

**Recruitment and presence of native migratory fish
species in the uThukela River estuary and lower
uMngeni River catchment, KwaZulu-Natal, South Africa**

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ABSTRACT

African rivers provide significant sources of freshwater and are ecologically and economically important to human livelihoods, especially regarding income and food sources. In Africa, ~200 million people consume freshwater fish daily, and ~10 million people are gaining an income associated with freshwater fisheries. Unfortunately, African rivers are some of the most unpredictable rivers as they fall victim to extreme variability in precipitation. These rivers and streams are under threat to anthropogenic activities, such as the building of dams, weirs and locks, water extraction, modified river embankments, water quality issues, flow modifications from hydropower dams, and climate issues, that are significant threats to all fish species. Estuaries are unique and highly productive systems that are rich in biodiversity, as they are tidal-driven. An intricate flow dynamic connecting freshwater systems, estuaries, and the sea needs to be maintained for optimum ecosystem functioning. Thus, rivers are fundamental to the connectivity they provide. Physical barriers decrease the ecological connectivity of river systems. This has a major impact on various fish species, especially migratory fish. Migratory fish are major ecological drivers that can shape the structure and function of ecosystems. They are fundamental in maintaining food webs as predators or prey. Many flagship migratory species (i.e. yellowfish (*Labeobarbus* spp.) and eels (*Anguilla* spp.) in South Africa are prevented from reaching their breeding grounds. Four of the globally nine recognised species of anguillid eels are located and documented along the East flowing African Rivers, including those in South Africa. A few studies have been conducted on the recruitment of glass eels into the rivers and estuaries in the Western Indian Ocean. There are limited studies on the location of spawning areas of African freshwater eels. Relatively little is known about the migratory requirements of African fish species; only a few quantitative studies have been conducted to support the understanding of the migratory habits of these fish

species and their dependency on free-flowing and connected rivers. This study investigated the recruitment of African freshwater glass eels into the uThuleka River. Environmental data were collected. Glass eel species were identified by their tail and caudal fin pigmentation together with DNA barcoding. The findings included seasonal variation in recruitment, but the majority of glass eels were caught in the wet season, in warmer temperatures, during high spring tides and at night. These findings should encourage more frequent sampling in estuaries across all seasons along the Western Indian Ocean coast, as the timing of glass eel recruitment can be used to locate where the African Freshwater glass eels' breeding area is. Additionally, this study aimed to characterise the risk of multiple stressors, including instream anthropogenic barriers, on the ecology of fish communities and their environmental drivers in the lower part of the uMngeni River catchment. Various fish sampling methods were used to capture fish and investigate their species diversity and evenness. Statistical analyses were used to evaluate the relationship between fish communities and environmental variables, including barriers. The findings showed distinct fish community structures found across all sites in the catchment, which were susceptible to multiple stressors impacting migratory fish, especially velocity and mean depth. These stressors result in impaired river connectivity, which reduces a fish's ability to recolonise a river's range sufficiently. Restoring and considering river connectivity in the lower uMngeni catchment can potentially improve fish communities.

PREFACE

The data described in this thesis were collected in KwaZulu-Natal, Republic of South Africa, from August 2020 to August 2021. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof Colleen T. Downs and co-supervision of Dr Celine Hanzen 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.



.....
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July 2024

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



.....
Prof Colleen T. Downs

Supervisor

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DECLARATION 1 - PLAGIARISM

I, Leawin Africa, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO DRAFT PUBLICATIONS that form part and/or include research presented in this thesis. (Note: These have not been submitted yet)

PUBLICATION 1

Africa, L., Hanzen, C., Burnett, M. & Downs, C.T.

Recruitment of African glass eels (*Anguilla* spp.) into the uThukela Estuary, South Africa

Author contributions:

LA conceived paper with CTD, CH and MB. CH, MB and CTD sought funding. LA collected the data with assistance from CH and MB. LA analysed the data with input from CH and MB. LA wrote the draft paper. CH, MB and CTD contributed valuable comments to the manuscript.

PUBLICATION 2

Africa, L., Hanzen, C., Burnett, M. & Downs, C.T.

Fish community assessment and their drivers on the lower uMngeni River, South Africa, with an emphasis on migratory species

Author contributions:

LA conceived paper with CTD, CH and MB. CH, MB and CTD sought funding. LA collected the data with assistance from CH and MB. LA analysed the data with input from CH and MB. LA wrote the draft paper. CH, MB and CTD contributed valuable comments to the manuscript.


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July 2024

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CONTENTS

ABSTRACT	ii
PREFACE	iv
DECLARATION 1 - PLAGIARISM	v
DECLARATION 2 - PUBLICATIONS	vi
ACKNOWLEDGEMENTS	vii
CONTENTS	viii
LIST OF FIGURE LEGENDS	x
LIST OF TABLE LEGENDS	xi
CHAPTER 1	1
Introduction	1
1.1 Background	1
1.2 Migratory fish.....	2
1.3 Fish migration in southern Africa	4
1.4 Threats and risks to migratory fishes	5
1.5 Aims and objectives	11
1.6 Structure of the thesis	11
1.7 References	12
CHAPTER 2	19
Recruitment of African glass eels (<i>Anguilla</i> spp.) into the uThukela Estuary, South Africa	19
2.1 Abstract	20
2.2 Introduction	21
2.3 Methods	24
2.4 Results	27
2.5 Discussion	30
2.6 Conclusions	33
2.7 Acknowledgements	33
2.7 References	34
CHAPTER 3	38
Fish community assessment and their drivers on the lower uMngeni River, South Africa, with an emphasis on migratory species	38
3.1 Abstract	39

3.2 Introduction	40
3.3 Methods	45
3.4 Results	48
3.5 Discussion	54
3.6 Acknowledgements	59
3.7 References	59
CHAPTER 4.....	65
General discussion, conclusions and recommendations	65
4.1 Background	65
4.2 Summary of findings	66
4.3 Recommendations	67
4.4 Conclusions	68
4.5 References	70

LIST OF FIGURE LEGENDS

- Figure 2.1:** Map of the study area showing a section of the uThukela River (formerly Tugela River) and its mouth on the eastern seaboard of KwaZulu-Natal Province, South Africa. The insert shows the locations for the placement of glass eel nets in the present study (Source: Google Maps).....26
- Figure 2.2:** Of the seven environmental variables we selected to identify the potential environmental drivers explaining eel recruitment in the uThukela River estuary, only photoperiod (proxy for flow) was shown to significantly affect the probability of glass eels in the present study.....30
- Figure 3.1:** A map showing the study area and the seven selected sample study sites (↓) as well as anthropogenic barriers (⊗) along the lower uMngeni River, one of the major rivers in KwaZulu-Natal, South Africa.....46
- Figure 3.2:** The Shannon–Weiner Index (H') and (b) Pielou's Index (J') for the different *study sites* across the lower uMngeni River catchment, *comparing those in* the mainstem (uMngeni), and the two tributaries (Palmiet River and Molweni River) in the present study.....52
- Figure 3.3:** Multivariate generalised linear model plots of the significant environmental variables against the probability of occurrence of selected fish species, namely a. *L. natalensis* and b. *O. mossambicus* in the present study.....53

LIST OF TABLE LEGENDS

Table 2.1: Summary of glass eel species caught in the uThukela River estuary from August 2020 to August 2021 in the present study.....28

Table 3.1: Summary of abundance and species diversity at the seven study sites along the lower uMngeni River, one of the major rivers in KwaZulu-Natal, South Africa, during this survey. Also included are the migratory requirements of each species as well as their conservation status (IUCN Red List of species): LC Least concern, NT Near threatened, VU Vulnerable, CR Critically endangered, IN Invasive. (Note: Study sites AL = Albizia Rd river entrance (upper Palmiet River); ML = Mclean Rd river entrance (lower Palmiet River); KK = Kranzkloof Conservancy (lower Molweni River); EV = Everton Reserve (upper Molweni River); TNB = Top Needle Bridge (upper uMngeni River); BTNB = Below Top Needle Bridge (lower uMngeni River); ES = uMngeni Estuary).....51

Table 3.2: Summary of mean values for water values measured at the different study sites in the lower uMngeni River and its tributaries during the present study. (See Figure 3.1 for site abbreviations).....54

CHAPTER 1

Introduction

1.1 Background

The diversity of aquatic environments in Africa stems from 60 international river basins (including 677 lakes), which hold a capacity of freshwater estimated at 30,000 km³ and the Eastern Indian and Western Atlantic Oceans (van As *et al.*, 2012). The presence of different oceanic currents, including Agulhas, Benguela, Somali Coastal, Guinea, Red Sea, Canary and Mediterranean currents, provides a variety of environmental conditions, especially climate and tide driven that affect both inland and marine waters across the continent (Cooper, 2002; O'Brien *et al.*, 2009; Van Niekerk *et al.*, 2013).

Estuaries are generally described as where the river and ocean meet (Whitfield, 1998; Elliot *et al.*, 2007; O'Brien *et al.*, 2009). Estuaries are unique and highly productive systems that are rich in biodiversity, as they are tidal-driven (Flint, 1985; Cooper, 2002). An intricate flow dynamic connecting freshwater systems, estuaries, and the sea needs to be maintained for optimum ecosystem functioning (Perissinotto *et al.*, 2010). Unfortunately, the ecological connectivity of these ecosystems is under significant threat by anthropogenically driven activities, such as industrial and domestic effluent discharges, and catchment-based schemes, such as the construction of impoundments (Harrison and Whitfield, 2006; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022).

Rivers and streams are among the most threatened ecosystems globally (Odume *et al.*, 2022). Human activities lead to various issues, such as the building of dams, weirs and locks, water extraction, modified river embankments, water quality issues, flow modifications from hydropower dams, and climate issues, that are significant threats to all fish species (Vorosmarty *et al.*, 2010; Gough *et al.*, 2012; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022). Worldwide, 48 % of the sum capacity of rivers is moderately

to severely modified by artificial flow regulation and river fragmentation (Grill *et al.*, 2015). As a result, many flagship migratory species (i.e. yellowfish (*Labeobarbus* spp.) and eels (*Anguilla* spp.) in South Africa) are prevented from reaching their breeding grounds (Brink *et al.*, 2018). In South Africa alone, 46% of main-stem rivers are classed as severely modified or critically endangered ecosystems (Driver *et al.*, 2012; O'Brien *et al.*, 2019). Relatively little is known about the migratory requirement of the African fish species; only a few quantitative studies have been conducted to support the understanding of the migratory habits of these fish species and their dependency on free-flowing and connected rivers (Brink *et al.*, 2018).

African rivers supply resources and services that are a significant component of the lives of people associated with them (Sadoff *et al.*, 2002; O'Brien *et al.*, 2019; Du Plessis, 2019). Fishes play a fundamental role in people's livelihoods: in Africa, ~200 million people consume freshwater fish daily, and ~10 million people are gaining an income associated with freshwater fisheries (van As *et al.*, 2012; FAO, 2022). The downside of depending on African rivers is that they are some of the most unpredictable rivers because of exceptional variability in precipitation, leading to anything from major flooding to major droughts (Cowx *et al.*, 2004; Gitz *et al.*, 2016; Brink *et al.*, 2018; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022).

1.2 Migratory fish

Migratory fish are major ecological drivers that can shape the structure and function of ecosystems (Flecker *et al.*, 2010). They are a fundamental component in maintaining food webs as either predator or prey (Brink *et al.*, 2018). There is a common hypothesis that migratory fish play a role in physically modifying a river system through nutrient cycling and the movement of biomass and energy contributed by both long- and short-distance migrations (Brink *et al.*, 2018). Ultimately, migratory fish fulfil a range of ecological niches and

functions and contribute to the natural diversity of fish assemblages (Holmlund and Hammer, 1999; O'Brien *et al.*, 2009).

Migratory fish require different habitats for different life cycle phases, including reproduction, nurseries, growth, and sexual maturation (Larinier, 2001). For fish found in freshwater, various forms of fish migration exist, including diadromous and potamodromous migrations. Diadromy is the migration of individuals between marine and freshwater ecosystems during a predictable phase of their life cycle, usually for foraging and reproductive means (McDowall, 1988; Bloom and Lovejoy, 2014). Bloom and Lovejoy (2014) described three types of diadromous migrations: catadromy, anadromy and amphidromy. Fish that carry out catadromous migration hatch in oceanic environments and migrate to freshwater environments (Myers, 1949; McDowall, 1992). In freshwater, they carry out most of their lives foraging and growing until they return to the ocean to reproduce (Lucas and Baras, 2001; Bloom and Lovejoy, 2014). Examples of fish species in South Africa which carry out catadromy include the iconic and flagship anguillid eels (*Anguilla* spp., Lucas and Baras, 2001; McDowall, 2007; Hanzen *et al.*, 2019). Fish that carry out anadromy do the opposite to catadromous species (Bloom and Lovejoy, 2014); they hatch in freshwater environments and migrate to oceanic environments (Lucas and Baras, 2001; McDowall, 2007). Here, at sea, they forage and grow until they are ready to return to freshwater to reproduce. Examples of these fish include the burrowing snake eel (*Pisodonophis boro*) found in some African estuaries (Castle, 1984). Amphidromy, on the other hand, is more intricate. McDowall (2006) refers to amphidromy as a distinctive “form of diadromy”, whereby a fish will migrate between the marine and freshwaters at particular life cycle stages but not for reproductive purposes (McDowall, 2007; Bloom and Lovejoy, 2014). These fish breed and spawn in freshwater environments, and the newly hatched larvae move immediately to marine environments for a period of foraging and growth for a relatively short period (Radtke and

Kinzie, 1987; Lucas and Baras, 2001; Franklin and Paul, 2019), then they make their way back to freshwater as their final destination, this includes small grown juveniles for a further period of foraging and growth. Here, they fully reach maturation and reproduce (McDowall, 2007). Examples of fish species which carry out amphidromous migration include eleotrids (McDowall, 1990) and Sicydiine gobies (Berrebi *et al.*, 2005), both families occurring in African aquatic ecosystems.

Lastly, potamodromous fishes have migrations occurring entirely in freshwater systems (Myers, 1949; Lucas and Baras, 2001). These fish species only migrate within freshwater environments for multiple reasons, including foraging and reproduction (Schmidt and Stillman, 1998). In South Africa, these include the yellowfishes (*Labeobarbus* spp.), the catfishes (*Clarias* spp.) and the barbs or minnows (*Enteromius* spp. and *Pseudobarbus* spp.) (Skelton, 2001).

1.3 Fish migration in southern Africa

In South Africa, 62 free-flowing rivers remain, and only 25 of these are longer than 100 km (Nel *et al.*, 2011). Approximately 100 fish species in South Africa are estimated to have requirements for migration to various degrees (Whitfield, 1990; Bok *et al.*, 2007; O'Brien *et al.*, 2018, 2019). South African inland waters are home to potamodromous and diadromous migratory fish species (Darwall *et al.*, 2009). Migratory fish are key indicator species of a given river system as they are exposed to a wide variety of habitats (O'Brien *et al.*, 2019). As they hold more specific requirements for different habitat types and connectivity, most of them are also considered flagship species (Harris, 1995; O'Brien *et al.*, 2019). In the past, fishermen have relied on the seasonal migrations of fish such as yellowfish (*Labeobarbus* spp.) seasonal movements (Impson *et al.*, 2009; Mitchell *et al.*, 2012; Burnett *et al.*, 2021, 2022), catfish (*Clarias* spp.) spawning runs in Lake Sibaya (Bruton, 1978) and included the

important economy associated with the sardine runs (*Sardinops* spp.) along the east coast (Coetzee *et al.*, 2015). Migratory fish are also a target of recreational anglers, especially yellowfish (*Labeobarbus* spp.) (O'Brien *et al.*, 2019), with a significant annual economic value of ~US\$ 9.5 million (Brand *et al.*, 2009; O'Brien *et al.*, 2019).

1.4 Threats and risks to migratory fishes

Concerns were raised by Baras *et al.* (2002) that various ecological functions delivered by migratory fish are gradually under threat by drivers related to land use alterations, including the development of impoundments/ dams, abstraction weirs, the expansion of land for agriculture and impacts from the mining industry. The probability of extinction for these fish is nearly double because of the vulnerabilities related to their migratory nature (Reide, 2004; O'Brien *et al.*, 2019). The true challenge lies in maintaining river connectivity and its related ecological services, especially in areas susceptible to drought (Arthington and Balcombe, 2011). Several fish species with obligatory and facultative diadromous and anadromous migratory patterns between freshwater, estuarine and marine systems constitute a significant component of South Africa's diversity of fish species (Whitfield, 1990; Wasserman *et al.*, 2011). The previously mentioned species have directly suffered from changes in water quality, habitat changes and reduced river flow, which all constitute the changes in continuous connectivity between river and sea (Wasserman *et al.*, 2011; O'Brien *et al.*, 2009, 2019). Regrettably, there are limited studies on the migratory ecology of almost all migratory species in South Africa, especially the relationship between migration patterns, land-use associated activities and the need for river connectivity (O'Brien *et al.*, 2019; Hanzen *et al.*, 2019, 2021; 2022).

1.4.1 The case of freshwater eels

Freshwater eels (*Anguilla* spp.) are catadromous species which spend their juvenile growth and sexual maturation phases in estuaries, rivers and lakes, while completing their spawning phases offshore in the ocean (Tesch and Rohlf., 2003). After hatching off the Mascarene Plateau, currents transport them as leptocephali (ribbon-like larvae) (Jespersen, 1942; Robinet *et al.*, 2008). They then undergo metamorphosis into glass eels after being transported by oceanic currents to their recruitment areas, where they enter estuaries and river systems (Arai *et al.*, 2002; Hanzen *et al.*, 2019, 2020, 2021, 2022). Once in river systems, they grow and spend years in freshwater as “yellow eels”, where they mature and become “silver eels” before returning to the ocean to spawn (Attaala and Rubaia, 2005; FAO-FIES, 2018). Silvering is the process whereby freshwater eel species undergo radical lifestyle changes to prepare for their oceanic migration: they stop feeding and acquire salinity tolerances while still in freshwater environments (Bruijs and Druif, 2009).

Four of these anguillid eel species are located and documented in South Africa, and the coast of east Africa, its rivers and associated islands (Hanzen *et al.*, 2019); these are namely *Anguilla bicolor*, *Anguilla marmorata*, *Anguilla mossambica* and *Anguilla bengalensis*. The long-finned eel *A. mossambica* has been documented only on the east African coast and in the Mascarene Islands (Pike *et al.*, 2020a), while the short-finned eel, *A. bicolor*, and African mottled eel, *A. bengalensis*, occur all throughout the Indian Ocean (Pike *et al.*, 2020b; Pike *et al.*, 2020c). The giant mottled eel, *A. marmorata*, is the most widely dispersed eel species, occurring across two different ocean basins, the tropical and subtropical western-central Pacific and Indian Oceans (Pike *et al.*, 2020d). These species are located in the tropical waters of the Western Indian Ocean and migrate from this area into the rivers of southern and eastern Africa. Relevant knowledge of the ecological aspects of our local African freshwater eels is limited. However, recent efforts in South Africa have focused on

their genetics (Hanzen *et al.*, 2020), their spatial ecology (Hanzen *et al.*, 2021) and their distribution (Hanzen *et al.*, 2022). A few studies have been conducted on the recruitment of glass eels into the rivers and estuaries in the Western Indian Ocean (WIO) (Jubb, 1957; Jackson, 1976; Robinet *et al.*, 2003a,b; Wasserman *et al.*, 2011).

Equally, there are limited studies on the location of spawning areas of African freshwater eels (Pous *et al.*, 2010). Jespersen (1942) first hypothesised that all East African eels spawn over the Mascarene Plateau, as he found leptocephali east of Madagascar. Two spawning grounds have been located for *A. bicolor*: one located south-west of Sumatra in the WIO (Jespersen, 1942; Arai *et al.*, 1999) and the other north-east of Madagascar (Robinet and Feuteun, 2002; Robinet *et al.*, 2008). Ishikawa *et al.* (2004) showed that *A. marmorata* has at least five peculiar geographical populations from Fiji, Madagascar, North Pacific, Sumatra, and Tahiti. The spawning ground of *A. mossambica* is located between the coast of Madagascar and the Mascarene Plateau (Robinet *et al.*, 2008), and is endemic to the African Agulhas current region (Hanzen *et al.*, 2019, 2022).

1.4.2 Threats to anguillid eel migrations

Little is known about the effect of various environmental factors on African freshwater eels, such as depth, salinity, and habitat modification (Arai and Chino, 2012; Arai *et al.*, 2020). Environmental drivers of change, such as biotic (competition and predation) and abiotic drivers (environmentally derived), are known to influence the life histories and development of anguillid eels (Jackson *et al.*, 2001). Biotic drivers such as competition and predation will influence the choice of prey and habitat as eels will move to habitats with less predation and competition pressure (Gilliam and Fraser, 2001), while abiotic drivers such as environmentally derived stressors (climate change, habitat destruction, water quality) will influence the physical habitat for anguillid eels which they can tolerate these changes over a

long period (Jackson *et al.*, 2001). In South Africa, declines in their distribution have been observed at extensive levels in KwaZulu-Natal (Hanzen *et al.*, 2022). A dangerous decline in the extent of occurrence, ranging from approximately 30 to 80%, depending on the time frame considered, was found (Hanzen *et al.*, 2022).

1.4.3 Barriers and connectivity

The nature of trophic interactions and life cycles in aquatic ecosystems relies on the connectivity of various habitats (Silva *et al.*, 2018; O'Brien *et al.*, 2019). Indicator species, like the African freshwater eels, have been used to infer the effects of the high diversity of endangered and threatened species to provide a potential cause of low migratory management (Driver *et al.*, 2012; O'Brien *et al.*, 2019). Physical barriers decrease the ecological connectivity of river systems by impeding flows and nutrient transfer, causing sediment build-up and preventing biota from migrating up or downstream (Zarfl *et al.*, 2015). River infrastructure for hydropower, water supply, irrigation, and recreation provides immediate benefits to people but hinders ecosystem services and negatively affects their well-being over time (Aylward *et al.*, 2005; MEA, 2005). Hydrological connectivity is important for the downstream movement of nutrients and the multidimensional dispersal of organisms (Pringle, 2010; Branco *et al.*, 2014). Terrestrial connectivity to aquatic ecosystems is equally crucial for nutrient sources as some species, through different life-stages, depend on both habitats (Jungwirth *et al.*, 2003). Dams negatively affect available habitat, migratory cues, reproduction and the feeding of many freshwater fish species (Brink *et al.*, 2018).

South Africa is ranked 8th among the countries with the most dams per land area (Asmal *et al.*, 2000; O'Brien *et al.*, 2019). The largest protected area in the country, the Kruger National Park (KNP) includes five major rivers within its borders, with origins outside and upstream of the park. All these river systems have dams or weirs, and additional planned

construction will result in a conservation area that hosts barriers that inhibit the function and biodiversity of aquatic ecosystems (Nel *et al.*, 2007; O'Brien *et al.*, 2018b; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022).

1.4.4 Water quality threats

Water pollution is a critical environmental problem throughout South Africa that will further intensify if no proper management is implemented (Singkran, 2017; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022). The degradation of water resources can be attributed to numerous causes, for example, natural: weathering of soils and rock, high and low flow fluctuations, or anthropogenic: domestic wastewater discharge, agricultural drainage and dam constructions (de Necker *et al.*, 2019; Toth *et al.*, 2019). To evaluate the impact of anthropogenic water use, it is important to understand how fish communities, including African freshwater eels, respond to the changes in water quality parameters (Schinegger *et al.*, 2016; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022). The most common and threatening water quality threats are chemical pollutants (nutrient pollution, heavy metal contaminants), as they are intensified through bioaccumulation (Kotze *et al.*, 1999; Coetzee *et al.*, 2002).

1.4.5 Flow regime threats

Natural flow alterations act as migratory, recruitment and spawning cues for specific species (Baumgartner *et al.*, 2014). Anthropogenic changes in the flow regime, caused by water abstractions, barriers, and channelisation, will disrupt available habitats, species distribution, hydrology and nutrient exchange (Bunn and Arthington, 2002; Poff *et al.*, 2007; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022). In turn, these changes will

affect anguillid communities through changes in their distribution, life histories and movement patterns (Bunn and Arthington, 2002; Hanzen *et al.*, 2022).

1.4.6 Habitat threats

Habitat alterations are one of the main causes of biodiversity loss (Tóth *et al.*, 2019). Habitat availability is vital for species survival as it is used to escape predation and competition. Habitats are mainly threatened due to agriculture, intensive farming, riparian vegetation removal, and instream sand mining (Carpenter *et al.*, 2011). Habitat availability and flow are strongly related, as changes in either of them will impact the other.

1.4.7 Other threats

Anguillid eels are categorised as the most cost-effective fish species as they are considered to have the largest economic value per weight of any other fish (Jackson, 1976; Zhang *et al.*, 2008; Kuroki *et al.*, 2014). A reduction in eel communities will result in losing their species-specific regulating and provisioning services, especially those concerning the ecosystem (Schabetsberger *et al.*, 2016). The overexploitation of eels may disrupt their community structure, causing a bottom-up effect in the ecosystem (Rosser and Mainka, 2002). While a large-scale export pattern has not been seen for African eels yet, international interest is growing (Hanzen *et al.*, 2019, 2022), and this threat could become significant in the next decades (Gollowk *et al.*, 2018).

Invasive species can cause changes in the way an ecosystem functions (MacRae and Jackson, 2001). Invasive species are disruptive as they are more abundant and aggressive than native species (Cucherousset and Olden, 2011; Marr *et al.*, 2017).

1.5 Aims and objectives

This study aims to fill in the gaps in knowledge regarding the African freshwater eel recruitment, especially its glass eel life stage and how river connectivity could affect the migratory patterns of other local migratory species in South Africa.

Two objectives were set to achieve this aim:

1. To evaluate the recruitment pattern of African freshwater glass eels in the uThukela River, South Africa
2. To characterise the risk of multiple stressors to the largely unknown ecology of our local migratory fish in the uMngeni River, South Africa.

1.6 Structure of the thesis

This thesis is comprised of four chapters, two of which are arranged as draft manuscripts for submission for publication in relevant international peer-reviewed journals. Thus, some repetition in the chapters was unavoidable. The hypotheses and or predictions are presented in each of these. The chapters are arranged as follows:

- Chapter 1: Introductory chapter providing a review of fish migration and ecological connectivity between marine and freshwater environments.
- Chapter 2: Recruitment of African freshwater glass eels (*Anguilla* spp.) into the uThukela Estuary, South Africa
- Chapter 3: Fish community assessment and their drivers on the lower uMngeni River, South Africa, with an emphasis on migratory species
- Chapter 4: General discussion, conclusions and recommendations chapter of overall findings of both projects, conclusions and recommendations.

1.7 References

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CHAPTER 2

Recruitment of African glass eels (*Anguilla* spp.) into the uThukela Estuary, South Africa

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Running header: Recruitment of African glass eels

2.1 Abstract

Migratory fish species form a significant part of South Africa's diversity of fish species. They provide various ecological functions that are in peril because of drivers related to anthropogenic influences, especially declining river connectivity. The iconic migratory anguillid eels (*Anguilla* spp.) of the Western Indian Ocean region have a complex life cycle using facultative catadromous migrations, including the glass eel phase, where juvenile eels enter estuaries and migrate up rivers. In this study, we investigated the recruitment of African freshwater glass eels into the uThuleka River. Glass eel nets were used to capture glass eels weekly from August 2020 to August 2021. Environmental data were collected. Glass eel species were identified by their tail and caudal fin pigmentation, together with DNA barcoding. Our findings included seasonal recruitment variation, with most glass eels caught in the wet season, in warmer temperatures, during high spring tides and at night. These findings should encourage more frequent sampling in estuaries across all seasons along the Western Indian Ocean coast, as the timing of glass eel recruitment can be used to locate where the African Freshwater glass eels' breeding area is.

Keywords: anguillid eels, connectivity, estuaries, glass eels, migration

2.2 Introduction

Several fish species with obligatory and facultative diadromous migratory patterns between freshwater, estuarine and marine systems constitute a significant component of South Africa's diversity of fish species (Whitfield, 1990; Wasserman *et al.*, 2011). Various ecological functions delivered by migratory fish in developing countries are under threat by drivers related to anthropogenic land-use alterations (Baras *et al.*, 2002). These threats include the development of impoundments/dams and abstraction weirs, land expansion for agriculture and impacts from the mining industry (Baras *et al.*, 2002). The trial lies in maintaining river connectivity and its related ecological services, more so in areas which are susceptible to drought, as in southern Africa (Arthington and Balcombe, 2011). The probability of extinction for these migratory fish species is nearly double because of the vulnerabilities related to their migratory nature (Reide, 2004; O'Brien *et al.*, 2019). In South Africa, migratory fish species populations have been directly and negatively impacted by changes in water quality, habitat changes and reduced river flow, which all affect the continuous connectivity between river and sea (O'Brien *et al.*, 2009, 2019; Wasserman *et al.*, 2011). There are limited studies on the migratory ecology of most migratory species in South Africa, especially the relationship between migration, land-use activities, and river connectivity (O'Brien *et al.*, 2019).

The anguillid eels (*Anguilla* spp.) of the Western Indian Ocean region have a dynamic life cycle that includes facultative catadromous migrations (Arai, 2002) from the Indian Ocean, possibly in the Mascarene Plateau (Pous *et al.*, 2010), into the estuaries and rivers flowing into the east coast of Africa (Robinet *et al.*, 2008). The newly hatched leptocephali (Lecomte-Finiger, 2003; Tsukamoto *et al.*, 2003) drift to the shores of Africa by oceanic current, where they undergo metamorphosis into cylindrical and transparent glass eels (Lecomte-Finiger, 2003). Glass eels enter estuaries, grow into elvers and migrate up rivers, then settle as yellow eels. They finally mature into silver eels to migrate back to the ocean to

breed and die (Arai *et al.*, 2002; Dekker, 2002). Although spawned at sea, anguillid eels can live most of their life in freshwater. This stage is usually between seven and 50 years, depending on the species, the sex thereof and its geographic location (McEwan and Hecht, 1984; Tesch *et al.*, 2003). Inter-specific competition might affect freshwater eels' habitat use and population size as riverine eels use the same freshwater system (Jellyman and Sykes, 2003). To counter this inter-specific competition, sympatric eels may exhibit local differences in habitat preference or feeding habits (Hanzen *et al.*, 2022).

Four anguillid eel species occur in eastern South Africa: *Anguilla bicolor*, *Anguilla marmorata*, *Anguilla mossambica* and *Anguilla bengalensis* (Hanzen *et al.*, 2019, 2022). Few studies have examined the recruitment of eels in the Western Indian Ocean region. Some research from Réunion describes glass eel migrations between November and April, which coincides with the rainy season (Robinet *et al.*, 2003). In South Africa, the recruitment of *A. mossambica* at 50 – 60 mm size from September to February was observed in the St Lucia estuary in KwaZulu-Natal Province (Harris and Cyrus, 1995). Wasserman *et al.* (2011) observed *A. marmorata* and *A. mossambica* recruitment in November and December in the Eastern Cape Province, South Africa. They are thought to migrate at night when river flows are high (Bruton *et al.*, 1987).

A high variation in the annual recruitment of eels is also expected as seasonal rainfall can be erratic in southern Africa, as observed in the Indian Ocean islands (Robinet *et al.*, 2003). In addition, lunar periodicity is singled out as one of the possible triggers for the synchrony of hatching (Tsukamoto *et al.*, 2003). Similarly, it is known that the recruitment of glass eels to the coast and estuaries is dependent on the lunar cycle and tidal times (McCleave and Wippelhauser, 1987), which suggests that the existence of an internal clock driven by the lunar cycle (Tsukamoto *et al.*, 2003). Thus, the lunar cycle could be a key regulator of African freshwater eel recruitment activity. Eel species are highly sensitive to light (Haddingh *et*

al., 1999), and some have suggested that light inhibition outpaces the stimulatory effect of flow (Bardonnet *et al.*, 2005). Eels tend to avoid bright lights, and this is where turbidity plays a critical role. Some studies illustrate the effect of wind and rainfall on rivers, causing increased water turbidity (Yin *et al.*, 2004; pers. obs.). No studies have been conducted in Africa on the effect of turbidity on the recruitment of eels.

In South Africa, the uThukela catchment is the second biggest in the country and is ecologically important and holds a good population of anguillid eels (Hanzen *et al.*, 2022). This system also plays an important role in forming the marine associated “uThukela Banks”, which is an inshore and offshore conservation area in South African waters (DST, 2007), as its estuary is river-dominated, small, and allows most matter to pass through it into the sea. The uThukela River mouth supports subsistence, commercial and recreational fishing (pers. obs.). Unfortunately, possible future reductions in flow from the uThukela River because of water abstraction, especially in the lower stretch of the system, may negatively impact the ecology of the bank (De Lecea and Cooper, 2016) as well as the maintenance of its eel populations. The lower reach of the uThukela River is important as it is the link between the river and the receiving marine environment; however, recent developments have impaired its ecological connectivity. Impacts on the water resources in the area include various water quality-related impacts, as well as water quantity and habitat state impacts (Stryftombolas, 2008), which could also be impacting the uThukela Estuary and, ultimately, the marine environment.

There is little to no research on the ecological connectivity within the lower uThukela River. A major hindrance to this connectivity is the ZAR1 Billion weir, abstraction works, and water treatment works built on the lower uThukela River; the Lower Thukela Bulk Water Supply Scheme (LTBWSS) has been supplying people with water since 2017 and is also classified as one of the largest bulk potable water infrastructures in KwaZulu-Natal (DWS,

2012). Physical barriers such as these degrade the ecological connectivity of a river by affecting flows, sediment buildup and the upstream and downstream migration of aquatic biota (Zarfl *et al.*, 2015). While these barriers directly benefit the community (i.e. water supply), they hinder ecosystem services and negatively affect their well-being as time passes (Aylward *et al.*, 2005; MEA, 2005).

In the present study we investigated the recruitment of African glass eels (*Anguilla* spp.) into the uThukela River estuary, South Africa. We hypothesised that the *Anguilla* spp. migration is seasonal, and predicted that they migrate into estuaries during the wet season or austral spring and summer, coinciding with high river flow periods in South Africa. We also hypothesized that glass eel recruitment is affected by light and lunar phases, so we predicted that they would recruit into estuaries at night and according to particular moon phases. In addition, we expected that the four different eel species would recruit into the estuary at different age/size classes and at different times of the wet season.

2.3 Methods

2.3.1 Study area

The area considered for this study is the uThukela River Mouth, KwaZulu-Natal, South Africa (Figure 2.1). The uThukela River spans from the Drakensberg mountains and flows eastward through the open Tugela River mouth, spilling into the Western Indian Ocean (De Lecea and Cooper, 2016). The uThukela catchment is the second largest in South Africa, with a collective catchment area of 28 000 km² (DWAF, 2003), and a mean annual runoff ~ 3,799 million m³ per annum (DWA, 2013). The rainfall patterns and climate differentiate widely from more wet and cold environments in the Drakensberg, to dry and hot environments in the valley of the uThukela River, to the humid and hot coastal environment (DWAF, 2004)

The lower reach of the uThukela River, from the confluence with the Nembe River to the uThukela Estuary, is a ~30 km stretch of river (DWAF, 2003c). The Lower uThukela Bulk Water Supply Scheme, an abstraction weir which was successfully commissioned in 2017 and supplies potable water to areas in the nearby KwaDukuza and Mandeni Local Municipalities (Umgeni Water, 2017), has been fitted with a fish pass and a “creeper-crawler” rock ramp designed for eels and migratory macro-invertebrates such as *Varuna lateralis* and *Macrobrachium* spp. (Burnett *et al.*, 2024)

2.3.2 Sampling techniques

We conducted monthly glass eel surveys on the northern bank of the estuary of the uThukela River from August 2020 to August 2021. For each survey, we used glass eel nets ($n = 1$ to 8) for four to six consecutive nights, depending on weather and river conditions, which were checked at sunrise and sunset each day. The number of nets used depended on the state of the river, procurement issues (number of nets available per month), and theft by local fishermen. Glass eel nets were set long on the river's bank (Figure. 2.1). The top of the net and one wing were tied to the vegetation on the bank, and the other wing was placed in the water flow, tied to, and supported by a wooden pole. Nets were checked every morning after sunrise and each evening before sunset. All glass eels caught were removed from the nets, measured for total length and tail pigmentation, and released in the same area caught. During each monthly survey, we also collected environmental data (moon illumination, high tide and low tide times, photoperiod, electrical conductivity, water temperature, and pH). We determined moon illumination using the My Moon Phase app (Playstore, 2022) and electrical conductivity, water temperature, and pH using a calibrated multimeter (Hanna Instruments, Johannesburg, RSA).

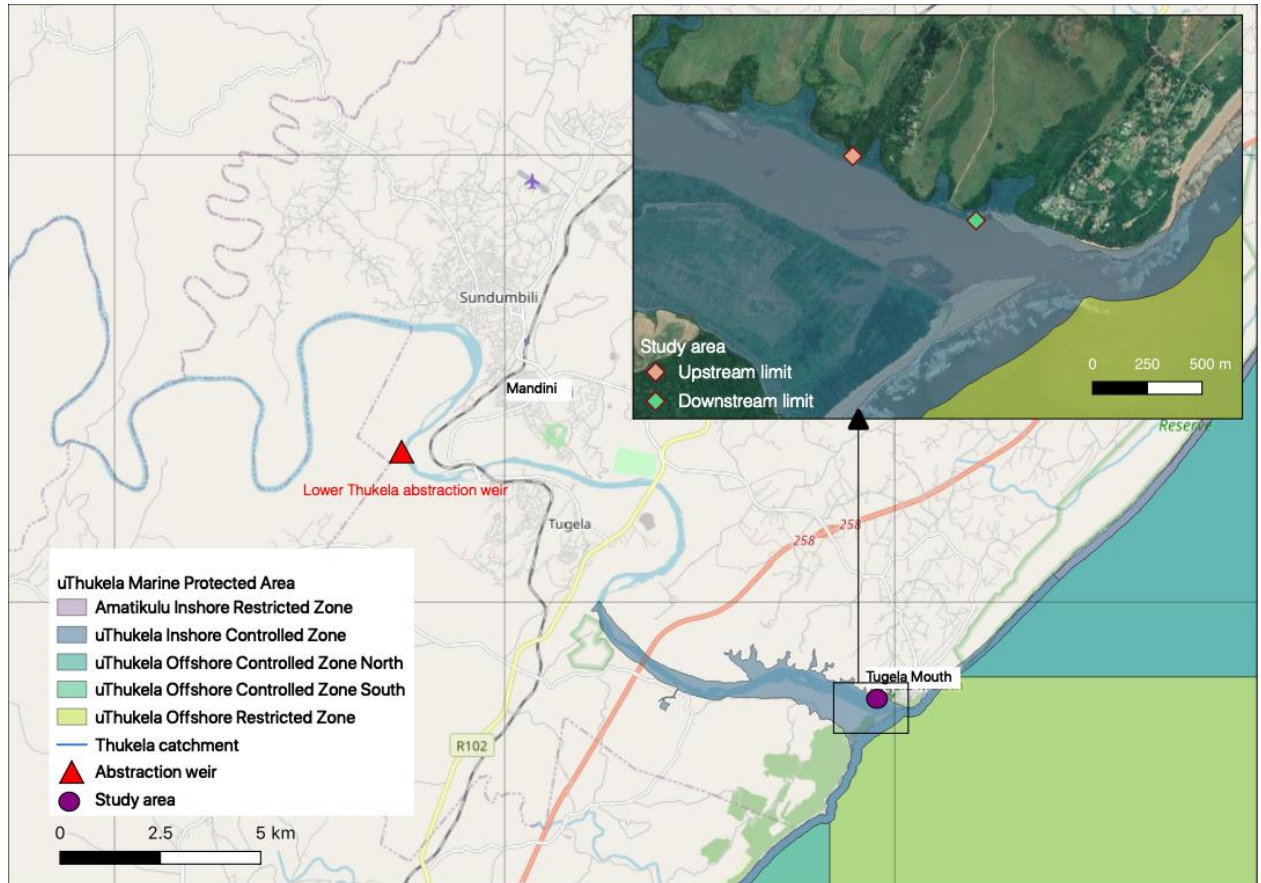


Figure 2.1: Map of the study area showing a section of the uThukela River (formerly Tugela River) and its mouth on the eastern seaboard of KwaZulu-Natal Province, South Africa. The insert shows the locations for the placement of glass eel nets in the present study (Source: Google Maps).

2.3.3 Glass eel identification

As mentioned, species identification at the glass eel stage is difficult because morphological characters are not clearly established (Aoyama *et al.*, 1999; Mochioka, 2003). We used the Ege (1939) guide for the identification of freshwater glass eel species by examining the morphological characteristics of the tail and the caudal fin pigmentation (Reveillac *et al.*, 2009).

In addition, a sub-sample size of glass eels was taken to confirm species identification using DNA barcoding following Hanzen *et al.* (2021). These glass eels were euthanised using

an overdose of 2-phenoxyethanol and then stored in 70 % Ethanol. Barcoding was then performed at the University of KwaZulu-Natal Conservation Genetics Laboratory, Pietermaritzburg campus, following the protocol developed by Hanzen *et al.* (2021). Sanger sequencing was conducted by the Central Analytical Facility at the University of Stellenbosch, Stellenbosch.

All sequences obtained were checked using Basic Local Alignment Search Tool (BLAST) against the National Centre for Biotechnology Information (NCBI) GenBank (<https://www.ncbi.nlm.nih.gov/genbank/>). Similarity scores >95% were accepted as confirming species identification.

2.3.4 Data analyses

We used a general linear model (GLM) approach (Wang *et al.*, 2012) to test the effect of environmental variables on eel recruitment. We selected seven environmental variables (moon illumination, high tide and low tide times, photoperiod, electrical conductivity, water temperature, and pH) to identify the potential environmental drivers explaining eel recruitment in the uThukela River estuary. We incorporated a Poisson distribution into these models. We evaluated the goodness of fit for the model with a Kolmogorov-Smirnov test using the DHARMA package (R Core Team, 2019).

2.4 Results

2.4.1 Glass eel species caught

We found the size of glass eels at recruitment for each species varied during recruitment as there was a variation in sizes between the two sampled species. We collected a total of 18 glass eels during this study in the uThukela River estuary from August 2020 to August 2021. All glass eels were collected when captured; morning checks following overnight netting

produced glass eels, while none were captured during the day. We identified two eel species by means of the tail and caudal fin pigmentation (Reveillac *et al.*, 2009), namely *A. marmorata* (n = 6) and *A. mossambica* (n = 12) (Table 2.1). The body length size of the glass eels caught in the uThukela River estuary varied with the mean (\pm SD) of *A. mossambica* 52.8 mm (n = 12; min = 48 mm, max = 61 mm) and for *A. marmorata* 54.2 mm (n = 6; min = 50 mm, max = 59 mm).

Table 2.1: Summary of glass eel species caught in the uThukela River estuary from August 2020 to August 2021 in the present study.

Individual	Species	Size (mm)	Season caught	Date caught	Moon illumination (%)	Tide
1	<i>A. mossambica</i>	51	Spring	28/10/2020	90.9	Spring
2	<i>A. mossambica</i>	58	Spring	28/10/2020	90.9	Spring
3	<i>A. mossambica</i>	55	Spring	30/10/2020	98.6	Spring
4	<i>A. mossambica</i>	49	Spring	18/11/2020	14.3	Spring
5	<i>A. mossambica</i>	51	Spring	18/11/2020	14.3	Spring
6	<i>A. mossambica</i>	48	Spring	19/11/2020	23.0	Spring
7	<i>A. mossambica</i>	61	Spring	19/11/2020	23.0	Spring
8	<i>A. mossambica</i>	52	Spring	20/11/2020	32.6	Neap
9	<i>A. marmorata</i>	55	Spring	20/11/2020	32.6	Neap
10	<i>A. marmorata</i>	57	Summer	03/12/2020	92.2	Spring
11	<i>A. mossambica</i>	49	Summer	05/12/2020	77.9	Spring
12	<i>A. mossambica</i>	52	Summer	05/12/2020	77.9	Spring
13	<i>A. mossambica</i>	56	Summer	30/01/2021	99.4	Spring
14	<i>A. marmorata</i>	59	Autumn	07/04/2021	20.3	Spring
15	<i>A. mossambica</i>	52	Autumn	07/04/2021	20.3	Spring
16	<i>A. marmorata</i>	50	Autumn	20/05/2021	60.6	Neap
17	<i>A. marmorata</i>	51	Winter	28/07/2021	83.6	Spring
18	<i>A. marmorata</i>	53	Winter	27/08/2021	80.4	Spring

We caught most glass eels in the wet season (72%, Table 2.1) during the austral spring and summer. Of these glass eels, 66% of *A. mossambica* (n = 8) and 17% of *A. marmorata* (n = 1) were caught in spring (Table 2.1). Only 25% of *A. mossambica* (n = 3) and 17% of *A. marmorata* (n = 1) were caught in the summer (Table 2.1). In autumn, only 8% of *A. mossambica* (n = 1) and 33% of *A. marmorata* (n = 2) were caught (Table 2.1). In winter, no *A. mossambica* (n = 0) and 33% *A. marmorata* (n = 2) were caught (Table 2.1). Overall, 92% of *A. mossambica* (n = 11) and 33% of *A. marmorata* (n = 2) were caught in the wet season (spring/summer) (Table 2.1). In comparison, 8% of *A. mossambica* (n = 1) and 66% of *A. marmorata* (n = 4) were caught in the dry season (autumn/winter) (Table 2.1).

The subsample size, which underwent DNA analyses, supported our species identifications. Of the 11 results, two were unconfirmed, while of the remaining nine glass eels selected, three were *A. marmorata*, and six were *A. mossambica*.

2.4.2 Drivers of eel recruitment

Of the seven environmental variables (moon illumination, high tide and low tide times, photoperiod, electrical conductivity, temperature and pH) we selected to identify the potential environmental drivers explaining eel recruitment in the uThukela River estuary, only photoperiod was shown to be significant (GLM, $P = 0.0008$; Figure 2.2). The P-values of all the other variables were greater than 0.05. In addition, we found that most glass eel recruitment occurred during high spring tides (83%, Table 2.1). However, 50% of the glass eels (n = 9) were caught during low moon illumination (Table 2.1) when there were high spring tides. As seen from the results above (Table 2.1), glass eel recruitment occurred mostly during the spring tide, then during the neap tides, and during or nearing the full moon (Moon illumination varies with a mean = 57.4%).

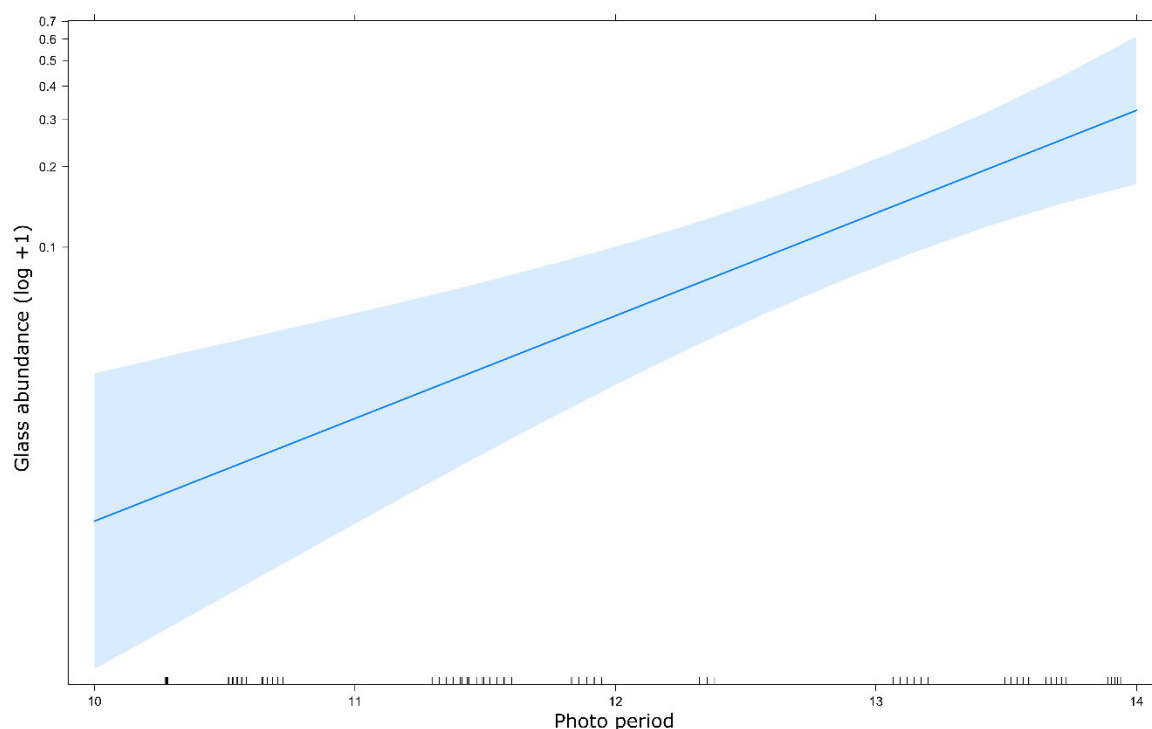


Figure 2.2: Of the seven environmental variables we selected to identify the potential environmental drivers explaining eel recruitment in the uThukela River estuary, only photoperiod (a proxy for flow) was shown to significantly affect the probability of glass eels in the present study.

2.5 Discussion

To our knowledge, this is the first study focused on glass eel sampling in South Africa with regard to the duration of sampling, with the nearest reference site in Madagascar. We only caught 18 glass eels of two species, namely *A. marmorata* (n = 6) and *A. mossambica* (n = 12), during our monthly sampling in the uThukela River estuary from August 2020 to August 2021.

Generally, there is variation in the body length size of glass eels at recruitment for the different species when they enter rivers (Robinet *et al.*, 2003; Reveillac *et al.*, 2009; Hanzen *et al.*, 2019). We found seasonal variation in the glass eel recruitment. Overall, we caught the

most glass eels in the wet season (72%), as predicted. This is the regular period of the year when most of the region's rainfall occurs (Suhardono, 2000). However, we caught most *A. mossambica* (92%) in the wet season (spring/summer), while most *A. marmorata* (66%) were caught in the dry season (autumn/winter). Previous studies have observed glass eels of *A. marmorata* and *A. mossambica* moving into South African estuaries during the wet season (November – December) (Wasserman *et al.*, 2011). Generally, the migration of these individuals appears to coincide with the higher South African river flow during the wet season (Jubb, 1957; Bruton *et al.*, 1987). Upstream migration of glass eels may also differ across the years as seasonal rainfall in southern Africa can be unpredictable and irregular, as there have been cases of prolonged extreme drought (Jackson, 1976; Hanzen *et al.*, 2019).

Generally, glass eel recruitment times differ between regions and according to species (Hanzen *et al.*, 2019). Although each species is known to have recruitment peaks (Robinet *et al.*, 2003), glass eels are expected to occur along the east African coastal regions throughout the year (Hanzen *et al.*, 2019, 2022). Although relatively few numbers of individuals were caught, most of them were caught during the wet season. While discharge was not available, we used the photoperiod as a proxy. Indeed, the duration of the photoperiod is dependent on the season, and the austral summer has the longest photoperiod as well as the highest discharge in the region (Houde *et al.*, 2022; Kamal *et al.*, 2023). Photoperiod, together with other environmental drivers (i.e., temperature, conductivity, pH and total dissolved solids), can affect the biological functionality of animals, thus influencing energy allocation, food utilization and movement (Biswas and Takeuchi, 2002; Alsqufi *et al.*, 2021). Almazán-Rueda *et al.* (2005) mention that the requirements for photoperiod are species-specific and vary for each developmental phase, in this case, the glass eel life stage. Photoperiod is considered an environmental cue for various fish species which regulates fish growth reproduction, locomotion, metabolic rates, sexual maturation, social behaviour survival, and body

pigmentation (Duston and Saunder, 1990; Silva-Garcia, 1996; Boeuf and Bail, 1999; Boeuf and Falco, 2001; Trippel and Neil, 2002; Biswas and Takeuchi, 2002; Biswas *et al.*, 2002, 2005; Mendonça *et al.*, 2009; Alsaqufi *et al.*, 2021).

It is commonly known that the recruitment of glass eels to coastal waters is reliant on the lunar cycle and tidal patterns (McCleave and Wippelhauser, 1987; Tsukamoto *et al.*, 2003), suggesting the existence of an internal clock is triggered by the lunar cycle. Generally, glass eels use selective tidal stream transport to migrate upstream with the tides (McCleave and Wippelhauser, 1987). We found most glass eel recruitment was during high spring tides when the highest volume of seawater enters the river systems (Dou *et al.*, 2003). Similarly, studies on other tropical eels in the Indian Ocean have found that the movement of glass eels occurs predominantly at night during high spring tides (Tesch, 1977; Sorensen and Bianchini, 1986). The tropical *A japonica* glass eels' activity was low at low temperatures (Dou *et al.*, 2003). Similarly, we found fewer glass eels during the colder, dry winter season. Generally, our study supports previous African studies that show that glass eels enter estuaries during high tides in summer, which is associated with higher temperatures, water temperatures, and river flows.

In the present study, we found that glass eel recruitment was at night. Other studies also show that glass eels enter rivers mostly at night in southern Africa (Kiener, 1963; Bruton *et al.*, 1987) and elsewhere (Tzeng, 1985; Dou and Tsukamoto, 2003). Furthermore, a few studies in southern Africa show that adult *A. marmorata* and *A. mossambica* are active mostly at night (Jubb, 1961; Pienaar, 1978; Skelton, 2001; Hanzen *et al.*, 2019). We found 50% of glass eels were caught during stages of low moon illumination, but this may be related to spring high tides or reduced predation.

The study did not come without its challenges. For starters, tides heavily impacted the sample site, and this could, thus, contribute to low catches. Some days were rainy and

overcast, making moon illumination data for glass eel recruitment unreliable. In addition, nets would be removed from the riverbank on occasional day and night at times by curious locals, which could have made us miss windows of catching more glass eels.

2.6 Conclusions

African freshwater glass eel recruitment occurred mostly in warmer temperatures consistent with spring tide occurrences and mostly at night. This showed similarities with its tropical cousins (*A. japonica*), who also portray tropical, spring tide recruitment, and a breeding site has been pinpointed. The findings of this study should encourage more sampling along the South African East Coast more frequently as the timing of glass eel recruitment can be used to locate where the African freshwater glass eels' breeding area is.

2.7 Acknowledgements

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CHAPTER 3

Fish community assessment and their drivers on the lower uMngeni River, South Africa, with an emphasis on migratory species

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Running header: Fish community assessment

3.1 Abstract

Freshwater ecosystems provide the most basic human/ animal needs but are severely being altered. This leads to several ecological degradations, including lack of river connectivity. Reduced river connectivity negatively affects migratory fish species that perform fundamental ecological functions. This study aimed to characterise the risk of multiple stressors to an unknown ecology of fish communities and their environmental drivers in the lower part of the uMngeni River catchment. We investigated the species diversity and evenness across seven sites in the lower part of the uMngeni River catchment using fish sampling methods: fyke, seine and electroshocking. We used various statistical analyses to evaluate the relationship between fish communities and environmental variables, including barriers. The results showed distinct fish community structures found across all sites in the catchment, which were susceptible to multiple stressors impacting migratory fish. These stressors result in impaired river connectivity, which reduces a fish's ability to recolonise a river's range sufficiently. Restoring and considering river connectivity in the lower uMngeni catchment can potentially improve fish communities.

Keywords: migratory species; river connectivity; multiple stressors; ecological condition.

3.2 Introduction

Freshwater ecosystems provide fundamental resources for the development of humanity, including flood control, habitat for plants and animals, and production of fish (Baron *et al.*, 2002; O'Brien *et al.*, 2009). Globally, growing human populations and the associated development and activities bring detrimental consequences. Consequently, freshwater ecosystems are being severely altered at a rate greater than that of any other time in human history and at a rate faster than they are being restored (NRC, 1992; Tejerina-Garro *et al.*, 2005; Dudgeon, 2014; Rodell *et al.*, 2018; Du Plessis, 2019). Similarly, South Africa's freshwater ecosystems are being negatively impacted. The Department of Environmental Affairs and Tourism (DEAT) declared that 82% of South Africa's main river ecosystems are threatened by flow modification, alien invasive species, and pollution from numerous anthropogenic activities (DEAT, 2009; Thirion and Jafta, 2021). This has affected freshwater availability (loss and degradation) and reduced river connectivity (Skowno *et al.*, 2019).

Water is increasingly becoming a limiting resource in South Africa; the supply of water will become a major constraint to the future socioeconomic development of the country in terms of both the amount and quality of available water (DEAT, 2006). Moreover, socio-political and economic inequalities affect access to clean, drinkable water and water-based sanitation (Swatuk, 2002; Van Deventer *et al.*, 2021). Increasing pressure from different sectors (including agriculture, mining, and industry) puts South Africa's rivers at even more risk (O'Brien *et al.*, 2019). As a result, the need to monitor water quality and river health is gaining rapid importance to guarantee sustainable use and mitigation against rising threats (Malherbe *et al.*, 2010; Evans *et al.*, 2022).

Ecosystem services provided by rivers include water purification, transportation, power generation, food supply, and water supply (for domestic, agricultural, and industrial use) (Tejerina-Garro *et al.*, 2005; Yeakley *et al.*, 2016). A given system's well-being and

ability to provide such services depend on the connectivity between all its components (O'Brien *et al.*, 2019). Fish species are excellent indicators of ecological connectivity in river systems because of their ability to move within the confines of a river system (Jungwirth *et al.*, 2003). Further, migratory fish are important indicator species of river health as they are exposed to a wide variety of habitats; they have specific habitat requirements for biology processes and rely on connectivity between these habitats (Harris, 1995; O'Brien *et al.*, 2019).

Various ecological functions delivered by migratory fish, especially in developing countries, are threatened by drivers related to anthropogenic land-use alterations, including the development of impoundments/ dams, abstraction weirs, the expansion of land for agriculture and impacts from the mining industry (Baras *et al.*, 2002). Fish migrations have multiple limitations, but the main limitation is the loss of connectivity within a riverine system (O'Brien *et al.*, 2009). This loss of river connectivity can lead to the interruption, delay, or failure of migration (O'Brien *et al.*, 2019), posing a threat to the reproduction, foraging and survival of a migratory species (Baras *et al.*, 2002). Furthermore, impoundment/ dam development and the construction of barriers (i.e., abstraction weirs) have disrupted the large-scale migration of several fish species (O'Brien *et al.*, 2019). These developments result in the fragmentation of and limited access to required aquatic habitats by migratory fish, decreasing their resilience and persistence (Fagan, 2002; Fullerton *et al.*, 2010). Consequently, worldwide extreme loss in aquatic biodiversity is expected as river connectivity is reduced (Pringle *et al.*, 2000; Rosenberg *et al.*, 2000). It is presumed that 10,000-20,000 freshwater species are at risk of or are already extinct because of loss of connectivity in water systems (Vörösmarty *et al.*, 2010).

A significant component of South Africa's diversity of fish species includes species exhibiting migratory patterns between freshwater, estuarine and marine systems (Whitfield, 1990; Wasserman *et al.*, 2011). Many of these species have been negatively impacted by

changes in water quality, habitat changes and reduced river flow, which all further contribute to disruptions in continuous connectivity between river and sea (O'Brien *et al.*, 2009, 2019; Wasserman *et al.*, 2011). Fish species threatened because of the loss of ecological connectivity, include, for example, freshwater eels *Anguilla* spp., for which dramatic declines have been observed in KwaZulu-Natal (Hanzen *et al.*, 2022).

Potamodromous fish species spend all their life in freshwater and migrate within a given system, depending on ecological connectivity to complete their life cycle (Bloom and Lovejoy, 2014). Potamodromous species are categorised by migrations associated with spawning activities, passive drift of larvae and juveniles, age-related habitat changes, response to flooding, seasonal habitat shifts, dispersal migrations and/or foraging activities (Waidbacher and Haidvogel, 1998; Jungwirth *et al.*, 2003). These migrations are often caused by multiple complex and interacting drivers (Lucas and Baras, 2001), such as water temperature and discharge. In South Africa, potamodromous species can provide fundamental information on river health on a local level (Kleynhans *et al.*, 2007; O'Brien *et al.*, 2019), such as yellowfish *Labeobarbus* spp. and minnows *Enteromius* spp. that have shown to use different habitats at different life stages and biological processes (Fouche, 2009; Burnett *et al.*, 2018; Burnett *et al.*, 2021)

In contrast, diadromous fish species complete their life cycle in both marine and freshwater environments (McDowall, 1988; Bloom and Lovejoy, 2014). These include catadromous, anadromous, and amphidromous species (Bloom and Lovejoy, 2014). For diadromous species, the ecological connectivity between freshwater and the sea is important for the interactions of physical, chemical, or biological processes between various terrestrial and marine ecosystems (O'Brien *et al.*, 2009). Connectivity between land and sea is characterised by two types: functional connectivity (allowing migration) and bio-geochemical connectivity (primarily produced by river nutrient transport) (Hanzen *et al.*, 2019). Functional

connectivity is needed for the migration of fish species between habitats during their various life stages and for growth (O'Brien *et al.*, 2019). Functional connectivity facilitates tidal migration, foraging migration, and breeding migration (Burnett *et al.*, 2021).

Consequently, many potamodromous, diadromous fish species in South Africa require functional connectivity (Whitfield, 1990; Wasserman *et al.*, 2011; O'Brien *et al.*, 2019). These include the iconic long-distance catadromous, a diadromous species, the African freshwater eel *Anguilla* species that depend on the connectivity between the river and sea (Hanzen *et al.*, 2019, 2022). These species spawn at sea, are transported as larvae to the coast, enter estuaries as glass eels, and migrate up rivers as elvers. At this stage, they can overcome considerable natural barriers (Hanzen *et al.*, 2019, 2022). In freshwater, they mature until they are ready for their downstream migration back to their oceanic spawning grounds (Jacoby *et al.*, 2015). Iconic species like these offer distinctive insight into the physical, chemical, and hydrological regimes and connectivity at a catchment level (O'Brien *et al.*, 2019). Another example of diadromous migratory fish is the amphidromous species, *Eleotris fusca*. This species requires connectivity between the lower reaches of rivers and its estuary, highlighting the importance of connectivity. *E. fusca* portrays a life cycle that breeds in freshwater, and their larvae drift downstream to the sea. Which we only located in one of our sites.

In South Africa, the uMngeni River is an ecologically and economically important catchment (Hughes *et al.*, 2018a,b). It provides for a population of ca. four million people, including the population of Durban and Pietermaritzburg in KwaZulu-Natal Province (Roberts and O'Donoghue, 2016; Ethekewini, 2018). Unfortunately, the water demand in the uMngeni catchment has surpassed the river's ability to supply resources (WRC, 2002; Hughes *et al.*, 2018a,b). Furthermore, the building of impoundments on the river for water supply has impacted the sections of the river downstream of these with significantly decreased river width, reduced flow, and modified habitats, resulting in fewer fish and reeds (Matongo *et al.*,

2015). The flow is prioritised for water consumption and industry demand, with ecological needs often neglected; this degrades the river and estuary compounded by the large volume of anthropogenic pollutants (WRC, 2002; Evans *et al.*, 2022). The lower uMngeni River, downstream of Inanda Dam, is in the eThekweni Municipality (Greater Durban) with multiple land use types and activities producing environmental stressors that impact this section of the river (Thirion and Jafta, 2021; Evans *et al.*, 2022). This part of the river was described as extensively modified during the River Health Program (Thirion and Jafta, 2021; Evans *et al.*, 2022). The riparian vegetation and river channel have been significantly modified to accommodate various human settlements along the river with their accompanying activities (WRC, 2002; Evans *et al.*, 2022).

For centuries, the natural landscape has been modified physically and chemically to meet socio-economic needs (i.e. water and food security), these modifications to land use and land cover has a huge impact on hydrological responses and therefore on water resources (Warburton *et al.*, 2012). Aquatic ecosystems are severely impacted by the degradation of urban streams via geomorphological and chemical changes to water bodies. Numerous studies have reported a loss of fish diversity, richness and biotic integrity, where sensitive species disappear, and tolerant species become more abundant (Wenger *et al.* 2009). An excellent instance of this phenomenon occurring throughout the entire uMngeni catchment, is the increase of algal blooms because of the expansion of informal settlements, stray livestock and poor sanitary systems creating urban run-off into the Palmiet, Molweni and uMngeni Rivers (Namugize *et al.*, 2018). In terms of fish communities, this site recorded an ecological status E/F (seriously to critically modified) because of all these negative impacts (WRC, 2002; Thirion and Jafta, 2021; Evans *et al.*, 2022).

In the present study, we aimed to characterise the risk of multiple stressors on fish communities, including known migratory fish and their associated drivers in the lower part of

the uMngeni River catchment. To do this, we investigated the species diversity and evenness across sites in the lower part of the uMngeni River catchment. We also investigated their associated habitats, water quality, and ecological connectivity at each site. We predicted that the range of anthropogenic factors especially impacts migratory fish species negatively.

3.3 Methods

3.3.1 Study area

The uMngeni River is one of the major rivers in KwaZulu-Natal, South Africa, with a catchment area of ~4418 km² and an estimated length of 225 km (WRC, 2002; Agunbiade and Moodley, 2014; Namigize *et al.*, 2018). Four major impoundments on the uMngeni River's main stem, namely Midmar Dam, Albert Falls Dam, Nagle Dam, and Inanda Dam, affect river connectivity. For this study, we considered the lower uMngeni River from below Inanda Dam as our upstream limit for the study (Fig. 3.1). From Inanda Dam, the river flows with a gentle gradient for 24 km before emptying into the Western Indian Ocean through the uMngeni River estuary at Blue Lagoon (WRC, 2002; Agunbiade and Moodley, 2014; Fig. 3.1). The lower river passes through a mosaic landscape including areas with natural vegetation, areas with a range of agricultural practices and numerous rural communities, as well as extensive built urban areas with industry and residential areas (Matongo *et al.*, 2015; Evans *et al.*, 2022). Importantly, several instream barriers prevent the movement of fish (Fig. 3.1), especially the anguillid species. If fishes that require movement cannot move with this reach, mitigation measures placed onto Inanda Dam to provide connection to the rest of the catchment may be futile, although anguillid eels can conquer most small barriers (e.g. causeways), but other freshwater fish have less ability to conduct such movements.

To assess the instream barriers and fish communities, we selected seven sampling sites along the lower uMngeni River catchment (Fig. 3.1), including one site on the mainstem, two

sites each on two tributaries (Palmiet River and Molweni River) and one site in the river mouth. The Palmiet River catchment drains an area of $\sim 37 \text{ km}^2$, and it also runs a length of 23 km before meeting the uMngeni River (du Preez and de Villiers, 1987; Naidoo, 2005). The Molweni River flows through the Kloof Conservancy (including the Kranzkloof Nature Reserve), where it joins the uMngeni River further downstream, a distance of $\sim 3.2 \text{ km}$. Finally, the uMngeni estuary is a river-dominated estuary, with its mouth artificially by a groyne, which keeps the estuary open unless the river discharge is exceptionally low (Cooper, 1993).

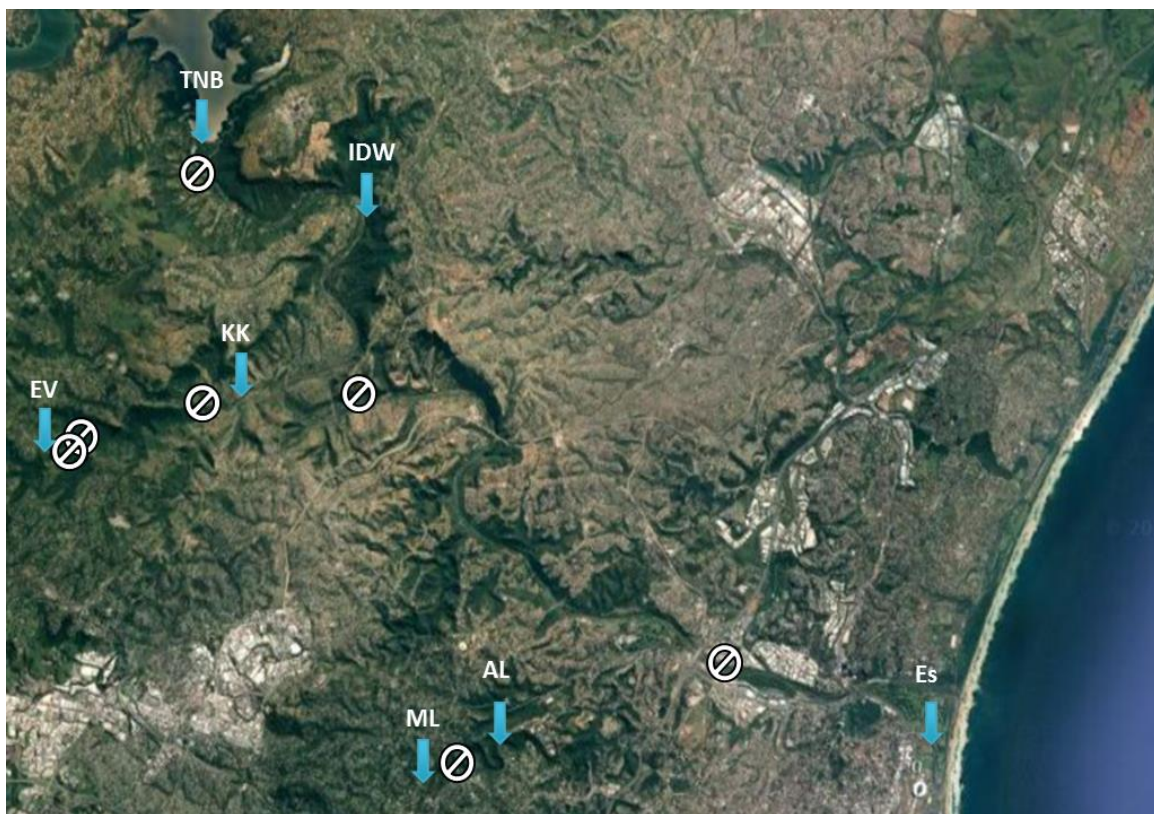


Figure 3.1: A map showing the study area and the seven sample sites (↓) as well as anthropogenic barriers (⊗) along the lower uMngeni River, one of the major rivers in KwaZulu-Natal, South Africa. Site AL = Albizia Rd river entrance (upper Palmiet River); ML = Mclean Rd river entrance (lower Palmiet River); KK = Kranzkloof Conservancy (lower Molweni River); EV = Everton Reserve (upper Molweni River); TNB = Top Needle Bridge (upper uMngeni River); BTNB = Below Top Needle Bridge (lower uMngeni River); ES = uMngeni Estuary)

3.3.2 Sampling techniques

Fish sampling took place in March, June and September 2021 at each site. We placed 3-5 fyke nets and 1-2 glass eel nets in the river from sunset to sunrise the following day. When overnight nets were collected, we did additional sampling using a running seine net and an electro-shocker (Eigevis group of companies, Cape Town, South Africa) in suitable habitats. We collected all fish caught and held them in 25 L containers until all collections at the site was completed. This allowed for fish to be kept in their respective sampling efforts for analyses. We measured fish, namely, the standard length (SL) and total length (TL) to the nearest millimetre. We assessed the available habitat visually and recorded dominant substrate, depth, water velocity, and substrate (which included sand, mud, sludge, gravel, cobble, boulders, and bedrock) following Kleynhans (1999). When sampling at each site, we measured several water variables, namely, temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) *in situ* using a calibrated multimeter (Hanna Instruments, Johannesburg, RSA). The surveys in this study were carried out with the approval from Ezemvelo KZN Wildlife (permit number: OP871/2021) and the Animal Research Ethics Committee at the University of KwaZulu-Natal.

3.3.3 Data analyses

We used a range of statistical analyses to assess the relationship between fish communities and a selection of environmental variables. All the statistical analyses were conducted in R version 3.6.3 (R core Team, 2020). To analyse the diversity and species evenness of the fish communities per study site, we calculated the Shannon-Weiner diversity index (H') and Pielou's species evenness index (J') from count data using the 'vegan' package in R (Oksanen

et al. 2019). We determined if the results were significant for H' and J' between rivers and between sites in the catchment using the Kruskal-Wallis test.

We used a modelling-based approach (Burnham and Anderson, 2002) to (1) ascertain the differences in the structure of the fish communities between rivers and between sites and (2) to determine associate drivers, as done in other similar studies. We used multivariate generalised linear models (MGLM) with the ‘mvabund’ package in R (Wang, 2012). We used species presence as an independent variable, and a binomial distribution was incorporated into the model. A full model was tested using the environmental variables dominant substrate, depth, water velocity, and substrate (which included sand, mud, sludge, gravel, cobble, boulders, and bedrock).

Significance testing of environmental variables at the $P > 0.05$ level was undertaken using the Wald Test. For visualisation purposes, we fitted species presence data to environmental variables through generalised linear modelling (GLM) to demonstrate some relationships between individual species and significant environmental variables.

3.4 Results

3.4.1 General trends

In the present study, we collected a total of 525 individuals from 18 fish species in the lower uMngeni River catchment (Table 3.1). A list of expected fish species (extracted from the Freshwater Biodiversity Information System (FBIS), fbis.org) and detected fish species are summarised in Table 3.1. From FBIS, 13 fish species were previously recorded in the study area; however, we caught an additional five species that were not recorded on FBIS (Table 3.1). These were *Ambassis gymnocephalus*, *Anguilla bengalensis*, *Awous aeneofuscus*, *Gambusia affinis*, and *Lepomis macrochirus*. The most abundant fish species caught were

Labeobarbus natalensis (n = 156, 29.7% of all individuals), *A. gymnocephalus* (n = 125, 23.8% of all individuals) and *Enteromius gurneyi* (n = 60, 11.4% of all individuals)

The site Below Top Needle Bridge (BTNB) had the highest diversity of fish species, while the Krantzkloof Conservancy (KK) site had the lowest diversity of fish species (Fig. 3.1, Table 3.1). The high diversity in the Below Top Needle Bridge site could be explained by this site being the most anthropogenically influenced site and directly downstream from Inanda dam. The dam could influence the diversity in this site as the site was easily accessible to the public, allowing the transposition of fish species to occur more easily. The species located at this site included the catadromous *Anguilla mossambica*, amphidromous *A. aeneofuscus*, potadromous *Clarias gariepinus*, *Micropterus salmoides*, *Oreochromis mossambicus*, *Pseudocrenilabrus philander*, *Coptodon rendalli*, *Tilapia sparrmanii*, and *L. natalensis*, and non-migratory *L. macrochirus*. Of the above-listed species, *M. salmonids* and *L. macrochirus* are invasive species in the area. The corresponding sampling site was located before a barrier, Top Needle Bridge. A total of four fish species were collected at this site, namely the near threatened catadromous *A. bengalensis*, potadromous *C. gariepinus* and *M. salmoides*, and *C. rendalli*. These two sites were the only locations where we found fish species which exhibit catadromous migration, *A. mossambica* and *A. bengalensis*

The Krantzkloof Conservancy, downstream in the Molweni River, had the least fish diversity (Table 3.1), and is a protected site where transposition of fish species is unlikely to occur. In this study, only one species was identified, *E. gurneyi*, which is identified as Vulnerable on the IUCN Red List of Species (IUCN, 2024). Regarding the location of this species, it could be the most protected at this site as there is not much outside influence on the river. Its counter site, which was sampled in the upper Molweni River, was in the Everton Conservancy, where only two species were found, *E. gurneyi* and *M. salmoides*, where the latter is a potadromous, invasive species (IUCN, 2024).

The sites sampled in the Palmiet River, Albizia and Mclean, held the non-migrative, invasive species *Xiphophorus helleri*, which were likely introduced to the river by aquarist releasing unwanted fish (Weyl *et al.*, 2020). The Albizia site had only fish species that exhibit potadromous migration, with the exception of *X. helleri* (Table 3.1). Site Mclean had four potadromous species (*C. gariepinus*, *G. affinis*, *L. natalensis* and *O. mossambicus*) and two non-migratory species (*E. gurneyi* and *X. helleri*) (Table 3.1). Of all the fish species found at the Mclean site, *E. gurneyi* and *O. mossambicus* have been declared vulnerable by the IUCN, and both are native species.

We found a variation in migratory fish species with different migratory habits, at the mouth of the uMngeni River. Amphidromous species (*A. gymnocephalus*, *Ambassis natalensis*, and *E. fusca*), potadromous species (*L. natalensis* and *O. mossambicus*) and the diadromous mullet fry, which were too juvenile to identify (Table 3.1). All these species are listed as of least concern status except *O. mossambicus*, which is of vulnerable concern.

Table 3.1: Summary of abundance and species diversity at the seven study sites along the lower uMngeni River, one of the major rivers in KwaZulu-Natal, South Africa, during this survey. Also included are the migratory requirements of each species as well as their conservation status (IUCN Red List of species): LC Least concern, NT Near threatened, VU Vulnerable, CR Critically endangered, IN Invasive. (Note: Study sites AL = Albizia Rd river entrance (upper Palmiet River); ML = Mclean Rd river entrance (lower Palmiet River); KK = Kranzkloof Conservancy (lower Molweni River); EV = Everton Reserve (upper Molweni River); TNB = Top Needle Bridge (upper uMngeni River); BTNB = Below Top Needle Bridge (lower uMngeni River); ES = uMngeni Estuary)

Expected species	Common name	Migration pattern	Status	Abundance at study sites							
				AL	ML	KK	EV	TNB	BTNB	Es	
<i>Ambassis gymnocephalus</i> *	Bald glassy	Amphidromous	LC								125
<i>Ambassis natalensis</i>	Natal glassy	Amphidromous	LC								19
<i>Anguilla bengalensis</i> *	Mottled eel	Catadromous	NT					1			
<i>Anguilla mossambica</i>	African longfin eel	Catadromous	LC								1
<i>Awous aeneofuscus</i> *	Freshwater goby	Amphidromous	LC								3
<i>Clarias gariepinus</i>	Sharptooth catfish	Potadromous	LC	2	1			11			3
<i>Coptodon rendalli</i>	Red-breasted tilapia	N/A	LC					6			9
<i>Eleotris fusca</i>	Dusky sleeper	Amphidromous	LC								7
<i>Enteromius gurneyi</i>	Orange-fin barb	Non-migratory	VU		1	51	8				
<i>Gambusia affinis</i> *	Mosquito fish	Potamodromous	IN		1						
<i>Labeobarbus natalensis</i>	KwaZulu-Natal yellowfish	Potadromous	LC	69	82						3
<i>Lepomis macrochirus</i> *	Bluegill sunfish	Non-migratory	IN								3
<i>Micropterus salmoides</i>	Largemouth bass	Potadromous	IN				1	8			3
<i>Oreochromis mossambicus</i>	Mozambique tilapia	Potadromous	VU		3						3
<i>Pseudocrenilabrus philander</i>	Southern mouth-brooder	Potadromous	LC								6
<i>Tilapia sparrmanii</i>	Banded tilapia	Potadromous	LC								8
<i>Xiphophorus helleri</i>	Swordtail fish	Non-migratory	IN	13	43						
Mullet	Mullet fry	Diadromous	N/A								3
*Found in the study but not in the Freshwater Biodiversity Information System (fbis.org) reference list for the area				Total Individuals	84	131	51	9	26	42	182
				Total Species	3	6	1	2	4	10	6

3.4.2 Diversity

Both the Shannon-Weiner and the Pielou's indices of the ichthyofauna communities varied across the lower uMngeni River catchment between the mainstem (uMngeni), and the two tributaries (Palmiet River and Molweni River) (Fig. 3.2). However, these differences were not significant (Kruskal–Wallis, $P > 0.05$). Both indices were not identical when calculated using site (H' and $J' = 0.4232$) and river (H' and $J' = 0.06866$).

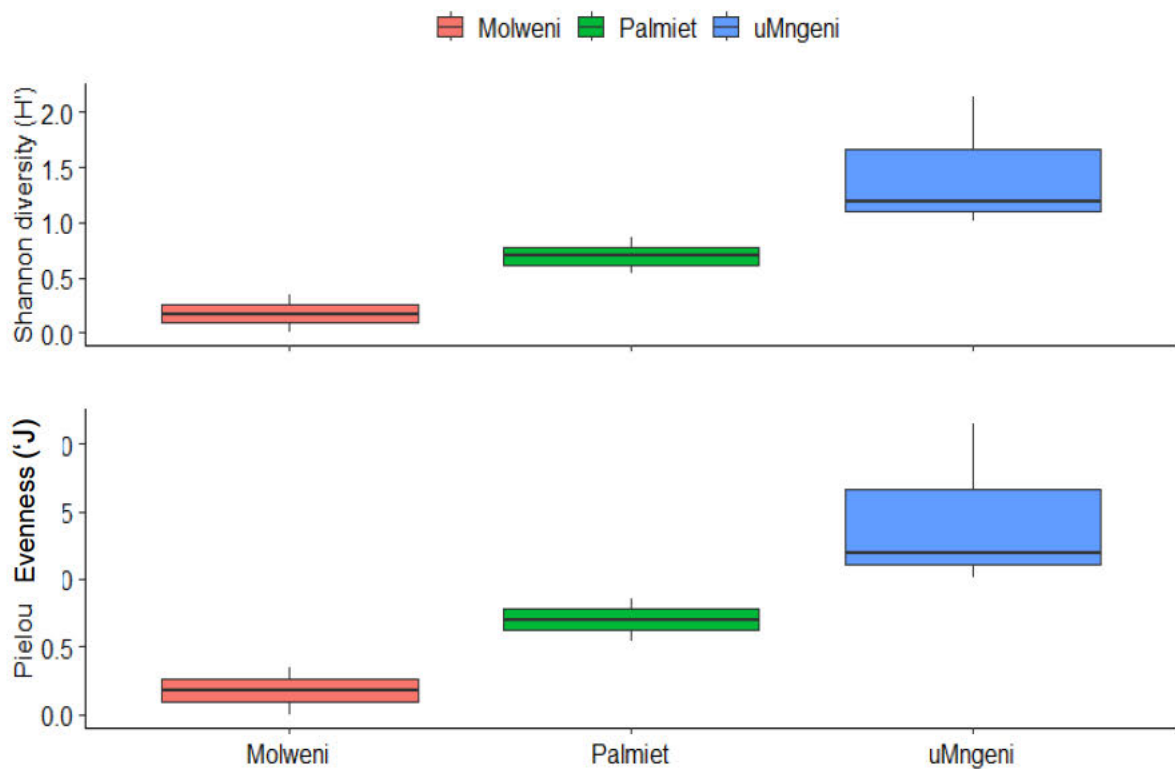


Figure 3.2: The Shannon–Weiner Index (H') and (b) Pielou's Index (J') for the different study sites across the lower uMngeni River catchment, comparing those in the mainstem (uMngeni), and the two tributaries (Palmiet River and Molweni River) in the present study.

The full model was tested using MGLM and showed that the significant environmental drivers influencing the structure of the fish communities in our study area included velocity ($P = 0.025$), mean depth ($P = 0.003$), pH ($P = 0.006$), and the substrate cobble ($P = 0.037$). For visualisation purposes, we plotted these significant environmental variables against the probability of occurrence of selected species, namely *L. natalensis* and *O. mossambicus* (Fig. 3.3).

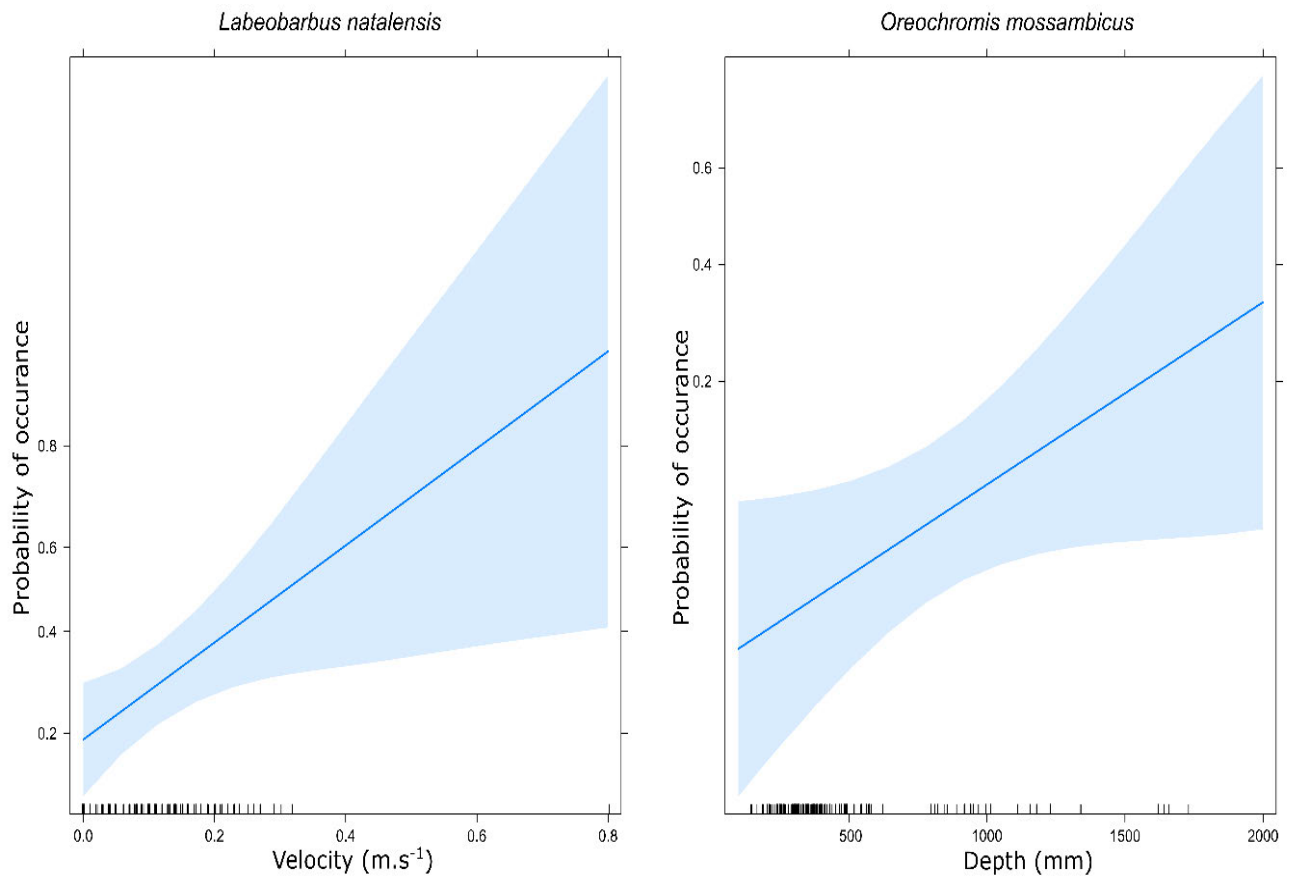


Figure 3.3: Multivariate generalised linear model plots of the significant environmental variables against the probability of occurrence of selected fish species, namely a. *Labeobarbus. natalensis* and b. *Oreochromis. mossambicus* in the present study.

3.4.3 Water quality

The overall mean for each water variable measured was calculated to determine the water quality of the lower uMngeni River and its tributaries. The variables used to determine water quality comprised of the following: pH; electrical conductivity, temperature, and total dissolved solids (Table 3.2). In addition, we observed raw sewage and altered habitat (pers. obs.) in the lower uMngeni River and its tributaries during our study.

Table 3.2: Summary of mean values for water values measured at the different study sites in the lower uMngeni River and its tributaries during the present study. (See Figure 3.1 for site abbreviations).

Sites	Water variables (Mean \pm SD)			
	pH	Temperature (°C)	Electrical conductivity (μ S/m)	Total dissolved solids (ppm)
ML	7.9 \pm 0.36	20.1 \pm 4.70	409.9 \pm 49.14	182.5 \pm 53.36
KK	7.8 \pm 0.43	19.3 \pm 6.08	260.3 \pm 110.5	101.3 \pm 23.92
EV	7.8 \pm 0.45	18.7 \pm 5.92	235.7 \pm 89.55	95.7 \pm 15.55
TNB	8.0 \pm 0.34	21.4 \pm 4.02	442.0 \pm 180.82	204.6 \pm 103.23
BTNB	7.9 \pm 0.21	20.0 \pm 4.04	338.5 \pm 11.18	161.4 \pm 28.04
Es	7.5 \pm 0.10	22.2 \pm 4.17	2845.4 \pm 1606.10	1424.3 \pm 801.55

3.5 Discussion

Little is known about the fish community ecology and their drivers in the lower uMngeni catchment. This section of the uMngeni River is highly impacted by anthropogenic stressors

originating from land cover types associated with human activities (Evans *et al.*, 2022). Importantly, catadromous migratory species were seemingly confined to certain sites over others, with anguillids only captured at the Inanda Dam weir site. Anecdotal evidence from conservancy members in the Palmiet area does show that eels are present there, as well as supported results from Hanzen *et al.* (2022). However, they were not recorded during sampling periods in the present study.

3.5.1 Water quality and abiotic drivers

The quality of freshwater is diminishing in the uMngeni River, and the rivers flowing into it, for the estuary site is a concern for catadromous migrators as this is a potential chemical barrier that they would transverse to get to freshwater. Urbanisation is the major contributor to river pollution, as seen in Evans *et al.* (2022), as urbanisation greatly impacts fish species richness. The ecological impacts of urbanisation are seen across large spatial areas, from localised impacts within the urban area to downstream effects in the estuarine and coastal waters (McGrane *et al.*, 2014). Drivers behind the pollution of streams and river systems are to be thoroughly identified to preserve the rivers' ecological state (Xaba and Onwubu, 2022; Evans *et al.*, 2022).

In the present study, we captured 18 fish species in the lower uMngeni River. The expected species list for the study area includes 13 fish species from the Freshwater Biodiversity Information System (fbis.org). However, we captured a further five species during our study which were not recorded, namely *A. gymnocephalus*, *A. bengalensis*, *A. aeneofuscus*, *G. affinis*, and *L. macrochirus*. This suggests that data on FBIS may be outdated (Desai *et al.*, 2021). This also reflects that researchers and anglers do not always record their findings on FBIS and that few studies address the uMngeni's biodiversity concerning fish species. Alternatively, rather than only there a lack of detection, the low abundance of each

species may be a factor. More extensive surveys over a longer period and with more sampling efforts must be conducted to fill the knowledge gaps and what inhabits these waters.

3.5.2 Diversity and drivers

Eleotris fusca (dusky sleeper) is an amphidromous species that requires movement between the estuarine and freshwater boundary to maintain its life cycle. The abundance of this species in the Blue Lagoon area shows that they can tolerate high levels of organic pollution, although the lack of the species upstream in the rivers indicated that their movement into the freshwater environment may be impaired.

Labeobarbus natalensis (KwaZulu-Natal yellowfish), a potamodromous migrator, was regularly detected in the Palmiet River and in relatively high abundances and across all size classes. This indicates a healthy population of these species in this tributary and is likely to be the stronghold for the species in the lower uMngeni River. The lack of detection for the species below Inanda Dam in the main stem is concerning and likely to be caused by the lack of environmental flow releases out of the dam, as seasonal flows are important for the species to access habitats required for breeding (Burnett *et al.*, 2021). The Pielou's index indicated that the species evenness of the uMngeni River was recorded as the highest from the catchment, indicating that the fish community within the system was dominated by only a few species in low abundances.

Ecohydraulic parameters, in this instance, depth and velocity, are recognised as significant environmental drivers influencing fish communities (Pyron and Lauer, 2004; Kennard *et al.*, 2007; Chakona and Swartz, 2012; Desai *et al.*, 2021). In our study, mean depth was the most significant variable influencing fish communities in the catchment. *Labeobarbus natalensis* abundances were most impacted by velocity, increasing in abundance with higher velocities recorded in the study.

Anguillid eel abundance and distribution were concerning as only two adult individuals were caught throughout the study. These were downstream of Inanda Dam and indicated that *Anguilla* spp. could migrate up to Inanda Dam but not past it. Unfortunately, the low abundances caught in the study could be an indication of the ecological fragmentation within the catchment and other stressors related to water quality and little variation in flow releases to the sea (Desai *et al.*, 2021; Evans *et al.*, 2022). Poor environmental flow releases out of Inanda Dam might impact cues stimulating glass eels from entering the uMngeni River to recruit. The upstream migration of these recruiting individuals past Inanda Dam is poor or non-existent. This likely limits the recruitment potential for African anguillids into the entire upper uMngeni River. However, different studies have observed anguillid eels in the catchment (Dlamini, 2019; Hanzen *et al.*, 2022). However, these individuals were all large and could also show poor or pre-impoundment recruitment (Dlamini, 2019; Hanzen *et al.*, 2022). The lower uMngeni is therefore considered to be important for the future conservation of these species in the catchment.

Another important fish found in the study was *O. mossambicus*, an important food source for local communities (Hlungwani *et al.*, 2023). Our study showed that this species increases in abundance with increased depth habitats. They were found in low abundance during our surveys, as with Evans *et al.* (2022); however, they occur in relatively high abundance in Albert Falls Dam, Nagel Dam and Inanda Dam (Dlamini, 2019).

Interestingly, our results showed distinct fish community structures found across the Palmiet and Molweni catchments. The Palmiet has a healthy population of *L. natalensis* from various size classes, while the Molweni tributary was a stronghold for *E. gurneyii*, a species on the IUCN list (IUCN, 2024) as vulnerable because of anthropogenic stressors. Both the Palmiet and Molweni have non-native invasive species that threaten the native fish populations. For the Molweni, largemouth bass *M. salmoides* were found, which is

categorised as moderately invasive, according to Weyl et al. (2020), and they negatively impact the abundance of native fish. This is concerning for *E. gurneyii*, and the species could further decline in the healthier Molweni River. *Micropterus salmoides* were present downstream of Inanda Dam and could have potentially caused low abundances of native fish and the absence of some expected species. In the Palmiet River, *G. affinis* and *X. helleri* were present in relatively high abundance. These species compete for habitat and resources with smaller *Enteromius* spp, such as *E. viviparus* and *E. anaoplus*. These were expected species for the lower uMngeni catchment but were not found in our study.

3.5.3 Conclusions

In conclusion, there were many stressors in the lower catchment of the uMngeni River, impacting the migratory fishes and fish community structures. As a result of varying stressors, such as chemicals, raw sewage and altered habitat (pers. obs.), the river's connectivity impairment reduces the fish's ability to adequately recolonise a river's reach after a stressor event that causes a fish kill. This is an important consideration as if mitigation of these pollution sources and land use practice changes, and it is important to allow fish movement into these once highly stressed systems. Glass eels have been known to surmount moist vertical surfaces such as the rocks of waterfalls. A small proportion of the recruiting population could, under certain circumstances, surmount the wall of a dam – provided it was moist during heavy rainfall. These conditions are unlikely to occur very often at the right place and time, and hence, large dam walls are usually barriers to riverine connectivity for all fish species, including eels. Dam walls also compromise the downstream migration of adult eels as they cannot surmount the wall to proceed downstream to the marine environment where spawning occurs. The presence of anguillids below Inanda Dam indicated that some, even if poor, river connectivity is maintained up to this site, and mitigation measures need to

be considered to restore the movement of *Anguilla* spp. into the upper uMngeni River catchment for effective recruitment. Restoring and /or considering river connectivity in the lower uMngeni catchment can potentially improve fish communities.

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CHAPTER 4

General discussion, conclusions and recommendations

4.1 Background

Out of all aquatic ecosystems, rivers and streams are among the most endangered ecosystems internationally (Odume *et al.*, 2022). The ecological connectivity of these ecosystems is in peril by anthropogenically driven activities that are significant threats to all fish species (Vorosmarty *et al.*, 2010; Gough *et al.*, 2012; O'Brien *et al.*, 2019; Du Plessis, 2019; Desai *et al.*, 2021; Evans *et al.*, 2022). Freshwater ecosystems are being severely altered at a rate greater than that of any other time in human history and at a rate faster than they are being restored, and this is no different for the uMngeni River and uThukela River, KwaZulu-Natal, South Africa. The increase in population growth and its consequent activities bring inimical consequences. All these factors ultimately build up in river catchments and trail down to estuaries.

Various aquatic organisms are affected by anthropogenic activities, especially fish species. This includes migratory fish, which are key indicator species of a given river system as they are exposed to a wide variety of habitats, as they have more habitat types and connectivity requirements (Harris, 1995; O'Brien *et al.*, 2019) and are fundamental indicators of river health (Wasserman *et al.*, 2011). Thus, many flagship migratory species in South Africa do not reach their breeding grounds (Brink *et al.*, 2018). Freshwater eels are considered South Africa's most iconic migratory species, and their catadromous nature relies on environmental conditions for recruitment purposes (Tesch *et al.*, 2003).

The present study evaluated the recruitment of glass eels into the rivers and estuaries in the Western Indian Ocean (WIO) (Jubb, 1957; Jackson, 1976; Robinet *et al.*, 2003a, b; Wasserman *et al.*, 2011), more specifically into the uThukela River estuary. Additionally, it

was aimed to outline the exposure of multiple stressors to the predominantly unknown ecology of fish communities, including recorded migratory fish and their associated drivers. The fish species diversity and evenness across sites in the catchment, and their associated habitats, water quality, and ecological connectivity at each site were investigated.

4.2 Summary of findings

The first main hypothesis was that African freshwater eel species (*Anguilla* spp.) are seasonal, and their migration into an estuary was predicted to occur during the wet season or austral spring and summer, coinciding with high river flow periods in KwaZulu-Natal (Chapter 2). Additionally, it was hypothesised that glass eel recruitment is affected by light and lunar phases. It was predicted that they would recruit into estuaries at night and according to particular moon phases, and four different eel species were expected to recruit into the estuary at different age/size classes and at various times of the wet season. The findings included seasonal variation in the glass eel recruitment. Predominantly, most glass eels were caught in the wet season, as predicted and found in other studies globally (Suhardono, 2000). However, only two glass eel species were caught, namely *Anguilla mossambica* (mostly in the wet season), and *Anguilla marmorata* (mostly in the dry season). It was found that most glass eel recruitment was during high spring tides, as in other studies (Dou et al., 2003), and that recruitment occurs at night.

The second main hypothesis predicted that the range of anthropogenic factors negatively affects migratory fish species. For this study, the lower uMngeni River was considered (Chapter 3). Seven sampling sites were selected along the lower uMngeni River catchment to evaluate the instream barriers and fish communities. A total of 525 individuals from 18 fish species in the lower uMngeni River catchment were collected. A list of expected fish species (expected from the Freshwater Biodiversity Information System (FBIS), fbis.org)

found 13 fish species were previously recorded in the study area; however, an additional five species we caught are not recorded on FBIS.

The most abundant fish species caught were *Labeobarbus natalensis*, primarily from the Palmiet River. The Inanda Dam Weir site recorded the highest diversity of fish species, while the Krantzkloof Conservancy site had the lowest diversity of fish species. Shannon-Weiner and Pielou's indices varied across the lower uMngeni River catchment between the mainstem (uMngeni) and the two tributaries (Palmiet River and Molweni River); these differences were significant, and indices were not identical. The recorded environmental variables possibly affecting the communities in the study area included velocity, mean depth, pH, and the substrate, cobble. Visually, the selected significant environmental drivers were plotted against the probability of occurrence of selected species. The quality of freshwater is deteriorating in the system.

The Palmiet had an abundant population of *L. natalensis* from various size classes, while the Molweni held ample vulnerable *Enteromius gurneyii* (IUCN, 2024). Both the Palmiet and Molweni have non-native invasive species that threaten indigenous fish. The low abundance and species richness found in this study may indicate ecological fragmentation and other stressors related to water quality and connectivity, as found in other KwaZulu-Natal studies (Desai *et al.* 2021; Evans *et al.* 2022).

4.3 Recommendations

In terms of specificities regarding migratory requirements for African fish species, very few quantitative studies have been conducted to substantiate the understanding of their migratory habitats and river connectivity needs. More studies on glass eel recruitment, with a larger sample size need to be conducted to gain more substantial information regarding migratory requirements and river connectivity dependency to advocate for an increase in the quality of

river connectivity and conditions in South Africa (Brink *et al.*, 2018). This could be achieved by using sampling gear which can generate larger fish sampling sizes, thus improving the cogency of the data set. More environmental variables could be included in the study, filling the gaps in knowledge regarding the connection between environmental drivers and relative abundance of different migratory fish species.

Stressors behind river pollution need to be comprehensively identified to preserve the rivers' ecological state (Xaba and Onwubu, 2022; Evans *et al.*, 2022). Anthropogenic activities (especially urbanisation) must be properly regulated as they significantly contribute to stream and river pollution (McGrane *et al.*, 2014; Evans *et al.*, 2022) and the declining richness of fish species and the deterioration of river connectivity.

Researchers and anglers must be encouraged to record their findings to their best ability on FBIS, as the presently recorded data are largely incomplete and outdated (Desai *et al.*, 2021), as seen in this study. Various comprehensive surveys must be conducted to complete knowledge gaps and what occurs in these rivers.

More protection of protected areas is needed. The uThukela Banks Marine Protected Area is not as protected as it should be. Studies cannot be conducted thoroughly as multiple anglers are in the area, and equipment is susceptible to external prying and theft.

4.4 Conclusions

The findings of this study could be of great benefit when devising management, biodiversity and conservation plans in the uThukela estuary and uMngeni catchment. Evidence presented in this study on incomplete river connectivity and the declining ecological state of KwaZulu-Natal rivers could assist local municipalities and environmental institutions/ groups on appropriate ecological management plans (e.g., removal of specific barriers and invasive species, construction of fish passageways) and create awareness, regulate and discourage

anthropogenic activities on rivers and streams which will, in turn, improve water quality and security.

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1 **Appendix**

2 Appendix 1: Glass eel net efforts in uThukela estuary

Effort	Out	Species	n	Temp (°C)	pH	EC (µS/m)	TDS (ppm)	Weight (g)	DF to AF (mm)	DG (mm)	DA (mm)	LH (mm)	LV (mm)	RH (mm)	RV (mm)	Pattern notes	Life stage	PIT
GEN_1_e	30/08/2020 08:00	<i>Anguilla bicolor</i>	1	18.7	7.87	1429	1021	545	15	190	10	7.8	6.4	7.42	5.96			
GEN_3_f	28/10/2020 08:45	<i>Anguilla bengalensis</i>	1	26.5	7.52	3100	2200										Glass Eel	
GEN_3_f	28/10/2020 08:45	<i>Anguilla bengalensis</i>	1	26.5	7.52	3100	2200										Glass Eel	
GEN_3_h	29/10/2020 07:25	<i>Anguilla bengalensis</i>	1	26.5	7.52	2810	1993											
GEN_3_j	30/10/2020 07:46	<i>Anguilla bengalensis</i>	1	23.6	7.44	14640	10380											
GEN_3_j	30/10/2020 07:46	<i>Anguilla bengalensis</i>	1	23.6	7.44	14640	10380											
GEN_3_j	30/10/2020 07:46	<i>Anguilla bengalensis</i>	1	23.6	7.44	14640	10380											
GEN_3_j	30/10/2020 07:46	<i>Anguilla bengalensis</i>	1	23.6	7.44	14640	10380										Glass Eel	
GEN_3_j	30/10/2020 07:46	<i>Anguilla bengalensis</i>	1	23.6	7.44	14640	10380											
GEN_4_a	18/11/2020 07:40	<i>Anguilla bicolor</i>	1	28.9	7.17	457	325	520	32	185	15	5.95	6.2	7.89	7.02	Olive tone, Yellow belly	Adult	
GEN_4_a	18/11/2020 07:40	<i>Anguilla bengalensis</i>	1	28.9	7.17	457	325										Glass Eel	

GEN_4_a	18/11/2020 07:40	<i>Anguilla bengalensis</i>	1	28.9	7.17	457	325											Glass Eel	
GEN_4_b	19/11/2020 07:35	<i>Anguilla bengalensis</i>	1	27.1	6.93	246	173.4											Glass Eel	
GEN_4_b	19/11/2020 07:35	<i>Anguilla bengalensis</i>	1	27.1	6.93	246	173.4											Glass Eel	
GEN_4_c	20/11/2020 07:30	<i>Anguilla bengalensis</i>	1	24	7.13	207	148.8											Glass eel	
GEN_4_c	20/11/2020 07:30	<i>Anguilla bengalensis</i>	1	24	7.13	207	148.8											Glass eel	
GEN_5_d	03/12/2020 16:40	<i>Anguilla spp.</i>	1	24.7	7.96	868	436											Glass Eel	
GEN_5_g	05/12/2020 07:39	<i>Anguilla spp.</i>	1	22	7.74	1476	728											Glass Eel	
GEN_5_g	05/12/2020 07:39	<i>Anguilla spp.</i>	1	22	7.74	1476	728											Glass Eel	
GEN_6.1_h	29/01/2021 17:00	<i>Anguilla mossambica</i>	1	faulty reader	faulty reader	faulty reader	faulty reader	210		75	65	9.76	9.38	9.88	9.07			Silver eel	
GEN_6.3_i	30/01/2021 08:15	<i>Anguilla mossambica</i>	1	faulty reader	faulty reader	faulty reader	faulty reader	110	60	55	55	7.59	6.76	6.84	7.33			Silver eel	3DD003DECA01F
GEN_6.4_i	30/01/2021 08:30	<i>Anguilla spp.</i>	1	faulty reader	faulty reader	faulty reader	faulty reader											Glass eel	
GEN_8.3_a	07/04/2021 08:37	<i>Anguilla spp.</i>	1	24.4	7.9	303	150											Glass Eel	
GEN_8.3_a	07/04/2021 08:37	<i>Anguilla spp.</i>	1	24.4	7.9	303	150											Glass Eel	
GEN_8.3_a	07/04/2021 08:37	<i>Anguilla spp.</i>	1	24.4	7.9	303	150											Elver	
GEN_9.3_a	20/05/2021 08:15	<i>Anguilla spp.</i>	1	19.3	7.85	1151	577											glass eel	
GEN_11.4_c	28/07/2021 09:42	<i>Anguilla spp.</i>	1	15	8.07	3999	2000											Glass eel	
GEN_12.5_f	27/08/2021 09:57	<i>Anguilla spp.</i>	1	22.5	7.99	3999	2000											Glass eel	

4 Appendix 2: Electroshocking efforts for Lower uMngeni river.

Site	Effort	Date	Duration (s)	Species	n	SL (mm)	TL (mm)	Ave Depth (cm)	Common Substrate	Ave Velocity
Palmiet River Down Weir	E1_P/DW	16/03/2021	20	<i>Labeobarbus natalensis</i>	1	130	160	49.4	Boulders	0
Palmiet River Down Weir	E1_P/DW	16/03/2021	20	<i>Xiphophorus hellerii</i>	1	49	60	49.4	Boulders	0
Palmiet River Down Weir	E2_P/DW	16/03/2021	50	<i>Labeobarbus natalensis</i>	1	120	142	37.4	Boulders	0.624
Palmiet River Down Weir	E3_P/DW	16/03/2021	120	No fish	-	-	-	33.4	Boulders	0.834
Palmiet River Down Weir	E4_P/DW	16/03/2021	142	<i>Labeobarbus natalensis</i>	1	120	150	31.6	Boulders	0.272
Palmiet River Down Weir	E5_P/DW	16/03/2021	85	<i>Labeobarbus natalensis</i>	1	120	145	29.4	Boulders	1.142
Palmiet River Down Weir	E5_P/DW	16/03/2021	85	<i>Labeobarbus natalensis</i>	1	116	140	29.4	Boulders	1.142
Palmiet River Down Weir	E5_P/DW	16/03/2021	85	<i>Labeobarbus natalensis</i>	1	125	155	29.4	Boulders	1.142
Palmiet River Down Weir	E5_P/DW	16/03/2021	85	<i>Labeobarbus natalensis</i>	1	120	140	29.4	Boulders	1.142
Palmiet River Down Weir	E6_P/DW	16/03/2021	132	<i>Labeobarbus natalensis</i>	1	20	42	14.8	Cobble	0.768
Palmiet River Down Weir	E6_P/DW	16/03/2021	132	<i>Xiphophorus hellerii</i>	1	22	30	14.8	Cobble	0.768
Palmiet River Down Weir	E7_P/DW	16/03/2021	60	No fish	-	-	-	29.6	Cobble	0.192
Palmiet River Down Weir	E8_P/DW	16/03/2021	120	<i>Xiphophorus hellerii</i>	1	52	55	38.4	Sand	0.192
Palmiet River Down Weir	E8_P/DW	16/03/2021	120	<i>Xiphophorus hellerii</i>	1	42	72	38.4	Sand	0.192
Palmiet River Down Weir	E8_P/DW	16/03/2021	120	<i>Xiphophorus hellerii</i>	1	30	45	38.4	Sand	0.192
Palmiet River Down Weir	E8_P/DW	16/03/2021	120	<i>Labeobarbus natalensis</i>	1	28	32	38.4	Sand	0.192
Palmiet River Down Weir	E9_P/DW	16/03/2021	20	<i>Xiphophorus hellerii</i>	1	45	78	33.8	Sand	0
Palmiet River Down Weir	E9_P/DW	16/03/2021	20	<i>Xiphophorus hellerii</i>	1	56	72	33.8	Sand	0
Palmiet River Down Weir	E9_P/DW	16/03/2021	20	<i>Clarias gariepinus</i>	1	31	45	33.8	Sand	0
Palmiet River Down Weir	E9_P/DW	16/03/2021	20	<i>Xiphophorus hellerii</i>	1	38	49	33.8	Sand	0
Palmiet River Down Weir	E9_P/DW	16/03/2021	20	<i>Xiphophorus hellerii</i>	1	25	32	33.8	Sand	0

Palmiet River Down Weir	E9_P/DW	16/03/2021	20	<i>Xiphophorus hellerii</i>	1	30	39	33.8	Sand	0
Molweni River Down Weir	E1_M/DW	17/03/2021	30	No fish	-	-	-	43	Sand	0.048
Molweni River Down Weir	E2_M/DW	17/03/2021	50	No fish	-	-	-	32	Boulders	0
Molweni River Down Weir	E3_M/DW	17/03/2021	30	<i>Enteromius gurneyi</i>				31.6	Boulders	0.202
Molweni River Down Weir	E3_M/DW	17/03/2021	30	<i>Enteromius gurneyi</i>				31.6	Boulders	0.202
Molweni River Down Weir	E4_M/DW	17/03/2021	40	No fish	-	-	-	37.6	Sand	0.144
Molweni River Down Weir	E5_M/DW	17/03/2021	84	<i>Enteromius gurneyi</i>	1	85	91	37.2	Boulders	0.394
Molweni River Down Weir	E6_M/DW	17/03/2021	40	No fish	-	-	-	57.2	Sand	0.286
Molweni River Down Weir	E7_M/DW	17/03/2021	30	No fish	-	-	-	21.4	Boulders	0.644
Molweni River Down Weir	E8_M/DW	17/03/2021	60	No fish	-	-	-	31	Boulders	0.748
Molweni River Down Weir	E9_M/DW	17/03/2021	75	No fish	-	-	-	31.6	Cobble	0.54
Molweni River Down Weir	E10_M/DW	17/03/2021	120	No fish	-	-	-	19.2	Boulders	0.41
Molweni River Down Weir	E11_M/DW	17/03/2021	60	No fish	-	-	-	16.8	Cobble	0.724
Molweni River Down Weir	E12_M/DW	17/03/2021	80	No fish	-	-	-	36.4	Boulders	0.334
Molweni River Down Weir	E13_M/DW	17/03/2021	73	No fish	-	-	-	47.2	Sand	0.226

Below Top Needle Bridge	E1_I/DW	19/03/2021		<i>Pseudocrenilabrus philander</i>	1	68	82	18.8	Sand	0.096
Below Top Needle Bridge	E1_I/DW	19/03/2021		<i>Pseudocrenilabrus philander</i>	1	80	96	18.8	Sand	0.096
Below Top Needle Bridge	E2_I/DW	19/03/2021		<i>Coptodon rendalli</i>	1	51	64	14.4	Sand	0
Below Top Needle Bridge	E2_I/DW	19/03/2021		<i>Coptodon rendalli</i>	1	47	58	14.4	Sand	0
Below Top Needle Bridge	E3_I/DW	19/03/2021		<i>Coptodon rendalli</i>	1	35	42	20.4	Sand	0.082
Below Top Needle Bridge	E3_I/DW	19/03/2021		<i>Pseudocrenilabrus philander</i>	1	69	85	20.4	Sand	0.082
Below Top Needle Bridge	E4_I/DW	19/03/2021		<i>Micropterus salmoides</i>	1	140	162	35.2	Sand	0
Below Top Needle Bridge	E4_I/DW	19/03/2021		<i>Clarias gariepinus</i>	1	49	56	35.2	Sand	0
Below Top Needle Bridge	E4_I/DW	19/03/2021		<i>Clarias gariepinus</i>	1	40	47	35.2	Sand	0
Below Top Needle Bridge	E4_I/DW	19/03/2021		<i>Coptodon rendalli</i>	1	47	56	35.2	Sand	0
Below Top Needle Bridge	E5_I/DW	19/03/2021		No fish	-	-	-	62.2	Bedrock	0.532
Below Top Needle Bridge	E6_I/DW	19/03/2021		No fish	-	-	-	31.2	Sand	0
Below Top Needle Bridge	E7_I/DW	19/03/2021		No fish	-	-	-	51.8	Boulders	0.454
Below Top Needle Bridge	E8_I/DW	19/03/2021		No fish	-	-	-	38.2	Mud	0.778
Below Top Needle Bridge	E9_I/DW	19/03/2021		No fish	-	-	-	57.4	Bedrock	0.854
Below Top Needle Bridge	E10_I/DW	19/03/2021		<i>Pseudocrenilabrus philander</i>	1	90	108	32	Boulders	0.75
Below Top Needle Bridge	E11_I/DW	19/03/2021		No fish	-	-	-	32.8	Mud	0
Palmiet River Down Weir	E1_P/DW	08/04/2021	36	<i>Labeobarbus natalensis</i>	1	153	197	36.4	Boulders	0.916
Palmiet River Down Weir	E1_P/DW	08/04/2021	36	<i>Labeobarbus natalensis</i>	1	139	179	36.4	Boulders	0.916
Palmiet River Down Weir	E1_P/DW	08/04/2021	36	<i>Labeobarbus natalensis</i>	1	145	178	36.4	Boulders	0.916
Palmiet River Down Weir	E2_P/DW	08/04/2021	24	<i>Labeobarbus natalensis</i>	1	136	166	30.6	Boulders	0.888
Palmiet River Down Weir	E3_P/DW	08/04/2021	48	<i>Labeobarbus natalensis</i>	1	164	202	37.2	Boulders	0.49
Palmiet River Down Weir	E3_P/DW	08/04/2021	48	<i>Xiphophorus hellerii</i>	1	50	58	37.2	Boulders	0.49
Palmiet River Down Weir	E4_P/DW	08/04/2021	60	<i>Labeobarbus natalensis</i>	1	133	164	35.4	Boulders	0.67
Palmiet River Down Weir	E5_P/DW	08/04/2021	42	<i>Labeobarbus natalensis</i>	1	130	167	29.4	Boulders	0.646
Palmiet River Down Weir	E6_P/DW	08/04/2021	54	No fish	-	-	-	25.8	Boulders	1.002
Palmiet River Down Weir	E7_P/DW	08/04/2021	54	No fish	-	-	-	22.4	Bedrock	0.754

Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	34	52	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	25	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	25	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	50	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	23	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	20	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	60	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	39	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	73	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Xiphophorus hellerii</i>	1	-	47	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Oreochromis mossambicus</i>	1	68	75	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Enteromius gurneyi</i>	1	33	40	36.8	Boulders	0.168
Palmiet River Down Weir	E8_P/DW	08/04/2021	54	<i>Gambusia affinis</i>	1	29	35	36.8	Boulders	0.168
Palmiet River Down Weir	E9_P/DW	08/04/2021	54	<i>Labeobarbus natalensis</i>	1	150	183	39.6	Sand	0.362
Palmiet River Down Weir	E9_P/DW	08/04/2021	54	<i>Labeobarbus natalensis</i>	1	119	149	39.6	Sand	0.362
Palmiet River Down Weir	E10_P/DW	08/04/2021	48	No fish	-	-	-	46.6	Sand	0.24
Molweni River Down Weir	E1_M/DW	09/04/2021	48	<i>Enteromius gurneyi</i>	1	55	66	46.8	Bedrock	0.144
Molweni River Down Weir	E2_M/DW	09/04/2021	54	<i>Enteromius gurneyi</i>	1	47	55	25	Boulders	0.1625
Molweni River Down Weir	E3_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	87	102	42.2	Sand	0.072
Molweni River Down Weir	E3_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	96	106	42.2	Sand	0.072
Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	92	109	35.6	Boulders	0.334
Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	89	102	35.6	Boulders	0.334

Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	81	96	35.6	Boulders	0.334
Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	49	60	35.6	Boulders	0.334
Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	50	60	35.6	Boulders	0.334
Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	66	74	35.6	Boulders	0.334
Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	54	65	35.6	Boulders	0.334
Molweni River Down Weir	E4_M/DW	09/04/2021	60	<i>Enteromius gurneyi</i>	1	48	58	35.6	Boulders	0.334
Molweni River Down Weir	E5_M/DW	09/04/2021	48	<i>No fish</i>	-	-	-	44	Sand	0.24
Molweni River Down Weir	E6_M/DW	09/04/2021	18	<i>No fish</i>	-	-	-	23.4	Boulders	0.708
Molweni River Down Weir	E7_M/DW	09/04/2021	54	<i>No fish</i>	-	-	-	29.6	Boulders	0.658
Molweni River Down Weir	E8_M/DW	09/04/2021	64	<i>No fish</i>	-	-	-	25.4	Cobble	0.42
Molweni River Down Weir	E9_M/DW	09/04/2021	42	<i>Enteromius gurneyi</i>	1	84	99	41.2	Sand	0.24
Molweni River Down Weir	E9_M/DW	09/04/2021	42	<i>Enteromius gurneyi</i>	1	76	90	41.2	Sand	0.24
Below Top Needle Bridge	E1_I/DW	10/04/2021	48	<i>No fish</i>	-	-	-	54.6	Bedrock	0.304
Below Top Needle Bridge	E2_I/DW	10/04/2021	48	<i>No fish</i>	-	-	-	27	Boulders	0.698
Below Top Needle Bridge	E3_I/DW	10/04/2021	42	<i>Tilapia sparrmanii</i>	1	43	56	43.2	Boulders	0.274
Below Top Needle Bridge	E3_I/DW	10/04/2021	42	<i>Tilapia sparrmanii</i>	1	54	68	43.2	Boulders	0.274
Below Top Needle Bridge	E4_I/DW	10/04/2021	48	<i>Tilapia sparrmanii</i>	1	67	84	30.4	Bedrock	0.3425

Below Top Needle Bridge	E5_I/DW	10/04/2021	54	<i>No fish</i>	-	-	-	35.4	Boulders	0.654
Below Top Needle Bridge	E6_I/DW	10/04/2021	48	<i>Awaous aeneofuscus</i>	1	53	65	48.6	Boulders	0.24
Below Top Needle Bridge	E6_I/DW	10/04/2021	48	<i>Awaous aeneofuscus</i>	1	39	47	48.6	Boulders	0.24
Below Top Needle Bridge	E6_I/DW	10/04/2021	48	<i>Awaous aeneofuscus</i>	1	90	110	48.6	Boulders	0.24
Below Top Needle Bridge	E7_I/DW	10/04/2021	60	<i>Tilapia sparrmanii</i>	1	75	102	26.8	Sand	0.178
Below Top Needle Bridge	E7_I/DW	10/04/2021	60	<i>Labeobarbus natalensis</i>	1	75	94	26.8	Sand	0.178
Below Top Needle Bridge	E7_I/DW	10/04/2021	60	<i>Labeobarbus natalensis</i>	1	52	66	26.8	Sand	0.178
Below Top Needle Bridge	E7_I/DW	10/04/2021	60	<i>Labeobarbus natalensis</i>	1	46	60	26.8	Sand	0.178

5

6 Appendix 3: Fyke efforts for lower uMngeni River

Site	Effort	Out	Duration	Species	n	SL (mm)	TL (mm)	Ave Depth (cm)	Common Substrate	Ave Velocity (m/s)
Palmiet River (AL)	F1.1_P/UW	16/03/2021 09:54	19.57	<i>Labeobarbus natalensis</i>	1	101	125	29.6	Cobble	0.194
Palmiet River (AL)	F2.1_P/UW	16/03/2021 09:46	19.35	<i>Labeobarbus natalensis</i>	1	103	129	29.4	Boulders	1.146
Palmiet River (AL)	F3.1_P/UW	16/03/2021 09:38	19.13	<i>Labeobarbus natalensis</i>	1	120	152	31.6	Boulders	0.272
Palmiet River (AL)	F4.1_P/UW	16/03/2021 09:30	18.92	<i>Labeobarbus natalensis</i>	1	86	109	33.4	Boulders	0.723
Palmiet River (AL)	F5.1_P/UW	16/03/2021 09:20	18.67	<i>Clarias gariepinus</i>	1	426	454	47.4	Boulders	0
Palmiet River (AL)	F5.1_P/UW	16/03/2021 09:20	18.67	<i>Labeobarbus natalensis</i>	1	83	101	47.4	Boulders	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	22	27	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	28	37	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	20	25	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	14	17	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	40	72	33.8	Sand	0

Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	47	59	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	33	49	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	30	32	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	28	35	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	25	31	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	29	37	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	27	31	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	23	30	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	28	34	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	21	25	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	21	29	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	24	30	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	20	24	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	28	31	33.8	Sand	0

Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	20	24	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	22	30	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	21	26	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Labeobarbus natalensis</i>	1	15	17	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	22	29	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	18	24	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	25	33	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	32	40	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	23	25	33.8	Sand	0
Palmiet River (AL)	GEN1.1_P/UW	16/03/2021 09:00	18.50	<i>Xiphophorus hellerii</i>	1	17	20	33.8	Sand	0
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	114	140	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	29	36	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	28	37	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	30	39	14.8	Cobble	0.756

Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	35	42	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	29	35	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	31	40	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	18	23	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	17	24	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	19	22	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	16	21	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	29	35	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	15	19	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	19	24	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	20	26	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	20	25	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	18	24	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	18	24	14.8	Cobble	0.756

Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	30	39	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	29	35	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	20	26	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	19	24	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	15	20	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	20	25	14.8	Cobble	0.756
Palmiet River (AL)	GEN2.1_P/UW	16/03/2021 09:10	18.50	<i>Labeobarbus natalensis</i>	1	13	17	14.8	Cobble	0.756
Palmiet River (ML)	F1.1_P/DW	16/03/2021 10:30	18.83	<i>Labeobarbus natalensis</i>	1	107	131	49.4	Boulders	0
Palmiet River (ML)	F1.1_P/DW	16/03/2021 10:30	18.83	<i>Labeobarbus natalensis</i>	1	120	149	49.4	Boulders	0
Palmiet River (ML)	F1.1_P/DW	16/03/2021 10:30	18.83	<i>Labeobarbus natalensis</i>	1	88	110	49.4	Boulders	0
Palmiet River (ML)	F1.1_P/DW	16/03/2021 10:30	18.83	<i>Labeobarbus natalensis</i>	1	88	99	49.4	Boulders	0
Palmiet River (ML)	F1.1_P/DW	16/03/2021 10:30	18.83	<i>Labeobarbus natalensis</i>	1	107	132	49.4	Boulders	0
Palmiet River (ML)	F1.1_P/DW	16/03/2021 10:30	18.83	<i>Xiphophorus hellerii</i>	1	49	65	49.4	Boulders	0
Palmiet River (ML)	F2.1_P/DW	16/03/2021 10:40	18.92	<i>Labeobarbus natalensis</i>	1	230	260	37.4	Boulders	0.62

Palmiet River (ML)	F2.1_P/DW	16/03/2021 10:40	18.92	<i>Labeobarbus natalensis</i>	1	125	160	37.4	Boulders	0.62
Palmiet River (ML)	F2.1_P/DW	16/03/2021 10:40	18.92	<i>Labeobarbus natalensis</i>	1	130	160	37.4	Boulders	0.62
Palmiet River (ML)	F3.1_P/DW	16/03/2021 10:50	19.00	<i>Labeobarbus natalensis</i>	1	escaped	-	33.4	Boulders	0.843
Palmiet River (ML)	F4.1_P/DW	16/03/2021 11:00	19.00	<i>Labeobarbus natalensis</i>	1	0	170	31.6	Boulders	0.272
Palmiet River (ML)	F4.1_P/DW	16/03/2021 11:00	19.00	<i>Labeobarbus natalensis</i>	1	145	150	31.6	Boulders	0.272
Palmiet River (ML)	F4.1_P/DW	16/03/2021 11:00	19.00	<i>Labeobarbus natalensis</i>	1	150	175	31.6	Boulders	0.272
Palmiet River (ML)	F4.1_P/DW	16/03/2021 11:00	19.00	<i>Labeobarbus natalensis</i>	1	110	140	31.6	Boulders	0.272
Palmiet River (ML)	F5.1_P/DW	16/03/2021 11:10	19.00	<i>Labeobarbus natalensis</i>	1	120	140	29.4	Boulders	1.142
Palmiet River (ML)	F5.1_P/DW	16/03/2021 11:10	19.00	<i>Labeobarbus natalensis</i>	1	90	110	29.4	Boulders	1.142
Palmiet River (ML)	F5.1_P/DW	16/03/2021 11:10	19.00	<i>Labeobarbus natalensis</i>	1	130	150	29.4	Boulders	1.142
Palmiet River (ML)	F5.1_P/DW	16/03/2021 11:10	19.00	<i>Labeobarbus natalensis</i>	1	125	150	29.4	Boulders	1.142
Palmiet River (ML)	F5.1_P/DW	16/03/2021 11:10	19.00	<i>Labeobarbus natalensis</i>	1	125	150	29.4	Boulders	1.142
Palmiet River (ML)	F5.1_P/DW	16/03/2021 11:10	19.00	<i>Labeobarbus natalensis</i>	1	95	115	29.4	Boulders	1.142
Palmiet River (ML)	F5.1_P/DW	16/03/2021 11:10	19.00	<i>Labeobarbus natalensis</i>	1	125	145	29.4	Boulders	1.142

Molweni River (EV)	F1.1_M/UW	17/03/2021 11:30	20.50	No fish	1	0	0	47.2	Sand	0.266
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	80	96	36	Boulders	0.333
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	79	92	36	Boulders	0.333
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	82	97	36	Boulders	0.333
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	77	92	36	Boulders	0.333
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	82	96	36	Boulders	0.333
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	77	92	36	Boulders	0.333
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	82	97	36	Boulders	0.333
Molweni River (EV)	F2.1_M/UW	17/03/2021 11:50	20.67	<i>Enteromius gurneyi</i>	1	77	92	36	Boulders	0.333
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	86	105	43	Sand	0.048
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	82	101	43	Sand	0.048
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	81	96	43	Sand	0.048
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	86	103	43	Sand	0.048
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	76	90	43	Sand	0.048

Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	75	92	43	Sand	0.048
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	80	97	43	Sand	0.048
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	87	104	43	Sand	0.048
Molweni River (KK)	F1.1_M/DW	17/03/2021 09:10	17.33	<i>Enteromius gurneyi</i>	1	84	101	43	Sand	0.048
Molweni River (KK)	F2.1_M/DW	17/03/2021 09:25	17.50	<i>Enteromius gurneyi</i>	1	82	100	32	Boulders	0
Molweni River (KK)	F2.1_M/DW	17/03/2021 09:25	17.50	<i>Enteromius gurneyi</i>	1	81	95	32	Boulders	0
Molweni River (KK)	F2.1_M/DW	17/03/2021 09:25	17.50	<i>Enteromius gurneyi</i>	1	87	94	32	Boulders	0
Molweni River (KK)	F2.1_M/DW	17/03/2021 09:25	17.50	<i>Enteromius gurneyi</i>	1	84	99	32	Boulders	0
Molweni River (KK)	F3.1_M/DW	17/03/2021 09:31	17.52	No fish	0	0	0	31.6	Boulders	0.202
Inanda (TNB)	F1.1_I/UW	18/03/2021 09:00	19.50	<i>Micropterus salmoides</i>	1	90	104	84.8	Gravel	-
Inanda (TNB)	F1.1_I/UW	18/03/2021 09:00	19.50	<i>Anguilla bengalensis</i>	1		1200	84.8	Gravel	-
Inanda (TNB)	F1.1_I/UW	18/03/2021 09:00	19.50	<i>Micropterus salmoides</i>	1	118	129	84.8	Gravel	-
Inanda (TNB)	F2.1_I/UW	18/03/2021 09:05	19.42	<i>Micropterus salmoides</i>	1	113	131	99.6	Gravel	-
Inanda (TNB)	F2.1_I/UW	18/03/2021 09:05	19.42	<i>Micropterus salmoides</i>	1	102	121	99.6	Gravel	-

Inanda (TNB)	F2.1_I/UW	18/03/2021 09:05	19.42	<i>Micropterus salmoides</i>	1	107	130	99.6	Gravel	-
Below Top Needle Bridge	F1.1_I/DW	18/03/2021 10:00	19.75	<i>Oreochromis mossambicus</i>	1	81	90	81.2	Sand	0.096
Below Top Needle Bridge	F2.1_I/DW	18/03/2021 10:20	19.83	<i>Coptodon rendalli</i>	1	85	100	115.6	Cobble	0.096
Below Top Needle Bridge	GEN1.1_I/DW	18/03/2021 10:15	19.63	<i>Oreochromis mossambicus</i>	1	90	100	31.4	Sand	0.096
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	63	84	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	69	87	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	60	77	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	59	76	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	77	86	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	58	77	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	60	76	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	76	87	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	74	81	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	60	74	>100	Sludge	-

uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	65	0	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	74	81	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	71	76	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	62	81	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	72	93	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	61	78	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	73	82	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	59	75	>100	Sludge	-
uMngeni Estuary	F1.1_Es	19/03/2021 09:30	19.00	<i>Ambassis gymnocephalus</i>	1	60	76	>100	Sludge	-
uMngeni Estuary	F2.1_Es	19/03/2021 09:40	19.00	<i>Ambassis gymnocephalus</i>	1	63	78	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	58	72	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	69	86	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	87	100	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	63	80	>100	Sludge	-

uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	75	96	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	66	82	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	64	81	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	62	80	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	65	82	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	66	87	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	67	87	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	65	82	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	70	91	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	66	85	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	66	81	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	61	79	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	65	84	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	64	81	>100	Sludge	-

uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	65	84	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	60	78	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	77	98	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	60	78	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	65	83	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	66	82	>100	Sludge	-
uMngeni Estuary	F3.1_Es	19/03/2021 09:46	18.93	<i>Ambassis gymnocephalus</i>	1	62	80	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	61	76	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	64	81	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	70	89	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	65	84	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	60	77	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	79	86	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	73	92	>100	Sludge	-

uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	65	84	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	64	84	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	63	80	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	64	80	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	78	99	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	73	94	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	63	0	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	68	84	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	73	94	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	60	79	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	65	84	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	62	81	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	61	79	>100	Sludge	-
uMngeni Estuary	F4.1_Es	19/03/2021 09:51	18.92	<i>Ambassis gymnocephalus</i>	1	67	82	>100	Sludge	-

uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	52	70	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	73	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	75	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	60	79	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	50	64	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	62	79	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	69	86	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	57	69	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	53	70	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	65	82	>100	Sludge	-

uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	64	82	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	70	84	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	75	84	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	60	79	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	85	74	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	69	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	70	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	73	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	75	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	60	75	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	57	75	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	60	75	>100	Sludge	-

uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	70	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	-
uMngeni Estuary	S1.1_Es	19/03/2021 10:07	0.27	<i>Ambassis gymnocephalus</i>	1	60	75	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Awaous aeneofuscus</i>	1	28	35	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Awaous aeneofuscus</i>	1	28	35	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	90	118	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	100	122	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	90	113	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	90	114	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	85	109	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	100	120	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	85	110	>100	Sludge	-
uMngeni Estuary	S2.1_Es	19/03/2021 10:20	0.15	<i>Mullet</i>	1	85	109	>100	Sludge	-

uMngeni Estuary	S3.1_Es	19/03/2021 10:42	0.18	<i>Mullet</i>	1	380	454	>100	Sludge	-
uMngeni Estuary	S3.1_Es	19/03/2021 10:42	0.18	<i>Mullet</i>	1	85	104	>100	Sludge	-
uMngeni Estuary	S3.1_Es	19/03/2021 10:42	0.18	<i>Awaous aeneofuscus</i>	1	40	62	>100	Sludge	-
uMngeni Estuary	S3.1_Es	19/03/2021 10:42	0.18	<i>Awaous aeneofuscus</i>	1	29	38	>100	Sludge	-
uMngeni Estuary	S3.1_Es	19/03/2021 10:42	0.18	<i>Awaous aeneofuscus</i>	1	27	37	>100	Sludge	-
Palmiet River (AL)	F1.2_P/UW	08/06/2021 08:38	19.13	<i>No fish</i>	0	0	0	62.8	Boulders	0.2
Palmiet River (AL)	F2.2_P/UW	08/06/2021 08:47	19.12	<i>Labeobarbus natalensis</i>	1	110	140	29.2	Cobble	0.25333333
Palmiet River (AL)	F3.2_P/UW	08/06/2021 08:49	19.48	<i>Labeobarbus natalensis</i>	1	140	170	24.6	Bedrock	0.655
Palmiet River (AL)	F4.2_P/UW	08/06/2021 09:05	19.35	<i>Labeobarbus natalensis</i>	1	123	147	50.4	Sand	0.06
Palmiet River (AL)	F5.2_P/UW	08/06/2021 09:11	19.28	<i>Clarias gariepinus</i>	1	420	460	61.8	Sand	0
Palmiet River (AL)	F5.2_P/UW	08/06/2021 09:11	19.28	<i>Clarias gariepinus</i>	1	380	420	61.8	Sand	0
Palmiet River (AL)	F5.2_P/UW	08/06/2021 09:11	19.28	<i>Clarias gariepinus</i>	1	405	444	61.8	Sand	0
Palmiet River (AL)	F5.2_P/UW	08/06/2021 09:11	19.28	<i>Labeobarbus natalensis</i>	1	0	0	61.8	Sand	0
Palmiet River (AL)	GEN1.2_P/UW	08/06/2021 09:14	19.40	<i>Labeobarbus natalensis</i>	1	110	138	78.6	Sand	0.08

Palmiet River (AL)	GEN1.2_P/UW	08/06/2021 09:14	19.40	<i>Labeobarbus natalensis</i>	1	140	174	78.6	Sand	0.08
Palmiet River (AL)	GEN1.2_P/UW	08/06/2021 09:14	19.40	<i>Labeobarbus natalensis</i>	1			78.6	Sand	0.08
Palmiet River (AL)	GEN1.2_P/UW	08/06/2021 09:14	19.40	<i>Labeobarbus natalensis</i>	1	145	189	78.6	Sand	0.08
Palmiet River (AL)	GEN1.2_P/UW	08/06/2021 09:14	19.40	<i>Labeobarbus natalensis</i>	1	15	0	78.6	Sand	0.08
Palmiet River (AL)	GEN1.2_P/UW	08/06/2021 09:14	19.40	<i>Labeobarbus natalensis</i>	1	38	49	78.6	Sand	0.08
Palmiet River (AL)	GEN1.2_P/UW	08/06/2021 09:14	19.40	<i>Labeobarbus natalensis</i>	1	37	39	78.6	Sand	0.08
Palmiet River (ML)	F1.2_P/DW	08/06/2021 10:06	18.60	<i>Labeobarbus natalensis</i>	1	138	161	43.4	Sand	0.08
Palmiet River (ML)	F1.2_P/DW	08/06/2021 10:06	18.60	<i>Labeobarbus natalensis</i>	1	123	152	43.4	Sand	0.08
Palmiet River (ML)	F1.2_P/DW	08/06/2021 10:06	18.60	<i>Labeobarbus natalensis</i>	1	130	160	43.4	Sand	0.08
Palmiet River (ML)	F1.2_P/DW	08/06/2021 10:06	18.60	<i>Labeobarbus natalensis</i>	1	168	203	43.4	Sand	0.08
Palmiet River (ML)	F2.2_P/DW	08/06/2021 10:17	18.50	<i>Labeobarbus natalensis</i>	1	146	184	30.8	Boulders	0.21666667
Palmiet River (ML)	F3.2_P/DW	08/06/2021 10:20	18.63	<i>Labeobarbus natalensis</i>	1	140	169	32.2	Sand	0
Palmiet River (ML)	F3.2_P/DW	08/06/2021 10:20	18.63	<i>Labeobarbus natalensis</i>	1	110	138	32.2	Sand	0
Palmiet River (ML)	F3.2_P/DW	08/06/2021 10:20	18.63	<i>Labeobarbus natalensis</i>	1	110	133	32.2	Sand	0

Palmiet River (ML)	F3.2_P/DW	08/06/2021 10:20	18.63	<i>Labeobarbus natalensis</i>	1	120	157	32.2	Sand	0
Palmiet River (ML)	F3.2_P/DW	08/06/2021 10:20	18.63	<i>Labeobarbus natalensis</i>	1	125	158	32.2	Sand	0
Palmiet River (ML)	F3.2_P/DW	08/06/2021 10:20	18.63	<i>Xiphophorus hellerii</i>	1	50	60	32.2	Sand	0
Palmiet River (ML)	F3.2_P/DW	08/06/2021 10:20	18.63	<i>Labeobarbus natalensis</i>	1	115	130	32.2	Sand	0
Palmiet River (ML)	F4.2_P/DW	08/06/2021 10:40	19.25	No fish	0	0	0	43.2	Sand	0.23833333
Palmiet River (ML)	F5.2_P/DW	08/06/2021 10:50	19.00	No fish	0	0	0	43	Boulders	0.49333333
Molweni River (EV)	F1.2_M/UW	09/06/2021 09:26	18.58	<i>Enteromius gurneyi</i>	1	78	91	50.2	Boulders	0.04
Molweni River (EV)	F1.2_M/UW	09/06/2021 09:26	18.58	<i>Enteromius gurneyi</i>	1	83	99	50.2	Boulders	0.04
Molweni River (EV)	F1.2_M/UW	09/06/2021 09:26	18.58	<i>Enteromius gurneyi</i>	1	80	96	50.2	Boulders	0.04
Molweni River (EV)	F2.2_M/UW	09/06/2021 09:35	18.60	No fish	0	0	0	22.4	Sand	0.2
Molweni River (EV)	F3.2_M/UW	09/06/2021 09:43	18.67	No fish	0	0	0	26	Boulders	0.51
Molweni River (KK)	F1.2_M/DW	09/06/2021 08:16	16.93	No fish	0	0	0	32.4	Bedrock	0.12833333
Molweni River (KK)	F2.2_M/DW	09/06/2021 08:29	17.22	No fish	0	0	0	59.6	Bedrock	0.04
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Coptodon rendalli</i>	1	117	135	88.2	Gravel	0

Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Micropterus salmoides</i>	1	125	148	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Coptodon rendalli</i>	1	112	138	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Coptodon rendalli</i>	1	112	138	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Clarias gariepinus</i>	1	283	309	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Clarias gariepinus</i>	1	320	368	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Clarias gariepinus</i>	1	194	219	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Clarias gariepinus</i>	1	233	270	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Clarias gariepinus</i>	1	215	245	88.2	Gravel	0
Inanda (TNB)	F1.2_I/UW	10/06/2021 09:20	18.65	<i>Coptodon rendalli</i>	1	113	139	88.2	Gravel	0
Inanda (TNB)	F2.2_I/UW	10/06/2021 09:35	18.72	<i>Coptodon rendalli</i>	1	118	144	85.8	Gravel	0
Inanda (TNB)	F2.2_I/UW	10/06/2021 09:35	18.72	<i>Micropterus salmoides</i>	1	116	137	85.8	Gravel	0
Inanda (TNB)	F2.2_I/UW	10/06/2021 09:35	18.72	<i>Clarias gariepinus</i>	1	226	246	85.8	Gravel	0
Inanda (TNB)	F2.2_I/UW	10/06/2021 09:35	18.72	<i>Micropterus salmoides</i>	1	124	143	85.8	Gravel	0
Inanda (TNB)	F2.2_I/UW	10/06/2021 09:35	18.72	<i>Clarias gariepinus</i>	1	308	328	85.8	Gravel	0

Inanda (TNB)	F3.2_I/UW	10/06/2021 09:45	18.77	<i>Clarias gariepinus</i>	1	245	271	89	Gravel	0
Inanda (TNB)	F3.2_I/UW	10/06/2021 09:45	18.77	<i>Clarias gariepinus</i>	1	242	271	89	Gravel	0
Inanda (TNB)	F3.2_I/UW	10/06/2021 09:45	18.77	<i>Clarias gariepinus</i>	1	254	285	89	Gravel	0
Inanda (TNB)	F3.2_I/UW	10/06/2021 09:45	18.77	<i>Coptodon rendalli</i>	1	113	119	89	Gravel	0
Inanda Down Weir	F1.2_I/DW	10/06/2021 10:30	19.17	<i>Micropterus salmoides</i>	1	120	148	95	Sand	0
Below Top Needle Bridge	F1.2_I/DW	10/06/2021 10:30	19.17	<i>Tilapia sparrmanii</i>	1	125	159	95	Sand	0
Below Top Needle Bridge	F2.2_I/DW	10/06/2021 10:42	19.30	No fish	0	0	0	>100	Boulders	0
Below Top Needle Bridge	GEN1.2_I/DW	10/06/2021 10:17	18.77	<i>Micropterus salmoides</i>	1	115	135	54.2	Sand	0
Below Top Needle Bridge	GEN1.2_I/DW	10/06/2021 10:17	18.77	<i>Tilapia sparrmanii</i>	1	115	138	54.2	Sand	0
Below Top Needle Bridge	GEN1.2_I/DW	10/06/2021 10:17	18.77	<i>Tilapia sparrmanii</i>	1	85	108	54.2	Sand	0
Below Top Needle Bridge	GEN1.2_I/DW	10/06/2021 10:17	18.77	<i>Tilapia sparrmanii</i>	1	76	97	54.2	Sand	0
uMngeni Estuary	F1.2_Es	11/06/2021 09:07	18.62	<i>Ambassis gymnocephalus</i>	1	70	92	>100	Sludge	0
uMngeni Estuary	F1.2_Es	11/06/2021 09:07	18.62	<i>Ambassis gymnocephalus</i>	1	80	99	>100	Sludge	0
uMngeni Estuary	F2.2_Es	11/06/2021 09:21	18.70	<i>Oreochromis mossambicus</i>	1	85	100	>100	Sludge	0

uMngeni Estuary	F2.2_Es	11/06/2021 09:21	18.70	<i>Oreochromis mossambicus</i>	1	160	190	>100	Sludge	0
uMngeni Estuary	F2.2_Es	11/06/2021 09:21	18.70	<i>Oreochromis mossambicus</i>	1	100	115	>100	Sludge	0
uMngeni Estuary	F2.2_Es	11/06/2021 09:21	18.70	<i>Ambassis gymnocephalus</i>	1	80	105	>100	Sludge	0
uMngeni Estuary	F2.2_Es	11/06/2021 09:21	18.70	<i>Ambassis gymnocephalus</i>	1	90	100	>100	Sludge	0
uMngeni Estuary	F2.2_Es	11/06/2021 09:21	18.70	<i>Ambassis gymnocephalus</i>	1	80	95	>100	Sludge	0
uMngeni Estuary	F2.2_Es	11/06/2021 09:21	18.70	<i>Ambassis gymnocephalus</i>	1	80	105	>100	Sludge	0
uMngeni Estuary	F3.2_Es	11/06/2021 09:32	18.77	<i>Eleotris fusca</i>	1	215	268	>100	Sludge	0
uMngeni Estuary	F3.2_Es	11/06/2021 09:32	18.77	<i>Eleotris fusca</i>	1	235	289	>100	Sludge	0
uMngeni Estuary	F4.2_Es	11/06/2021 09:52	19.02	<i>Eleotris fusca</i>	1	281	295	>100	Sludge	0
uMngeni Estuary	F4.2_Es	11/06/2021 09:52	19.02	<i>Ambassis gymnocephalus</i>	1	56	71	>100	Sludge	0
uMngeni Estuary	F4.2_Es	11/06/2021 09:52	19.02	<i>Ambassis gymnocephalus</i>	1	55	72	>100	Sludge	0
uMngeni Estuary	F4.2_Es	11/06/2021 09:52	19.02	<i>Ambassis gymnocephalus</i>	1	66	85	>100	Sludge	0
uMngeni Estuary	F4.2_Es	11/06/2021 09:52	19.02	<i>Ambassis gymnocephalus</i>	1	66	76	>100	Sludge	0
uMngeni Estuary	F4.2_Es	11/06/2021 09:52	19.02	<i>Ambassis gymnocephalus</i>	1	6	76	>100	Sludge	0

uMngeni Estuary	F4.2_Es	11/06/2021 09:52	19.02	<i>Ambassis gymnocephalus</i>	1	71	92	>100	Sludge	0
uMngeni Estuary	F5.2_Es	11/06/2021 10:10	19.18	<i>Ambassis gymnocephalus</i>	15		>100	>100	Sludge	0
uMngeni Estuary	F5.2_Es	11/06/2021 10:10	19.18	<i>Ambassis gymnocephalus</i>	22		>90	>100	Sludge	0
uMngeni Estuary	F5.2_Es	11/06/2021 10:10	19.18	<i>Ambassis gymnocephalus</i>	8		>80	>100	Sludge	0
uMngeni Estuary	F5.2_Es	11/06/2021 10:10	19.18	<i>Ambassis gymnocephalus</i>	3		>70	>100	Sludge	0
Palmiet River (AL)	F1.3_P/UW	15/09/2021 08:42	19.10	<i>Labeobarbus natalensis</i>	1	97	117	56	Sand	0.3
Palmiet River (AL)	F1.3_P/UW	15/09/2021 08:42	19.10	<i>Labeobarbus natalensis</i>	1	243	285	56	Sand	0.3
Palmiet River (AL)	F2.3_P/UW	15/09/2021 08:57	19.30	<i>Labeobarbus natalensis</i>	1	137	172	29.8	Gravel	0.27833333
Palmiet River (AL)	F2.3_P/UW	15/09/2021 08:57	19.30	<i>Labeobarbus natalensis</i>	1	255	314	29.8	Gravel	0.27833333
Palmiet River (AL)	F2.3_P/UW	15/09/2021 08:57	19.30	<i>Labeobarbus natalensis</i>	1	230	280	29.8	Gravel	0.27833333
Palmiet River (AL)	F2.3_P/UW	15/09/2021 08:57	19.30	<i>Labeobarbus natalensis</i>	1	110	120	29.8	Gravel	0.27833333
Palmiet River (AL)	F2.3_P/UW	15/09/2021 08:57	19.30	<i>Labeobarbus natalensis</i>	1	127	159	29.8	Gravel	0.27833333
Palmiet River (AL)	F2.3_P/UW	15/09/2021 08:57	19.30	<i>Labeobarbus natalensis</i>	1	114	141	29.8	Gravel	0.27833333
Palmiet River (AL)	F3.3_P/UW	15/09/2021 09:03	19.28	<i>Labeobarbus natalensis</i>	1	120	145	21.2	Bedrock	0.31333333

Palmiet River (AL)	F3.3_P/UW	15/09/2021 09:03	19.28	<i>Labeobarbus natalensis</i>	1	190	235	21.2	Bedrock	0.31333333
Palmiet River (AL)	F3.3_P/UW	15/09/2021 09:03	19.28	<i>Labeobarbus natalensis</i>	1	120	145	21.2	Bedrock	0.31333333
Palmiet River (AL)	F4.3_P/UW	15/09/2021 09:11	19.23	No fish	0	0	0	44.4	Bedrock	0.30666667
Palmiet River (AL)	F5.3_P/UW	15/09/2021 09:18	19.20	<i>Labeobarbus natalensis</i>	1	180	150	51	Sand	0.14833333
Palmiet River (AL)	GEN1.3_P/UW	15/09/2021 09:10	19.40	No fish	0	0	0	64.2	Sand	0.16
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	103	130	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	104	129	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	119	148	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	148	183	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	129	150	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	117	146	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	129	155	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	185	225	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	195	235	58	Sand	0.23833333

Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	168	208	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	175	213	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	180	220	58	Sand	0.23833333
Palmiet River (ML)	F1.3_P/DW	15/09/2021 09:42	19.20	<i>Labeobarbus natalensis</i>	1	175	225	58	Sand	0.23833333

7

8