Effects of land restoration on the habitat integrity of rivers based on biological water quality and habitat condition assessments with a focus on the eThekwini Municipality, Durban, South Africa

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ABSTRACT

Riparian ecosystems are natural areas that offer an extensive range of ecosystem services. Their functionality aids in diverting and mitigating the impacts of surface water runoff, thereby reducing soil erosion. Riparian ecosystems also play an important role in sequestering nutrients and organic matter. The degradation of river systems impairs riparian ecosystem health and results in dysfunction, lack of ecosystem services provision and other deleterious effects. This study examined the effect of restoring riparian habitats across two study sites in Durban, Ethekwini Municipality, South Africa. The study aimed to a) measure and assess habitat integrity across three river systems as a result of reforestation efforts, and b) monitor the biological water quality using the Mini Stream Assessment Scoring System (MiniSASS) and the Index of Habitat Integrity indices. In addition, a systematic review was undertaken to provide an introduction and background to ecological restoration work involving freshwater ecosystems in the general South African context. The Index of Habitat Integrity and MiniSASS data were collected over ten months at two sites reforested by eThekwini Municipality, which were compared with data collected from a third river site used as the reference. Two sampling points were selected per site (namely upstream and downstream). It was predicted there would be a significant difference in MiniSASS scores between river sites under reforestation and reference sites not exposed to reforestation. However, it was found that MiniSASS and Index of Habitat Integrity scores differed between and across sites. The reference site had the highest scores. The sites with greater habitat integrity had improved ecological conditions based on macroinvertebrate responses to anthropogenic disturbances. This study highlighted the important role of naturally functioning riparian habitats in cleaning water and provides a baseline for reforestation impact monitoring, as well as informing local governance strategies for restoring degraded rivers in urban areas.

PREFACE

The data described in this thesis were collected in Buffelsdraai and Paradise Valley, KwaZulu-Natal, Republic of South Africa, from April 2014 to July 2015. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof Mathieu Rouget, Prof Colleen T. Downs and Dr Matthew J. Burnett.

This thesis, submitted for the degree of Master of Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

………[redacted]……………….

Kholosa Magudu

January 2024

I certify that the above statement is correct, and as the candidate's supervisor, I have approved this thesis for submission.

[redacted]

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Professor Colleen T. Downs

Supervisor

January 2024

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DECLARATION 1 - PLAGIARISM

I, Kholosa Magudu, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO DRAFT PUBLICATIONS that form part and/or include research presented in this thesis.

PUBLICATION 1 (Not submitted)

Systematic review and assessment of river restoration research globally and especially in South Africa to contextualise reforestation and river restoration in eThekwini Municipality, KwaZulu-Natal, South Africa

K Magudu, MJ Burnett & CT Downs

Author contributions:

KM conceived paper with MJB and CTD. KM collected and analysed data. KM drafted the manuscript. CTD and MJB contributed valuable comments to the draft manuscript.

PUBLICATION 2 (Not submitted)

Effects of land restoration on the habitat integrity of two different rivers in the eThekwini Municipality, Durban, South Africa: Based on biological water quality and habitat condition assessments

K Magudu, M Rouget, MJ Burnett & CT Downs

Author contributions:

KM conceived paper with MR, MJB and CTD. MR sought funding. KM collected and analysed data. MJB assisted with data analyses. KM drafted the manuscript. CTD and MJB contributed valuable comments to the draft manuscript.

Signed: [redacted] ………………………………………………………

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January 2024

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Finally, I thank God for creating enabling environments, placing supportive hearts and resources in my life, and providing the strength needed to navigate challenges.

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CHAPTER 1

Introduction

1.1 Background

Freshwater systems are the most threatened water sources globally in terms of ecological status and biodiversity conservation (Clapcott et al. 2012; Desai et al. 2021). Similarly, the majority of South African wetlands, rivers and riparian ecosystems are in a degraded state (Amis et al. 2007; Bunn et al.2010; Agboola et al. 2020a). Fluvial systems like rivers and streams are particularly more degraded and perturbed than wetlands because of their linear structure and dynamism (Richardson et al. 2007).

The location of rivers in lower-lying areas in the landscape increases their susceptibility to environmental pressures and human impacts (Beater et al. 2008; Agboola et al. 2020a). Rivers are generally in a better condition higher up in the catchments, and as use and impacts increase downstream, their condition and utility value diminishes (Amis et al. 2007; Kleynhans et al. 2008; Bunn et al.2010; Agboola et al. 2020a).

1.1.1 Riparian ecosystem value and functions

Riparian ecosystems serve multiple functions provided they are intact or naturally-functioning (Reid et al. 2008; Agboola et al. 2019; Desai et al. 2021). These roles can be biological, social or economic in nature (Dosskey et al.2010; Agboola et al. 2019). Some notably essential biological functions offered by healthy riparian ecosystems include retaining nutrients and sediments that would otherwise be lost during periods of elevated runoff from rivers. Dosskey et al. (2010) also mention the maintenance of river channel structures, amongst other key functions. Compromised freshwater ecosystems result in water quality and quantity issues (Clapcott et al. 2012; Agboola et al. 2019; 2020a) and often lead to the loss of associated ecosystem benefits or ecosystem services for humans (Nalau et al. 2018).

Various anthropogenic pressure sources, such as organic pollution and intense agriculture, contribute to riparian ecosystem degradation, alteration and loss (Agboola et al. 2019; 2020a). In addition, even site-specific riparian land use changes such as grazing and overharvesting of indigenous vegetation impact riparian ecosystems, particularly the vegetation structure and function (Dosskey et al. 2010).

1.1.2 The role of vegetation in riparian ecosystem function

Natural vegetation cover is one of the most important predictors of riparian ecosystem integrity (Amis et al. 2007; Beater et al. 2008; Dosskey et al. 2010). Therefore, it is pertinent to understand the impact of riparian vegetation removal and restoration on critical resources like instream water quality (Eubanks 2004; Ruwanza et al. 2013; Rafferty et al. 2018). According to Dosskey et al. (2010), the overall level of site disturbance and water quality condition before implementing restoration efforts determine the time it takes for the ecosystem to start showing signs of repair. Mildly disturbed ecosystems are expected to take a much quicker time to show water quality improvement (Eubanks 2004). Sites described as mildly disturbed include sites that do not require active restoration but simpler interventions such as vegetation clearing (Richardson et al.2007; Beater et al.2008; Dosskey et al. 2010).

1.1.3 Challenges to riparian ecosystem restoration

Increasing research has supported growing restoration work globally and locally (Heinrich et al. 2014; Douwes et al. 2017; Gann et al. 2019; Kittipalawattanapol et al. 2021). However, the enduring challenge across various communities of practice in freshwater ecosystem restoration is that the approach towards restoring these ecosystems is generally made in silos and needs to happen at multiple levels to show quantifiable impacts globally (Gann et al. 2019). Furthermore, another concern is that most of the work is conducted at relatively small scales for freshwater ecosystems and is not integrated into official conservation plans (Amis et al. 2007; Gann et al. 2019).

Another important factor to consider is determining whether restoration objectives are achieved (Douwes et al.2017) and to what end or for whose benefit (Nalau et al. 2018). Ideally, ecosystem restoration aims to recover lost biodiversity and ecological infrastructure and linked ecosystem services (Marchand et al. 2021). Recent research by Marchand et al. (2021) affirmed that implementing restoration activities does not guarantee immediate and full recovery of ecosystem integrity and functions. It is to be expected, therefore, that recovered ecological functions do not match the desired reference ecosystem conditions (Adie and Bowker et al. 2012; Marchand et al. 2021). Consequently, it is common that the achieved ecosystem functionality after restoration can only support ecosystems of lower ecological integrity than anticipated (Marchand et al. 2021). Restoration efforts need to be monitored and understood, especially in comparison to the initial intentions for riparian ecosystem restoration and anticipated restoration goals (Douwes et al.2017; Nalau et al. 2018; Gann et al. 2019).

The restoration of freshwater ecosystems should result from multi-faceted initiatives driven by scientific, social, economic and political efforts (Ruwanza et al. 2013). There is still a gap in terms of collaborative impetus to restore freshwater ecosystems and monitor restoration success (Richardson et al. 2007; Rebelo 2012; Ruwanza et al. 2013; Rafferty et al. 2019). Therefore, it is important that monitoring takes place (*albeit* with complexity) because it is a significant driver of river restoration success (Eubanks 2004; Pander and Geist 2013).

1.1.4 Monitoring riparian ecosystem restoration

Various standards and indicators are used to monitor the benefits and success of restoration programmes as guided by the Society of Ecological Restoration (Gann et al.2019; Marchand et al. 2021). The indicators used are generally measured according to the benefit of interest

(Pander and Geist 2013; Douwes et al. 2015; eThekwini Municipality 2020). Ecological restoration is costly; hence, river restoration efforts, in particular, should be followed by monitoring of the river condition (with biotic and abiotic indicators) at fine scales (Kauffman et al. 1997; Pander and Geist 2013; Heinrich et al. 2014).

It is important to realise the role of scientific assessment and monitoring of riparian ecosystem health, forming the basis from which legal frameworks, policy-making and decision-making are streamlined to focus on indicators of stream restoration success (Pander and Geist 2013; Gann et al. 2019). For the interest of this study, one key focus is on how biodiversity indicators such as aquatic invertebrate taxa are measured over time to assess the benefits of restoration in terms of improvement of river ecological function for aquatic communities.

1.1.5 Riparian restoration work in South Africa

In South Africa, relatively few published studies document ecological restoration work involving freshwater ecosystems (Table 1.1). These few studies document published ecological restoration work involving freshwater ecosystems countrywide. Despite ecological restoration being a relatively young discipline locally compared with internationally, it is still concerning that much of the aquatic restoration efforts implemented by various national departments and organisations are not captured and shared widely. For instance, Ruwanza et al. (2013) confirmed that only one study had assessed the effectiveness of active restoration in riparian ecosystems in the Western Cape at least by 2012. Their study highlighted the potential for active restoration techniques to facilitate the recovery of indigenous vegetation after invasive vegetation clearing (Ruwanza et al. 2013).

Closer to home, the ‘Take Back Our Rivers’ initiative, is a local flagship project of the eThekwini Conservancies Forum (managed through the Kloof Conservancy) that spearheads river restoration in eThekwini Municipality through building local agencies for monitoring activities and community-based rehabilitation interventions (Martel et al. 2022). However, the focus is increasingly on establishing governance frameworks and building local community capacity for rehabilitation compared to documented active river restoration efforts and technical upskilling for scale and expertise (various pers. comm.).

Table 1.1: Summary of peer-reviewed articles documenting ecological restoration work involving river ecosystems in South Africa.

River or stream	**Assessment used**	**Reference**
Various rivers in Durban	Analysis of the 'governmentality' through capacity development processes within three river rehabilitation projects in Durban, South Africa	Martel et al. 2022
Various Western Cape rivers	Review of an 8-year-old restoration project on the effectiveness of sowing a mixture of seeds in restoring riparian vegetation. Two active replanting techniques were compared, i.e. direct seeding and the transplanting of seeds.	Ruwanza et al. 2013
Kromme River System	Land-use mapping (aerial photography) for an ecological and hydrological evaluation of the effects of restoration on ecosystem services in the Kromme River System, South Africa.	Rebelo 2012

Restoration of the veld and hydrogeology in the Nama Karoo, Beaufort West	Effect of *Prosopis* removal by a Working for Water team on the water table was investigated.	Blignaut et al. 2010.
Upper Tsitsa River Catchment	Planned restoration work: biophysical monitoring surveys in progress on- rivers, soils, vegetation, flood peak cycles, erosion	Huchzermeyer et al. 2019 (unpublished/non-peer-reviewed funder's report)

In the KwaZulu-Natal Province, the 'Take Back Our Rivers' initiative is a local flagship of the eThekwini Conservancies Forum (managed through the Kloof Conservancy) that spearheads river restoration in eThekwin, through building local agency for monitoring activities and community-based rehabilitation interventions (Martel et al. 2022).

Furthermore, Rebelo (2012) noted that although some progress has been made regarding freshwater restoration work in South Africa, it is still lacking in some aspects. Restoration benefits are still not monitored and captured accordingly across all existing restoration projects (Blignaut et al. 2010). As a result, instream restoration is typically driven by a "trial and error" approach since lessons from previous restoration projects are not documented because of a lack of effective monitoring (Rebelo 2012). Recommendations for restoration of the Nama Karoo hydrogeology included the need to reseed areas with palatable plants following removal of alien plants (specifically *Prosopis* spp.) (Blignaut et al. 2010). Another interesting lesson is that grazers should be excluded from the treated site for establishing palatable plants (Blignaut et al. 2010).

In addition, continuous threats to riparian ecosystem habitats and biodiversity, in particular, make the process of riparian ecosystem restoration even more challenging (Huchzermeyer et al. 2019; Burnett et al. 2021). Nevertheless, multiple examples of South

African freshwater restoration projects in progress were showcased at the 2019 Society for Ecological Restoration Conference in Cape Town. Ideally, all this steady work by the growing South African ecological restoration practice will contribute towards the UN Decade of Ecological Restoration targets.

For most restoration projects, success hinges on the efficiency of conservation action, cost-effectiveness, and user-friendliness of techniques (Simaika and Samways 2009; Pander and Geist 2013; Blachuta et al.2014). The recent Society for Ecological Restoration Conference held in Cape Town in 2019 showcased local projects that had achieved many of these successes.

1.1.6 Indicators of riparian ecosystem integrity

Aquatic communities can provide a holistic and integrated measure of the integrity or health of the river (Pander and Geist 2013; Agboola et al. 2019). Furthermore, the benefits of using bio-indication to assess freshwater ecosystem health following restoration stem from using rapid, cost-effective, easy-to-use, and effective monitoring techniques (Feld et al. 2009). Bio-indication is advantageous because it allows for short to long-term monitoring of ecological integrity, particularly where financial resources are the constraint (Feld et al. 2009; Boonsong et al. 2010).

Biological indicators are organisms whose responses to changing ecosystem conditions can be used to infer the ecological integrity of those ecosystems in which they thrive (Pander and Geist 2013; Blachuta et al. 2014). Mortality and survival rates are ways with which indicator organisms indicate the impact of environmental pressures (Feld et al. 2009; Pander and Geist 2013). However, the response within the same biological community can vary by taxonomic group and habitat (Barbour et al. 2010; Pander and Geist 2013). A suite of physiological, morphological and behavioural factors determine how an organism responds to its environment (Blachuta et al. 2014; Ruaro et al. 2016). It is imperative that the indicator organism is confined to a narrow ecological range, responds rapidly to environmental changes and is widely distributed and easy to sample (Graham et al. 2014; Ruaro et al. 2016; Desai et al. 2021). Macroinvertebrates, fish, algae and macrophytes fit into the bioindication criteria and are presently used worldwide as bioindicators for aquatic ecosystems (Barbour et al. 2010; Ruaro et al. 2016; Burnett et al. 2021).

Two ecological health assessments are generally used in South African rivers (Kleynhans 1996; Graham et al. 2004; Van Rensburg et al. 2012). Firstly, the Mini Stream Assessment Scoring System (MiniSASS), which is a simplified biological sampling method derived from the Stream Assessment Scoring System (SASS) and uses aquatic macroinvertebrates to indicate river health based on the sensitivity of invertebrates, especially to water pollution (Graham et al. 2004). Macroinvertebrates are most sensitive to eutrophication, primarily through oxygen depletion in the water (Feld et al. 2009; Blachuta et al. 2014). Taxa most sensitive to pollution include *Plecoptera* spp.*,* *Ephemeroptera* spp. and *Trichoptera* spp. (Blachuta et al. 2014; Agboola et al. 2019). These taxa tend to be intolerant to reduced levels of dissolved oxygen and thus indicate a good ecological status of any river site (Graham et al. 2004; Blachuta et al. 2014). Gastropoda and Diptera are examples of taxa that are more tolerant of low dissolved oxygen levels and commonly adapted to polluted water. Therefore, these groups often indicate the poor ecological status of a river (Blachuta et al. 2014; Agboola et al. 2019).

Secondly, the Index of Habitat Integrity, an indicator of the overall condition of the physical habitat, including the riparian and instream areas as developed by Kleynhans (1996), is used. The Index of Habitat Integrity indicates how well a particular ecosystem's diverse components function and thus indicates habitat quality, which accounts for an overall ecosystem health condition (Kleynhans 1996; 2008; Van Rensburg et al. 2012).

Amis et al. (2007) described ecological integrity as the ability of an ecosystem to support a balanced biological community with functionality, structural diversity, and species composition similar to that of natural habitats within the same region. This study adopts their definition of ecological integrity or river systems' health and physical habitat integrity.

1.2 Ecosystem vulnerability to climate change

Ecosystems are increasingly becoming vulnerable to the impacts of climate change (Barbour et al. 2010; Nalau et al. 2018; Reid et al. 2018; Richerzhagen et al. 2019). This vulnerability manifests in how ecosystems function, resulting in their compromised ability to render ecosystem services (DEA and SANBI 2016; Reid et al. 2018; Richerzhagen et al. 2019). Furthermore, findings by Barbour et al. (2010) showed a link between an ecosystem's recovery from past stressors and its responses to climate change impacts.

Notably, ecosystem structure and function conservation and restoration are at the core of ecosystem-based approaches (Reid et al. 2018). Robust ecosystems sustain ecosystem services and are more resilient to climate change impacts (DEA and SANBI 2016; Nalau et al. 2018; Richerzhagen et al. 2019). Ecosystem-based approaches address the crucial links between climate change, biodiversity, and sustainable resource management, whereby societies are enabled to adapt better and gain more resilience to the effects of climate change (Munang et al. 2013; DEA and SANBI 2016).

1.2.1 Ecosystem-based adaption in Durban

The role of ecosystem-based approaches in climate change adaptation strategies for urban areas is advocated worldwide (Roberts et al. 2012; Nalau et al. 2018; Reid et al. 2018; Richerzhagen et al. 2021). However, despite the increasing popularity of the implementation of ecosystem-based approaches interventions worldwide, the full quantification and evidence of its environmental and socio-economic benefits in practical contexts are still in gradual progress (Nalau et al. 2018; Richerzhagen et al. 2021).

Similarly to many cities worldwide, with first-hand experience of disastrous climate-related impacts, the city of Durban is bolstering its climate adaptation strategy through ecosystem-based approaches' benefits (Roberts and O'Donoghue 2013). Yet, ecosystem-based approaches benefits take time to accrue, and it is still early days for Durban (Laros et al. 2013; Douwes et al. 2015), especially with heavy floods continuing to dismantle existing adaptation efforts. After experiencing the aftermath of recent floods, particularly those experienced in 2022, there is hope that eThekwini Municipality understands the urgent need to build long-term resilience against climate change for the local economy and communities to thrive.

Many socio-political and economic factors hamper local government efforts to adapt to climate change (Roberts and O'Donoghue 2013). However, Roberts et al. (2012) highlighted the degradation or damage of ecological (green) infrastructure as the main culprit. Ecological infrastructure consists of natural ecosystems such as forests, rivers, grasslands and wetlands (Roberts et al. 2012; DEA and SANBI 2016). However, little action has been taken to revitalise and maintain the built (grey) infrastructure, such as sewer systems, stormwater drains, and roads (Roberts et al. 2012). The supposition is that ecosystem-based approaches fundamentally support community-ecosystem-based adaptation models, and it is common for ecosystem-based approach initiatives to be led by local communities (Nalau et al. 2018).

1.2.2 Need for community-based ecosystem adaption

Using the community-ecosystem-based adaptation model (eThekweni Municipality 2020; Douwes et al. 2015a) to address climate change, the eThekwini Municipality's Environmental Planning and Climate Protection Department initiated a Community Reforestation Programme primarily aimed to offset CO_2 emissions following the 2010 Fifa World Cup, which was hosted by the city of Durban (Roberts and O'Donoghue 2013; Douwes et al. 2015a). The method used restorative planting of indigenous forests to sequester carbon and improve the quality of ecosystem services in selected areas (Roberts et al. 2012; Douwes et al. 2017). Positive spin-offs resulted from the recruitment of vulnerable groups (unemployed women, children, and pensioners) as "Treepreneurs" (Wildlands Conservation Trust 2011; eThekweni Municipality 2020). Hence, "the community-ecosystem based adaptation model demonstrated the strong and vital link between socio-economic upliftment and biodiversity conservation, enhanced ecosystem functioning and carbon sequestration" (Douwes et al. 2015b; eThekweni Municipality 2020).

1.3 Community reforestation programmes

Three community-ecosystem-based adaptation projects were prioritised for the implementation of reforestation activities by the eThekwini Municipality (Douwes et al. 2015a; 2015b). These projects were the Buffelsdraai Landfill Site Community Reforestation Project, the Inanda Mountain Ecosystem Services Areas Project (Dosskey et al. 2010), and the Umbilo River Catchment Project (Laros et al. 2013). This study focused on the Buffelsdraai Landfill Site Community Reforestation Project and the Umbilo River Catchment Project.

1.3.1 Buffelsdraai Landfill Site Community Reforestation Project

In 2008, the eThekwini Municipality, in partnership with Wild Trust and Durban Solid Waste (DSW), embarked on a reforestation initiative called the Buffelsdraai Landfill Site Community Reforestation Project (BLSCRP) (Wildlands Conservation Trust 2011). The objective of the rehabilitation of this site was to plant indigenous trees to achieve an indigenous forest ~400 ha surrounding the Buffelsdraai Landfill Site (Douwes et al. 2015a; eThekweni Municipality 2020). According to Douwes et al. (2015a), many parts of the catchment and the land adjoining the wetland were planted with trees. An average of 200 trees per hectare was planted in riparian areas by January 2015 (Douwes et al. 2015a).

The sought-after restoration goals were to enhance carbon sequestration and other ecosystem services that directly benefit the environment, the Buffelsdraai Landfill Site and surrounding communities (Wildlands Conservation Trust 2011; Douwes et al. 2015a). Examples of such anticipated ecosystem services are improved instream water quality from sites restored in the river catchment (Wildlands Conservation Trust 2011). However, because of the disturbance of the landscape resulting from previous sugarcane (*Saccharum officinarum*) cultivation, encroachment of invasive alien plants, specifically *Chromolaena odorata* and *Lantana camara*, was extensive (Wildlands Conservation Trust 2011; Laros et al.2013). As such, the majority of the shrub-like vegetation signatures on satellite imagery were attributed to the presence of either of these invasive species (Douwes et al.2015a). Further research into the benefits of this programme, such as flood mitigation, erosion control flow regulation, and fire-risk reduction, is still underway.

1.3.2 UMbilo River Catchment Project

The uMbilo Community Reforestation Project encompasses uMbilo River Catchment in the Paradise Valley area, eThekwini Municipality (Wildlands Conservation Trust 2011). The uMbilo River catchment is one of the largest catchments in the region after the uMngeni catchment. Hence, the catchment is an important part of the local and national economy since it provides relatively large amounts of water to certain areas of Durban, particularly into Durban Bay (Douwes et al. 2015b). In addition, the uMbilo River catchment is included in Durban's community ecosystem-based adaptation strategy and the city's conservation plans (Wildlands Conservation Trust 2011; Laros et al. 2013).

One of the key objectives of the uMbilo River Project was the delineation and restoration of Paradise Valley and Roosfontein Ecosystem Services Area (Wildlands Conservation Trust 2011; eThekweni Municipality 2020). Another key objective was to initiate restoration activities on the uMbilo River catchment. The restoration activities initiated on the uMbilo River Catchment included restorative planting following the clearing of alien invasive plants. Working for Ecosystems has been working on this site, clearing alien invasive plants since 2011 (Wildlands Conservation Trust 2011).

The restoration of the uMbilo River and its catchment area aims to improve ecosystem health and the ability to render ecosystem services such as water quality and water supply (Sanpath 2012). For example, the removal of alien vegetation in the Paradise Valley area aimed to restore diverse ecosystems affected, such as the river, grassland and wetland systems (Sanpath 2012; Laros 2013). A vast area at Paradise Valley has already been cleared of alien invasive plants in the hope that river species diversity would increase, particularly the diversity of fish species breeding in the river (Sanpath 2012).

1.4 Aims and objectives

The eThekwini Municipality restoration projects in Buffelsdraai and Paradise Valley attempted to create indigenous forests and offset carbon dioxide whilst conserving biodiversity, promoting protection and improving ecosystem functions (Roberts et al. 2012; Douwes et al. 2015). In addition, it was envisaged that clearing the catchments infested with alien invasive plants would restore ecosystem functionality (Douwes et al. 2015b). Consequently, in the present study, the measuring and monitoring of what impacts different interventions had on the ability of the riparian habitat to render ecosystem services were assessed. The overall aim of the present study was to assess the ecological state (in-stream biological water quality) and the impact of land restoration on the habitat integrity of three different rivers in the eThekwini

Municipal area. In particular, the impact of land-use change, namely reforestation, on the ability of a river system to restore itself was assessed. It was assumed that there would be an improved understanding of how the riparian ecosystem condition impacts other ecosystem components, such as the aquatic invertebrate community. The biological water quality was measured using MiniSASS and riparian habitat condition-based indices were used as response measures of reforestation impact on the river systems.

1.5 Structure of the thesis

The main body of this thesis is organised as manuscripts prepared for publication in peer-reviewed journal articles. The chapters are formatted according to the journal to which they are intended to be submitted. As a consequence of the thesis format, a certain degree of repetition, especially in the methods section, was unavoidable. The first chapter (Chapter 1) is an introduction, which provides the introduction and general literature review of the concepts covered in this study. Chapter 2 is a systematic review that contextualises the topic in South Africa relative to the world. Chapter 2 frames the problem broadly and outlines some recommendations for the next focus areas in local river restoration research and implementation. Chapter 3 is an experimental chapter with two study objectives. In Chapter 3, Objective 1 investigated biological water quality assessment using MiniSASS. Objective 2 of Chapter 3 investigated the overall ecological condition of sites using the Index of Habitat Integrity field assessment technique. The last chapter (Chapter 4) is a concluding chapter that provides general conclusions and recommendations for the overall study.

1.6 References

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CHAPTER 2

Systematic review and assessment of river restoration research globally and especially in South Africa to contextualise reforestation and river restoration in eThekwini Municipality, KwaZulu-Natal, South Africa

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Running header: Systematic review and assessment of river restoration research

2.1 Abstract

The ability of an aquatic ecosystem habitat to respond to river restoration effects is particularly useful for monitoring restoration progress and long-term ecosystem change. River restoration has advanced from its experimental phase into a mainstream environmental management practice globally. This systematic review aimed to investigate the trends in the documentation of river restoration work, focusing on Africa, particularly South Africa, compared with the rest of the world. Using the PRISMA 2020 process, we particularly focussed on studies of the macroinvertebrate response to reforestation impacts and assessment of riparian habitat conditions following reforestation. The findings revealed a lag phase in the publication of river restoration interventions in the southern hemisphere, with most publications coming from the northern hemisphere, especially Europe and North America. South Africa has the highest number of river restoration records in Africa, but despite knowledge of increasing implementation, there was limited reported research. Furthermore, few of the records found were related to either macroinvertebrate response to reforestation impacts or assessment of riparian habitat conditions following reforestation, which we focused on. Monitoring macroinvertebrate composition and habitat integrity improvement guides efforts towards water quality improvement, sustaining river health and overall ecosystem restoration over time. Other studies showed no statistically significant differences in macroinvertebrate communities exposed to river restoration effects. This can also be attributed to the time expected for macroinvertebrate species recovery in response to river restoration, which is generally long.

Keywords: ecosystem integrity; river restoration; freshwater; biological assessment, habitat condition assessment, reforestation

2.2 Introduction

The literature claims that restoration is a relatively new practice and that river restoration is in its emergence (Jahnig et al. 2011). Yet, some authors argue that river restoration has matured exponentially as a practice over the past decades (Bernhardt et al. 2011; Pander and Geist 2011; Smith et al. 2014; Wohl et al.2015). According to Pander and Geist (2011), river restoration as a practice has seen an immense application over approximately 40 years in the environmental management sector and is likely to influence future policy decisions. Furthermore, recent literature maintains that river restoration is an expanding practice of environmental management globally, particularly concerning the urban context (Griffiths and MacManus 2020; Adonis 2021; Feio et al. 2021; Diep et al. 2022). As restoration has advanced from its experimental phase into a mainstream practice (Kondolf 2006; Eden and Tunstall 2006; Moore and Rutherford 2017), researchers and practitioners should take stock of what works and what needs improvement (Lyu et al. 2020; Marchand et al. 2021).

We conducted this systematic review to explore the trends in the documentation of river restoration work in Africa further compared with the rest of the world. The growth trajectory of river restoration work in South Africa was of interest. Our objectives were 1) to determine how the availability of literature on river restoration work conducted in Africa compared with the rest of the world, and 2) to document the ecological restoration work involving rivers in South Africa (Supplementary information Table S2.1). We particularly focussed on studies of the macroinvertebrate response to reforestation impacts and assessment of riparian habitat conditions following reforestation.

Overall, we sought to understand what river restoration research has been conducted in South Africa, the river restoration publications to date, and to discuss some of the emerging themes aligned with our study objectives. Ultimately, we sought ways to improve the documentation of research work on river restoration in the future, especially in relation to contributions to the UN Decade of Restoration. Our analyses were based on a review of recorded river restoration work (grey and peer-reviewed journal articles) from across the globe over time. Ultimately, this study highlighted the publications made on river restoration in South Africa to date.

2.3 Methods

2.3.1 Data collection

This systematic review was conducted through a series of steps aligned with the PRISMA 2020 method checklist for systematic reviews as outlined in McKenzie et al. (2021). The first step of the review was to state the research objectives, and for each objective, a corresponding research question was formulated (Supplementary information Table S2.1). The research questions assisted in dissecting the topic further and refining the eligibility criteria for studies to be selected.

As a point of departure, we compiled a list of key search words for use during the literature search to address the main study objectives. We drafted the list and had it verified by fellow researchers. The keywords articulated what topics should be included and those to be excluded from the review. "River restoration" was the main phrase used.

We performed the search using Publish or Perish, an automated search tool. We opted for Publish or Perish as a platform to search for and sort the literature. One advantage of Publish or Perish is that it auto-downloads bulk references simultaneously. It then presents the records in spreadsheet format, as shown in Supplementary Information Figure S2.1, from which we could sort and undertake analyses.

In addition to the database and registers obtained using the Publish or Perish tool, we collated all relevant pre-existing literature to the study. These included academic and grey literature sources previously used in our research or those recommended by colleagues.

Examples of grey literature sources included municipal reports, conference papers and presentations.

To define the eligibility criteria for which studies to include in the final review, we adopted the approach outlined in PRISMA 2020 (McKenzie et al. 2021). PRISMA provides a guideline for the process of reporting new systematic reviews in three key steps, namely 1) identification, 2) screening, and 3) included literature. For this study, the process was executed in steps summarised in Fig. 2.1., which provides an overview of the methods used to collect the records, from initiating the search to narrowing the article sample size for analysis. As part of the screening process, language and access were important variables. We also considered the freshwater ecosystem type, study area and relevance of article critical. All research publications (regardless of whether grey literature or peer-reviewed journal articles) were included on the basis that a) they were written in English and b) sources were accessible in PDF (full-text) for download. In Step 4 'Studies included' (Fig. 2.1), it was important to note that key data variables used to collect the data (from abstract summaries) were those addressing the research objectives, i.e. all studies about macroinvertebrate response to river restoration efforts, or improvement of habitat condition as a response to river restoration interventions were included.

The region in which the study was conducted was also important. African studies on river restoration were limited in number but took priority. These were followed by studies from a "new region" that were not from the typically dominant North American or European countries and were thus included to provide a different perspective. However, most of the publications were from the northern hemisphere, and articles covered other topics on river restoration that were not directly linked to the study objectives but provided useful information to include. Lastly, the asterisk next to the selection criteria indicated that a particular parameter was likely subjective, regardless of how much we avoided the risk of bias (Fig. 2.1).

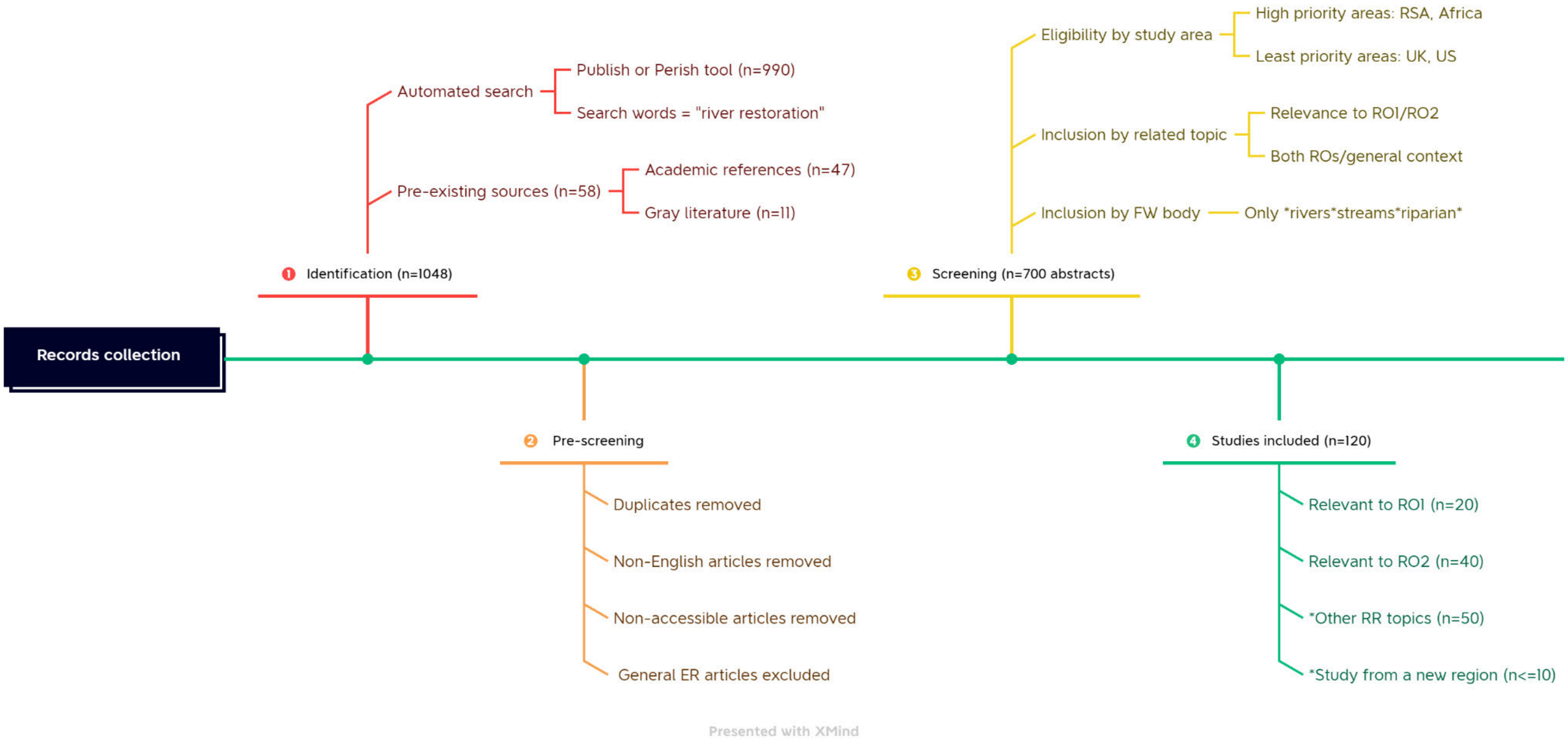

Figure 2.1: The literature sorting process from identification of records to the inclusion of relevant studies.

2.3.2 Data analyses

A total of 990 records resulted from the initial search using Publish or Perish. An additional 58 articles were from the researcher's own collection' were making the total identified records 1048. After screening records (n = 700), an analysis of the included literature (n = 120) followed. We created a spreadsheet in Microsoft Excel© summarising each record. It included the type of article (A for academic, NA for grey), author details, key points from the abstract, alignment of objectives to study objectives, year published and region published from. To aid in fast-tracking this process, we used the 'FIND' advanced find and 'COUNTIF' Excel© functions to filter records. At the screening stage, we verified sources through a manual online search for unclear/missing elements to fill gaps in data that were considered for inclusion. Initially, we assumed that all datasets would be completed using Publish or Perish. In contrast, this assumption deviated from reality in that some columns were missing data, e.g., the publication date, or the hyperlink to the article was not working. We assessed the risk of bias by having a large sample size (number of records) before screening the sources for relevance. Also, we followed a thorough process to establish the criteria for which studies to include.

Working with a large dataset can make it difficult to decide on which studies to include. However, using a credible organising tool, such as PRISMA, helped streamline records. Pre-existing records in the researchers' collection were manually integrated into the systematic review list post-analysis/ outside of Publish or Perish database/dataset. All these references were selected based on two criteria: relevance and publication time. The criteria used here were relevance to the study objectives and condition that the articles were recently published or added elements of novelty to the study. Before analysis, the integrated list of articles (pre-existing and automated) was cleaned for duplicates in Excel.

We used descriptive statistics to summarise trends. We made reference to methods used by other researchers and selected suitable ones based on the quality of the data available and its ability to address the study objectives. For example, we used a visual map to illustrate the distribution of publications on river restoration projects globally. We collected region-specific data to compare over time across research topics for two specific objectives in this study.

2.4 Results and Discussion

2.4.1 Global trends

We found most publications were from the northern hemisphere, especially Europe and North America (Fig. 2.2 and Fig. 2.3). South Africa had the highest number of river restoration records in Africa, but despite knowledge of increasing implementation, there was limited reported research (Fig. 2.2 and Fig. 2.3). Furthermore, none of the records found were related to the two study objectives we focused on. The findings revealed a lag phase in the publication of river restoration interventions in the southern hemisphere.

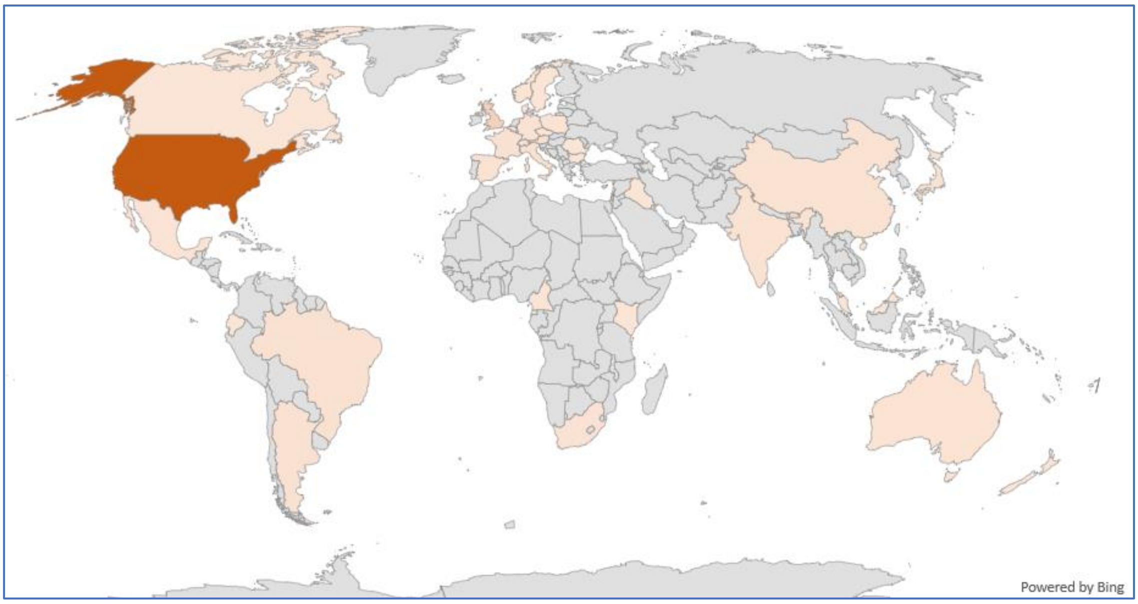

Figure 2.2: River restoration records found in the present study according to country. (Note: n = 700; found by region (dark brown > 500 records; light pink = 1-499 records; blue = 0 records).

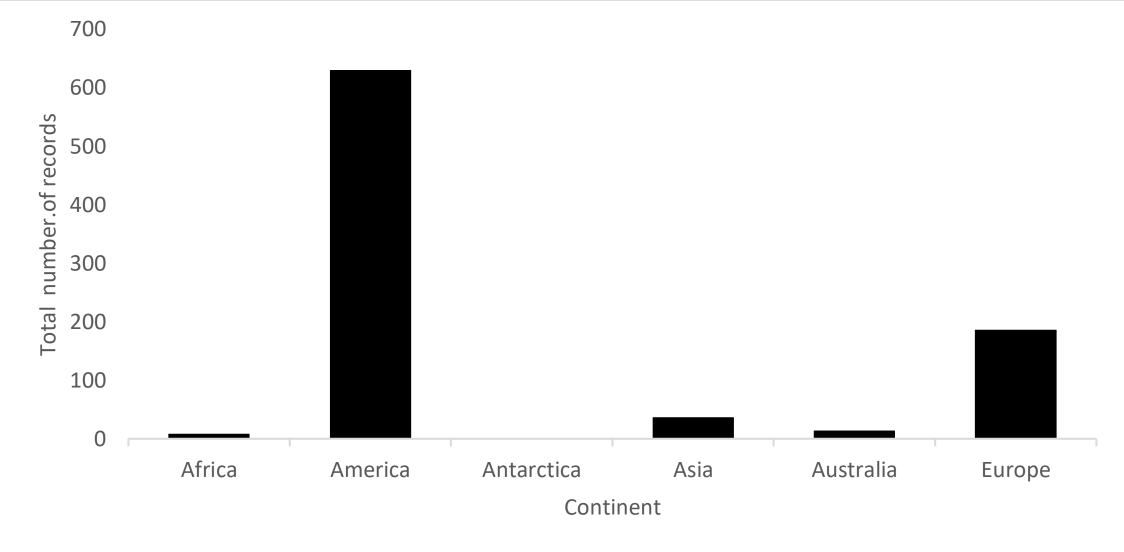

Figure 2.3: Overview of river restoration records (total numbers) published/available from across the world (earliest to date) based on Publish or Perish results.

2.4.2 Emerging themes

It was evident that the bulk of river restoration publications were from countries in the northern hemisphere (Fig. 2.2 and Fig. 2.3). To corroborate these results, a plethora of literature maintains that river restoration is becoming increasingly important in North America and Europe as shown by the increase in publications from 1984 to 2023 (Fig. 3.4) (Clarke et al. 2003; Kondolf 2006; Buchanan et al. 2012; Gilvear et al. 2012; Friberg et al. 2014; Moore and Rutherford 2017). Nevertheless, this does not nullify the contributions made to river restoration by countries in the southern hemisphere. South America, Australia and Asia have made notable contributions to the practice (Fig. 2.2 and Fig. 2.3) (Brooks et al. 2007; Zhang et al. 2022). Although Africa is still lagging in river restoration (Richardson et al. 2007; Blignaut et al. 2010; Wildlands Conservation Trust 2011) implementation, South Africa is among the countries recognised for successful river restoration projects alongside Brazil and Peru (Feio et al. 2021). The scale and rate at which river restoration (Blignaut et al. 2010; Moyo et al. 2021) and general ecosystem restoration projects (Nsikani et al. 2023) are implemented in Africa are rather fragmented. This patchy pattern is not unique to Africa, as Fig. 2.2 illustrates. However, Africa had the least records documenting river restoration work, excluding Antarctica, which has none (Fig. 2.3).

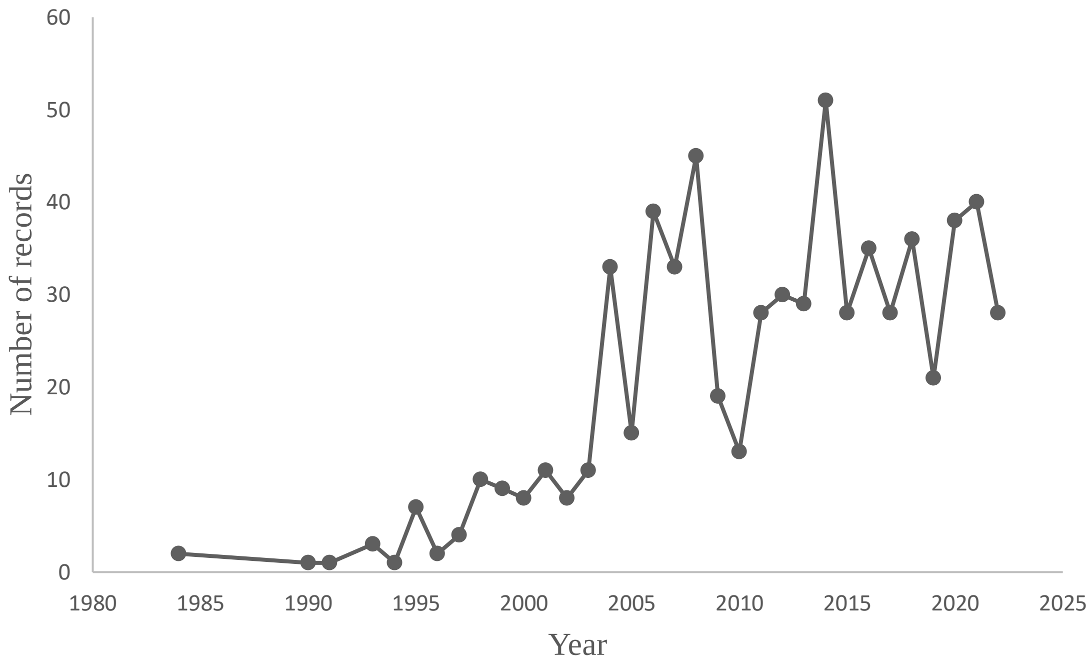

Figure 2.4: Number of international articles published yearly from 1984 to 2023 focusing on river restoration. Articles were mainly obtained using the Publish or Perish tool, which (mined data from) automated a search through Google Scholar in databases such as Wiley Online Library, Elsevier, science.org, JSTOR, Springer, etc.

The global north not only started implementing more river restoration earlier (Goodwin et al. 1997; Kaufmann et al. 1997), but also documented more of their restoration efforts over time in comparison to their southern counterparts (Kondolf 1998; Feld et al. 2011; Jahnig et al. 2011; Griffith and McManus 2020). For the global south, there was likely a lag phase between the implementation and publication of river restoration interventions. Numerous reasons are validated for this lag phase (Viswanathan and Schirmer 2015; Feio et al. 2021). For example, South Africa is notorious for its flagship rehabilitation programme, Working for Water, which clears Invasive Alien Plants in freshwater ecosystems. For most clearing projects, documenting the processes started much later than the implementation (Feio et al. 2021). Furthermore, Fill et al. (2017) investigated the short-term recovery of indigenous vegetation following invasive alien plant clearing. Yet follow-up work on the initial clearing efforts is still not timeously implemented, let alone the work undertaken published.

Following the findings made from the systematic review in this study, international river restoration publications date back to as early as 1984 (Fig. 2.4). As expected, the northern regions leading restoration work to date have been the most developed in Europe and North America (Kauffmann 1997; Eubanks 2004; Gilvear et al. 2012; Lorenz and Feld 2013).

Feio et al. (2021) referred to river rehabilitation in Africa, except for South Africa, as "almost non-existent". In Africa, South Africa had the highest number of records (Fig. 2.2 and Fig. 2.3). In East Africa, one record was found in Kenya, while one record was found in West Africa (Cameroon) (Scholte 2006). Moreover, both records are unrelated to either of the objectives of the present study.

It is a harsh reality that a continent as vast as Africa has a dearth of publications focusing on river restoration, especially given the deteriorating state of freshwater resources in many African countries. According to Feio et al. (2021), implementation of river restoration work will continue to be challenging for many African countries, including South Africa, should limiting factors stay unaddressed. Such limiting factors include a lack of enforcement and compliance monitoring, non-penalisation of polluters, and a lack of coordinated rehabilitation efforts (Moyo et al. 2021). Presumably, finance is also a limiting issue in developing countries. Much of the government's funding may be diverted to other 'priorities'.

Furthermore, it is evident from the literature that European and North American projects have diverse themes and cover multiple topics on river restoration work (Johnson et al. 2020). Examples include those indicating where successes have been found, identifying opportunities for scaling river restoration work and cost-benefit analyses on some projects (Bernhardt et al. 2007; Katz et al. 2007; Muhar et al. 2016). These examples address some of the key challenges river restoration agencies, and practitioners encounter in working towards improving the practice worldwide (Pander and Geist 2013). Despite trailblazing an array of river restoration interventions, challenges similar to those encountered by underdeveloped/developing countries are still imminent in European and American countries (Lorenz and Feld 2013; Lyu et al. 2020; Feio et al. 2021). Moore and Rutherford (2017) cite the lack of maintenance as a challenge, which is also common in South African projects. One example involves issues about the piece-meal approach with which river restoration projects are implemented, posing pertinent questions on how temporal and spatial scaling can be affected to optimise the impact of future river restoration work (Palmer and Bernhardt 2006; 2011).

It was encouraging that South Africa's flagship programme in river restoration, Working for Water, was recognised as a successful programme internationally (Feio et al. 2021). Nationwide efforts to clear invasive alien plants in South African catchments were coordinated and boldly showcased the importance of a coordinated effort in tackling restoration and targeted investment over time, amongst other success factors (Woolsey et al. 2007; Rafferty et al. 2019). Furthermore, albeit with opportunities to improve, the benefits of the now almost 30-year-old program are being documented (Feio et al. 2021), as well as the lessons learned for best practice (Ruwanza et al. 2013).

2.4.3 Macroinvertebrate response time

Benthic macroinvertebrate communities have long been used as biological indicators in monitoring projects worldwide, particularly in river restoration (Barbour et al. 1999; Dudgeon et al. 2005; Funnel 2019; Chen et al. 2022). Despite the growth in records and geographical distribution of such studies, there are still contrasting findings on how macroinvertebrate communities respond to river restoration efforts (Sundermann et al. 2011; Haase et al. 2013; Al-Zankana et al. 2020; Griffith and MacManus 2020; Chen et al. 2022).

Griffiths and MacManus (2020) observed that various biomonitoring studies showed no statistically significant differences in macroinvertebrate communities exposed to river restoration effects. However, other authors argue that the level of ecosystem disturbance shapes macroinvertebrate responses and that the time required to observe the slightest changes in macroinvertebrate community composition can be relatively long (Verdonschot et al. 2015). According to Bernhardt et al. (2011), the expected time for macroinvertebrate species recovery in response to river restoration is generally long. Observations made through different projects show that in North Carolina, for example, river restoration had no demonstrable effect even after years of restoration implementation (Bernhardt et al. 2011). Both habitat diversity and macroinvertebrate communities barely changed after restoration (Bernhardt et al. 2011).

Wohl et al. (2015) and Leps et al. (2011) also emphasised that some restoration projects do not result in positive macroinvertebrate community responses. Similarly, records from Germany showed no measurable improvement in macroinvertebrate composition, except for streams found near intact forested catchments (Bernhardt et al. 2011). The interesting intervention in our study is reforestation, which will likely affect the aquatic fauna similarly to some of the European rivers studied by Bernhardt et al. (2011).

Bernhardt et al. (2011) argued that restored streams are found in less improved ecological conditions in some cases than non-restored sites. For example, urban restored streams in North Carolina had significantly higher temperatures than their unrestored urban streams/counterparts (Bernhardt et al. 2011). This rise in temperatures was attributed to the absence of shade from riparian trees in the restored sites, which were removed for restoration (Bernhardt et al. 2011). Furthermore, despite 15 years of river restoration in several streams in Finland, macroinvertebrates were largely depauperate compared with unrestored reaches on upstream river sites (Bernhardt et al. 2011).

It is encouraging that there are studies following restoration impacts on macroinvertebrate responses (Pilotto et al. 2013; Kupilas et al. 2015; White et al. 2017). Different restoration outcomes have been reported in other regions, such as Germany (Haase et al. 2004), China (Li et al. 2018; Zhang et al. 2022) and New Zealand (Funnel 2019), which are plausible. Nonetheless, cases of short-term recovery of macroinvertebrates are scant, especially in urban settings (Sundermann et al. 2013; Khumalo et al. 2021; Zhang et al. 2022).

A recent study on macroinvertebrate recovery after flash floods was conducted by Khumalo et al. (2021) in the Palmiet River in Durban. This local example showed that aquatic invertebrates can take as little as 3 to 7 months to start recovery following a flash flood. Full recovery can range between a year to three years, depending on site-specific conditions such as habitat integrity and surviving individuals. This study is interesting, relevant, and applicable to the present study since it can be used to monitor macroinvertebrate assemblages when restoring degraded urban streams (Khumalo et al. 2021).

Secondly, Khumalo et al. (2021) drive the case that habitat integrity is integral to macroinvertebrates' species diversity and composition, as per the rationale within which our present study was conducted. Consequently, the next section seeks to synthesise literature trends addressing research objective 2, which focuses on improving habitat conditions following river restoration.

2.4.4 Habitat integrity improvement

The importance of naturally functioning riparian ecosystems cannot be emphasised enough (Arthington et al. 2009). Good riparian and instream habitat conditions are fundamental to thriving aquatic biodiversity (Lorenz and Feld 2013). Land use as a function of habitat integrity is an important indicator of any ecological impact (Moore and Rutherford 2017). This can have a negative or positive impact, which can be traced to any land use disturbance or restoration activity. The ability of an aquatic ecosystem habitat to respond to river restoration effects is particularly useful for gauging restoration progress and for monitoring long-term ecosystem change.

2.4.5 Recommendations

To fully understand the impacts of river restoration interventions in South Africa, there needs to be a concerted effort to streamline the process of initiating, implementing and evaluating such projects. The step-wise approach that all effective restoration efforts should have is illustrated in Fig. 2.5. Four thematic areas are fundamental to the process (Fig. 2.5). The monitoring and review stage is largely where restoration research work is publicised, which is a dire need in our ongoing restoration work in South Africa and the African context.

According to the South African Water Research Commission manual (Day et al.2016), the following are focus areas recommended for rehabilitation work in South Africa:

1. Understand the baseline conditions.
2. Plan river restoration projects.
3. Implement river restoration plans.
4. Monitor and review river restoration projects.

In Africa, the implementation of river restoration projects remains a challenge because of a myriad of constraints (Feio et al. 2021). As a result, Goal 6.6 in the Sustainable Developmental Goals highlights the need for the world to address urban river restoration in working towards the United Nations Decade on Ecosystem Restoration (2021-2030) (Adonis 2021).

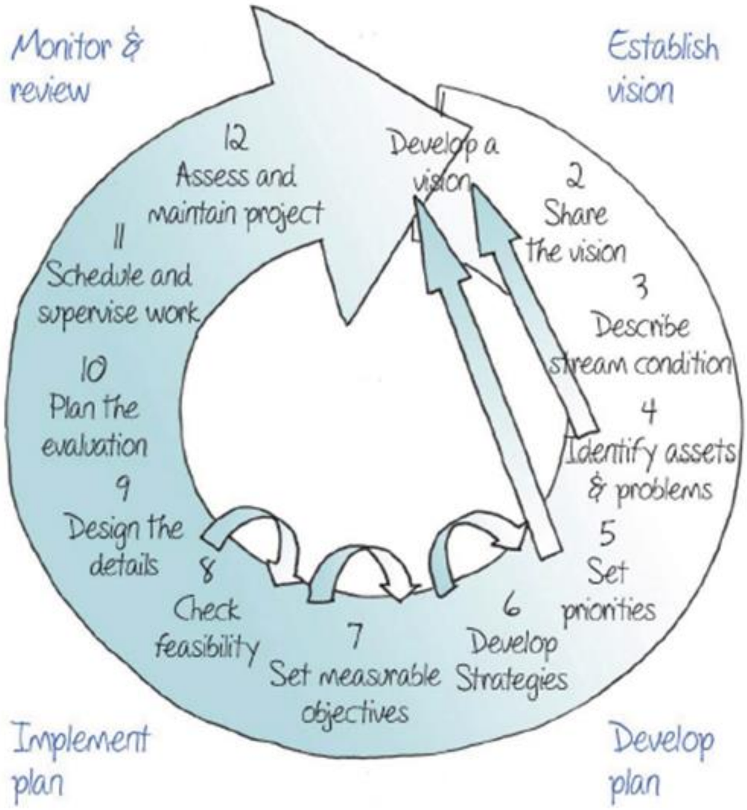

Figure 2.5: The 12-step process for river rehabilitation adapted from Rutherford et al. (2000) in Day et al. (2016).

The lack of effective monitoring of project impact on ecological conditions is particularly concerning (Woolsey et al. 2007; Pander and Geist 2013; Kujanova and Matouskova 2016). Even in developed countries, empirical evaluation of river restoration projects is still lacking, which is attributed largely to the lack of monitoring programs (Bernhardt et al. 2011; Pander and Geist 2013).

Of the few publications focusing on South Africa, most river restoration projects documented are in the Western Cape Province (Ruwanza et al. 2013; Fill et al. 2017; Rafferty et al. 2019; Adonis 2021). For the rest of the country, a few examples of river restoration work are cited (Blignaut et al. 2010). Recent examples are from KwaZulu-Natal (Douwes et al. 2015a; Moyo et al. 2021) and the Eastern Cape, although the latter site is still in the developmental stages of the restoration process (Huchzermeyer et al. 2019). The Durban eThekwini Buffelsdraai Project study is one of the most studied and documented river restoration projects in KwaZulu-Natal (Cirrus Group 2014; Douwes et al. 2015a; 2015b; Mugwedi et al. 2018; Moyo et al. 2021).

It is worth noting that a substantial amount of African research studies on ecological restoration and river restoration (Nsikani et al. 2023), including the eThekwini Buffelsdraai Project, were shared at the 2019 SER Conference in Cape Town, despite the lagging records in terms of the overall number of peer-reviewed articles. This work is captured through internal municipal reports and other grey literature sources, although authors such as Moyo et al. (2021) and Mugwedi et al. (2018) focus on restoration outputs.

Similarly to other parts of the world, in cases where a few of the projects on river restoration are documented, there are still glaring gaps in how cases of success or failure in river restoration are profiled and communicated (Schmidt et al. 1998; Palmer et al. 2005; Woolsey et al. 2007; Roni et al. 2008; Zhang et al. 2022). For South Africa, documentation of river restoration efforts is surpassed by the actual projects implemented on the ground (Downs pers. comm.). The reasons for this challenge emanate from diverse sources, which limited the scope of the present study's exploration.

2.5 Conclusions

A systematic literature review was conducted to understand river restoration research's historical trajectory and present trends. The trend emerging from the systematic analysis conducted in this study is a clear difference in the number of publications related to river restoration made between countries in the northern and southern hemispheres. Altogether, Africa had the least number of records compared with the rest of the world. This implies that there are few published research projects on river restoration in South Africa despite the increasing implementation of restoration projects on the ground. The SER Conference in 2019 provided an international platform for restoration ecology practitioners to showcase their work. Of the shared South African examples, the bulk was mainly unpublished research, either in the pipeline for publishing or pending implementation.

The literature provides no consensus on evidence of restoration impact on macroinvertebrate species composition or habitat function as yet. Addressing objectives one and two is challenging, given the range of ecological disturbances and the scale at which restoration projects are implemented. Chapter 3 of this thesis comprises the experimental work conducted to understand the responses of macroinvertebrate communities and habitat conditions to reforestation efforts undertaken in eThekwini Municipality, South Africa.

Understanding the drivers of macroinvertebrate community structure and habitat integrity is important for integrated catchment management practices (Lyu et al. 2020). Monitoring macroinvertebrate composition and habitat integrity improvement can guide efforts towards improving water quality, sustaining river health and overall ecosystem restoration.

2.6 Acknowledgements

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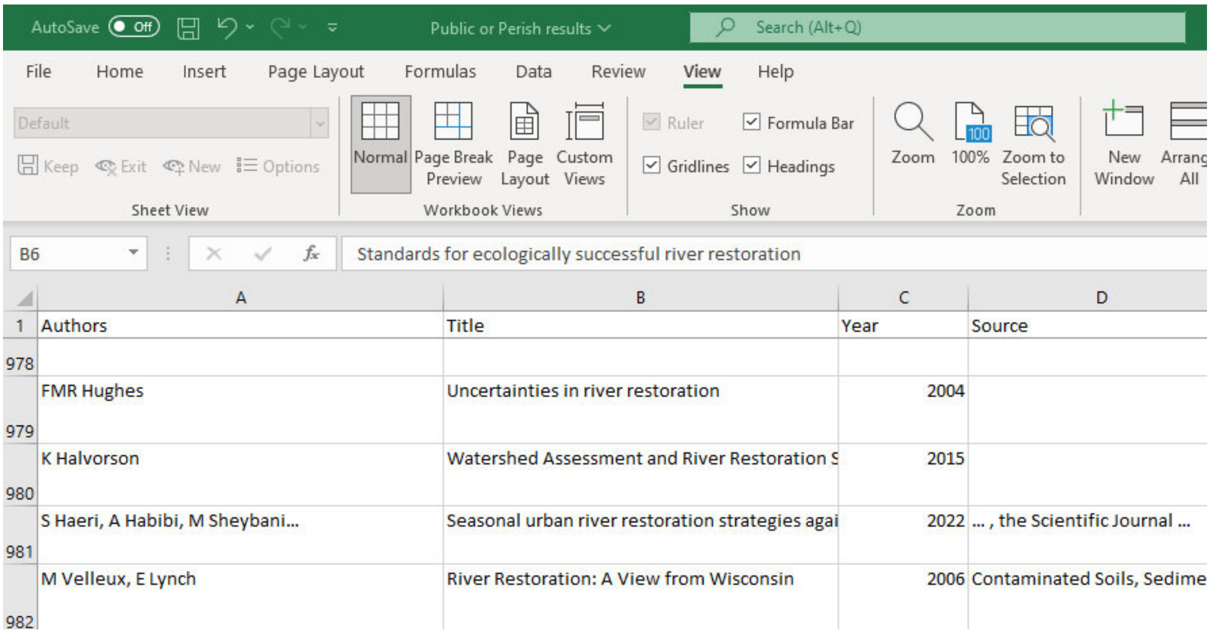
2.8 Supplementary information

Supplementary information Table S2.1: Study objectives and research questions for the systematic review

Research Objectives	**Research Questions**
To document the ecological restoration work involving rivers in South Africa.	How does availability of literature on river restoration work done in Africa compare to the rest of the world?
RO 1: Objective 1 aims to investigate the macroinvertebrate response to reforestation impacts.	RQ1: What publications are available which study macroinvertebrate response to river restoration efforts?
R0 2: Objective 2 seeks to determine improvement in riparian habitat condition following reforestation.	RQ2: What records are available which study the impact of river restoration on riparian ecosystem integrity?



	A	B	C	D
1	Authors	Title	Year	Source
978				
979	FMR Hughes	Uncertainties in river restoration	2004	
980	K Halvorson	Watershed Assessment and River Restoration S	2015	
981	S Haeri, A Habibi, M Sheybani...	Seasonal urban river restoration strategies agai	2022	... , the Scientific Journal ...
982	M Velleux, E Lynch	River Restoration: A View from Wisconsin	2006	Contaminated Soils, Sedime

Supplementary information Figure S2.1: A screenshot image of some of the river restoration publication records (raw data) collected using the Publish or Perish tool.

CHAPTER 3

Effects of land restoration on the habitat integrity of two different rivers in the eThekwini Municipality, Durban, South Africa: Based on biological water quality and habitat condition assessments

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Running header: Biological water quality and habitat condition assessments following reforestation

3.1 Abstract

Naturally functioning riparian ecosystems are natural areas that offer an extensive range of ecosystem services. The degradation of river systems impairs riparian ecosystem health and results in dysfunction, lack of ecosystem services provision and other deleterious effects. The role of these riparian habitats in water quality and the quantity of water available for ecosystem processes, biodiversity, and water users is critical. We investigated the impact of restoring riparian habitats on riparian conditions and stream water quality through reforestation in two sites managed by Durban, eThekwini Municipality, KwaZulu-Natal, South Africa, in 2014. We used the Mini Stream Assessment Scoring System (Mini-SASS) and Index of Habitat Integrity and assessed stream ecological conditions based on macroinvertebrate sampling in reforested sites in comparison to the reference site. Results show a positive correlation between the Index of Habitat Integrity and MiniSASS indices. The sites with greater habitat integrity also had the more pollution-intolerant (sensitive) macroinvertebrate taxa present. Recommendations were made for an extended sampling of macroinvertebrate responses using diatoms, for example, and an extension of spatial scale in terms of habitat integrity assessments in reforested areas.

Keywords: macroinvertebrates, riparian condition, instream habitat, biomonitoring; index of habitat integrity, ecological assessments, river health; reforestation

3.2 Introduction

Understanding the drivers of macroinvertebrate community structure and habitat integrity is important for integrated catchment management practices (Pander and Geist 2013; Heinrich et al. 2014; Agboola et al. 2019; Lyu et al. 2020). Monitoring macroinvertebrate composition and habitat integrity improvement can guide efforts towards water quality improvement, sustaining river health and overall ecosystem restoration over time (Kauffman et al. 1997; Blachuta et al.

2014; Robertson et al. 2021). Habitat integrity is integral to the well-being of macroinvertebrates' diversity and composition (Khumalo et al. 2021).

Based on findings from the systematic review (Chapter 2), the literature provides no consensus on evidence of restoration impact on macroinvertebrate species composition, nor habitat function. In the present study, we conducted experimental work to understand the responses of macroinvertebrate communities and habitat conditions to reforestation efforts undertaken in eThekwini Municipality, KwaZulu-Natal, South Africa.

Effectively implementing river management to improve ecosystem integrity necessitates monitoring different taxa and how they respond to ecosystem disturbances (Chutter 1998; Richardson et al. 2007; Chen et al. 2022; Bellingan et al. 2022). Generally, indicator organisms respond differently to changing environmental conditions (Holt and Miller 2011; Bellingan et al. 2022). Compared with natural streams, urban rivers tend to be neglected regarding their ecological potential to self-purify and support aquatic communities (Lebepe et al. 2021). Using the Palmiet River near Durban as an example, Lebepe et al. (2021) found the Palmiet River to have highly variable habitat types available for invertebrates. A similar observation was made for the water quality (high variable stretches in terms of water quality) based on the macroinvertebrate richness and abundance found in the Palmiet River (Lebepe et al. 2021).

Various factors make aquatic macroinvertebrates ideal indicators for use in biological assessments compared with other aquatic organisms (Dickens and Graham 2002; Ruaro et al. 2016; Bellingan et al. 2022). Firstly, aquatic macroinvertebrates are the primary consumers within the rivers (Bellingan et al. 2022). Secondly, they have rapidly changing life cycles (attuned to seasonality); thirdly, they are largely sedentary lifestyles; and lastly, they are easy to sample because of visibility to the naked eye (Gerber and Gabriel 2002; Bellingan et al. 2022; Khatri et al. 2022). The abovementioned factors affirm that aquatic macroinvertebrate faunas are responsive indicators of both environmental and biotic factors (Bellingan et al. 2022; Khatri et al. 2022). Therefore, invertebrates are instrumental in developing biomonitoring tools and scoring systems for river health (Dickens and Graham 2002; Graham et al. 2004; Graham and Taylor 2018).

Further afield, benthic macroinvertebrates were used to differentiate between impacted and reference sites in neotropical streams from Brazil (Ruaro et al. 2016). Aquatic macroinvertebrate assemblages proved to be a more effective measure in the discernment of reference vs impacted sites than using fish communities (Ruaro et al. 2016). This effectiveness is from aquatic macroinvertebrates being more accumulative indicators of general environmental changes (Bellingan et al. 2022). They are more readily responsive to changing stream conditions and riparian impacts than conventional chemical pollution assessments (Ruaro et al. 2016; Khatri et al. 2022).

The history of restoration efforts has aimed to improve the structure of a river channel. The improvement in biodiversity recovery follows as a secondary impact of channel morphology improvement (Khumalo et al. 2021; Lebepe et al. 2021; Robertson et al. 2021). Another difficulty with monitoring the improvement of biodiversity is its gradual rate of unassisted recovery or non-negligible changes in the immediate to short term (Ruwanza et al. 2013; Khumalo et al. 2021; Robertson et al. 2021).

Consequently, the focus on morphological improvement alone has since been surpassed by the importance of improving the functionality of a river system. Restoring river functionality includes taking a holistic approach to river structure and function. ‘Functional’ river restorations aim to restore a river's various ecological and hydrogeomorphic processes. Descriptions of functional restoration outcomes in South Africa are still in their infancy and developmental stages, especially in terms of available publications (Rebelo 2012; Ruwanza et al. 2013) compared with elsewhere (Muhar et al. 2016; Johnson et al. 2020; Robertson et al.

2021; Zhang et al. 2022). The functionality of riparian and instream habitats is crucial in diverting and mitigating the impacts of surface water runoff and reducing soil erosion (Muhar et al. 2016). Additionally, riparian ecosystems play a significant role in sequestering nutrients and organic matter (Kleynhans 2008).

The composition of invertebrate assemblages in rivers, responding to gradients and anthropogenic influences, has been studied in South Africa (Tenza 2018; Lebepe et al. 2021; Khumalo et al. 2021) and elsewhere (Bellingan et al. 2022; Khatri et al. 2022; Zhang et al. 2022). All these studies reflect the influence of the upstream-downstream gradient, coined as a River Continuum Concept (Vannote et al. 1980). This mechanism is essential when using macroinvertebrates for monitoring (Tenza 2018). In headwaters with canopy cover, particles produced are broken up by scraping and shredding invertebrates, and downstream collector invertebrates process these particles in a trophic escalade (Bellingan et al. 2022). Macroinvertebrates are reliable indicators because of their rapid life-cycle turnover and biological importance in the food chain. They are valuable tools for examining conservation questions and responding predictably to factors such as water temperature, season, and water quality (Bellingan et al. 2022). The composition of aquatic macroinvertebrates' community changes in response to ecological impacts, whether emanating from anthropogenic sources or natural disturbance (Tenza 2018; Bellingan et al. 2022).

The first objective of our study aimed to assess the in-stream biological water quality in eThekwini Municipality’s reforestation sites using the mini-stream assessment scoring system (MiniSASS). We expected that the water quality results would indicate whether the reforested riparian sites were in good ecological condition or not. We used the MiniSASS results as a response measure of reforestation's impact on a riparian system. We predicted that if the water quality was good, then it could be assumed that the riparian system was functional, and this would show whether reforestation was a contributing factor or not. We expected the

MiniSASS to show an increased abundance and diversity of macro-invertebrates that are intolerant of pollution in naturally functioning areas, thereby showing the highest scores in reforested areas.

The second objective of our study aimed to investigate the role of habitat conditions in riverine ecosystem integrity, particularly in the context of reforested riparian areas. The range of ecological disturbances and the scale at which restoration projects are implemented remains challenging, especially in South Africa. Here, we provide a brief background of the role of biological indicators and habitat conditions in riverine ecosystem integrity, particularly in riparian areas with some reforestation activity.

3.3 Methods

3.3.1 Sampling area

eThekwini (Durban) is a popular coastal city in KwaZulu-Natal Province, South Africa, which is governed by the eThekwini Metropolitan Municipality. eThekwini strives to be one of the country's leading sustainable cities and has made internationally recognised efforts to address climate change and build future resilience (Mugwedi et al. 2018). eThekwini has actively invested in its climate adaptation and mitigation strategies, which are being channelled through the city's Municipal Climate Protection Programme (MCPP) since 2004 (Mugwedi et al. 2018). Study sites were selected because they fall within the eThekwini Municipality's community reforestation areas (control sites). These reforested/control sites were compared with reference sites of the Krantzkloof Nature Reserve, also within eThekwini Municipality.

Our objective was to create a river health baseline for the two areas, monitoring reforestation activities, varying land use and variation in river health between them. A total of six study sites were sampled (Fig. 3.1).

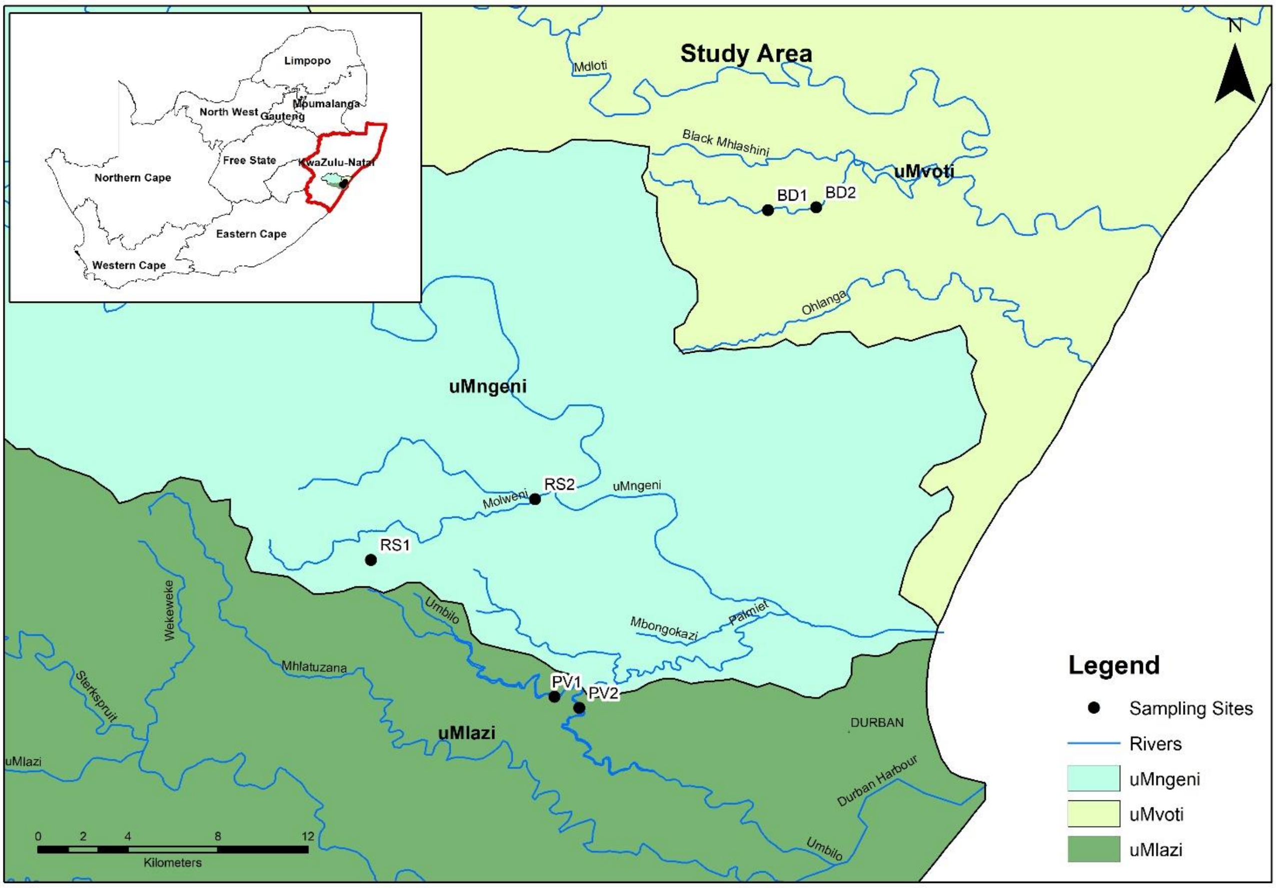

Figure 3.1: A map showing the sampling sites in the present study in eThekwini Municipality, Durban, KwaZulu-Natal, South Africa. (Note: Cluster 1: two sites on White Mhlasini River, Buffelsdraai, BD1 site upstream and BD2 site downstream; Cluster 2: two sites on the uMbilo River, Paradise Valley; PV1 = site upstream and PV2 = site downstream; Cluster 3: two sites on the Molweni River, Krantzkloof; RS1= site upstream, RS2 = site downstream).

In summary, Fig. 3.1 depicts the following river site clusters (Cluster 1: two sites on White Mhlasini River, Buffelsdraai; Cluster 2: two sites on the uMbilo River, Paradise Valley; Cluster 3: two sites on the Molweni River, Krantzkloof) where we sampled. We intended to have sites along different river parts, i.e., upstream and downstream. For each site, the coding represents the area sampled, and the number reflects the position in which we sampled that study site along each river. For example, BD 1= Buffelsdraai upstream site and RS 2= Krantzkloof downstream site (Fig. 3.1).

3.3.1 Buffelsdraai Landfill Site

The sites sampled on eThekwini Municipality's community reforestation areas were Buffelsdraai (a transformed environment with a landfill site and sugarcane farming) and Paradise Valley (a largely protected environment with a nature reserve and a wastewater treatment plant). The Buffelsdraai Landfill Site Community Reforestation Project area (BLSCRP) (~800 ha) is located near Verulam, a small town found about 25 km north of Durban, in KwaZulu-Natal, South Africa (Cirrus Group 2014). The area comprises a landfill zone where the eThekwini Municipality has commenced reforestation work since 2008 and is the largest of all reforestation sites. Several projects are run in Buffelsdraai, such as the landfill site community reforestation project and the nursery and tree-preneurs project run by the local community and Wild Trust. The reforestation efforts are aimed at rehabilitating an old sugarcane plantation. At the Buffelsdraai Landfill Site Community Reforestation Project, eThekwini Municipality implemented reforestation activities in the buffer zone between the landfill site and surrounding communities to further maintain the area as a nature reserve (Durban SBR 2014/2015; Douwes et al. 2015). The peri-urban communities neighbouring the landfill are Buffelsdraai and Osindisweni Villages (Cirrus Group 2014). The portion of the buffer zone set aside for reforestation was land previously used for sugarcane farming and later encroached with invasive alien plants. The estimated size of the total area to be reforested was ~520 ha (Cirrus Group 2014).

The aims of eThekwini Municipality with regard to water quality and riparian ecosystem health in Buffelsdraai following restoration included improving water yields, sediment, and water flows in the overall uMdloti River Catchment. The sites chosen for the present study at Buffelsdraai were located on the tributary of the White Mhlasini River (Fig. 3.1), which is located southeast of the Buffelsdraai Landfill Site. The White Mhlasini is one of two large tributaries of the Mdloti River. As an important tributary of the uMdloti River, the White Mhlasini impacts the ecological condition of the tourist beaches and uMdloti estuary downstream. The entire site and associated catchment (Quaternary Catchment U30B) have historically been under sugarcane cultivation for over 100 years (Douwes et al. 2015). The topography of the landfill site is quite variable and integrates the Black Mhlasini River flowing from high altitudes along the northern side of the site and the White Mhlasini flowing from the south. The elevation between the rivers is between 200m and 325 m.a.s.l. along the slope boundary lines (Mugwedi et al. 2017).

In a year of *normal climatic conditions, the area receives an annual average rainfall of 766 mm. Findings suggest that the area is considered to have relatively low rainfall in the region, although it supports immense sugarcane production (Cirrus Group 2014). Also, the average daily temperatures reach an average of 27.4°C in summer and a maximum of 22.2°C in the winter months.

The vegetation type of Buffelsdraai broadly forms part of the KwaZulu-Natal Coastal Belt Grassland (Ezemvelo KZN Wildlife 2010). This broad vegetation type is an assortment of forest, woodland and grassland types (R. Scott-Shaw pers. comm.) The vegetation composition within the site differed markedly based on previous and present land use. Fallow sugarcane fields dominated some parts of the site, while the drainage lines had pockets of riparian forest remnants, and there was limited indigenous vegetation like grassland and forest types. Forest patches characterise the south-facing slopes, while in some cases, sugarcane fields were left fallow, facilitating encroachment by transitional weeds and invasive alien plants (Cirrus Group 2014). To address the contrasting degrees of wetness between the zones, a different planting strategy was used in each. The density of trees planted was higher (approx. 2000 trees per ha) in the lowlands compared with the 1000 trees planted in the uplands (Mugwedi et al. 2017).

The dominant geology parent material onsite is the Dwyka Tillite, which is resistant to pressure and other effects such as weathering (Mugwedi et al. 2017). The upland and lowland areas are characterised by different soil types of varying depths, namely lithosoil for the former at shallow depths and acrisoil for the latter at deeper levels (Mugwedi et al. 2017). The soil is shallower in the uplands because of increased runoff and soil erosion attributed to intensified agricultural activity (cultivation) (Mugwedi et al. 2017). The lowlands area is therefore dominated by deeper soils likely emanating/deeper soils could be traced from the deposition of soils from the uplands/ from accumulated deposition material from uplands (Mugwedi et al. 2017). The Dwyka Tillite was dominant in most parts of the site, and shales were found in the eastern sections of the study site. The slopes on the site are unstable site because of the weathering of the shales, which form part of the Pietermaritzburg Formation. The site has diverse soil types, such as Glenrosa soils and red Hutton soils.

3.3.2 UMbilo community-ecosystem based adaptation project

The uMbilo River flows through Paradise Valley and traverses Paradise Valley Nature Reserve (Fig. 3.1). It is a popular reserve located along the uMbilo River and features nature attractions ranging from its waterfall, small mammals, trails and tranquil picnic sites along the river banks. Upstream of the reserve, ~ 1 km before the river enters the reserve, the river bed is canalised. The site sampled upstream of the reserve is often polluted. Downstream of the reserve, closer to the Wild Trust Offices, past the uMngeni Water Waste Water Treatment Works, the Working on Ecosystems team and tree-preneurs were working when we began sampling in 2014. The alien-clearing work continued further down where a contractor working under WESSA had been working (Working for Ecosystem teams).

One of the key objectives of the uMbilo Community Reforestation Project was the delineation and restoration of Paradise Valley and Roosfontein Ecosystem Services Areas (uMbilo community-ecosystem-based adaptation project, undated). Restoration efforts that eThekwini Municipality implemented at this site include the clearing of alien plants followed by reforestation. Working for Ecosystems has been working in this area, clearing alien invasive plants since 2011. A relatively small portion of this area (~ 200 ha in size) is a proclaimed nature reserve, Roosfontein Nature Reserve, and zoned for protection by eThekwini Municipality. The uMbilo River flows through Paradise Valley and forms part of the uMbilo River catchment, providing water to certain areas of Durban and particularly into the Durban Bay.

3.3.3 Reference sites

In this study, reference sites were selected to compare the two eThekwini reforested sites, i.e. Buffelsdraai and Paradise Valley sites (study focus areas) with a river in near-natural condition (the Kranzkloof). The Krantzkloof sites were selected as reference sites because they are in a natural forested area, which is somewhat similar to Paradise Valley. Krantzkloof also has a nature reserve, thus making it plausible to compare with the reforested sites. Furthermore, Krantzkloof Nature Reserve is one of the oldest reserves in the province, which also happens to be near at least one of the sites, the Mbilo River (Fig. 3.1).

3.3.2 Sampling techniques

Monitoring is essential to facilitate the success of the ecological restoration process (Graham et al. 2004; Li et al. 2018; Lyu et al. 2020). The mini stream assessment scoring system (MiniSASS) has grown to be particularly useful in river health assessments and monitoring in southern Africa. The tool is valuable for catchment health management. The data collected, and the information derived have not been only for aquatic scientists, but the tool has and is increasingly linking/connecting the ecological status of rivers to locals, decision-makers, water authorities, researchers and conservation practitioners. Monitoring becomes essential to operationalize reporting into governance and translate into localized, action-oriented solutions (Holt and Miller 2011; Tenza 2018; Olomukoro and Dirisu 2014).

MiniSASS is an abridged version of the SASS5 monitoring protocol implementable by a range of people who are not riverine biologists. MiniSASS data and criteria were obtained from the MiniSASS website for the Southern Drakensberg Strategic Water Source Area (miniSASS.org). We used MiniSASS scores to calculate ecological categories based on the river category (Table 3.1). Limitations of the MiniSASS data include the lack of verification and consistency between samplers and sampling events. There is no certification process for samplers and MiniSASS is regularly undertaken by citizen scientists.

Table 3.1: Summary of the MiniSASS ecological categories for interpreting river conditions. (Source: MiniSASS scoresheet, www.miniSASS.org).

Ecological Category (condition)	River Category	
	Sandy River	Rocky River
NATURAL CONDITION (Unchanged/untouched – Blue)	> 6.9	> 7.2
GOOD CONDITION (Few modifications – Green)	5.9 to 6.8	6.2 to 7.2
FAIR CONDITION (Some modifications – Orange)	5.4 to 5.8	5.7 to 6.1
POOR CONDITION (Lots of modifications – Red)	4.8 to 5.3	5.3 to 5.6
VERY POOR CONDITION (Seriously to Critically modified – Purple)	< 4.8	< 5.3

We selected three river sites for comparison (Fig. 3.1), all with different restorative stages. Two sampling points were positioned at each river site, an upstream and downstream sampling location of the impacted site (Fig. 3.1). The site descriptions and coordinates are provided in Table 3.2.

Table 3.2: A summary of sampling site locations and descriptions for biological water quality and habitat integrity assessments in eThekwini Municipality, Durban, KwaZulu-Natal, South Africa. (See also Fig. 3.1)

Site code	Position on river	Latitude (DMS)	Longitude (DMS)
White Mhlasini River sites (Buffelsdraai)			
BD1	upstream, site u/s Buffelsdraai Village	29°38'27.1"S	30°58'15.2"E
BD2	downstream, site downstream of the wetland and a small footbridge on the river	29°38'23.0"S	30°59'24.8"E
UMbilo River sites (Paradise Valley (PV))			
PV1	u/s PV Nature Reserve	29°50'07.7"S	30°53'07.7"E
PV2	d/s Umbilo WWTW	29°50'23.6"S	30°53'43.5"E
Molweni River sites (Krantzkloof Nature Reserve (KKNR))			
RS1	U/s KKNR access via Everton Rd, u/s Everton Conservancy	29°46'50.7"S	30°48'43.2"E
RS2	At KKNR exit, d/s Fannin Rd near Lunyhezi Farming	29°45'23.13"S	30°52'39.709 "E

Note: For each site, the coding represents the area sampled, and the number reflects the position in which that study site was sampled along each river. For example, BD 1= Buffelsdraai upstream site and RS 2= downstream reference site. Therefore 1 =site upstream (u/s), and 2 = site downstream (d/s). Sites were sampled for the MiniSASS and index of habitat integrity assessments.

In southern Africa, commonly used methods based on invertebrate sensitivity to in-stream pollution and environmental conditions, e.g., the South African Scoring System (SASS) method, have become standardised rapid bioassessment of rivers (Dickens and Graham 2002).

Consequently, the SASS method now forms the backbone of the national river health programme (Dickens and Graham 2002; Day and Davies 2023). The SASS method samples aquatic macroinvertebrate taxa, each with differing sensitivities to pollution, and produces an index of the system's health based on observed taxa (Olomukoro and Dirisu 2014; Tenza 2018). The SASS sampling focuses on four river or stream biotopes (habitats) from which the macroinvertebrates are collected. These are stones (subtypes: in-flow and out-of-flow), vegetation (aquatic and marginal), and gravel, sand and mud (GSM)(Graham et al. 2004; Lebepe et al. 2021).

Monitoring is essential to facilitate the success of the ecological restoration process (Graham et al. 2004; Robertson et al. 2021). The mini stream assessment scoring system (MiniSASS) has grown particularly useful in southern Africa's river health assessments and monitoring (Agboola et al. 2019; Day and Davies 2023). The tool is valuable for catchment health management (Day and Davies 2023). MiniSASS is a citizen science tool derived from the SASS 5 method/technique (Graham and Taylor 2018). The MiniSASS is a technique that aims to monitor any stream or river ecological condition and it is readily used by citizens who are not biologists. The data collected and the information derived have not been only for aquatic researchers, but the tool has and is increasingly linking/connecting the ecological status of rivers to locals, decision-makers, water authorities, researchers and conservation practitioners (Day and Davies 2023).

We used MiniSASS scores to calculate ecological categories based on the river category (Table 3.1). In addition, we undertook an index of habitat integrity assessment (Kleynhans 1996; van Rensburg 2012). As described by Kleynhans (1996), an index of habitat integrity assessment comprises two components: a riparian habitat and an in-stream habitat assessment. Integrity classes derived from both the instream and riparian habitat health assessments comprise one integrity category for a specific site/ habitat. An important point to note is that the integrity categories are described for habitats ranging from largely pristine/unmodified or natural (Integrity class A) to habitats modified to an unacceptable state (Integrity class F), as shown in Table 3.3.

Table 3.3: Habitat integrity assessment categories and impact scoring by category of Kleynhans (1996).

Category	Description	Score (% of total)
A	Unmodified, natural.	100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-99
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions have occurred.	40-59
E	The loss of natural habitat, biota and basic ecosystem functions are extensive.	20-39
F	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

As a habitat assessment method, the index of habitat integrity provides an overall index/indication of the impact level on each river section. This information complements the biomonitoring data and is useful for understanding the land use type and surrounding impacts. The benefit of knowing the state of the abiotic components is as critical as that of understanding the state of an ecosystem's biotic components (Holt and Miller 2011), which largely rely, if not entirely, on functioning abiotic components of the habitat (Simaika and Samways 2009; Johnson et al. 2020). As illustrated in the field sampling section, the class/condition category has management and ecological perceptions to consider (Graham and Louw 2008).

We conducted MiniSASS sampling inside the Paradise Valley Nature Reserve, upstream and downstream of the reserve, and at Buffelsdraai across three main sampling sites (Table 2.2). We sampled each site once monthly. At the various study sites, we collected the MiniSASS data monthly for 10 months, from April 2014 to July 2015. We used the MiniSASS sampling techniques according to Graham et al. (2004) and as tested and refined by Graham and Taylor (2018). Identification of the invertebrate classes was informed by knowledge and experience gained by conducting SASS 5 assessments with accredited SASS 5 practitioners. An additional field identification guide (Gerber and Gabriel 2002) was used for quality assurance. The monthly sampling was done at relatively the same time in the morning at the same sites repeatedly. At all sites, MiniSASS sampling began downstream and progressed upstream to ensure no disturbance of subsequent reaches sampled downstream.

We sampled the length between the upstream and downstream sampling sites at variable intervals (site-specific accessibility to riparian zone influenced sampling intervals). This was a once-off visual-impact assessment using the method of Kleynhans (1996). We used the index of habitat integrity data sheet to capture observations for the instream and riparian zones (Supplementary information Table S4.1) and later input the data into an automated Excel© sheet of the index of habitat integrity (Kleynhans 1996).

3.3.3 Data analyses

We used descriptive statistics and generalised linear models for repeated measures analysis of variance (ANOVA) to compare results. For the index of habitat integrity, data collected were transferred to a Microsoft Excel© automated sheet, which extrapolated the outputs and assigned the ecological condition standards based on the built-in formulae. Summary data values were then presented in a summary data table to characterise the sites. We later ran simple statistical analyses to visually present the index of habitat integrity percentage scores across sites and to compare results between reference sites and reforested sites assessed in this study.

3.4 Results

The MiniSASS scores determined the macroinvertebrate responses and were generally higher in July than in November across all the sampling sites (Fig. 3.2). There was a significant difference in MiniSASS scores between sites (ANOVA, $F = 15.732$, $df = 5, 45$, $P < 0.05$), supporting our predictions. MiniSASS scores are essentially representative of macroinvertebrate sensitivity to pollution levels in rivers.

Macroinvertebrate community structure indicated that the macroinvertebrate taxa found across the three river sites were dominated by taxa such as Ephemeroptera and Diptera. This was based on the number of recorded occurrences of macroinvertebrate taxa, as summarised in Table 3.4. Of the taxa observed, none were Plecoptera (stoneflies)-which are the most sensitive to pollution and are generally found in near-natural /unmodified sites. The reference sites, in comparison, had occurrences of Plecoptera and higher Mini-SASS scores as a result. The Mini-SASS and index of habitat integrity scores complemented the trends observed for the reference and non-reference sites.

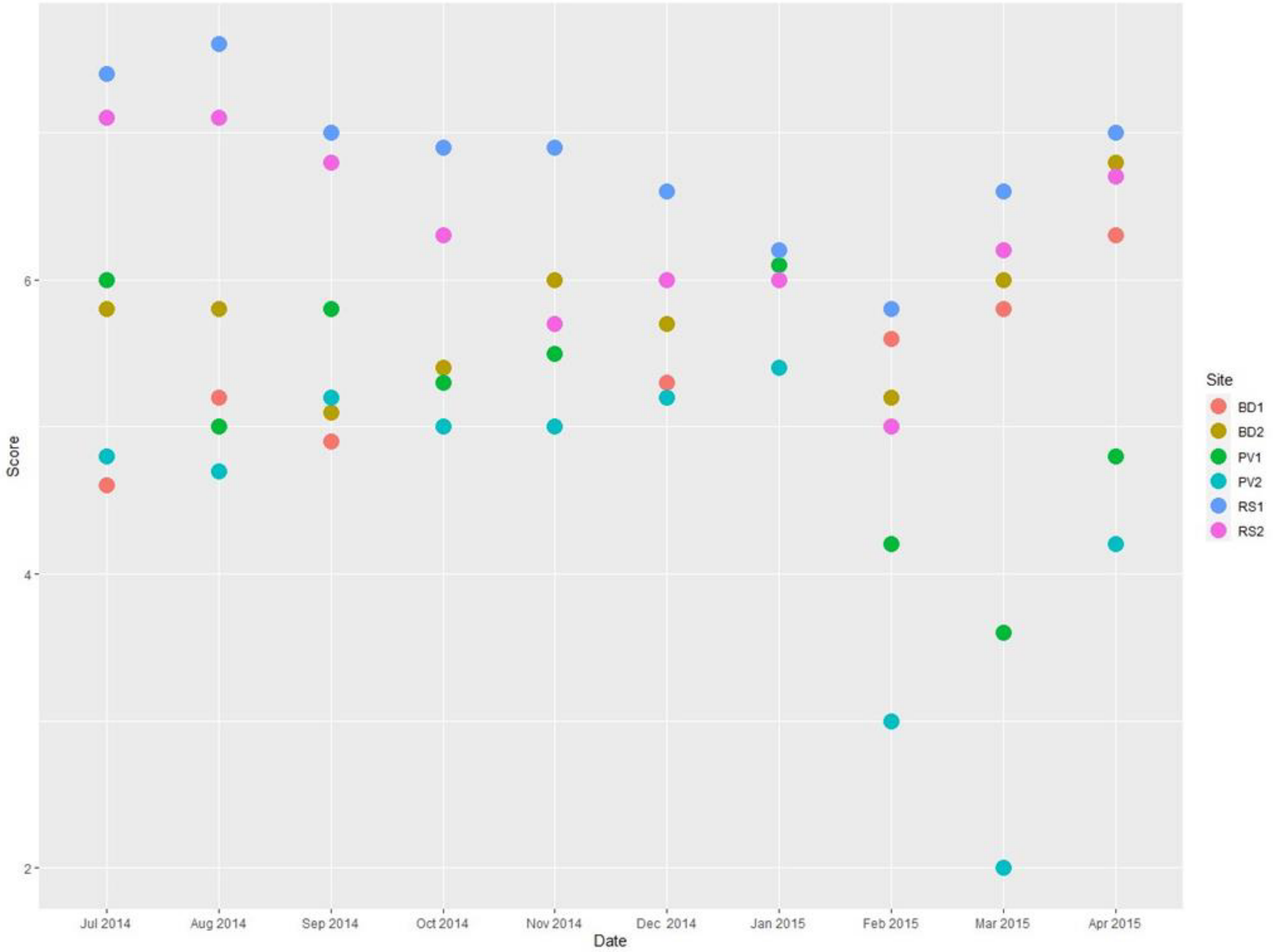

Figure 3.2: Monthly comparison of MiniSASS scores across study sites from July 2014 to April 2015 in the present study. (Note: Site names Buffelsdraai = BD, Paradise Valley = PV, Reference site (Molweni River) = RS; S1- downstream sites, S2-upstream sites).

Table 3.4: Number of macroinvertebrate taxa occurrences at the various sampling sites. (Dashboard below provides a demonstration of the monthly tallying process for one site (Paradise Valley) with highly sensitive taxa highlighted).

Presence/absence											
PV1: u/s	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	**Total**
Anisoptera (Dragonflies)	1	0	0	0	1	0	1	1	0	0	4
Annelida (Leeches)	0	1	0	0	0	1	0	0	0	0	2
Baetidae (Minnow mayflies)	1	1	1	1	1	0	1	1	0	1	8
Hemiptera (bugs), Coleoptera (beetles)	1	0	0	1	0	0	1	1	0	0	4
Diptera (Trueflies)	0	1	1	1	1	0	0	1	0	1	6
Decapoda (Crabs, shrimps)	1	0	1	1	0	0	1	1	0	0	5
Ephemeroptera (other mayflies)	1	1	1	0	1	1	0	0	0	0	5
Oligochaeta (worms)	0	0	0	0	0	0	0	1	0	0	1
Platyhelminthes (flatworms)	0	0	0	0	0	0	1	0	1	0	2
Plecoptera (stonefly)	0	0	0	0	0	0	0	0	0	0	0
Trichoptera (caddisflies)	0	0	1	0	0	1	1	0	0	1	4
Gastropods (snails)	0	0	1	1	0	1	1	0	1	1	6
Zygoptera (damselflies)	0	0	1	1	0	1	1	1	1	1	7
tot occurrences/month											**54**
PV2:d/s											
Anisoptera (Dragonflies)	0	0	0	0	1	1	0	0	0	1	3
Annelida (Leeches)	0	1	0	1	0	0	0	0	1	1	4
Baetidae (Minnow mayflies)	1	0	1	0	1	0	1	0	0	1	5
Hemiptera (bugs), Coleoptera (beetles)	0	1	0	0	1	0	1	0	0	0	3
Diptera (Trueflies)	1	0	0	0	0	1	0	1	0	1	4
Decapoda (Crabs, shrimps)	0	1	0	1	0	1	1	0	0	0	4
Ephemeroptera (other mayflies)	1	0	1	1	0	0	0	0	0	0	3

Oligochaeta (worms)	1	0	0	0	0	0	0	0	1	1	3
Platyhelminthes (flatworms)	0	0	0	0	0	0	0	0	0	0	0
Plecoptera (stonefly)	0	0	0	0	0	0	0	0	0	0	0
Trichoptera (caddisflies)	0	0	0	0	0	1	0	0	0	1	2
Gastropods (snails)	0	1	1	0	0	1	1	0	0	0	4
Zygoptera (damselflies)	1	0	1	1	1	1	1	1	0	1	8
											43

The reference sites (RS 1 and RS 2) had the least pollution-intolerant taxa, denoted by the highest MiniSASS scores ranging between 6.8 and 7.9 compared with other sites (Fig. 3.2). These MiniSASS scores for the reference sites show a river in good ecological condition, meaning it is largely natural with few modifications. The two sites on uMbilo River, below and upstream of Paradise Valley Nature Reserve, had the lowest MiniSASS scores, less than 5.1, indicating that this section of the river was in relatively poor condition or seriously modified (Fig. 3.2).

The Paradise Valley upstream site (before the Nature Reserve) had a greater number of occurrences per taxa, although the number of occurrences in February and March 2015 were generally lower than for the other months (Table 3.4). The site downstream of the Paradise Valley Nature Reserve showed severe impacts, with substantially low macroinvertebrate scores in February and March 2015 (Fig. 3.2). The poor macroinvertebrate community composition observed could be attributed to a major industrial waste spill that had occurred during this time further upstream, but results without the physicochemical data and long-term monitoring were inconclusive. In Buffelsdraai, the sites furthest from disturbance and human interference had higher macroinvertebrate sensitivity scores than the site downstream with solid waste dumping as it was closer to the road going into Osindisweni Village (Fig. 3.2).

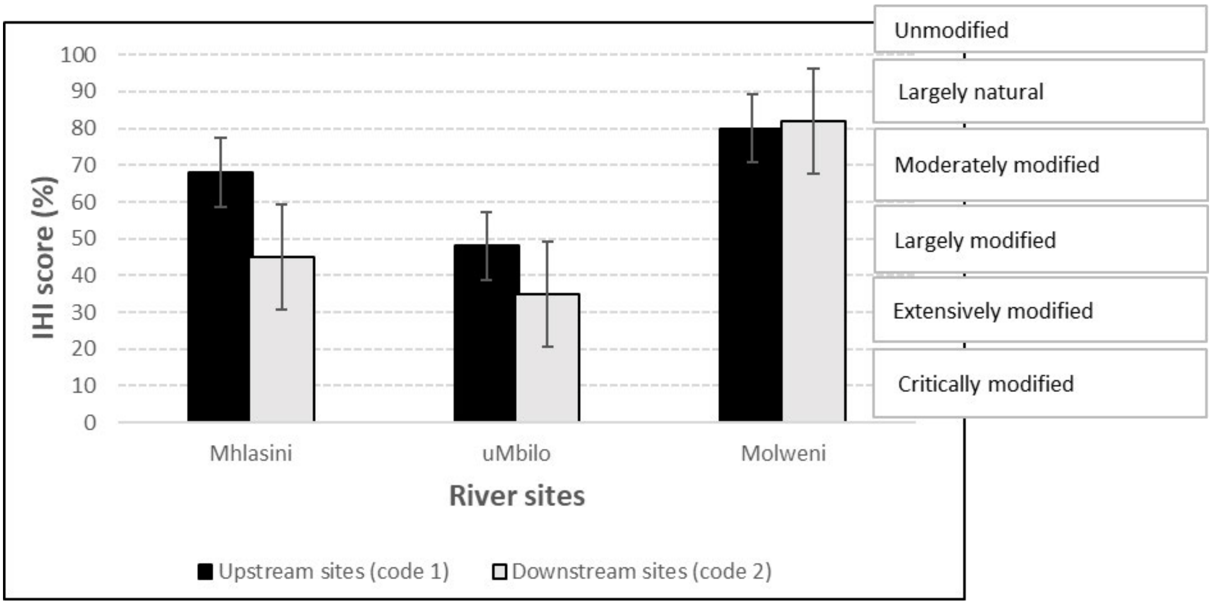

Figure 3.3: Summary index of habitat integrity (IHI) score (Percentage of total and Standard Error) results across the river sites following once-off sampling. (Note: Text boxes on the dotted line (right-hand side of the graph) depict the different levels of site modification and ecological health conditions according to Kleynhans (2008)).

The summary results for the index of habitat integrity across the reforestation sites (in comparison with the reference sites showed that both reforested sites, although at different locations had considerably lower integrity than reference sites (Fig. 3.3, Table 3.5). The ecological integrity of the Molweni River sites was characterised as class B (Fig. 3.3, 3.4 and 3.5, Table 3.5). Both upstream and downstream sites were in a largely natural condition.

Table 3.5: The index of habitat integrity scores and ecological integrity implications for the sampling sites in the present study. (See Table 3.3 and Fig. 3.1 for site abbreviations).

River site	Site code (position along river)	Integrity class	Score	Ecological condition
Mhlasini 1	BD 1	C	68	Moderately modified
Mhlasini 2	BD 2	D	45	Largely modified
uMbilo 1	PDV 1	D	48	Largely modified
uMbilo 2	PDV 2	E	35	Extensively modified
Molweni 1	RS 1	B	80	Largely natural
Molweni 2	RS 2	B	82	Largely natural

Note: *All upstream site codes =1, downstream sites = 2

The ecological integrity of the Molweni River sites were characterised as class B (Table 3.5). Both upstream and downstream sites were in largely natural condition, which was justified since this was a reference site, thus expected to 'model' near-pristine ecological conditions. The three river sites assessed showed differences in ecological condition based on the index of habitat integrity scores.

Relative to the reference sites, both reforestation sites appeared to have poor ecological integrity (Table 3.5). The Mhlasini River in Buffelsdraai (the oldest reforestation site) was associated with moderately healthy ecological conditions based on the index of habitat integrity scores, while the uMbilo River sites were both in poor ecological condition (Table 3.5). The ecological condition results for these reference sites based on the index of habitat integrity score analysis reflected a similar result to the macroinvertebrate sensitivity analysis results.

For the uMbilo sites, there was a substantial deviation from the reference or “natural conditions” despite having a protected area (Paradise Valley Nature Reserve) separating the two sites (Table 3.5). The ecological integrity of uMbilo (PV) sites ranged from a largely modified to an extensively modified state (Class D to E, upstream to downstream) (Table 3.5). The poor ecological condition was largely attributed to alien invasive plant infestations. The ecological condition of the White Mhlasini River sites ranged from class C to D (Table 3.5).

3.5 Discussion

There was a significant difference between sites in ecological conditions based on macroinvertebrate sensitivity scores to pollution. The reference sites had the most pollution-sensitive taxa, with the highest MiniSASS scores (range 6.8 - 7.9) compared with other sites. This highlighted that the reference sites were in good ecological condition, meaning the river is near-natural with few modifications. In contrast, sites on uMbilo River, had the lowest MiniSASS scores (less than 5.1), highlighting that this section of the river was in relatively poor condition or seriously modified. Compared with other studies, these results support the general notion that urban river systems are under pressure from a diverse range of anthropogenic impacts, including physicochemical disturbances (Feld et al. 2009). For example, a study by Dias-Silva et al. (2010), assessed the effect of physicochemical impacts on freshwater habitat integrity and insect community assemblages in Brazilian riparian forests. The results showed a positive relationship between habitat integrity and the composition of the Heteropteran insect community (Dias-Silva et al. 2010). Physicochemical impacts had modified riparian habitats and thereby significantly changed the composition of the

Heteropteran community, although species richness was not affected, as found in other studies (Dias-Silva et al. 2010).

Furthermore, we inferred from the results that river sites with greater integrity provided more easily accessible shelter in marginal vegetation, thus favouring the more sensitive species to physicochemical disturbances. Based on these results, the Heteroptera were found to be a reliable indicator of habitat integrity, as found in other studies (Dias-Silva et al. 2010). Similarly, a local study conducted by Fouche et al. (undated) in the Great Letaba River showed a positive correlation between invertebrate communities and habitat conditions.

Overall, the study's alternative hypothesis was accepted, which stated that there would be differences in ecological habitat integrity across river sites. The results showed differences across sites and even more substantial differences in ecological conditions between the reforested and reference sites. It was observed that reforestation efforts can indeed take a long time to impact ecosystem function and structure (pers. obs.).

The site downstream of the Paradise Valley Nature Reserve showed severe impacts, with substantially low macroinvertebrate scores, especially in February and March 2015. The poor macroinvertebrate community composition observed could be attributed to a major industrial waste spill that had occurred during this time further upstream, but results without the physicochemical data and long-term monitoring were inconclusive (various pers. comm). In comparison, Buffelsdraai sites furthest from disturbance and human interference had higher macroinvertebrate sensitivity scores because the site downstream had solid waste dumping as it was closer to the road going into Osindisweni Village. Since the macroinvertebrate analyses and habitat condition assessments were the first to be collected at the reforestation sites, without comparison to a prior community or records of impacts, the response to effects of reforestation were not measured on the ecosystem-based indices, rather a baseline dataset was established. Macroinvertebrate community composition was likely an indication of impacts at the time of assessment or reflective of both recent /past land-use impacts, such as sugarcane farming in Buffelsdraai. However, there was a general similarity in macroinvertebrate sensitivity scores across the three sites except for a few months in 2015, which was an exception for the uMbilo sites. Also, there was a general trend of increasing pollution-tolerant taxa from upstream to downstream sites.

The ecological integrity of the Molweni River sites were characterised as class B, with upstream and downstream sites largely in natural condition, supporting these as reference sites. They had near-pristine ecological conditions and were associated with sound ecological integrity because of the site's prevailing and or historical ecological conditions (various pers. comm.). These results were justified based on long-term improvements in river conservation efforts by local conservancies and interventions through eThekwini Municipality's "Take Back Our Rivers" flagship project (Martel et al. 2022). Relative to the reference sites, reforestation sites appeared to have poor ecological integrity. The ecological condition results for these reference sites based on the index of habitat integrity analysis reflected a similar result to the macroinvertebrate sensitivity analysis results. The Krantzkloof Nature Reserve between the sites can be attributed to the near-natural condition of this section of the Molweni River. Vegetated riparian buffers, alien invasive plant clearing, and limited direct human access are among the factors which enable the protected environment to self-regulate from human impacts, which in turn allows the river and its biota spatial-temporal recovery from disturbances to an extent (pers. obs.). However, for the uMbilo sites, there was a substantial deviation from the reference or "natural conditions" despite having a protected area separating the two sites. The poor ecological condition was largely attributed to alien invasive plant infestations, which were still prevalent as the Working for Ecosystems was clearing during the index of habitat integrity sampling.

The observed trend within upstream and downstream sites was declining ecological integrity. The only exception to this observation was the ecological integrity trajectory within the reference sites. Therefore, for Molweni River, the index of habitat integrity score for the downstream reference site was slightly higher than the index of habitat integrity score for the upstream site.

3.6 Conclusions

We sampled the two river sites and had the reference site to establish the baseline ecological conditions of the riparian ecosystem based on macroinvertebrate community and habitat condition indicators. Findings from the study suggest that a longer time plan is needed to monitor macroinvertebrate responses to habitat change, as found in other studies (Friburg et al. 2014).. In this case, the effect of reforestation interventions manifests differently at each site because of various pre-existing land uses. For example, the effect of a nature reserve in an urban area is different from the results of the previous sugarcane site. Longer-term monitoring will be necessary to show conclusively ecosystem responses to reforestation efforts. Based on these results, the ability of each river system to restore itself is still open to investigation, as restoration impacts. The responses of the discrete macroinvertebrate communities to reforestation will differ within and across sites because different environmental variables influence them, and macroinvertebrate responses to habitat changes take a long time to manifest/materialise.

This study formed the baseline from which future studies and post-restoration interventions could be amplified. This study reinforces that habitat integrity is integral to macroinvertebrate community composition and responses. The role of riparian vegetation in protecting and improving water quality cannot be overemphasised. Numerous studies have investigated the effect of vegetated riparian zones in ameliorating chemical water quality in streams (Dosskey et al. 2010).

Recommendations are that post-restoration research work should be conducted and focus on different ecological indicators and mechanisms to monitor reforestation's impacts, successes, and benefits. Monitoring physicochemical parameters to complement the biomonitoring indicators of stream ecological integrity is recommended for future studies. The physicochemical parameters can link the impacts on water quality to anthropogenic impacts such as agriculture more profoundly; for example, macroinvertebrate sampling indicates organisms that have physiological adaptations to low dissolved oxygen levels in water, whereas the physicochemical parameters would account for the reason dissolved oxygen levels decline and link to the potential source for the excess nutrient loads in water.

3.7 Acknowledgements

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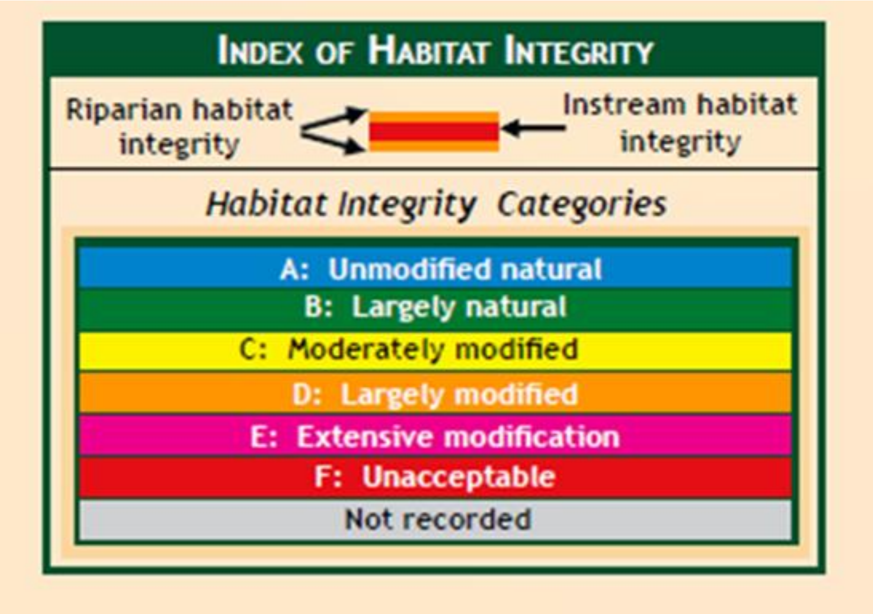
3.9 Supplementary information



Supplementary information Figure S3.1: Index of Habitat Integrity categories for instream and riparian integrity assessments (classes and colour-coding indicate ecological condition). (Image source: Adapted from Kleynhans (1996)).

Supplementary information Table S3.1: Index of Habitat Integrity field datasheet

Site Name:

Instream Zone		
Attribute	**Rating**	**Comments**
Water abstraction		Effect on water supply-often a marked decrease in supply of water. Directly impacts habitat condition (size, abundance and habitat type). Water quality features may also be affected including riparian vegetation.
Flow modification		A result of either abstraction or regulation by impoundments. This impact becomes evident on habitat attributes such as an extended season of low flow, thereby reducing the availability of certain habitat types for key animal/plant stages such as breeding and flowering.
Bed modification		Any excessive deposition of sediments into a river bed that can be traced back to catchment-related impacts. Sedimentation may be indirectly linked to erosion activity such as riparian zone erosion and stream bank erosion.
Channel modification		A change in flow characteristics may impact on the quality of the channel. The nature of channel modifications may be driven by catchment impacts or through deliberate changes to improve drainage, in most instances.

Phys-chem modification		Drivers of water quality inputs may be of point-pollution sources or diffuse point-pollution sources/origins. Water quality impacts may be exacerbated by reduced water volume in low-flow or no-flow season.
Inundation		This impact manifests as a form of obstruction to aquatic fauna movements, or water quality and sediment transport. May arise from the distraction of mini biotopes such as rapid, riffles and riparian habitats.
Alien macrophytes		The infestation of instream habitat by aquatic exotic plants. Impacts flow through obstruction and may influence water quality. Degree of impact is dependent on the scale of infestation intensity and species involved.
Introduced aquatic fauna		Introduced animal invaders disrupt stream bottom feeders, which may influence water quality and increase turbidity. Also dependent on the invader species involved and their abundance.
Rubbish dumping		A direct impact to instream habitat which may alter habitat structure. Also a general indication of river mismanagement, especially in urban areas.
Riparian Zone		
Attribute	**Rating**	**Comments**

Vegetation removal		Vegetation removal: Impairment of the buffer the vegetation forms to the movement of sediment and other catchment runoff products into the river. Refers to physical removal for farming, firewood and overgrazing. Includes both exotic and indigenous vegetation.
Exotic vegetation		Excludes natural vegetation because of vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochthonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced.
Bank erosion		Decrease in bank stability will cause sedimentation and possible collapse of the river bank, resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.
Channel modification		May be the result of a change in flow, which may alter channel characteristics, causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.
Water abstraction		Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.

Inundation		Distraction of raffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments.
Flow modification		As in in-stream habitat, the key drivers are either abstraction or regulation by impoundments. Results in flow characteristic modification (temporally and spatially). Can have an impact on riparian habitat structure and condition.
Phys-chem modification		Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.

CHAPTER 4

Conclusions and recommendations

4.1 Background

There is a general consensus that a weakened functional role of any natural ecosystem results in the loss of ecosystem services or benefits for humans (Simaika and Samways 2009; Clapcott et al. 2012; Kunene 2018; Nalau et al. 2018; Reid et al.2018). Similarly, the ability of a riparian ecosystem to provide ecosystem services is optimal in its naturally functioning state (Agboola et al. 2019; Agboola et al. 2020a). According to Kunene (2018), eThekwini Municipality undertook community reforestation projects to improve the cultural value of ecosystem goods and services for the local community's benefit. Douwes et al. (2017) illustrated the value of reforestation for carbon sequestration to improve ecosystem resilience and adaptive capacity to climate change impacts. In this study, the importance of improved habitat integrity for overall ecosystem function and support to macroinvertebrates was explored. Linking to Chapters 2 and 3, the rationale for studying the impact of such a renowned reforestation example in the context of other riparian ecosystem restoration work as well as climate mitigation and ecosystem resilience in eThekwini provides lessons for future restoration work elsewhere (Douwes et al. 2017).

4.2 General conclusions

Following a systematic review, South Africa had the highest number of river restoration records in Africa, but despite knowledge of increasing implementation, there was limited reported research (Chapter 2). Furthermore, few of the records found were related to either macroinvertebrate response to reforestation impacts or assessment of riparian habitat conditions following reforestation, which were focused on in the systemic review of this study

(Chapter 2). Relatively little has been documented on the effects of river restoration in Africa, including South Africa (Chapter 2), and this needs to change.

The general trend emerging from this study was that downstream sites were in worse ecological health than upstream sites despite restoration efforts. More information is needed to understand the conditions of downstream sites in this study or potential impacts in the areas between upstream and downstream sites. In the present study, the macroinvertebrate communities in all reforested sites, including those of reference sites, were significantly impacted by numerous land-use impacts such as invasive alien plants, agriculture, industrial effluent and general domestic effluent, amongst other stressors typical of an urban riparian ecosystem (Chapter 3).

The long-term monitoring and improvement of management efforts (e.g. continued alien invasive clearing, concerted efforts to reduce illegal dumpsites) on the two rivers sampled and their tributaries remains critical to reduce negative impacts on macroinvertebrate communities and safeguard the riparian ecosystem integrity. The eThekwini Community Reforestation Programme is a world-class example of climate change mitigation and ecosystem improvement interventions (Douwes et al. 2017; Mugwedi et al. 2017). To uphold its status as such, multiple stakeholder investments and actions are required to maintain the riparian ecological infrastructure and support the ongoing efforts through local implementing agents such as the Ethekwini Municipality's local conservancies.

The integrity of the collaborative river management work done at such scales is already showing great ecosystem service benefits (hiking trails along Molweni River) and attracting river users in numerous eThekwini river sites where such cohesive and concerted local management efforts are already taking place (Martel and Sutherland 2022).

4.3 Recommendations

Based on the findings of this study, it is recommended that restoration success monitoring be conducted across extended temporal and spatial scales. It is recommended a strong focus on river management at the catchment scale.

- Catchment-scale interventions

The formation of a Catchment Management Agency (CMA) to manage the rivers at the catchment scale and facilitate the inclusion of social, economic and ecological interests. The inclusion of these diverse interests should be coupled with a Freshwater Reserve study. Alternatively, while building towards the Freshwater Reserve study, conducting simple physicochemical measurements using a multiparameter instrument (temperature, dissolved oxygen, electrical conductivity, and pH) would provide valuable information into the ecological categories of the different sites that inform local, provincial and national interests.

Future research can revisit known reforested sites where there has been evidence of tree growth to focus on site-specific details. One such site of interest would be close to the wetland by the downstream site at Buffelsdraai Landfill. Furthermore, the recommendations outline a comprehensive approach to addressing riparian ecosystem impacts in general, yet with reference to the uMbilo and White Mhlasini rivers as follows:

- Long-term monitoring

One way in which longer-term macroinvertebrate community structures could be monitored is through comprehensive sampling through the use of different tools. These examples include the South African Scoring System (SASS), Macroinvertebrate Response Assessment Index (MIRAI), Riparian Vegetation Response Assessment Index (VEGRAI), Fish Response Assessment Index (FRAI) and Rapid Habitat Assessment Method (RHAM). The inclusion of the South African Diatom Index would also be useful, although it has been excluded by DWS' EcoClassification measures. Moreover, a rigorous riparian assessment that includes riparian vegetation diversity and abundance is recommended. This level of sampling would provide in-depth information on community structure, species, or genus level for diversity, distribution, and richness, as found in other studies (Friberg et al. 2014). Spatial and temporal variations in physico-chemical parameters influenced macroinvertebrate communities.

- Prioritise research gaps that Ethekwini Municipality needs to be addressed through the Durban Research Action Partnership (D'RAP)

Extend the sampling period to capture changes in habitat integrity as well as macroinvertebrate responses over at least two years (for a longer research study/routine sampling embedded in the eThekwini Reforestation project management component of the programme at various sites). The frequency of sampling and data parameters will have to meet the criteria/research or long-term research questions that Ethekwini Municipality needs to address.

For this study's restoration work (Chapter 3), which solely included riparian revegetation, it is worth noting that such findings are likely to have implications for the reforested sites in terms of aquatic macroinvertebrate response and habitat condition improvement. It is recommended that the municipality and relevant stakeholders, through D'RAP, investigate the likely benefit of having an extended monitoring program which will complement existing data to create a robust system from which the ecosystem management could be improved for the resilience of the city's green infrastructure in the face of changing climate.

- Focus on macroinvertebrate responses as indicators of reforestation impact

Regardless of location/prevailing climates and other ecological drivers, the response of macroinvertebrate taxa to river restoration efforts takes much longer time periods than originally anticipated/envisaged.

- Plan and finance scaling efforts

Planning how to scale reforestation impact monitoring is invaluable for long-term management and ecosystem services. By incorporating these recommendations, there is potential for more sustainable, concerted efforts to integrate the restoration and conservation work in the rivers in question. This holistic approach should focus on scaling efforts, considering ecological health, regulatory compliance, stakeholder involvement and citizen-led advocacy. Ongoing monitoring and enforcement will be crucial to ensuring the long-term effectiveness of these measures.

- Polluter accountability and enforcement measures

There is a dire need to form CMAs to promote and regulate polluter accountability and enforcement. The dumping of physical waste is rampant and should be managed at the local catchment scale by making polluters accountable. In most cases, such polluters have been found to be small-scale contractors who work on behalf of the municipality to remove solid waste in communities but seldom dispose of it in landfill sites. Revitalise local municipal task teams and establish CMAs to respond to the waste issue, restoring riparian areas for provisioning and aesthetic ecosystem services, not for solid waste dumping.

4.4 References

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