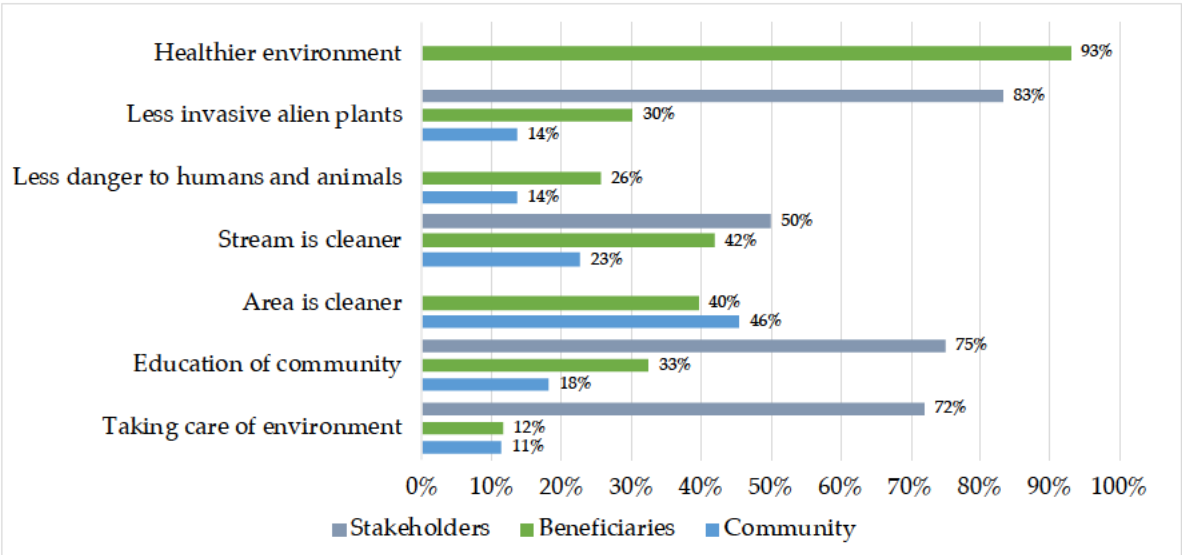


*Figure 2.2: Beneficiary (*N = *60), community (*N = *60), and stakeholder (*N = *6) perceptions of social–ecological changes due to WWWC (stakeholders ranked their agreement with the changes as either minor, moderate, or high achievement, and scores above indicate the weighted average).*

From all the community respondents who reported to consume vegetables in the survey, more than half of the vegetables consumed were purchased from the WWWC, which shows that the programme provided a significant source of vegetables to the community. This has a positive impact on nutrition through facilitating improved access to a wider variety of fruit and vegetables, resulting in a more balanced diet, with positive effects on health and well-being (Govender et al. 2017). WWWC vegetable irrigation was solely from river water.

The community held knowledge of the different programmes being undertaken by the WWWC. Most of the community respondents heard about or interacted with the community engagement (88.2%), invasive alien plant (IAP) control (64.7%), solid waste removal and management (58.8%), vegetable gardening (54,9%), recycling (49%), and river water quality monitoring (23,5%) teams. All respondents who noted the area being cleaner also had knowledge of all the WWWC programmes, showing that community members could relate the work being done by beneficiaries to the positive changes taking place in their community. Comments made in the survey indicated that beneficiaries were appreciated by the community for the knowledge that they shared with respect to environmental education and management.

Half of the external stakeholders, and over 40% of beneficiaries noted that the stream was cleaner after the programme was operational (Fig. 2.2). Over 80% of stakeholders and one-third of beneficiaries noted that there was a decrease in invasive alien plants since the interventions were implemented. This was also visible from site observations (see Fig. SM 2.1).

Of the nine benefits beneficiaries experienced from working as part of the WWWC (survey) (Fig. 2.3), more than 60% of beneficiaries experienced six or more benefits, with 96% of beneficiaries listing education on the environment as a benefit, followed by new business opportunities (76%), and increased water security (72%). The first formalised community-based small business was developed by some of the beneficiaries, Envirocare Management Systems (Pty) Ltd., providing prospects for income through invasive alien plant control and water quality monitoring services. External stakeholders similarly perceived the benefits to beneficiaries as high, with 83% noting increased education, 92% noting increased business opportunities, and 83% recognising personal development as benefits to beneficiaries (Fig. 2.3).

From the nine personal interviews that were conducted with WWWC beneficiaries, it was apparent that the WWWC programme had a positive impact on all nine individuals in terms of personal development through education and training, feelings of self-improvement, and increased hope for the future (see Appendix 2.2a,b). WWWC also experienced some challenges related to cost recovery, entry requirements for training courses, and illegal dumping (see Appendix 2.2c).

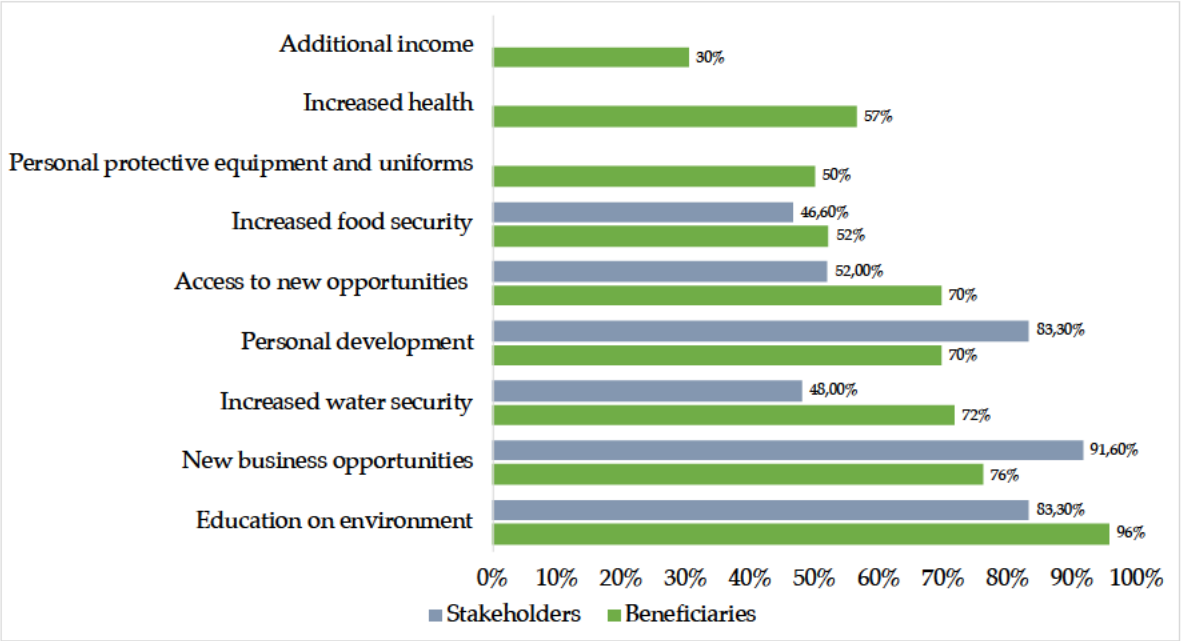


Figure 2.3: WWWC programme benefits experienced by beneficiaries and perceived by beneficiaries and stakeholders (PPE: personal protective equipment) (stakeholders ranked their agreement with the benefits as either minor, moderate, or high achievement, and scores above indicate the weighted average).

An aspect of success that served to encourage sustainable participation in civic ecology initiatives was the increased knowledge, education, and training, which resulted in new skills that benefitted beneficiaries and the broader community, for example, transitioning from subsistence farmer to small scale producer and undergoing first aid training (Appendix 2.2a). Such spin-off benefits to the broader community have strengthened social cohesion.

2.3.2 Nature and Ecosystem Services Enhanced by Civic Ecology Interventions

The natural areas that were enhanced by the interventions included terrestrial and aquatic habitats, for example, wetlands, rivers/streams, riparian vegetation, and open space (natural areas zoned as public open space). The interventions made positive impacts on ecological areas, and were thus considered to have the potential to enhance ecosystem services. The habitats

improved by the interventions are linked to the enhancement of numerous ecosystem services, including regulating services or Nature's Contributions to People (NCP), of water purification, flood mitigation, biological regulation, and/or disease control, as well as maintenance of biological diversity (genepool protection) (previously considered a supporting service (MEA 2005), but now captured in regulating NCP (Díaz et al. 2018); cultural or non-material NCP of aesthetic, recreational, cultural, and education service; and provisioning services or material NCP of water supply, food, and harvesting products (Groot et al. 2010; Díaz et al. 2018). People accessed ecosystem services for water, agricultural production, and harvesting of medicinal plants and wood (see Table S1), and increased use of natural spaces for cultural and spiritual activities, since it had been cleaned by the beneficiaries, for example, using the wetland in Ezimbokodweni for cultural rituals (*Umemelo*—Zulu traditional coming of age ceremony for women) (see SM Fig 2.1).

2.3.3 Ecosystem Services Uses and Values

Ecosystem services were widely used and valued by the broader community (randomly selected residents) and beneficiaries (Fig. 2.4). Ecosystem services used most were agricultural use (crop and livestock production), followed by subsistence use (use of natural resources to sustain life), and cultural uses. Beneficiaries valued subsistence ecosystem services the most, followed by aesthetic value and cultural value, while broader community members valued aesthetic, economic, and cultural services the most (Fig. 2.4).

River water was used most for the irrigation of subsistence crops, followed by livestock and personal use (see SM Fig 2.2). Participants also used river water for recreation, which was reported to have increased due to the improvement in the cleanliness of the area and the water, since WWWC had been operating. People reported to use the "now clean" river water for washing clothes and cars, as well as for flushing toilets. Business use (by beneficiaries and community members) of river water was for car washing, brick making, livestock, and sales from crop production. More beneficiaries used river water than broader community members for each category. During the workshop, locations of access to ES were reported, including wood and medicinal plant harvesting collection points in adjacent forests, recreational areas, and religious gathering sites. Threats and opportunities related to WWWC operation were also identified (see Table S1). In terms of frequency of river water use by community members and beneficiaries, respectively 28.5% and 40.7% used river water daily, 35.7% and 0% weekly (no beneficiaries reported to use river water weekly), 21.4% and 3.7% used river water monthly, and 14.2% and 48.1% used river water seasonally.

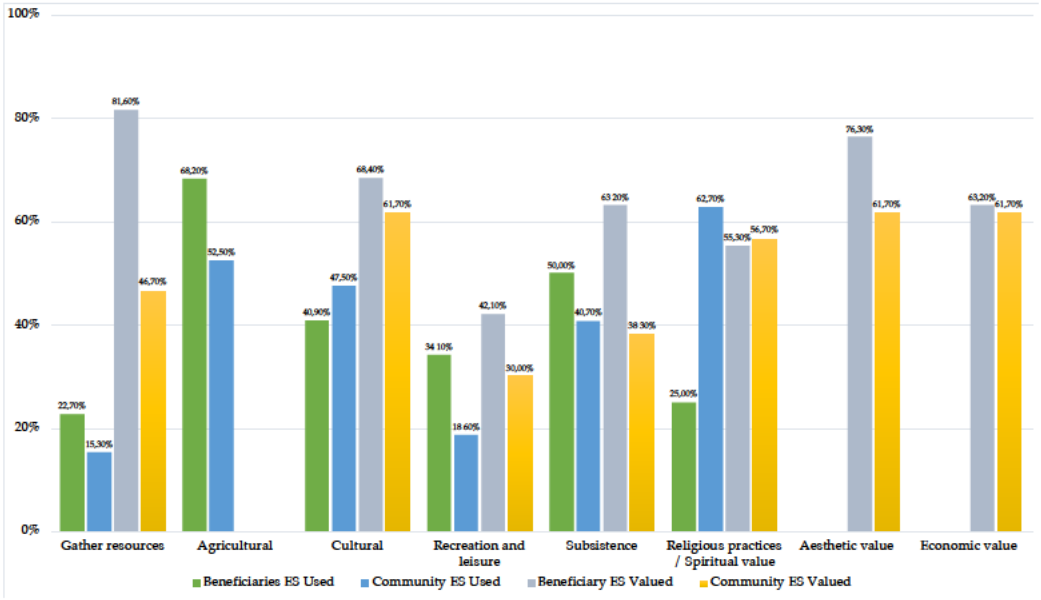


Figure 2.4: Ecosystem services used and valued by community and beneficiaries. Percentage of respondents that noted they used or valued ecosystem services. Ecosystem Services Used*: Gather resources—gathering natural materials for use, for example, medicinal plants, wood; Agricultural use: crop or livestock production; Cultural practices—use of natural areas for cultural practices or rituals;* Ecosystem Services Valued*: Recreation and leisure—use of natural areas for leisure and outdoor activities; Subsistence use—use of natural resources to sustain life, for example, food, water; Aesthetic value: I enjoy the scenery and beauty of nature; Economic value—I benefit from nature through the sale of products, for example, traditional medicine, vegetables, wood; Recreational value—I use natural spaces for leisure and outdoor activities. Life sustaining value—it produces goods, and renews air, water, and soil; Spiritual value—natural spaces are valued as being sacred for my religious practices. Cultural value—Natural spaces are important for my cultural practices and rituals and as a place for transferring cultural knowledge through generations; Subsistence value—it provides me with goods to sustain my life, for example, food and water.*

2.4 Discussion

2.4.1 Civic Ecology Contributes to Social–Ecological System Benefits and Ecosystem Service Protection and Enhancement

High use of ecosystem services highlights the importance of natural capital for the livelihoods of people in the community. Similar to other studies, ecosystem services were widely used and valued by the community, and even more so by the beneficiaries as a means to enhance well-being through the mitigation of poverty and diversifying household livelihoods, enhance food security and access to nutritious food, enhance health, improve personal safety and security, access clean water and air, and promote social cohesion (MEA 2005, Thondhlana et al. 2012, Angelsen et al. 2014).

As found in similar studies, civic ecology practices were also initiated in response to a natural disaster (flood in 2016) (Tidball and Krasny 2014). In so doing, the beneficiaries were able to mitigate ecosystem disservices, through environmental management and enhancement of ecosystem services. This led to positive outcomes for both the beneficiaries and their communities (Elmqvist et al. 2015).

This study confirms that civic ecology practices contribute to the provision of a variety of ecosystem services, including cultural services such as education and learning, social relations, and recreation (Krasny et al. 2013). We confirmed links between spiritual values and resource management (Cox et al. 2014), whereby management, environmental protection, and stewardship, increase when people associate spiritual and cultural value with natural areas (Novacek 2009).

The social–ecological interactions in the community influence the manner in which people value the environment, whereby valuation of biodiversity is determined by the practical function obtained from the ecosystems and ecosystem services that enhance the livelihoods of individuals (Haines-Young and Potschin 2010). The perceptions of values identified in this study assert that there is strong dependence of people on ecosystem services, and their understanding of this dependence has, in turn, motivated them towards voluntary environmental stewardship.

We confirm that civic ecology practices both sustain human health (Tzoulas et al. 2007) and lead to the creation of new natural capital (TEEB 2010). Our study supports the understanding that local communities can benefit from projects that aim to integrate sustainable development and environmental management, and can create positive attitudes and perceptions towards conservation initiatives (Ezebilo and Mattsson 2010). Such projects should aim to incorporate the environmental, social, and economic dimensions, including sustainable use of ecosystem goods and services, promoting dignified standards of life, and providing employment opportunities (Ezebilo and Mattsson 2010).

The results have governance implications. The interventions were able to address some of the impacts on Durban's rivers (eThekwini Municipality 2017) and enhance terrestrial habitats within Critical Biodiversity Areas that are crucial to meet biodiversity targets (McLean et al. 2016), thereby reducing the pressure on government authorities who are mandated to manage these areas for conservation purposes. The outcomes of this study related to ecosystem service uses by disadvantaged communities can also be considered by authorities in preparing conservation plans, where such understanding may assist in determining the capacity of ecosystems to support both social and ecological communities (Nkambule et al. 2016). This study highlights that local communities can leverage natural capital for well-being and social-

ecological improvements and encourages policy support of civic ecology initiatives.

2.4.2 Civic Ecology Provides Opportunities for Social Cohesion and Personal Development

We show that social cohesion is critical for the achievement of sustainability and well-being (MEA 2005), and that ecosystem services provide a basis for spiritual, cultural, and social cohesion experiences (Díaz et al. 2018). Such perceptions, when coupled with scientific evidence of positive outcomes of management interventions, provide a powerful combination for ensuring the sustainability of civic ecology programmes.

Positive perceptions of community members of the impacts of environmental management can ensure both support for, and long-term sustainability of, management initiatives (Bennett 2016). The perceptions of the direct relationships between the positive social–ecological changes taking place in the area and the work being done by the beneficiaries has strengthened social cohesion in the community.

The involvement of the community in the selection and implementation of the interventions strengthened the sustainability of the interventions. Our study provides evidence that, contrary to the notion of the tragedy of the commons (Hardin 1968), by taking ownership and control of natural capital, local communities can successfully contribute to improved collective human well-being.

2.5 Conclusions

Our study showed that increased knowledge of ecosystems through civic ecology practices contributed to the protection and increased use and benefit of ecosystem services, both for beneficiaries and other members of disadvantages communities. Civic ecology practices have the potential to uplift impoverished communities through providing opportunities for education, as well as enhanced ecosystem service protection and access, and should, therefore, be encouraged and supported by government and policy. Given that contributions of civic ecology groups are increasingly recognised by governments for their contribution to natural capital, they need to be supported by the government and the private sector through policies aimed at achieving sustainability and well-being (United Nations Development Programme 2016).

This study provides evidence of the potential for civic ecology initiatives, supported by private practice, to overcome the tragedy of the commons and enhance ecosystem services for low-income communities who are directly dependant on ecosystem services for their livelihoods

and well-being. We call for increased governance support of similar civic ecology initiatives as a means to capacitate local communities to take ownership of natural capital and make gains in the plight against poverty and environmental degradation.

SUPPLEMENTARY MATERIAL

SM Figures

SM Figure 2.1: Ezombokodweni Wetland 2015 (before WWWC) and 2018 (after WWWC)

SM Figure 2.2: Natural water used by beneficiaries and community members

SM Tables

SM Table 2.1: Social-ecological system workshop findings

SM Appendices

SM Appendix 2.1: Questionnaires/Surveys

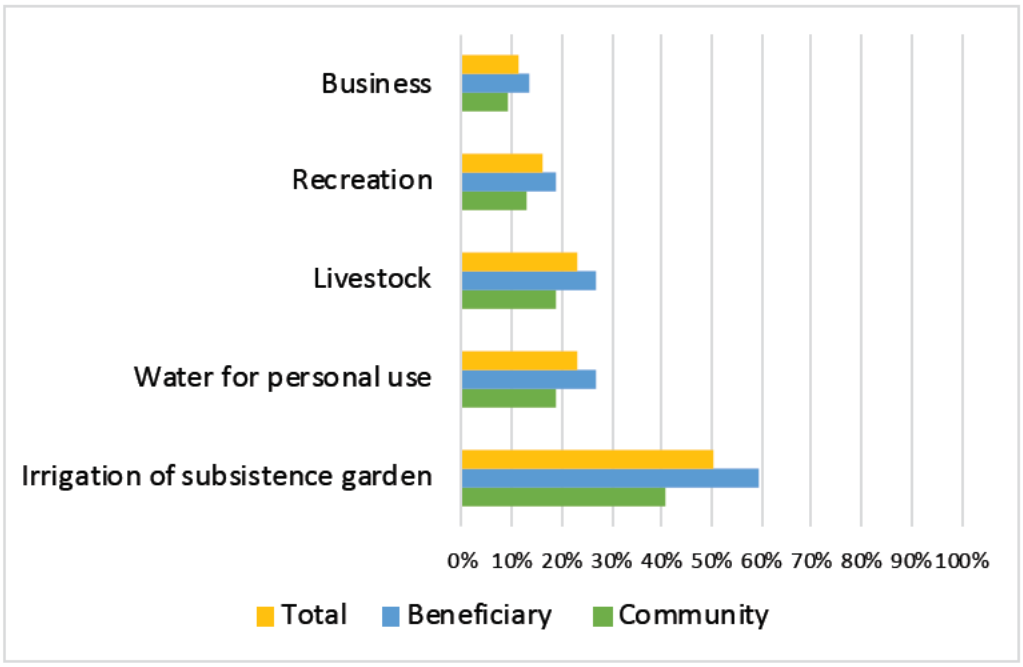
SM Appendix 2.2: Stories of change, personal comments, and challenges:

SM Appendix 2.2a: Stories of change

SM Appendix 2.2b: Comments made by beneficiaries, community members and external stakeholders.

SM Appendix 2.2c: WWWC Challenges

SM Figure 2.1: Ezombokodweni Wetland 2015 (before WWWC) and 2018 (after WWWC)



SM Figure 2.2: Number (%) of respondents who reported to use natural water by category of use

SM Table 2.1: Spatial analyses workshop: points of interest for ecosystem services, opportunities and threats. During a workshop, beneficiaries identified various points of interest in the landscape where ES were accessed and also noted opportunities and threats related to implementation of interventions

	Folweni	Ezimbokodweni
Ecosystem services	Beneficiaries identified collection points for wood, indigenous plants and herbs in the adjacent D'MOSS thicket and forest areas. The 'Adopt-a spot' where beneficiaries have been working was identified as a space of recreation. It was noted that the community has now started using this spot for cultural activities, including Umemelo ceremony. Locations of where community members were using river water for swimming (children), collection of drinking water for cattle and washing clothes were identified. Locations along the river where animals (cattle) drink water were identified.	A Shembe Temple adjacent to the community hall was noted as an important natural space for religious and cultural activity. Two locations of where community members were collecting water and one where the municipality was collecting were identified. Wetland rehabilitation has taken place which has balanced the ecosystem and also facilitated vegetable gardening through the provision of cleaner water.
Threats	Numerous dumping sites, including scrap metal, rocks and dead animals were identified along the river. Two locations of where illegal sand mining was taking place were identified. Beneficiaries noted that the banks of the stream keep widening in these areas and that the work they are doing there is resultantly compromised. Area under the bridge where the D'MOSS wetland is located, was identified as a blockage point for sand after illegal sand mining activities upstream of the site have occurred. The area close to a brick making and car wash business was identified as a difficult area to get through (not easy to work there). The WWWC work site next to a tuck shop was noted to have little to no improvement due to recurrent dumping, littering and leaking sewer pipes.	Two locations of leaking sewer pipes were identified. Pollution from a local business (pot making) including air, noise and water pollution was identified. A site of high infestation of invasive alien plants was identified and linked to crime and illegal dumping. A donga posing danger and safety risk was noted. A stream and wetland where there is sinking mud was identified.

Opportunities	A Learning Centre, soup kitchen and a Red Cross Community hall were identified as a potential spaces for social networking. 'Baba Majola' has been operating a vegetable garden for many years and was identified as a source of indigenous knowledge for growing food. Locations of where other community groups are growing vegetables, working on cleaning the stream and recycling (school) were identified.	The Hukukushu and Thola streams and wetland were identified as areas of opportunity for WWWC to work in. A location of a traditional healer who showed interest in working on the WWWC programme was noted. An alternative location of a traditional healer was also noted to both release 'good and bad spirits' into the community. Two sports grounds and a community hall were identified as areas for social activities.

SM APPENDIX 2.1: QUESTIONNAIRES (Questionnaire modified from Nkambule 2017)

Questionnaire No		**Date**		**GPS Coordinates**
WWWC Project/s				
Folweni team (tick)		**Ezimbokodweni team (tick)**		

1. PERSONAL INFORMATION AND HOUSEHOLD DEMOGRAPHICS							
Name (optional):				**Address (optional):**			
Your age: **Your gender (circle): Male** **Female**	**Total no. of males in household:** **Ages of males in household:**			**Total no. of females in household:** **Ages of females in household:**			
How many people in your household are employed in these categories?	*Full time*:	*Part-time:*	*Contract:*	*Unemployed:*			*Pensioners:*
What type of dwelling you live in?	Formal brick	Informal	Traditional	Other, please specify:			
Type of activities are occurring at your household?	Shop	Crop farming	Livestock farming	Recycling for income	Business (specify)	Other, please specify	
What type of energy sources do you use in your household?	Electricity	Gas	Wood	Paraffin	Candles		Other, please specify:

2. WATER, SANITATION AND WASTE							
What is the source of potable water for your household?	Inside pipe	Communal tap	Communal tank	River/stream		Other, please specify	
What type of toilet do you use?	VIP toilet	Flushing toilet	Septic tank system	Other, please specify:			
How do you store your waste?	Refuse bags	Bin	Communal dump	Communal waste skip		Other, please specify	
How do you dispose of household waste?	Collected by municipality (DSW)	Collected by contractor	Take it to waste dump	Recycle	Burn it	River	Other:
Which of the following do you practice in your household? (Circle often, seldom or never)	Re-use of water Often Seldom Never	Composting Often Seldom Never	Recycling Often Seldom Never	Energy conservation Often Seldom Never		Other, please specify:	

1. NATURAL CAPITAL AND ECOSYSTEM SERVICES

DEFINITIONS OF TERMS

Nature: Living things of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, as opposed to humans or human creations.
Biodiversity: the variety of different types of plants/trees and animals. (field assistant to explain to respondent)
Environment: the surroundings or conditions in which humans, animals, or plants exist, including physical, chemical and other natural forces.
Ecosystem: an interconnected community of natural living organisms and their physical environment.
Ecosystem services: the goods and services (benefits) we as humans derive from nature / natural systems (for example, water, air, soil, plants and animals (food).
Conservation: the act of preserving, guarding or protecting an ecosystem or wildlife. (field assistant to explain to respondent)
Invasive alien species: species of plants, animals and other organisms that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health.

3. NATURAL CAPITAL AND ECOSYSTEM SERVICES		
Which of the following do you value from the natural environment? (Multiple responses permitted- ask for each)		
1.**Aesthetic value**: I enjoy the scenery and beauty of nature	2.**Economic value**- I benefit from nature through the sale of products for example, traditional medicine, vegetables, wood	3.**Recreational value**- I use natural spaces for leisure and outdoor activities
4.**Life sustaining value**- it produces goods, renews air, water and soil for me	5.**Spiritual value**- natural spaces are valued as being sacred for my religious practices	6.**Cultural value**- Natural spaces are important for my cultural practises and rituals and as a place for transferring cultural knowledge through generations
7.**Subsistence value**-it provides me with goods to sustain my life for example, food, water		

3.NATURAL CAPITAL AND ECOSYSTEM GOODS AND SERVICES								
What do you consider to be part of nature/biodiversity in your community? (Multiple responses permitted- ask for each)	Gardens *	Open space	Rivers	Insects	Plants/trees	Animals	People	Other
Please rank the following according to what you consider to be an important part of nature in your community - Codes: 0=not important 1=slightly important 2=Important 3=Moderately important 4=Very important	Gardens *	Open space	Rivers	Insects	Plants/trees	Animals	People	Other
Which of the following ecosystem services are you aware? (Multiple responses permitted)	None	Climate control for example, shade	Flood control	Water supply	Water purification	Sediment retention	Pest control	Other
What are the main ecosystem services you use?	Gather resources	Agricultural use	Cultural practices	Recreation and leisure	Subsistence	Religious practices or	Other, please specify	

						sites	
Are you using river water for personal use, recreation, business or irrigation?	Personal use. Please specify.	Recreation	Irrigation of subsistence garden	Livestock If yes, do your livestock graze in the local area?	4. Business (specify) 4a. Car wash 4b. Brick making 4c. Livestock (for sale) 4d. Vegetables/crop (for sale)		Other, please specify:

*The word Garden in this questionnaire is associated with vegetable gardens in isiZulu as *ingadi yemifino*. Where necessary specify a flower garden as *ingadi yezimbali*.

	Yes/No	Where do you get it and what do you use it for?	How often do you use it? (1 – Daily, 2- weekly, 3-monthly, 4 – seasonally)	Amount (per month in Rands of value to you)
1.Do you use water that is not from a tap?				
2. Do you use natural soil or sand?				
3. Do you use animals from your natural area?				
4. Do you own animals? If so which animals do you own? (circle) Chicken Goats Cows Sheep Other		Do your animals use or depend on the natural environment for: Grazing: Yes No Water supply: Yes No If chickens, what is their source of food? If chickens, do you use their manure and what for?		

	Yes/No	Where do you get it and what do you use it for?	How often do you use it? (1 – Daily, 2- weekly, 3-monthly, 4 – seasonally)	Amount (per month in Rands of value to you)
5. Do you use <u>insects</u> from your area? If so which insects and what are these used for? **4a. Do you eat any insects? Name these.**		If eaten, how often? Daily Weekly Monthly Yearly		
7. Do you use <u>plants</u> from your area? If so which plants and what are these used for? **7a. Do you use any invasive alien plants? Please name these.** **7b. Do you use any indigenous plants? Please name these.** **7c. Do you eat any of these?** **7d. Are they used for medicinal purposes?**		If eaten, how often? Daily Weekly Monthly Yearly		
Do you use <u>fuelwood</u> from your area?				
Do you use <u>clay</u> from your area?				
Do you use <u>thatch/logs/wood</u> from your natural area?				
Do you use <u>stones</u> from your area?				
Other resources you use from nature:				

Have you noticed any changes in the quality of the river and when?	Yes	No	Describe the changes and when they occurred:
Have you noticed any changes to the natural environment (after the work has been undertaken by the Wise Ways Water Care team?	Yes	No	Describe the changes and when they occurred:

4 HEALTH AND DIET									
What are the main food items you consume in your household?	**Maize** Daily Weekly Monthly Never	**Bread** Daily Weekly Monthly Never	**Red meat (beef, lamb, etc)** Daily Weekly Monthly Never	**Chicken** Daily Weekly Monthly Never	**Fish** Daily Weekly Monthly Never	**Vegetables** Daily Weekly Monthly Never	**Fruit** Daily Weekly Monthly Never	**Dairy (milk, cheese, yoghurt etc)** Daily Weekly Monthly Never	**Other, please specify:**
Do you consume vegetables that you grow yourself? **Yes** **No**	**Do you consume chicken that you grow yourself?** **Yes** **No** **Do you consume eggs from your own chickens?** **Yes** **No**	**Do you consume meat or milk from your livestock?** **Yes** **No** **Goats** **Cows** **Sheep** **Milk**	**Do you exhange/barter and food items with community members?** **Yes** **No** Daily Weekly Monthly Never	**Do you sell vegetables to the community?** Yes No Which vegetables: **Do you sell livestock to the community?** Yes No					

Do you consume vegetables that you buy from: **Community member: Yes No** **WWWC garden: Yes No**	**Do you consume chicken or that you buy from:** **Community member: Yes No** **WWWC garden: Yes No**	**Do you consume meat or that you buy from:** **Community member: Yes No** **WWWC garden: Yes No** **Goats** **Cows** **Sheep** **Milk**	Which items?	Which livestock: **How often do you slaughter for personal consumption?** **Or for events?**			
Have you or a family member fallen ill after consuming produce from the local community or your own?	Yes, please note illness:		No				
Have you or any family member experienced any ill health after interacting with the natural environment in your area?	Yes, please explain activity:	No	Don't know				
If yes, to the above question, what was experienced?	Diarrhoea	Skin rashes	Vomiting	Injury	Bilharzia	Worms	Other, please specify:
Have you noticed a change in the incidence of any of the above health issues? When did the change occur and why do you think the change occurred?	Yes	No	When	Why			
What do you feel could be done to avoid the above health issues in your community?							

5. WISE WAYZ WATER CARE							
Are you part of any community group?	Religious	Community safety (neighbourhood watch)	Farmer group	Political	Finacial group (credit/borrowing/stokvel)	Other:	
Are you aware of the Wise Ways Water Care Project?	Yes	No					
Which of the Wise Wayz Water Care Projects have you seen, interacted with or heard about?	Invasive alien plant control and removal	Community engagement on issues of solid waste, water leaks, infrastructure monitoring and education	Community vegetable gardens	Recycling	Water quality monitoring	Solid waste removal from water courses None	
What type of benefits do you feel the Wise Wayz Water Care project brings to your community?	None	Source of income to community (how)	Increased food security	Increased water security	Improved natural environment and rivers	Social upliftment, skills development and education	Increased water security Improved health
Are there any other benefits you feel the Wise Wayz Water Care project brings to the community?	If yes, please specify:						
Has the WWWC project affected your views towards the natural environment? How?	No effect	More caring about the environment	Provided more knowledge about the importance of the environment		Increased sense of pride in community	Other, please specify:	

Do you think the Wise Wayz Water Care project has caused conflict or challenges in the community?	**No**	**If yes, please specify:**
Do you feel that the WWWC project has shared information on their work in your area adequately?	No	If yes, please specify:
Do you have any recommendations improve the Wise Wayz Water Care project?	None	If yes, please specify:
Are there any additional comments you would like to share?		

SM APPENDIX 2.2A: STORIES OF CHANGE

Summary

One participant had the ambition for tertiary education, but due to a lack of funding, could not pursue his dreams of further education, until he joined the programme. Another felt that her involvement in the programme gave her the ability to make positive contributions to her community, which she would otherwise not have been able to do. A beneficiary also noted that the increase in his knowledge base through education and training has increased his vision and drive to advance his business skills – whereby he is in the process of transitioning from a subsistence farmer to a small-scale producer with aspirations to become a commercial farmer. One beneficiary was proud of the range of course certificates she had obtained through the programme, including plumbing, water safety, safety, health and environment (SHE), invasive alien plant training, and door-to-door training, through which she also gained the opportunity to travel to another city. She felt empowered as a woman doing plumbing work and wanted to "show men that women can do this work!" Similarly, another beneficiary and Director of Envirocare Management Systems (Pty) Ltd, also proudly mentioned the list of training he had received, including invasive alien plant control, SHE, first aid, door-to-door and snake handling. From the interviews, it was clear that being part of the WWWC programme had changed the lives of beneficiaries for the better.

Respondent 1: Male

Respondent 1 is a WWWC Youth beneficiary from KwaMakhutha. He obtained access through the RCU eZimbokodweni group. His learning pathway has been through starting a B Com Marketing, but he was unable to continue due to funding constraints. He has embraced the many opportunities offered within WWWC training and skills development. The training

includes Geo ODK, Sinqonqozela Ulwazi (which fits well with his marketing studies), Plant identification, a driver's licence and being part of the Executive. Respondent 1 confirmed that being part of the Executive has enabled professionalism, understanding and application of governance. As part of the WWWC Executive (acting as secretary) for the last year, he feels he has grown immensely. He was honoured with the Community Builder Award at the 2017-year-end function but remains humble and committed. He feels older people in the programme can teach the younger people and that a balance is required where the generations can learn together. He has focused on environmental learning opportunities. This is substantiated in his Directorship with Envirocare Management Systems (Pty) Ltd, the first formalised small business to grow out of the WWWC programme.

Respondent 2: Female

Respondent 2 matriculated in Umlazi and lives eZimbokodweni with her family. She is part of the RCU group. She has participated in many different types of training such as invasive alien plant control, water safety and Door-2-Door. She is an important member of the Sinqonqozela Ulwazi team and emphasises that she likes this role in assisting community members to understand more about water and the work of WWWC. She added that she loved plants and grows spinach, sugar cane and cabbage at home. The sugar cane is eaten at home for sugar. As she describes her training her knowledge of plants is evident. She mentions Iboza (Tetradenia riparia) and its medicinal use, so too Bugweed and Syringa, isigqikisomkhovu (cycads) and explains she likes indigenous plants the most.

Respondent 3: Female

Respondent 3 is a passionate young woman and hails from eZimbokodweni. She is the Vice Chairperson of RCU and a member of the WWWC Executive. Respondent 3 noted that

although she does not earn a salary, she has a vision to improve her long-term future being for herself and her family. She regards WWWC as an opportunity to uplift herself and her children and speaks often of the importance of leaving a legacy. Prior to becoming part of RCU, she trained in security and obtained a welding certificate. She is a member of the African Gospel Church and explains she wants to leave a legacy of her life. It is this legacy that motivates her to participate in all the training that is offered. She has attended a Woman in Leadership training course in Richmond and is currently undertaking a counselling course as well. She feels that the members of RCU have helped to groom one another and is proud to be part of this group.

Respondent 4: Female

Respondent 4 has been part of Emvelo-wise in Folweni for 11 years. She noted that joining WWWC has changed how she related to growing vegetables. As one of the older more established members of the Folweni Emvelo-wise team, she mentions adding lettuce, (both green and purple) to the spinach, beans, peanuts and cabbage they grow. Cabbage is bought by the local Boxer store at R10.00 each. She mentions the many training opportunities and has participated in First Aid as well as Water Safety.

Respondent 5: Female

Respondent 5 hails from Folweni and is a member of the Emvelo-wise group. She has joined the WWWC Executive where she represents Emvelo-wise. Her biggest change has come through "working as a team, we did not know what to do, we were behind". She has embraced training and has completed poultry production training and now successfully raises 'broilers'. Other training, she mentions is Water Safety, plant identification and invasive alien plant control and herbicide application. The Women's Leadership training she has completed was also proudly mentioned.

Respondent 6: Male

Respondent 6 is from Folweni and a member of the Emvelo-wise group. He felt that WWWC has brought the two teams together and has taught them a lot. He has a desire to share his knowledge. His training has been in vegetable gardening, including the three-month training in Mpumalanga that has changed the way he regards vegetable growing. He mentions aspects such as creating their own seedlings, land preparation, vegetable storage and sales as well as herbicide and pesticide use. He too is proud of the lettuces they grow as well as the many additional 'new' vegetables not grown before.

Respondent 7: Male

Respondent 7 is from Folweni and a member of the Emvelo-wise team. He stated that "I am going to be a farmer, and Agrobusiness farmer". He explained how attending training in Mpumalanga has increased his vision and desire to advance his business skills. Before he was at 'a ground level and a street vendor', but now he will be able to 'plant more hectares' and become a 'commercial farmer'. He added that WWWC has changed his life.

Respondent 8: Female

Respondent 8 is part of the RCU group and lives in eZimbokodweni. She had completed many of the training courses and noted that "I have many certificates". Certificates in plumbing, water safety, SHE, IAPs and community engagement (Door-to-Door). She valued her association with WWWC as "these opportunities have enabled me to travel to Cape Town and practice the Travel and Tourism I learnt at school". In addition, she explained that her understanding and attitude towards environment has shifted, stating that "WWWC has given me a chance to understand environment". She sees herself in future as a female plumber in a business that "will show the men that women can do this work"!

Respondent 9: Male

Respondent 9 is from Folweni and a member of the Emvelo-wise team. He is also a member of the WWWC Executive. He has completed many different training courses. He mentions, IAPs and PCO, Safety, Health and Environment, First Aid, Community Engagement (Door-to-Door) and snake handling. As part of Emvelo-wise he worked in the streams and the vegetable gardens. He mentioned clean-up campaigns in Folweni and how people should not waste water and litter. He felt that WWWC has helped to open people's eyes that "impilo or life is connected to the environment and we should not be wasting water at our homes". As a director in Envirocare Management Systems (Pty) Ltd, the first formalised small business to grow out of the WWWC programme, he is a valued member who has a code 10 drivers licence and his own car.

SM APPENDIX 2.2B: COMMENTS MADE BY PARTICIPANTS ON THE WWWC PROGRAMME

Comments on beneficiary benefits of WWWC made by external stakeholders

"The enthusiasm and subject knowledge displayed by the beneficiaries is a marvel to witness"

"The lives of those young people and their generations will never be the same again."

"I see them growing becoming better people than before, the Project gave them the purpose in life, they are confident, proud on what they are doing, and their generations will never be the same again."

"I have come across comments from beneficiaries whom were doing Adult Education and Training where one elderly lady said it does not matter if I fail, what is important is that I can now write and read my name. To her this was utmost achievement. Another lady made a similar account stating my grandchildren used to rob me of my pension money as I did not know how to count but through AET I can now count, and they are finding it difficult to rob me. I have come across plenty of similar statements."

Comments by beneficiaries on benefits of WWWC

"I now have a reason to get up in the morning, compared to other youth in the community who don't work and waste their time with drugs."

"I just want to thank the way WWWC is moving, it is developing the people."

"WWWC teaches us to be independent and to create more job opportunities with the skills the project provided."

"So far the project has motivated the people to have faith and start their own businesses."

Comments by community members on benefits of WWWC

"I wish for it to grow, because they are our hope now. We would like for our children to join them in future and be exposed to opportunities."

"WWWC had taught me a lot about the importance of the environment, I am thankful."

"Taking of the environment should be shared with schools too so that the whole Africa can have access to water."

"Thank you for visiting our home, I have learned a lot and I will pass the knowledge to others"

"We appreciate the work you do."

SM APPENDIX 2.2C: PERCEIVED CHALLENGES OF WWWC

Two beneficiaries and six community members (8% in total), noted that WWWC causes conflict in the community. This was related to the perception that some beneficiaries received cost recovery (provided to beneficiaries for carrying out activities in addition to basic activities), while others did not. Another challenge was that some training courses needing a minimum of Grade 9 level secondary school education, which a few of the older beneficiaries did not have. This issue was subsequently addressed by i4WATER through the provision of adult education courses geared towards obtaining the required levels of education for course enrolment. Other challenges that were effecting the progress of the WWWC interventions were continued illegal dumping, especially of used diapers, in certain areas, and sewer pipe leakages into the river (SM Table 2.1).

CHAPTER 3: **Civic Environmental Management, Ecosystem Services and Social-Ecological System Outcomes: An Impact Assessment**

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Photo: Wise Wayz Water Care Beneficiaries Credit, Rashieda

Abstract

Using an impact assessment methodology, we provide a novel approach to assessing contributions to social-ecological outcomes from civic ecology interventions. In our Southern case study, we highlight how social-ecological systems and ecosystem services (ES) perspectives can be used to effectively select - and encourage policy support for - local interventions that will contribute to a multitude of human well-being outcomes. Environmental Assessment is an international policy tool allowing for more sustainable outcomes, through quantification of ecological, socio-economic, and health impacts. Using mixed methods (household surveys, interviews, field observations and environmental assessment), we quantified the impact significance of six civic interventions (solid waste management, water quality monitoring, invasive alien plant control, crop production, recycling and community engagement), in two communities situated in urban to peri-urban/rural environments. Interventions resulted in a total of 38 outcomes, of which 37 were positive and one negative. The socio-economic outcomes were the greatest (21), followed by ecological (11), and health outcomes (6). The greatest ecological outcomes resulted from invasive alien plant control (score of 57 from four outcomes), followed by solid waste removal (score of 50 from three outcomes), and water quality monitoring (score of 22 from two outcomes). Solid waste removal and vegetable gardens resulted in the greatest health outcomes (scores of 16 from 3, and 13 from one outcome, respectively), whereas general operation of WWWC, solid waste removal, and invasive alien plant control, resulted in the greatest socio-economic outcomes. Outcomes included access to education and training; improved quality of life; improved terrestrial and aquatic ecosystems; increase in recreation and cultural uses of natural areas; reduced health risks; increased nutrition. Although the majority of the interventions were targeted for environmental management, we demonstrate that investments in natural areas can deliver not only on enhancements in ecosystems and their services, but also for socio-economic and health benefits. We provide an intervention quantifying tool for practitioners to select local optimal sustainability interventions, that can be aligned with desired outcomes related to specific community challenges and policy requirements.

Keywords: ecosystem services, environmental management, stewardship, civic ecology, social-ecological system, sustainable development

3.1 Introduction

Human well-being and natural capital are inextricably linked through ecosystem services (Costanza et al. 1997, Daily 1997, MEA 2005, Díaz et al. 2018). Natural capital and ecosystem services are under pressure and at risk due to rapid urbanisation and increasing population growth (Steffen et al. 2015) raising the importance of the management and sustainable use of resources, as policy issues (Greenhalgh and Hart 2015).

Ecosystem services provide a powerful lens to advance resilient and sustainable urban development as it relates the condition of natural systems to human well-being (Biggs, Schlüter and Schoon 2015). Key to this is the understanding that ecosystem services do not flow directly from natural capital to human well-being without the presence and interaction of human capital (people), social capital (communities), and built capital (built environment) (Costanza et al. 2014). Negative impacts on biodiversity and ecosystem services, including habitat loss and transformation, can result from local land-use decisions (Seto et al. 2012). Despite their importance, ecosystem services are inadequately addressed in strategic development planning and management is lacking (Daily et al. 2009, Groot et al. 2010, Davids et al. 2018). Furthermore, the management of natural capital to secure ecosystem services for well-being could be unaffordable and unmanageable if they are not prioritised (Mace et al. 2015).

Environmental management is critical to protect biodiversity and ES that support human well-being (Davids et al. 2016), and will require multidisciplinary approaches that involve all stakeholders (Honey-Rosés and Pendleton 2013, Davids et al. 2016). In Africa, the production of ES declined due to inadequate management (Munang et al. 2011). South Africa has the world's highest Gini income coefficient of 0.68, with high levels of poverty and inequality (World Bank 2014). Many indigent communities are directly dependent on ES for their basic needs and well-being, raising the importance of managing natural capital to ensure the continued supply of ES. Cities play a crucial role in managing biodiversity and responding to global environmental change issues (Puppim de Oliveira et al. 2011). More locally, in the city of Durban, there are numerous factors limiting the effective management of ES, including that the majority of important ES areas are located outside of formally managed conservation areas, and within jointly administered communal lands, i.e. under joint tribal authority and municipal administration (Davids et al. 2016). Civic ecology initiatives are crucial to support more formal environmental management in cities, as they improve enhance natural capital, ecosystem services, and human well-being through environmental stewardship and participatory approaches (Krasny et al. 2013). However, the challenge remains to assess civic ecology interventions in terms of their contribution to ecological, social and economic outcomes.
In this paper, we show that civic interventions play a critical role to ensure sustainability. Our key questions are: What are the ecological, socio-economic and health outcomes of the

community-based environmental management interventions? What is the significance of the impacts of community-based environmental management interventions on the social-ecological system? How can the significance of the ecological, social and health outcomes associated with different local scale civic management interventions be measured, in a practical way that is accessible to decision-makers? We used an impact assessment methodology to quantity and assess the socio-economic, health, and ecological impacts and outcomes from community environmental management (or 'civic ecology') interventions, as a mechanism for selection of interventions by practitioners for maximum impact. As a case study, we use the private sector funded Wise Wayz Water Care (WWWC) programme, being implemented by community members of two low-income peri-urban communities (the beneficiaries), along the Golokodo and Mbokodweni Rivers, within Durban, South Africa (Fig 3.1).

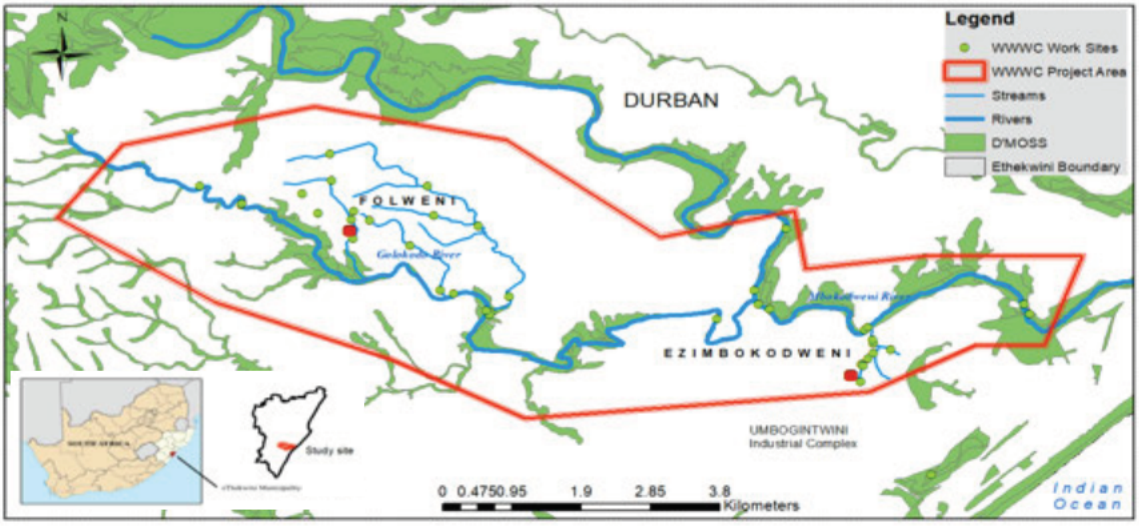

Figure 3.1: Study area: Wise Wayz Water Care Work Areas in eThekwini Municipality (Durban), South Africa

3.2 Methods

3.2.1 Study area

The WWWC work area, the study area (Fig 3.1), is situated in two rural/peri-urban communities, Folweni (more urban) and Ezimbokodweni (rural-peri-urban), located in Durban, in the province of KwaZulu-Natal, South Africa. The study area is characterised as one of the poorest in Durban, with low education, employment and income levels and low service delivery (Folweni 53% of households have piped water inside the dwelling, 42% have flush toilets connected to sewer, and Ezimbokodweni 10.7% households have piped water inside the dwelling, 4% have a flush toilet connected to sewer).

The study site is traversed by the Mbokodweni and Golokodo Rivers, which fall within the U60E U60E quaternary catchment and the North Eastern Coastal Belt aquatic ecoregion (Kleynhans, Thirion and Moolman 2005). The study area falls within in the KwaZulu-Natal Coastal Belt vegetation type within the Indian Ocean Coastal Belt Bioregion (Mucina and Rutherford 2006), which is classed as endangered. Numerous wetlands are present along the rivers, and the site is traversed by the Durban Metropolitan Open Space System (D'MOSS) (Fig 3.1). D'MOSS is a formal municipal planning policy instrument which identifies a series of interconnected open spaces that incorporate areas of high biodiversity value and natural areas (Davids et al. 2016), with the purpose to protect the globally significant biodiversity (located within the Maputo-Pondoland Biodiversity Hotspot), and ES within the city (Roberts and Donoghue 2013).

3.2.2 Case study: Wise Wayz Water Care Programme

The Wise Wayz Water Care (WWWC) programme is a civic ecology programme that commenced in 2016, where volunteer groups mainly did litter removal along the Mbokodweni and Golokodo river systems. WWWC was later formalised through funding from the private sector, which facilitated education and training for beneficiaries (community members implementing civic ecology interventions) to implement the six interventions assessed in this study, within the community and in natural areas in and around Ezombokodweni and Folweni.

3.2.3 Identification and assessment of social-ecological system impacts, and outcomes of interventions

In order to do the impact assessment, data on the changes to the ecologial, socio-economic and health conditions of the community, in response to the interventions, needed to be identified. Data for the environmental impact assessment (EIA) was collected through site visits, interviews and through a social-ecologial workshops, as described below.

3.2.3.1 Site visits

Site visits of WWWC work sites were done to identify the general living conditions of the community in the study areas (including housing, water supply, waste management, etc.), and the biophysical condition of the areas where the WWWC interventions were implemented (including wetlands and rivers, open spaces, etc.), through direct field observations and, socio-economic effects of the programme were captured through on-site discussions with beneficiaries.

3.2.3.2 Social-ecological system workshop with beneficiaries

In order to better understand the social-ecological system of the study area, we hosted a workshop with WWWC beneficiaries (n=60), who were randomly selected from the list of beneficiaries. We used A0 size maps as the focus of discussions, which showed the locations of WWWC work areas (WWWC programme boundary and locations of management intervention sites, for example, water quality monitoring points and solid waste removal sites). Maps were drawn using ArcGIS 10.4, and showed the WWWC work sites relative to other landscape attributes and ecological habitats, namely, the D'MOSS, including wetlands, rivers and vegetation habitats, using. Beneficiaries reflected on the maps and related their experiences in the study area. Key questions that were explored in the workshop related to existing or perceived understandings of: (1) opportunities related to social activity, knowledge sharing and natural resource use (for example, water extraction, livestock grazing, and watering); (2) potential expansion of WWWC work areas; and (3) threats relating to health and safety, such as sources of pollution, and illegal dumping of solid waste.

3.2.3.3 Intervention Impact Assessment

We identified social-ecological outcomes of the WWWC programme from the surveys (responses were coded/categorised using Grounded Theory and intercoder reliability (Charmaz 1996, Lombard et al. 2005), workshop (notes from comments and discusions were coded/categorised) and site visits (field observations) (Chapter 2). From survey, workshop and site visit data, outcomes were identified for each of the six interventions, and were categorised into three themes, (1) ecological, where the intervention resulted in the impacts on nature (or 'natural capital') (n = 6), (2) socio-economic, where the intervention resulted in the impacts on social or economic aspects (n = 16), and (3) health, where the intervention resulted in impacts on health (n = 3). We then scored the impact significance, either positive (+) or negative (-), for each outcome.

An adapted EIA method , based on the general approach to impact significance assessment applied in South Africa (Department of Environmental Affairs and Tourism 2002 and the requirements for impact assessment in the 2017 Amendments of the Environmental Impact Assessment Regulations, 2014 (DEA GNR 326, 2017).), was used to quantify the significance of the outcomes of the WWWC interventions. We believed Environmental Assessment was a suitable approach, potentially the most successful environmental policy intervention of our time, that is used internationally (Taylor et al. 2012), and which allows for more sustainable outcomes to be achieved (Sandham and Retief 2016), through the quantification of ecological, socio-economic, and health impacts. The lead author also a Registered EIA (Environmental Assessment Practioners Association of South Africa) and drew on her experience in

undertaking impact assessments in South Africa.

Outcomes were ranked and scored in terms of five assessment criteria (Department of Environmental Affairs and Tourism 2002): (1) Extent: spatial scale of the impact; (2) Magnitude: degree of the impact; (3) Duration: time scale of the impact; 4) Reversibility: degree to which the outcome can be reversed; and 5) Probability: of the impact occurrence (SM Table 3.1). Using these five assessment criteria, the significance of each outcome was determined, whereby the significance (**S**) of the impact is determined by the probability (**P**) of the particular impact occurring, and the consequence (**C**) of the impact. The consequence is determined by combining the spatial (geographical) extent (**E**), magnitude (**M**), duration (**D**), and reversibility (**R**), applicable to the specific impact (see formula below) (Table 3.1).

Table 3.1: Evaluation and ranking criteria to assess the impact significance of intervention outcomes (based on (Department of Environmental Affairs and Tourism, 2002)

Evaluation components	Ranking scale and description critera
MAGNITUDE of NEGATIVE IMPACT (at the indicated spatial scale)	5 - Very high: Bio-physical and/or social functions and/or processes might be severely altered. 4 - High: Bio-physical and/or social functions and/or processes might be considerably altered. 3 - Medium: Bio-physical and/or social functions and/or processes might be notably altered. 2 - Low : Bio-physical and/or social functions and/or processes might be slightly altered. 1 - Very Low: Bio-physical and/or social functions and/or processes might be negligibly altered. 0 - Zero: Bio-physical and/or social functions and/or processes will remain unaltered
MAGNITUDE of POSITIVE IMPACT (at the indicated spatial scale)	5 - Very high (positive): Bio-physical (air, water, soil, wetlands) and/or social (human well-being) functions and/or processes might be substantially enhanced. 4 - High (positive): Bio-physical (air, water, soil, wetlands) and/or social (human well-being) functions and/or processes might be considerably enhanced. 3 - Medium (positive): Bio-physical and/or social (human well-being) functions and/or processes might be notably enhanced. 2 - Low (positive): Bio-physical and/or social (human well-being) functions and/or processes might be slightly enhanced. 1 - Very Low (positive): Bio-physical and/or social (human well-being) functions and/or processes might be negligibly enhanced. 0 - Zero (positive): Bio-physical and/or social (human well-being) functions and/or processes will remain unaltered.
DURATION (timeframe during which the impact will be experienced	5 - Permanent 4 - Long term: > 10 years or until the activity ceases. 3 - Medium term: 1- 10 years 2 - Short term: < 1 year. 1 - Immediate
EXTENT (spatial scale/influence of impact)	5 - International: Beyond National boundaries. 4 - National: Beyond Provincial boundaries and within National boundaries. 3 - Regional: Beyond 5 km of the proposed development and within Provincial boundaries. 2 - Local: Within 5 km of the proposed development. 1 - Site-specific: On site or within 100 m of the site boundary. 0 – No impact
REVERSIBILITY of impact (can the impact of the intervention be reversed?)	5 – Impact cannot be reversed. 4 – Low potential that impact might be reversed. 3 – Moderate potential that impact might be reversed. 2 – High potential that impact might be reversed. 1 – Impact will be reversible. 0 – No impact.
PROBABILITY	5 - Definite: The impact will occur.

(of occurrence). In most cases, the impact has occurred as the intervention has been implemented. Thus, many impacts score 5 in this category.)	4 - High probability: It is most likely that the impact will occur (>75% chance) 3 - Medium probability: the impact may occur (50% - 75% chance) 2 - Low probability: 25% - 50% chance that the impact may occur. 1 - Improbable: <25% chance of the potential impact occurring.
CUMULATIVE Impacts	High: The activity is one of several similar past, present or future activities in the same geographical area, and might contribute to a very significant combined impact on the natural, cultural, and/or socio-economic resources of local, regional or national concern. Medium: The activity is one of a few similar past, present or future activities in the same geographical area, and might have a combined impact of moderate significance on the natural, cultural, and/or socio-economic resources of local, regional or national concern. Low: The activity is localised and might have a negligible cumulative impact. None: No cumulative impact on the environment.

Positive impacts resulted in (+) scores, while negative impacts, resulted in (-) scores. Thus, negative impacts would reduce overall impact significance scores, when totalled with positive scores.

S = C (E+M+D+R) / 4) x P.

Outcomes were scored and classified into three categories of impact significance (high, moderate, or low (Table 3.2). Interventions were also scored to assess their relative cumulative impact across the three broad categories of ecological, socio-economic, and health, whereby high impact = 10, moderate = 5 and low = 3. This was done to compare interventions in terms of outcome categories (SM Table 3.2).

The assessment considered outcomes related to the six WWWC interventions, and the general operation of the programme. While the sixth intervention, community engagement, does not involve practical management, it provides a critical component that facilitates the achievement of environmental management actions, through education of the community, and, also, indirectly results in social-ecological improvements. Similarly, the 'general operation of WWWC programme' was also assessed, to consider those impacts that fell outside of specific interventions.

Table 3.2: Rating scale for intervention outcomes

Significance Score	Significance	Description
≥ 17	High	This impact will affect ecological, socio-economic and health functions and will result in a significant benefit or risk.
≥10 <17	Moderate	The impact is of medium significance may have an effect on ecological, socio-economic and health functions, and could result in a moderate benefit or risk.
< 10	Low	The impact of low significance is not likely to affect the ecological, socio-economic and health functions in a noticeable way and is unlikely to result in significant benefit or risk.

3.2.3.3.1 Verification of ecological impacts

To verify ecological impacts of the project for the impact assessment, we used two specialist studies commissioned by the private sector funder, AECI, to monitor the impact of the WWWC interventions on the aquatic environment within the study area, just after commencement of the interventions and again a year later (GroundTruth 2016; 2017). The first study was a baseline assessment of Golokodo and Mbokodweni Rivers conducted in 2016 (wet and dry season sampling, i.e. August and November respectively), which included biological and chemical assessments of both rivers namely, assessment of present ecological state; South African Scoring Systems (SASS5); bethnic diatoms (algea); riparian health audit, and physico-chemical water quality assessments. This baseline assessment was used as a benchmark in 2017 wet and dry seasons to measure change after WWWC interventions had been implemented. River health was classified into five classes, from natural, good, fair, poor, and being seriously modified.

3.2.3.4 Identifying natural capital and ecosystem services in the system

Natural resources included in the definition of 'natural capital' are locally available, and are directly and regularly used by households (for example, freshwater from a natural source, fuel wood, rangeland for grazing livestock) (Hamann et al. 2015, Reynolds et al. 2020). NC provisioning areas in the study area were classified according to spatial information contained in the D'MOSS (Fig. 3.1). These include the Mbokodweni and Golokodo rivers, wetlands, forest patches, woodlands, thickets, and grassland habitats. ES expected to be enhanced by the community-based management interventions were identified, based on literature (de Groot et al. 2010, Díaz et al. 2018), relative to the type of ecological habitat affected, or mitigated habitat impacts, and ecosystem functions (SM Table 3.1). In addition, ES were identified from survey responses, based on the existing use or demand for that service. Surveys (as described above) were used to collect data on ES usage by (access), and values of, beneficiaries and community members. The ES included in the survey were (1) River water use: use of natural water from river or stream (for example, for washing clothes and cars or for general household use; (2) Natural material harvesting: gathering natural materials for various uses, for example, medicinal plants and wood; (3) Subsistence use: direct use of natural resources to sustain life, for example, food and water (4) Agricultural use: crop or livestock production; (5) Cultural practices: use of natural areas for cultural practices or rituals; and (6) Recreation and leisure: use of natural areas for leisure and outdoor activities.

3.3 Results

3.3.1 Impact Assessment of Civic Interventions

We identified and assessed the impact significance of 38 outcomes in total, from the six civic interventions (SM Table 3.1), of which, the socio-economic outcomes were the greatest (n=21), followed by ecological (11), and health outcomes (6). The impact significance of the outcomes for each individual intervention were identified (Fig. 3.2, SM Table 3.1, SM Appendix 3.1).

All the interventions assessed were found to have positive impacts on the beneficiaries, the broader community, and their natural surroundings, including both aquatic and terrestrial environments. Only one negative impact was identified from general operation of WWWC, namely, that the programme caused 'conflict in the community' related to some beneficiaries having received cost recovery (provided to beneficiaries for carrying out activities in addition to basic activities), while others did not (SM Table 3.1). Invasive alien plant control and solid waste removal had the most positive outcomes (eight each), followed by community engagement and general operation of WWWC (five outcomes) (Fig. 3.2).

Significance scores were ranked as high, medium or low and ranged from a score of 4,5 (low positive impact) to 22,5 (high positive impact). The two outcomes that had the highest significance scores (22,5 and 21,25) were from the general operation of WWWC, namely, access to education and training of beneficiaries, and improved quality of life of beneficiaries and community members (denoted by the thicker links in Fig. 3.2). This was followed by increase in recreation and cultural uses of natural areas, from the solid waste removal intervention, with a significance rating of 18,75.

3.3.2 Nature and ecosystem services enhanced

The natural areas that were enhanced by the interventions include terrestrial and aquatic habitats, for example, wetlands, rivers/streams, riparian vegetation, and open space (natural areas zoned as public open space). The interventions made positive impacts on ecological areas, and were, thus, considered to have the potential to enhance ES (SM Table 3.1).

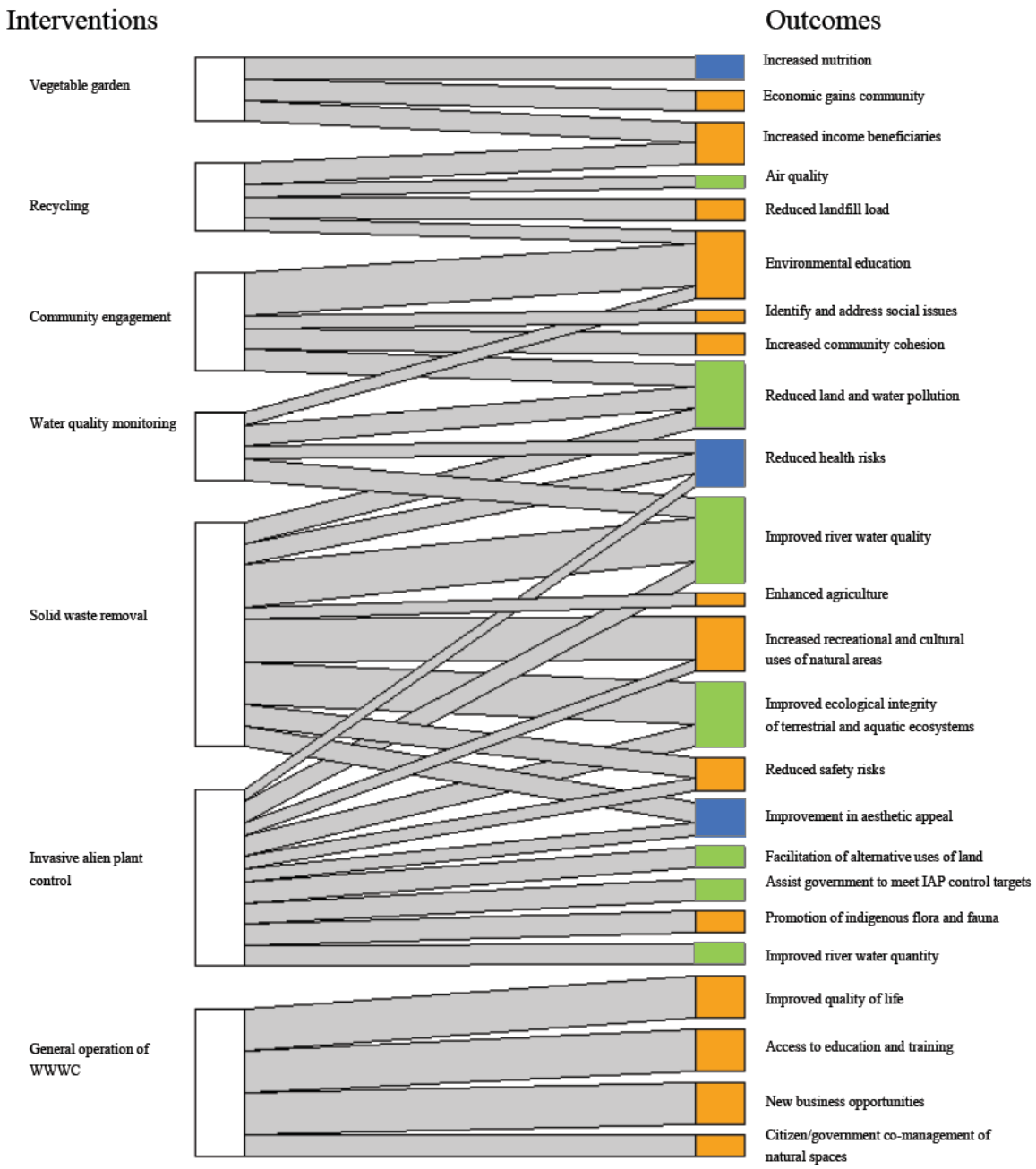

Figure 3.2: Impact significance of intervention outcomes: Here we show the interrelationships between the interventions (on the left) and all the resulting social (orange), ecological (green) and health (blue) impacts/human well-being outcomes (on the right). The width of bars denote the significance scores as calculated in the impact assessment (the higher the score, the thicker the line). Significance scores were calculated using an Environmental Impact Assessment methodology, whereby the significance (S) of the impact was determined by the probability (P) of the impact occurring, times the consequence (C) of the impact. The consequence is determined by combining the extent (E), magnitude (M), duration (D), and reversibility (R) of the impact). IAP has an extra arrow in this diagram compared to the number of impacts in the assessment, where 'improvement of 1) water quality and 2) water quantity' were combined (now they are listed as two separate outcomes).

The habitats improved by the interventions are linked to the enhancement of numerous ES, including regulating services or Nature's Contributions to People (NCP), of water purification, flood mitigation, biological regulation, and/or disease control, and maintenance of biological diversity (genepool protection) (previously considered a supporting service (MEA 2005), but now captured in regulating NCP (Díaz et al. 2018); cultural or non-material NCP of aesthetic, recreational, cultural, and education service; provisioning services or material NCP of water supply, food, and harvesting products (de Groot et al. 2010; Díaz et al. 2018). People accessed ES for water, agricultural production, and harvesting of medicinal plants and wood (SM Table 1.1), and increased use of natural spaces for cultural and spiritual activities, since it had been cleaned by the beneficiaries, for example, using the wetland in Ezimbokodweni for cultural rituals (*Umemelo* - Zulu traditional coming of age ceremony for women) (Chapter 2).

3.3.3 Comparison of impact categories per intervention

WWWC interventions resulted in a combination of socio-economic, ecological, and health outcomes. Outcomes resulted in an enhancement of the social-ecological system as a whole, and were able to address a multitude of community issues. When comparing the outcomes of interventions per category (Fig. 3.3, SM Table 3.2), the interventions that resulted in the impacts of the greatest ecological significance were invasive alien plant control (score of 57 from four outcomes), followed by solid waste removal (score of 50 from three outcomes), and water quality monitoring (score of 22 from two outcomes).

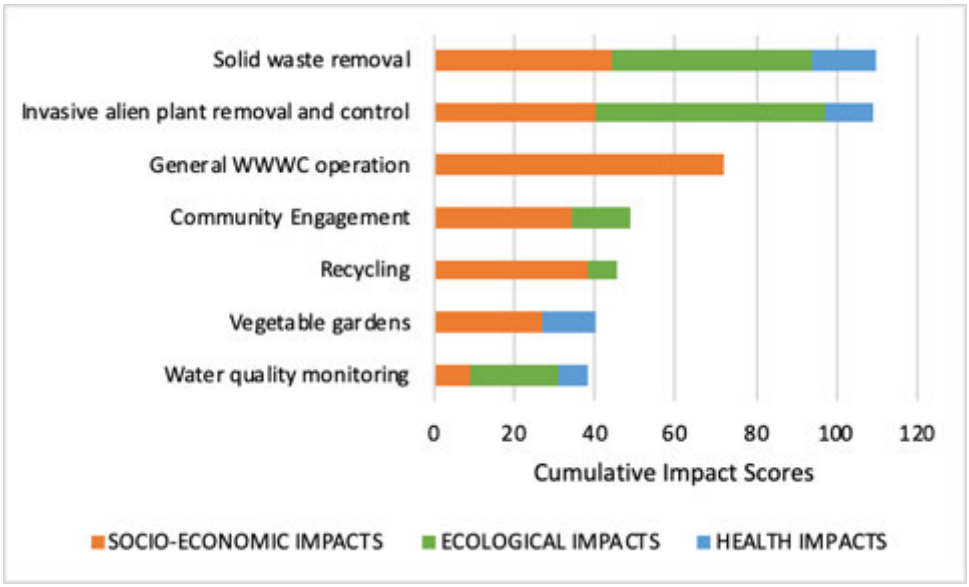

Figure 3.3: Cumulative impact significance scores as calculated for each community intervention, relative to three categories of outcomes, i.e. socio-economic, ecological and health.

Solid waste removal and vegetable gardens resulted in the greatest health outcomes (scores of 16 from 3, and 13 from one outcome, respectively), whereas general operation of WWWC, solid waste removal, and invasive alien plant control, resulted in the greatest socio-economic outcomes. Overall, solid waste removal scored highest in terms of cumulative impacts combined for all categories, followed very closely by invasive alien plant control.

In most cases, a particular positive outcome resulted from multiple interventions (Fig. 3.2, SM Table 3.2). Examples of these include: (1) 'Improved river water quality' and 'reduction in health risks; resulted from three interventions, namely, solid waste removal, invasive alien plant control, and water quality monitoring; (2) 'Improved ecological integrity of terrestrial and aquatic systems' resulted from solid waste removal and invasive alien plant control; 3) 'Reduced safety risks', 'improvement in aesthetic appeal', and 'increase in recreational and cultural uses of land', resulted from solid waste removal and invasive alien plant control. Thus, the interventions resulted in cumulative impacts, that together increased the significance of those positive outcomes.

3.4 Discussion

This study makes three important contributions to the science on civic ecology: (1):We confirm that civic ecology interventions can result in improvements in human well-being, through numerous socio-economic, health and ecological enhancements; (2) We provide a novel tool for assessing civic ecology interventions; and (3) We provide recommended mitigation and enhancment measures, for negative impacts and postivie impacts respectively, of civic ecology interventions.

By considering the 'whole system' civic ecology contributions to human-wellbeing can be identified

Our study confirms that civic interventions are important in the protection and management of natural areas that produce ES, while, at the same time, constitute social-ecological processes that enhance a multitude of ecosystem services and human well-being (Ezebilo and Mattsson 2010; Krasny et al. 2013; Díaz et al. 2018). Although the majority of the interventions were targeted for environmental management, we demonstrate that investments in natural areas can deliver not only on enhancements in ecosystems and their services, but also for socio-economic and health benefits (Krasny et al. 2013).

Food secirty is on both the South Africa Dvelopment Agenda (National Planning Commission 2011) and the global agenda for Sustanable Development (SDG 2). Another aspect of this work

is that it can inform policy towards achieving national and international goals and targets. For example, this study shows that local management of natural systems plays an important role in supporting local agriculture, a key feature of food systems that can only be sustainable if natural resources, such as water, soil, and land, are managed appropriately (High Level Panel of Experts on Food Security and Nutrition (HLPE), 2015, 2016). The vegetable gardens implemented by the benficiaries were grown using natural river water and were shown to result in socio-economic and health outcomes. Our study provides evidence through civic ecology, that natural resources and ecosystems play important roles in food production, and have influences on food security, nutrition and health (Pinstrup-Andersen 2013). The provision of education and skills to community members also had a positive impact on socio-economic aspects of the community, which has been shown to influence food security (HLPE, 2017). These local actions towards enhancing food security can thus be counted towards national (National Development of South Africa) and global (SDG) targets.

Novel method for assessing contributions of civic ecology interventions and selecting optimal interventions

This study contributed to the science of measuring civic ecology, which was last proposed by Krasny et al. (2013), by providing a novel method of assessing the contributions of civic ecology interventions. Our application of an environmental assessment methodology to quantify impacts of civic ecology interventions provides a novel tool for government practitioners and business funders to select interventions for maximum impact, related to desired outcomes (for example, Fig. 3.2). Our study also contributes to the literature by providing a tool for comparing the significance of civic ecology interventions, which can be useful to determine which interventions to select, particularly when budgets are limited. This allows for sources of improvement (i.e. investments) to be compartmentalised and for impacts of investments to be quantified in an auditable manner. Thereby enhancing both an understanding of return on investment, but also providing for government at various levels (local, provincial, national) to account across sectors. Furthermore, the scoring of intervention impacts can assist government and other implementing agents to identify and select interventions that will have the most significant impacts in response to specific community challenges and policy requirements. For example, one of the most significant social outcomes was increased education of the community on environmental issues (high positive significance). Thus, other practitioners wishing to achieve similar outcomes may wish to incorporate community enagagement as an intervention.

Recommendations for the mitigation of negative impacts and enhancement of positive impacts of civic ecology

This study provided a number of unique reflections on civic ecology intitiatives: (1) The financial support received from private industry was instrumental for the success of the WWWC programme. Although the community originally started with basic activities such as solid waste clearing voluntarily, the result of 37 positive outcomes, as identified in this study, relied on the education and skills training that beneficiaries received. For example, the clearing of invasive alien plants was only possible with the knowledge (education) of the legislation guiding the requirements for their removal, which plants needed to be removed, tools for their removal and ecologically accepted methods of removal. Majority of which require funding to to be achieved. (2) The beneficiaries received stipends for the work they did. This stipend, although small in amount, covered some basic needs of beneficiaries (with some noting they were able to buy food therefrom). As such, the programme was a means of livelihood for many beneficiaries. (3) The funding was managed by an implementing agent, who worked closely with the community members and benficiaires to identify the specific needs of community (in relation to challenges they were facing) and then, sourced the required training, skills and equipment, and assisted with drafting of a schedule of activities/tasks that the beneficiaries implemented, in response to the community's needs. For duplication of the interventions discussed in this study, sourcing of funding would be crucial. Furthermore, time is needed to understand specific challenges faced in a particular community, to allow for adequate planning of responses through the civic ecology interventions.

The civic ecology interventions, such as those considered in this study, could be initiated by local governments who are mandated to ensure service delivery, for example, job creation, supply of water and sanitation and management of natural resources. Such intiatives should then be jointly managed and implemented in partnerships with private actors or community organizations (Bai et al., 2010; Castán Broto and Bulkeley, 2013).

A limitation of this study is that the financial costs of implementation of each intervention was not factored. This study could be expanded by taking into account the costs of training needs, number of people workdays and equipment needed, which would provide an additional factor in determining the optimal interventions to be selected by practitioners. Such interventions should aim to incorporate environmental, social, and economic dimensions, including sustainable use of ecosystem goods and services, promoting dignified standards of life, and providing employment opportunities (Ezebilo and Mattsson 2010).

3.5 Conclusion

By using the ES concept, we emphasised the importance of the 'whole system' and not just humans (Costanza et al. 2017). Our use of EIA methodology for assessing the impact of civic interventions can be easily duplicated, and thus provides an additional tool to assist decision-makers and funders in the selection of interventions that can result in improved social-ecological system outcomes. The multiple benefits of improving the environment while also achieving health improvements and social upliftment is a model that can be duplicated in other parts of the world with similar social-ecological conditions. We provide, test, and learn from a conceptual framing that is holistic and systematic, and demonstrate the opportunities can be brought about through mutually beneficial relationships between humans and the environment at the local community level, but which could be effectively upscaled for broader societal impact.

3.6 Acknowledgements

We would like to acknowledge Georgina Mace, Alan Dangour and Belinda Reyers for substantial comments on the manuscript, which resulted in revisions and improvements.

SUPPLEMENTARY MATERIAL

SM Tables

SM Table 3.1: Intervention Impact Assessment Scoring Table

SM Table 3.2: Intervention Ecological, Health and Socio-economic Impacts Categories: Cumulative Impact Scoring

SM Appendices

SM Appendix 3.1: Descriptions of intervention impact significance

SM Table 3.1: Intervention Impact Assessment Scoring Table

WWWC Intervention	Category of impact	No.	Outcomes	Magnitude	Duration	Extent	Reversibility	Probability	Total Impact Significance Points (Total) x P	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to
Solid waste removal This activity results in the reduction of waste on land and in water courses.	**Ecological**	**1**	1. Improved river water quality.	4	4	2	4	5	17,5	High (+)	Riparian vegetation, rivers, streams, wetlands		Water purification	Solid waste pollution
		2	2. Improved ecological integrity of terrestrial and aquatic ecosystems.	4	4	2	4	5	17,5	High (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Water flow regulation Maintenance of ecological balance	Flood mitigation Hazard mitigation Maintenance of biological diversity (genepool protection)	Poor waste collection service delivery
		3	3. Reduction in land and water pollution.	5	4	1	2	5	15	Moderate (+)	Riparian plants and soil	Biotic and abiotic processes in breakdown of organic matter, nutrients and compounds	Waste assimilation	Solid waste pollution
	Socio-economic	**4**	4. Reduced safety risks to animals and children.	3	4	1	4	4	12	Moderate (+)			Recreational service	
		5	5. Improvement in aesthetic appeal of the area.	4	4	1	4	5	16,25	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Aesthetic quality of natural area	Aesthetic service	Injury to animals and children from solid waste pollution Unsightly pollution dumps
		6	6. Increase in recreational and cultural uses of natural areas.	5	4	2	4	5	18,75	High (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features	Recreational service Cultural service	Lack of recreational space due to pollution

WWWC Intervention	Category of impact	No.	Outcomes	Magnitude	Duration	Extent	Reversibility	Probability	Total Impact Significance Points (Total) x P	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to
		7	7. Enhancement of agriculture due to improved water quality	3	4	1	4	3	9	Low (+)	Aquatic habitats, for example, wetlands, rivers/streams	Water supply and purification for irrigation Soil retention by vegetation preventing loss of topsoil	Agricultural service Erosion control	Food insecurity
	Health	**8**	8. Reduction in health risks related to diseases linked to pollution, for example, skin rashes, cholera.	4	4	1	4	4	13	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Control of pest populations	Biological regulation/disease control	Water-borne diseases
Recycling Impacts form recycling are indirect and result from removal of solid waste.	**Ecological**	**9**	1. Reduction in air pollution due to avoided burning of waste.	3	4	3	4	2	7	Low (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Capacity of ecosystems to extract pollutants for example, vegetation/leaf cover	Air purification	Burning of waste due to poor of waste collection service
	Socio-economic	**10**	2. Source of income to recyclers.	1	4	1	5	5	13,75	Moderate (+)				Poverty and low employment
		11	3. Provides environmental education to community members on recycling.	2	4	1	4	3	8,25	Low (+)			Environmental education	Low education
		12	4. Reduced load on local landfill and waste removal services.	2	4	2	5	5	16,25	Moderate (+)			Waste assimilation	
Invasive alien plant removal and control This activity controls the spread of	**Ecological**	**13**	1. Promotion of indigenous species of flora and fauna.	4	4	3	3	4	14	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Maintenance of ecological balance	Maintenance of biological diversity (genepool protection) Pollination Harvesting products	Infestation of invasive alien plants Lack of access to resources

WWWC Intervention	Category of impact	No.	Outcomes	Magnitude	Duration	Extent	Reversibility	Probability	Total Impact Significance Points (Total) x P	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to
invasive alien plants.		**14**	2. Improved water quality and quantity.	4	3	3	3	5	16,25	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Water flow regulation	Water supply Water purification	Loss of water from rivers due to IAPs
		15	3. Improvement in ecological integrity of natural spaces, particularly wetlands and improvement of flow of water and mitigation of flooding.	4	3	3	4	3	10,5	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Water flow regulation	Flood mitigation	Loss of water from rivers due to IAPs
	Socio-economic	**16**	4. Facilitation of alternative and more appropriate uses of land, for example, more land available for community gardens.	4	3	1	3	5	13,75	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Water supply and purification for irrigation Soil retention Soil formation	Agricultural service Erosion control	Loss of land due to encroachment by IAPs
		17												
		18	5. Improvement in aesthetic appeal of the area.	3	3	1	3	3	7,5	Low (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Aesthetic quality of natural area	Aesthetic service	Unsightly overgrown areas.
		19	6. Increase in recreational and cultural uses of natural areas.	3	3	1	4	5	13,75	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features	Recreational service Cultural service	Loss of land due to encroachment by IAPs
		20	7. Reduced safety risks (related to crime)	3	4	1	4	3	9	Low (+)	Terrestrial and aquatic habitats.			Use of IAP infested areas for criminal activity
		21	8. Assist municipality to achieve IAP control targets.	2	3	1	4	2	5	Low (+)	Terrestrial and aquatic habitats, for example, wetlands,	Maintenance of ecological balance	Maintenance of biological diversity (genepool protection)	No municipal IAP programme in the study area

WWWC Intervention	Category of impact	No.	Outcomes	Magnitude	Duration	Extent	Reversibility	Probability	Total Impact Significance Points (Total) x P	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to
											rivers/streams, open space			
	Health	**22**	9. Reduction in health risks associated with invasive plants, for example, through removal of poisonous plants.	2	3	1	3	2	4,5	Low (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space			Skin rashes due to contact with certain IAPs
Water quality monitoring	**Ecological**	**23**	1. Improved river water quality	3	2	2	4	4	11	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Control of pest populations water filtration by wetlands	Water purification	Pollution of rivers due to littering and dumping
		24	2. Reduction in land and water pollution.	3	4	1	3	4	11	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Biotic and abiotic processes in breakdown of organic matter, nutrients and compounds	Water purification	
	Socio-economic	**25**	3. Environmental education of community (Empowering community to understand the natural environment and creating awareness of water pollution).	4	3	1	4	3	9	Low (+)	Aquatic habitats, for example, wetlands, rivers/streams	Presence of natural features of educational value	Educational service	Low education
	Health	**26**	4. Reduced health risks of water borne diseases.	4	1	1	4	3	7,5	Low (+)	Aquatic habitats, for example, wetlands, rivers/streams	Control of detrimental organisms/ecological processes, for example, pest and pathogens	Biological regulation/disease control	Water-borne diseases

WWWC Intervention	Category of impact	No.	Outcomes	Magnitude	Duration	Extent	Reversibility	Probability	Total Impact Significance Points (Total) x P	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to
WWWC vegetable gardens Two vegetable gardens are part of the programme that grow a variety of vegetable, fruit and herbs, which are consumed by beneficiaries and sold to the local community and local grocery store.	**Socio-economic**	**27**	1. Increased income for beneficiaries for example, though sale of vegetables.	2	4	1	5	5	15	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Water supply and purification for irrigation Soil retention by vegetation preventing loss of topsoil	Agricultural service Erosion control Pollination Harvesting products	Poverty and low employment
		28	2. Positive economic impact on community members due to availability of cost effective fresh vegetables locally and reduction in need to travel to purchase vegetables.	3	4	1	4	4	12	Moderate (+)				
	Health	**29**	3. Health (nutritional) benefits to community through increased accessibility and consumption of a large variety of nutrient rich vegetables.	4	4	1	4	4	13	Moderate (+)				Food insecurity Lack of access to affordable nutritious food
Community engagement This activity shares information with the local community on environmental management through household visits.	**Socio-economic**	**30**	1. Increased education of community members on environmental issues.	5	4	1	4	5	17,5	High (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features of educational value	Environmental education	Poor practices by community members, for example, littering, dumping, wastage of water
		31	2. Increased community cohesion through engagement.	3	4	1	4	4	12	Moderate (+)				Poor communication between community members

WWWC Intervention	Category of impact	No.	Outcomes	Magnitude	Duration	Extent	Reversibility	Probability	Total Impact Significance Points (Total) x P	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to
		32	3. Opportunity to identify and address social issues in the community.	3	3	1	3	2	5	Low (+)				Poor communication between community members
	Health	33	4. Reduction in land and water pollution due to improved waste management for example, reduction in dumping and littering by community members.	4	4	2	4	4	14	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space		Water purification	Solid waste pollution Dumping and littering
General Operation of WWWC Programme	Socio-economic	34	1. Improved quality of the life of the beneficiaries and community members.	5	4	3	5	5	21,25	High (+)				Low employment Low education Poverty Lack of access to nutritious food Pollution
		35	2. Access to education and training of beneficiaries and potential improved prospects of employment.	5	5	3	5	5	22,5	High (+)				Low education and skills
		36	3. New business opportunities for beneficiaries, for example, SMME.	3	4	3	4	5	17,5	High (+)				Lack of economic opportunities
		37	4. Opportunities for co-management of natural spaces between citizens and authorities.	3	4	3	4	4	14	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features of educational value	Educational service	Poor service delivery
		38	5. Conflict in the community.	2	2	1	1	2	3	Low (-)				Poor communication between community members

SM Table 3.2: Intervention Ecological, Health and Socio-economic Impacts Categories: Cumulative Impact Scoring

Nature of impact/outcomes	Interventions							
	Solid waste removal	Recycling	Invasive alien plant removal and control	Water quality monitoring	Vegetable gardens	Community Engagement	General	Cumulative impact score
ECOLOGICAL IMPACTS	**50 (3)**	**7 (1)**	**57 (4)**	**22 (2)**	**0 (0)**	**14 (1)**	**0 (0)**	**150**
1. Improved river water quality	17,5		16,25	11				44,75
2. Improved river water quantity			16,25					16,25
3. Improved ecological integrity of terrestrial and aquatic ecosystems	17,5		10,5					28
4. Reduction in land and water pollution	15			11		14		40
5. Promotion of indigenous species of flora and fauna.			14					14
6. Reduction in air pollution		7						7
HEALTH IMPACTS	**16 (3)**	**0 (0)**	**12 (2)**	**7,5 (1)**	**13 (1)**	**0 (0)**	**0 (0)**	**48,5**
7. Reduced safety risks to children and animals	13		9					22
8. Reduction in diseases linked to pollution, for example, skin rashes, cholera.	3							3
8. Health (nutritional) benefits to community through increased accessibility and consumption of a large variety of nutrient rich vegetables.					13			13
9. Reduction in water related health risks (water borne disease			3	7,5				10,5
SOCIO-ECONOMIC IMPACTS	**44 (3)**	**38,25 (3)**	**40 (4)**	**9 (1)**	**27 (2)**	**34,5 (3)**	**72,25 (5)**	**265,5**
10. Improvement in aesthetic appeal of the area.	16,25		7,5					23,75
11. Increase in recreational and cultural uses of natural areas.	18,75		13,75					32,5

Nature of impact/outcomes	Interventions							
	Solid waste removal	Recycling	Invasive alien plant removal and control	Water quality monitoring	Vegetable gardens	Community Engagement	General	Cumulative impact score
12. Enhancement of agriculture due to improved water quality	9							9
13. Increased income for beneficiaries		13,75			15			28,75
14. Increased environmental education of community		8,25		9		17,5		34,75
15. Reduced load on landfill		16,25						16,25
16. Facilitation of alternative and more appropriate uses of land, e.g. more land available for community gardens.			13,75					13,75
17. Positive economic impact on community members due to availability of cost effective fresh vegetables locally and reduction in need to travel to purchase vegetables					12			12
18. Increased community cohesion						12		12
19. Opportunity to identify and address social issues in the community						5		5
20. Assist government to achieve invasive alien plant control targets			5					5
21. Improved quality of the life of the beneficiaries and community members.							21,25	21,25
22. Access to education and training of beneficiaries and potential improved prospects of employment.							22,5	22,5
23. New business opportunities for beneficiaries, for example, SMME.							17,5	17,5
24. Opportunities for co-management of natural spaces between citizens and authorities.							14	14
25. Conflict in the community.							-3	-3
Cumulative impact score	**110**	**45,25**	**109**	**38,5**	**40**	**48,5**	**72,25**	

SM APPENDIX 3.1: DESCRIPTIONS FOR INTERVENTIONS IMPACT ASSESSMENT

Solid Waste Removal intervention

The solid waste removal intervention resulted in eight positive outcomes of which three were ecological, two health and three socio-economic (SM Table 3.1 and SM Table 3.2). Impacts for the solid waste removal intervention ranged from low to high positive. Improved river water quality improved ecological integrity of terrestrial and aquatic ecosystems, and increase in recreational and cultural uses of natural areas scored high positive significance ratings. This intervention also contributed to reduced impact of downstream marine pollution. This activity was linked to the enhancement of ecosystem services, namely, water purification, flood mitigation, waste assimilation, cultural and recreational services. However, the benefits of this intervention were at risk due to continued illegal dumping both by business and trucks coming into the area.

Recycling intervention

Four outcomes were identified for the recycling intervention, one of which was ecological and three socio-economic (SM Table 3.1 and SM Table 3.2). This intervention provided some income to recyclers and the activity of collecting waste for recycling also educated the broader community on alternative uses of waste. Recycling reduced the load of waste to be collected by service providers and also reduced the volume of waste going to the landfill. This recycling activity also reduced the risk of waste being burned, thereby avoiding additional air pollution in the area. The outcomes related to the recycling intervention ranged from low to moderate positive significance, with ‘source of income to recyclers’ and ‘reduced load to landfill’ being ranked as moderate positive.

Invasive alien plant removal and control

This intervention resulted in the most outcomes; ten outcomes, four of which were ecological, two health and four were socio-economic impacts (SM Table 3.1 and SM Table 3.2). The removal of invasive alien plants through this intervention cleared areas that were previously infested, and opened up these areas for alternative uses, for example, vegetable gardens and recreation (for example, picnicking), reduced potential for injury and crime and improved the aesthetic appeal of the area. In addition, this activity rehabilitated a wetland and resulted in improved hydrological regulation and the increase of biodiversity in natural areas, for example, more birds and frogs were noticed by community members. The removal of poisonous invasive alien plants reduced health risks to the community. The impacts related to the removal of

invasive alien plants intervention ranged from low to moderate positive. The most significant outcome was 'improved water quality and quantity,' which was rated as moderate positive.

Water quality monitoring

The water quality monitoring intervention resulted in four outcomes, two of which were ecological, one health and one socio-economic (SM Table 3.1 and SM Table 3.2). The monthly measuring of water quality by the beneficiaries facilitated an increased understanding of water quality and pollution levels and assisted to identify sources of pollution. The findings were relayed to the community and thus served as a source of education to community members, which also reduced health risks (for example, water borne diseases) associated with the use of polluted water. This education resulted in the mitigation of sources of pollution and improved water quality, for example, increased *E. coli* counts was linked to a location along the river where nappies were dumped, and engagement resulted in nappies no longer being dumped there. The outcomes associated with the monitoring of water quality intervention were considered to be of moderate and low positive significance, with 'improved river water quality and reduction in land and water pollution' rated as moderate positive in significance.

Vegetable Gardens

The vegetable gardening intervention resulted in three outcomes, one of which was health and two were socio-economic (SM Table 3.1 and SM Table 3.2). The two vegetable gardens of the programme grew a variety of vegetables, fruit and herbs, which were either consumed by beneficiaries or sold to the local community and local grocery store. The availability of a large variety of vegetables from the WWWC gardens provided an opportunity for beneficiaries and community members to improve their nutritional intake of fresh vegetables, made the produce available in proximity to households and were thus cost effective. The sale of produce by beneficiaries also provided a source of income for them and a means to reinvest into the production of vegetables. Beneficiaries were using natural water for irrigation, which was dependent on water availability that was also threatened by pollution and drought. All the outcomes that resulted from the vegetable gardens intervention were considered to be of moderate positive significance, with the most significant outcome being 'increased income for beneficiaries through sale of vegetables'.

Community Engagement

Eight outcomes were identified from this intervention, five of which were ecological and three socio-economic (SM Table 3.1 and SM Table 3.2). The community engagement intervention enhanced social cohesion in the community as it provided for people to feel a sense of inclusion

and to build relationships that facilitated the improvement of living conditions and the sharing of knowledge and resources. The regular dialogue with community members provided an opportunity for the community to be educated on environmental matters while gaining an understanding and appreciation of the work the WWWC teams were doing. This education resulted in the improvement of waste and water management practices, and resulted in reduced water wastage and pollution. The outcomes from this intervention ranged from low to high positive significance. The greatest outcome was increased education of community members on environmental issues (high positive significance).

General operation of the WWWC programmes

The general operation of the programme resulted in five outcomes, all of which are socio-economic (SM Table 3.1 and SM Table 3.2). The quality of life of beneficiaries has improved though the availability of 'free' education and training, and the opportunity to gain work experience. This led to the establishment of the first SMME, which was a direct result of the education, training and experience of the beneficiaries through the programme. The establishment of the SMME provided an opportunity for social and economic upliftment of those beneficiaries involved that is both independent and sustainable. The quality of life of the broader community has also been impacted positively, through the WWWC programme, including that the areas are cleaner and safer, there is increased availability and accessibility of fresh vegetables and health benefits. The programme has provided a platform for engagement with authorities and has facilitated the opportunity for the co-management of natural spaces between citizens and authorities (Durban Solid Waste, eThekwini Natural Resources Division and Environmental Planning and Climate Protection Branch).

During the surveys, some issues were raised related to WWWC programme, namely, that some beneficiaries get 'cost recovery' and the manner of selection of volunteers to the programme. Although these issues are considered to be of low significance due to the fact the people who are part of the programme were already volunteers. The outcomes associated with the general operation of the WWWC programme are mostly high and moderate positive, with only one low negative impact related with minor conflict caused (SM Table 3.1 and SM Table 3.2). However, this negative outcome could be avoided altogether if the recommended mitigation measures are adopted.

CHAPTER 4: PAPER 3: Local Enhancement of Ecosystem Services for Achievement of the SDGs: A Systems Analysis

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Photo: Sustainable Development Goal Icons
Credit, United Nations

Abstract

We provide a novel approach to assessing contributions from civic ecology interventions to human well-being, in the context of the Sustainable Development Goals (SDGs). Using a Southern case study, we highlight how social-ecological systems and ecosystem services perspectives can be used to effectively encourage policy support for local interventions that will contribute to national and global sustainability targets. Using mixed methods (survey and interview data, environmental assessment, system mapping), we quantified the systemic linkages between six civic interventions (solid waste management, water quality monitoring, invasive alien plant control, crop production, recycling and community engagement), ecosystem services, SDGs, and well-being outcomes. Interventions resulted in 37 positive outcomes, contributed to 15 SDGs, most notably SDG 11 and SDG 6, and 29 and 66 SDG targets, from social and ecological interventions, respectively. Outcomes included improved terrestrial and aquatic ecosystems, reduced health risks, increased nutrition, and enhanced quality of life. Our system map showed that well-being increased cumulatively when considering social, ecological, and governance outcomes. We demonstrated how civic interventions could mitigate global environmental change and address sustainability issues, and highlight the importance of considering a combination of social, ecological, and political factors through a systems lens. We also provide a novel method of showing the synergestic relationships between the SDGs, from civic ecology initiatives, which can aid in decision-making.

Keywords: ecosystem services, environmental management, social-ecological system, sustainable development goals, transdisciplinary approach, systems thinking

4.1 Introduction

The 2030 Sustainable Development Goals (SDGs) aim to achieve human well-being, through a broad range of goals, including to conserve the environment and eliminate poverty, malnutrition, and hunger (United Nations Development Programme 2016). The nature of human 'health and well-being', happiness, and good-life have been contemplated for decades and a variety of conceptualisations have been proposed (Lent 2004). Health is defined as much more than the absence of disease, and includes being in physical, mental and social states of well-being (World Health Organisation 1948). The Millennium Ecosystem Assessment defined human well-being in terms of: "*security; an adequate supply of basic materials for livelihood (for example, food, shelter, clothing, energy, etc.); personal freedoms; good social relations; and physical health*" and confirmed that ecosystem services are crucial for the achievement of well-being (MEA 2005). Thus, the concept of human well-being encompasses social, economic and ecological factors. This is why the SDGs have been crafted to balance the social, economic and environmental dimensions of sustainable development, underpinned by the efforts of the United Nations to ensure that the 17 SDGs and 169 targets are indivisible and intergated (United Nations 2015; Jiménez-Aceituno et al. 2020)

For continued human well-being or 'good quality of life' (Díaz et al. 2018), the challenges of global environmental change need to be addressed, which requires a more comprehensive understanding of the complex relationships between humans and the environment (Ostrom 2009; Folke et al. 2011; Future Earth 2013; Diaz et al. 2015). It further requires that the role of natural systems, including biodiversity and ecosystem services (ES), are recognised for their contributions to fulfilling the SDGs through their inclusion in a broad range of development sectors (Blicharska et al. 2019). By aiming for sustainability for present and future generations, we ultimately aim for human well-being for present and future generations, and vice versa.

The SDGs (United Nations Development Programme 2016), Future Earth (Mauser et al. 2013), and global discourse on concepts like planetary boundaries (Johan Rockstrom 2009; Mace et al. 2014) are founded on a planetary scale. It is, however, argued that the consideration of both regional and planetary dimensions are required to achieve global sustainability (Dearing et al. 2014). Furthermore, in order to transform the planet towards greater sustainability, urban sustainability challenges must be addressed (Elmqvist et al. 2019). The notion of local action contributing to global goals has been explored in other studes, where it was shown that SDGs

can be addresed by diverse actions undertaken at the local level (Jiménez-Aceituno et al. 2020, Moallemi et al. 2020).

There is an understanding that natural capital underpins human, economic, societal, and cultural well-being (Costanza et al. 2014), whereby well-being is "embedded in and rests on a resilient biosphere" (Folke et al. 2010; 2016). Ecosystems and societies are intertwined from local to global scales, forming social-ecological systems (Folke et al. 2016). Interactions occurring across scales in social-ecological systems often result in feedbacks that either benefit system changes or inhibit them (Levin et al. 2013), and influence the capacity of the biosphere to sustain human development (Fischer et al. 2015). While it is uncertain how to achieve a balance between improvements in human well-being and ecosystem integrity at different scales (Fischer et al. 2015), aiming to improve the local environment, for example, through environmental management, could yield benefits at multiple scales (Folke et al. 2016), and investments in natural capital will result in ecological, social and economic benefits (Groot et al. 2010).

Transdisciplinary approaches aim to integrate social, natural, and health sciences, to address complex problems through actively involving non-academic stakeholders (Roux et al. 2010). While it is the role of governments to actualise the SDGs, financing of the agenda is expected to come from the private sector (United Nations Development Programme 2016). Actors in the private sector are pursuing roles that are typically regarded as public dominion, and participating in several local partnerships on urban sustainability experiments, for example, for climate change (Castán Broto and Bulkeley 2013). The case study presented here is on civic ecology initiatives that are improving social-ecological conditions (Krasny et al. 2013) through local business funding (Chapter 2). In this paper, we explore the contributions of local civic ecology interventions towards sustainability, through environmental management, natural capital, and ecosystem services enhancements, and how these can be counted at the planetary level of assessment through the SDGs.

As a case study, we use the private sector funded Wise Wayz Water Care (WWWC) programme, a civic ecology programme being implemented by community members of two low-income communities (the beneficiaries), one urban and the other peri-urban/rural, along the Golokodo and Mbokodweni Rivers, within Durban, South Africa (SM Fig. 4.1). We developed a novel transdisciplinary conceptual framework to quantify the socio-economic, health, and ecological outcomes from community environmental management (or 'civic ecology') interventions. In Durban, ES were defined, mapped, and quantified (Davids et al. 2016). However, the challenge remains to assess ES interventions in terms of their contribution to various components of well-being, as defined by the SDGs. Using a mixed-methods

approach and results from two associated studies (Chapter 2 (Davids et al. 2021); Chapter 3) (household surveys, interviews, field observations and impact assessment), this study identified the systemic linkages between civic interventions, ES, SDGs, and human well-being. In so doing, we highlight the potential for grassroots actions to have global policy impact, through the lens of social-ecological systems linkages, and call for policy support for the same.

4.2 Methods

4.2.1 Study area

The WWWC work area, the study area (SM Fig. 4.1), is situated in Folweni and Ezimbokodweni, located in Durban, in the province of KwaZulu-Natal, South Africa. Both fall within the eThekwini Municipal boundary. Folweni is more urban and is administered by eThekwini Municipality, while Ezimbokodweni is more peri-urban/rural, and is jointly administered by eThekwini Municipality and Ingonyama Trust Board (Traditional Authority of communally owned rural lands). The study area is characterised as one of the poorest in Durban, with low education, employment and income levels (Department of Statistics South Africa, 2020). The study site is traversed by the Mbokodweni and Golokodo Rivers. All of the civic ecology work sites are found in the endangered KwaZulu-Natal Coastal Belt vegetation type within the Indian Ocean Coastal Belt Bioregion (Mucina and Rutherford 2006). Numerous wetlands are present along the rivers, and the site is traversed by the Durban Metropolitan Open Space System (D'MOSS) (SM Fig. 4.1). D'MOSS is a formal municipal planning policy instrument which identifies a series of interconnected open spaces that incorporate areas of high biodiversity value and natural areas (Davids et al. 2016), with the purpose to protect the globally significant biodiversity (located within the Maputo-Pondoland Biodiversity Hotspot), and ES within the city (Roberts and Donoghue 2013).

4.2.2 Case study: Wise Wayz Water Care Programme

The objectives of the WWWC programme include improving the environmental health of the lower Mbokodweni Catchment (the study area), and supporting sustainable livelihoods of beneficiaries, and the greater community. The programme started in 2016, and implements six interventions within natural areas in and around Ezombokodweni and Folweni, namely, (1) *Solid waste management and removal*: removal of waste from aquatic and terrestrial areas; (2) *Recycling*: waste collection and storage for recycling; (3) *Invasive alien plant control*: identification and control of invasive alien plants along rivers and streams (4) *Water quality monitoring*: monthly biophysical monitoring of river water quality; 5) *Community vegetable gardens*: vegetable production (two gardens) using permaculture methods; (6) *Community*

engagement: door-to-door community engagement, surveys, and knowledge sharing. Interventions were identified by beneficiaries in response to related challenges faced in the community, and were implemented with support from business funding, within the lower Mbokodweni catchment, at 20 sites, within Folweni (11) and Ezomkodweni (9), along various rivers, tributaries, wetlands, and open areas (SM Fig. 4.1).

4.2.3 Social-ecological system analyses

This study applied a social-ecological-systems approach. Social-ecological-systems describe an integrated system of humans and nature, within which social and ecological components influence each other in a continually evolving and interdependent manner (Berkes et al. 2003; Folke 2006; Ostrom 2009). Figure 4.1 provides the conceptual framework that was developed for this study. Three broad themes underpin our framework: (1) Ecological: the provision of natural capital (NC), (2) Social: the ownership of NC (including economic and health), and (3) Governance: policy support of NC. Using a variety of methods described below, we undertook a holistic social-ecological systems analysis (1 in Fig. 4.1) to assess the impact of community management interventions implemented by the WWWC programme (2 in Fig. 4.1) on baseline (a.1), and future, states (a.2) of well-being (3 in Fig. 4.1) resulting from enhancements in NC (4 in Fig. 4.1) and ES (5 in Fig. 4.1), and the resultant contributions to policy achievements through the SDGs (6 in Fig. 4.1). For the purpose of this study, in line with the MEA definition of well-being, all activities that resulted in positive impacts on ecological, social, economic and health conditions, were considered to increase human well-being. Detailed results for a.1, a.2, b, and c in Fig. 4.1 were reported on in two associated studies (Chapter 2 (in press) and Chapter 3).

4.2.4 Quantifying management intervention outcomes on natural capital, ecosystem services, well-being, and the SDGs

4.2.4.1 Content analysis to identify the SDGs and targets affected by the interventions

We used simlar approach to Jiménez-Aceituno et al. (2020) and used content analysis to identify the SDGs and related targets addressed by the civic ecology interventions. However, in our study, we analysed first hand data of civic ecology initiatives underaken in particular geographical contexts, and not online data as was assessed for multiple local initiatives considered in a variety of local contexts across Africa. For each intervention outcome assessed, we identified the SDGs, and the associated SDG targets, that would be affected as a result of the intervention (or for which the intervention would contribute to the achievement of the SDGs and related targets). This was done by reviewing each SDG and its target, and categorising the

intervention outcomes for each of them. Only those SDGs wherein the intervention outcomes were categorised, were included for quantification. For example, the solid waste removal intervention was linked to the SGD 11 *Make cities and human settlements inclusive, safe, resilient and sustainable*, and its targets and affected Targets 11.4 and 11.7 , as the removal of solid waste contributed to the potection of cultural and natural heritage (after the interventions the wetland were used for cultural ceremonies and for recreation) and Target 11,6 and 11,7 were contributed to as the interventions reduced environmental impacts related to waste management.

4.2.4.2 Quantifying social-ecological system contributions to improved well-being

Despite varying definitions (Neve and Sachs 1992), there is no agreement on how to measure well-being (Cooke et al. 2016). This paper uses the definition of well-being from the Millennium Ecosystem Assessment, namely, including security of livelihood, personal freedoms, good social relations, and physical health. In terms of this definition, health is the basic component of well-being, and is influenced by changes in economic, psychological, social, residential, political, and behavioural circumstances, which, in turn, are all influenced by the availability and continuous supply of ES (MEA, 2005). For the purpose of this study, well-being increases when positive impacts are experienced on social, health, economic, and ecological conditions. To visualise the multiple contributions to well-being in the study area, we compiled a system map to show the various linkages between the variables assessed and increasing levels of well-being, using Visual Understanding for Environment (VUE) Version 3.30 (Tufts University 2015). The variables included (1) WWWC community interventions; (2) NC; (3) ES; (4) policy: achievement of the SDGs; and (5) human well-being.

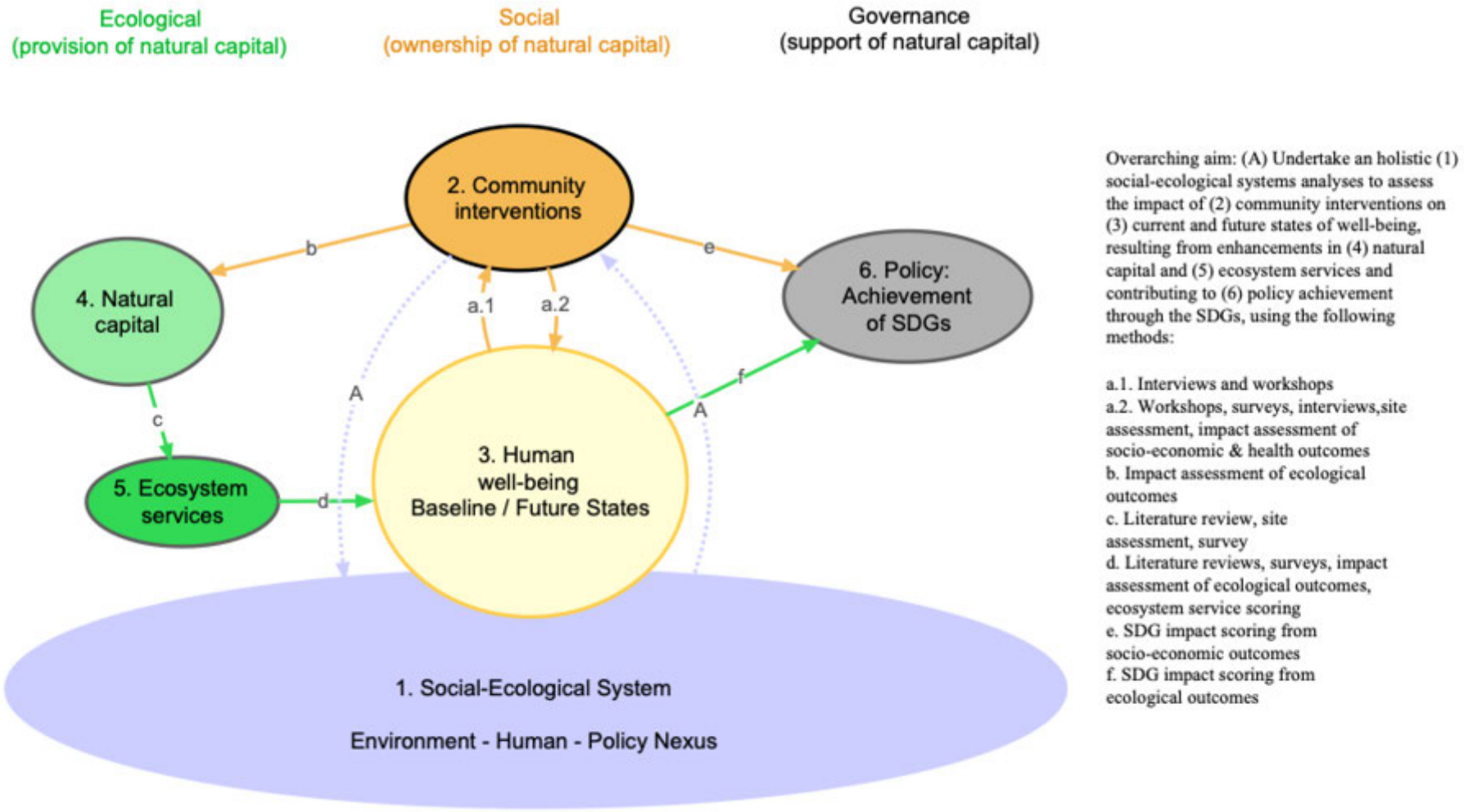


Figure 4.1: Social-ecological system conceptual framework: Methods indicated in the text to the right of the diagram (a.1 – f), were used to assess the impact of civic ecology interventions on the social-ecological system (purple arrows) and current and future states of well-being and the SDGs, from ecological (green arrows) and social interventions (orange arrows).

This was done to assess and demonstrate how these variables in the social-ecological system influence each other and contribute to increasing levels of well-being. Intervention outcome scores (from the impact assessment, SM Table 4.1) were calculated for (1) direct contributions to well-being through socio-economic or health improvements (a.2 in Fig. 4.1), and (2) indirect contributions to well-being through enhancement of NC, and associated ES (d in Fig. 4.1).

4.2.4.3 Quantifying intervention contributions to the achievement of the SDGs

We identified the contributions of the interventions to the achievement of the SDGs (e and f in Fig. 4.1 and Section 4.2.4.1). This was also done to test the potential for the methods to be used by practitioners, to guide the selection of interventions that will result in the most significant impacts on policy achievement (Chapter 3). The scores identified during the impact assessment (Chapter 3), were then used to calculate total impact scores for the affected SDGs, whereby individual impact scores for each intervention contributed to the total score for the SDG target (for example, Table 1: Impact assessment for the 'solid waste removal' intervention. No changes to scores were made when transfering scores from the impact assessment to the SDGs. This could be seen as a limitation to the study, however, it was done to avoid bias between the different SDGs, that could have been brought about by transfering scores according to differing ranks/importance of the SDGs. See SM Table 4.1 for the impact assessment for all other interventions). Target scores were then added up for each SDG (SM Table 4.2) to show the total contribution of the intervention to each SDG, relative to ecological and social (including economic and health) interventions.

4.3 Results

4.3.1 Local intervention contributions to the SDGs

All interventions contributed to the achievement of the SDGs (Fig. 4.2), with solid waste removal and general operation of WWWC contributing to the most targets (SM Table 4.2). The most affected Goal was Goal 11: *Make cities and human settlements inclusive, safe, resilient and sustainable*: from solid waste removal (97 points), invasive alien plant control (85.8 points), and community engagement (59.5 points). This was followed by Goal 6: *Ensure availability and sustainable management of water and sanitation for all:* including from solid waste removal (85 points), general operation of WWWC (28 points), and invasive alien plant control (17.5 points) (Fig. 4.3).

Table 4.1: Impact Assessment of interventions contributions and linkages to ES, community issues responded to the SDGs (solid waste removal shown here as an example of the methodology, See SM Table 4.1 for all other calculations)

WWWC Intervention	Category of impact	Impacts	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to	SDGs Contributed to
Solid waste removal This activity results in the reduction of waste on land and in water courses.	**Ecological**	Improved river water quality.	17,5	High (+)	Riparian vegetation, rivers, streams, wetlands		Water purification	Solid waste pollution	**Goal 6.** Ensure availability and sustainable management of water and sanitation for all. **Target 6.3.** By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally. **Target 6.6.** By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes **Target 6.b.** Support and strengthen the participation of local communities in improving water and sanitation management. **Goal 15.** Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss **Target 15.1:** 15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.
		Improved ecological integrity of terrestrial and aquatic ecosystems.	17,5	High (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Water flow regulation Maintenance of ecological balance	Flood mitigation Hazard mitigation Maintenance of biological diversity (genepool protection)	Poor waste collection service delivery	**Targets 6.6 and 15.1**
		Reduction in land and water pollution.	15	Moderate (+)	Riparian plants and soil	Biotic and abiotic processes in breakdown of organic matter, nutrients and compounds	Waste assimilation	Solid waste pollution	**Targets 6.3 and 15.1** **Goal 11.** Make cities and human settlements inclusive, safe, resilient and sustainable. **Target 11.6.** By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management. **Goal 14.** Conserve and sustainably use the oceans, seas and marine resources for sustainable development. **Target 14.1.** By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution. **Target 15.3.** By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land

WWWC Intervention	Category of impact	Impacts	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to	SDGs Contributed to
									degradation-neutral world.
	Socio-economic	Reduced safety risks to animals and children.	12	Moderate (+)			Recreational service		**Target 11.7.** By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.
		Improvement in aesthetic appeal of the area.	16,25	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Aesthetic quality of natural area	Aesthetic service	Injury to animals and children from solid waste pollution Unsightly pollution dumps	Targets 11.7 and 11.4. Strengthen efforts to protect and safeguard the world's cultural and natural heritage
		Increase in recreational and cultural uses of natural areas.	18,75	High (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features	Recreational service Cultural service	Lack of recreational space due to pollution	**Targets 11.4 and 11.7**
		Enhancement of agriculture due to improved water quality	9	Low (+)	Aquatic habitats, for example, wetlands, rivers/streams	Water supply and purification for irrigation Soil retention by vegetation preventing loss of topsoil	Agricultural service Erosion control	Food insecurity	**Goal 2.** End hunger, achieve food security and improved nutrition and promote sustainable agriculture. **Target 2.1.** By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round. **Target 2.3.** By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment. **Target 2.4.** By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather,

WWWC Intervention	Category of impact	Impacts	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced	Community issues responded to	SDGs Contributed to
									drought, flooding and other disasters and that progressively improve land and soil quality. **Goal 12.** Ensure sustainable consumption and production patterns. **Target 12.2.** By 2030, achieve the sustainable management and efficient use of natural resources.
	Health	Reduction in health risks related to diseases linked to pollution, for example, skin rashes, cholera.	13	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Control of pest populations	Biological regulation/disease control	Water-borne diseases	**Goal 3.** Ensure healthy lives and promote well-being for all at all ages. **Target 3.3.** By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.

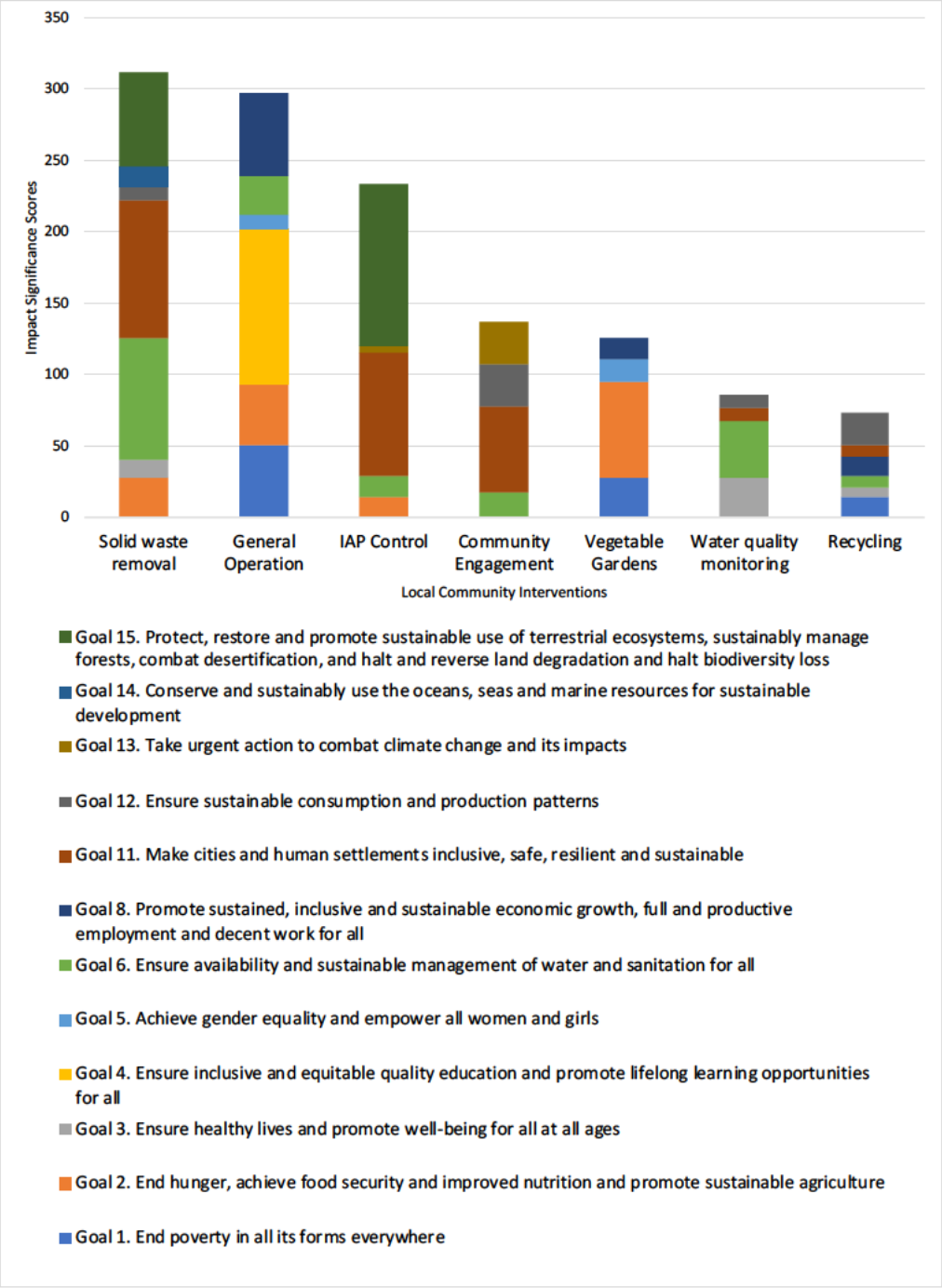


Figure 4.2: Contribution of each intervention to the achievement of the SDGs.

Scores from the impact assessment were allocated to each target affected by the intervention. Intervention SDG target scores were then totalled to compare the significance of intervention contributions to each SDG. IAP = invasive alien plant.

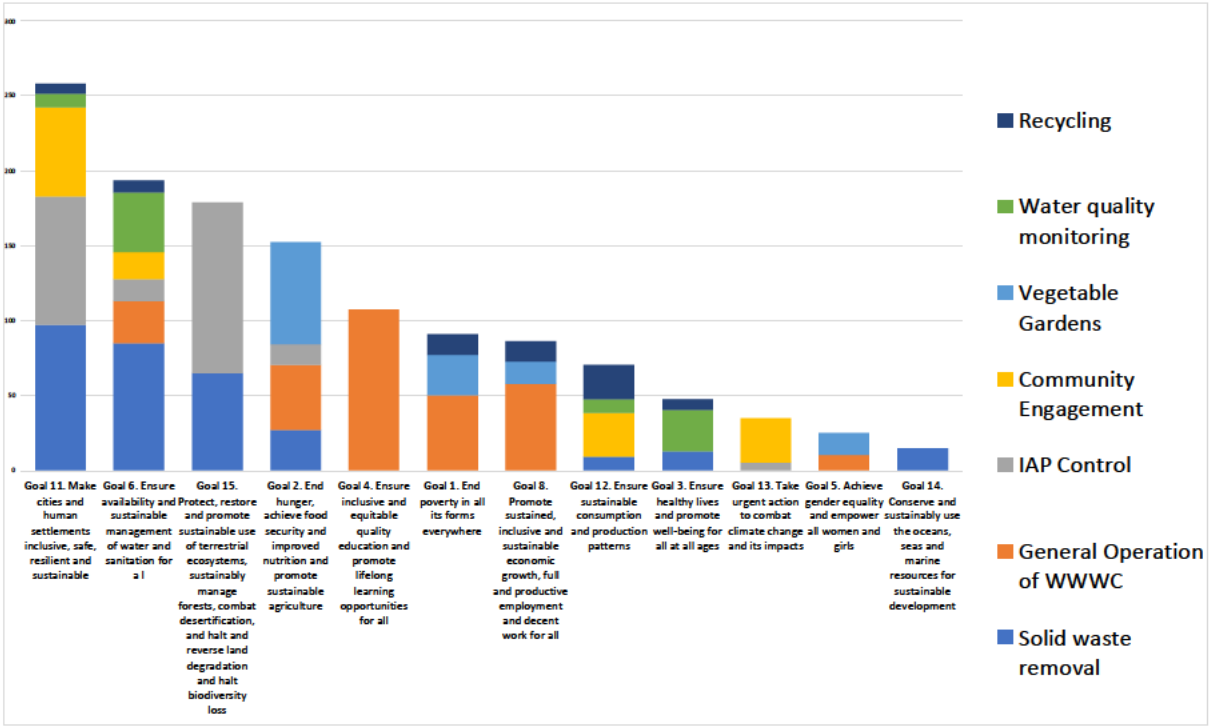


Figure 4.3: Intervention contributions per SDG. Scores from the impact assessment were allocated to each target affected by the intervention. Intervention SDG target scores were then totaled to compare the significance of intervention contributions to each SDG. IAP = invasive alien plant.

4.3.2 System interactions contributing to increases in well-being

The significance scores from the impact assessment (SM Tables 4.1) were used to calculate contributions to well-being related to the ecological, social, and governance (policy) aspects in the social-ecological system (Fig. 4.4). SDGs were classified as a policy components given that they are included in the mandates of government to actualise (United Nations Development Programme 2016).

Well-being increased in stages and cumulatively when considering the different aspects, from social, to ecological, and to governance, affected by management interventions in the social-ecological system (Fig. 4.4, greater sizes of circles indicate higher levels of achievement). The state of human well-being, before the implementation of the community interventions (Fig. 4.4, ***2***) is represented by the smallest circle of well-being (Fig. 4.4, ***3***), and includes 'baseline' contributions from natural capital and ES and social capital in the community prior to the interventions being implemented. The socio-economic and health outcomes from community interventions (Fig. 4.4, ***2***) increased the level of well-being by 159 significance scores (or 'points') to human well-being circle 'ii'. Well-being was further increased to human well-being circle 'iii', when considering ecological outcomes, which contributed an additional 294

significance points, through natural capital and ES improvements combined (Fig. 4.4, ***4*** and ***5***).

The achievement of the SDGs (Fig. 4.4, ***6***) from social interventions (Fig. 4.4, ***2***), i.e. those that did not involve practical management to enhance the state natural areas, and ES, was calculated at 720 points from 29 SDG targets. The ecological interventions that enhanced ES contributed an additional 1569 points to SDGs, from 66 targets.

Through the community interventions, ecological habitats (NC) and ES were enhanced (ecological: provision of natural capital), and social dynamics (ownership of natural capital) were improved through empowerment, education, and social cohesion. This led to greater achievement of well-being, as reflected in contributions to the SDGs. The translation of environmental management interventions to social value, has led to the broader community taking ownership of natural areas and further enhancing ES use and values, with even greater levels of well-being achieved (Fig. 4.4).

In addition to contributions to well-being that have been quantified in this study, even greater levels of well-being can be achieved when policies are implemented to support local communities in environmental management (Fig. 4.4, dotted grey arrows).

4.4 Discussion

This study provides a Southern response to the call for the concept of a social-ecological systems perspective to improve sustainability outcomes through highlighting the dependence of humanity on ecosystems, better understanding ecosystem stewardship, and developing a stronger science-policy interface (Fischer et al. 2015). We confirm the important role that cities play in responding to global environmental change issues, through managing biodiversity and natural capital (de Oliveira et al. 2011). Our study adds to growing evidence that transformative change led by local communities, businesses, and cities, contribute positively to sustainability, in specific contexts (Moallemi et al. 2020). We show that, through community environmental management implementation at the local scale, grand challenges of global environmental change and sustainability can be addressed. This can be achieved by improving environmental conditions and their consequences for society, encouraging innovation in policy responses, and acknowledging that input is required from a variety of sources, including science, government, society, and business (Mauser et al. 2013).

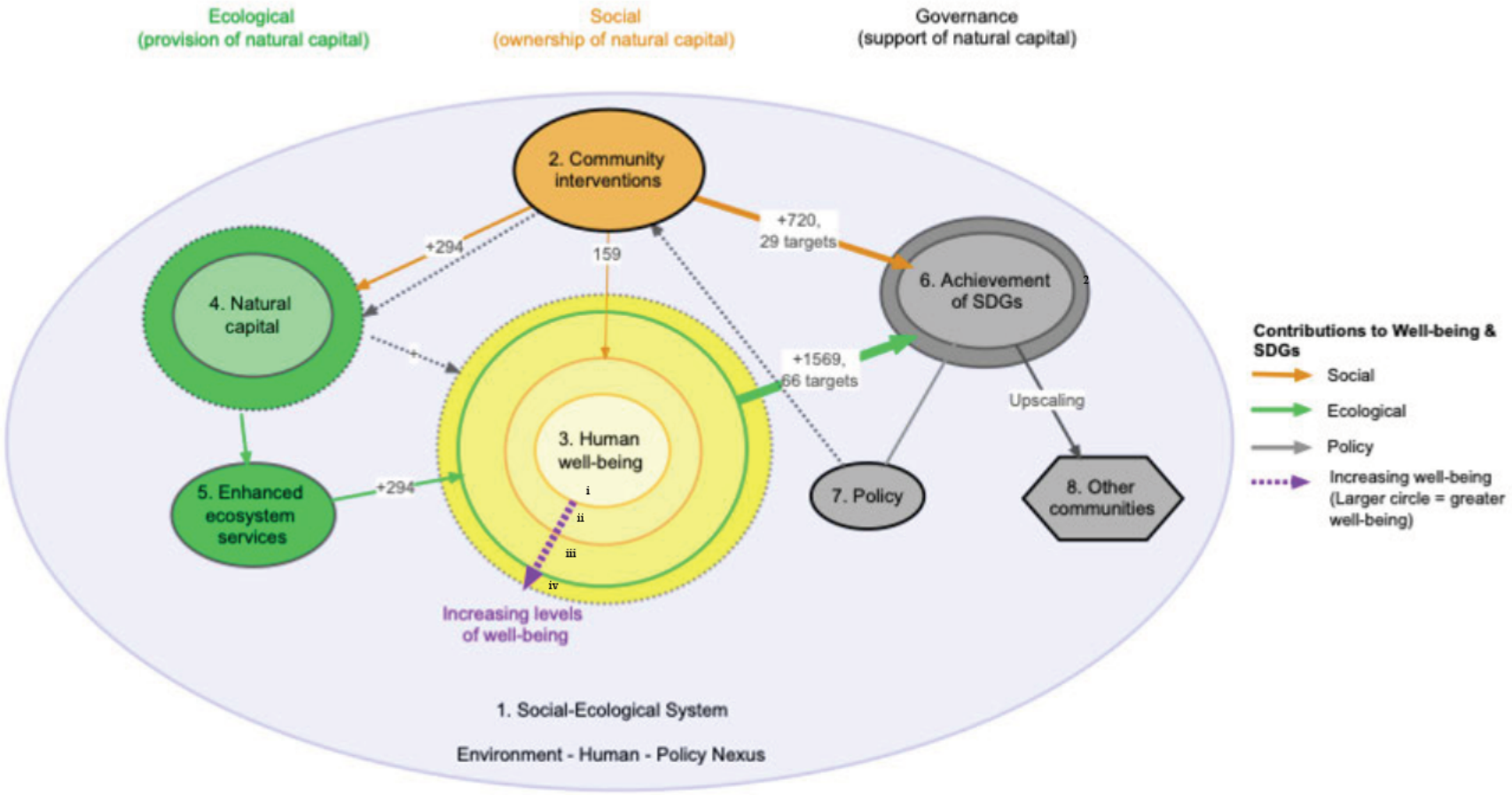


*Figure 4.4: Systems diagram showing enhancement of well-being (yellow) at different stages: Inner circle (i) of well-being (3) denotes the baseline. Community interventions (2) improved natural capital (4) and ecosystem services (5), which contributed to increases in well-being (purple arrow, outer rings ii, iii, iv). Socio-economic (orange) and ecological (green) intervention contributions to well-being were calculated (arrows showing contributions where width of arrows indicate significance of contribution), and increased in stages relative to impact significance scores (scores were calculated using an Environmental Impact Assessment methodology, whereby the significance (**S**) of the impact was determined by the probability (**P**) of the impact occurring, times the consequence (**C**) of the impact. The consequence is determined by combining the extent (**E**), magnitude (**M**), duration (**D**), and reversibility (**R**) of the impact). Ecological and socio-economic interventions were then linked to SDG Goals and targets, to show relative contributions to the SDGS (6). Even greater levels of well-being could be achieved when policies (7) are implemented to support local communities in environmental management and to upscale interventions to other communities (8). Grey arrows illustrate future potential contributions to well-being (not measured in this study), should policy support be considered.*

We also show that ES can be used as a powerful lens to advance resilient and sustainable urban development, by demonstrating relationships between human well-being and the health of natural systems (Biggs et al. 2015). The systemic linkages between ES and human well-being, as shown here, support the framing of the ES concept where humans are both dependant on nature for their survival, and, at the same time, integral components of the biosphere (Costanza et al. 2017). Our system view highlights that investments in natural areas can deliver not only on enhancements in ecosystems and their services, but also for socio-economic, health, and political benefits (Groot et al. 2010; Krasny et al. 2013).

The South African National Development Plan (NDP), which actualises the SDGs at country level, recognises that it is not possible for government alone to achieve the goals, but rather a collaborative approach with the private sector is needed (National Planning Commission 2011). Furthermore, the achievement of the SDGs requires coherence between local- and national-level policies and programmes (Casazza and Chulu, 2016). This study is important as it highlights that local transdisciplinary interventions can have significant national and global policy impacts, through assisting government to achieve sustainability targets related to various international (SDGs) and associated national NDP (National Planning Commission 2011) directives that inform sustainability pathways (Department of Environmental Affairs (DEA) 2014). For example, increased job creation, a crucial component of South Africa's development Agenda (target of 11 million jobs by 2030) and the targets in the SDGs (Targets 4.4. and 8.3) was provided through the civic ecology programme assessed in this study, whereby the beneficiaries established a business, offering services in invasive alien plant clearing and water quality monitoring (Davids et al. 2021). These can be calculated and added to the national and global sustainbility achievements, on the aforementioned targets.

Local interventions therefore provide a 'bottom-up' approach whereby actions that lead to sustainable development are enacted primarily at local, regional and national levels (Jiménez-Aceituno et al. 2020). As much as local interventions may contribute to national and international objectives, interventions at national, transboundary, and international levels, through policy considerations, may also be required to maintain natural systems at the local scale (Blicharska et al. 2019). A comination of bottom-up and top-down approaches will therefore be required to achieve the SDGs (Jiménez-Aceituno et al. 2020).

Despite confirmations of overall improvements in South Africa of reduced poverty, quality of life and political freedom (General Economics Division (GED) 2014), there remained uneven progress for the most vulnerable. Thus, the call for national and local policies and programmes to be designed to address the needs and development outcomes of all societal members, particularly the poor and disadvantaged (Casazza and Chulu 2016). As shown in this study, higher levels of achievement of well-being could be achieved with policy support (dotted grey

arrows in Fig. 4.4). This serves as motivation for policy responses and increased governance support to upscale the concept of civic ecology elsewhere, as a means to uplift low-income communities. This could, in turn, reduce the impacts of persistent poverty on the achievement of a range of SDGs, and the learning from which can be upscaled across multiple communities. In line with Satterthwaite (2016), our study motivates for local actions to be considered in the implementation of the SDGs and shows how local interventions are best designed to specific contextual development needs, instead of applying blanket interventions across systems.

Some limitations of this study could be linked to the calculations of contributions of interventions to the SDGs being based on the scores from the impact assessment. Including that the scores were based on the authors' understanding of the interventions and their impact. Furthermore, the scoring assumes that all SDG targets have equal weight or value. The consideration of the financial costs of each intervention against the potential benefits, not done in this study, could also further assist in prioritizing the interventions for maximum impact. Despite these limitations, our study can be used to measure contributions to the SDGs. For example, Local 2030 (United Nations 2011) initiated the Aloha+ Challenge, that works with state leadership, businesses, and communities towards a more sustainable, resilient, and secure future for Hawai‘i (United Nations Environment Programme (UNEP) 2016). The Challenge aims to actualise six sustainability targets by 2030, namely, (1) Clean Energy (increase energy from renewables); (2) Local Food (double local food production); (3) Natural Resource Management (reverse the natural resource loss, increase watershed protection and freshwater security, community-based marine management, invasive species control and native species restoration); (4) Waste Reduction (reduce the solid waste stream prior to disposal by 70 percent, through recycling, bioconversion and landfill diversion); (5) Smart Sustainable Communities (increase liveability and resilience in the built environment), and (6) Green Workforce and Education (increase local green jobs and education) (United Nations Environment Programme (UNEP) 2016). While our study only focussed on two local communities, the strength of the study is in showing that what the Aloha+ Challenge is aiming to do, to achieve these six SDGs is highly possible. Our study motivates for civic ecology initiatives like these to be upscaled – as the greater number of smaller communities that improve, the greater the improvement for the country, and ultimately, for the world. By showing how interventions responded to community issues, this study further provides a reflection of desired outcomes, for the future of the community, that can be used by local actors to identify actions that are socially desirable and within environmental limits (Moallemi et al. 2020).

We confirm that human well-being is dependent on a combination of natural, social, and political capital (MEA 2005; Krasny et al. 2013; Diaz et al. 2015), and assert that, for the greatest improvements in well-being to be achieved in a social-ecological system, contributions of social, ecological, and governance spheres must be considered holistically. By using the ES

concept, we emphasised the importance of the 'whole system' and not just humans (Costanza et al. 2017).

Increased levels of human well-being can be achieved through the enhancement of ES (MEA 2005; Díaz et al. 2018). However, this increase can only be sustainable through a transdisciplinary approach (Mauser et al. 2013), which combines social ownership of natural capital that includes civic ecology and stewardship practices, with support from government and the private sector, through policies aimed at achieving sustainability and the SDGs, and financing (United Nations Development Programme 2016). Our study supports the notion that stewardship is more than just the management of ES, but has potential to influence economic, social, and cultural contexts, and shape operations within social-ecological systems (Folke et al. 2016). By taking ownership of natural capital, through social cohesion, local communities can successfully contribute to human well-being (MEA 2005), and the achievement of the SDGs.

4.5 Conclusion

We provide, test, and learn from a conceptual framing that is holistic and systematic, and demonstrate that opportunities can be brought about through mutually beneficial relationships between humans and the environment at the local community level, but which could be effectively upscaled for broader societal impact. Through integrating ES into strategies to achieve the SDGs, the key aims of the goals to achieve well-being for all, while protecting the environment, can be achieved (Wood et al. 2018). The multiple benefits of improving the environment while also achieving health improvements and social upliftment, is a model that can be duplicated in other parts of the world with similar social-ecological conditions.

SUPPLEMENTARY MATERIAL

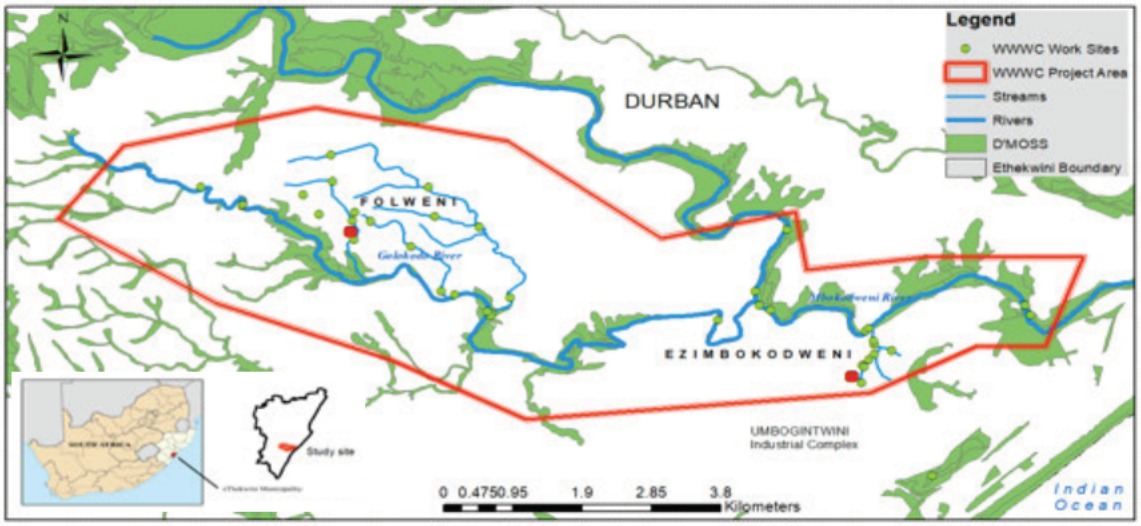
SM Figures

SM Figure 4.1: Study area and WWWC work sites

SM Tables:

SM Table 4.1: Intervention Impact, Ecosystem Service and SDG Linkages and Scoring Table

SM Table 4.2: Intervention Linkages and Scores Relative to SDGS



SM Figure 4.1: Study area: Wise Wayz Water Care Work Areas in eThekwini Municipality (Durban), South Africa

SM Table 4.1: Intervention Impact, Ecosystem Service and SDG Linkages and Scoring Table (M-Maginitude, D- Duration, E- Extent, R-Reversibility, P – Probability)

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
Solid waste removal This activity results in the reduction of waste on land and in water courses.	**Ecological**	Improved river water quality.	4	4	2	4	5	17,5	High (+)	Riparian vegetation, rivers, streams, wetlands		Water purification	Solid waste pollution	**6.3, 6.6, 6.b, 15.1**				17,5	135	1
		Improved ecological integrity of terrestrial and aquatic ecosystems.	4	4	2	4	5	17,5	High (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Water flow regulation Maintenance of ecological balance	Flood mitigation Hazard mitigation Maintenance of biological diversity (genepool protection)	Poor waste collection service delivery	**6.6, 15.1**				17,5	85	3
		Reduction in land and water pollution.	5	4	1	2	5	15	Moderate (+)	Riparian plants and soil	Biotic and abiotic processes in breakdown of organic matter, nutrients and compounds	Waste assimilation	Solid waste pollution	**6.3, 11.6, 14.1, 15.1, 15.3**				15	127,5	1
	Socio-economic	Reduced safety risks to animals and children.	3	4	1	4	4	12	Moderate (+)			Recreational service		**11.7**				12	47	1

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Signifi-cance Points	Significa-nce rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
		Improvement in aesthetic appeal of the area.	4	4	1	4	5	16,25	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Aesthetic quality of natural area	Aesthetic service	Injury to animals and children from solid waste pollution Unsightly pollution dumps	**11.4, 11.7**				16,25	82	1
		Increase in recreational and cultural uses of natural areas.	5	4	2	4	5	18,75	High (+)	Terrestrial and aquatic habitats, for example,. wetlands, rivers/streams, open space	Presence of natural features	Recreational service Cultural service	Lack of recreational space due to pollution	**11.4, 11.7**				18,75	82	2
		Enhancement of agriculture due to improved water quality	3	4	1	4	3	9	Low (+)	Aquatic habitats, for example, wetlands, rivers/streams	Water supply and purification for irrigation Soil retention by vegetation preventing loss of topsoil	Agricultural service Erosion control	Food insecurity	**2.1, 2.3, 2.4, 12.2**				9	36	2
	Health	Reduction in health risks related to diseases linked to pollution, for example,. skin rashes, cholera.	4	4	1	4	4	13	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Control of pest populations	Biological regulation /disease control	Water-borne diseases	**3.3**				13	13	1

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Signifi-cance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
Recycling Impacts form recycling are indirect and result from removal of solid waste.	**Ecological**	Reduction in air pollution due to avoided burning of waste.	3	4	3	4	2	7	Low (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Capacity of ecosystems to extract pollutants for example, vegetation / leaf cover	Air purification	Burning of waste due to poor of waste collection service	**3.9, 11.6, 12.5**						
																		7	37,25	1
	Socio-economic	Source of income to recyclers.	1	4	1	5	5	13,75	Moderate (+)				Poverty and low employment	**1.2, 8.3**	13,75	27,5				
		Provides environmental education to community members on recycling.	2	4	1	4	3	8,25	Low (+)			Environmental education	Low education	**6.3**	8,25	8,25	1			1
		Reduced load on local landfill and waste removal services.	2	4	2	5	5	16,25	Moderate (+)			Waste assimilation		**12.5**	16,25	23,25	1			1
Invasive alien plant removal and control This activity controls the spread of invasive alien plants.	**Ecological**	Promotion of indigenous species of flora and fauna.	4	4	3	3	4	14	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Maintenance of ecological balance	Maintenance of biological diversity (genepool protection) Pollination Harvesting products	Infestation of invasive alien plants Lack of access to resources	**11.4, 15.1, 15.5, 15.8, 15a**						
																	3	14	149,5	3

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
		Improved water quality and quantity.	4	3	3	3	5	16,25	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Water flow regulation	Water supply Water purification	Loss of water from rivers due to IAPs	**6.6, 15.1, 15.3, 6.b**			2	16,25	60,75	2
		Improvement in ecological integrity of natural spaces, particularly wetlands and improvement of flow of water and mitigation of flooding.	4	3	3	4	3	10,5	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Water flow regulation	Flood mitigation	Loss of water from rivers due to IAPs	**6.6, 11.4, 13.1, 15.1, 15.5, 15.8**			1	10,5	150,5	1
	Socio-economic	Facilitation of alternative and more appropriate uses of land, for example, more land available for community gardens.	4	3	1	3	5	13,75	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Water supply and purification for irrigation Soil retention Soil formation	Agricultural service Erosion control	Loss of land due to encroachment by IAPs	**2.1, 11.7**			2	13,75	48,75	2
		Improvement in aesthetic appeal of the area.	3	3	1	3	3	7,5	Low (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Aesthetic quality of natural area	Aesthetic service	Unsightly overgrown areas.	**11.4, 11.7**			1	7,5	80,75	1

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
		Increase in recreational and cultural uses of natural areas.	3	3	1	4	5	13,75	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features	Recreational service Cultural service	Loss of land due to encroachment by IAPs	**11.4, 11.7**			2	13,75	80,75	2
		Reduced safety risks (related to crime)	3	4	1	4	3	9	Low (+)	Terrestrial and aquatic habitats.			Use of IAP infested areas for criminal activity					9		
		Assist municipality to achieve IAP control targets.	2	3	1	4	2	5	Low (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Maintenance of ecological balance	Maintenance of biological diversity (genepool protection)	No municipal IAP programme in the study area	11.a, 15.9			1	5	10	1
	Health	Reduction in health risks associated with invasive plants, for example, through removal of poisonous plants.	2	3	1	3	2	4,5	Low (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space			Skin rashes due to contact with certain IAPs							
Water quality monitoring	**Ecological**	Improved river water quality	3	2	2	4	4	11	Moderate (+)	Aquatic habitats, for example, wetlands, rivers/streams	Control of pest populations water filtration by wetlands	Water purification	Pollution of rivers due to littering and dumping	**6.6, 6.b**			1	11	20	1

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
		Reduction in land and water pollution.	3	4	1	3	4	11	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Biotic and abiotic processes in breakdown of organic matter, nutrients and compounds	Water purification		**3.3**			1	11	27,5	1
	Socio-economic	Environmental education of community (Empowering community to understand the natural environment and creating awareness of water pollution).	4	3	1	4	3	9	Low (+)	Aquatic habitats, for example, wetlands, rivers/streams	Presence of natural features of educational value	Educational service	Low education	**3.3, 6.6, 6.b, 11.6, 12.8**			1	9	76,5	1
	Health	Reduced health risks of water borne diseases.	4	1	1	4	3	7,5	Low (+)	Aquatic habitats, for example, wetlands, rivers/streams	Control of detrimental organisms/ecological processes, for example, pest and pathogens	Biological regulation /disease control	Water-borne diseases	**3.3**			1	7,5	27,5	1

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Signifi-cance Points	Significa-nce rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
WWWC vegetable gardens Two vegetable gardens are part of the programme that grow a variety of vegetable, fruit and herbs, which are consumed by beneficiaries and sold to the local community and local grocery store.	**Socio-economic**	Increased income for beneficiaries for example, though sale of vegetables.	2	4	1	5	5	15	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Water supply and purification for irrigation Soil retention by vegetation preventing loss of topsoil	Agricultural service Erosion control Pollination Harvesting products	Poverty and low employment	**1.2, 2.3, 2.4, 5.a, 8.3**			4	15	87	4
		Positive economic impact on community members due to availability of cost effective fresh vegetables locally and reduction in need to travel to purchase vegetables.	3	4	1	4	4	12	Moderate (+)					**1.2, 2.1, 5a**			4	12	67	4
	Health	Health (nutritional) benefits to community through increased accessibility and consumption of a large variety of nutrient rich vegetables.	4	4	1	4	4	13	Moderate (+)				Food insecurity Lack of access to affordable nutritious food	**2.1, 2.2**			4	13	38	4

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
Community engagement This activity shares information with the local community on environmental management through household visits.	**Socio-economic**	Increased education of community members on environmental issues.	5	4	1	4	5	17,5	High (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features of educational value	Environmental education	Poor practices by community members, for example, littering, dumping, wastage of water	**6.b, 11.6, 12.8, 13.3**	17,5	108	1			1
		Increased community cohesion through engagement.	3	4	1	4	4	12	Moderate (+)			Cultural	Poor communication between community members	**12.8, 13.3**	12	59				
		Opportunity to identify and address social issues in the community.	3	3	1	3	2	5	Low (+)			Cultural	Poor communication between community members		5		1			1
	Health	Reduction in land and water pollution due to improved waste management for example, reduction in dumping and littering by	4	4	2	4	4	14	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space		Water purification	Solid waste pollution Dumping and littering	**11.4, 11.6, 11.7**	14	77	1			1

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
		community members.																		
General Operation of WWWC Programme	Socio-economic	Improved quality of the life of the beneficiaries and community members.	5	4	3	5	5	21,25	High (+)				Low employment Low education Poverty Lack of access to nutritious food Pollution	**2.1**	21,25	21,25				
		Access to education and training of beneficiaries and potential improved prospects of employment.	5	5	3	5	5	22,5	High (+)				Low education and skills	**1.a, 2.4, 4.4, 4.5, 4.6, 4.7, 8.6**	22,5	210				
		New business opportunities for beneficiaries,	3	4	3	4	5	17,5	High (+)				Lack of economic opportunities	**1.2, 1.a, 4.4, 5.5, 8.3, 8.6**	17,5	157,5				

Intervention Impact Assessment										Affected Natural Capital and Ecosystem Services			Community issues responded to	SDGs Contributed to	Contributions to Well-being					
WWWC Intervention	Category of impact	Impacts	M	D	E	R	P	Total Significance Points	Significance rating (+/-)	Natural capital affected	Ecosystem function	Ecosystem services enhanced			Socio-economic intervention score	Socio-economic intervention SDG Score	Ecosystem service contribution - social	Ecological intervention score	Ecological intervention SDG Score	No. of ecosystem services affected
		for example, SMME.																		
		Opportunities for co-management of natural spaces between citizens and authorities.	3	4	3	4	4	14	Moderate (+)	Terrestrial and aquatic habitats, for example, wetlands, rivers/streams, open space	Presence of natural features of educational value	Educational service	Poor service delivery	**6.5, 6.b**	14	28	1			1
		Conflict in the community.	2	2	1	1	2	3	Low (-)				Poor communication between community members		-3					
Total															159	719,75	34	294,25	1569,25	47

SM Table 4.2: Intervention Linkages and Scores Relative to SDGS

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
Goal 1. End poverty in all its forms everywhere	**2**	0	0	13,75	0	27	0	50	90,75
1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions				13,75		27		10	50,75
1.a Ensure significant mobilization of resources from a variety of sources, including through enhanced development cooperation, in order to provide adequate and predictable means for developing countries, in particular least developed countries, to implement programmes and policies to end poverty in all its dimensions								40	40
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	**4**	27	0	0	13,75	68	0	43,75	152,5
2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round		9			13,75	25		21,25	69
2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons						13			13

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment		9				15			24
2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality		9				15		22,5	46,5
Goal 3. Ensure healthy lives and promote well-being for all at all ages	**2**	13	27,5	7	0	0	0	0	47,5
3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases		13	27,5						40,5
3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination				7					7
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	**4**	0	0	0	0	0	0	107,5	107,5

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
4.4 By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship								40	40
4.5 By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations								22,5	22,5
4.6 By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy								22,5	22,5
4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development								22,5	22,5
Goal 5. Achieve gender equality and empower all women and girls	**2**	0	0	0	0	15	0	10	25
5.5 Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life								10	10

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
5.a Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws (for example, over agricultural production)						15			15
Goal 6. Ensure availability and sustainable management of water and sanitation for all	**4**	85	40	8,25	15	0	17,5	28	193,75
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally		32,5		8,25					40,75
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate								14	14
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes		35	20		10				65
6.b Support and strengthen the participation of local communities in improving water and sanitation management		17,5	20		5		17,5	14	74
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	**2**	0	0	13,75	0	15	0	57,5	86,25

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services				13,75		15		17,5	46,25
8.6 By 2020, substantially reduce the proportion of youth not in employment, education or training								40	40
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	**4**	97	9	7	85,75	0	59,5	0	258,25
11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage		35			45,75		14		94,75
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management		15	9	7			31,5		62,5
11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities		47			35		14		96
11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning					5				5

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
Goal 12. Ensure sustainable consumption and production patterns	**3**	9	9	23,25	0	0	29,5	0	70,75
12.2 By 2030, achieve the sustainable management and efficient use of natural resources		9							9
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse				23,25					23,25
12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature			9				29,5		38,5
Goal 13. Take urgent action to combat climate change and its impacts	**2**	0	0	0	5	0	29,5	0	34,5
13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries					5				5
13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning							29,5		29,5
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	**1**	15	0	0	0	0	0	0	15
14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution		15							15

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	**6**	65	0	0	113,75	0	0	0	178,75
15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements		50			40,75				90,75
15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world		15			5				20
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species					24,5				24,5
15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species					24,5				24,5
15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts					5				5

SDG	No of targets Affected	Solid waste removal	Water quality monitoring	Recycling	IAP Control	Vegetable Gardens	Community Engagement	General Operation of WWWC	Total
15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems					14				14
Total	36	311	85,5	73	233,25	125	136	296,75	

CHAPTER 5: The environmental impact of research meetings: a mixed-methods case-study from the Sustainable and Healthy Food Systems research programme

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Abstract

This paper highlights the potential for learning and virtual collaboration in international teams, while actively contributing to global sustainability and climate change mitigation. Despite knowledge and awareness of their environmental impacts, the global research community contributes significantly towards greenhouse gas (GHG) emissions through international travel and related research activities. Here, we describe the measured and perceived constraints and benefits for climate, personal development, economic costs, and efficiency of holding large-scale multi-site and inter-disciplinary virtual conferences (VCs). Using the Sustainable and Healthy Food Systems (SHEFS) research programme as a case study, we estimate 'saved' GHG emissions (using a carbon calculator), costs, and time, of using VCs as an alternative for in person meetings. Furthermore, we used surveys to collect data on strengths, weaknesses, opportunities, and threats of VCs, as perceived by participants opting for a VC as alternative for a planned in-person meeting in Chennai, India. We found that changing the meeting from in-person to virtual format reduced the meeting's carbon emissions by 123,009 kg CO_2Eq or 2.5 tonnes CO_2Eq per person. Furthermore, 60% of travel costs were avoided. The main strengths of VCs reported by participants were inclusivity and access for researchers at every level to attend conferences: 20% more emerging or mid-level researchers could attend the VCs that would not have been able to attend the in-person meetings. Key opportunities included reduced travel stress and less interference with family responsibilities. Weaknesses of VCs included connectivity issues, and distractions of personal commitments when attending meetings from home. Our study highlights that hosting virtual international meetings substantially reduces costs, emissions, and travelling time, reduces North-South and gender inclusivity concerns, and is more inclusive for emerging researchers. These benefits outweigh weaknesses reported by participants. Some objectives, such as group learning were not evaluated in this study, although increasing opportunities for individual engagement may contribute to learning in VCs. Our case study identifies opportunities for international research partnerships to mitigate or avoid their environmental impacts, while continuing to deliver effective collaborative research meetings.

Key words: sustainability, climate change, virtual conference, transdisciplinary team, virtual team

5.1 Introduction

As research scientists, we are tasked to pave the way towards a more sustainable future. Evidence based research is geared to identify prospects to enhance opportunities, and mitigate risks, to achieving the sustainable development goals (United Nations 2015), while staying within +1.5°C above pre-industrial levels (Zhong et al. 2010). Despite frequently having first-hand knowledge of sustainability and climate change challenges, the international research community still contributes significantly towards greenhouse gas (GHG) emissions. For example, American ecologists were found to have carbon footprints over twice that of average Americans, and more than 10 times the global average (4.5 tonnes of CO_2 equivalents a year) in 2009, predominantly due to air travel for one international collaborative meeting (Fox et al., 2009; Govia et al., 2019). Although international collaboration, communication, and travel are a core part of global research activities, alternative technological solutions for such communication and collaboration are available and more frequent use of them should be urgently explored.

Research and knowledge sharing in the context of sustainability is increasingly needed (Renner et al. 2013). Transformational changes are needed across all sectors, to ensure that we bridge the science-action gap (Hegger and Dieperink 2014), and actively mitigate climate change (Steffen et al. 2015). Researchers could take the lead in acting upon the evidence that is generated around these solutions, and inspire others to follow their example (Govia et al. 2019). Virtual, online, team collaboration could be part of the solution. Virtual teams comprise geographically dispersed members working towards a common goal, using technology such as computers, video cameras, and online collaboration software, as the main means of communication and collaboration.

Despite virtual teams gaining increasing popularity, there remains uncertainty regarding the effectiveness of virtual teams over face-to-face teams (Purvanova 2014). While there are some obvious benefits in terms of avoided costs, greenhouse gas emissions, and travel time, there could be other, more hidden, advantages. Virtual meetings could, for example, increase inclusivity, particularly related to attendance by researchers from the Global South, partularly females and by emerging researchers, for whom travel budget could restrict their face-to-face participation more often than for their counterparts from the Global North. Academic literature describes the gender bias, where women have been found to publish and participate in collaborations less than their male counterparts, particularly in the fields of science, technology engineering, mathematics and medicine (STEM) (Holman et al., 2018). Furthermore, scientists with young families could be restricted in time spent away from the home, but would be able to participate virtually. This calls for solutions to barriers for women in STEM (Grogan 2019). There are also several draw-backs of virtual meetings, including lack of personal contact,

restricted possibilities for networking, and full reliance on IT equipment.

Here we present the results of our study looking at the benefits and constraints of virtual communication and collaboration. The key questions in this study were: (1) How can learning and collaboration in virtual teams assist to enhance inclusivity for marginalised scientists, such as those in the Global South, or emerging researchers who may be constrained by funding; or women? (2) How can international research teams more effectively use virtual collaboration to actively contribute to global sustainability and climate change mitigation efforts? (3) How can systems thinking principles assist to unpack learnings and improve virtual research collaboration processes going forward? To answer these, we used a mixed methodologial approach (learning organisation surveys and SWOT analyses, greenhouse gas emmisions and cost analyses of virtual vs face-to-face meetings). We describe the measured and perceived constraints and benefits for climate, personal development, costs, and efficiency, of holding large-scale multi-site and multi-disciplinary virtual conferences (VCs), as compared to similar face-to-face in-country meetings. We use the Sustainable and Healthy Food Systems (SHEFS) research programme as a case study.

5.1.1 Description of Case Study

SHEFS is a multi-disciplinary boundary organisation operating across three country sites: South Africa, the United Kingdom, and India. SHEFS aims to influence policy towards achieving sustainable food systems that deliver improved health outcomes and reduced environmental impacts (SHEFS Global 2019). The SHEFS research programme includes 13 institutions, with over 100 academics, government practitioners, and other stakeholders, from over 20 different disciplines, within and related to the agriculture-environment-health nexus. SHEFS started in 2017 and Annual Meetings have been hosted since, with staff and students from each country site personally attending the first two meetings held in London, United Kingdom (2017), and Durban, South Africa (2018). In the face of increasing awareness of the climate costs of meeting physically, the SHEFS management team decided to host the Annual Meeting in 2019 via a VC, in place of the originally planned in-person meeting in Chennai, India. This meeting offered a unique opportunity to determine whether operations within the programme could be conducted more sustainably in terms of costs, time, and ecological and carbon footprints, while maintaining or improving upon the level of group learning and engagement that was previously experienced in face-to-face conferences.

The team assembled physically in groups in five virtual rooms (one in the UK, two in India, two in South Africa), plus several individuals joining from their personal computers. Zoom (Barbosa et al. 2019) virtual meeting software was used for communication during the conference, with some of the preparatory work recorded using Microsoft Collaborate

(Microsoft 2020). Conference organisers identified innovative ways to increase opportunities for engagement at the VC. First, several presentations were recorded ahead of the meeting. Participants were encouraged to watch pre-recorded presentations and send questions and comments to the presenter ahead of the meeting. The "live" time during the VC was then used for more in-depth discussion.

Furthermore, presenters were encouraged to make use of interactive tools, such as Mentimeter (John, 2018), to encourage active participation during the conference. In each of the "physical" rooms, a venue-leader was assigned, who registered any potential contributions (questions, comments, etc.) of participants in their respective rooms, and alerted the moderator of a session accordingly. Hand raising and 'question and answer' typing functions of the Zoom software were used in addition to this.

In March 2020, a second virtual meeting was held with all participants attending virtually and individually, as the COVID-19 pandemic restricted movement and face-to-face meet-up. The VC linked 73 participants from South Africa, United Kingdom, and India. Learnings from the first VC allowed for more effective preparation, and, this time, SHEFS emerging researchers from each country planned and prepared the agenda and conference activities before the VC. Multiple activities were facilitated for engagement and direct discussions of research before the conference, namely 'journal club discussions' which allowed participants to meet virtually to discuss publications; 'feedback workshops' for in-depth discussions for problem-solving and enhancement of specific research projects; and 'presenter of another team member's output' where participants discussed the research of another researcher, to present the outputs to the broader team during the VC. Online presentations were delivered via the Zoom platform during the conference. Breakaway 'meeting rooms' (in Zoom), linked to the VC, were used for small group discussions, where up to five participants were able to brainstorm particular topics before returning into the main virtual room for plenary feedback.

5.1.2 DATA AND METHODS

5.1.2.1 Greenhouse gas emissions

We estimated the transport-related GHG emissions for the face-to-face conference in 2018, and those that would have occurred if the 2019 virtual conference had been held in Chennai as initially planned, to estimate the reductions in carbon footprint achieved by holding the 2019 and 2020 conferences virtually. We used the preferred flying route of the researchers – often a combination of flight time and costs – to calculate distance from their respective locations to Chennai. Assuming economy class flights, we used the ClimateCare carbon calculator

(ClimateCare 2012) to estimate flight emissions in kg CO_2 equivalents. The methods used by the ClimateCare calculator have been published elsewhere (ClimateCare 2012), but in short: the calculator estimates orthodromic distance between two airports and estimates associated carbon emissions. Additional multipliers are applied for first or business class, long-haul flights (>3700km), and for flying at high altitude (the radiative forcing index multiplier).

5.1.2.2 Inclusion

We listed the level of seniority (emerging, mid-career, and senior level) of each attendee of the virtual meeting, and proposed attendees of the Chennai meeting, and compared the proportion of emerging and mid-career level attendees (defined as researchers below Associate Professor level or equivalent) between the two scenarios. We also calculated the percentages of attendees, and their genders, from the Global South, which comprised of team members from South Africa and India.

5.1.2.3 Costs

We estimated the flight prices at economy class fares (prices listed in August 2019) for each researcher who indicated that they were attending the annual meeting in Chennai in person, and compared these against costs incurred for the 2018 annual meeting. Additionally, we included venue hire, food and beverages, airport transfers, and lodging costs of all attendees in the "Chennai scenario." We did not consider local hotel-to-venue commuting costs, nor the "usual" home-work costs for the virtual scenario. We included costs for equipment hire, needed for the online meeting for each institution – if not yet in place.

5.1.2.4 Learning Organisation Survey and SWOT Analyses

To analyse the perceptions of participants before and after the virtual conferences, two online surveys were conducted using Survey Monkey (McDowall and Murphy, 2018) for each meeting. The surveys comprised both multiple choice and open questions, and aimed at capturing participants' perceptions on the advantages and disadvantages of the VCs.

The emerging main and sub-themes were identified and discussed by the authors and data were extracted and categorised/coded by theme, using Grounded Theory (Charmaz 1996). Four authors reviewed the data and reached consensus on coding, to ensure intercoder reliability (Lombard et al. 2005)Themes were summarised – using participants quotes as illustration – and Strength (S), Weaknesses (W), Opportunities (O), and Threats (T) (SWOT) were identified in each main and sub-theme. Each SWOT was ranked based on its significance, calculated using an online SWOT analysis tool (Mind Doodle, 2018).

Scores for strengths (S) and weaknesses (W) were calculated as a product of 'importance,' ranked on a scale of 1 (Low/minimal effect) – 5 (High, vitally important) and 'internal rating,' ranked on a scale of 1 (Minor, could be done better/don't do it too poorly) – 3 (Major, excel at this/do it poorly).

The significance of the opportunities (O) and threats (T) were calculated as a product of 'importance,' and 'likelihood,' ranked on a scale of 1 (Low, unlikely) – 3 (Major, highly likely). The results were displayed in a bubble graph to show the relative significance of each SWOT (SM Appendix 5.1). Weaknesses and threats were assigned negative scores for display purposes on the graph.

We explored the learning component by assessing systems thinking principles (Morecroft 2010) of our learning organisation through qualitative causal loop analysis. This was done to further understand the impact of the large-scale, multi-site, and multi-disciplinary virtual processes, to explore the underlying forces at play when considering research collaboration. Interlinkages among the SWOT analysis components, reflexivity (Popa et al. 2015), and ongoing learning were heuristically expressed, to demonstrate how learning can lead to desired change, i.e. mitigating identified weaknesses and threats to successful collaboration and partnership, thereby enhancing project outcomes.

5.2 Results

In total, 107 researchers attended the virtual meeting in October 2019. Of these, 49 indicated that they would also have attended a physical meeting if this would have taken place in Chennai (Figure 5.1). In total, 63 participants completed the survey before the start of the meeting and 41 the "after" survey. The numbers by location can be found in Appendix 5.2.

5.2.1 Environmental footprints, and costs

Carbon footprints of 37 international flights and 12 national flights, plus airport transfers, were estimated to total 123,009 kg CO_2Eq. This would have amounted to 2.5 tonnes of CO_2Eq per attendee, which is just over half of the global annual average footprint of a single person in 2009 (Fox et al. 2009). The total flight time of all researchers combined was estimated to have been 881 hours, and total travel time 1080 hours (i.e., 45 person-days): an average of 22 hours per person was, hence, saved by holding the meeting in a virtual format.

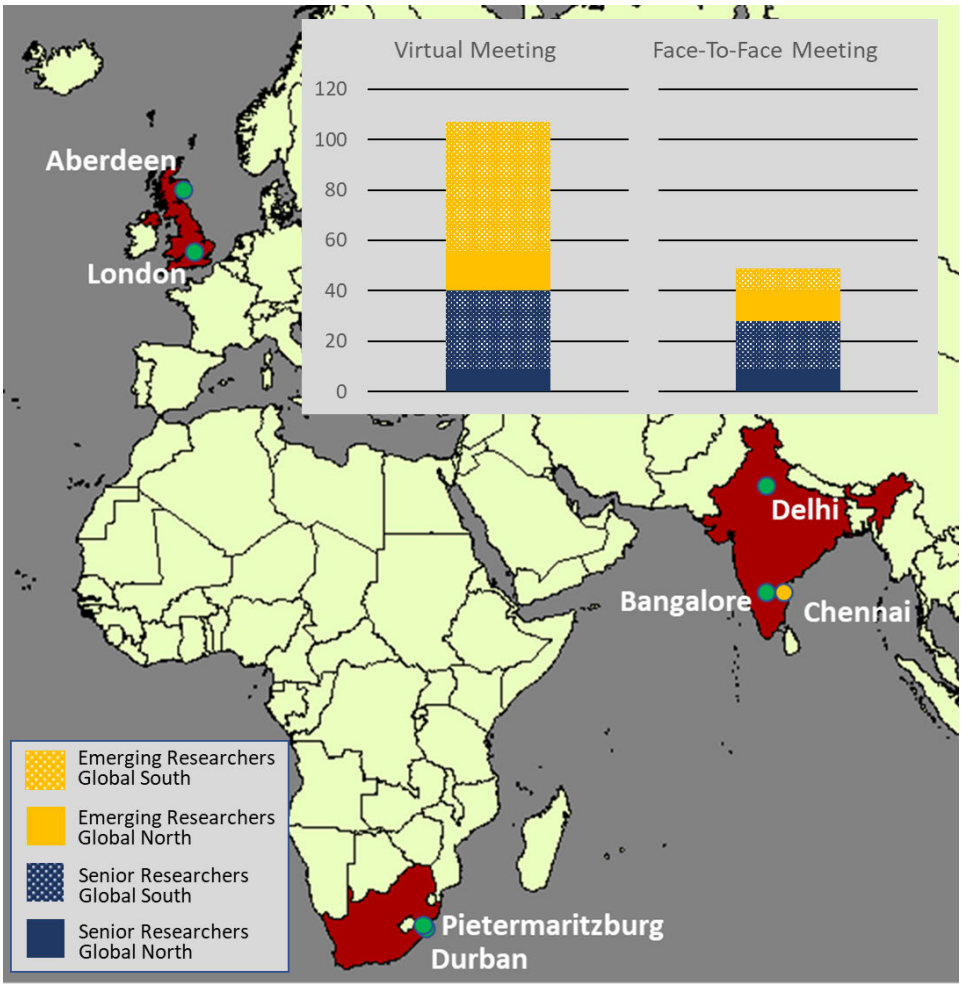


Figure 5.1: Location of research institutions (green), numbers and level of seniority of researchers that attended the virtual meeting and that would have attended the face-to-face meeting in Chennai (orange)

Total costs associated with the 2019 face-to-face meeting were estimated to be £51,720. Approximately 60% of these costs involved air travel (Figure 5.2). Actual costs related to virtual annual meeting attendance were £12,485 for all institutions combined, of which the majority (£11,325) was spent on equipment hire and purchase. Furthermore, the amount used in purchasing equipment during this initial virtual meeting was a onetime investment, and the equipment purchased could be used for subsequent VCs, unlike costs incurred in air-travel which would keep rising in the subsequent in-person meetings. Incidentally, there were no equipment costs for the VC in South Africa, as this was already available at the institution. The average per person cost of £1,055 for the initially planned face-to-face meeting with 49 attendees, decreased to £117 per person in the virtual meeting in which 107 researchers participated.

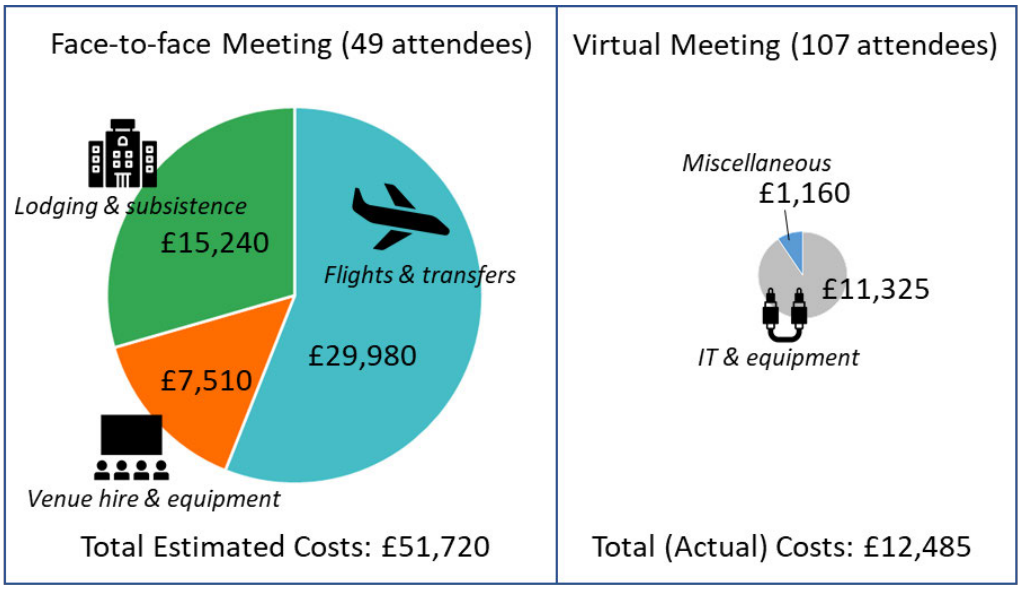


Figure 5.2**:** Estimated conference costs for face-to-face left and virtual meeting (right)

Costs, greenhouse gas emissions and travel time commitments related to the preceding 2018 face-to-face meeting in Kloof, South Africa (57 participants) were slightly lower on average per person than the estimated figures of the Chennai meeting due to more in-country participants, totalling £26,573 (£466 per person) (Exchange rate R16.97/£1), 92,475 kg CO2eq (1.6 tonnes of CO2 eq per person) and 880 hours (15.4 hours per person). For the South Africa meeting, the flights accounted for 83% of the costs.

In 2017 and 2018 the SHEFS research community held annual meetings; however, the shift to a virtual mode allowed conducting bi-annual meetings. This allowed for more frequent interaction and allowed researchers from across countries to share their work and get feedback in a more efficient manner.

5.2.2 Inclusion and participation: Gender and Global South

For the 2018 meeting, a total of 57 people attended, of which, 30 were from South Africa (including 5 external South African policy stakeholders who attended part of the meeting), 25 from the UK and two from India. Of this, 22 were emerging researchers (9 from Global South and 13 from Global North) and 35 were senior (23 from Global South and 12 from Global North).

Of the 107 participants that attended the virtual meeting, 63% (67) were emerging researchers, of which 59% (44) were from the Global South. In the case of the face-to-face meeting, this would have been 43% (21), with 42% (9) from the Global South (Figure 5.1, SM Appendix 5.2). In terms of gender, the number of female participants that attended was 65% (68), compared to 59% (29) that would have participated at the face-to-face meeting. Of these, 78%

(53) females who attended were from the Global South, compared to 55% (16) that would have attended the face-to-face meeting.

5.2.3 Learnings and SWOT Analyses

We identified SWOT from open-ended comments participants made on their perceptions of the virtual meetings; 14 strengths, 3 weaknesses, 12 opportunities, and 9 threats, and assigned scores for each (SM Appendix 5.1 and 5.3). From these, we identified three main themes, namely, 1) project productivity, 2) personal development; and 3) opportunities for participation. Within these, we identified 10 sub-themes (Appendix 5.3). Figure 5.3 shows the top seven strengths, weaknesses, opportunities, and threats, in relation to each other.

Strengths

The most significant strengths were under the 'participation' theme. Enhanced opportunities to participate and increased inclusivity was a recurrent comment in the surveys, especially by emerging scholars from the Global South. Furthermore, despite limitations of the virtual meeting format, social interaction was frequently mentioned as a strength, particularly for communication across countries. This included positive views of this type of virtual communication for research progress.

> *"[…] people who normally could not be part of international meetings could attend - socially just approach !!!" - Senior researcher, Global South*

> *"The virtual meeting format is an effective learning platform that allows interaction between countries." - Senior researcher, Global South*

> *"It is convenient and easy. All countries can share their views, knowledge and information in one "room" thus saving traveling costs" - Emerging Researcher, Global South*

> *"[…] we could engage and share with each other in very challenging times, students of mine logged in to the conference from some of the most remote places in South Africa and just loved being part of the learning experience […]" Senior Researcher, Global South*

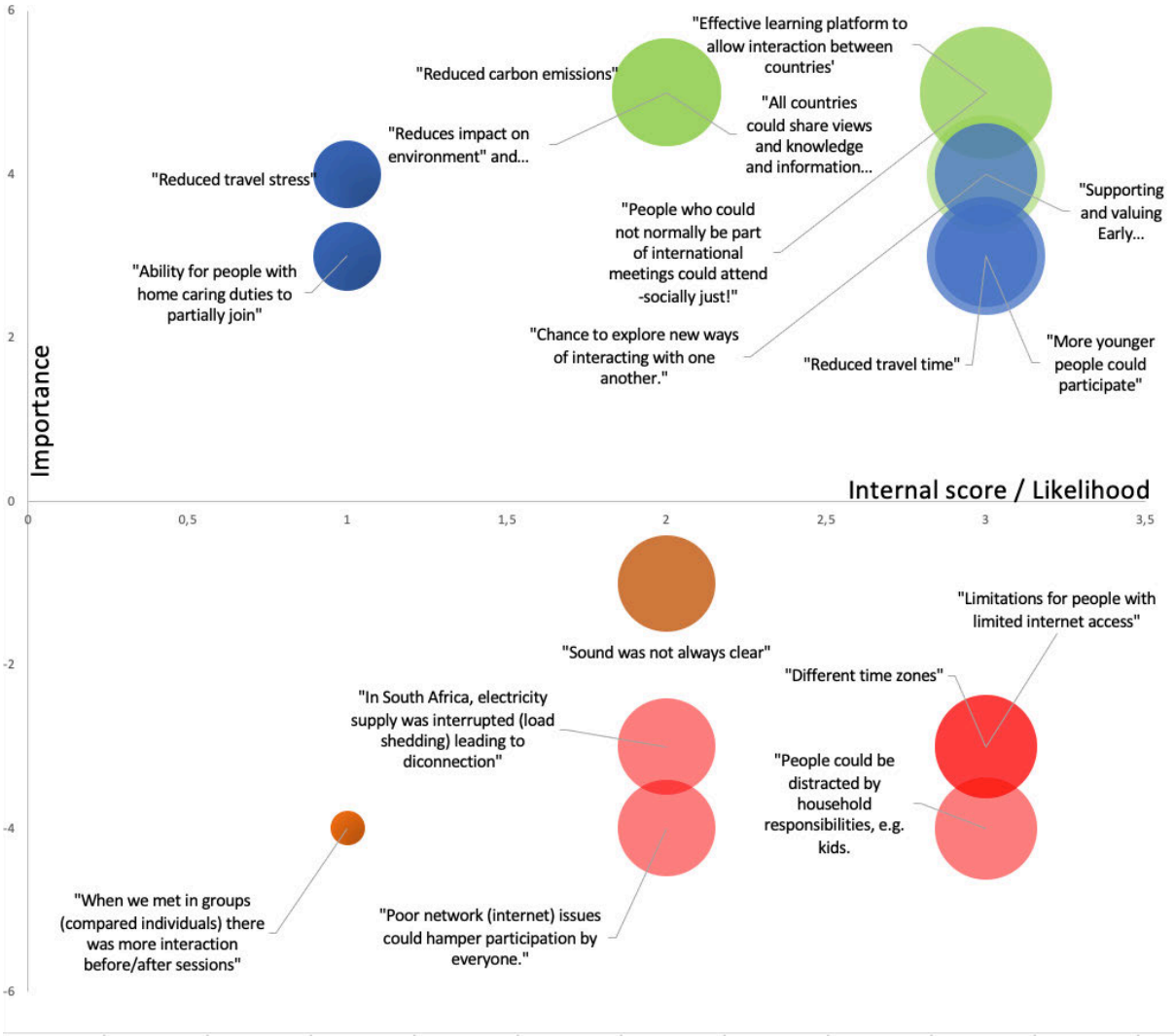


Figure 5.3: SWOT Analyses: Plotted based on the value of importance (X-axis), internal rating (for Strengths (green) and Weaknesses (brown)) or likelihood (for Opportunities (blue) and Threats (red)) (Y-axis). The size of the bubbles signify the significance of SWOT. Only the top seven SWOT was shown here.

Other key strengths of hosting the VC were under 'personal development' related to personal time management, and active contribution to a low carbon economy. With the research consortium focusing on sustainability issues, the reduced environmental footprint of the VC was a frequently mentioned sub-theme, and seen as a major strength of the VC format. Participants indicated that they appreciated the fact that, in this way, they were themselves "actively" contributing to lowering environmental footprints.

> *"It was less disruptive to my work day to be able to join individually" – Emerging Researcher, Global North*

"The benefit was [that] this was logistically useful as it saved a lot of valuable time which would otherwise be spent in travelling and upsetting schedules. This initiative was also feasible at a carbon-footprint level" - Emerging Researcher, Global South

"Significantly lower carbon footprint for the meeting and, thus, for the SHEFS project as a whole." - Senior Researcher, Global North

"In the current time frame, where the effects of climate change are becoming frequent and more calamitous, virtual conferences are one of the ways to reduce our carbon footprint." Junior/Mid-Level Researcher, Global North

Weaknesses

In terms of weaknesses, under the 'participation,' theme it was felt that social interaction was hindered at the 2020 VC, where everyone met via Zoom as individuals during COVID-19, compared to the 2019 VC (where countries met virtually in groups). Other weaknesses related to technical issues such as weak internet connections, which was mentioned numerous times, and was also identified as a threat in SWOT.

"…When we met in groups (compared to individuals) there were more interactions before/after sessions but the experience was pretty similar for me during the actual sessions." Senior researcher, Global North

"[Disadvantages of hosting the VC was] Not being able to have the direct connection and social interaction. Not being able to ask how people are really doing. Not being able to ask more sensitive questions to someone after a nice meal when the mood is relaxed and people have built some rapport. All the small human connections as social beings that make use of all non-verbal cues." Senior researcher, Global North

"I wish more time could have been given to some of the discussions as they were very interesting" Senior Researcher, Global South

Opportunities

Far more opportunities were identified than threats. Many opportunities were highlighted related to 'work-life balance,' for 'personal well-being,' most significantly that attending VCs resulted in reduced travel stress, the ability for more emerging researchers and people with home caring duties to participate, and a saving of personal time and energy.

"If the meeting had been held in person I wouldn't have been able to go (as I have a young child), but with a virtual meeting I am able to attend." Senior Researcher, Global North

"More younger people could participate…More engagement by participants. Empowering for different sites as they could all participate and influence" - Senior Researcher, Global South

"[…] Better use of time, resources (money and natural) and energy (human)… Allows part-time workers to engage etc. Just so many wins." - Senior Researcher, Global North

Opportunities related to 'social interaction' were also noted, where participants felt that the VCs provided a platform to explore new ways of connecting with each other, on equal terms. Other comments were centred around the ability of the VC to facilitate continued 'research progress' despite the COVID-19 pandemic, and that the VC enabled 'progressiveness and innovation' related to learning and use of new technical skills and tools.

"It will give a chance to connect members from different places and they can share their opinions and have discussions live. Annual meeting can be left online and be accessible in future" – Emerging Researcher, Global North

"Maintaining a sense of community and partnership despite [the] pandemic. Keeping partnerships strong and driving forward research. Supporting and valuing Early Career Researchers." - Senior Researcher, Global North

"Good to sustain momentum[during] COVID-19 ... [the VC], will provide support and encouragement to each other"- Senior Researcher, Global South

"[A benefit of the VC is] "learning new technical knowledge." - Senior Researcher, Global North

"[...] Scientific side of the meeting was as good/better than face-to-face. Great for widening participation and access." - Senior Researcher, Global North

Threats

Threats were identified under each main theme, most of which fell under the 'logistical efficiency' and 'time productivity' sub-themes. The fact that the VC had to consider different time zones across South Africa, the United Kingdom, and India, meant that the conference duration for each day needed to be limited to four hours. This was about half of the time allocated for the face-to-face conference. This threat was compounded in the 2020 VC by 'time productivity', whereby participant mentioned that household distractions hindered their participation. Other issues raised were related to 'social interaction,' limited time for personal interactions, and poor internet connectivity.

"*People could be distracted by household responsibilities, for example, kids" – Emerging Researcher, Global South*

"More difficult to remain focussed when everything is online" - Emerging researcher, Global North

"I think the limited time also meant that new partnerships did not have enough time to be formed" – Senior Researcher, Global South

"The lack of the opportunity to meet/network with people face to face and interact more comprehensively." - Emerging researcher, Global South

"Sometimes the sound was not very good. It was harder to have real back-and-forth discussions" - Emerging researcher, Global North

"The internet connectivity in my area was terrible and this meant that I missed parts of the meeting" - Emerging researcher, Global South

"For me it was a network problem which prevented (me) from participating in (the breakout) room discussion" - Emerging researcher, Global South

Heuristic Model of SWOT Analyses

The main reinforcing loop (R_1 in Figure 5.4) highlights the interconnections among the meetings as a set of processes enabling reflexive thinking through the interplay of the linkages between various aspects of the collaborative system, namely, the benefits, contraints, opportunities for reflexivity and responses to learnings. These linkages, through learning, can be leveraged to enhance benefits and address constraints associated with the virtual meetings. Reflexivity, here, relates to how the virtual meeting processes, including the surveys, enable the researchers to evaluate how, while trying to achieve a specific set of sustainability objectives through the lens of sustainable diets, they are, in turn, actively contributing towards other aspirational goals, such as reduction of the carbon footprint through reduced international travel. The heuristic model shows that the process of learning is iterative, and only through learning and reflecting, and then, amending actions, can processes of collaboration be improved.

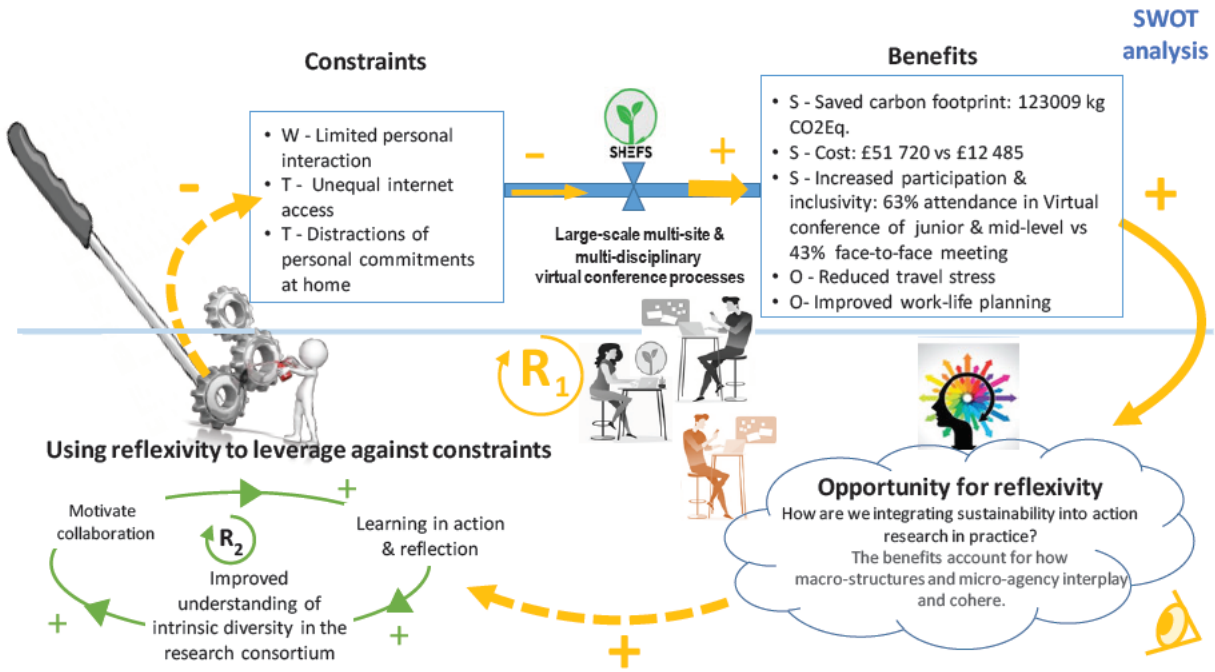


Figure 5.4: A heuristic model of multi-disciplinary virtual conferences as a constituent form of sustainability practice. The output of the SWOT analysis is shown in the upper half of the diagram, while when considered together with the lower second half, the systemic perspective, as a virtuous reinforcing loop (R_1), is designated. Solid yellow arrows: what was found through the surveys. Blue linkage highlights that virtual meeting processes give rise to benefits and constraints. Yellow dashed arrows: how to harness the virtual meeting processes to leverage against constraints. Green arrows: Core of learning processes required for effective collaboration, denoted through a virtuous reinforcing sub-loop, R_2. S = Strengths, W = Weaknesses, O = Opportunities, T = Threats.

5.3 Discussion

Our study provides evidence that virtual collaboration is generally perceived as a good alternative to face-to-face meetings, and shows three major advantages above face-to-face meetings: significant contribution to avoiding greenhouse gas emissions; enhanced participation by emerging scholars, especially from the Global South, and lower barriers for inter-country interaction, communication, and collaboration. However, effective research planning is crucial for research progress through VCs, and a number of trade-offs, such as limited possibilities to network, lack of opportunities for personal interaction, technical difficulties, and distractions/disengaging from the meeting, were experienced by participants.

Enforced mandatory confinement during the COVID-19 pandemic majorly restricted business and leisure travel, and resulted in a major decline of CO2 emissions in the first half of 2020 as

compared to 2019 (-17%) (Quéré et al. 2020). This study supports the understanding that positive environmental effects such as reduced carbon are not expected in the post-COVID 19 era, however, the pandemic showed the great potential for improved environmental health from redesigning multi-institutional collaboration and communication for reduced travel (El Zowalaty et al. 2020). Since SHEFS research community already conducted the VC in October 2019 and was planning for the one held in March 2020, many challenges of suddenly shifting to virtual meetings were avoided.

The option to join virtually allowed more than double the number of females and emerging researchers from the Global South to attend, than would have attended the face-to-face conference. Our findings show that virtual collaboration can assist to bridge research science gaps, such as the North-South divide (for example, 10:1 ratio of scientific and technical articles produced in 2011 were by Northern vs Southern authors) (Blicharska et al. 2017) and the gender gap (for example, 87 of 115 article disciplines examined had fewer than 45% women authors) (Holman et al. 2018). Specifically, the VC opened up opportunities for inclusion and participation of larger numbers of emerging researchers, Global South scientists, and women. In so doing, virtual collaboration can be used as an additional tool to address the gender biases that exist in science, technology, engineering, and mathematics (Grogan 2019).

Estimated cost savings of hosting VCs were substantial, with an approximate 76% reduction, majority of which was from flights. Other costs, not assessed in this study, include lengthy and financially burdensome visa applications to attend international conferences, most of which are hosted in the Global North and are thus unaffordable for many Global South researchers (Sidney 2019). Utilizing part of the foregone travel costs to build better infrastructure in places where it is lacking, could ensure further inclusivity and participation improvement.

Some trade-offs will likely to be resolved and/or tackled over the next few years: with faster connectivity (such as fibre internet and 5G networks) being rolled out in virtually every country in the world – though with regional differences in connectivity – mentioned IT and connectivity problems could become less of a problem in the near future. However, other trade-offs, and particularly those related to social interaction and face-to-face networking, which have been found to be crucial for developing trust and bonding social capital in business (Townsend et al. 2016), are more complicated to overcome.

Certain threats appear to have more impact on emerging to mid-career researchers, compared to senior researchers, which may be intrinsically linked with the nature of the weaknesses and threats mentioned by the researchers. This was due to limited finances or fewer previous opportunities to build relationships or network. Senior researchers typically have had more face-to-face meetings in the past years (or decades) to build up their networks, whilst emerging researchers are yet to establish their collaborations.

By effectively planning opportunities around VCs for personal interaction between participants, VCs present several strengths and opportunities that not only enhance research efficiency and potential but also provide opportunities for enhancement of personal well-being of researchers (Gilson et al. 2015). Our study also supports the use of hybrid communication options: part of the reason for the success of the VCs presented here can be attributed to the hybrid nature of SHEFS, having had foundational personal face-to-face interactions and learnings before engagement in VCs, which allowed for interpersonal relationships to be built. However, the ongoing fostering of such relationships, including aspects of trust and shared understanding, is critical, and we show that virtual communication can effectively be used for this purpose (Jones et al. 2011). Another contributor to the success was that the participants were in locations where time difference between countries are not too (India, SA and UK). The VC model may not work if the locations are too far away (for example, US and India 9.5 hours to 12.5 hours difference).

There is a need for iterative reflection and learning of all participants in transdisciplinary teams (Mauser et al., 2013), to continually evolve towards active achievement of improved sustainability outcomes. By analysing participant feedback, and through sharing of possibilities as they emerge (for example, through new interactive tools), the research experience can be further enhanced, and high-quality research collaboration can be maintained while reducing costs and improving research sustainability.

While solutions to sustainable development challenges are predominantly, and rightly, based on science (United Nations, 2015), there is a need to give equal emphasis to the learning processes while conducting research, to contribute new solutions in a complementary way. The challenge resides in successfully demonstrating the occurrence of concepts, such as reflexivity, that strengthen virtual research collaboration by applying a constructivist perspective (Kaye 2018). As such, the SHEFS programme has interdisciplinary overarching objectives and is a complex space for collaboration. The inclusion of the virtual meeting processes promote participation in concrete problem-solving, experimentation, and learning processes, which eventually improve the researchers' reflexivity (Popa et al. 2015). Consideration of context specificity is essential when trying to sustain complex virtual meetings across sites, as it could influence the gap between short- and medium-term outcomes, and perceptions of inclusivity and participation. For instance, not all organisations had the optimal technology arrangement for hosting virtual meetings.

Some limitations of the study include that the results are reflective of a case study for which the boundary organisation, SHEFS, is already focussed on achieving sustainability outcomes. This may have influenced some of the responses by participants. Other limitations include that the surveys were taken voluntarily, and, thus, the entire team was not represented and that both conferences assessed in this study were from the same boundary organisation, namely, SHEFS.

Despite these limitations, this study has relevance for planetary health research, policy, and practice. Specifically, that the benefits outweigh the trade-offs of hosting VCs over face-to-face conferences. However, multiple improvements are needed, namely, investing in efficient IT equipment; planning for conferences to include more time for inter-personal connections, albeit online; facilitating enhanced networking for emerging researchers; finding the right balance of face-to-face vs VCs, that is acceptable to research funders; and sharing of learnings through scientific publications.

5.4 Conclusion

This study confirms that;1) Virtual communication and collaboration have many benefits that - in several circumstances – appear to outweigh the constraints posed by the lack of face-to-face interaction, especially in times of severe disruptions, such as experienced in the ongoing COVID-19 pandemic; 2) Virtual collaboration is critical to reduce carbon emissions of the international scientific community; and 3) Virtual teams are more inclusive of marginalised scientists, such as those in the Global South, or emerging researchers who may be constrained by funding, or women. This paper highlights that VCs can successfully enable continued progress of transdisciplinary research, and the achievement of climate and sustainability goals, despite physical distances between team members. Our transformative approach, based on using technology more fully, and effective planning to accentuate strengths and opportunities, and to mitigate weaknesses and threats, provided platforms for inclusion, participation, and influence on the project outputs and outcomes, vastly improving the innovation, robustness, and application of our science.

Although the current global situation in some way forces research collaboration to take place virtually (Klöwer et al. 2020), the benefits of VCs must not be forgotten, if and when the pandemic ceases. At that time, it would be incumbent upon the research community to reflect on the multiple benefits for people and the planet, and the strengths and opportunities of VCs, that outweigh the weaknesses and threats.

SUPPLEMENTARY MATERIAL

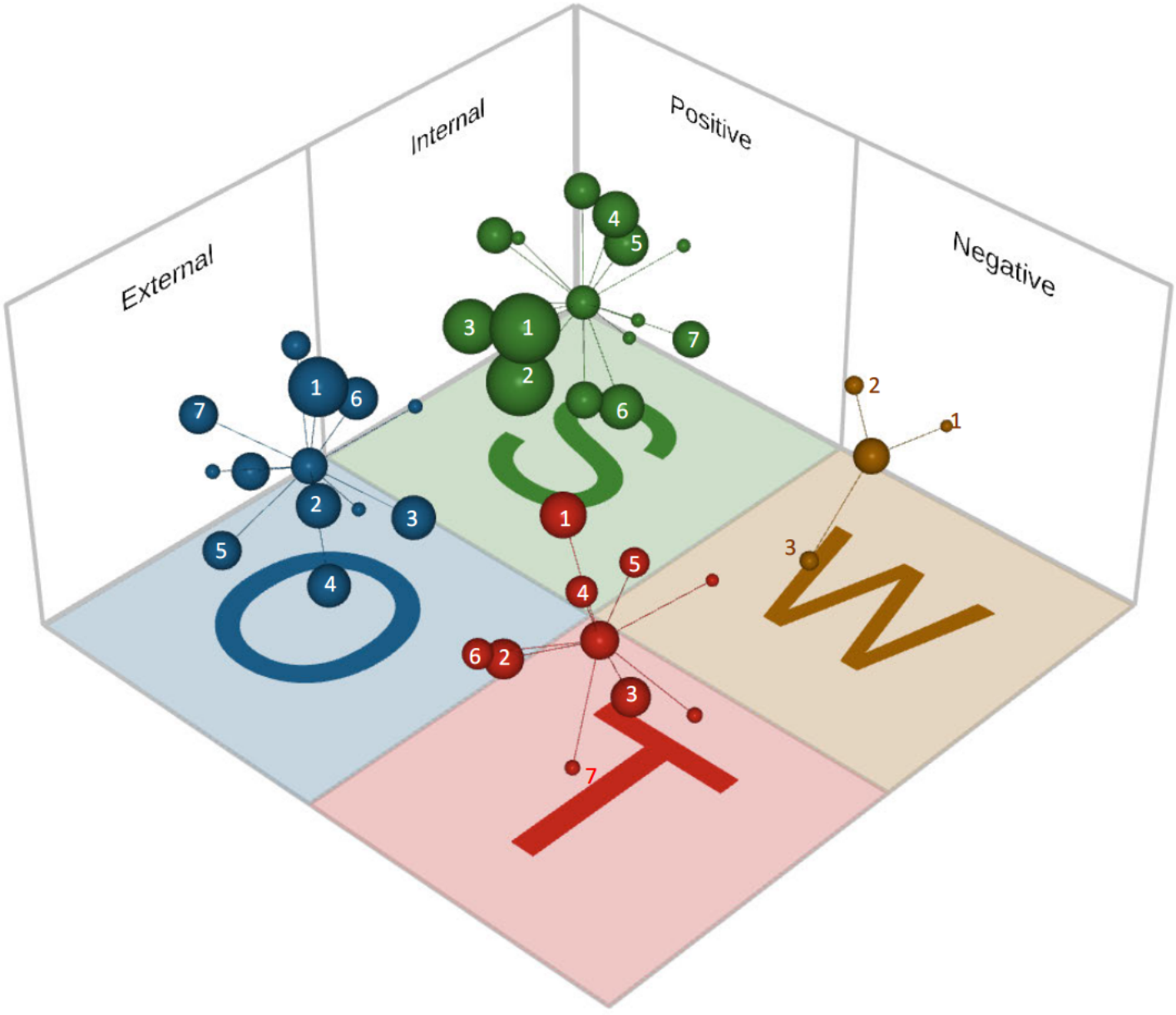
APPENDICES:

SM Appendix 5.1: SWOT Bubble Diagram and SWOT Analyses Scores Table

SM Appendix 5.2: List Of Actual Attendees For The 2019 Virtual Meeting And Proposed Attendees For The Face-To-Face Meeting. Attendees Categorised Into Emerging/Mid-Career And Senior Level, Male and Female And Global South.

SM Appendix 5.3: Survey Themes and Sub-Themes

SM APPENDIX 5.1: (a) SWOT Bubble diagram and (b) SWOT Analyses Scores Table: The bubble diagram was drawn in MindDoodle, using the significance calculations for each SWOT in the Table, as calculated using the formula:
Score = Significance / Importance x Internal ratings / Likelihood



(a). SWOT Bubble diagram

(b) SWOT Analyses Scores Table

No.	Strengths	Significance	Internal rating	Score	Weaknesses	Importance	Internal rating	Score	Opportunities	Importance	Likelihood	Score	Threats	Importance	Likelihood	Score
1.	"Effective learning platform to allow interaction between countries'	5	3	15	"Not enough time for discussions."	-4	1	-4	"Reduced travel stress"	3	3	9	"Different time zones"	-3	3	9
2.	"People who could not normally be part of international meetings could attend -socially just!"	5	3	15	"When we met in groups (compared individuals) there was more interaction before/after sessions"	-4	1	-4	"Reduced travel time"	3	3	9	"People could be distracted by household responsibilities, e.g. kids.	-4	2	8
3.	"Supporting and valuing Early Career Researchers."	4	3	12	"Sound was not always clear"	-1	1	-1	"Ability for people with home caring duties to partially join"	3	3	9	"Poor network (internet) issues could hamper participation by everyone."	-4	2	8
4.	"All countries could share views and knowledge and information in one 'room' without travel"	5	2	10					"Ability to still meet and keep work going despite the COVID-19 lockdown."	3	3	9	"In South Africa, electricity supply was interrupted (load shedding) leading to diconnection"	-3	2	6
5.	"Reduced carbon emissions"	5	2	10					"More younger people could participate"	3	3	9	"Lack personal interaction means we don't build collaborations"	-3	2	6
6.	"Reduces impact on environment" and "environmentally friendly"	5	2	10					"Chance to explore new ways of interacting with one another."	4	2	8	"Limitations for people with limited internet access"	-3	2	6
7.	"Cost effective and cheaper"	4	2	8					"Save my personal energy"	4	2	8	"Less sharing of individual ideas"	-3	1	3
8.	"Cost saving in terms of transport and catering" "savings used for future research"	4	2	8					"We should practice what we preach"	4	2	8	"Limited time meant new partnerships could not be formed"	-3	1	3
9.	"Could understand voices better because everyone had microphone"	4	2	8					"Annual meeting can be left online and be accessible in future""	3	2	6	"More difficult to interact electronically"	-2	1	2
10.	"People who cannot travel could join"	4	2	8					"Learn new technical knowledge"	3	1	3				
11.	"Equal participation from all three countries."	3	1	3					"We are showing global leadership on how to run virtual meetings" "the reality of future"	3	1	3				
12.	"Individual screens improve focus on presentations"	3	1	3					Everyone connecting in the same way means participation is equal"	3	1	3				
13.	"More people get to participate than just a few members from each country."	3	1	3												
14.	"More time to work on other things, less disruptive"	3	1	3												

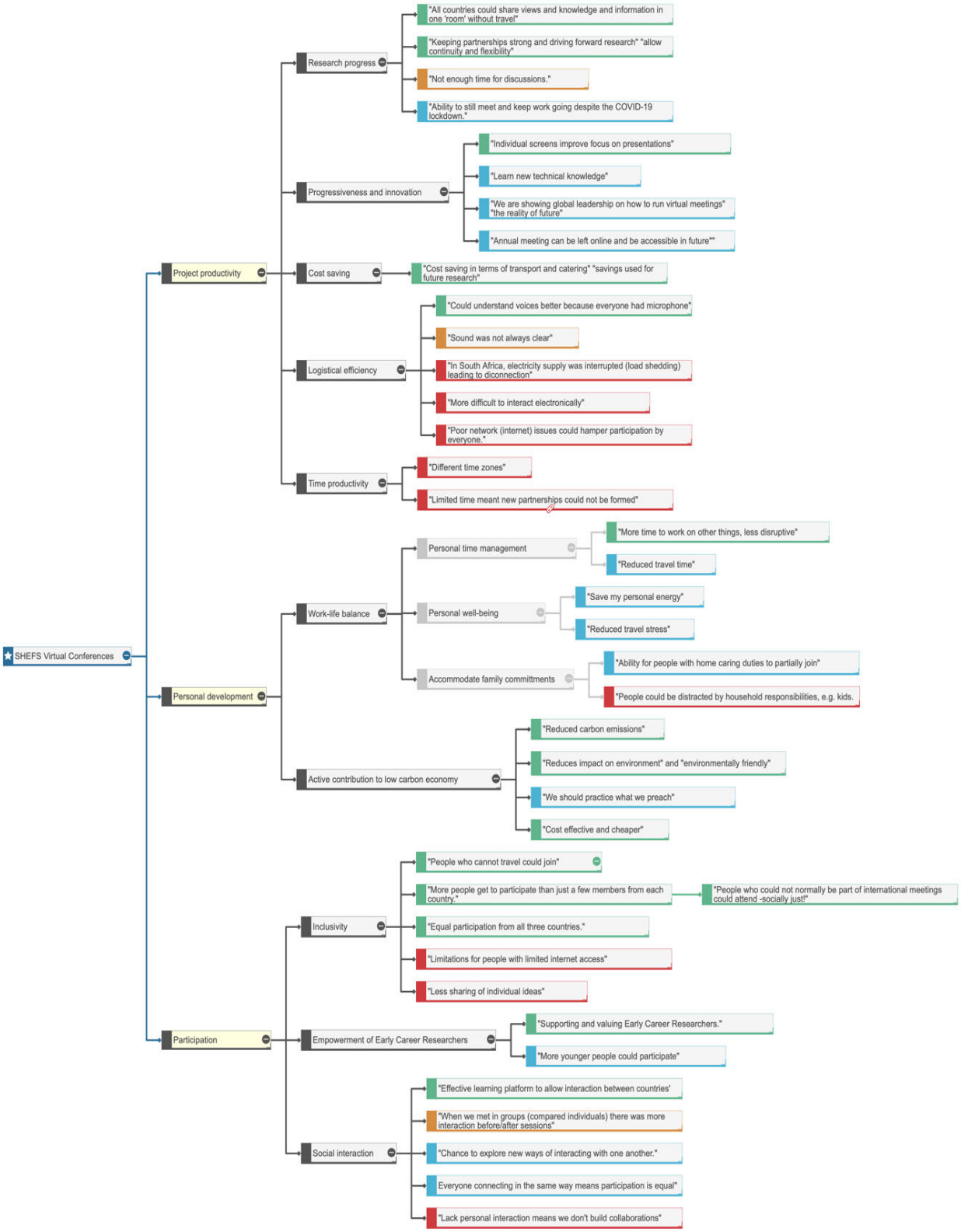
SM APPENDIX 5.2

Table 5.1: List of actual attendees for the 2019 virtual meeting and proposed attendees for the face-to-face meeting. Attendees categorised into emerging/mid-career and senior level, male and female and Global South.

Location	Attendees Virtual Meeting		Proposed attendees Face-to-face Meeting	
	N	*Level of seniority*	*N*	*Level of seniority*
Pietermaritzburg	27	15 senior researchers 12 emerging/mid-career researchers	10	9 senior researchers 1 emerging/mid-career researchers
London	23	8 senior researchers 15 emerging/mid-career researchers	19	8 senior researchers 11 emerging/mid-career researchers
Aberdeen	2	1 senior researchers 1 emerging/mid-career researchers	2	1 senior researchers 1 emerging/mid-career researchers
Delhi	6	2 senior researchers 4 emerging/mid-career researchers	3	2 senior researchers 1 emerging/mid-career researchers
Bangalore	16	9 senior researchers 7 emerging/mid-career researchers	10	4 senior researchers 6 emerging/mid-career researchers
Other	7	0 senior researchers 7 emerging/mid-career researchers	0	-- --
TOTAL	104	41 senior researchers 63emerging/mid-career 68 female, 36 male 75 Global South (31 senior; 44 emerging/mid-career, 53 female)	49	28 senior 21 emerging/mid-career 29 female, 20 male 28 Global South (19 senior; 9 emerging/mid-career, 16 female)

SM APPENDIX 5.3: SURVEY THEMES AND SUB-THEMES

The figure shows the themes and sub themes that were identified from survey responses in 2019 and 2020, before and after the two virtual conferences. Three main themes identified were: 1) Project productivity; 2) Personal Development and 3) Participation. For each sub-theme, comments were extracted for each category of the Strength (green boxes), Weakness (orange boxes), Opportunities (blue boxes) and Threats (red boxes) (SWOT).



CHAPTER 6: LINKING SOCIAL OUTCOMES TO ECOSYSTEM SERVICES: A DEMANDS ANALYSIS FOR LOCAL STRATEGIC PLANNING TOWARDS URBAN SUSTAINABILITY

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Abstract

Natural capital and ecosystem services are crucial for human well-being, and their protection and management must, therefore, be incorporated into government planning processes. In order to optimise planning, the links between natural capital, ecosystem services, and social outcomes, need to be better understood. In this study, we report on the outcomes of a transdisciplinary science-action expert engagement process undertaken under the auspices of the Durban Research Action Partnership (D'RAP) (test case). This work was framed to inform sustainability decision-making at the local government level, with a focus on identifying natural capital and ecosystem services that support desired social outcomes, in Durban, South Africa. We first identified the social outcomes from the Integrated Development Plan, and then linked them to natural capital and ecosystem services. We then explored methods for prioritising linkages in light of local expert knowledge, and different lenses/perspectives, including social, ecological economic and political. In total, 17 social outcomes and 14 ecosystem services were identified as important to sustainability, amounting to 239 possible social outcome – ecosystem service relationships/linkages, with 64 linkages identified as important to Durban's sustainability. Of these, 46 linkages were identified as priorities through expert engagement. Priority relationships included, for example, increased food security (social outcome), linked to ecosystem services of water supply, carbon storage, flood attenuation, soil formation, nutrient retention, pollination and maintenance of biological diversity. Water supply (ecosystem service) was linked to social outcomes of natural resource-based job creation, eco-toursim and revenue, increased food security, environmental education, recreation, reduced water treatment costs, improvement in human health, access to potable water and climate change mitigation. We confirm that natural capital and ecosystem services are crucial for well-being, and achieving social outcomes in urban centres. Our study showed that collaborative transdisciplinary approaches can result in improved decision-making, contributing to more sustainable outcomes. Specifically, the ecosystem services approach is multidisciplinary, and, therefore, serves the broad range of challenges that strategic plans aim to address.

Key words: sustainable development goals, ecosystem services, natural capital, policy, governance, ecosystem-based approach, science-action approach, transdisciplinary approach

6.1 Introduction

The Anthropocene is the current epoc, in which humans dominate over, and outcompete, the environment and natural processes, over all scales (Crutzen 2006). Pressure on natural resources is projected to continue with increasing population growth, raising the importance of the planning, management and sustainable use of natural resources as policy issues (Greenhalgh and Hart 2015). Decades of work by countries and the United Nations have resulted in policies and plans that aim to protect people and the planet, and achieve sustainability through environmental protection, social development and economic growth (United Nations 1992; 2002;2012; 2015).

Each Strategic Plan, up to and including the 2020 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs), recognised that, to achieve sustainable development, socio-economic outcomes for basic human well-being are essential, including poverty alleviation, access to water and sanitation, and food security (United Nations 2015). Equally important was the identification of environmental goals, including to sustainably manage natural resources and take urgent actions against climate change (United Nations 2015).

All countries are required to adopt and prepare national strategies and plans for sustainable development that integrate the various operational, sectoral, economic, social, and environmental policies and plans (United Nations 1992; 2002). The implementation of sustainability plans is particularly important for the well-being of citizens in developing countries, where higher rates of poverty and inequalities exist, for example, in South Africa, about half of the population lives below the poverty line, with high levels of income inequality (Gini coefficient of 0,68) (Department of Statistics South Africa 2014).

Natural resources, or ‘natural capital,’ (Mace et al. 2015) is foundational to the achievement of the SDGs, whereby socio-economic development is confined within the limits of the environment (Rockström and Sukhdev 2017). Natural capital can benefit people through ecosystem services, however, the presence and interaction of human capital (people), social capital (communities), and built capital (built environment) is required to facilitate the flow from ecosystem services to human well-being (Costanza et al. 2014). This is in line with a sustainability concept. Core to this concept is that economic and social development are intimately linked to nature and ecosystem services, whereby the loss of ecosystem functions will ultimately impact on future socio-economic development (Department of Environmental Affairs 2011).

Various studies have been undertaken internationally to quantity ecosystems services and their direct or indirect contribution to human well-being in the urban context (Bolund and Hunhammar 1999; Gómez-Baggethun and Barton 2013). Direct links between ecosystem services and human well-being are numerous. For example, the use of public spaces is affected by the availability of 'heat stress mitigation' ecosystem service (Égerházi et al. 2013), and air purification ecosystem service is important to human well-being, health and death rates due to links between air pollution and the occurrence of certain diseases (Nowak et al. 2014). The links between threats to ecosystem services and socio-economic variables are, resultantly, also numerous. For example, the effects of climate change and increasing intensity of precipitation and temperature extremes, has negatively impacted food and water security, and human health (Intergovernmental Panel on Climate Change (IPCC) 2017). These linkages highlight the importance of the protection and management of ecosystems services to ensure sustainability.

Efforts for the management of natural capital could be unaffordable and unmanageable if they are not focused on priority contextual needs (Mace et al. 2015), for example, focussing on boosting recreational services in areas prone to food insecurity, would not be as important as focussing on agricultural or water provisioning services. Furthermore, natural capital plays an important role in the ability of cities to achieve social outcomes, however, the links between natural capital, ecosystem services, and social outcomes may differ in different social-ecological contexts (Beauchamp et al. 2018). In cities, managers and planners are faced with increasing demands to protect ecosystem services to ensure their continued supply, and to achieve healthy and liveable cities that are prepared for global environmental change impacts, such as climate change (Elmqvist et al. 2015). However, despite the importance of ecosystem services, strategic development planning and management still fail to adequately incorporate them (Daily et al. 2009; Groot et al. 2010; Davids et al. 2018). Factors that contribute to ecosystem services not receiving deserved attention include: that they are often produced at some distance from urban beneficiaries; they rarely conform to property or administrative boundaries; those who are most affected by the loss of ecosystem services are often the least economically and politically influential (such as the urban poor); and, that public agencies find difficulty managing and regulating them (McGranahan et al. 2005).

The South African National Development Plan (NDP) and Vision 2030 of 2012, is the strategic guide for the country's policies and development activities until 2030 (National Planning Commission 2011). The primary goals of the NDP include the eradication of poverty and reduction in inequalities and unemployment. Other goals include increased access to social and health services, and to address unsustainable resource management, social division, and corruption (National Planning Commission 2011). In the NSSD, a systems approach to sustainability is applied, providing for the economic system, the socio-political system, and the ecological ecosystem, to be embedded within each other, and further integrated through the

governance system that provides a legitimate regulatory framework that holds all the systems together (Department of Environmental Affairs 2011). Furthermore, NSSD emphasizes the importance of ensuring sustainable development that allows for the aforementioned systems to remain mutually compatible (Department of Environmental Affairs 2011).

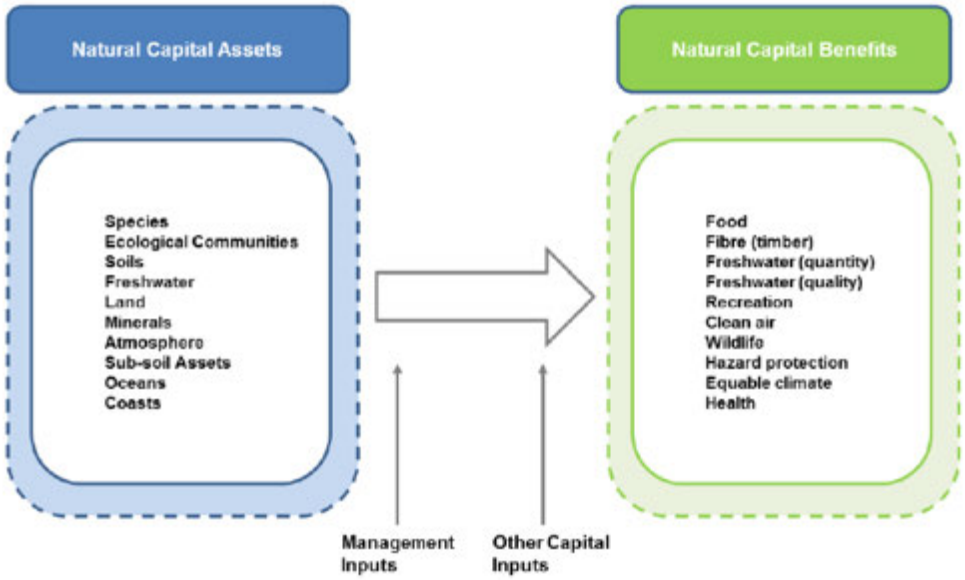
The effective facilitation of sustainable development policies require that regional and subregional frameworks are enabled towards concrete action at the national level (United Nations 2015). The successful implementation of the NDP relies on the capacity of the country to implement plans that support its development goals (National Planning Commission 2011). Such plans would include the NSSD, local (municipal) Integrated Development Plans (IDPs), and their associated Strategic Development Plans (SDPs).

The concept of ecosystem services can effectively be used to advance sustainable and urban development (Biggs, et al. 2015). The recognition by scientists and governments of the interactions between ecosystems and humans, whereby humans are negatively impacting ecosystems and ecosystems influence well-being, has led to large scale interdisciplinary and transdisciplinary collaborations becoming increasingly common (Sakai and Umetsu 2014). Transdisciplinary research is characterised by the interactive involvement of science, management, planning, policy and practice, in issue framing, knowledge production and application (Roux et al. 2010). The key aim of a transdisciplinary approach is to resolve complex issues across social-ecological systems, that cannot be resolved in social or natural disciplines alone (Roux et al. 2010).

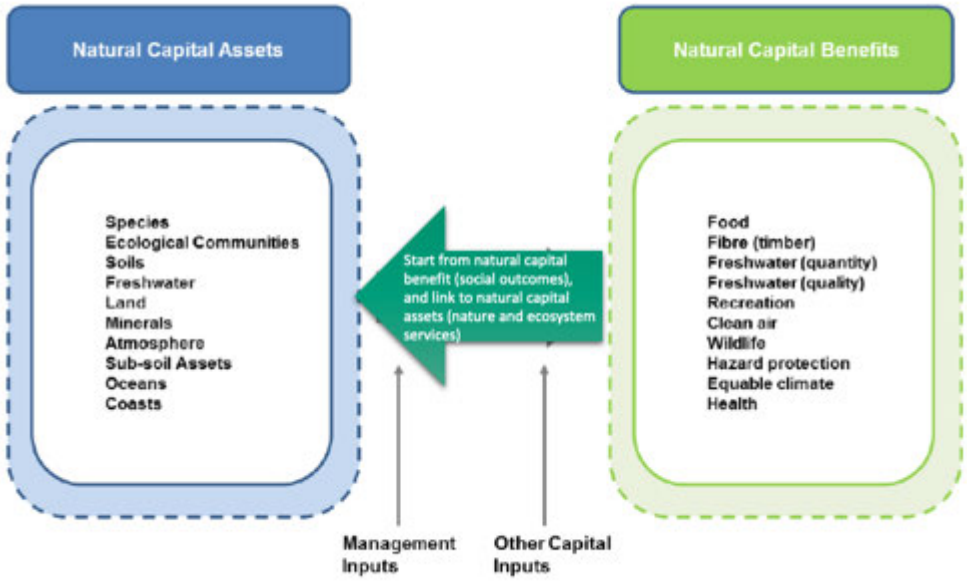
In the South African context, high per-capita carbon emissions, and increasing and severe pressures on the natural resource base, have resulted in the degradation of many ecosystems, to the extent that South Africa was considered to be on an unsustainable development path (Department of Environmental Affairs 2011). The depletion of natural resources will result in impacts on food security, increased housing costs and impacts on health due to reduced availability of traditional medicines. Such impacts pose a long-term threat to achieving the goal of a sustainable society (Department of Environmental Affairs 2011).

The main aim of this study was to investigate means to achieve urban sustainability through municipal planning (focusing on the IDP of eThekwini Municipality), from an ecosystem services perspective. To achieve this, we linked desired social outcomes (SO) from the IDP, to ecosystem services (ES) that support those outcomes (SO – ES linkages) , which city managers could then use to prioritise the protection and management of natural capital, to ensure continued supply of services for social outcomes to be achieved. However, this component of the methodological process followed an unusual flow of actions – instead of identifying natural capital and ecosystem services that exist and motivating for their preservation in light of the

general ecosystem services they provide (Mace et al. 2015, Fig. 1) – our work started from social outcomes that are needed to ensure sustainability – then linking and identifying natural capital and ecosystem services that support those specifically.



(a)



(b)

Figure 6.1: Flow of actions between social outcomes and natural capital. In (a), researchers started from natural capital and then identified the types of benefits that are be produced . In (b), which is the method adopted in this study, we started from desired social outcomes (natural capital benefits) and linked them to natural capital and ecosystem services (Green arrow indicates flow of actions adopted in this study), that will be needed to support social outcomes towards achieving urban sustainability, and which can inform specific management requirements to meet social outcomes (Original Figure (a) from Mace et al. 2015)

In line with this, studies have been undertaken to spatially prioritise ecosystem services for land use planning, however, far less has been done to adequately consider values ascribed to ecosystem services, and their social, political, and technological contextual aspects (Casalegno et al. 2014). Furthermore, while sustainability plans are in place, they do not preclude unequal development, conflicts or injustices, and scientist have therefore identified the blockage to realising the sustainable flow of contributions of nature to people, being related to the differences in how we relate to nature (Jacobs et al. 2021). How nature is valued, meaning, how its importance and significance to people's lives are assessed, is considered an important aspect for effective societal decision-making, on the management and use of nature (Jacobs et al. 2021). The valuation of nature differs between individuals and groups with unequal levels of power and is based on "*lenses through which human-nature relations are perceived*" (Jacobs et al. 2021). Plural valuation is proposed as a solution to improve decision making through knowledge generation, as it encompasses a science-policy process in which multiple values as they are attributed to nature by social actors, are assessed (Rincón-Ruiz et al. 2019). We have, therefore, also considered the multiple viewpoints/lenses from which linkages may be prioritised by managers from different sectors, in this study.

This study aims to provide a novel methodology to influence policy and governance processes towards achieving desired social outcomes for urban sustainability, using an ecosystem service perspective. The key research questions are: (1) What are the linkages between natural capital, ecosystem services and social outcomes (that are required to achieve sustainability), relative to the city of Durban? (2) What are the most critical ecosystem service – social outcome relationships for Durban, and how can those relationships be prioritised? The following three steps were undertaken, using a transdisciplinary approach; (1) Identify desired social outcomes from the IDP (IDP 2014-2015): the six Strategic Priority (SP) areas from the IDP were unpacked in relation to the goals and value statements for each SP (Table 6.1); (2) Identify natural capital and ES that can support desired SO (literature review and local knowledge), i.e. SO – ES relationships/linkages; and (3) Explore methods for prioritising SO - ES linkages, using both literature and, local knowledge on the ES demands,.

6.2 Study area

This study is positioned in the city of Durban, administered by eThekwini Municipality, situated in KwaZulu-Natal, South Africa. Durban has a 98 km long coastline that is dissected by the rivers of 18 major water catchments and 16 estuaries. Durban lies within the Maputaland-Pondoland-Albany global biodiversity hotspot, classified as such due to its high levels of plant endemism and habitat loss (Mittermeier et al. 2005). The biota of Durban comprises three biogeographical components: a warm temperate complex from the south-west;

a tropical complex from the north and a small localised complex, placing it in a transitional biogeographic zone with high levels of biodiversity. The climate is sub-tropical with mild winters and humid and warm summers (McLean et al. 2016).

Durban has a high Gini coefficient of 0.72, placed fifth on the world cities list of income inequality (Chelangat 2019), and has the highest percentage (42%) of people in poverty in South Africa (McLean et al. 2016; eThekwini Municipality 2017). The study area included urban and peri-urban/rural environments, with approximately two-thirds of the municipal area being rural or semi-rural, where a large proportion of local inhabitants are indigent and directly reliant on ecosystem services for basic needs (Roberts and Donoghue 2013).

Durban has progressively mainstreamed biodiversity and ecosystem services into it municipal planning processes, mainly through the Durban Metropolitan Open Space System (D'MOSS). D'MOSS is a formal municipal planning policy instrument which identifies a series of interconnected open spaces that incorporate areas of high biodiversity value and natural areas (Davids et al. 2016), with the purpose to protect the globally significant biodiversity and ES within the city (Roberts and Donoghue 2013). Durban's achievements in mainstreaming biodiversity and ecosystem services into planning have been lauded for being both socially just and scientifically effective and for managers who are able to navigate scientific and political landscapes (Shih and Mabon 2018).

6.2.1 Durban Research Action Partnership

This research was undertaken under the auspices of the Durban Research Action Partnership (D'RAP). D'RAP was first initiated between eThekwini Municipality and the University of KwaZulu-Natal in 2004, and formalised in 2011 (Cockburn et al. 2016). The aim of D'RAP is to close the research-action gap, through the provision of human capacity, research, and specialist skills from the academic sector, to support local government biodiversity and environmental planning, implementation, and decision making in Durban (Roberts et al. 2012; Cockburn et al. 2016). Transdisciplinary research projects of this nature have received much attention in literature in response to global environmental change, and the identified need for decision-making to be informed by the best available science (Mauser et al. 2013).

For this present study, a research team (the 12 Authors) was formed under D'RAP, including academics from the University of KwaZulu-Natal, government officials from eThekwini Municipality (Durban), and researchers from the parastatal Council for Scientific and Industrial Research (CSIR).

6.3 Methods

6.3.1 Identify desired social outcomes from the IDP

In order to identify priority social outcomes for Durban, the research team decided to unpack what sustainability means related to the IDP. This was done in the context of natural capital and ecosystem services, given that the focus of the study was to link social outcomes to ecosystem services. Six strategic priority (SP) areas, as per the IDP, were adopted as the key social outcomes, from where to start, in order to identify the contribution of natural capital, both positive and negative, to these outcomes. The overarching vision for eThekwini Municipality is '*To be Africa's most caring and liveable city by 2030.'* The six key priority areas identified in the IDP to realise this vision are: (1) A safe city; (2) An accessible city; (3) An environmentally sustainable city; (4) A city creating sustainable livelihoods; (5) A socially cohesive city; and (6) A financially sustainable city. The aim was to unpack the ability of natural capital to deliver on the vision of the city and the desired social outcomes, as listed above. The IDP contained goals and value statements, which defined each strategic priority (eThekwini Municipality 2014). Those goals and value statements were discussed, and specific outcomes were identified in line with these, and which had direct or indirect links to natural capital and ecosystem services.

6.3.2 Identify natural capital and ecosystem services that can support desired social outcomes

Three workshops were held with broad stakeholders (Appendix 6.1). The first two workshops were held to (1) unpack methodologies around translating global science concepts to the local realm and discuss the methodological approach of the research to be undertaken; and (2) discuss the sustainability of Durban as it relates to the IDP and natural capita. The third workshop was an Expert Engagement Workshop, that was held to identify SO – ES relationships that were important for Durban. As part of the planning and preparation for the Expert Engagement Workshop, and to streamline the process, the research team identified all potential SO-ES linkages related to the IDP prior to the workshop.

The research team (authors) undertook an internal prioritization process, that identified and ranked SO – ES relationships perceived by each team member (n=8), to be of greatest importance for the achievement of the desired social outcomes in Durban. To do this, the project team was asked to review the Social-Ecological Linkages Table (Table 6.2) and rank each relationship from 1 to 5 (1 highest rank to 5 lowest rank). The motivations for linkages from the literature was also updated to reflect motivations provided by team members for their

selections. The green boxes in Table 6.1 indicate relationships that had the highest ranking/levels of agreement (5), orange boxes show moderate levels of agreement (3-4), and yellow boxes show lowest ranking/low levels of agreement (somewhat agree) (1-2).

Thereafter, the Expert Engagement Workshop was held to test the priority relationships identified by the research team. Experts discussed the important social-ecological relationships that underpin sustainability in Durban, and provided their perspectives on the importance of these relationships. There were 42 experts at the workshop: 23 local government officials (eThekwini Municipal Managers/Staff from various Departments, namely: Environmental and Climate Protection, Catchment Management (Coastal and Stormwater), Policy Strategy and Economic Development, Water and Sanitation, Parks and Recreation, Human Settlements, Town Planning, Transport Planning, Engineering, Restoration Ecology, Scientific Services, Community Safety and Emergency and Disaster Risk Management); as well as eight academics (social and environmental scientists), three provincial government officials (Ezemvelo KZN Wildlife and Provincial Environmental Planning Department), three parastatals (Transnet, Dube TradePort), one NGO (ecological practitioner) and one private industry actor (Tongaat Hullett). This workshop was designed to facilitate discussions based on local information and knowledge, on why these relationships may be important to plan for sustainability in Durban, and if any additional relationships needed to be added to the list of priorities, or removed. Table 6.1 was shared with participants prior to the workshop, for discussion at the workshop.

6.3.3 Identify ecosystem service demands from different perspectives

Part of the discussions at the above workshop were focused on the different reasons/motivations for linking social outcomes/benefits to ecosystem services. Depending on the lens you're looking through or your viewpoint, the motivations for maintaining the benefit may change, which could affect the prioritization of linkages, or provide insights into the geographical locations of natural capital that are of importance for management and protection. In order to provide an understanding of the social-ecological relationships, RD shared two examples with participants, indicating the links between social outcomes and ecosystem services (SM Appendix 6.2).

For example: for the relationship linking **Social outcome: Improvement in water borne disease (Social outcome) – Water purification (Ecosystem service):**

- **Social motivation**: When people consume polluted water, they get sick. When people are sick, they will experience reduced quality of life. It is therefore better to prevent disease. **Ecological motivation**: High water quality is symptomatic of healthy ecosystems, so clean water reflects sound ecological infrastructure providing good quality water.

- **Economic motivation**: Focusing on improved water quality is important to ensure that downstream impacts related to tourism, eco-tourism, and sustainable livelihoods practices are minimized.
- **Political motivation**: The incidence of water-borne diseases is particularly problematic in areas where water treatment facilities are not available.

The different relationships between SOs and ESs were discussed within four groups, with between 4 and 6 experts in each group. Each group was facilitated by two members of the research project team (total number participants in each group was thus 6 – 8). Between two and four relationships were allocated to each group for discussion, and certain relationships were discussed in multiple groups (number of relationships discussed per group varied, on the basis of the length of discussions per relationship and time availability). Each group provided motivations as to why they felt the need to prioritise the relationships as important, or why relationships needed to be added or replaced. Groups then discussed which relationships they felt should be included as priorities to be considered by municipal managers.

The comments made on SO-ES relationships, were categorised in terms of the following lenses: social, economic, ecological, or political. Table 6.2 was updated to reflect the outcomes of the Expert Engagement Workshop, whereby an (*) was added to cells for priority relationships agreed to, or further motivated as a priority (green cells), strengthened (orange cells) or added (blank cells) as priorities by experts. The motivations for relationships that experts felt needed to be added, changed, deleted or replaced, were captured in a separate table.

6.4 Results

6.4.1 Identified social outcomes

Table 6.1 shows the goals and value statements of the six priority areas as per the IDP, and the identified social outcomes linked to each SP, through the lens of natural capital and sustainability objectives (see SM Table 6.1 for sustainability objectives). For example, for SP1, A city creating sustainable livelihoods, seven social outcomes were identified from the goals and values, namely, poverty alleviation, promotion of a green economy, sustainable job creation, for citizens to earn a decent living, improvement of skills, meeting current and future demands, and respect and compassion for those in need. From these, those with links to natural capital were selected for further consideration, namely, natural resource-based job creation, such as conservation, eco-tourism jobs etc. The two social outcomes, namely, ‘Environmental sustainability’ and ‘Supportive policy environment for Green Economy’ were also identified as social outcomes, but are omitted from the table as these did not have direct links to natural

capital.

Table 6.1: Six Strategic Priority Areas, Goals and Value Statements (as listed in the IDP) and identified social outcomes linked to sustainability objectives (adapted from eThekwini Municipality, 2014)

Strategic Priority (SP)	***Goal***	***Value Statement***	***Identified social outcomes linked to sustainability objectives***
SP 1: Creating Sustainable Livelihoods	All citizens in a prosperous eThekwini earn a decent living and support a sustainable lifestyle.	Ensure that initiatives undertaken by the Municipality contributes to strong economic growth, sustainable job creation, poverty alleviation, improved skills and promotes a Green Economy.	Natural resource-based Job creation: livelihood creation, jobs, conservation Eco-tourism job creation Use of harvestable goods Informal agricultural productivity Formal agricultural productivity Supportive policy environment for green Economy
SP 2: Caring and Empowering City	eThekwini has well rounded and caring citizens who act to support the common well-being of eThekwini and embrace mutual respect, tolerance and compassion for those in need.	Ensuring the development of a Municipality where the current and future skills needs of key commercial, industrial and government players are understood and can be met by our local, public and private educational and training institutions. Ensuring that adult literacy rates are impacted positively through partnerships with the public and private sectors.	Environmental education
SP 3: A Financially Sustainable City	To maximise the Municipality's financial resources to ensure long-term financial viability and sustainability, thus improving service delivery.	Achieve confidence of all internal and external stakeholders in the Municipality's financial management, excellence in the service delivery of municipal financial services, and compliance with prevailing municipal financial legislation and reforms.	Eco-tourism revenue Recreation Reduced water treatment costs Reduced natural hazard damage costs

SP 4: Creating a Safer City	All those who live, work, play and invest in eThekwini feel and are safe in private and public spaces.	The safety, health and security of citizens are critical to quality of life. The Municipality has committed itself to creating a caring city, with all citizens, businesses and visitors feeling safe and confident that their health and security needs are being met.	Improvement in human health: respiratory diseases, heat stroke, water-borne diseases Improved psychological well-being related to natural resources Access to potable water from natural sources
SP 5: Promoting an Accessible City	All citizens of eThekwini can easily and affordably access the facilities and service that they require for a sustainable lifestyle.	The Municipality is committed to a sustainable development path that strives to balance social, ecological and economic priorities. As far as possible, all development must function in harmony with the natural resource base upon which human well-being and the economy depends. An accessible city will ensure that all our citizens have access to facilities, basic services (either interim or equitable) and public transport options.	Green spaces as public transport corridors Natural resource protection for future generations, existence value of biodiversity
Strategic Priority 6: Environmentally Sustainable City	The environment of eThekwini protects and promotes the health of its citizens and its biodiversity.	To ensure the protection of the municipality's ecosystems and finite natural resources, which deliver essential environmental services (for example; water supply, flood attenuation, climate control, building materials) and which therefore provide the foundation for human life and development. The application of environmental sustainability principles will help to ensure the protection of biodiversity and the maintenance of ecological integrity within eThekwini Municipality as well as helping to meet the development objectives of the Municipality.	Climate change mitigation Climate change adaptation

6.4.2 Natural capital and ecosystem services that support desired social outcomes

Selected SOs were considered in light of natural capital that may be required to contribute towards the achievement of each social outcome (SM Table 6.1 and 6.2). SM Table 6.2 identified natural habitats that supply ecosystem services in relation to each SP area. Several linkages were identified, for example, promoting a green economy is a key component of **SP 1**, and ecosystems are essential for activities that support the green economy through eco-tourism, for example, beaches and estuaries that accommodate fishing, bird watching, water sports, or provide recreation services, and grasslands are crucial for material harvesting such as thatch, that also supports the green economy (SM Table 6.2).

Similarly, for **SP 4**, meeting health needs, was identified as a key social outcome for Durban. Various factors within the natural environment can impact on, or contribute to, health. For example, due to climate change, increased flooding could lead to contamination of water supplies, result in an increase in heat related vector- and water-borne diseases (particularly malaria and cholera), possible injuries, and malnutrition. Rising temperatures in Durban are predicted to cause heat stress, respiratory diseases, and cardiovascular diseases, and may exacerbate diabetes, mental health problems, and infectious diseases. Natural capital is critical to provide flood attenuation and climate control services to reduce potential health impacts. Climate change adaptation and mitigation are again critical towards meeting of health needs for the citizens of Durban.

Table 6.2 is the result of the process of identifying key SOs, natural capital and ESs relationships, based on the strategic priorities of the IDP. In total, 17 social outcomes and 14 ecosystem services were identified as key to sustainability, amounting to a total of 239 potential SO-ES relationships (each cell in the table represents a potential relationship). Each relationship was justified from the literature (SM Appendix 6.3). From the internal ranking exercise undertaken by the research team, 64 combinations were identified as important relationships (coloured boxes), 12 of these relationships were ‘strongly agreed’ as priorities by the research team (green boxes are those where there was strong agreement amongst the research team), 14 relationships were ‘moderately agreed’ (orange boxes), and 39 relationships had some agreement (yellow boxes).

Table 6.2: Social Outcomes and Ecosystem Services Linkages Table. The Six Strategic Priorities (SP) are from the eThekwini Municipality Integrated Development Plan: SP1: A safe city; SP2: An accessible city; SP2: An environmentally sustainable city; SP4: A city creating sustainable livelihoods; SP5: A socially cohesive city; and SP6: A financially sustainable city. Social outcomes were identified for each SP. Ecosystem services (A-N) were identified that have direct links to social outcomes (colour boxes indicate level of agreement (low to high: somewhat agree-yellow boxes, moderately agree-orange boxes, strongly agree-green boxes) from a researcher ranking exercise undertaken prior to expert engagement, to confirm linkages. Asterixis (*) indicate relationships agreed to (green), strengthened (orange and yellow) or added (blank) by experts.

			A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.
Strategic priorities	No	ECOSYSTEM SERVICES	Water supply	Water purification	Air purification	Carbon storage	Flood attenuation	Sediment retention	Soil formation	Nutrient retention	Cultural services	Nurseries provision for fish reproduction	Urban cooling	Pollination	Harvesting products (fuel, wood, thatch, food)	Maintenance of biological diversity
		DESIRED SOCIAL OUTCOMES														
SP1	1.	Natural resource-based job creation: livelihood creation, jobs, conservation/management	*			*										
SP1	2.	Eco-tourism job creation and revenue	*	*												*
SP1	3.	Use of harvestable goods										*			*	*
SP1	4.	Increased food security: Informal and formal agricultural productivity	*			*	*		*	*				*		*
SP2	5.	Environmental education	*	*	*	*	*	*	*	*	*	*	*	*	*	*
SP3	6.	Recreation related to natural resources	*	*								*				
SP3	7.	Reduced water treatment costs	*													
SP3	8.	Reduced natural hazard damage costs					*									
SP4	9.	Improvement in human health: respiratory diseases			*											
SP4	10.	Improvement in human health: heat stroke	*													
SP4	11.	Improvement in human health: water-borne diseases	*	*												*
SP4	12.	Improved psychological well-being related to natural resources									*					
SP4	13.	Access to potable water from natural sources	*	*												
SP5	14.	Use of green spaces as public transport corridors			*											
SP5	15.	Natural resource protection for future generations, existence value of biodiversity		*				*				*			*	*
SP6	16.	Climate change mitigation	*			*										
SP6	17.	Climate change adaptation											*	*		*

Overall, *water supply* was identified as important for nine social outcomes, of which three social outcomes were identified as priority linkages with *water supply*: *natural resource-based job creation, increased food security*, and *access to potable water from natural resources*. *Water purification* was identified as important for eight social outcomes, of which three were identified as priorities: *eco-tourism job creation, improvement in human health (water borne diseases)*, and *access to potable water from natural resources*. *Cultural services* were linked to seven social outcomes, of which one was identified as a priority: *improved psychological well-being related to natural resources*. The social outcome, *increased food security*, was linked to eight ecosystem services, of which two were priorities: *water supply* and *soil formation. Natural resource-based job creation* was also linked to eight ecosystem services, of which *water supply* was the only priority. Similarly, *climate change adaptation* was linked to eight ecosystem services, of which *carbon storage* was identified as a priority (Table 6.2).

6.4.3 Demands for ecosystem services based on experts' understanding of their contributions to social outcomes: multi perspective motivations for priority SO – ES relationships

The motivations of the SO - ES linkages (Table 6.2) were presented to experts at the workshop and discussed in four groups. Using local information and knowledge, experts provided motivations for the 12 priority SO – ES relationships that were previously identified by the research team (Table 6.2: green boxes, SM Table 6.3), confirming these as priorities. In addition to these, experts identified and motivated for 34 other relationships as being important to the sustainability of Durban (giving a combined total of 46 priority relationships).

Of these, three had moderate agreement from the internal prioritisation done by researchers: *eco-tourism job creation - water supply*; *reduced water treatment costs – water purification* and *climate change mitigation - carbon storage* (Table 6.2: orange boxes with *), seven that had low agreement by the researchers, for example: *environmental education – cultural services* (all services were linked here by the experts); *climate change mitigation – urban cooling* and *climate change mitigation – maintenance of biological diversity* (Table 6.2: yellow boxes with *, Appendices 3 and 4). The remaining SO – ES linkages that were discussed and received motivations to be included by experts are indicted in Table 6.2 (blank boxes with *).

For example, *recreation related to natural resources – (1) water purification* and (2) *nurseries provision for fish production*:

> *"If water quality is bad people would not want to visit these places for recreation."*

> *"Angling and recreational fishing requires fish production."*

Another motivation was for the addition of the *natural resource-based job creation – carbon storage* linkage:

> *"Increased conservation management jobs will result in areas supplying carbon to be protected."*

The experts identified a SO that was missing from the table, *sustainable public transport system* – and linked this to '*all ecosystem services*,' with the reasoning that:

> *"Sustainability will be hard to achieve without a sustainable public transport system. Sustainable public transport should be a priority social outcome for Durban."*

Groups also discussed and suggested reasons for relationships to be amended or deleted (SM Table 6.4).

From the discussions, it was clear that positive and negative elements were affecting the SO – ES relationships, and that effects went both ways. For example, the SO – ES relationships that received the most motivations/comments (29 comments, SM Table 6.3) was 1A – *natural resource-based job creation , livelihood creation, jobs – water Supply.* Discussions here raised issues for water supply related to pollution of rivers due to industry, poor sewerage infrastructure, dumping, and poor service delivery. Other comments on this relationship included that natural water sources provided important supplementary consumption needs for those communities that depend on trucks to deliver water, or during times of water shortages where people only received plumbed water for certain periods during the day due to water restrictions being in place. One comment that was expressed numerous times was the contribution of poor service delivery to the lack of available water and poor water quality in rivers and estuaries. Discussions around this linkage raised social, ecological, economic, and political motivations.

Social motivations included:

> *"In Kwandengezi, people depend on water trucks to deliver water once or twice a day. The amount of water being supplied is not sufficient. People depend on natural water sources and collect water using buckets as there are no boreholes. The lack of service delivery results in people needing to use water from natural sources."*

> *"Rapid urbanization and growing informal settlements affect water quality due to poor sanitation in these areas. Unfortunately, the municipal Land Invasion Department cannot control all areas. Water quality impacts are thus strongly linked to poverty and the economy needs to be developed to reduce poverty."*

Ecological motivations included:

> *"Water supply is important for conservation areas such as nature reserves and can create natural resource jobs through conservation and management of the water resource and associated environments. Sustaining our natural resource base contributes to eco-tourism and training opportunities such as training of guides. Based on a good natural resource base that can support these opportunities."*

> *"Long-term supply of water can result in jobs as you have to maintain the ecosystem service, for example, clearing of alien plants, wetland rehabilitation, etc. Catchment based management that creates jobs and helps with maintaining water supply (EPWP programmes)."*

Economic motivations included:

> *"Water supply is directly and indirectly linked to jobs."*

> *"Existing programmes (for example, Buffelsdraai) – teaching people to grow their own food through home gardens through water efficient techniques – created jobs as young people have been trained to undertake the training."*

Political motivations included:

> *"Lack of service delivery exacerbates pollution of water courses and increases reliance on natural resources"*

> *" Water pollution has resulted from illegal dumping close to water courses. This dumping is taking place since the municipality does not collect refuse. These dump sites affect water quality."*

> *"The backlog in municipal wastewater treatment works facilities and services has led to a decrease in water quality in river and estuary systems. There is a strong link between inadequate infrastructure and water quality."*

> *"People that are using the rivers are also polluting them due to the backlog of infrastructure. The city must think about the solution – either provide potable water or keep rivers clean. Both options offer solutions, but different with time horizons. There is also an issue of costs – keeping rivers clean vs cost of water treatment."*

> *"Municipality needs to identify streams where people are using water for drinking and prioritise those for protection."*

The expert workshop similarly provided a wealth of contextual information relative to lenses for the other relationships discussed by the experts, albeit some of which had more motivations than others (SM Appendices 3 and 4).

6.5 Discussion

This study contributes to research evidence that natural capital and ecosystem services are crucial for well-being, and achieving social outcomes in urban centres (MEA 2005; Elmqvist et al. 2015). The linking of social outcomes to ecosystem services in the matrix (Table 6.2) highlighted that it is seldom only one service that is needed to support social outcomes, and, in most cases, multiple services were required. For example, natural resource-based job creation, food security, and climate change adaptation were supported by eight ecosystem services each. The matrix also allowed for the most important ecosystem services to be identified and

discussed, that are needed to achieve desired social outcomes, in a specific context. The groups were able to justify and motivate, for the most part, all the priority relationships that were identified by the research team, using local information. The workshop provided a wealth of contextual information, which only local experts could have added, and which would not have been possible to bring to light by the researchers alone. Such local contextual information and knowledge can provide a base for government action (Hunter et al. 2020). The process of the workshop highlights the value of expert engagement to better understand contextual information, that can assist in improving service delivery. This study is, however, limited in that it was focussed on a municipal planning process, as an initial test case, which predominantly included high level experts. To be fully effective, the implementation of this method of establishing and motivating for SO – ES linkages to identify management priorities must be done with a far broader set of stakeholders, including traditional authorities and local community members (Davids et al. 2016; Sutherland et al. 2016).

The discussion of the linkages based on actual on-the-ground knowledge of the experts on the benefits, or risks, of natural systems to human well-being in Durban, were more tangible, and, thus, easier to engage with, than discussions on detailed climate change or biodiversity science (Shih and Mabon 2018). Furthermore, multiple lenses/reasons for linkages were motivated, from social, ecological, economic and political perspectives. The lenses allowed for further interrogation of reasons and demands for prioritising linkages – as the more disciplines covered by the linkage, the greater the potential for that ecosystem service to respond to the broad ranging issues that are faced by government actors. This is especially important when budgeting for maximum return on investments from responses, whereby choosing to invest in a particular ecosystem service could yield more benefits over other services (Chapter 4). It's also the basis from which to motivate for political action, given that ecosystem-based approaches provide wins for people and the ecosystems on which they depend (Roberts et al. 2012).

The concern that substantial portions of important ecosystem service areas lie outside of formally regulated and managed conservation areas in Durban (Davids et al. 2016), highlights a risk for the attainment of desired the social outcomes, of which so many were found to be directly linked to ecosystem services. This further brings to bear the importance of incorporating ecosystem services into municipal planning processes, to avoid projected losses of ecosystem service provisioning areas due to the implementation of planning proposals (Davids et al. 2018). This study proposed a pro-active approach to ensure that ecosystem services are considered by municipal planners upfront in planning processes, to avoid undue, further, losses, and risks to human well-being for the citizens of Durban (Davids et al. 2018).

The transdisciplinary approach applied in this study satisfies the concept of sustainability, as

called for in the global, national, and local policies and plans (Department of Environmental Affairs 2011; National Planning Commission 2011; United Nations 2015; eThekwini Municipality 2017), whereby the social, ecological, economic, and governance systems are integrated and equally considered, as far as possible. Specifically, we show the important role of ecosystem services for achieving South Africa's key development goals (National Planning Commission 2011). By using a transdisciplinary approach, policy actors can be empowered with scientific solutions to urban challenges such as poverty, food insecurity, and climate change adaptation and inadequate resource management (Mauser et al. 2013; Cockburn et al. 2016; Taylor et al. 2017; Moallemi et al. 2020). We show that science-action partnerships can contribute positively to government planning and management processes, by addressing specific issues that require scientific responses (Cockburn et al. 2016, Rouget et al. 2016, Taylor et al. 2017). Local governments have a crucial role to play towards achieving the global SDGs, and National Sustainability and Development Plans. Our study shows that negative impacts on biodiversity and ecosystem services that often result from local land-use decisions (Seto et al. 2012) can be avoided through science-action research. In so doing, planning and management processes can be positively influenced, and solutions can be identified that yield maximum positive and sustainable results (Moallemi et al. 2020).

This study further contributes to the literature that confirms direct links between ecosystem services and human well-being in urban contexts (Gómez-Baggethun and Barton 2013). We found that the process of making direct links between social outcomes that are required to fulfil IDP objectives, and ecosystem services, yielded multiple benefits, including: (1) Raising the importance of natural capital and ecosystem services to be managed and protected in urban areas (Förster et al. 2015; Davids et al. 2016); (2) Highlighting opportunities for multiple social, economic, and political sustainable development outcomes, that can be achieved through focussing on natural capital and ecosystem service management (Wood et al. 2018); (3) Enhancing adaptive capacity and resilience through increasing environmental education and awareness of politicians, officials, private actors and community members who participated in the linking processes (Monroe 2003; Krasny and Roth 2010); (4) broadening the perspectives of participants, and highlighting multiple pathways that encourage natural capital investments (Shih and Mabon 2018), through showing the different lenses behind motivations for prioritising SO - ES relationships; and, (5) building more detailed contextual information on the local social-ecological system linkages and knowledge on the importance of local ecosystem services (Andersson et al. 2007), for further research.

The methodologies applied here can be duplicated in other urban centres to yield similar benefits. This research can be taken further through detailed assessment and mapping of specific geographical areas that need to be managed to ensure the continued supply of ecosystem services that contribute to the identified priority desired social outcomes in Durban.

The linkages related to socio-economic development are particularly important, to combat poverty, food insecurity, and inequalities, which have been exacerbated by the COVID-19 pandemic (Gupte 2020). Options other than government funded management interventions can be explored to increased positive outcomes for well-being, through natural capital and ecosystem service enhancement, such as civic ecology approaches (Chapter 2 (in press); Andersson et al. 2007).

Although linkages were focussed on one SO and ES variable each, the discussions highlighted the systemic nature of linkages, with many being influenced by or influencing, other social-ecological aspects and ecosystem services, either directly or indirectly. This work is presented as an explorative framework that could be modified and used by others to test its usefulness in other transdisciplinary contexts. It can be improved by engaging expert groups in identifying management options to safeguard ecosystem services and ensure the achievement of desired social outcomes and unpacking the social-ecological context through to identify the strengths, weaknesses, opportunities and threats to sustainability in the system.

Ecosystem services can be viewed from two separate, yet often blended lenses: a generalising perspective and a context-specific perspective (for example, how ecosystem services are co-produced by people and nature, for the co-production of food, can be seen through two cultural lenses, (1) the "practice of care" through social relationships and connections with spiritual entities, or (2) the actual increasing of yields through biological or technical inputs (Díaz et al. 2018). Although our study did not specifically class motivations in terms of these two categories, the notion of lenses in discussing ecosystem services is an important one.

A key innovation of the approach taken in this study, was to structure the process in such a manner as to ensure that it was not only transdisciplinary in terms of expertise that was applied to the problem, but also ensuring that it was interdisciplinary in that it required multiple lenses from vastly different disciplinary spaces, to be applied to the problem. This study contributed to emerging research on the plural values ascribed to nature. Specifically, we show how values are influenced based on the lenses through which they are perceived and how those lenses influence the manner in which values are ascribed to biodiversity, socio-cultural heritage and economy-related profit values (Jacobs et al. 2021). The lenses through which experts viewed SO – ES relationships in this study facilitated the construction of knowledge among knowledge systems and disciplines (Díaz et al. 2018). Through understanding the different viewpoints through lenses, we were able to importantly avoid seeking the "*single right view of the situation, or how to improve it,"* which is *"a common short coming of professional practice*" (Ulrich and Reynolds 2010). Furthermore, lenses discussed in this social-ecological context facilitated reflection and discourse towards mutual understanding of differences in perspectives of the experts (Ulrich and Reynolds 2010). By providing a space for discussion amongst the

diversity of disciplines from which the experts ranged, this approach also provided opportunities to respond to the call for integration across operational, sectoral, socio-economic, and environmental policies and plans (United Nations 1992; 2002). The identification of lenses from which SO-ES linkages were motivated, confirms the strength of the ecosystem services concept to satisfy transdisciplinary team agendas, and asserts that ecosystem services can be used to link multiple planning outcomes, and integrate goals and strategies across sectors (Woodruff and BenDor 2016).

6.6 Conclusion

We confirm that urban sustainability can be achieved, through investments in natural capital and ecosystem services (Elmqvist et al. 2015; Jennings et al. 2016; Wood et al. 2018a; Chapter 2). By linking social outcomes to ecosystem services through a transdisciplinary process, we highlighted the multiple benefits that can be gained from managing priority natural capital and ecosystem services. Our study also motivates for political action towards ecosystem-based approaches, which provide wins for both people and the ecosystems on which they depend (Roberts et al. 2012). We show that, by using a transdisciplinary ecosystem services approach, policy actors can be empowered with scientific solutions to urban challenges such as poverty, food insecurity, and climate change adaptation (Mauser et al. 2013; Cockburn et al. 2016; Taylor et al. 2017; Moallemi et al. 2020). Planning and management processes can thereby be positively influenced, and solutions can be identified that yield sustainable results (Moallemi et al. 2020). However, for research to be embedded into society, the process of social learning, structured around a broad accountability framework, that cultivates reciprocal relationships between researchers, research users and funders, will be required (Roux et al. 2010).

SUPPLEMENTARY MATERIAL

SM Appendix 6.1: Details of stakeholder and expert workshops held

SM Appendix 6.2: Examples of motivations for linking social outcomes to ecosystem services and how motivations affect the geographical area of the natural capital that requires management and protection to ensure that the desired social outcomes are achieved.

SM Appendix 6.3: Motivations for social ecological linkages from literature and research team

SM Tables:

SM Table 6.1: eThekwini Municipality Strategic Priority Areas, Desired Social Outcomes, Natural Capital and Ecosystem Services Relationships Table

SM Table 6.2: Linking social priorities to natural capital and ecosystem services

SM Table 6.1: Expert group motivations for social-ecological relationships

SM Table 6.2: Expert group motivations for social-ecological relationships to be amended or deleted

Appendix 6.1. Details of stakeholder and expert workshops held

NAME OF MEETING	TYPE OF MEETING	PURPOSE OF MEETING	LOCATION	DATE	DURATION OF MEETING	ATTENDEES
1. From global thinking to local implementation	Workshop	To unpack methodologies around translating global science concepts to the local realm for sustainability in Durban	Tala Game Reserve, Durban	29 – 30 October 2015	2 days	UKZN: Rashieda Davids, Mathieu Rouget, Sarah Bracking, Rob Slotow, Chantal Taylor, Edilegnaw Wale, Rowan Naiker, Laila Bahaa-El-Din, Chuma Chinzila CSIR: Patrick O Farrell, Nadia Sitas, Ryan Blanchard, Benis Egoh EM: Debra Roberts, Natasha Govender, Sean O'Donoghue, Nokuthula Dubazane Other: Georgina Mace (UCL); Duncan Hay (INR), Jessica Cockburn (Rhodes University), Georgina Cundill (Rhodes University),
2. Key Stakeholders Meeting	Meeting	Meeting to present and discuss research approach in relation to sustainability in Durban	City Engineers Building, Durban	22 January 2016	1 day	UKZN: Rashieda Davids, Mathieu Rouget, Sarah Bracking, Rob Slotow, Bahle Mazeka EM: Jo Boule, Debra Roberts, Cameron McLean, Natasha Govender, Chris Fennemore, Emmanuel Letebele, Eric Parker, Errol Douwes, Faizal Seedat, Geoff Tooley, Helene Epstein, John Parkin, Londiwe Satimburwa, Malcolm Cauham, Noelene Chellan, Poven Akkiah, Richard Boon, Rob Dyer, Sean O'Donoghue, Sibongile Dlamini, Susanna Godehart
3. EM SEA Expert Engagement Workshop	Workshop, Durban Botanic Gardens	Stakeholder engagement workshop		8 November 2016	9:00 to 15:00	EM: Jo Douwes, Nokuthula Dubazane, Cameron McLean UKZN: Rashieda Davids, Mathieu Rouget, Yashfeeka Taliep, Sarah Bracking, Rob Slotow CSIR: Ryan Blanchard, Michelle Audouin, Benis Egoh EM: Mimi Ndokweni, Phila Buthelezi, Faizel Seedat, Geoff Tooley, Navin Badasar, Roshini Bob, Linda Mbonambi, Nongcebo Hlongwa, Kenneth Mabila, Sphelele Gumede, Sthembile Zulu, Victor Mkhize, Emanuel Letebele, Richard Boon, Loganathan

						Moodley, Siobhan Jackson, Andrew Mather, Jamila Ndovela, Kwazi Sithole, Thandeka Vilakazi Ezemvelo KZN Wildlife: Phindile Xulu, Nonhle Mngadi, Felicity Elliott, Transnet: Nelson Mbatha, Andre Ras, Vishern Beakam Ground Truth: Mark Graham Dube Tradeport: Mpume Myeni, Thamsanqa Mthethwa, Zama Masinga

SM APPENDIX 6.2: Examples of motivations for linking social outcomes to ecosystem services and how motivations may affect the geographical area of the natural capital that requires management and protection to ensure that the desired social outcomes are achieved.

Example 1:
Social outcome: Improvement in water borne disease
Ecosystem service: Water purification

Social motivations:

- When people consume polluted water, they get sick. When people are sick, they will experience reduced quality of life. It is therefore better to prevent disease.
- Recreation associated with water sports, for example, canoeing and fishing depend on the supply and condition of water to be of a safe quality.
- Water purification is critical to assist in purifying water in natural water sources, as some rural and peri-urban communities in Durban use water from natural sources for consumptive use, while many others use these for recreational uses.
- Water-borne disease can be preventable through the consumption of clean water, which can be provided cheaply by nature.

Geographical locations of importance: Areas where people directly consume water from natural sources.

Economic motivations:

- Sick people cost money, which increases the burden on health infrastructure.
- Focusing on improved water quality is important to ensure that downstream impacts related to tourism, eco-tourism, and sustainable livelihoods practices are minimized.
- Eco-tourism associated with water sports, for example, Durban Green Corridors, depend on supply and condition of water to be of a safe quality for recreation by tourists.
- Poor water quality affects fish reproduction and can have impacts on the subsistence and commercial fishing.

Geographical locations of importance: This will prioritise areas where tourist companies are operational, for example, uMgeni River and Estuary.

Political motivation:

- The incidence of water-borne diseases is particularly problematic in areas where water treatment facilities are not available or when informal settlement communities are not linked to the required infrastructure services.
- The city cannot afford to service all people with potable water, so an alternative would be desirable.

Geographical locations of importance: This will prioritise wards with limited potable water services, where people are directly reliant on water from rivers.

Ecological motivation:

- High water quality is symptomatic of healthy ecosystems, so clean water reflects sound ecological infrastructure providing good quality water.
- We need to maintain ecosystem health to ensure good water quality.

Geographical locations of importance: All rivers and wetlands

Example 2:
Social outcome: Eco-tourism
Ecosystem service: Maintenance of biological diversity

Social motivation:

- Natural spaces or parks with higher diversities of species are more attractive and would therefore be preferred for social outings, for example, hiking or picnics.
- Society may benefit through education or medicines associated with greater diversities of species.

Geographical locations of importance: Nature reserves, parks, forests, grasslands

Economic motivation:

- The maintenance of biological diversity contributes to eco-tourism in terms of, for example, sense of place.
- Natural spaces or parks with higher diversities of species are more attractive to visitors and would therefore generate more income from visitation by tourists.
- Geographical locations of importance: Nature reserves, parks, forests, grasslands
- Political motivation
- Higher levels of biodiversity or the presence of biodiversity hotspots facilitates positive profiling for Durban.

- As signatories to the International Biodiversity Convention and in terms of the National Biodiversity Strategy and Action Plan and the National Biodiversity Act, the maintenance of biological diversity must be ensured by government.
- Geographical locations of importance: Biodiversity hotspots

Ecological infrastructure motivation:

- Higher levels of biodiversity have been found to be related to higher levels of ecosystem services in certain areas.
- Maintenance of biological diversity underpins genetic diversity. Biodiverse ecosystems require minimum management input when systems are healthy and functional.

Geographical locations of importance: Healthy and biodiverse ecosystems

SM APPENDIX 6.2: Motivations for important social ecological linkages for Durban based on literature and local context

1A, 1B, 1G, 1N, 1J, 1M, 1F: Natural resource based livelihood creation: conservation/management jobs, fishing, green jobs etc.

Jobs associated with natural resource management include those related to ecosystem restoration, biodiversity conservation and water, land and soil management (for example, Working for Water, working for wetlands, Working on Fire, Working for Land programmes and NGOs including the World Wildlife Fund, Wildlands Conservation Trust, Wildlife and Environment Society of South Africa and Greenpop). These jobs predominate over the short, medium and long terms due to South Africa's exceptional endowments of natural capital. The share of such activities in the estimated total employment potential rises from around 45% in the short term to almost 50% in the long term (Maia et al. 2011). The existence of natural capital of conservation significance supports these jobs, for example, vegetated areas that must be managed to control invasive alien pants and rivers. Ecosystem services associated with the maintenance of natural capital and biodiversity, for example, water supply, (A) water purification (B), Soil formation (G) and maintenance of biological diversity (N) would thus be important for green jobs in this category. The potential for Durban's natural resources to provide significant opportunities for job creation in the green economy sector has not been fully explored. Given Durban's context of poverty and unemployment, it is critical that biodiversity is managed in a way that also provides long-term job opportunities (N). Nurseries provision (J) supports small-scale fishing and therefore job creation. Harvesting products (M) contributes significantly to livelihood creation and decent jobs. As a symbiotic benefit, jobs that aim to increase vegetation cover also aim to retain soil and avoid excessive erosion.

2A, 2B, 2H, 2I, 2N: Eco-tourism job creation and revenue

Jobs associated with water sports (2A, 2B), for example, the Durban Green Corridor (canoeing (Dusi Canoe Marathon) and mountain biking adventures), depend on availability of natural spaces and the supply and condition of water to be of a safe quality for recreation. Currently, declining water quality in rivers and estuaries affects the ability of these to be used for recreation and also compromises the quality of Durban's beachfront, which is a key source of revenue for the city (B). Durban's beachfront and estuaries are key to the 'attraction factor' of Durban as a tourist destination and the city derives significant economic value from this. Nutrient retention service (H) would contribute to the prevention of pollution or eutrophication of water bodies that would negatively impact on eco-tourism. The maintenance of biological diversity (N) contributes significantly to eco-tourism in terms of, for example, sense of place.

The characteristics of natural and cultivated landscapes often influence where people choose to spend their leisure time (I) (MEA 2005). Eco-tourism associated with water sports (A and B), for example, the Durban Green Corridors, depend on supply and condition of water to be of a safe quality for recreation. The Durban Green Corridor, in partnership with the eThekwini Municipality (Durban) and City of Bremen in Germany, are focused on supplying responsible tourism products which reduces negative social, economic and environmental impacts, while generating increased economic benefit and well-being of local people and host communities (Durban Green Corridor 2016).

3A, 3G, 3L, 3J, 3N: Use of harvestable goods

Numerous products are derived from ecosystems, including wood, silk, hemp, medicines, biocides and food additives (MEA, 2005). Majority of medicinal uses are derived from plants and forests/woodlands provide a source of fuelwood and timber, all of which depend on water supply (A), healthy soils (G), pollination (L) and the maintenance of biological diversity (N) to be sustained and to reproduce. Maintaining biological diversity (N) ensures the continued availability of naturally occurring harvestable goods. The distribution, abundance, and effectiveness of pollinators are affected by changes in ecosystems (MEA, 2005). Fish production is used for consumption (J). Many people are directly dependent on materials from the natural environment for their well-being (for example, firewood, medicines, building materials). Given the existing vulnerability of many communities that have such reliance, protection of these natural assets is critical for human well-being (N). Harvestable goods are also used for cultural services (I)

4A, 4B, 4F, 4G, 4M, 4L, 4I: Increased food security: Informal agricultural productivity and subsistence fishing

Water supply (A) and purification (B) services are critical to support agricultural production, as the absence of water would make it impossible to produce crops. Similarly, without fertile soils (G), agricultural productivity would be extremely limited. The provision of harvesting products (M), namely, fruit, vegetables and fish stock are critical for food security. The benefit of food for consumption (for example, fruit) is provided through pollination (L) and food provision is a final service (Fisher et al. 2008).

Subsistence fishing takes place in rivers and dams. Nurseries provision (L) makes it possible for fish to reproduce. Water supply (A), water purification (B) and nutrient retention (H) are critical for fishing as fish only exist in water and if water is of poor quality or polluted, fish populations will be reduced or wiped out completely. Sediment retention (F) upstream of dams and rivers are important for preventing the reduction in water quality and quantity and

associated impacts on fish populations. Though broad, traditional productive land/owning cows can serve the purposes fulfilment and food production (H).Though broad, traditional productive land/owning cows can serve the purposes fulfilment and food production (I).

5I: Environmental education

In many societies, the processes and components of ecosystems provide the basis for both formal and informal education through cultural services (I) (MEA 2005). Urban protected areas or coastal areas are important for school tours to promote environmental education. This could incorporate multiple services.

6A, 6B, 6H, 6I: Recreation related to natural resources

The characteristics of natural and cultivated landscapes often influence where people choose to spend their leisure time (I) (MEA 2005). Recreation associated with water, for example, water sports or recreational fishing depend on supply (A) and condition (B, H) of water to be of a safe quality for recreation. Biological diversity (N) enhances recreational experiences such as hiking. . Recreation can also be linked to maintenance of biological diversity (N) related to birdwatching or botanizing or endangered species activities.

7B, 7H: Reduced water treatment costs

Organic wastes introduced into inland waters and coastal and marine ecosystems can be filtered out and decomposed by ecosystems (MEA 2005). Water purification (B) done naturally reduces the levels of treatment and associated costs of chemicals for treatment needed for consumptive use. Nutrient retention service (H) would contribute to the prevention of pollution or eutrophication of water bodies that would negatively impact on water treatment costs. Durban's population is growing, and the rate of growth exceeds the ability to provide appropriate water treatment facilities. It is critical that alternative mechanisms be found to reduce the impact of wastewater in natural systems and to improve the water quality in existing ecosystems. If this is not done, the functioning of river and estuarine ecosystems will be compromised, with associated biodiversity and recreational/subsistence livelihoods impacts (B). Flood attenuation systems (E) in critical areas could also reduce the risk of contaminants/excessive sediments entering the water/river system.

8D, 8E, 8F, H: Reduced natural hazard damage costs

Climate change is expected to result in increased natural hazards, including droughts, floods and storm events. These events may result in damage to private and public property and loss

of business, for example, in the agricultural sector. Flood attenuation (E) Sediment retention (F) is important for the prevention of landslides and damage caused by storms or large waves can be reduced due to the presence of coastal ecosystems such as mangroves and coral reefs (MEA 2005).

Carbon storage (D) is a key component of climate change mitigation is needed to mitigate climate change and associated extreme weather events. Disease outbreaks could occur due to polluted water, which raises the importance of nutrient retention services (H).

9C, 9D: Improvement in human health: respiratory diseases

Ecosystems both extract from and contribute chemicals to the atmosphere, influencing many aspects of air quality (MEA 2005). Rising temperatures in Durban are predicted to cause heat stress, respiratory diseases and cardiovascular diseases, and may exacerbate diabetes, mental problems and infectious diseases. Natural capital is critical to provide air purification (C) and climate control services (D) to reduce potential health impacts. Climate change mitigation (D) is critical towards meeting of health needs for the citizens of Durban. Parts of Durban (for example, South Durban basin) are already severely compromising human health because of high levels of industrial pollution. This happens in areas where there are already higher levels of vulnerability. Improving air quality would improve quality of life (for example, reduced asthma) and reduce the burden on clinics and other health facilities, resulting in reduced costs and an ability to focus on other health issues (for example, human immunodeficiency viruses/tuberculosis) (C). Sediment and dust could also lead to respiratory ailments if not controlled (F).

10D, 10K: Improvement in human health: heat stress

Rising temperatures in Durban are predicted to cause heat stress. Natural capital is critical to provide urban cooling (K) and climate control services (D) to reduce potential health impacts. Local and global climates are influenced by ecosystems, for example, local changes in land cover can affect precipitation and temperature while at the global scale, and ecosystems play important role in climate regulation through either sequestering carbon or emitting greenhouse gases (MEA 2005).

11A, 11B, 11H: Improvement in human health: water-borne diseases

The abundance of human pathogens, for example, cholera and disease vectors such as mosquitos can be altered due to changes in ecosystems (MEA 2005). Water purification (B) and nutrient retention (H) services are critical to assist in purifying water in natural water

sources as some rural and peri-urban communities in Durban use water from natural sources for subsistence, agriculture and business uses, while many others use these for recreational uses. The incidence of water-borne diseases is particularly problematic in areas where water treatment facilities are not available or when informal settlement communities are not linked to the required infrastructure services. Focusing on improved water quality in such areas is important for human health reasons (with links to human well-being and reduced costs of treatment) but also to ensure that downstream impacts (with impacts on tourism, eco-tourism, and sustainable livelihoods practices) are minimized (B). Wetland restoration for flood attenuation (E) could also help to remove toxins from water.

12I, 12N: Improved psychological well-being related to natural resources

The characteristics of natural and cultivated landscapes often influence where people choose to spend their leisure time (I) (MEA 2005). Humans derive numerous non-material benefits from ecosystems, including spiritual enrichment, aesthetic experiences, recreation, cognitive development and reflection (MEA 2005). Natural areas with higher levels of biodiversity (N) are generally more attractive and aesthetically appealing to users. Biodiversity and our natural environment contribute to mental well-being when people can access open spaces. Removing this could exacerbate mental health problems and reduce mental well-being in a society that is already stressed due to unemployment, crime etc. (N).

13A, 13B, 13H: Access to potable water from natural resources

Certain communities in Durban are directly dependent on natural resources for water and water supply (A) is thus critical. Water supply is a fundamental human need. Given that our natural systems are the providers of water, these need to be appropriately protected (A). The abundance of human pathogens, for example, cholera can be altered due to changes in ecosystems (MEA 2005). Water purification (B) and nutrient retention (H) services are critical in areas where people abstract water directly from rivers for personal use.

14I, 14K: Use of green spaces as public transport corridors

The provision of walking and cycling routes in green spaces (I) may provide additional motivation or appeal and encourage non-motorised transport. Urban cooling (K) along non-motorised transport routes would increase comfort levels for users of such routes. Additionally, air purification (C) is important for walking and cycling. As a symbiotic benefit, for carbon storage (D), these corridors could provide an opportunity to maximise carbon capturing species along these corridors.

15A, 15G, 15J, 15L, 15N: Natural resources protection for future generations, existence value and biodiversity

Biodiversity is the source of many ecosystem services, such as food and genetic resources, and changes in biodiversity can influence the supply of ecosystem services (MEA 2005). Water supply (A), soil formation (G), nurseries provision (J), pollination (L) all contribute to the maintenance of biological diversity (N). In order to protect natural resources and biodiversity, numerous ecosystem functions would need to be safeguarded. All natural living things have a right to life and humans have a fundamental responsibility to protect biodiversity not only because of the ecosystem services they provide, but also because they have an 'existence right'. There is also a need to comply with existing policy guidelines regarding habitat/biodiversity protection targets.

16D: Climate change mitigation

Ecosystems can contribute to climate change adaptation and mitigation, e for example, carbon storage (D) of various habitats reduce the amount of carbon in the atmosphere. Local and global climates are influenced by ecosystems, for example, local changes in land cover can affect precipitation and temperature while at the global scale, ecosystems play important role in climate regulation through either sequestering carbon or emitting greenhouse gases (MEA 2005). The maintenance of biological diversity (N) may provide opportunities to improve the resilience of a system to withstand the effects of climate change.

17B, 17C, 17D, 17E: Climate change adaptation

Ecosystems can contribute to climate change adaptation. Climate change is expected to result in increased incidence and durations of droughts, increased flooding and potential contamination of water supplies, increase in heat related vector and water-borne diseases (particularly malaria and cholera), possible injuries and malnutrition. Rising temperatures in Durban are predicted to cause heat stress, respiratory diseases and cardiovascular diseases, and may exacerbate diabetes, mental problems and infectious diseases raising the importance of water purification (B), air purification (C) and carbon storage (D) services. Natural capital is critical to provide flood attenuation (E) and climate control services (D) to reduce potential impacts and facilitate adaptation to these changes. The rationale here is similar for A, E and F. Climate change will have a significant impact on cities like Durban in terms of increasingly unpredictable rainfall, resulting in more extreme periods of drought and floods. It will also impact on human health and the economy, for example through water shortage challenges etc. In an existing context of population vulnerability (in Durban this is linked to poverty, unemployment and lack of services for some), Durban's ability to prepare for and adapt to

these impacts will be critical in order to reduce further impacts on the city's population and to ensure that the city can remain financially sustainable, since unexpected impacts on people and/or infrastructure come with associated costs.

SM Table 6.1: eThekwini Municipality Strategic Priority Areas, Desired Social Outcomes, Natural Capital and Ecosystem Services Relationships. Strategic Priorities and IDP definitions were taken directly from the IDP, while Sustainability objectives, social outcomes, ecosystem services and key natural capital requirements were identified by the authors. Cells were left blank where no direct links were identified.

Strategic Priority	IDP definition	Sustainability Objectives	Social outcome	Ecosystem Service	Key Natural Capital requirements –
SP 1: Creating Sustainable livelihoods	Ensure that initiatives undertaken by the Municipality contributes to strong economic growth, sustainable job creation, poverty alleviation, improved skills and promotes a **Green Economy.**	To ensure that natural resource management initiatives undertaken by the Municipality contribute to economic growth, sustainable job creation, poverty alleviation and improved skills as part of the city's Green Economy	Natural resource-based Job creation, livelihood creation, conservation, eco-tourism job creation	Water supply Nurseries Eco-tourism (water sports, adventure, hospitality)	Natural assets such as rivers and estuaries Restoration and climate change projects Natural open spaces in any condition (good and/or degraded condition) Nature reserves, Protected Areas, Coastal recreational areas (tourism)
		Increase the ecological integrity of those systems that support food security for sustainable livelihoods	Informal agricultural productivity Formal agricultural productivity	Water supply Water purification Soil production Nitrogen fixing	Land for agriculture; water quality and soil = also important
		To facilitate sustainable agricultural practices	Informal agricultural productivity Formal agricultural productivity	Water supply Water purification Soil production Nutrient cycling	Land for agriculture; water quality and soil = also important Rivers, natural vegetation that provides for run-off

Strategic Priority	IDP definition	Sustainability Objectives	Social outcome	Ecosystem Service	Key Natural Capital requirements –
		Develop and implement an enabling policy environment for the green economy Ensure the implementation of an integrated policy environment (for example, environment access etc.) supporting food security	Supportive policy environment for green Economy		Not applicable.
SP 2: Caring and empowering city	Ensuring the development of a Municipality where the **current and future skills needs** of key commercial, industrial and government players are understood and can be met by our local, public and private educational and training institutions. Ensuring that adult literacy rates are impacted positively through partnerships with the public and private sectors.	To be confirmed.	Environmental education	Cultural and recreational services	Natural spaces, conservation areas, parks

Strategic Priority	IDP definition	Sustainability Objectives	Social outcome	Ecosystem Service	Key Natural Capital requirements –
SP 3: Financially sustainable city	Achieve confidence of all internal and external stakeholders in the Municipality's financial management, excellence in the service delivery of municipal financial services, and compliance with prevailing municipal financial legislation and reforms.	To be confirmed.	Eco-tourism revenue	Recreation services Water supply Water purification	High water quality in estuary, beach condition in compliance with Blue Flag standard
		To change perceptions of natural spaces to encourage peoples use thereof	Recreation		
		To reduce costs of services through enhancing and protecting 'free' ecosystem service benefits	Reduction in water treatment costs	Water purification Flood attenuation Sediment retention	High water quality, intact riparian streams and functional wetlands Intact vegetation to reduce clogging of water infrastructure
		To protect and maintain natural systems to reduce costs associated with hazards	Hazard protection Reduced damage costs	Flood attenuation Sediment retention Carbon storage	Intact flora habitats - Grasslands, forests, woodlands etc. Functional wetlands
SP 4: Creating a safer city	The safety, **health** and security of citizens are critical to **quality of life**. The Municipality has committed itself to creating a caring city, with all citizens, businesses and visitors feeling safe and confident that their **health and security needs are being met**.	To improve human health through natural resource conservation and management	Improvement in human health	Air purification	High air quality, natural vegetation providing air purification service
			Improvement in human health	Urban cooling Carbon storage	Natural vegetation providing urban cooling: Forests
			Improvement in human health	Water purification	High water quality in rivers and estuaries. Regular flow Wetlands

Strategic Priority	IDP definition	Sustainability Objectives	Social outcome	Ecosystem Service	Key Natural Capital requirements –
			Psychological well-being related to natural resources	Cultural services Recreational services Urban cooling	Minimum area of natural capital (safe and accessible) within a certain proximity to natural space
		To ensure equal access to all for basic services	Access to potable water Access and availability of basic services	Water supply Water purification Sediment retention	Base flow in winter upper catchment
SP 5: Promoting an accessible city	The Municipality is committed to a sustainable development path that strives to balance social, ecological and economic priorities. As far as possible, all development must function in harmony with the natural resource base upon which human well-being and the economy depends. An accessible city will ensure that all our citizens have access to facilities, basic services (either interim or equitable) and public transport options.		Green spaces as public transport corridors	Recreation services	Green spaces as public transport corridors.
		To be confirmed.	Natural resource protection for future generations, existence value of biodiversity		Natural capital required to meet biodiversity targets
SP 6: Environmental Sustainability	To ensure the **protection of the municipality's ecosystems and finite natural resources, which deliver essential environmental**	To be confirmed.	Environmental sustainability Natural resource	Water purification Sediment retention Flood attenuation Maintenance of	Restoration of natural capital Increase in quantity and quality to meet needs of expanding future population

Strategic Priority	IDP definition	Sustainability Objectives	Social outcome	Ecosystem Service	Key Natural Capital requirements –
	services (for example, water supply, flood attenuation, climate control, building materials) and which therefore provide the foundation for human life and development. The application of environmental sustainability principles will help to ensure the protection of biodiversity and the maintenance of ecological integrity within eThekwini Municipality as well as helping to **meet the development objectives** of the Municipality.		protection for future generations, existence value of biodiversity	biological diversity	
		To be confirmed.	Climate change mitigation Climate change adaptation	Carbon storage Sediment retention Flood attenuation Soil production Nitrogen fixing Urban cooling	Vegetation and other natural features that store carbon (forests, grasslands, wetlands, etc)
		To be confirmed.		River flow for hydropower Water supply	Rivers

SM Table 6.2: Linking social priorities to natural capital and ecosystem services. Strategic Priorities were taken from the IDP. Links were identified to natural capital and specific habitats that support each Strategic Priority

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
Strategic Priority 1: A city creating sustainable livelihoods										
Poverty Alleviation	Clean streams provide water for communities in rural areas that have limited access to potable water. Subsistence farming requires access to water provided by natural capital. Small scale fishing provides a food source to the poor. Natural capital is essential to the fishing industry for water purification and nurseries. Drought as a result of climate change may lead to dehydration and starvation due to water shortages, water contamination and reduced food supply. Natural capital can supply clean water need to avoid dehydration and impacts on food supply.	Water supply Food supply (fishing) Water purification	Nurseries supporting fishing	Surface sub-surface water storage, maintaining dry river flows and attenuating downstream flooding. Water purification.	Agricultural land supplying food and jobs.	Medicinal harvesting Carbon sequestration	Carbon sequestration	Nutrient cycling Soil formation		Pollination

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
Promote Green Economy	Climate change effects include increased extreme weather events and droughts. Securing natural capital that plays a climate change mitigation function can assist in safeguarding the green economy by reducing potential impacts on agriculture and supporting green activities that rely on water. A low carbon economy is essential for a green economy. Natural capital can contribute towards carbon reduction. Eco-tourism and beach tourism support a green economy and natural capital is essential to the success of these businesses. Natural capital can contribute towards green energy production.	Water supply Water treatment Sustained water flows for hydropower	Tourism (water sports, bird watching)		Green urban spaces providing drainage to reduce impacts on economic activities.	Carbon sequestration Medicinal plants	Carbon sequestration Thatch harvesting	Hazard protection		Eco-tourism Biofuels for alternative energy
Sustainable job creation	Access to clean water									
Earn a decent living										

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
Improve skills										
Meet current and future needs										
Respect, compassion for those in need										
Strategic Priority 2: Caring and Empowering City										
Meet current and future needs										
Respect, compassion for those in need										
Strategic Priority 3: A Financially Sustainable City										
Maximise resources	Reduced water purification costs can be achieved with intact natural capital that provide purification functions Rising temperatures in Durban are predicted to cause heat stress, respiratory diseases and cardiovascular diseases, and may exacerbate diabetes, mental problems and infectious diseases. Natural	Water supply Water purification Water treatment	Freshwater quality	Water purification		Carbon sequestration Urban cooling	Carbon sequestration	Nutrient cycling Soil formation		Pollination

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
	capital can provide an urban cooling service and climate mitigation services that can lead to reduced health care costs. Nutrient rich soils can increase agricultural yields and maximise resources. Natural capital is needed to ensure pollination of crops.									
Service delivery (NRM, Climate Change Adaptation, Coastal Management, Water and Sanitation, Waste management, Health, Transport)	Climate Change Mitigation and Adaptation is a critical service of the EM that has been committed to Functioning natural capital provides hazard protection that assist with disaster risk management services Natural waste management to assist with water purification and treatment services Coastal dunes provide hazard protection on the coast Pollution reduction Natural capital provides air purification and pollution	Water supply Water purification Water treatment	Freshwater quality	Water purification Water treatment Flood attenuation		Air quality control Carbon sequestration	Carbon sequestration			

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
	prevention contributing to health services.									
Strategic Priority 4: Creating a Safer City										
Health needs are met	Access to clean water and air is essential to achieve human health needs. Natural capital provides important water purification functions that reduce engineered water purification costs and mitigate the spread of disease. Air quality control also provides a vital service to mitigate respiratory diseases. Due to climate change, increased flooding could lead to contamination of water supplies result in an increase in heat related vector and water-borne diseases (particularly malaria and cholera), possible injuries and malnutrition. Natural capital is critical to provide flood attenuation and climate control services to	Clean water supply	Nurseries for fisheries	Disease control Flood attenuation	Flood attenuation Erosion protection	Carbon sequestration Climate regulation Purification of air Flood attenuation Erosion protection Urban cooling	Carbon sequestration Flood attenuation Erosion protection	Flood attenuation Erosion protection	Air quality control	Recreation services Cultural services Spiritual experience and sense of place

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
	reduce potential health impacts. Rising temperatures in Durban are predicted to cause heat stress, respiratory diseases and cardiovascular diseases, and may exacerbate diabetes, mental problems and infectious diseases. Natural capital can provide an urban cooling service. Drought may lead to dehydration due to water shortages and water contamination and reduced food supply and may lead to starvation. Natural capital can supply clean water need to avoid dehydration and impacts on food supply. Natural capital can provide important cultural services that contribute to well-being.									

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
Safety and security needs are met	Natural capital can effectively reduce hazard risks associated with flooding and erosion. The effects of climate change can impact on security through increased extreme events. Climate change mitigation provided by natural capital is therefore critical in the face of anticipated global climate change.			Flood attenuation	Flood attenuation Erosion protection		Flood attenuation Erosion protection			
Citizens feel safe in private and public spaces										
Strategic Priority 5: Promoting an Accessible City										
Access to facilities and basic services and transport	Provision of transport results in GHG emissions contributing to climate change that can be mitigated through natural capital. Natural capital contributes to basic services delivery of water and sanitation services.	Water supply Water purification		Water purification		Carbon sequestration	Carbon sequestration			
Development in harmony with										

Strategic Priority Area and Social Outcomes	Description of link to natural capital	Habitats and Ecosystem services that support the social outcomes								
		Freshwater	Estuaries	Wetlands	Land	Forest	Grasslands	Soils	Air	Biodiversity
nature to facilitate human well-being and support the economy										
Strategic Priority 6: Environmentally Sustainable City										
Protect and promote health of citizens	See Priority Area 4: Health needs are met	Water supply				Carbon sequestration	Carbon sequestration			
Protect and promote biodiversity	Natural capital is enhanced through the protection and promotion of biodiversity.		Nurseries	Water purification		Carbon sequestration	Carbon sequestration	Soil formation		

SM Table 6.3: Linking social priorities to natural capital and ecosystem services. Table indicates the different relationships between social outcomes and ecosystem services which were discussed amongst the four groups at the Expert Engagement Workshop. Each group was facilitated by two members of the research project team with between 4 and 6 experts in each group. Between two and four relationships were allocated to each group for discussion. Each group provided motivations, based on their local knowledge, as to why they felt the need to prioritize these relationships as important.

RELATIONSHIPS		MOTIVATIONS
Social outcome	**Ecosystem service**	**Social, ecological, economic or political lenses and motivations**
1. Natural resource-based job creation: livelihood creation, jobs, conservation / management	Water supply	***Social motivations*** 1. In Kwandengezi, people depend on water trucks to deliver water once or twice a day. The amount of water being supplied is not sufficient. People depend on natural water sources and collect water using buckets as there are no boreholes. 2. Not sure if people use water from natural sources for consumption, however, people are getting sick, mainly due to cholera. People can't afford to go to private hospitals and public hospitals often do not have the needed medication for treatment, so this affects quality of life. 3. Some communities use rivers for washing clothes and other uses and depend on city to supply water for drinking. 4. Rivers are also getting polluted by industry. 5. Recreation: Paradise valley has a local water fall and not many people would have the opportunity to experience it. 6. Education: Transfer of skills is as important as job creation. Existing programmes (for example, Buffelsdraai) – teaching people to grow their own food through home gardens through water efficient techniques – created jobs as young people have been trained to undertake the training. Had they not had this training they would be worse off (education a key social outcome). ***Political motivations*** 7. The lack of service delivery results in people needing to use water from natural sources, such as boreholes. 8. Municipality needs to identify streams where people are using water for drinking and prioritise those for protection. 9. Water is only available from 5am to 9am due to water restrictions. This leads to people accessing water from natural sources. 10. The above-mentioned water restrictions are being applied in response to the current drought. However, issues related to water and health were not prevalent before the drought. In light of data from the municipal Water and Sanitation Department, it is possible to identify which areas are affected due to the drought. Most affected areas in North of the municipality. 11. Lack of service delivery exacerbates pollution of water courses and increases reliance on natural resources 12. The backlog in municipal wastewater treatment works facilities and services has led to a decrease in water quality in river and estuary systems. There is a strong link between inadequate infrastructure and water quality. 13. There was a case where people were using water from the river to supplement their demand. However, due to a blockage in the river related to pollution, the water quality was even worse for consumption. 14. Water pollution has resulted from illegal dumping close to water courses. This dumping is taking place since the municipality does not collect refuse. These dump sites affect water quality. 15. The backlog of service infrastructure is also linked to a lack of roads in certain areas where trucks cannot access areas to collect refuse there.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
		16. The lack of provision of sanitation services also results in pollution of water courses due to people's poor sanitation habits. 17. In response to pollution, the municipality does clean up pollution in rivers, however, but soon after this the areas are polluted again. These streams also get polluted or blocked due to extreme weather, including heavy rains and floods. 18. There are cases where the municipality cannot provide services to informal settlements due to issues with land ownership. 19. People that are using the rivers are also polluting them due to the backlog of infrastructure. The city must think about the solution – either provide potable water or keep rivers clean. Both options offer solutions, but different with time horizons. There is also an issue of costs – keeping rivers clean vs cost of water treatment. 20. Rapid urbanization and growing informal settlements affect water quality due to poor sanitation in these areas. Unfortunately, the municipal Land Invasion Department cannot control all areas. Water quality impacts are thus strongly linked to poverty and the economy needs to be developed to reduce poverty. This may start to address these collective issues. 21. Lack of political awareness among traditional authority around the relative importance of natural areas in the context of livelihoods. ***Ecological motivations*** 22. There is a link between water quality and quality. 23. Sustaining our natural resource base contributes to eco-tourism and training opportunities such as training of guides. Based on a good natural resource base that can support these opportunities. ***Economic motivations*** 24. Water supply is directly and indirectly linked to jobs. 25. Water supply is important for conservation areas such as nature reserves and can create natural resource jobs through conservation and management of the water resource and associated environments. 26. Long-term supply of water can result in jobs as you have to maintain the ecosystem service, for example, clearing of alien plants, wetland rehabilitation, etc. Catchment based management that creates jobs and helps with maintaining water supply (EPWP programmes). 27. Link between water supply, natural areas and local communities. Opportunities for job creation are linked to the natural systems and therefore water supply in rural communities; unlike the jobs that have been created as a result of sand mining that undermine the environment. 28. Innovation: when under pressure innovative water efficiency techniques such as rainwater harvesting and groundwater harvesting techniques come up. 29. High level of unemployment, high poverty, harvesting firewood, can use policy instruments to enhance this. Natural resource job creation fund, as an option.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
		30. No water supply can result in a loss in jobs. 31. Rainwater harvesting and leakages as potential jobs to improve/protect supply.
2. Eco-tourism job creation and revenue	Water purification	***Social motivations*** 1. There is a lack of clarity around people's understanding of the linkages between rivers, estuaries, and the ocean. 2. People are the main driver of water pollution in rivers and beaches etc. 3. If we want eco-tourism, we need to change people's mind-set (it isn't someone else's job to pick up my litter. People need to take ownership – it needs to become a personal issue). ***Political motivations*** 4. Maintenance of infrastructure (or lack thereof) also contributes to water pollution. 5. Sometimes there are no fines for pollution (or ones that are too little). We need proper enforcement of legislation. ***Economic motivations*** 6. The quality of the water (for example, at the beach) affects how people perceive a tourist venue. Water pollution can create a 'reputational risk'. If the Golden Mile, for example had Blue-Flag status, how much more tourism would it attract? 7. If your water body becomes polluted, then it is no longer used for recreation and then you lose tourism and associated revenue. 8. If you lose tourism revenue, jobs are also lost. People are dependent on, for example, Inanda Dam, for jobs. If the Dam becomes polluted, then jobs are lost.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
3. Increased food security: informal and formal agricultural productivity	Soil formation	***Social motivations*** 1. Utilisation of the natural resource – who will use it – this is important for poverty pockets and areas that utilise community parks. There is a need to teach people how to treat the resources. Scientific and social responsibilities may differ. 2. Element of change management and how to engage with the communities 3. Highlights things like literacy – poverty (67% - border municipality) – the potential target audience, not the urban people. 4. Cemeteries – people burying in yards – this can impact on soils in nearby locations where people grow crops. 5. Peoples habits – use of streams as dumping grounds which have further negative impacts – linked to irrigation problems and other negative issues. 6. Education and training capacities are important as this can drill down to the root of the problem as stated above. 7. We have not captured the social fabric as yet as more research is needed. To understand the whole system, unpack the system and the social linkages to the soil and human practices. **8.** Food security outcomes (social cohesion) – looks at the soil differently. And how they link to different social outcomes. A potential intervention point in increasing social cohesion. ***Political motivations*** 9. Cities role in food security – identify which foods can be planted in certain areas – a need for education and research in the food system used by local people (planting the wrong crops in a landscape can 10. A governance perspective – to what extent do we have the agenda of the community in mind. 11. There is a need to reinforce governance structures – to improve use of services or soil governing practices. If we follow this process – we will regulate via by-law and will alienate people – not address the problem.
4. Increased food security: informal and formal agricultural productivity	Water supply	***Social motivations*** 1. Example of Durban dig out port where there were informal farmers using the water for irrigation. 2. There are hygiene issues that can be associated with less water. Water quality and quantity is inherently linked. 3. Education around water use and farming, traditional knowledge incredibly important, and transfer of this knowledge. Informal considered to be a negative term. As these are the large natural areas and important for food security. ***Political motivations*** 4. There is a need to differentiate between what is formal and informal, or is it just registered vs unregistered. ***Ecological motivations*** 5. Grey water solutions important for water supply in contexts where this is possible and the use of alternatives such as rainwater through harvesting such as Jojo tanks.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
		6. More water you can harvest more productivity – focus should not be on increased food security but rather sustainable food production through water efficient practises. ***Economic motivations*** 7. Economic: there is a direct link between water supply, food security and cost of food. 8. Water affects food prices (economic). Subsistence scale faming creates an issue for individuals, outside supply results in pressure on the entire system. 9. Costs of food supply increases with lower water supply which has an overall impact on the economy.
5. Improvement in human health: respiratory diseases	Air purification	***Social motivations*** 1. In the South Durban Basin area there are about 73 chemical industries that are all in proximity to each other and to residences and schools. There are many industries that emit polluting gases. People that live in the South Durban Basic suffer from bronchitis and respiratory illnesses. 2. In addition to the direct connection between industry emission and human health, industry pollution also results in climate change due to industrial pollution that in turn affects human health. 3. Publicly Listed Companies must establish their social ethics committee where they accommodate for their business activities on society. For example, where the cost of air pollution is borne by communities, the Company Act requires that companies give back to the communities they are impacting on. This is happening in Wentworth, Merebank, Jacobs, etc. ***Political motivations*** 4. The EM has an Air Quality Officer that checks the Atmospheric Impact Reports of industries. The Air Quality Officer must take measures if the companies are in transgression with their Atmospheric Emission Licenses. 5. The city has network of monitoring stations to monitor air quality.
6. Improvement in human health: water-borne diseases	Water purification	***Social motivations*** 1. Both water borne and water wash diseases (for example, skin diseases) must be considered as part of this social outcome. 2. Due to the lack of recreational facilities in some low income communities, your likelihood of being exposed to poor water quality is higher (for example, swimming in polluted rivers) 3. Mind-set change is needed in relationship to environment and services, that results in empowerment of the community. 4. This relationship is important for eco-tourism but also recreation of city inhabitants, for example, paddling on the Umgeni (recreation by local users) can result in people getting sick afterwards which limits use of the system – potentially further resulting degradation. 5. There is also a direct link to water quality. Relationship is important in high density developments – where kids are forced to play in the street or streams – results in more exposure to the water quality and links to health are important. Similarly people doing washing in the stream and using/contaminating the water for crops which is a food source. Both

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations

are based on geographic area for use and water quality – also affects what can be done about the situation. Relationship is important as it can be linked to sustainable livelihoods of people – where farming takes place in the river courses and is affected by the water quality leading to potential health issues. There are many examples in the city, especially in high density urban areas.

Political motivations

6. There is a legal requirement to purify water to a certain standard.
7. It's a constitutional issue. It's a basic human right. The Constitution speaks about access both in terms of human access to good quality water, but also in terms of taking care of the environment.
8. In many low income communities there is a lack of services, so people are directly dependent on extracting water for use. If the water is of poor quality, then they are going to get sick. This is compounded by the fact that there are limited health facilities in some low income communities, so diseases can spread very quickly.
9. There is a need to understand the scale of the problem for this relationship. We know that increased incidences of sickness will result in pressure on the public health system and increase pressure on available resources. But, what are the consequences? The scale of impacts can be seen as - Long term - [degraded river systems reduces the effect of life supporting systems and affect the provision of dignity – people's quality of life], Medium or Short term [immediate safety issues linked to quality of living environment]. There is a difference in users base that needs to be considered (those who receive water from a tap – incur a cost (increased costs to purify water); but those who acquire resources directly from nature/river are a different group of people whose needs must be considered).

Economic motivations

10. If alternative low-cost water options are available (for example, good water quality directly from a river), this reduces the burden on the municipality both in terms of service provision and financial costs. This also reduces costs (i.e. costs related to payment for water services) to the people who are using the water directly from a river.
11. If the water source (i.e. a river) that the Municipality draws from in order to provide water services to citizens is of high quality then the costs to the Municipality are less because less investment needs to be made in treating that water, and consequently, the costs to the consumer are less.
12. Through the provision and purification of water, there is potential to create jobs and these opportunities should be explored.
13. Water availability and quality has an impact on subsistence agriculture and farming of cattle. If water is of poor quality it can impact not only on human health but also on food security. (This potentially also supports the importance of one of the other social-ecological relationships).

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
		Other perspectives: 14. There was a query as to why we had prioritised 'quality of water' in this social outcomes, over water volume, depth, flow, velocity etc. These all interact and in some instances the water doesn't have to purified to the same level if the water volume, velocity and depth are such that they help improve the overall risk
7. Improved psychological well-being related to natural resources	Cultural services	***Social motivations*** 11 Exposure to the natural environment can assist in increasing workplace productivity. As an example, Microsoft is trying to bring the natural environment into the workspace. Green buildings and access to natural space create a better work ethic. 12 When you are more exposed to the natural environment this can increase your energy levels and help you address stress levels. The natural environment provides a huge service in relation to quality of life. 13 Cultural practices linked to natural resources are important to ensure connection. 14 Part of the problem is the societal disconnect with the natural environment. This enables pollution to a greater degree. 15 Access to safe natural space is a right for all children. ***Ecological motivations*** 16 Durban is relatively well-equipped in terms of its natural environment and spaces. It is an important asset of the city. ***Economic motivations*** 17 Evidence for some of the above points can be seen in the fact that the natural environment is also linked to property values. If there is a good quality natural environment, the property prices are higher (for example, good views, near a forest etc). There is a whole industry around well-being and the natural environment. Spa's and well-being estates etc. could become an important economic sector. As the environmental sector, we fail to market and sell the green spaces. We need to do this.
8. Access to potable water from natural sources	Water supply	***Political motivations*** 1. Linking people to piped water infrastructure places pressure on the system politically in terms of service provision. 2. Important for all life in the city. Although most water comes from outside the boundaries. The city is involved in programs that work in the upper catchments. ***Ecological motivations*** 3. There are areas such as Ward 105 which covers 5 traditional areas that still use water directly from Illovo and uMkhomazi rivers.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
		Economic motivations 4. There is a health and economic link to water supply in terms of number of people visiting hospitals. 5. How do you fit water supply in a circular link? 6. Pollution impacts on water abstraction in the upper areas.
9. Natural resource protection for future generations, existence value of biodiversity	Maintenance of biological diversity	*No discussion was captured for this relationship as the group ran out of time.*
10. Climate change adaptation	Carbon storage	***Political motivations*** 1. The Disaster Management Department keeps data on the state of rainfall. Over the past few years, it can be seen that there has been an increase in the amount of rainfall and there is usually heavy rainfall that comes intensely that then stops. ***Ecological motivations*** 2. The increased rainfall and lack of drainage can be linked back to climate change. 3. The increase in heat due to climate change could be the reason for the current increase in mosquitos. 4. Incidences of lighting has increased and an increase in lightning fatalities has also occurred, which could be linked to climate change.
11. Eco-tourism job creation and revenue	Water supply	***Ecological motivations*** 1. One can't separate water quality from the supply. Both need to contribute to eco-tourism.
12. Environmental education	All ecosystem services	***Social motivations*** 1. Appropriate environmental education could help to improve the quality of all ecosystem services

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
13. Reduced water treatment costs	Water purification	***Economic motivations*** 1. Inadequate water supply means that your water is generally poor quality and so the costs go up. If you're having to treat water to improve its quality, then costs go up.
14. Reduced water treatment costs	Water supply	***Economic*** 1. See above comment
15. Improvement in human health – heat stroke	Water supply	***Social motivations*** 1. If you do not have water, you get heat stroke.
16. Improvement in human health – water-borne diseases	Water supply	***Social motivations*** 1. If we expand the social outcome description to also include 'water wash' diseases (along with water borne diseases), then this relationship needs to be included. Human health goes beyond water borne diseases to include aspects related to hygiene.
17. Climate change adaptation	Urban cooling	***Ecological motivations*** 1. One of the end results of climate change is temperature increase and we need urban cooling to reduce these impacts.
18. Climate change mitigation	Water supply	***Ecological motivations*** 1. The rationale given here was that, if there is sufficient water, then vegetation cover is maintained, and this acts as a carbon sink.
19. Use of green spaces as public transport corridors	Air purification	***Ecological motivation*** **1.** Green spaces (as a public transport corridor) provide a function as a carbon sink and air purifier. ***Social motivation*** **2.** Green spaces as a transport corridor mean less polluting motorized transport.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
20. Natural resource protection for future generations, existence value of biodiversity	Harvesting products	***Social motivation*** 1. Because of high levels of poverty, the provision of these products becomes critical.
21. Use of harvestable goods	Harvesting products	***Social motivation*** 1. Linked to the above point (Because of high levels of poverty, the provision of these products becomes critical), to be able to harvest the products, these products have to exist and thrive for harvesting purposes.
22. Increased food security	Carbon storage; Flood attenuation; Pollination; Maintenance of biological diversity	***Ecological motivation*** 1. Agricultural production is likely to happen in floodplain areas and riparian corridors with opportunities for increased carbon storage, flood attenuation, pollination and improved biological diversity.
23. Climate change adaptation	Maintenance of biological diversity	***Ecological motivation*** 1. Maintenance of biodiversity is key to climate change adaptation.
24. Eco-tourism job creation	Maintenance of biological diversity	***Social motivations*** 1. Angling activities taking place at Port would depend on maintenance of diversity. Due to pollution, angling is also affected. 2. The Port has large recreational activities including crafts, skis, etc. ***Economic motivations*** 3. There are two or three main rivers leading to the Port. Three or four times per year there's industrial effluent coming into the Port via rivers resulting in oil spills and boats being covered in oil. Recent one African Sun Oil in Mobeni burnt. All product that was in tanks ended up on the Port. Although African Sun Oil paid for clean-up, the spill impacted on the eco-tourism activities in the Port. 4. Victoria street market has fish, but not sure of the source of the fish. Not a big fish culture in Durban. 5. Transnet in 2012 approved the expansion of the Port that includes the downsizing of the Port. This increased the susceptibility of marine life to be affected by pollution.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
		6. The city places more importance on the expansion of the Port in terms of increasing economic growth and forsakes the environmental integrity of the area. To respond, business that promotes economic growth must also protect biodiversity. Transnet undertook and Environmental Impact Assessment (EIA) and economic assessments for the Port expansion. The socio-economic benefits from the expansion were identified to be significant. The South Durban Community Environmental Alliance (SDCEA) raised issues as part of the EIA and are now part of environmental management team. ***Ecological motivations*** 7. There problem with the city in eco-tourism job creation is that it's focussed on beach and the sea. There are only small nature reserves inland, that are limited in the number of jobs they can create and how much people can charge to visit them. At these inland reserves, there may not be the Big 5 that can draw crowds, however, maybe bird watching will be the biggest draw. 8. There are large areas in the North owned by Tongaat Hullet that are dedicated to open space conservation. Tongaat Hullet is looking at increasing eco-tourism there, for example, Non-motorised transport bike trails. Currently thinking about the extent to which people should be allowed into areas that are earmarked for biodiversity. The more people interact with the environment, the more they appreciate it. A combination of use and protection could be achieved by designating areas for certain uses. 9. There is massive potential, for example, with the Estuary systems in the North, to be used better for eco-tourism. 10. Ezemvelo KZN Wildlife (EKZNW) is investigating ecosystem services for use of medicines. 11. The city has many nature reserves that can promote eco-tourism. The Aquarium, while not natural, also has a diversity of species on display for tourists. The aquarium provides an opportunity for raising awareness that if we lose out on biodiversity, we will have nothing to display in the aquariums.
25. Reduced natural hazard cost	Flood attenuation	***Social motivations*** 1. During heavy rain, flash floods occur whereby water accumulates in low lying areas, where informal settlements are affected. 2. Water streams get blocked and starts flooding and debris also starts flowing with water and causes obstructions. ***Ecological motivations*** 3. Stormwater drains cannot absorb the amount of rain that is more intense due to climate change. In Chatsworth, Bottlebrush and surrounding areas the drains get blocked and water finds its own path. Water has ended up flowing through private properties.

Social outcome	Ecosystem service	Social, ecological, economic or political lenses and motivations
		4. Floods can also have ecological consequences through erosion and loss of vegetation. However, an ecologically sound environment might have less flooding impacts. In areas that are already developed, cannot retrofit ecological infrastructure. ***Political motivations*** 5. There was a case in Chatsworth where stormwater drains were blocked, and the community blamed the eThekwini Municipality. An investigation was done, and it was found that the amount of rain was too much for stormwater drains to accommodate. In this case it's not really the city's responsibility to remedy. However, if it was a stormwater drain that got blocked, the city would have to remedy this. The Engineering Department deals with blocked drains. 6. The city must look at the holistic picture, include for example, the maintenance of roads and bridges to minimise natural hazard impacts. ***Economic motivations*** 7. In response to damage due to extreme weather events, budget is available to assist people, for example, for monthly food parcels and to supply bedding and clothing through NGOs. The Department of Human Settlements have to work with people from informal communities for alternative housing or temporary shelter. 8. Tongaat Hulled is looking at sustainable urban design and green infrastructure limiting hard surfaces, etc., as an approach to mitigate against natural disasters. 9. Floods also affect eco-tourism due to the pollution that travels with the water during floods to beaches and other natural areas. The municipality have to clean up these areas after extreme weather events, which is done at a cost.
26. Recreation	Water supply	***Social motivation*** 1. Water supply is important since if dams are dry, there will be no recreation.

SM Table 6.4: Social Ecological Relationships: Motivations To Add, Amend or Replace Relationships. The following table indicates the different relationships between social outcomes and ecosystem services, which were discussed amongst the four small groups for the Expert Engagement Workshop. Each small group was facilitated by two members of the research project team with between 4 and 6 experts in each group. Each group provided motivations as to why they felt relationships needed to be added or replaced.

RELATIONSHIPS		MOTIVATIONS
Social outcome	Ecosystem service	Reasons for adding or replacing relationships
	REMOVE RELATIONSHIPS	
1. Natural resource-based job creation: livelihood creation, jobs, conservation / management	Water supply	**Group 3** There was a motivation to remove this relationship because catchment-based activities (i.e., beyond the boundaries of eThekwini Municipality (Durban)) could improve water supply but this is unlikely to be the case if the focus is only on the eThekwini Municipal Area.
2. Access to potable water from natural sources	Water supply	**Group 3** There was a motivation to remove this as the social-ecological relationship doesn't make intuitive sense.
3. Sustainable viable and affordable public transportation	Carbon storage	**Group 3** Motivation to remove this relationship as carbon storage/mitigation issues are more relevant at a global scale.

	RELATIONSHIPS Social outcome	Ecosystem service	MOTIVATIONS Reasons for adding or replacing relationships
			REPLACE OR CHANGE RELATIONSHIPS
4.	Eco-tourism job creation and revenue	Replace water purification with – Maintenance of biological diversity	**<u>Group 1</u>** The drive for eco-tourism is more related to the protection of biodiversity than to water purification. The protection of biodiversity will ensure that these areas are pristine and allow for people to see them and experience nature.
5.	Increased food security	Replace Soil formation with- Nutrient retention	**<u>Group 2</u>** The time period for soil formation makes it something that is not too important as it's something we can't just influence in our lifetime. Nutrient retention places emphasis on keeping the soil that we have, which should be important.
			ADD RELATIONSHIPS
6.	Eco-tourism job creation and revenue	Water supply	**<u>Group 3</u>** Add this relationship. Water quality and water supply cannot be separated as both are needed to contribute to eco-tourism.
7.	Environmental education	All ecosystem services	***Social motivation*** Environmental education can improve ecosystem services in terms of their use, for example, water management to reduce water use. The social outcome should be changed to cover other elements of education such as research. There is stronger link between education and maintenance of biological diversity.

RELATIONSHIPS		MOTIVATIONS
Social outcome	Ecosystem service	Reasons for adding or replacing relationships
		Ecological motivation Appropriate environmental education could help to improve the quality of all ecosystem services.
8. Reduced water treatment costs	Water purification	***Economic motivation*** Inadequate water supply means that water is generally of poor quality, which result in increased costs related to water treatment.
9. Reduced water treatment costs	Water supply	***Economic motivation*** See above comment.
10. Improvement in human health – heat stroke	Water supply	***Social motivation*** If you don't have water, you get heat stroke.
11. Improvement in human health – water-borne diseases	Water supply	***Social motivation*** Water supply and improvement in human health: water borne diseases are directly linked. Poor water supply will exacerbate water borne diseases. If we expand the social outcome description to also include 'water wash' diseases (along with water borne diseases), then this relationship needs to be included. Human health goes beyond water borne diseases to include aspects related to hygiene.
12. Improvement in human health – water-borne diseases	Maintenance of biological diversity	***Ecological motivation*** Mangroves provide a function of water purification that can help to alleviate water borne diseases.

RELATIONSHIPS		MOTIVATIONS
Social outcome	Ecosystem service	Reasons for adding or replacing relationships
13. Climate change adaptation	Urban cooling	***Social motivation*** One of the end results of climate change is temperature increase and urban cooling will be needed to reduce this impact.
14. Climate change mitigation	Water supply	***Social motivation*** The rationale given here was that, if there is sufficient water, then vegetation cover is maintained, and this acts as a carbon sink.
15. Climate change mitigation	Carbon storage	***Political motivation*** If we add measures for reducing emissions, we can meet targets for mitigating climate change.
16. Climate change mitigation	Air purification	***Social motivation*** Projects such as those of Durban Solid Waste (DSW) of capturing methane demonstrate the existence and importance of this relationship.
17. Use of green spaces as public transport corridors	Air purification	**Group 3** Green spaces (as a public transport corridor) provide a function as a carbon sink and air purifier. Also, green spaces as a transport corridor mean less polluting motorized transport.
18. Natural resource protection for future generations, existence value of biodiversity	Harvesting products	**Group 3** Because of high levels of poverty, the provision of these products becomes critical.
19. Natural resource protection for future generations, existence value of biodiversity	Water purification	**Group 2** Add this relationship.

RELATIONSHIPS		MOTIVATIONS
Social outcome	Ecosystem service	Reasons for adding or replacing relationships
20. Natural resource protection for future generations, existence value of biodiversity	Sediment retention	**Group 2** Add this relationship.
21. Use of harvestable goods	Harvesting products	**Group 3** Linked to the above point, to be able to harvest the products, these products have to exist and thrive for harvesting purposes.
22. Use of harvestable goods	Maintenance of biological diversity	Traditional areas and harvesting of medicinal plants make this a relationship that should be considered.
23. Increased food security	Carbon storage Flood attenuation Pollination Maintenance of biological diversity	***Ecological motivation*** Agricultural production is likely to happen in floodplain areas and riparian corridors with opportunities for increased carbon storage, flood attenuation, pollination and improved biological diversity.
24. Climate change adaptation	Maintenance of biological diversity	Maintenance of biodiversity is key to climate change adaptation.
25. Sustainable public transport solution is missing	All services	***Political motivation*** Sustainability will be hard to achieve without a sustainable public transport system. Sustainable public transport should be a priority social outcome for Durban.
26. Recreation related to natural resources	Water supply	***Social motivation*** If dams are dry, there will be no recreation.

RELATIONSHIPS		MOTIVATIONS
Social outcome	Ecosystem service	Reasons for adding or replacing relationships
27. Recreation related to natural resources	Water purification	***Social motivation*** If water quality is bad people would not want to visit these places for recreation.
28. Recreation related to natural resources	Nurseries provision for fish production	***Economic motivation*** Angling and recreational fishing requires fish production.
29. Natural resources protection for future generations	Nurseries provision for fish reproduction	***Ecological motivation*** If juvenile nurseries are destroyed fish populations will be impacted.
30. Use of harvestable goods	Nurseries provision for fish production	***Ecological motivation*** Nurseries are critical for fish production. Without fish production, there will be no harvesting of fish products.
31. Natural resource job	Carbon storage	***Economic motivation*** Increased conservation management jobs will result in areas supplying carbon to be protected.

CHAPTER 7: **GENERAL DISCUSSION**

I have demonstrated that the application of an holistic perspective through social-ecological systems, can provide solutions to problems that involve both people and nature (Carpenter 2002), and that transdisciplinary collaborations can address negative feedbacks between ecosystems and well-being (Sakai and Umetsu 2014). As social-ecological systems undergo transformations (Weichselgartner and Kasperson 2010), there is a need for an adaptive balance between the ongoing maintenance and health of Earth's life support systems and actual human development needs (Posner 2015). By better understanding social-ecological systems and making the links between human well-being, social outcomes, ecosystem services and adaptive management actions at three local levels of implementation, this research makes a positive contribution towards balancing natural capital and development (Chapters 2, 3, 4. 5 and 6, Figure 1.4 in Chapter 1). This Thesis has also contributed to the sparse literature that has aimed to understand how local local sustainability initiatives are addressing the SDGs (Jiménez-Aceituno et al. 2020). I have shown that contributions to the Sustainable Development Goals (SDGs) can be gained from civic and governance actions through transdisciplinary approaches (**Chapters 4 and 6**).

This thesis made the following key contributions, each of which are described in detail below:

1. Identification, quantification, and assessment of civic ecology interventions as a tool to improve human well-being, using a social-ecological systems approach.
2. Linking local interventions to global policy outcomes – quantified systems mapping of civic ecology, natural capital, and ecosystem services enhancement related to the SDGs.
3. Linking ecosystem services to human well-being improvements and policy implementation through transdisciplinary approaches:
    a. Application of social-ecological and ecosystem service approaches towards improving livelihoods of disadvantaged communities.
    b. Application of an ecosystem service approach to identify and plan for the management of priority ecosystem services that contribute to local government planning and management, with respect to desired social outcomes from the eThekwini Municipality Integrated Development Plan (IDP).
    c. Application of a transdisciplinary approach for sustainable development, showing the benefits of bridging the science-action gap.

7.1 Identification, quantification and assessment of civic ecology interventions as a tool to improve human well-being, using a social-ecological systems approach

The findings of this thesis shed light on the potential for civic ecology interventions to uplift impoverished communities, while allowing for significant contributions to improved human well-being, from natural capital and ecosystem service enhancements. This work confirms that civic ecology initiatives can provide diverse environmental and socio-economic benefits (Cock and Fig 2000), and, through environmental stewardship actions, can enhance natural capital, ecosystem services, and human well-being, in social-ecological landscapes, such as cities (Krasny et al. 2013) (**Chapters 2 and 3**).

Civic ecology practices are increasing and contributing to global sustainability initiatives; however, their contributions to ecosystem services are rarely measured (Krasny et al. 2013). This research responded to this gap by identifying, assessing and quantifying civic ecology interventions. My approach of quantifying civic ecology impacts using an adapted impact assessment methodology (**Chapter 3**), provides a novel tool that could be used by a variety of actors to identify and select interventions for maximum impact, that are tailored to specific needs/desired outcomes and contexts. This work provides evidence of the importance, and potential, of civic interventions to protect and manage natural areas that produce ecosystem services, while, at the same time, constitute social-ecological processes that enhance a multitude of ES and human well-being (Ezebilo and Mattsson 2010; Krasny et al. 2013; Díaz et al. 2018). In so doing, I motivate for government and the private sector to support civic ecology initiatives, and call for such initiatives to be upscaled for maximum impact (**Chapter 4**).

Another contribution of the thesis is in further establishing the concept of soial-ecolgical systems by incorporating the 'economic' aspect in the social, ecological and economic triad of sutainability, that was found to be under reported in previous studies

7.2 Linking local interventions to global policy outcomes – quantified systems mapping of civic ecology, natural capital and ecosystem services enhancement related to the SDGs

Using a social-ecological systems approach, this research established the linkages between natural capital and social outcomes at the local level – towards achieving national and global sustainable development. I did so through a lens of natural capital and ecosystem services enhancements. I demonstrated that by improving the local environment, for example, through

environmental management, and linking it to the SDGs, social-ecological benefits can be realised at multiple scales (Folke et al. 2016).

The protection, conservation, and restoration of ecosystem services needs a more effective science-policy interface (Neßhöver et al. 2013). The transdisciplinary approach aims to combine research and implementation disciplines in order to move ecosystem service theory into practice (Nahlik et al. 2012). Apart from the need to educate the general public, there should be efforts to teach decision makers the value and importance of biodiversity. Personal experiences will shape values, and values will shape policy decisions. Thus, policy makers need to have direct positive experiences with biodiversity, and urban areas may be a reliable venue for creating experiences that can lead to a positive feedback loop of experience and policy (Dearborn and Kark 2010). This challenge to engage policy actors towards actions that protect and enhance biodiversity and ecosystem services was addressed in **Chapter 6**, where the links between ecosystem services and social outcomes were unpacked through expert engagement.

In so doing, stakeholders from diverse backgrounds and government actors, with diverse mandates, were able to see the numerous benefits that ecosystem services yield, for a variety of social outcomes that are set to be achieved in the city of Durban. Experience from practice shows that complex assessments are not necessarily more helpful for decision support (Ruckelshaus et al. 2015). Decision makers do not necessarily need a full understanding of the social-ecological system, but rather require sufficient arguments to make a choice between land-use options (Honey-Rosés and Pendleton 2013). Therefore, designing problem-oriented ecosystem service assessments, which focus on the information demand by decision makers (**Chapter 6**), can help make ecosystem service assessments more decision relevant (Honey-Rosés and Pendleton 2013; Förster et al. 2015).

By providing local level evidence on actions from three local level sources of change: (1) civic/community action (**Chapters 2, 3 and 4**); (2) research community actions (**Chapter 5**), and (3) local government actions (**Chapter 6**) (eThekwini Municipality), this research contributes to the evolution of the application of sustainability frameworks, from global to local level (Rockström et al. 2009; Raworth 2012; Nykvist 2013; Dearing et al. 2014; Cole 2014).

7.3 Linking ecosystem services to human well-being improvements and policy implementation through transdisciplinary approaches

Contributions of this work, related to linking ecosystem services to human well-being improvements and policy, are described under the three sub-themes below.

7.3.1 Application of social-ecological and ecosystem service approaches towards improving livelihoods of disadvantaged communities

In South Africa, there are still local communities that are directly dependant on natural systems for basic needs, such as water (Department of Statistics South Africa 2020). Poor land use has resulted in many natural areas being degraded, and as a result, impacting on poor communities. For example, riparian vegetation serves as a buffer to river water quality from runoff of pollutants from land, whereby healthy buffers can mitigate the impacts of land-based activities and maintain healthy freshwater ecosystems (Meier et al. 2005; Camporeale et al. 2013). This purification of water by riparian vegetation is considered as an ecosystem service. However, in South Africa, many buffer zones have been degraded, for example, through being invaded by invasive alien vegetation, or unsuitable land use practices, with resultant costs of water loss (Le Maitre et al. 2002) and reducing their ability to perform certain ecosystem services that serve poor communities.

The WWWC case study used in this thesis (**Chapters 2, 3 and 4)** provides a grassroots example of how local communities can improve ecological conditions of natural areas, and, thereby, reverse degradation that is affecting the ability of natural areas to provide essential ecosystem services. Through the WWWC case study, this thesis confirmed that access and beneficiation from natural capital can improve social outcomes, reduce inequality in social outcomes, empower individuals, and create a sense of community cohesion. The strength of the case study was that it allowed for a variety of interventions to be assessed, in relation to current social-ecological challenges faced not only in Durban, but more broadly in many other national and international contexts.

By using the WWWC case study (**Chapters 2 and 4**), this research shows that environmental management initiatives do not necessarily need to be elaborate or expensive, they simply need to be coordinated and structured through targeted education and skills training of communities who live in these areas, and by applying the ecosystem services approach, the benefits of initiatives can be amplified. In so doing, the tragedy of the commons (Hardin 1968) can be avoided, while empowering community members with education, and, thereby, increasing their prospects for career development and employment. Furthermore, the funding from the private sector, allowed for this community to improve their human well-being. This highlights the important role that the private sector plays in achieving the SDGs, and shows that improvements are indeed possible, with coordinated local community actions.

7.3.2 Application of an ecosystem service approach to identify and plan for the management of priority ecosystem services that contribute to local government planning and management, with respect to desired social outcomes from the IDP

The ecosystem service approach was further applied in a local government setting (**Chapter 6**), whereby my research linked ecosystem services to desired social outcomes from multiple viewpoints. In so doing, I provided a methodological, transdisciplinary, science-action process (Cockburn et al. 2016), for identifying priority ecosystem services and natural capital that need to be managed for the city to achieve its goals, as per the IDP. This work highlights the positive contributions that science-action partnerships can make to local government planning and management processes, by addressing specific issues that require scientific responses (Cockburn et al. 2016; Rouget et al. 2016; Taylor et al. 2017).

In South Africa, land use management takes place at the local level, whereby the IDP is actualised through strategic development plans of local government (Davids et al. 2016). A study in 2016 on Durban's ecosystem service areas revealed that ecosystem services were under threat due to proposed strategic development proposals, with potential negative consequences for climate change, disaster risks (flooding), and aquatic impacts (affecting water quality and food production) (Davids et al. 2016). By working with diverse government stakeholders and practitioners to deepen understanding and appreciation of ecosystem services and their linkages to social outcomes (**Chapter 6**), this research could contribute to the structured incorporation of ecosystem services into decision-making and land use planning for a variety of sectors (Daily et al. 2009). Furthermore, by boosting efforts to manage and protect ecosystem services at local government level, national targets can more easily be achieved, and, ultimately, increased contributions towards global sustainability. Furthermore, this work shows that, by using a transdisciplinary ecosystem services approach, policy actors can be empowered with scientific solutions to urban challenges such as poverty, food insecurity, and climate change adaptation (Mauser et al. 2013; Cockburn et al. 2016; Taylor et al. 2017; Moallemi et al. 2020).

7.3.3 Application of a transdisciplinary approach for sustainable development, showing the benefits of bridging the science-action gap

In line with the SDGs and the South African National Strategy for Sustainable Development, to achieve sustainable development, natural heritage must be protected while mitigating environmental impacts and strengthening environmental, economic, social links. This study responded to this need in a number of ways: (1) by highlighting interventions that can protect natural areas and ecosystem services, with a focus on poverty alleviation and enhancement of social outcomes through civic ecology (**Chapters 2, 3 and 4**), (2) by showing potential for an

international research team's organisational processes to reduce their environmental impacts and mitigate carbon emissions, for example, by adopting virtual over face-to-face conferences (**Chapter 5**), and, (3) by making the links between ecosystem services and desired social outcomes, towards improved municipal management and planning for sustainability through transdisciplinary science-action approaches (**Chapter 6**).

This research was limited in that the findings of civic ecology interventions were confined to two communities, who were working under the same programme. Future studies could look at different civic ecology groups, and compare outcomes or identify additional benefits or constraints that may improve civic ecology outcomes elsewhere. Another limitation was related to the mostly qualitative nature of this work. Although I have extensive experience in the spatial distribution, mapping and planning of ecosystem services in Durban (Davids et al. 2016, 2018), this work could be strengthened by considering ecosystem services in the study area (**Chapters 2 and 3**) in relation to geographical and spatial attributes, which would further assist practitioners to select interventions that have maximum benefits. Further studies could also consider financial costs related to management interventions, that were not considered here. Another gap identified was that there is no set method for measuring contributions to the SGDs. I hope that my application of the impact assessment methodology can be used by others wishing to quantify contributions to the SDGs.

The key recommendations for implementation and policy, that I identified through this work include:

1. Civic ecology interventions play an important role in sustainability, as it touches on social, economic and ecological issues, thereby providing holistic solutions that can be duplicated in similar environments. This finding provided motivation for policy responses and increased governance support to upscale the concept of civic ecology, as a means to achieve sustainability. This could, in turn, reduce the impacts of poverty on the achievement of a range of SDGs, and the learning from which can be upscaled across multiple communities.
2. This is the first time that an impact assessment method was used to quantity civic ecology outcomes. This method was practical and allowed for the standardisation of impact scoring, and could be used by others in a variety of applications, both as a proactive (potential impacts) and reactive (actual impacts) quantification tool, allowing for benefits to be quantified across in a uniform way.
3. This research contributed to the growing evidence that the management of natural capital can yield multiple benefits for social-ecological systems. However, a key contribution here is that environmental management does not only need to be the responsibility of government, but can effectively be supported by local communities and businesses, as called for in the SDGs implementation policy (United Nations Development Programme 2016).

4. I showed that the use of a systems approach can be effective when considering sustainability processes, as it allowed for multiple aspects in a social-ecological system to be considered holistically. The systems approach was able to highlight the multiple benefits of improving the environment while also achieving health improvements, social upliftment and policy outcomes (**Chapter 4**).
5. This work also provided recommendations for more sustainable operations by international research teams (**Chapter 5**). I showed that virtual collaboration can be an effective alternative over face-to-face meetings, with three major advantages being: significant contributions to avoiding greenhouse gas emissions; enhanced participation by emerging scholars, especially from the Global South, and lower barriers for inter-country interaction, communication, and collaboration. Virtual practices should be encouraged, but will require key weaknesses and threats such as poor connectivity and limited interpersonal interactions, to be overcome. Furthermore, the study encourages continued use of virtual communication and meetings, as a means to mitigate environmental impacts of travel in perpetuity, even after global economic activities return post COVID-19.
6. The heuristic model of the SWOT analyses (**Chapter 5**) allowed for reflexive thinking related to operations of the SHEFS transdisciplinary research programme. Such reflexivity can strengthen a virtual research collaboration such as the SHEFS programme, that has interdisciplinary overarching objectives and which is a complex space for collaboration. The inclusion of the virtual meeting processes promote participation in concrete problem-solving, experimentation, and learning processes, which eventually improve the researchers' reflexivity (Popa et al. 2015). Consideration of context specificity is essential when trying to sustain complex virtual meetings across sites, as it could influence the gap between short- and medium-term outcomes, and perceptions of inclusivity and participation.
7. By linking ecosystem services directly to social outcomes for Durban (**Chapter 6**), I provided a tool that can be used by government practitioners to prioritize the management of associated natural capital yielding those services, thereby increasing the potential for successful service delivery by government actors. Facilitating discussions by experts on the different perspectives (lenses) for prioritizing social outcome – ecosystem service relationships, allowed for further interrogation of reasons and demands for prioritising linkages – as the more disciplines covered by the linkage, the greater the potential for related ecosystem services to respond to the broad ranging issues that are faced by government actors. This is especially important when budgeting for maximum return on investments, whereby choosing to invest in a particular ecosystem service, could yield more benefits over other services (**Chapters 3 and 6**).
8. This is work also contributed to evidence on the importance of understanding the pluralistic values ascribed to nature, and how such values are influenced by a variety of differences in, for example, aspirations, culture, age and gender, and through the articulation of values,

through a context specific process (such as the Expert Workshop in Chapter 6), that considers different socio-ecological interactions, power, influence and world views. Similar to (3) above, valuation of nature was also highlighted to be the responsibility of all actors, including decision makers, scientist and funders. (Jacobs et al. 2021) (**Chapter 6**).

9. The transdisciplinary approach applied in this study satisfies the concept of sustainability, as called for in the SDGs, Agenda 21, Rio+20, the South African NDP and associated IDPs, whereby the social, ecological, economic and governance systems are integrated and equally considered, as far possible. This approach should be more encouraged, particularly in sustainability research and practice, and supported by implementation policies.

7.4 Conclusion

My research shows that natural capital can be leveraged to achieve social outcomes in an urban context, and in turn, can contribute to national and international sustainability goals. In this thesis, I demonstrated three levels of local interventions that contribute to sustainability: (1) local community (civic ecology grassroots implementation), (2) local government transdisciplinary (city level planning practices) and (3) institutional transdisciplinary (international research community practices). The key highlights from each chapter are listed in Table 8.1.

By highlighting the important role that natural capital and ecosystem services play in supporting human well-being, this work calls for the structured inclusion of ecosystem services into local, national and international policies and planning. I show that a transdisciplinary science-action approach can provide numerous social, economic, ecological and governance benefits, while generating learnings that can be used elsewhere towards achieving balance between humans and the environment.

Table 8.1: Key highlights from each Chapter of the Ph.D. Thesis

Chapter	Highlights
Chapter 2	Ecosystem services are crucial for livelihoods of disadvantaged communities. Civic ecology enhances ecosystem services and mitigates ecosystem disservices. Civic ecology produces social-ecological system improvements. Civic ecology increases social cohesion, knowledge and employment opportunities. Local communities can leverage natural capital for livelihoods and well-being.
Chapter 3	Environmental Impact Assessment of social-ecological outcomes from civic ecology. Novel approach to quantify outcomes of civic ecology interventions. Investments in natural areas can deliver ecosystem services, socio-economic and health benefits. We provide a tool to select optimal management interventions for enhanced outcomes. We motivate for policy support of civic interventions.
Chapter 4	Environmental Impact Assessment of social, economic and health outcomes from civic interventions. Quantified linkages amid interventions, ecosystem services and Sustainable Development Goals. Local civic interventions can address global environmental change and sustainability concerns. Motivate for policy support of civic interventions using a social-ecological systems approach. We provide a tool to select optimal management interventions for enhanced outcomes.
Chapter 5	Virtual teams can successfully collaborate across countries, and significantly mitigate or avoid their contributions to climate change. Virtual team collaboration can facilitate more inclusive participation and influence by youth and women, and the Global South, thereby addressing the gender bias and North-South inequalities. Virtual conferences can serve as effective alternatives to face-to-face meetings, for international research teams, when planned appropriately. Purposeful learning and reflection in virtual teams can enhance benefits of virtual collaboration.
Chapter 6	Identified social outcomes from municipal integrated development plan. Linked social outcomes to ecosystem services to identify priority relationships. Priorities differed depending on the viewpoint from which relationships were motivated. Certain ecosystem services served numerous social outcomes and could therefore be selected for management. Showed how science-action research through transdisciplinary approach can yield numerous social-ecological systems benefits.

This thesis provides a variety of practical recommendations, methods, insights and tools, for local scale actions, that yield broad-ranged, transdisciplinary, national and global sustainability achievements. Such actions, if duplicated elsewhere, can make cumulative strides towards addressing the greatest challenges we face in the Anthropocene, of combating global environmental and climate change, and restoring balance between humans and natural systems. This 'good fight' is one that is the responsibility of all people, from every culture, religion, race, and from every corner of the Earth.

"And it is He (God) who has made you successors upon the earth…" (Quran 6:165) "The servants of the Most Merciful are those who walk gently upon the earth…" (Quran 25:63), "…truly, God does not change the condition of a people until they change what is in themselves…" (Quran 13:11).

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