

**An evaluation of present and potential inland fisheries in
dams and rivers in the uThukela and uMngeni
Catchments, KwaZulu-Natal, South Africa**

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ABSTRACT

Globally, freshwater systems and their biodiversity and ecosystem services are threatened. Freshwater fisheries in South Africa are understudied despite their economic importance to fishers, especially subsistence fishers. Little is known about the potential for rivers and impoundments to support subsistent fisheries and the resilience of native fish species impacted by invasive alien fish species. The main aim of this study was to address the lack of knowledge about economically and biologically important indigenous fish species that support inland fisheries in KwaZulu-Natal Province, South Africa. The composition and contribution of native and invasive fish species and their offtake by fishers were assessed. Fishers across the uThukela and uMngeni catchments were interviewed using in-person questionnaires. In addition, assessment of fish communities and population structures in Midmar Dam and Henley Dam, two selected dams on the uMngeni River, coupled with questionnaire data, were used to determine the offtake trends by fishers (subsistence and recreational). These will contribute to a potential subsistence fisheries management plan for these dams based on the findings to guide the development of the provincial and national inland fisheries plan.

Firstly, in a systematic review, the present and potential inland fisheries in dams and rivers across Africa to guide inland fisheries in KwaZulu-Natal, South Africa, were assessed. The results showed diverse inland fisheries types with distinct characteristics and shared challenges. National and regional importance of African inland fisheries was found, but there was a lack of understanding of the definitions and boundaries between the categories of inland fisheries. Subsistence fisheries, focusing on local food provision through traditional methods, face threats like overfishing. Recreational fisheries, contributing to food, income, and recreation, require effective conservation in developing nations. Small-scale fisheries showcase resilience and

successful conservation, emphasising adaptive management. Commercial fisheries involving professional fish exploitation encounter challenges, especially in regions like South Africa, demanding sophisticated approaches for long-term viability. Across Africa, common challenges such as overfishing and habitat destruction persist. In KwaZulu-Natal, a significant research gap exists, impacting sustainability. Addressing issues like monitoring systems, invasive species, and species knowledge is crucial for sustainable fisheries management in the region.

Secondly, to address the paucity of knowledge of economically beneficial fish species and their offtake based on the perceptions of fishers present in selected sections of the uMngeni and uThukela catchments, KwaZulu-Natal, South Africa, a questionnaire interview method was used to obtain fishers' responses during 2021-2023. Findings from this study revealed difficulties in categorising fishers because of present inland water policies similar to the “fuzzy boundary” concept for inland fisheries globally, with some individuals identifying as recreational because of nondisclosure fears. Fishers’ knowledge illustrated the ecological imbalances between native (*Labeobarbus natalensis*) and invasive (*Cyprinus carpio*, *Micropterus* spp.) species, as well as the economic importance of fish based on market valuations, with *C. carpio* having a greater market value. Additionally, the results showed that subsistence fishers preferred river fishing compared with recreational fishers that targeted impoundments. Importantly, a considerable percentage of subsistence fishers ate fish mostly once a week or once a month. These results highlighted the importance of holistic management of water regulations, fish ecology, and economics to promote sustainable inland fisheries.

Thirdly, an ecological assessment of fish communities in Midmar Dam and Henley Dam during the winter and summer seasons of 2022 and 2023 was conducted. Diverse fishing methods were used to capture a broad spectrum of fish species. Additionally, questionnaires were

administered in selected areas of KwaZulu-Natal to gather complementary data on fish species in inland fisheries. A total of six fish species (three native species and three invasive species) were found in the two impoundments. Midmar Dam had significantly higher total fish catch than Henley Dam, highlighting the role of environmental factors such as dam size, depth, and temperature in shaping fish populations and influencing overall productivity. The KwaZulu-Natal yellowfish (*L. natalensis*) was significant to local inland fisheries, while invasive fish species posed challenges to maintaining the native fish species. These results emphasised that incorporating fish catch data into decision-making processes is crucial for making informed, science-based choices that ensure the long-term viability of fish populations and promote the overall health of freshwater ecosystems.

In conclusion, the findings underscore the necessity for tailored fisheries management strategies that consider the unique environmental characteristics of each dam and the structures of fish populations. By integrating water quality data, catch-per-unit-effort (CPUE) results, and insights from fishers, decision-makers can formulate science-based approaches to preserve fish populations, support local livelihoods, and safeguard vulnerable communities dependent on subsistence fishing. Ultimately, successful conservation and sustainable management of fish populations hinge on informed decision-making prioritising ecosystem health and resilience across KwaZulu-Natal's freshwater habitats.

PREFACE

The data described in this thesis were collected in KwaZulu-Natal, Republic of South Africa, from February 2022 to September 2023. 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, Dr Matthew J. Burnett and Dr Celine Hansen.

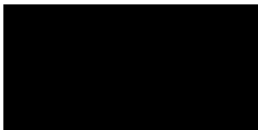
This thesis, submitted for the degree of Master of Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma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



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Ntandokayise Makhathini

February 2024

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



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Prof Colleen T. Downs

Supervisor

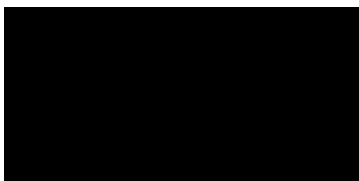
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DECLARATION 1 - PLAGIARISM

I, Ntandokayise Makhathini, declare that

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

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

PUBLICATION 1- not submitted

Evaluating the present and potential inland fisheries in dams and rivers across Africa to guide inland fisheries in KwaZulu-Natal, South Africa: A systematic review

Ntando Makhathini, Matthew J. Burnett, Céline Hanzen and Colleen T. Downs

Author contributions:

NM conceived the paper with CTD, MJB and CH. NM collected and analysed data, and wrote the draft paper. CTD, MJB and CH contributed valuable comments to the manuscript.

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An evaluation of present and potential inland fisheries in dams and rivers in the uThukela and uMngeni Catchments, KwaZulu-Natal, South Africa, based on fishers' perceptions

Ntando Makhathini, Matthew J. Burnett, Mxolisi Nkomo, Céline Hanzen and Colleen T. Downs

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NM conceived the paper with CTD, MJB and CH. NM collected the data with MN. NM analysed the data and wrote the draft paper. CTD, MJB and CH contributed valuable comments to the manuscript.

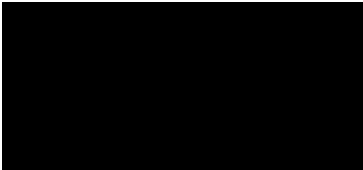
PUBLICATION 3- not submitted

**An evaluation of the present inland fisheries in impoundments and associated rivers in
KwaZulu-Natal, South Africa, with a focus on Midmar Dam and Henley Dam**

Ntando Makhathini, Matthew J. Burnett, Céline Hanzen and Colleen T. Downs

Author contributions:

NM conceived the paper with CTD, MJB and CH. NM collected and analysed data, and wrote the draft paper. CTD, MJB and CH contributed valuable comments to the manuscript.



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Ntandokayise Makhathini

February 2024

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I dedicate this thesis to my grandparents and my deceased parents.

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CHAPTER 1

Introduction

1.1 Background

Inland fisheries (excluding plants, mammals, crustaceans, echinoderms, and molluscs) account for more than 40% of global catch fisheries and aquaculture production (Welcomme, 2011). Data from the Food and Agriculture Organisation of the United Nations (FAO) Fish Catch (2019) show that Asia and Africa have the highest contribution to the global inland water catch by 7 866 687 tons and 3 255 405 tons, respectively in 2019 (FAO, 2019). This shows that these continents contribute the most to the global inland fish catch. In 2008, the FAO reported that 10.8 million tons of developing countries' freshwater fish yields were mainly from the Mekong River, Asia (FAO, 2008; De Graaf et al., 2015). Generally, developing countries have rural communities that use rivers more than dams (impoundments) since rivers are relatively easily accessible (Magombeyi et al., 2008). Generally, dams are used more than rivers in recreational and development projects (e.g., hydropower, irrigation, and recreation) (Ellender et al., 2009; Zeng et al., 2012).

Importantly, inland fisheries contribute to poverty prevention globally, especially in rural communities in low-income food-deficit countries (Lynch et al., 2017; Ahern et al., 2021; Viridin et al., 2023). They also improve food and economic security in those countries (Lynch et al., 2017). About 4.8 million people in these developing countries are potentially positively impacted by inland fisheries and improving social and cultural values (Hara, 2021). Over 60 million people in low-income countries depend on inland fisheries for their livelihoods, and more than half of those working in inland fisheries supply chains are women (FAO, 2014).

As a food source, inland fisheries are a reliable source of Omega 3, organic compounds (meat protein), and calcium, which are essential for human nutrition (Belton and Thirsted, 2014).

Native inland fish are more accessible and cheaper to harvest, making them their reliable source of protein. For example, small native fish in some developing countries are the main source of protein (Youn et al., 2014; Loring et al., 2019).

Inland fisheries are differentiated into three categories: commercial, subsistence, and (subsistence) small-scale fisheries. Commercial fisheries involve large yields of fish to be sold commercially for profits, carried out by professional fishers, and are the major source of their income (Cowx, 2015). On the other hand, subsistence fisheries are differentiated into two: subsistence fisheries for recreational use (e.g., fly fishermen and bass tournament anglers) and subsistence fisheries for human consumption (small-scale fisheries) (Viswanathan and Center, 2003; Sunde and Erwin, 2020).

Small-scale fisheries are usually defined as low technology labour intensive compared with recreational fishing (Kolding et al., 2016; Smith and Barsuto, 2019). The definition of these terms is completely different in continents like Africa. This is because, in most African countries, government policies around inland fisheries locate them under the same category as recreational activities (wildlife, game, and tourism) instead of being a stable food supplier because of the effect of colonial history (Kolding et al., 2016). A good example is South Africa; because its policies limit subsistence anglers from using gillnets and traps, they use recreational fishing methods, creating a grey spot between recreational and subsistence fishers (Nyboer et al., 2022).

1.2 Importance of inland fisheries in Africa

The FAO (2010) lists Africa as having the highest production of two inland fish taxa, cyprinids and cichlids (Youn et al., 2014). In 2012, the FAO reported that 80% (~7 million tons) of inland capture was from seventy-one low-income food-deficit countries in Africa (FAO, 2012; Youn et

al., 2014). African inland fisheries are generally categorised into rivers, Great Lakes (Malawi, Tanganyika, and Great Lakes Victoria), and floodplains (Marshall, 2015) (Fig. 1.1). The great lake in Malawi features the world's most diverse multi-species among these three groups (Weyl et al., 2010). These great lakes are particularly significant in food security and nutritional status, especially in landlocked countries, as fish provide 22% protein (Marshall, 2015; Table 1.1).

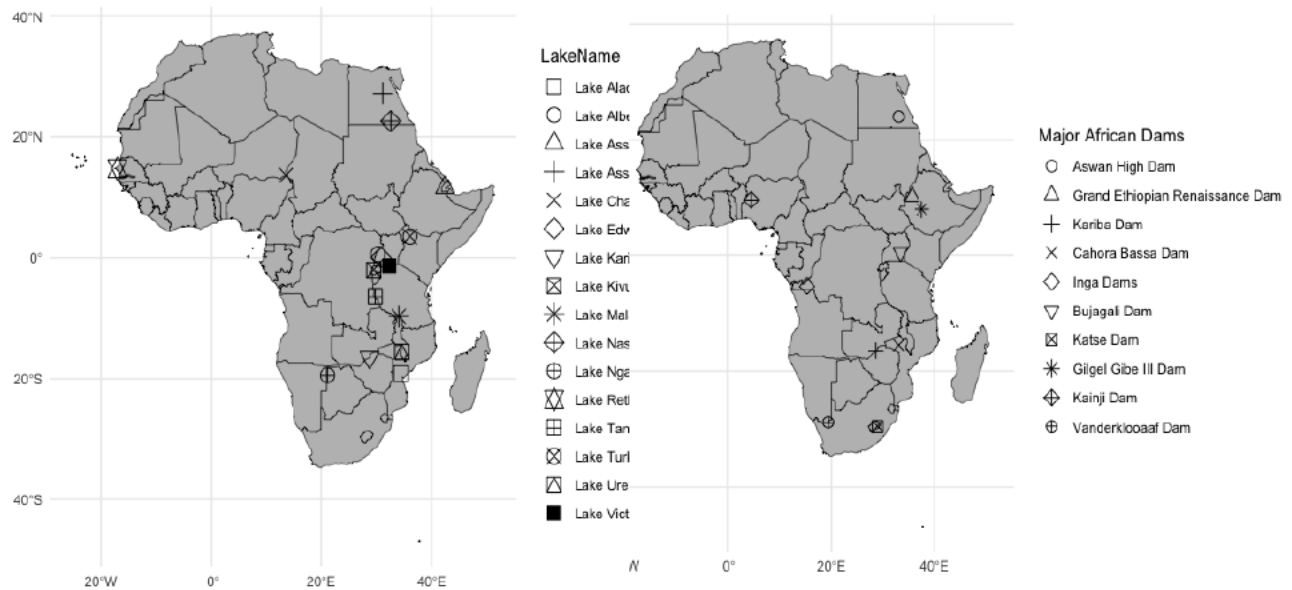


Figure 1.1: Major African inland waters (lakes and dams) that support inland fisheries for various African countries (Source: Nyboer et al., 2019).

The World Bank reported that in 2012 sub-Saharan Africa poverty and equity data was 501 million individuals, which was second to Asia (512 million), mainly because of the large population (Adeyeye et al., 2012). Poverty is identified as the primary cause of hunger in Africa. The primary reasons for poverty are destructive economic systems, violence, natural issues such as drought and climate change, and population increase (Youn et al., 2014; Egbetunde and Adesina, 2022). Despite this, inland fisheries indirectly contribute to African countries' national

food self-sufficiency through trading and exporting fish and creating job opportunities (Béné and Heck, 2005; Adeleke et al., 2020, Table 1.1). This is an important contribution to preventing poverty in Africa (Chan et al., 2019).

Table 1.1: African countries that depend on inland fisheries (Source: Vanden Bossche and Bernacsek, 1990).

Inland fisheries dependent African countries		
African Republic	Ghana	Senegal
Algeria	Guinea	Seychelles
Angola	Guinea-Bissau	Sierra Leone
Benin	Kenya	Somalia
Botswana	Lesotho	Sudan
Burkina Faso	Liberia	Swaziland
Burundi	Libya	Tanzania
Cameroon	Madagascar	Togo
Cape Verde	Malawi	Tunisia
Central	Mali	Uganda
Chad	Mauritania	West Sahara
Comoros	Mauritius	Zaire
Congo	Morocco	Zambia
Côte d'Ivoire	Mozambique	Zimbabwe
Djibouti	Namibia	
Egypt	Niger	
Equatorial Guinea	Nigeria	
Ethiopia	Reunion	
Gabon	Rwanda	
Gambia	San Tome and Principe	

Fishing has been a vital dietary component in northern Africa for millennia (Gabriel et al., 2007; Youn et al., 2014). Because of extreme arid temperatures in North Africa, countries like Egypt have various fish, the Nile tilapia *Oreochromus niloticus*, cyprinids fish family and several species of catfish (e.g., *Clarias gariepinus*), as their most common fisheries species (Marshall, 2015). This is because these fish species have a high tolerance to salinity, so saline coastal lakes

are considered part of inland fisheries (Marshall, 2015). These fish species are used for trade in the informal market and/ or for food consumption. Egypt is one of the African countries where fisheries are important for food security, livelihoods, and employment (Weyl and Cowley, 2015). With this, fishery management strategies have been implemented through monitoring and licensing (Samy-Kamal, 2015; Weyl and Cowley, 2015). However, there is little information available on the use of rivers compared with the use of dams here for inland fisheries.

Throughout Africa, inland fisheries are among the crucial factors that play a key role in food security and improving nutritional status (Youn et al., 2014; Arthur et al., 2022). In underdeveloped and developing African countries like Malawi, Ghana, and Uganda, micronutrient intake depends on small native fish (Kawarazuka and Béné, 2011). The main reason is that they are cost-effective and relatively available compared with other nutritional food sources. In addition, this food source improves well-being. In Malawi, infants fed fermented porridge mixed with whole dried fish decreases the risk of common infectious illnesses and anaemia (Kawarazuka and Béné, 2011). Tanganyika sardine, also known as kapenta (*Limnothrissa miodon*) in Zambia, helps in the wound-healing of people with HIV/AIDS, and in sub-Saharan Africa, consumption of freshwater fish has had a positive impact on preventing the development of rickets (Craviari et al., 2008; Youn et al., 2014). In Tanzania, pregnant and lactating women who consume relatively high quantities of native freshwater fish showed elevated levels of docosahexaenoic acid (DHA), an Omega-3 fatty acid, in their breast milk (Daniels et al., 2004). This improves the health and growth of their infants (Daniels et al., 2004).

1.3 Threats to inland fisheries in Africa

African inland fisheries' contribution to food security has been largely ignored or overshadowed by the use of rivers and dams for hydropower, municipal use, and agriculture (Oyewo et al., 2018; Tatlhego and D'Odorico, 2022). In particular, their contribution has been ignored by water policymakers (Hayes et al., 1996; Weyl et al., 2021). Anthropogenic activities, through habitat modifications, alter the natural flow of freshwater and therefore reduce the native fish abundance and diversity (reduced productivity) and, thus, less food for communities dependent on fish for subsistence (Ziv et al., 2012; Barbarossa et al., 2020; Santana et al., 2021). Despite their importance, inland fisheries in Africa face numerous challenges, including overfishing, habitat degradation, climate change, and pollution (Chakona et al., 2022; Imbwaie et al., 2023).

Due to the easily accessible protein food loss, rural communities from developing countries need to source other protein sources, and often these are more expensive, e.g., farmed fish (aquaculture) (Kawarazuka, 2010). Furthermore, these fish from aquaculture are generally not as nutritious as wild or native fish, degrading the nutrition of rural communities dependent on fish as a source of protein (Roos et al., 2007; Youn et al., 2014).

1.4 Inland fisheries in South Africa

In South Africa, inland fisheries have been important to rural communities for a long time (Weyl et al., 2021). In 2012, a literature review on the use of water resources for inland fisheries in South Africa was conducted (McCafferty et al., 2012, Supplementary information Table S1.1). The literature was divided into the following categories: rural fisheries development/potential, traditional subsistence fisheries, recreational fisheries, commercial fisheries potential, and production potential (McCafferty et al., 2012, Supplementary information Table S1.1). However,

at present, most South African inland fisheries are primarily recreational, and these are generally categorised into social anglers and national angling organisations (Ender et al., 2010, Table 1.2). Throughout South Africa, there are more than 3000 dams that were primarily built for domestic use, water agriculture, and industrial use (Weyl et al., 2007; Mantal et al., 2017; Fig. 1.2). These dams are mostly used for recreational purposes like sport fishing and boating (Tapela et al., 2015). Generally, dams are being used more than rivers for fishing.

In South Africa, non-native fishes were introduced in the 19th century for recreational fishing purposes (Hargrove et al., 2017). The non-native fishes included common carp *Cyprinus carpio*, three species of bass (*Micropterus salmoides*, *Micropterus dolomieu*, and *Micropterus punctulatus*) and two species of trout (*Salmo trutta* and *Oncorhynchus mykiss*) which are now common in various rivers in South Africa and are now the basis for subsistence and recreational angling (Weyl and Cowley 2015). Relatively little inland fisheries-related research has been conducted in South Africa, and what has been done is frequently outdated and no longer useful (Nyboer et al., 2022; Table 1.2).

South African subsistence (small-scale) fisheries have been largely overlooked because of the grey boundary between subsistence and recreational fisheries influenced by the inland fisheries policies (Nyboer et al., 2022). Most studies on subsistence fisheries in South Africa are focused chiefly on coastal or marine fisheries (Sowman, 2006; Kalina et al., 2019), including the study of the effect of COVID-19 on subsistence fisheries, which was mainly focused on coastal areas (Sowman et al., 2021). When examining subsistence inland fisheries, there is a paucity of present quantitative data on fishery output, participation, and catch rates, especially concerning subsistence inland fisheries, compared with marine or coastal subsistence fisheries (Kalina et al.,

2019; Nyboer et al., 2022). This highlights the need for further research on inland fisheries in South Africa, especially on fish catch or yield (Weyl et al., 2021).

Table 1.2: Literature on inland fisheries focused research in South Africa since McCafferty et al., (2012; Supplementary information Table S1.1).

Authors	Year	Title
Jewitt et al.	2015	Systematic land-cover change in KwaZulu-Natal, South Africa: Implications for biodiversity.
Tapela et al.	2015	Scoping study on the development and sustainable utilization of inland fisheries in South Africa: Volume 2. Case studies of small-scale inland fisheries. Report No TT 615/2/14, Water Research Commission, Pretoria, South Africa.
Weyl and Cowley	2015	Fisheries in subtropical and temperate regions of Africa.
Hargrove et al.	2017	Reconstructing the introduction history of an invasive fish predator in South Africa
Mngomezulu	2017	Jozini Dam infrastructure and its role on local economic development.
Sunde and Erwin	2020	Cast out: The systematic exclusion of the KwaZulu-Natal Subsistence Fishers from the fishing rights regime in South Africa Policy Research Report. SDCEA Policy Research Report
Weyl et al.	2021	Ten research questions to support South Africa’s inland fisheries policy
Evans et al.	2022	Assessing fish community response to water quality and habitat stressors in KwaZulu-Natal, South Africa. African Journal of Aquatic Science
Nyboer et al.	2022	Overtuning stereotypes: The fuzzy boundary between recreational and subsistence inland fisheries.

1.5 Inland fisheries in KwaZulu-Natal

With an estimated mid-year population of 11.1 million people in 2016, KwaZulu-Natal Province, South Africa, is the second most populous province in the nation (Stats SA, 2016). The province is losing its natural habitat, which has serious ecological repercussions for this region's diversity of animals, including native inland fish species (Jewitt et al., 2015; Evans et al., 2022). With increasing human populations in KwaZulu-Natal, there has been an increase in anthropogenic land

use change and other impacts, adding to freshwater stressors (Evans et al., 2022). These freshwater stressors include the abstraction of water for agriculture and industry, resulting in fish habitat loss, and anthropogenic waste causing significant adverse effects on water quality (high salinity levels and high levels of faecal microbes)(Evans et al., 2022).

The northern KwaZulu-Natal's Jozini/ Pongolapoort Dam was initially constructed as an economic asset for agriculture and hydropower and to ensure local economic development (Mngomezulu 2017). Nearby rural communities fish from the dam “illegally” as they generally do not have the authorised licensing required (Mngomezulu, 2017). Before the Jozini/ Pongolapoort Dam was built, the natural flow of the Pongola River (located in the Jozini area) supported local fisheries in the communities and agricultural activities with minimum disturbances or no to the natural ecosystem (Brown et al., 2018). After the dam was constructed, the natural ecosystem was disturbed, resulting in fisheries collapsing and local farmers' crops dying, resulting in a decline in food security for the local communities (Mngomezulu, 2017; Brown et al., 2018). Furthermore, prolonged droughts and poor management lead to water shortages in the dam. This threatens inland fisheries downstream and can potentially lead to more severe outcomes for the entire fish population in the Pongola floodplains (Mngomezulu, 2017; Brown et al., 2018).

In implementing the management plan for the province, nature conservation organisations, like Ezemvelo KwaZulu-Natal Wildlife, have been involved in the co-management plan of fisheries, where subsistence fishers were as involved in the management of fisheries as the policy makers (Napier et al., 2005; Mann and Mann-Lang, 2021). Some KwaZulu-Natal communities rejected this inland fisheries management because they believed the permitting system would limit them from fishing freely (Napier et al., 2005). In KwaZulu-Natal, the recreational use of these dams is mainly managed by Ezemvelo KZN Wildlife. Subsistence fishers also use these dams

when fishing for food to provide for their families and as a source of income when selling their catch (Weyl et al., 2007; Mann and Mann-Lang, 2021). There is a need to protect these dams and rivers because they are ecosystems for many native freshwater fish species, which provide sustainable livelihoods for poor or rural communities residing next to these freshwater bodies (Sayer et al., 2018). With this, a management plan must be implemented to protect these native freshwater fish and the subsistence fishers.

1.6 Problem statement

Freshwater fisheries in South Africa are largely overlooked and understudied despite their economic importance to fishers, especially subsistence fishers (McCafferty et al., 2012; Supplementary information Table S1.1, Table 1.2). In addition, fisheries are essential to vulnerable communities as a source of protein or income. Little is known about the potential for rivers and impoundments to support subsistent fisheries and the resilience of indigenous species impacted by invasive alien species. Native yellowfish *Labeobarbus natalensis*, catfish *Clarias gariepinus* and tilapia *Cichlidae* are socio-economically important fish species harvested by subsistence fishers and targeted by recreational anglers (Welcomme et al., 2010; Funge-Smith and Bennett, 2019; Potts et al., 2022). However, knowledge about the biology and ecology of these species, how they interact and compete with large growing invasive species, and offtake from fishers are sparse. How inland fisheries categories are defined or understood also alters how fishers view fishing (Nyboer et al., 2022), opening another knowledge gap in the definitions of inland fisheries in South Africa. The proposed study hopes to address this.

1.7 Aims and objectives

The main aim is to address the paucity of knowledge about economically and biologically important indigenous fish species that support inland fisheries in KwaZulu-Natal. The composition and contribution of native and invasive fish species and their offtake by fishers were assessed. Fishers across the uThukela and uMngeni catchments were interviewed using in-person questionnaires. In addition, an assessment of fish communities and population structures in Midmar Dam and Henley Dam, two selected dams on the uMngeni River, coupled with questionnaire data, were used to determine the offtake trends by fishers (subsistence and recreational). These will contribute to a potential subsistence fisheries management plan for these dams based on the findings to guide the development of the provincial and national inland fisheries plan.

1.8 Structure of the thesis

The main body of this thesis is organised as manuscripts prepared for publication in peer-reviewed journal articles. The first chapter (Chapter 1) is the Introduction, which provides a literature review of the concepts covered in this study. The next three chapters (Chapters 2, 3, and 4) are empirical, each covering a specific objective. Each chapter is formatted according to the journal it is intended to be submitted to. Because of this thesis format, a certain degree of repetition was unavoidable, especially in the methods section. However, this is deemed to be of little concern as this format allows the reader to read each chapter separately without losing the overall context of the thesis.

The data chapters are as follows:

Chapter 1- Introductory chapter to the thesis

Chapter 2- A systematic review of literature pertaining to inland fisheries on a global level with a focus on inland fisheries for Africa was conducted.

Chapter 3- Using questionnaire surveys, fishers in the uThukela and uMngeni catchments, KwaZulu-Natal, South Africa, were used to evaluate the present and potential inland fisheries in dams and rivers based on fishers' perceptions.

Chapter 4- Using two impoundments (Midmar Dam and Henley Dam) near urban environments in the upper uMngeni catchment in KwaZulu-Natal, South Africa, the fish communities and population structure were assessed.

Chapter 5- Concluding chapter of the thesis with a synthesis and recommendations.

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1.10. Supplementary information

Supplementary information Table S1.1. Summarised list of inland fisheries publications

(McCafferty et al. 2012).

Rural fisheries development/potential
Andrew et al. 2000; Andrew 2001; Burton et al. 2002; de Satge 1978; Duncan–Brown 1980; Roode 1978; Rouhani and Andrew 1998; Rouhani 2001 2003 2004; Rouhani and Davies 2003; Schramm 1993; Seti 2002; van den Berg et al. 1975; van der Waal 1978 2000; Weyl et al. 2007.
Traditional subsistence fisheries
Coke and Pott 1973; Heeg and Breen 1982; Jubb 1973; La' Hausse' De' Lalouviere 1987; Merron et al. 1993; Merron and Weldrick 1985; Tinley 1964; van der Waal 1978.
Recreational fisheries
Alletson et al. 2004; Anon 1970; Ashton et al. 1986; Bruwer 1982; Cadieux 1980a 1980b; Clark 2004; Cochrane 1987; de Villiers 1998; du Plessis and le Roux 1965; Eccles et al. 1983; Ellender et al. 2009 2010a 2010b; Granek et al. 2008; Hey 1926a 1926b 1941; Jackson 1976 1989; le Roux 1965; Leibold and van Zyl 2008; McVeigh 1978; Nel 1988; Pott 1973; Rouhani 2003 2004; Rouhani and Davies 2003; Rouhani et al. 2010; Winker 2007; Weyl et al. 2010a.
Commercial fisheries potential
Allanson and Jackson 1983; Anon 1948; Eccles et al. 1983; Hamman 1981; Jackson 1973 1974 1976 1981a 1981b; Jubb 1962; Koekemoer and Steyn 2005; Nel 1988; Richardson et al. 2009; Tomasson et al. 1983; Tomasson et al. 1985; van Senus et al. 1992; Weyl et al. 2007, 2010a; Whitehead 1978.
Production potential
Allanson and Jackson 1983; Andrew et al. 2001; Andrew 2001; Cochrane 1987; Potts 2003; Richardson et al. 2009; Rouhani 2004; Weyl et al. 2010a.

CHAPTER 2

Evaluating the present and potential inland fisheries in dams and rivers across Africa to guide inland fisheries in KwaZulu-Natal, South Africa: A systematic review

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Running header: Present and potential inland fisheries in dams and rivers of Africa

2.1 Abstract

Inland fisheries are crucial for food security, income, and ecological roles, particularly in developing countries. They provide a significant portion of protein consumed by people living near rivers, lakes, and other freshwater bodies, supporting the livelihoods of fishers and their families. In Africa, inland fisheries provide livelihoods for millions of people, contributing significantly to the GDP. However, challenges such as overfishing, habitat degradation, climate change and pollution persist. Inland fisheries are divided into recreational, subsistence, small-scale, and commercial categories. In this systematic review, we assessed present and potential inland fisheries in dams and rivers across Africa to guide inland fisheries in KwaZulu-Natal, South Africa. After systematically filtering literature on African inland fisheries up to 2023, we categorised the relevant papers and analysed these to determine trends. The results showed diverse inland fisheries types with distinct characteristics and shared challenges. National and regional importance of African inland fisheries was found, but there was a lack of understanding of the definitions and boundaries between the categories of inland fisheries. Subsistence fisheries, focusing on local food provision through traditional methods, face threats like overfishing. Recreational fisheries, contributing to food, income, and recreation, require effective conservation in developing nations. Small-scale fisheries showcase resilience and successful conservation, emphasising adaptive management. Commercial fisheries involving professional fish exploitation encounter challenges, especially in regions like South Africa, demanding sophisticated approaches for long-term viability. Across Africa, common challenges such as overfishing and habitat destruction persist. In KwaZulu-Natal, a significant research gap exists, impacting sustainability. Addressing issues like monitoring systems, invasive species, and species knowledge is crucial for sustainable fisheries management in the region.

Keywords: Inland fisheries; economic value; subsistence; recreational fisheries; small-scale fisheries; commercial fisheries

2.2 Introduction

According to the Food and Agriculture Organisation (FAO), inland fisheries are any activity in inland waters to extract fish and other aquatic organisms (Fisheries FAO, 2012). Inland fisheries are globally important for many reasons, and they are a critical source of food and income for millions of people worldwide, particularly in developing countries (Smith, 1942; FAO, 2020). They provide a significant portion of the protein consumed by people living near rivers, lakes, and other freshwater bodies (FAO, 2020). They also support the livelihoods of millions of fishers and their families, as well as the communities that depend on their catch (Welcomme et al., 2010; Funge-Smith and Bennett, 2019). In addition to their importance for food security and livelihoods, inland fisheries also play important ecological roles (Bénéand and Neiland, 2004; Birdsong et al., 2021). They aid in maintaining healthy freshwater ecosystems by controlling invasive species, cycling nutrients, and supporting other wildlife (Birdsong et al., 2021). They also provide recreational opportunities for people to enjoy fishing, boating, and other outdoor activities (Lashari et al., 2020; Birdsong et al., 2021). Despite their importance globally, inland fisheries face numerous challenges, including competition with the water security sector, overfishing, pollution, habitat degradation, and climate change, which hinder inland fisheries' potential (Welcomme et al., 2010; Marshall, 2015; Funge-Smith and Bennett, 2019). All these hinder inland fishery production (Dugan et al., 2007; Marshall, 2015).

Despite these challenges, in Africa, inland fisheries play an important role in being an alternative source of protein in rural areas for people who may have limited access to other sources

of protein (Marshall, 2015; Njaya and Kang'ombe, 2016; Gondwe et al., 2022). They also play a crucial role in the economic development of sub-Saharan African countries, contributing significantly to the gross domestic product (GDP) (Marshall, 2015; Jembe and Njaya, 2018; FAO, 2018, 2020). Inland fisheries in the African region provide livelihoods for millions of people, with many relying on them for daily sustenance (Jembe and Njaya, 2018). For instance, in Malawi, inland fisheries provide food security and income to rural households, where fish are the main source of protein (Chikowi et al., 2021). Similarly, inland fisheries in several countries in sub-Saharan Africa contribute to the country's rural livelihoods and food security (Temesgen et al., 2019).

Despite their importance, inland fisheries in Africa face numerous challenges, including overfishing, habitat degradation, climate change and pollution (Chakona et al., 2022; Imbwaie et al., 2023). An example is the decline in Lake Kariba's native fish, the Kariba tilapia (*Oreochromis mortimeri*) an important food and livelihood source (Imbwaie et al., 2023). These challenges are partly because of a lack of research and management of inland fisheries (Welcomme, 2006; Beard et al., 2011). For example, the absence of a sustainable management framework for small-scale fisheries in the Lake Victoria Basin has led to overfishing and the depletion of fish stocks (Njiru et al., 2014).

In addition to economic benefits, inland fisheries in Africa contribute to food and nutritional security (Temesgen et al., 2019). They are an important source of nutrition for poor communities, who often lack access to other protein sources like meat (Belton and Thilsted, 2014). Moreover, fish from inland fisheries provide essential micronutrients, such as vitamin A, iron, and zinc, which are crucial for the health and development of children (Temesgen et al., 2019). Overall,

the sustainable management of inland fisheries is crucial to supporting and ensuring the livelihoods of millions of people and achieving food and nutrition security in Africa.

Inland fisheries are differentiated into four categories: recreational, subsistence, small-scale and commercial inland fisheries. Recreational fisheries are described as fisheries that exploit the resource primarily for recreational purposes, often including hook and line anglers (Weyl et al., 2007). They can also be defined as the type of fisheries that is mostly driven by angler satisfaction (Hendee, 1974; Birdsong et al., 2021), but it can also change depending on the region and the economic state of the country they are defined under (Nyboer et al., 2022). Users are not reliant on the resource for survival or profit. These fisheries may be managed to increase participation by instituting measures like daily bag restrictions and catch-and-release policies (Weyl et al., 2007). Generally, subsistence fisheries include recreational fishing activities such as fly fishing and bass competitions, as well as fishing for human consumption, which is generally, but not always, carried out by small-scale fisheries. Small-scale fisheries differ from recreational fishing because they are distinguished by being low-tech and labour-intensive and also play an important part in subsistence fishing, with their catch often sold (Kolding et al., 2016; Smith and Barsuto, 2019). Commercial fisheries involve large-scale fish extraction for profit, which serves as the primary source of revenue for professional fishers (Cowx, 2015).

In this systematic review, we examined the existing literature to define inland fisheries, highlighting their global, national, and regional importance. We predicted a scarcity of publications and a notable absence of well-defined categories, substantiated by literature that unveiled a grey boundary in their conceptualisation.

2.3 Methods

For our study selection criteria, we assessed papers related to inland fisheries or freshwater fisheries from a broad perspective and narrowed them down to local literature. We assessed literature published globally and narrowed it down to Africa, then focused on South Africa and, lastly, KwaZulu-Natal. From this selection, the keywords that were included were subsistence, small-scale, and recreational fisheries. For our exclusion criteria, papers related to marine/saltwater fisheries or not focused on the specific topics mentioned above were excluded.

Between May 2022 and June 2023, we comprehensively explored the existing literature, encompassing both primary and grey sources. Our approach involved multiple stages. Initially, diverse search engines and databases were used to scrutinise the literature using comparable keywords. We acquired pertinent publications from a variety of academic journal databases, including but not limited to government databases (Department of Environment, Forestry and Fisheries (DEFF): Website: <https://www.environment.gov.za/>, Department of Water and Sanitation: Website: <http://www.dws.gov.za/>, PubMed, Scopus, Web of Science, and JSTOR. Additionally, we utilized search engines such as Google Scholar© (<https://scholar.google.co.za/>) and platforms like ResearchGate©(<https://www.researchgate.net>) to supplement our search. These were then exported directly into an Excel© spreadsheet to filter them further.

We searched for publications using the following keywords: inland fisheries, native fish, inland waters, recreational fisheries, subsistence fisheries, small-scale fisheries, commercial fisheries, the value of inland fisheries, subsistence inland fisheries, recreational inland fisheries, small-scale inland fisheries, inland fisheries in South Africa, and inland fisheries in KwaZulu-Natal. We conducted an additional literature search using these water bodies as keywords: flood plains, rivers, lakes and dams. Additionally, we examined peer-reviewed studies and grey

literature, giving due consideration to publications in English. The exclusion criteria involved identifying irrelevant publications, some of which required a fee for access, thereby limiting our ability to obtain them. Publications from theses, including MSc and PhD, were integrated when accessible.

The screening process adhered to PRISMA guidelines (Moher et al., 2009; O'Dea et al., 2021), where each article's title and abstract were briefly evaluated. Non-relevant articles, including duplicates and marine or saltwater-based articles, were subsequently eliminated. A secondary screening involved a thorough reading of the entire article to identify additional relevant articles and analysed data from pertinent studies. The reference sections of selected papers were also explored for supplementary studies. Under data extraction, we extracted the following data on subsistence, small-scale, and recreational inland fisheries in South Africa, including socio-economic data.

The reviewing process was a top-down approach, where we searched for globally published literature and narrowed it down to Africa, South Africa and the South African province of KwaZulu-Natal. A database encompassing all relevant papers was established to facilitate organisation, according to authors, year, title, publication type, topic(s), country, water body type, inland fisheries category, and other relevant information. These keywords made the literature search more precise because we could eliminate estuaries and other saltwater-related publications automatically. We analysed the data using Microsoft Excel©, including conducting descriptive statistics and identifying patterns and trends. Some articles included multiple data, so increasing the frequency when analysing, e.g. for rivers, lakes and dams.

2.4 Results

2.4.1 African inland fisheries

During the first stage, we retrieved 7000 papers globally and implemented our study selection process. Firstly, only fish-related papers were selected. Following this, we eliminated marine/saltwater papers. To further filter out any marine/saltwater related fisheries publications, we filtered publications based on major lakes, rivers and dams in Africa. Then, we kept all African inland fisheries papers (n = 5205 papers). We eliminated duplicates and were left with 3,355 African inland fisheries papers and categorised those. We then examined only the South African-focused papers (20.6%, n = 690 publications). Finally, we selected the KwaZulu-Natal-focused papers (1.9%, n = 13 papers). We found more African inland fisheries publications in South Africa (20.6% overall) than in other African countries (Fig. 2.1). The heat map in Fig. 2.2 shows that most publications were from southern Africa and middle to East Africa. In most parts of Africa, there was a lack of publications on inland fisheries, according to available literature (Fig. 2.1 and Fig. 2.2).



Figure 2.1: A map showing the focus of African inland fisheries per country based on the publications found in the present systematic review.

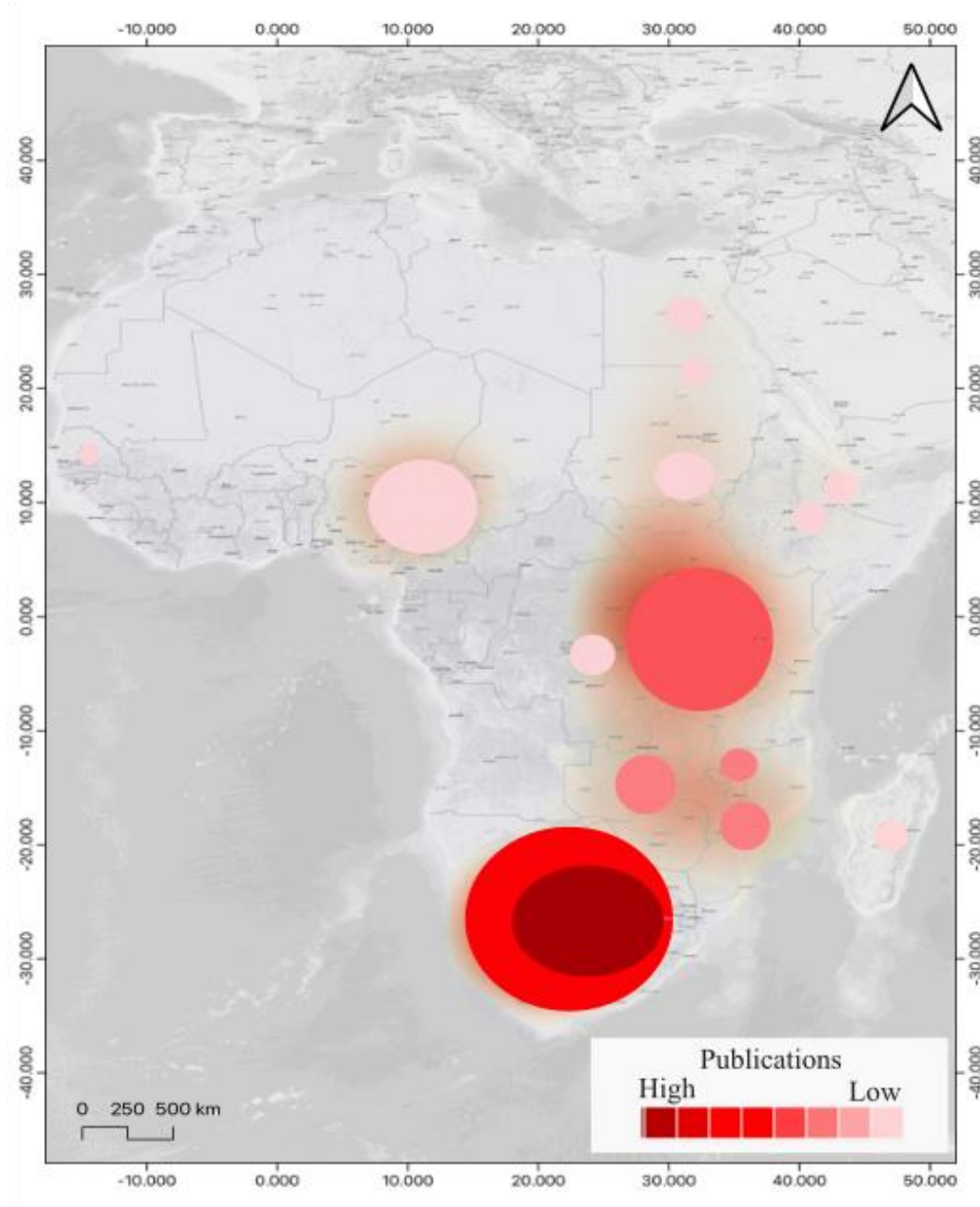


Figure 2.2: Heat map of inland fisheries publications in African regions based on different water bodies (Some countries may share publications because of a similar water body like a river).

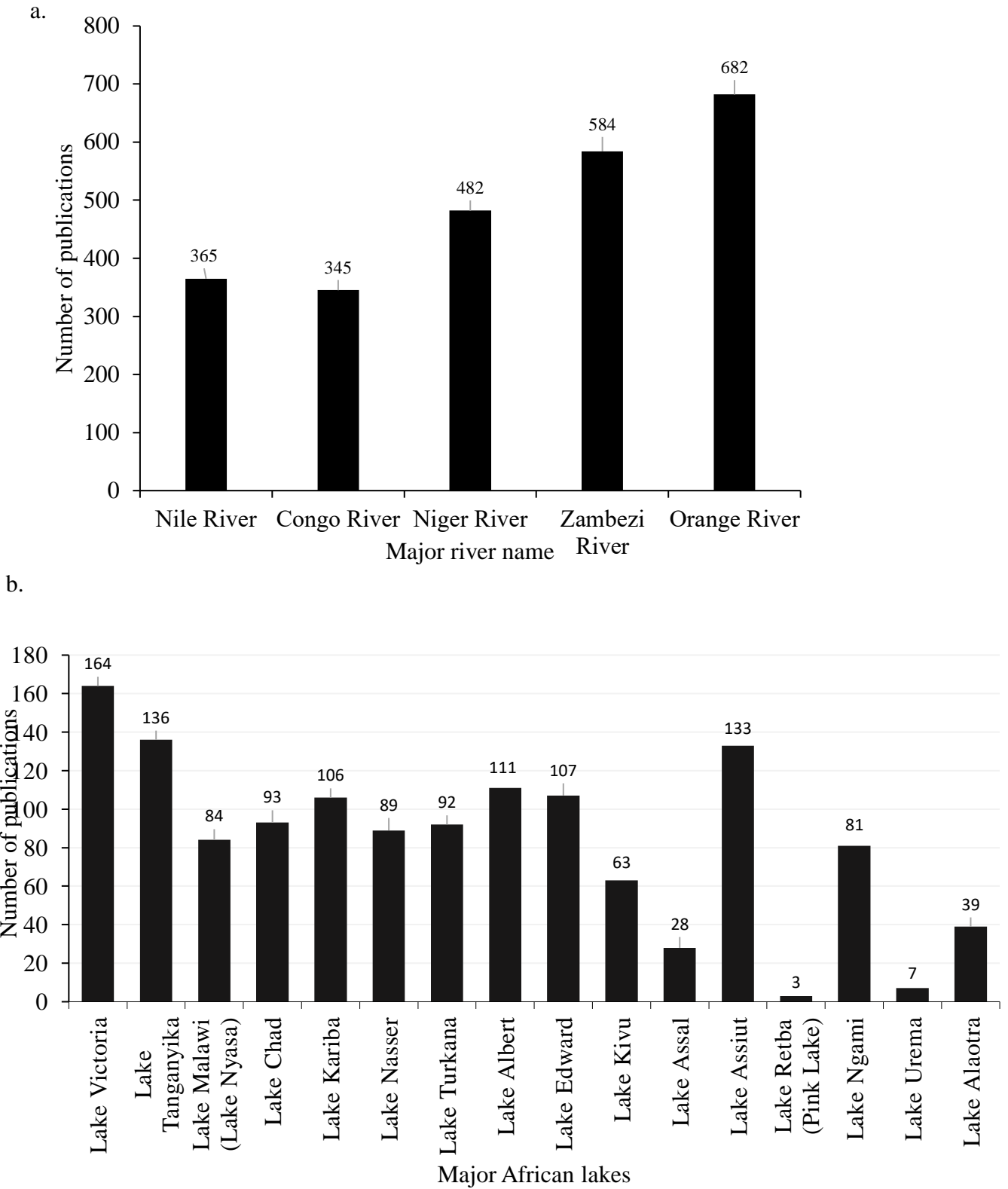


Figure 2.3: African inland fisheries publications a. explicitly referencing major African river names, and b. referencing major African lake names in the present review up to 2023.

Of the African inland fisheries publications, more publications focussed on rivers (54.3%, $n = 2458$), followed by lakes/flood plains (25%, $n = 1084$) and the least number of publications for dams (27%, $n = 834$). Of the African inland fisheries studies focussed on rivers, the Orange River (Lesotho and South Africa) had 682 publications (27.7%), more than any other major African river. The Zambezi River followed with 584 publications (23.7%), the Niger River with 482 (19.6%), the Nile River with 365 (14.8%) and lastly, the Congo River with the least publications ($n = 345$, 14%, Fig. 2.3a). In Africa, the most inland fisheries literature on lakes/ flood plains ($n = 1084$) was published on Lake Victoria (164 publications, 15.1%), followed by Lake Tanganyika (136 publications, 12.5%) and Lake Assiut (133 publications, 12.3%) (Fig. 2.3b).

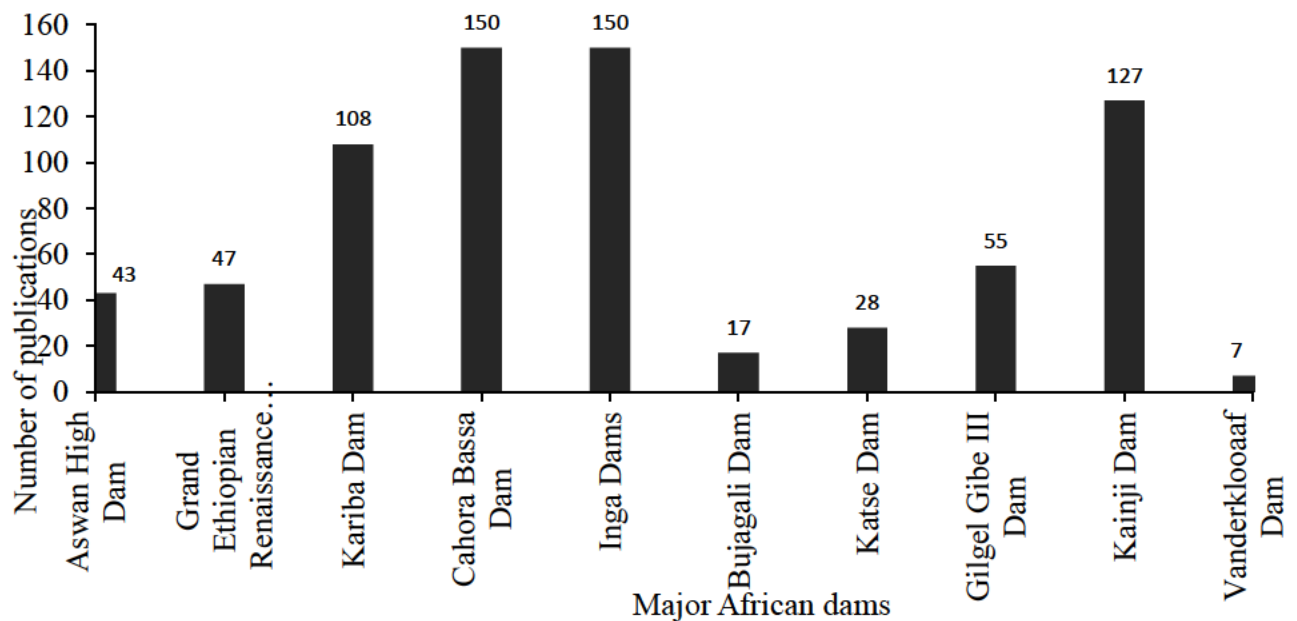


Figure 2.4: Number of inland fisheries publications on ten major African dams to date (2023).

Out of the ten major African dams that we selected according to available literature, most publications were from Cahora Bassa Dam ($n = 150$) in Mozambique and Inga Dam ($n = 150$) in

the Democratic Republic of the Congo (Fig. 2.4). These were then followed by Kainji Dam (n = 127) in Nigeria, Gilgel Gibe III Dam (n = 55) in Ethiopia, Grand Ethiopian Renaissance Dam (n = 47) in Ethiopia, Aswan High Dam (n = 43) in Egypt, Katse Dam (n = 28) in Lesotho, Bujagali Dam (n = 17) in Uganda, and lastly Vanderkloof Dam (n = 7) in South Africa, with the least number of publications (Fig. 2.4). The major flood plains of Africa important for inland fisheries in Africa are shown in Table 2.1. In Africa, publications focused on small-scale inland fisheries (n = 197 publications), subsistence inland fishers (n = 20 publications), recreational inland fisheries (n = 322 publications), and commercial inland fishers (n = 218 publications).

Table 2.1: Selected major flood plains of Africa important for inland fisheries in Africa.

Flood plain	Country
Okavango Delta	Botswana
Niger River Delta	Nigeria
Sudd	South Sudan
Selous Game Reserve	Tanzania
Bangweulu Wetlands	Zambia
Luangwa Valley	Zambia and Malawi
Lower Zambezi Valley	Zambia and Zimbabwe
Limpopo Floodplain	South Africa, Botswana, Zimbabwe, Mozambique
Senegal River Delta	Senegal and Mauritania
Lake Chad Basin	multiple countries
Liuwa Plain	Zambia

2.4.2 South Africa inland fisheries

In South Africa, more publications focused on the recreational inland fisheries category (n = 387 publications), followed by publications on commercial inland fishers (n = 145 publications), small-scale inland fisheries (n = 140 publications) and lastly, subsistence inland fishers (n = 18 publications) (Fig. 2.5). The change in publications over time in South Africa showed the focus was primarily on recreational inland fisheries, with small-scale and commercial competitors receiving less attention (Fig. 2.6). However, the number of articles devoted to subsistence inland fisheries over time was far fewer than the other categories (Fig. 2.6). A concerning trend closer to 2023, was that publications in all of these inland fisheries categories were generally declining (Fig. 2.6). We found that few native freshwater fish species in KwaZulu-Natal, South Africa, were included in publications on inland fisheries (Table 2.2).

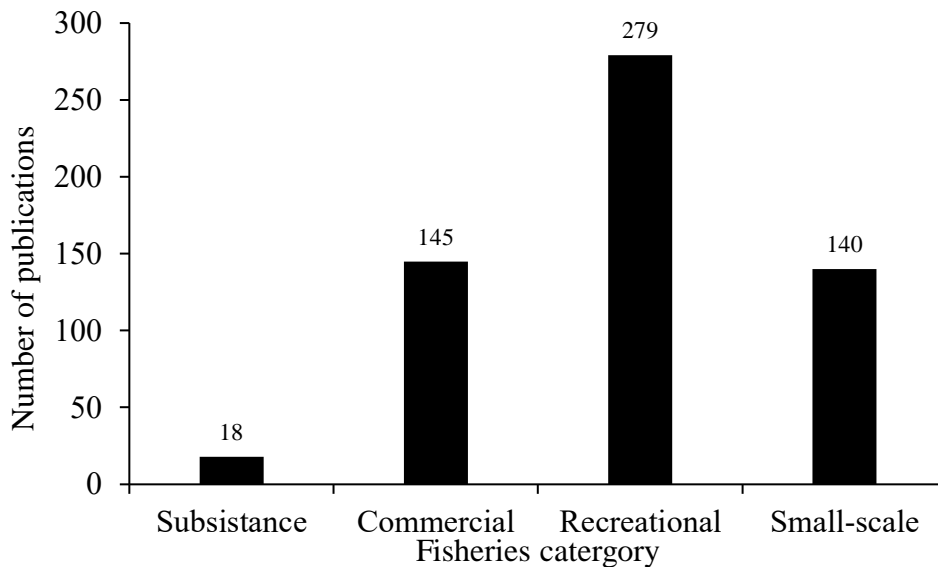


Figure 2.5: Number of publications for different inland fisheries categories in South Africa in the present study.

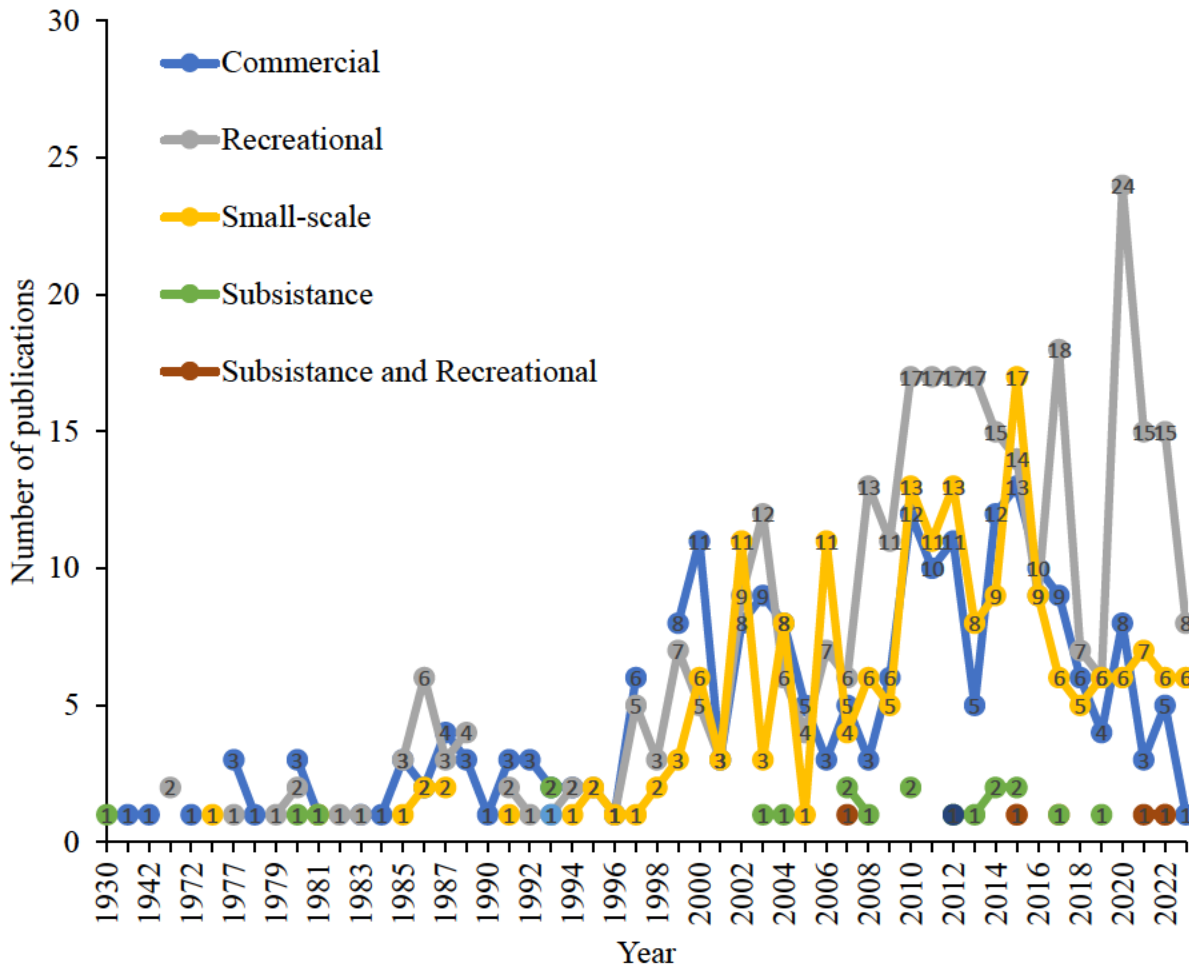


Figure 2.6: South African inland fisheries categories publication trends from available literature between 1930 to 2023.

Table 2.2: Native fresh water (excluding estuaries) fish species in KwaZulu-Natal, South Africa (Department of Water and Sanitation, n.d) assessed in this study.

Common Name	Species Name	Species of interest for this study
Natal-mountain catfish	<i>Amphilius natalensis</i>	No
African mottledeel	<i>Anguilla bengalensis labiata</i>	No
Madagascar mottled eel	<i>Anguilla marmorata</i>	No
African longfin eel	<i>Anguilla mossambica</i>	
Natal topminnow	<i>Aplochilichthys myaposaе</i>	No
Freshwater goby	<i>Awaous aeneofuscus</i>	No
Chubbyhead barb	<i>Enteromius anoplus</i>	No
Redtail barb	<i>Enteromius gurneyi</i>	No
Straightfin barb	<i>Enteromius paludinosus.</i>	No
Bowstripe barb	<i>Barbus viviporus</i>	No
Sharptooth catfish	<i>Clarias gariepinus</i>	Yes
Grass carp	<i>Ctenopharyngodon idella</i>	No
Common carp	<i>Cyprinus carpio</i>	Yes
Dusky sleeper	<i>Eleotris fusca</i>	No
Mosquito fish	<i>Gambusia affinis</i>	No
Sleepy goby	<i>Glossogobius biocellatus</i>	No
River goby	<i>Glossogobius callidus</i>	No
Tank goby	<i>Glossogobius giuris</i>	No
Golden sleeper	<i>Hypseleotris cyprinoids</i>	No
KwaZulu-Natal yellowfish	<i>Labeobarbus natalensis</i>	Yes
Bluegill	<i>Lepomis macrochirus</i>	Yes
Freshwater pipefish	<i>Microphis fluviatilis</i>	No
Smallmouth bass	<i>Micropterus dolomieu</i>	Yes
Spotted bass	<i>Micropterus punctulatus</i>	Yes
Largemouth bass	<i>Micropterus salmoides</i>	Yes
Freshwater mullet	<i>Myxus capensis</i>	No
Rainbow trout	<i>Oncorhynchus mykiss</i>	Yes
Brown trout	<i>Salmo trutta</i>	

2.5 Discussion

2.5.1 Differences in the role of fisheries in the different parts of Africa

We found many publications on inland fisheries globally, but relatively few were specific to Africa.

In South Africa, we found relatively few publications focused on freshwater fisheries. This showed a significant research gap in this area, and further studies are needed to understand better the

freshwater fish populations and fisheries management strategies in Africa, especially KwaZulu-Natal (Harrison and Cowx, 2012).

Inland fisheries play a crucial role in the livelihoods of people in Africa. A comparative analysis conducted by Abate et al. (2015) revealed that fishery contributions to livelihoods were higher in inland Africa than in marine systems. The importance of inland fisheries in Africa for food security and economic development was emphasised, and the challenges faced by inland fish in Africa, such as overfishing, illegal fishing practices, and weak governance systems, were discussed (Weyl and Tweddle, 2016). Similarly, the challenges in managing inland fisheries in South Africa were highlighted, including the impact of climate change, overfishing, and the introduction of non-native fish species (Weyl and Ellender, 2016).

Protecting freshwater resources is critical for conserving fish species and the livelihoods of people who depend on these resources (Weyl et al., 2011; Abate et al., 2015). In another study, Weyl and Nagelkerke (2016) provided a comprehensive overview of African inland fisheries, discussing the diversity, ecology, and management of these systems. The authors highlighted the need for integrated approaches to manage inland fisheries, taking into account the social, economic, and environmental factors that influence the sector. In Tanzania, artisanal fishery productivity has contributed to food security (Kashindye et al., 2020). The study by Kashindye et al. (2020) showed that fishing activities provided a significant source of protein for households in the region. In West Africa, fishing gear and environmental factors were found to influence the catch and bycatch in a West African estuary (Berté et al., 2015). The authors emphasised the need to develop sustainable fishing practices to protect fish populations and promote the livelihoods of local communities.

Fisheries are an important economic activity in West Africa, providing livelihoods for millions of people in the region (Ogutu-Ohwayo et al., 2017). However, these fisheries face several challenges, including overfishing, habitat destruction, and illegal fishing (Chimatiro et al., 2019). Additionally, ineffective fisheries management policies have led to declining fish stocks and reduced incomes for fishing communities (Ogutu-Ohwayo et al., 2017). Co-management has been proposed as a solution to these challenges, as it promotes collaboration between government authorities and fishing communities in decision-making processes and resource management (Fondo et al., 2019). Successful implementation of co-management initiatives in West Africa has led to increased fish stocks and improved livelihoods for fishing communities (Fondo et al., 2019).

Fisheries play a crucial role in food security in East Africa, providing a major source of protein and income for millions of people in the region (Cochrane et al., 2016). However, small-scale fisheries in the region face several challenges, including climate change impacts, overfishing, and inadequate governance (Cinner et al., 2018). Governance plays a crucial role in addressing these challenges, as it provides a framework for effective fisheries management and the implementation of sustainable practices (Cinner et al., 2018). In Tanzania, for example, bio-economic modelling has been used to assess the sustainability of small-scale fisheries and identify strategies for sustainable management (Mwaipopo et al., 2021). By improving governance and adopting sustainable management practices, small-scale fisheries in East Africa can contribute to the region's food security and economic development.

Fisheries are an important source of food and income in southern Africa, particularly in countries with large inland water bodies, such as South Africa and Zimbabwe (Dube et al., 2016). However, unsustainable fishing practices and poor management have led to declining fish stocks and reduced incomes for fishing communities (Weyl et al., 2019). In Lake Victoria, one of the

largest freshwater bodies in the world, overfishing and invasive species have led to a decline in fish stocks, threatening the livelihoods of millions of people in the region (Ogutu-Ohwayo et al., 2018). To address these challenges, ongoing management initiatives such as introducing mesh size regulations and using community-based approaches have been implemented (Lwenya et al. 2019). These initiatives aim to promote sustainable fisheries management practices and improve the livelihoods of fishing communities in the region.

2.5.2 The use of rivers and dams

The importance of dams, rivers, and lakes for inland fisheries varies depending on the region and ecosystem (Welcomme, 1985; Cowx et al., 2004; Gupta et al., 2011; Dube et al., 2016)). In some regions, rivers are the most important water bodies for inland fisheries (Alexander and Bowler, 2015; Chikafumbwa et al., 2015). However, dams and reservoirs can also be significant for fish production in other areas (Cieri et al., 2019). The construction of large dams can negatively affect river fisheries, causing reduced fish populations and changes in species composition (McCully, 1996). Nevertheless, reservoirs can also provide valuable habitat for fish, particularly in regions where natural lakes are scarce (Cieri et al., 2019). The relative importance of lakes for inland fisheries may vary depending on the specific ecosystem and type of fishery (Tarekegn et al., 2019). For example, Lake Tana in Ethiopia is an important source of fish, particularly for local communities (Tarekegn et al., 2019). However, other lakes may have limited fish populations because of factors such as pollution, overfishing, and habitat degradation (Gupta et al., 2011; The World Bank, 2009). To effectively manage inland fisheries, it is important to understand the complex relationships between fish populations, water bodies, and human activities (Cowx et al.,

2004). This requires a holistic approach that involves stakeholder participation, ecosystem-based management strategies, and adaptive management (Gupta et al., 2011).

Overall, the importance of dams, rivers, and lakes for inland fisheries varies depending on the region and ecosystem in question. While rivers tend to be the most important water bodies for inland fisheries in some regions, dams and reservoirs can also be significant for fish production in other areas. Similarly, the relative importance of lakes may vary depending on the specific ecosystem and type of fishery (Tarekegn et al., 2019).

2.5.3 Subsistence, recreational, small-scale and commercial inland fisheries

Subsistence inland fisheries refer to fishing activities that are primarily intended to provide food for local communities living near freshwater bodies (Funge-Smith and Bennett, 2019). Subsistence inland fisheries can contribute significantly to the food security and livelihoods of rural populations, especially in developing countries where access to alternative sources of protein is limited (Youn et al., 2014; Funge-Smith and Bennett, 2019; Gondwe et al., 2022). However, the sustainability of subsistence inland fisheries is threatened by various factors, including overfishing, habitat degradation, and pollution (Dugan et al., 2016).

In many cases, inland subsistence fisheries are not well regulated or monitored, which can exacerbate the challenges facing these activities (Jentoft et al., 2009; Bhilave, 2018). For example, the lack of clear property rights for fisheries resources can result in overexploitation and conflicts among different user groups (Jentoft et al., 2009). Additionally, the impacts of climate change, such as altered precipitation patterns and rising temperatures, can affect the availability and quality of freshwater resources, thereby affecting the productivity and sustainability of inland fisheries

(Ficke et al., 2007; Marshall, 2015). Thus, effective management and conservation strategies are essential for ensuring the long-term viability of subsistence inland fisheries.

Several studies have examined the social and economic implications of subsistence inland fisheries for local communities in Africa. For example, research conducted in the Okavango Delta in Botswana found that fishing activities provided an important source of income and employment for local households, especially during the dry season when other livelihood options were limited (Chiwona-Karltun et al., 2011). Similarly, a study conducted in the Congo Basin found that subsistence fishing played a crucial role in the livelihoods of rural communities, contributing to food security, income generation, and cultural identity (Kolding et al., 2016). However, the benefits of inland subsistence fisheries are not evenly distributed, and gender and social inequalities can limit access to and control over fisheries resources (Choudhury and Mearns, 2011). Thus, efforts to promote sustainable subsistence inland fisheries should also address issues of equity and social justice.

In Africa, recreational inland fisheries are an important source of food, income, and recreation for millions of people (De Graaf et al., 2019). According to Weyl et al. (2015), recreational fishing is defined as fishing for non-commercial purposes, such as sport, leisure, or subsistence. However, recreational fisheries are not just a pastime; they also provide valuable ecosystem services that support local economies and livelihoods (De Graaf et al., 2019). For example, recreational fisheries in South Africa generate significant economic benefits through tourism and angling-related expenditures (Bruijns and Cocks, 2019).

Despite the benefits that recreational fisheries provide, managing these recreational fisheries is often challenging, particularly in developing countries like Guinea (Camara and De Graaf, 2019). The lack of data and resources can hinder effective management and conservation

efforts. Birnie-Gauvin et al. (2020) suggest that tracking recreational fishers could help to improve management and conservation by providing valuable information on catch and effort, angling behaviour, and fishing hotspots. This information can then be used to inform policy and management decisions.

Recreational fisheries in Africa are diverse, and include activities such as shore-angling, estuary fishing, and sport fishing (Cowley et al., 2015; Weyl et al., 2016; Ficke et al., 2020). In Tanzania, sport fishing is an important tool for conserving fisheries resources, as it promotes catch-and-release practices and encourages sustainable use of fish stocks (Kilongozi and Lyimo, 2017). However, the sustainability of these fisheries depends on effective management and conservation measures, including proper regulation, monitoring, and enforcement.

Small-scale inland fisheries, sometimes referred to as artisanal fishing, small-scale inland fishing, use modest equipment (boats, engines, nets, and lines) that quickly depreciates. These methods rely on age-old skills handed down through the centuries and adapted to various environments (Bhilave, 2018). These fisheries, which are vital village industries that greatly boost local economies, are frequently disregarded (Bhilave, 2018). These are an important source of food and livelihood for many African communities (Béné et al., 2015; Pauly, 2018). However, they face numerous challenges, including overfishing, climate change, and poverty (Kolding and Van Zwieten, 2016; Quinlan et al., 2017). Despite these challenges, small-scale fisheries can be resilient and adapt to changing conditions, as demonstrated by the mangrove swamp fishery in São Tomé and Príncipe (Kolding and Van Zwieten, 2016).

In Ghana, small-scale fishers face multiple challenges, including declining fish stocks, competition with industrial fleets, and lack of access to credit and markets (Asante and Asiedu, 2021). Their livelihoods are also affected by policies and regulations that prioritise large-scale

commercial fishing operations (Asante and Asiedu, 2021). Evaluating the impacts of small-scale fisheries management interventions is crucial for ensuring their sustainability and supporting the livelihoods of small-scale fishers (Quinlan et al., 2017). Conservation and development efforts in small-scale fisheries should be approached with an understanding of the complexity of social-ecological systems (Blythe et al., 2018). Such efforts should recognise small-scale fisheries' cultural and social importance and the need to balance conservation goals with fishers' livelihoods (Crona et al., 2016). While small-scale fisheries face numerous challenges, there are also "bright spots" where conservation efforts have successfully led to the recovery of fish stocks and improvements in the well-being of fishing communities (Cinner et al., 2018).

In Lake Tana, Ethiopia, bioeconomic modelling has been used to assess the sustainability of small-scale fisheries targeting the Nile tilapia *Oreochromus niloticus* (Mekonnen et al., 2021). The study found that policies aimed at reducing fishing efforts could improve the ecological and economic sustainability of the fishery but also noted the importance of considering the social and cultural aspects of small-scale fisheries in management decisions (Mekonnen et al., 2021).

Commercial inland fisheries involve the professional exploitation of fish in natural and semi-natural waters, with distinctions for various fishers based on their engagement levels. Fishing serves as either the primary or exclusive source of income for these individuals (Cowx, 2015).

Although inland commercial fisheries have existed in South Africa since the early 20th century, difficulties emerged in the 1960s and 1970s when dams were being built (McCafferty et al., 2012; Britz, 2015). Although there was initial excitement about the fisheries potential of impoundments, most commercial projects encountered challenges because there was a limited market demand for freshwater fish, which led to low production (Batchelor, 1988; McCafferty et al., 2012; Britz, 2015). This hardship highlighted the complicated dynamics within the industry

and the necessity for sophisticated approaches to deal with productivity issues and market complications to maintain the long-term viability of such initiatives in the area (Batchelor, 1988; McCafferty et al., 2012; Britz, 2015).

2.5.4 Links between different types of inland fisheries

Subsistence, recreational, and small-scale inland fisheries are connected by relying on inland fish resources (Garcia et al., 2017). Subsistence fisheries are focused on providing food for local communities, often using traditional fishing methods and targeting species important for local diets (Kolding et al., 2018). Small-scale inland fisheries typically involve low-impact fishing methods and often focus on providing income or livelihoods for local communities (Jahan and Ahmed, 2016). On the other hand, recreational fishing is focused on leisure and enjoyment, often using more modern and intensive fishing methods and targeting specific sport fish species (Cooke et al., 2016).

Despite their differences, subsistence, small-scale, and recreational inland fisheries can all impact fish populations and aquatic ecosystems (Welcomme and Cowx, 2006; Quinlan et al., 2017). Overfishing, habitat degradation, and the introduction of non-native species pose significant threats to the sustainability of inland fisheries (Murchie et al., 2017). As such, sustainable management practices are necessary to ensure the long-term viability of these fisheries and the resources they rely on (Lapointe et al., 2014).

Potential synergies exist between subsistence, small-scale, and inland recreational fisheries (Lorenzen et al., 2012; Gebremedhin et al., 2021). For example, sustainable management practices can help maintain healthy fish populations and ecosystems that benefit all three types of fisheries (Lorenzen et al., 2012; Gebremedhin et al., 2021; Cooke et al., 2023). Furthermore, subsistence

and small-scale fisheries can provide important local knowledge and expertise to inform sustainable management practices and benefit recreational fisheries (Kolding et al., 2018). In some cases, recreational fisheries can also provide funding for conservation and management efforts that benefit subsistence and small-scale fisheries (Cooke et al., 2020).

Subsistence, small-scale, and recreational inland fisheries are linked through their reliance on inland fish resources and their potential impacts on fish populations and ecosystems (Lynch et al., 2016; Nyboer et al., 2022). Sustainable management practices are necessary to ensure the long-term viability of these fisheries and the resources they rely on, and there is potential for synergies between different types of fisheries (Lorenzen et al., 2012). A holistic approach that considers the social, economic, and ecological dimensions of inland fisheries is necessary to promote sustainable management and conservation of these important resources (Hunt et al., 2013).

2.5.5 Threats to inland fisheries in Africa

Inland fisheries are an essential resource for African communities, providing a critical source of food, income, and employment (Jahan and Ahmed, 2016). However, Africa's inland fisheries face various threats that compromise their sustainability (Robarts and Zohary, 2018; Murchie et al., 2017). Reports show that overfishing, pollution, climate change, and habitat destruction are some of Africa's primary threats to its inland fisheries (Robarts and Zohary, 2018). In particular, the loss of habitats like wetlands, swamps, and floodplains is devastatingly impacting fish populations in many African countries (Murchie et al., 2017). In Central Africa, the Congo Basin, one of Africa's most significant inland fisheries, is experiencing severe habitat loss because of deforestation and land-use changes (Grill et al., 2019). These changes have disrupted fish migration patterns, spawning, and breeding, leading to declining fish populations.

Conservation of inland fisheries in Africa is critical to ensure the sustainable use of this vital resource (Weyl et al., 2011; Abate et al., 2015). Studies show that the conservation of inland fisheries in Africa faces several challenges, including inadequate funding for research, management, and monitoring, as well as the lack of policies and regulations to protect fish stocks (Allison, 2004). Furthermore, the rapid increase in population growth and urbanisation is leading to higher demand for fish, resulting in unsustainable fishing practices (FAO, 2018).

The impact of anthropogenic activities on freshwater fish populations is a growing concern in Africa (Ogutu-Ohwayo et al., 2013, 2016, 2018; Kaufman and Chapman, 2016). The decline of the Lake Victoria fisheries has significantly and negatively affected the welfare of communities in East Africa (Ogutu-Ohwayo et al., 2013, 2016, 2018). Additionally, the fish fauna of Lake Victoria is under threat because of various factors, including overfishing, habitat destruction, and pollution (Kaufman and Chapman, 2016). The situation is similar in Lake Malawi/Nyasa, where artisanal fisheries impact fishery resources and exacerbate poverty levels (Kasulo et al., 2020). These studies highlight the need for sustainable fishing practices and effective management strategies to preserve freshwater fish biodiversity and support the livelihoods of local communities.

Another major challenge facing freshwater fish in Africa is climate change (Ogutu-Ohwayo et al., 2016; Robarts and Zohary, 2018). Rising temperatures, altered precipitation patterns, and other climate-related impacts affect fish populations and their habitats (Ogutu-Ohwayo et al., 2016; Magoro and Woodford, 2018). In South Africa, for example, climate change contributes to the decline of some species and the spread of invasive species (de Moor and Bruton, 2016). Therefore, it is important to develop adaptive management strategies to mitigate the effects of climate change on freshwater fish (Magoro and Woodford, 2018).

Some African countries, like Ethiopia, show promising developments in the aquaculture sector, with improved feed and hatchery technologies that could support the industry's growth (Ayalew et al., 2018). A similar approach is happening in Namibia, where the country's government is helping drive the aquaculture sector (Itembu et al., 2022).

2.5.6 Case study: KwaZulu-Natal Province, South Africa, inland fisheries

KwaZulu-Natal's inland fisheries are diverse, but like many African regions, they face several challenges that affect their sustainability (Evans et al., 2022). However, these studies provide only limited insight into the fishery and its biology, and it remains unclear whether the populations are sustainable.

KwaZulu-Natal has several rivers and dams that provide habitats for various freshwater fish species (Table 2.2). Additionally, estuaries, such as the Mngeni and Mlalazi, play an essential role in KwaZulu-Natal's inland fisheries. The Mngeni Estuary, for example, is a critical nursery area for many fish species. According to James et al. (2012), seasonal variation in the diet of the white-breasted cormorant (*Phalacrocorax lucidus*) in the uMngeni Estuary highlights the importance of these ecosystems for many species. Habitat type and environmental variability are also significant determinants of fish distribution in estuaries, as evidenced in the St Lucia estuarine lake system, where environmental variability affects fish distribution (Begg et al., 2013). Ecological models can potentially provide significant insights into managing freshwater fish populations in South Africa. However, using ecological models in KwaZulu-Natal's fisheries management has been limited. According to Hecht and Kaiser (2014), developing robust ecological models that consider the impacts of various stressors, such as overfishing and environmental change, on the sustainability of fish populations is necessary. Additionally, the

success of fisheries management plans in the region will depend on the effective implementation of policies and regulations that consider the unique characteristics of the region's inland fisheries.

Concerning impoundments in KwaZulu-Natal, the Mzingazi Dam, for instance, is home to tilapia (*Oreochromis*) species, which are abundant in the area. A study showed that tilapia comprised 76.3% of the fish, with *Oreochromis mossambicus* being the most abundant species (Moloi, 2012). Furthermore, the study highlighted the need for fisheries management interventions to avoid overfishing and protect the fish populations in the dam (Moloi, 2012; Smith, 2020). By determining the behaviour and habitat of these species, they can be better managed and protected, ultimately benefiting the ecosystem and the livelihoods of those who rely on these fisheries for their income (Smith, 2020; Evans et al., 2022).

Although not a permanently freshwater body, Lake St. Lucia is another vital inland fishery in KwaZulu-Natal (Perissinotto et al., 2013). The water level fluctuations in the lake affect fish assemblages, and overfishing threatens the fish populations (James et al., 2012). Fish species decreased significantly with low water levels, making them more susceptible to fishing pressure (James et al., 2012). Therefore, fisheries management strategies that consider the lake's water level changes and the fish populations' reproductive cycles are necessary (James et al., 2012).

Impoundments have significant implications for fish assemblages in African rivers, including those in South Africa, especially KwaZulu-Natal (Dlamini, 2019). A study examined the fish populations in the Sabie River, Mpumalanga, and found that impoundment resulted in the loss of fish species, reduced fish diversity, and a shift in the dominant fish species (Matthews et al., 2006). The study recommended the removal of barriers that hinder fish movement, such as dams and weirs (Matthews et al., 2006).

Invasive fish species also threaten the native fish populations in KwaZulu-Natal's rivers (Evans et al., 2022). The growth and size of the invasive eastern mosquitofish (*Gambusia holbrooki*) at first maturity were investigated in a headwater stream in KwaZulu-Natal (Aldridge and Erasmus, 2010). It was recommended that the invasive species be removed and the native fish populations restored (Aldridge and Erasmus, 2010). Alien fish species introduced into the region have also had a negative impact on indigenous fish species. The decline of native species such as southern mullet (*Liza richardsonii*), river sardine (*Mesobola brevianalis*), and spotted tilapia (*Oreochromis andersonii*) in the Incomati River system in Mpumalanga and northern KwaZulu-Natal is a result of alien fish species (Næsje et al., 2009). The negative impact of alien species has highlighted the need to develop and implement effective control measures to prevent further damage to the region's fisheries (Evans et al., 2022).

Various factors, including water level fluctuations, overfishing, impoundments, invasive species, and climate change, significantly impact the state of inland fisheries in KwaZulu-Natal. Fisheries management strategies that address these factors are necessary to protect the fish populations and the industry's sustainability. Studies provide useful insights into the challenges facing inland fisheries in KwaZulu-Natal and the interventions necessary to address them (James et al., 2012; Evans et al., 2022).

Fisheries management in KwaZulu-Natal is a significant challenge, as it requires a comprehensive understanding of the fishery's biology and population dynamics. Capture-recapture methods applicable to estimating survival rates for freshwater fish in South Africa are vital for effective management plans (Hecht and Kaiser, 2014). Having robust monitoring methods, which are still lacking in the region, is crucial for successful management planning.

2.5.7 Conclusions

When looking at insights from existing literature, the categorisation of inland fisheries unfolds, revealing distinctive types. Subsistence inland fisheries prioritise providing local communities with food, relying on small-scale and traditional fishing methods. Threats like overfishing demand robust management for long-term viability, which is essential for rural food security. Recreational inland fisheries contribute to food, income, and recreation, relying on various activities such as sport and leisure. Challenges in developing countries necessitate effective conservation measures for sustainability. Small-scale inland fisheries, or artisanal fishing, employ modest equipment and traditional skills, supporting local economies. Despite challenges, these fisheries showcase resilience and successful conservation efforts, emphasising adaptive management. Commercial inland fisheries involve professional fish exploitation, serving as the primary income source. Challenges in regions like South Africa underscore the need for sophisticated approaches, ensuring long-term viability through nuanced management strategies.

Inland fisheries play a significant role in Africa's economic development and food security, including those in the West, East, and southern Africa. However, these fisheries face several challenges, including overfishing, habitat destruction, impacts of climate change, and inadequate governance. Co-management and community-based approaches have been proposed as solutions to these challenges and have successfully improved fish stocks and the livelihoods of fishing communities in the region. Sustainable fisheries management is crucial for the continent's continued development, as it promotes the conservation of fish stocks and supports the livelihoods of millions of people in Africa. Moving forward, efforts should be made to improve governance and promote sustainable management practices to ensure the long-term viability of fisheries in Africa.

In KwaZulu-Natal, inland fisheries face several challenges that affect their sustainability. A clear gap in the literature on South African, KwaZulu-Natal inland subsistence fisheries needs to be addressed and investigated further. This information gap must be closed to improve our understanding and create practical plans to help the region's sustainable subsistence fisheries. Some of the primary issues that must be addressed are a lack of systematic monitoring systems, the impact of invasive species, and the lack of knowledge of many inland fish species and their habitat (Hecht and Kaiser, 2004; Næsje et al., 2009). Therefore effective fisheries management strategies that take into account the unique characteristics of KwaZulu-Natal's inland fisheries are essential for the region's inland fisheries sustainability.

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CHAPTER 3

An evaluation of present and potential inland fisheries in dams and rivers in the uThukela and uMngeni Catchments, KwaZulu-Natal, South Africa, based on fishers' perceptions

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Running header: Evaluation of inland fisheries in dams and rivers of KwaZulu-Natal

3.1 Abstract

An intricate relationship of stakeholders shapes the governance of inland fisheries in South Africa, each deriving value from the resources contained in public dams. In South African inland fisheries, small-scale, commercial, subsistence and recreational fishers are included in this group, but recreational fishers take a more prominent role because they contribute directly to the economy more than the other inland fisheries sectors. These fishing sectors are essential for sustaining local sustenance and livelihoods. However, recognising subsistence fishing rights from recreational and small-scale fishers remains unclear, leading to conflicts. Our study aimed to address the paucity of knowledge of economically beneficial fish species and their offtake based on the perceptions of fishers present in selected sections of the uMngeni and uThukela catchments, KwaZulu-Natal, South Africa. We used a questionnaire interview method to obtain fishers' responses during 2021-2023. Findings from this study revealed difficulties in categorising fishers because of present inland water policies similar to the “fuzzy boundary” concept for inland fisheries globally, with some individuals identifying as recreational because of nondisclosure fears. Fishers’ knowledge illustrated the ecological imbalances between native (*Labeobarbus natalensis*) and invasive (*Cyprinus carpio*, *Micropterus* spp.) species, as well as the economic importance of fish based on market valuations, with *C. carpio* having a greater market value. Additionally, the results showed that subsistence fishers preferred river fishing compared with recreational fishers that targeted impoundments. Importantly, a considerable percentage of subsistence fishers stated that they ate fish mostly once a week or once a month. Our study highlighted the importance of holistic management of water regulations, fish ecology, and economics to promote sustainable inland fisheries.

Keywords: Inland fisheries; market value; subsistent fishers; recreational fisheries; small-scale fisheries; fisheries management

3.2 Introduction

Freshwater ecosystems that include lakes, rivers, and dam impoundments are vital in supporting inland fisheries. In addition to providing drinking water and contributing to the complex dynamics of the hydrological cycle, these environments support biodiversity (Allan, 2004; Vörösmarty et al., 2010). To maintain the resilience and longevity of these essential ecosystems, proactive conservation efforts and sustainable management techniques are necessary as human activities and environmental stressors pose an increasing threat to the health of freshwater systems, including fish species (Allan, 2004; Carpenter et al., 1998; Vörösmarty et al., 2010; Jaiswal et al., 2021).

Presently, South African inland fisheries tend to focus on water resource management, biodiversity, and conservation and have little cognisance of the support of livelihoods, food security, and economic contributions (Hara and Backeberg, 2014; Department of Forestry, Fisheries and the Environment (DFFE), 2021). This was highlighted in a study showing the need for an inland fisheries policy in South Africa (Weyl et al. 2007), mentioning that under national policies and international obligations, the national Department of Water Affairs and Forestry (now Department of Forestry, Fisheries and the Environment) should be designated as the leading agency to improve inland fisheries in South Africa (Weyl et al., 2007). It was suggested that local inland fisheries create management plans that formalise fishing rights, strongly emphasised co-management, and identify rural populations as the key beneficiaries (Weyl et al., 2007). In addition, it was proposed to simplify inland fishing regulation, promote cooperative governance, increase capacity, and unify provincial regulations (Weyl et al., 2007).

According to the South African National Department of Forestry, Fisheries and the Environment 2021 policy brief on inland fisheries, two fisher groups, recreational and small-scale, are essential for sustaining local sustenance and livelihoods (DFFE, 2021). Despite being unregulated, small-scale fishing benefits underprivileged communities and maintains food security while having narrow value chains (Béné et al., 2007).

Early in the 20th century, fish species like largemouth bass (*Micropterus salmoides*) were introduced into South African inland waters for recreational fishing purposes, successfully invading native fish waters (De Moor, 1996; Hargrove et al., 2017; Weyl et al., 2017; Khosa et al., 2019). These invaders' negative impacts highlight the necessity for cautious stocking techniques for invasive species, with little about stocking native species in their native range (Hargrove et al., 2017; DFFE, 2021). However, the early protection of invasive species regulated their harvest, often excluding small-scale fishers (Burnett et al., 2023).

The purely recreational fisher and fisher angling for subsistence is much debated, and the boundary between these groups is often blurred or “fuzzy” (Nyboer et al., 2022). While recreational fishing is firmly established in South Africa, the recognition of subsistence fishing rights remains unclear, resulting in conflicts (Weyl et al., 2007; Potts et al., 2022). The responsibility for managing biodiversity in impoundments/dams lies with provincial environmental agencies, which generally prioritise conservation over development (Nyboer et al., 2022; Burnett et al., 2023). The establishment of Catchment Management Agencies (CMAs) and Water User Associations (WUAs), which promote user participation and inclusive governance, could facilitate co-management of inland fisheries (Hara and Backeberg, 2014; Hara et al., 2021). However, rural communities often find themselves underrepresented in these organisations (Hara and Backeberg, 2014; DFFE, 2021). The present South African inland water policies require

subsistence fishers to register with recreational societies or clubs to have their voice heard by the government as a body (DFFE, 2020). Most subsistent fishers do not register with recreational societies because of costs and conflicts of interest (Nyboer et al., 2022). Despite this, both parties use similar angling gear, rod and line, as gillnets are illegal unless permitted by local conservation authorities (Barkhuizen and Weyl, 2020; DFFE, 2021). As such, by appearance, rod and line fishers are indistinguishable between recreational and subsistence (Nyboer et al., 2022).

In some cases, fishers in rural communities make use of rivers more than dams to fish for subsistence (Magombeyi et al., 2008; Ellender et al., 2009; van der Waal, 2010; Zeng et al., 2017). This is partly because dams are predominantly used for development projects (e.g., hydropower, irrigation, and water supply for cities and industry) and some recreation (Ellender et al., 2009; Zeng et al., 2017) and are not easily accessible for poorer, rural, subsistence communities (Richter et al., 2010). In the context of rivers used by rural communities, rivers play a significant role in livelihoods because of the value of goods and services provided by rivers, including providing fish as a protein (Van der Waal, 2000; Turpie, 2008; Zeng et al., 2017).

Fisheries governance in South Africa is shaped by an intricate relationship of stakeholders, who each derive value from the resources contained in public dams (Hara et al. 2021). This group of stakeholders includes small-scale fishers and recreational anglers (Hara et al., 2021). However, a notable division becomes apparent within this intricate framework, with recreational fisheries taking on a prominent role. This benefit is primarily attributable to the limitations placed on small-scale (subsistence) fisheries, which are principally caused by the prohibitions on particular fishing gear (Arlinghaus et al., 2017). The impending implementation of the national inland capture fisheries policy offers hope for overcoming problems related to resource access and sector classification (Nyboer et al., 2022). However, the proposed policy's criteria constitute a special

problem since they risk mistakenly designating certain subsistence-oriented people as leisure fishers (Hara et al., 2021).

The aim of our study was to address the scarcity of knowledge of economically beneficial fish species and their offtake based on the perceptions of fishers (subsistence, small-scale, recreational, and commercial) in selected rivers sections and impoundments of the uMngeni and uThukela catchments, KwaZulu-Natal, South Africa. Our objectives were to determine the fisher communities' perspectives on inland fish, targeted fish species, and offtake. In addition, the offtake by fishers was determined. We predicted that more subsistence fishers would use rivers than dams, with the inverse true for recreational fishers, partly because of access. We also predicted that there would be fewer recreational and commercial fishers because of fishing regulations in inland waters in South Africa.

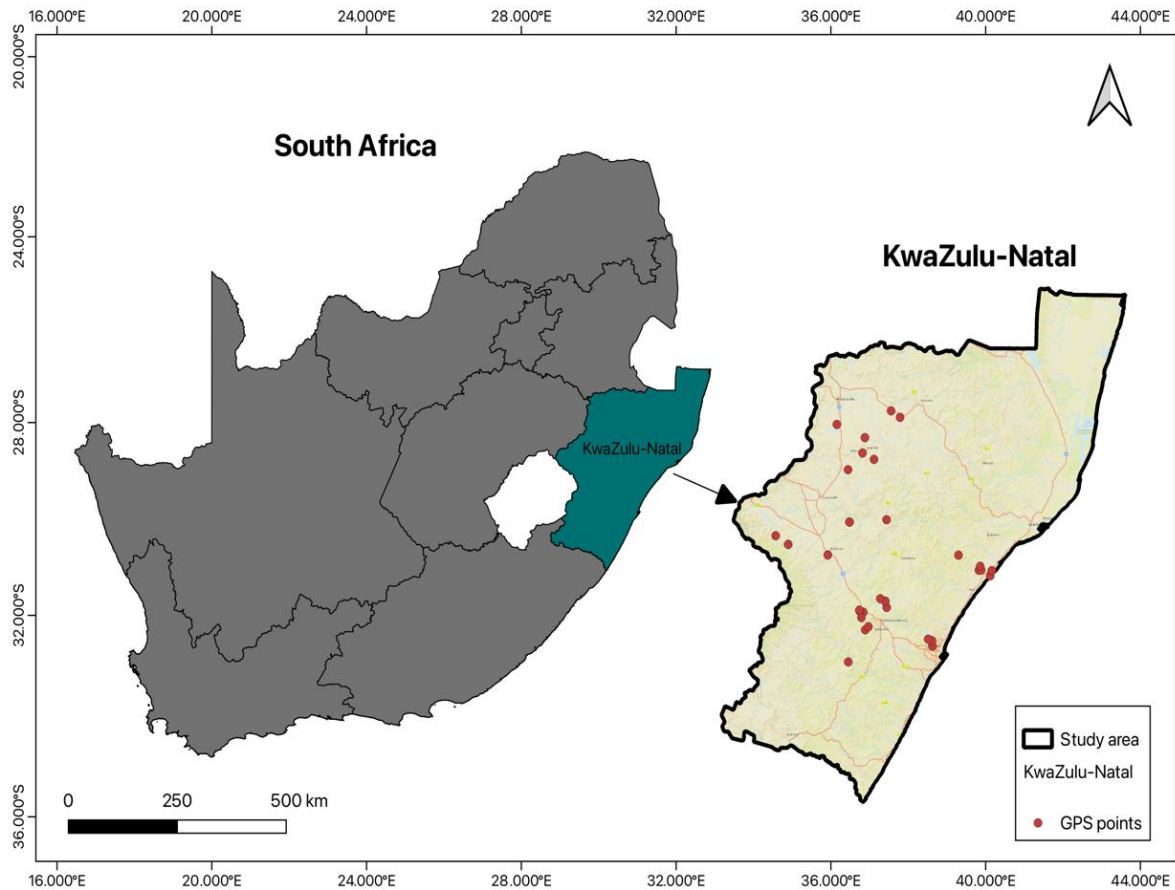


Figure 3.1: Map illustrating the study area in KwaZulu-Natal Province, South Africa, and showing geographical positioning system (GPS) points where questionnaires were administered in the present study.

3.3 Methods

3.3.1 Study area

Our study was conducted in selected sections of the uMngeni and uThukela catchments, KwaZulu-Natal, South Africa, in 2022 and 2023 (Fig. 3.1). The geographical positioning system (GPS) points indicate the locations where interviews were conducted with fishers in the present study. These points were marked after interviews were completed. The sites for conducting

questionnaires included communities near rivers, around selected dams of the mentioned catchments, along the rivers/streams, inside conserved areas (dams) and outside conservation areas (rivers and dams) (Fig. 3.1).

3.3.2 Questionnaires

We first obtained ethical clearance from the University of KwaZulu-Natal Humanities Ethics Committee (HSSREC/00003175/2021) to collect data using a questionnaire (Supplementary information Table S3.1). We used the questionnaire to interview fishers from March 2021 until October 2023 in the uMngeni and uThukela catchments in KwaZulu-Natal, South Africa (Fig. 3.1). Some of the questions were used in a corollary study examining the importance of the river for cultural and domestic reasons, and the importance of African freshwater eels (Nkomo, 2023). In some instances, fishing groups were interviewed under a group leader's details; however, other members contributed to the catch details for questions 3.9, 3.10, 3.11, and 3.12 (Supplementary information Table S3.1).

Following guidelines from the ethical clearance, we only interviewed fishers above the age of 18. Each individual first had to confirm if they would be interviewed since it was voluntary, and they were informed they could withdraw at any stage. We clarified to the participants what we were recording in the data sheets (time, date, location, and other questions, including their reasons for fishing), while also gathering demographic information such as age, gender, occupation, and education level during the interviews. (Supplementary information Table S3.1). If an individual did not want to participate, they were exempted. Each interview was ~15 min. We approached people fishing or with a fishing rod along the selected rivers or dams. Ezemvelo KwaZulu-Natal

Wildlife kindly assisted with contacts of local fishers to interview them around Midmar, Chelmsford, and Wagensdrift Dam.

3.3.3. Data analyses

We employed a blend of methods for comprehensive data analyses involving R Studio, Excel©, and QGIS. Initially, R Studio and Microsoft Excel served as the primary platforms for pre-processing, encompassing data importing and cleaning using packages like tidyverse and ggplot2 (R Core Team, 2016; Wickham et al., 2022, 2023). This allowed for efficient data wrangling, visualisation, and statistical computations (e.g., frequency analyses), generating plots and geographical maps (in QGIS). To answer the research questions, what fish species are fishers catching, what are their fishing purposes, and how much are they selling those fish? We used Excel for data clean-up, descriptive analyses, and additional visualisation through charting tools. This facilitated basic data checks and summary statistics and provided complementary insights to those obtained from R Studio.

We used QGIS (<https://qgis.org/es/site/about/index.html>), a geographic information system software, for geospatial analyses. We integrated geographical data with the fish species dataset, enabling the creation of spatial visualisations. This facilitated an enhanced understanding of fish species distribution across geographic locations, emphasising spatial relationships and aiding in the interpretation of regional dominance of both native and invasive species as perceived by fishers.

To account for different common names received from respondents, we recorded the name given and matched it with the most likely species known to science; here, we used Skelton (2001, 2016) for common names and descriptions. We listed the various species given and then further

grouped species into families to avoid misrepresenting the species level during data analyses. Here, we grouped Mozambique tilapia *Oreochromis mossambicus*, red-breasted tilapia *Coptodon rendalii*, and all bream and tilapia were named cichlids. All black bass fish were grouped as *Micropterus* spp., and both brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* were named as trout, and all common carp *Cyprinus carpio* common names given were grouped as *Cyprinus carpio*. All common names of KwaZulu-Natal yellowfish *Labeobarbus natalensis*, for example, ‘scaly’, ‘yellowfish’, ‘yellows’, were grouped as *L. natalensis*. All common names for the Tugela labeo *Labeo rubromaculatus* and Laeden labeo *Labeo molybdinus*, for example, ‘mudfish’, and ‘Tugela labeo’ were grouped as *Labeo* spp. All African sharptooth catfish *Clarias gariepinus* common names, for example ‘barber’, ‘barbel’, ‘catfish’, and ‘bhabuli’ were group as *C. gariepinus*. Common names for blue gill *Lepomis macrochirus*, for example, ‘blue gill’, and ‘panfish’ were grouped as *L. macrochirus*. All African freshwater eels were grouped as *Anguillid* spp.

3.4 Results

We interviewed 324 fishers, and these included group leaders for 27 groups of fishers varying in size from 2 to 3 fishers (Table 3.1). We removed one respondent who fished for research purposes and two respondents because they were related to marine fisheries, leaving 321 respondents. In addition, 88 fishers did not provide answers to questions 3.9-3.12 (Supplementary information Table S3.1) and were not used in those analyses. The other group members only contributed to the catch sizes of sales of species they caught ((Supplementary information Table S3.1, Questions 3.11, 3.12). Of these fishers, 265 (82.6%) were men, and 56 (17.5%) were female. Of the surveyed females, significantly more (n = 48) never fished in rivers, while eight indicated that they had

fished in rivers (Table 3.2, Chi-squared = 70.829, df = 1, $p < 2.2e-16$). Among males, 67 reported never having fished in a river, while significantly more (n = 198) reported fishing in rivers (Table 3.2, Chi-squared = 70.829, df = 1, $p < 2.2e-16$), indicating a strong association between gender and the likelihood of fishing among males.

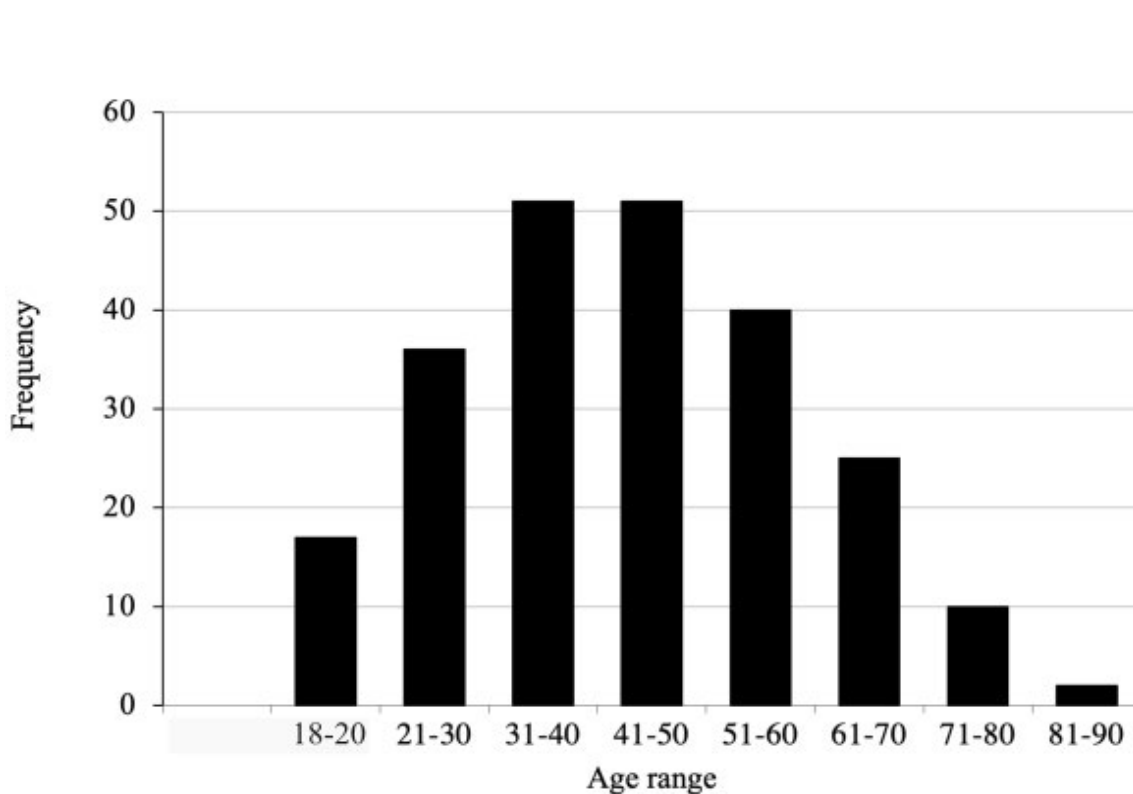


Figure 3.2: Histogram showing the age categories of fishers interviewed (subsistence/small-scale and recreational) in selected sections of the uMngeni and uThukela catchments, KwaZulu-Natal, South Africa, that were interviewed between 2021 and 2023.

The fishers interviewed ranged in age (Fig. 3.2). The age groups 31-40 and 41-50 were the most highly represented, with each having 51 people (Fig. 3.2). These age categories have the highest frequency among fishers; showing a strong presence of people in these age groups who were actively participating in fishing activities in the community (Fig. 3.2). The age categories 71-

80 and 81-90 had the lowest representation, with only 10 and 2 people, respectively, showing comparably lesser participation of older people in fishing within these communities (Fig. 3.2). It must be noted that researchers stopped several interviews because the respondent/s were below the age of 18, despite the fisher actively fishing both with and without adult supervision. Many cases involved groups of school-age children participating in fishing activities along rivers outside of school. Thus, this study's findings are limited to adult fishers.

A number of fishers (19.3%) were unemployed (Table 3.1). We found that fishing was part of their income-generating activities for 153 (47.7%) fishers. We found more subsistence fishers ($n = 130$, 40.5%) than recreational fishers ($n = 121$, 37.7%). Seventy (21.8%) fishers were unwilling to disclose their fishing type (recreational, subsistence, or small-scale), which was concerning. When looking at the fishing gear, two (1%) fishers used cast nets as their method of fishing, while most ($n = 319$, 99%) fishers used a rod and reel.

When fishers were asked, 'Why do you fish?', fishers who primarily fished in dams responded that they fish for recreational purposes (113 fishers, 35.2%) (Fig. 3.3). Only four (1.2%) respondents under the recreational fishers' type fished in rivers (Fig. 3.3). When examining those who responded that they fish for subsistence purposes, 58 (18.1%) said that they fish in dams, and 21 (6.5%) responded that they fish in rivers (Fig. 3.3). Additionally, 13 respondents (4.0%) who fish in rivers did not disclose their fishing purposes, and seven (2.1%) who fished in dams did not disclose their reasons for fishing (Fig. 3.3).

Table 3.1: Summary of those fishers (subsistence/small-scale and recreational) in selected sections of the uMngeni and uThukela catchments, KwaZulu-Natal, South Africa, that were interviewed between 2021 and 2023.

Why do you fish ?		
Recreational	Subsistence	No answer
121	130	70

Marital status	4.4 How often do you consume fish?
Married	109
no answer	5
Single	207

Occupation	Female	Male
Business	8	53
Domestic Worker	3	3
Farmer	6	18
Fisher (full-time)	0	11
No answer	5	37
Pensioner	4	5
Retired	1	1
Salaried employment	14	84
Student	1	5
Unemployed	14	48

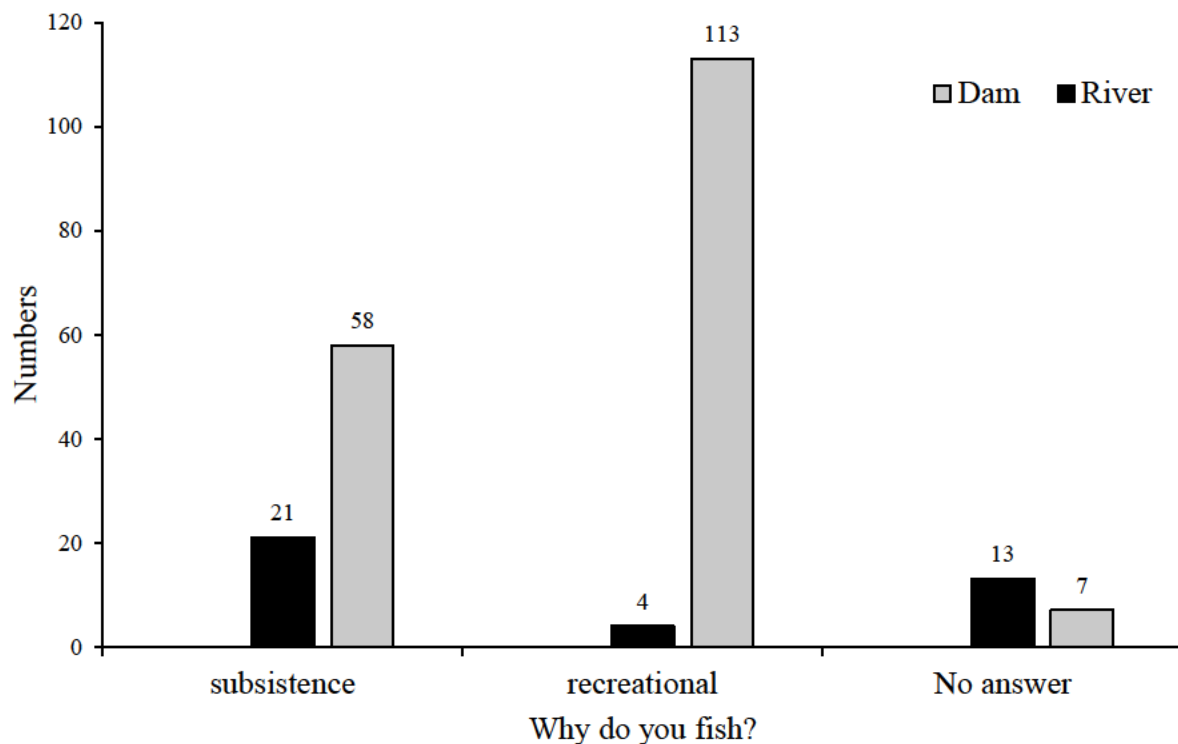


Figure 3.3: Number of fishers (subsistence or recreational) responses to why they fished in selected sections of the uMngeni and uThukela catchments between 2021 and 2023.

Subsistence and recreational fishers had different consumption habits (Fig. 3.4). Fishers who fish for subsistence primarily reported eating fish more frequently, with a clear preference for weekly (more than 80 respondents, > 24.9% of all fishers) and monthly (more than 30 respondents) consumption (9.3% of all fishers). However, recreational fishers also admitted to eating the fish they captured, but in a different way. Less than 20 recreational respondents reported monthly fish consumption, and more than 80 recreational fishermen (24.9% of all fishers) said they never ate any fish they captured.

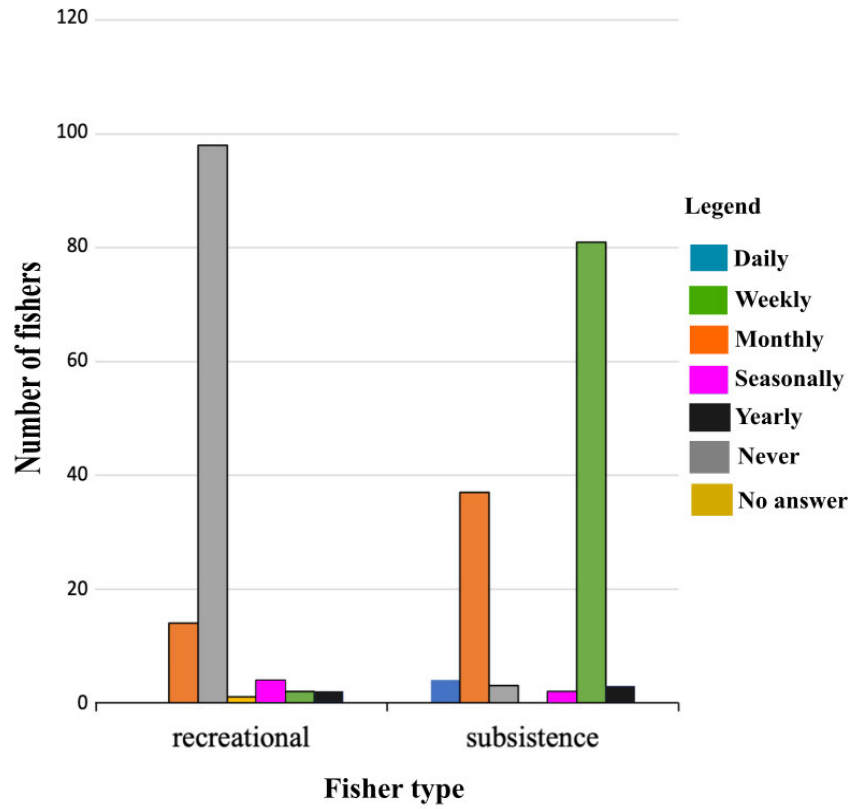


Figure 3.4: Summary showing how often fishers (recreational/subsistence) consumed the fish they caught in selected sections of the uMngeni and uThukela catchments.

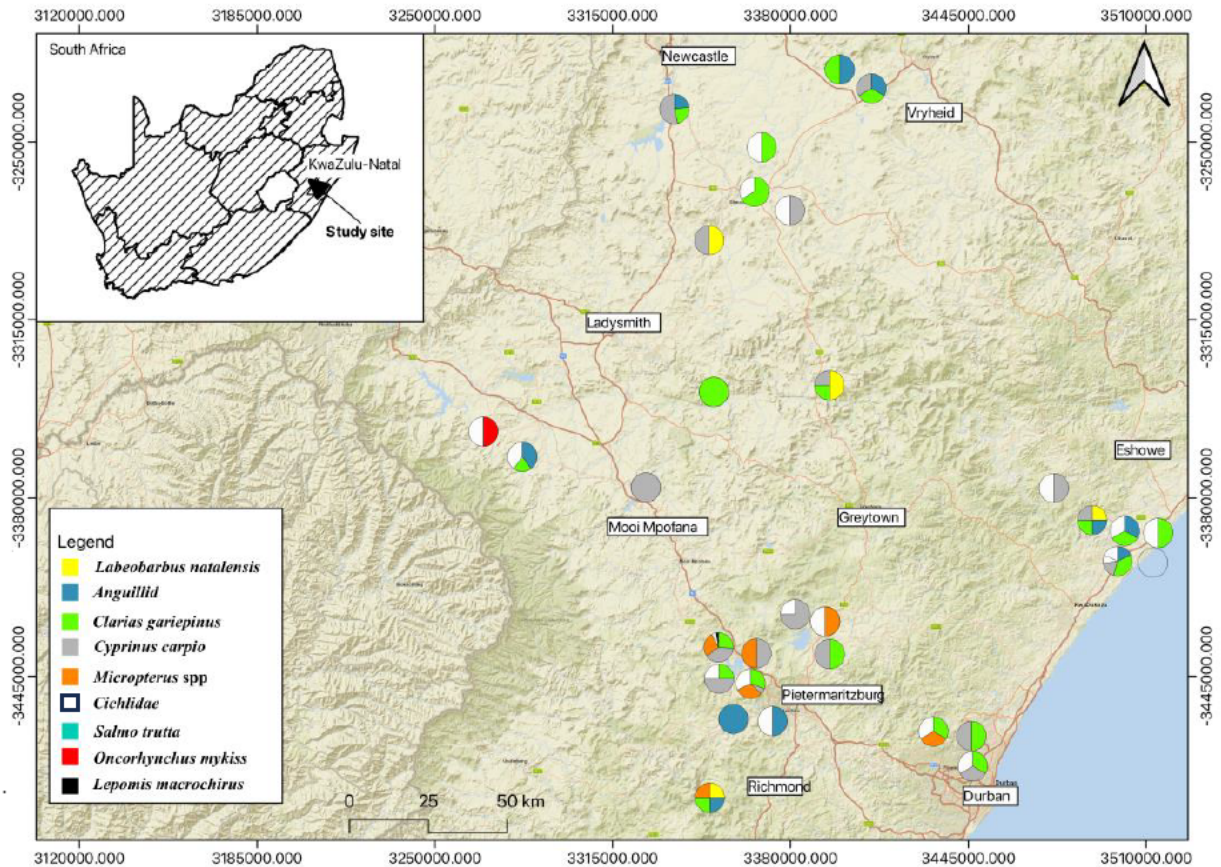


Figure 3.5: Analysis of responses from question 4.9 “what are the five most common fish you’ve caught” from 2021-2023 in selected sections of the uMngeni and uThukela catchments.

Responses to the question "4.9 “What are the five most common fish you’ve caught” in selected sections of the uMngeni and uThukela catchments in KwaZulu-Natal from 2021 to 2023 showed a preference for native sharptooth catfish *Clarias gariepinus* throughout the study area (Fig. 3.5). These were followed by invasive fish species, common carp *Cyprinus carpio* and bass *Micropterus* spp. (Fig. 3.5). Respondents were able to provide 13 common fish species in the region, namely river bream *Acanthopargus berda*, *O. mossambicus*, and *C. rendalii* group as cichlids, *S. trutta*, and *O. mykiss* grouped as trout, *Mi. dolomieu*, and *M. salmoides* grouped as *Micropterus* spp., and *C. gariepinus*, *C. carpio*, *L. natalensis*, *L. macrochirus*, grouped as

individual species for the present study. No individual species of Anguillid were recorded as these species are generally poorly known and referred to as 'eels' by respondents.

Invasive fish species were caught more than the native KwaZulu-Natal yellowfish *L. natalensis* (Fig. 3.5). Results from questionnaire interviews with fishers around the uMngeni catchment showed that around Midmar Dam, fishers were catching more *C. carpio* followed by *Micropterus* spp. and then *C. gariepinus* (Fig. 3.5). The results also showed that fishers here were catching a significant number of *L. natalensis* (Fig. 3.5). Fishers in Albert Falls Dam also caught more *C. carpio* than other fish species (Fig. 3.5). Around Henley Dam, fishers were mostly catching freshwater eel species (*Anguillid* spp.), cichlids, *L. natalensis*, *C. gariepinus*, *Micropterus* spp. and *C. carpio* (Fig. 3.5).

In northern KwaZulu-Natal, around the Ladysmith and Newcastle areas where Wagensdrift Dam and Chelmsford Dam are located, the fishers were catching *C. gariepinus*, *C. carpio*, *L. natalensis* and cichlids (Fig. 3.5). Fishers caught *O. mykiss* south-west of Ladysmith near Estcourt (Fig. 3.5). Trout species *O. mykiss* and *S. trutta* were not reported caught in most locations in this area of KwaZulu-Natal, except for the Estcourt area (Fig. 4.5).

Based on replies to the question "3.10 How many fish do you catch on a good day?", the number of freshwater fish species that fishermen had successfully captured is shown in Table 3.2. *Cyprinid carpio* had a cumulative count of 651, while *C. gariepinus*, with a higher cumulative count of 1033, were the main species. Other noteworthy contributions to the catch include KwaZulu-Natal yellow fish (*L. natalensis*), with a cumulative total of 227 captures, and bass (*Micropterus* spp.), with 766 captures. *Oncorhynchus* spp. and *L. kimberleyensis*, for example, had comparatively lower numbers, indicating that they were less common in the fisheries that were investigated.

The fishers' responses to “4.12 How much do you sell them for? (Rands)”, provide insights into the pricing dynamics of various fish species within the surveyed communities (Table 3.2). *Anguillid* spp. had a maximum price of ZAR 92.50 and a minimum of ZAR 20.00, with an average price of ZAR 56.25 per individual. *Clarias gariepinus* has a higher market value, ranging from ZAR 250.00 (maximum) to ZAR 25.00 (minimum), resulting in an average price of ZAR 137.50 per individual. *Cyprinus carpio* was priced between ZAR 300.00 (maximum) and ZAR 50.00 (minimum), with an average of ZAR 175.00. *Labeobarbus natalensis* had a maximum price of ZAR 240.00, a minimum of ZAR 60.00, and an average price of ZAR 150.00. *Lepomis macrochirus* had a maximum price of ZAR 100.00 and a minimum of ZAR 0.00 with an average price of ZAR 50.00. *Micropterus* spp. prices ranged from ZAR 250.00 (maximum) to ZAR 20.00 (minimum), with an average price of ZAR 135.00. Cichlids were priced between ZAR 120.00 (maximum) and ZAR 20.00 (minimum), with an average of ZAR 75.00. Brown trout *S. trutta* had a maximum price of ZAR 30.00, a minimum of ZAR 24, and an average price of ZAR 27.00. These diverse pricing patterns underscore the importance of understanding the economic nuances associated with different fish species in the context of local fisheries management.

Table 3.2: Presentation of targeted fish per fishers, the catches per fish species, and price per catch from respondents.

Species	4.9 "What are the 5 most common fish you catch?"			4.10 "How many fish do you catch on a good day?"				4.12 "How much do you sell them for? (ZAR)"		
	Fisher targets per species	% of targeted fish per fisher	% of total targeted fish	Catch sizes (Mean +-SD)	Max catch	Min catch	Cumulative catch	Max price sold per catch	Minimum price per catch	Average price per catch
<i>Anguillid</i> spp.	21	6.71	3.15	2.3 ± 1.74	6	1	42	R 92.50	R 20.00	R 56.25
Cichlid	116	37.06	17.42	7.2 ± 6.56	38	1	804	R 120.00	R 20.00	R 75.00
<i>Clarias gariepinus</i>	163	52.08	24.47	7.7 ± 9.91	100	1	1239	R 250.00	R 25.00	R 137.50
<i>Cyprinus carpio</i>	114	36.42	17.12	8.1 ± 11.28	100	1	872	R 300.00	R 50.00	R 175.00
<i>Labeobarbus natalensis</i>	99	31.63	14.86	6.2 ± 4.58	20	1	537	R 240.00	R 60.00	R 150.00
<i>Lepomis macrochirus</i>	38	12.14	5.71	4.2 ± 3.53	15	1	151	R 100.0	R 0.00	R 50.00
<i>Micropterus</i> spp.	109	34.82	16.37	7.0 ± 9.68	100	1	924	R 250.00	R 20.00	R 135.00
Trout	5	1.60	0.75	6.6 ± 7.53	20	2	33	R 30.00	R 24.00	R 27.00
<i>Labeo</i> spp.	1	0.32	0.15	-	-	-	-	-	-	-

3.5 Discussion

We found that the relatively poorly developed inland fisher types were not clearly distinguished from one another, other than separated into the two groups of fishers, recreational and subsistence. Fishers did not identify themselves as small-scale and commercial fishermen. The absence might be attributed to a knowledge gap regarding how fishers self-identify, a factor defined in literature by the fishing gear employed or the general “fuzzy boundary” between these two fisher groups in literature and inland fisheries management (Nyboer et al., 2022). Only recreational and subsistence fisher types were acknowledged by respondents when asked to identify themselves out of the four types of fishers, namely, commercial, small-scale, recreational, and subsistence.

Weyl et al. (2015) defined recreational fishing as non-commercial activities encompassing sport, leisure, or subsistence fishing, mainly using rods and reels as fishing gear. Subsistence fishers can be defined as fishers that predominantly eat their catch, or their livelihoods (including their family and immediate community) depend directly on fish consumption from their catch (Nyboer et al., 2022). In addition, subsistence inland fisheries specifically refer to fishing activities primarily intended to provide food for local communities residing near freshwater bodies (Funge-Smith and Bennett, 2019). As such, the boundary between subsistence and small-scale fishers can also be “fuzzy”, as small-scale fishers can vary from one individual eating their catch to several individuals working together to maximise their profits from selling their catch (DFFE, 2021). The present study predominantly interviewed individuals who classed themselves as subsistence fishers, although they are likely to fall in the small-scale fisher type as they regularly sell their catch. However, this was a low percentage of respondents ($n = 8, 2.5\%$) in our study.

In South Africa, small-scale fishing involves various ancillary activities, and its emergence is a post-Apartheid phenomenon, while gill netting is only allowed unless

permitted (Britz et al., 2015; Tapela et al., 2015). In other parts of Africa, small-scale fisheries involve traditional methods and modern equipment, often employing gear such as gill nets (Bhilave, 2018). Commercial fisheries are limited in South Africa as they do not match the scale of local marine-based commercial fisheries (DFFE 2021), with profit-oriented operations requiring provincial-level access permissions, nor having water bodies large enough to sustain the same outputs as marine-based commercial fisheries (Barkhuizen et al. 2016; Barkhuizen and Weyl, 2020). The present study did not find any commercial operations as expected.

The existing inland water policies in South Africa result in many subsistence fishers not qualifying as ‘small-scale fishers,’ potentially marginalising low-income recreational fishers who rely on fishing for nutritional needs (Hara et al., 2021; Nyboer et al., 2022). Despite this distinction, the findings indicated that recreational and subsistence fishers commonly employ rod and reel as their main fishing gear, regardless of whether they engage in fishing for leisure or subsistence purposes. This shift has made distinguishing between recreational and subsistence fishers challenging even in the present study. However, the impending implementation of the national inland capture fisheries policy brings hope for resolving issues related to resource access and sector classification when done properly (Nyboer et al., 2022). Concerns still linger about potentially mislabelling subsistence-oriented individuals as leisure fishers because of the outlined criteria in the proposed policy.

Of the two fisher types revealed by the respondents, more respondents considered themselves subsistence fishers rather than recreational fishers, despite fishing in well-known recreational angling localities, for example, Wagendrift, Albert Fall and Midmar dams. Some fishers were unwilling to disclose their fishing reasons, which may indicate distrust in identifying the type of fisher because they fear prejudice. The fear of disclosing their fishing reasons may also result in many fishers not being completely honest with why they fish

(recreational/subsistence) or misconceptions about the legalities of being able to fish. This may have resulted in some fishers identifying as recreational fishers because of the perceived taboo against harvesting fish imposed by recreational fishers. This may also have been influenced by a lack of comprehension regarding policies concerning fisheries when conservation authorities regulate access to fisheries and permits (Hara and Backeberg, 2014; DFFE, 2021; Williams, 2023).

A considerably larger proportion of recreational fishers in the present study primarily fished in dams, citing recreational purposes as their main motive, with only a few indicating that they fished in rivers. We found fishers who fished for subsistence focussed primarily on dams; however, a number reported fishing in rivers. This pattern underscored the tendency for subsistence fishers to engage in river fishing more frequently than recreational fishers. This is likely influenced by the easier access and unrestricted nature of rivers within their communities, unlike the more restricted access to dams that often require permits or entrance fees. Therefore, several subsistence fishers preferred the more accessible river environments for their fishing activities.

The catch-related responses matched similar fish population distributions and structures common with the uMngeni and uThukela catchments (Chapter 4). The abundance of *C. gariepinus* was evident throughout KwaZulu-Natal. Invasive fish species, including *Micropterus* spp. and *C. carpio*, were next in abundance, highlighting the presence or availability of these in the catchments. The results also highlight potential ecological imbalances where they may exert competitive interactions with native species like *L. natalensis*. How these native fish species are found in these freshwater systems with invasive fish species was also shown in a study in KwaZulu-Natal that showed that invasive fish species like *Micropterus* spp. were found present in areas with native fish species, including *L. natalensis* and cichlids (Evans et al., 2022). However, further research is needed to show

how the invasive fish species may be outcompeting native fish species. Furthermore, some of the invasive cichlids may hybridise with native species (D'Amato et al., 2007; Evans et al., 2022; Mashaphu et al., 2023).

When examining the value of caught fish, the estimated price of catch per species varied. Fishers determined the price according to various factors such as the body mass, length, and health of the fish, but many fishers could not mention or remember exact prices as these varied per catch, species, and market. According to the respondents, the average price per catch differed between what each fish species could be sold for. The results showed that *C. carpio* were priced highest and sold for a maximum price of ~ZAR175. These species were followed by the *L. natalensis*, *C. gariepinus*, and *Micropterus* spp., which had maximum selling prices of ZAR150, ZAR137.50, and ZAR135, respectively, per fish. This revealed the economic importance of various fish species targeted by the fishers. While native species showed competitive market values, invasive alien species such as *Micropterus* spp. and *C. carpio* demanded equal or greater prices, respectively. This pricing variety highlighted the economic potential and difficulties related to fishery management and commerce by reflecting the varying demand and values assigned to each fish species in the market (Burnett et al., 2023).

It is important to understand fishing methods and consumption trends, especially in connection with the seasonality of fishing and available markets (Weyl et al., 2007, 2020). In the present study, subsistence fishers reported frequently eating fish, primarily weekly and monthly, while recreational fishers seldom ate the fish they captured. The differences in consumption patterns amongst these groups highlight the fishers' different connections with their catch and the need to distinguish between subsistence and recreational fisher groups when relating to policy and conservation of key species.

Freshwater ecosystems are managed by several national and provincial departments in South Africa, and this could confuse fishers when trying to access water and potential fishing regulations and permits. The South African National Department of Water and Sanitation (DWS), previously known as the Department of Water Affairs and Forestry, is primarily in charge of water security and water use licensing and owns many of the built dams primarily for water provision but house many recreational fisheries, for example, Midmar Dam and Albert Falls Dam in our study. In addition, conservation authorities, both on a provincial and national level, have advocated for the removal of alien invasive species to protect smaller, less economical species with high conservation status, for example, the redbfin barb (*Pseudobarbus* spp.) and the requirements of the National Environmental Management Biodiversity Act (NEM:BA) for invasive fish species listed (NEM:BA, 2021; Burnett et al., 2023).

To add to the confusion, the inland fisheries sector in South Africa seemingly was not assigned directly to a national department until the Department of Agriculture Forestry and Fisheries was formed (Weyl et al., 2007; Van Zyl et al., 2020). Previously, it was uncertain whether this role fell under the then Department of Water Affairs and Forestry or the then Department of Agriculture, Conservation and the Environment (Weyl et al., 2007). Many restructurings of these national departments have presently found inland fisheries fall under the Department of Forestry, Fisheries and the Environment (DFFE). The recreational angling plays a significant role in South African leisure/recreational activities and could fall under the Department of Sport and Recreation South Africa (SRSA), which is committed to encouraging sports and physical activity in the country (Van Zyl, 2010; DFFE, 2021).

The South African Sport Anglers and Casting Confederation (SASACC), the South African Freshwater Bank Angling Federation (SAFBAF), and provincial angling organisations all play crucial roles in managing recreational fishing activities in the private

sector. These groups bridge the public and private sectors, promoting recreational fishers' interests (DFFE, 2021). Additionally, the development and sustainability of the industry are substantially influenced by the formal business sector, which comprises suppliers, manufacturers, importers, wholesalers, and retailers (Van Zyl, 2010).

The results of this study highlighted the difficulties South African subsistence fishers experience and their nuanced interaction with the laws in place. Respondents' revelation of the fuzzy boundary separating subsistence and recreational fishermen highlights how inadequate the present classifications are (DFFE, 2021; Nyboer et al., 2022). The notable lack of small-scale and commercial fishermen among the self-identification options suggests that there may be misconceptions about how fishers classify themselves according to their perceptions of the regulations, permitting, and nestling around inland fisheries. The national inland capture fisheries strategy has important ramifications, especially regarding resource access, sector classification, and poverty alleviation. The national inland capture fisheries strategy has important ramifications that align with the sustainable development goals of the United Nations, especially in resource access, sector classification, and poverty alleviation (Lynch et al., 2017).

The policy's impending implementation presents hope for resolving problems with resource access and sector classification. However, given the parameters in the proposed policy, worries about mistakenly classifying people who prioritise subsistence fishing as recreational fishers continue. One potential improvement could involve providing a more understandable definition of these categories of fishing within the policies to better differentiate between subsistence fishing and recreational angling. This issue is particularly pertinent given that a sizable percentage of respondents described themselves as subsistence fishermen. The study also highlighted the difficulties in obtaining consent from the fishers, as a sizable portion of them were reluctant to disclose their fishing motivations. This hesitation

could be the result of ignorance of fisheries policy or fear of discrimination because of their disposition in the fisheries sector for so many years (Hara et al., 2021; DFFE, 2021). These concerns are thought to present an opportunity to address the national inland capture fisheries policy, which the present DFFE report will address (DFFE, 2021).

Furthermore, the economic significance of various fish species is highlighted through the pricing variations observed in the market. *Cyprinus carpio*, *L. natalensis*, and *C. gariepinus* were among the species with competitive market values, while others demanded higher prices. Understanding these economic dynamics is crucial for effective fishery management and commerce (Béné et al., 2010; Ouma and Dedy, 2016; Gupta and Dasgupta, 2018). Connecting our results to the importance of the study, it is clear that the difficulties subsistence fishers have identifying themselves and their possible mismatch with policy requirements have wider ramifications. This study highlighted the importance of addressing this issue at a policy level, considering the special needs of subsistence fishing and preventing the marginalisation of subsistence fishers. To further ensure efficient and fair fisheries management, addressing the obstacles to disclosure and enhancing fishers' comprehension of policies is imperative. Despite this, it is still important to consider the tragedy of the commons and construct adequate management measures for subsistence fishers (Berkes, 1985; Mandl, 2023).

3.5.1 Conclusions

According to our findings, there is a misalignment in inland fisheries policies, particularly the neglect of finding a home for subsistence fishers. The “fuzzy boundary not only relates to between subsistence and recreational fishers, but also between subsistence and small-scale fishers. This confusion relates to fishers classifying themselves as either subsistence or recreational fisher, with little inclusion of small-scale fishers, and some fishers defaulting to

being recreational fishers because of the fear of disclosing their reason for fishing. The recent DFFE (2021) policy-induced shift made it difficult to distinguish between these categories, raising worries about potential misclassifications and further marginalising subsistence fishers. Furthermore, this study emphasised ecological imbalances caused by competitive interactions between native and invasive fish species and the economic relevance of various fish species based on market values. Invasive fish species like *C. carpio* also had the highest market value compared with other species, showing that the fishers view them as valuable species regardless of being invasive. The observed differences in fish-eating patterns between subsistence and recreational fishers highlighted different ties to their catch.

Our study emphasised the importance of implementing holistic management techniques, including inland fisheries regulations, fish ecology, and economics. These multiple elements significantly impact inland fisheries and their sustainability, particularly in meeting the demands of rural people relying on these resources and poverty alleviation. A comprehensive management framework is essential because of the complex interactions between the economic aspects of fisheries activities, the influence of invasive fish species on native fauna, and the regulatory framework controlling inland waters. Maintaining the delicate balance of freshwater ecosystems and guaranteeing the long-term benefits received by rural populations that depend on these fisheries for income and subsistence requires a comprehensive approach. This study emphasises the value of inclusivity and truthful portrayal of the range of fishing methods that are used. Enacting policies that consider this diversity is crucial to efficient and just management, as it promotes a peaceful coexistence of economic concerns, environmental preservation, and the varied requirements of fishing communities.

3.6 Acknowledgements

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3.8. Supplementary information

Supplementary information Table S3.1. The questionnaire used in the present study for in-person interviews with fishers.

Fisher ID	DATE	TIME	ID	COUNTRY	RIVER/DAM	Water_body	day of the week	x	Village
Gender	Marital Status	Education (yrs)	Age	Tribe/Ethnicity	Religion	Monthly Income	Are other people in your household earning an income	Occupation	
3. Can you tell us about the river(s) around your village? How important are they to you	3.1 How often do you use the rivers around your community for the following purposes? [Drinking water]	3.2 How often do you use the rivers around your community for the following purposes? [Washing utensils]	3.3 How often do you use the rivers around your community for the following purposes? [Washing clothes]	3.4 How often do you use the rivers around your community for the following purposes? [Washing yourself]	3.5 How often do you use the rivers around your community for the following purposes? [Irrigating crops]	3.6 How often do you use the rivers around your community for the following purposes? [Watering livestock]	3.7 How often do you use the rivers around your community for the following purposes? [Fishing]		
3.8 How often do you use the rivers around your community for the following purposes? [Aesthetic]									

3.9 How often do you use the rivers around your community for the following purposes? [Spiritual]	3.10 How often do you use the rivers around your community for the following purposes? [Cultural]								
4. How often do you use the rivers around your community for the following purposes? [Other]	4.1 Have you ever fished in the river?	4.2 If yes. how frequently?	4.3 Why do you fish?	4.4 How often do you consume fish?	4.5 Where do you sell extra fish caught?	4.6 Do you use a boat. if so what type?	4.7.1 Which income generating activities do you and other members of your household participate in?rank(no of people) [Fishing]	4.7.2 Which income generating activities do you and other members of your household participate in? [Agriculture]	
4.7.3 Which income generating activities do you and other members of your household participate in? [Informal trade]									

4.7.4 Which income generating activities do you and other members of your household participate in? [Salaried employment]	4.7.5 Which income generating activities do you and other members of your household participate in? [Tourism]								
4.7.6 Which income generating activities do you and other members of your household participate in? [Other]	4.7.2 If you are no longer fishing. why?	4.8.1 Which fishing gear do you own and use? [Rod and ril]	4.8.1 Which fishing gear do you own and use? [Longline(Many hooks)]	4.8.1 Which fishing gear do you own and use? [Gill nets]	4.8.1 Which fishing gear do you own and use? [Seine nets]	4.8.1 Which fishing gear do you own and use? [Harpoon/Spear-gun]	4.8.1 Which fishing gear do you own and use? [Fish traps/pots]	4.8.1 Which fishing gear do you own and use? [Fish Weirs]	
4.8.1 Which fishing gear do you own and use? [Cast net]	4.8.2 If you do not own gear. do you borrow or rent the gear?			4.9 What are the 5 most common fish you catch?	4.10 How many fish do you catch on a good day?				
4.11 How many fish do you catch on a bad day?	4.11.1	4.11.2	4.11.3	4.11.4	4.11.5	4.12 How much do you sell them for?(Rands)	4.12.1	4.12.2	4.12.4

5.1 Do you know if there are eels in your rivers/dam?	5.2 How many different types of eels do you know from your river(s) and their local names?	5.3 How do you differentiate between the different types of eels?	5.4 Do you know about the different eel stages?	5.5 What are the local names for the different eel stages?	5.6 Have you ever caught eels in your river(s)?	5.7.1 If yes. what kind of eel and what stage do you catch? [Glass]	5.7.1 If yes. what kind of eel and what stage do you catch? [Elver]	5.7.1 If yes. what kind of eel and what stage do you catch? [Natal Labeobarbus natalensis]	
5.7.2 From the answers above. how often do you catch the selected eels and stages?	5.8 Do you specifically target eels?	5.9 Why do/don't you target eels?	5.10 How often do you fish for eels?	5.11 How do you catch eels?					
5.12 Where in the river do you catch the most eels?	5.13 When is the best time of the year to catch eels?	5.14 Why do you fish for eels?	5.15 Where do you sell the eels caught?	5.16 How much do you sell the eels for?	5.17 In your opinion. has the fishery changed in the recent past?	5.18 In your opinion. what are the reasons for the change?	5.19 Do you like fishing for eels?	5.20 And why?	
5.22 If yes. what are they?	5.23 Are there any beliefs associated with this river. known by the community?								

CHAPTER 4

An evaluation of the present inland fisheries in impoundments and associated rivers in KwaZulu-Natal, South Africa, with a focus on Midmar Dam and Henley Dam

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Running header: Present and potential inland fisheries in dams and associated rivers

4.1 Abstract

Inland fisheries are integral to ensuring food security, human health, and overall well-being, yet they encounter multifaceted challenges threatening their sustainable existence. The health of inland fisheries heavily relies on the diversity and robustness of fish communities. Our study addresses a significant knowledge gap related to fish catch data in impoundments and associated rivers in KwaZulu-Natal, South Africa, focusing on Midmar Dam and Henley Dam. Our primary aim was to offer valuable insights that inform fisheries research and promote sustainable management practices. We conducted an ecological assessment of fish communities in Midmar Dam and Henley Dam during the winter and summer seasons of 2022 and 2023. We used diverse fishing methods, such as gillnets and fyke nets, to capture a broad spectrum of fish species. Additionally, questionnaires were administered in selected areas of KwaZulu-Natal to gather complementary data on fish species in inland fisheries. We found a total of six fish species (three native species and three invasive species) in the two impoundments. Midmar Dam had significantly higher total fish catch than Henley Dam, highlighting the role of environmental factors such as dam size, depth, and temperature in shaping fish populations and influencing overall productivity. The KwaZulu-Natal yellowfish (*Labeobarbus natalensis*) was significant to local inland fisheries, while invasive fish species posed challenges to maintaining the native fish species. Our study emphasised that incorporating fish catch data and ecological data into decision-making processes is crucial for making informed, science-based choices that ensure the long-term viability of fish populations and promote the overall health of freshwater ecosystems.

Keywords: inland fisheries; uMngeni catchment; KwaZulu-Natal yellowfish; water quality parameters; fish population dynamics; fisheries management.

4.2 Introduction

Across Africa, subsistence fishers provide food to their families and communities with wild-caught fish (Cooke et al., 2016; Funge-Smith and Bennett, 2019). However, the management of these fisheries is generally poor and often not sustainable as the resource is generally exploited to meet increasing demands to feed the human population (Allison, 1995; Welcomme et al., 2010; Musinguzi et al., 2021). Inland fisheries play a crucial role in food security, human health, and well-being, but in undeveloped rural communities, they face numerous threats to their sustainability (Youn et al., 2014; Lynch et al., 2016; Funge-Smith and Bennett, 2019). Inland fisheries in Africa are threatened by demand, governance, regulations, bad management, natural and anthropogenic factors, population growth, unemployment, and changing consumer tastes (Welcomme et al., 2010; Mokhaukhou, 2022).

Policy objectives, political actions, cross-border collaboration, natural catastrophes, land allocation, and recreational fishing also impact the long-term viability of inland fisheries (Welcomme et al., 2010; Cooke et al., 2021). Improving water resource management, environmental health, and ecosystem rehabilitation is crucial for maintaining the long-term viability of inland fisheries, highlighting the importance of understanding and addressing these factors (Welcomme et al., 2010; Youn et al., 2014).

Assessing the status of freshwater fish communities, which are vital components of freshwater ecosystems and play a pivotal role in preserving the health and biodiversity of rivers and streams (Gebrekiros, 2016; Dutta et al., 2017; Lynch et al., 2023). For example, a study conducted in South Africa in KwaZulu-Natal's uMngeni River emphasised the importance of preserving instream habitats for *Labeobarbus* spp., particularly KwaZulu-Natal *Labeobarbus natalensis*, to ensure successful spawning events and refugia during periods of food scarcity (Burnett et al., 2021). The significance of managing anthropogenic impacts and implementing flow releases per temperature cues to facilitate *L. natalensis* movement while

understanding their behavioural and spatial ecology is crucial (Burnett et al., 2021). To understand the associated ecology of inland fisheries, evaluating the status of fish communities becomes imperative for gaining insights into the ecological integrity of freshwater systems and the species inhabiting them (Gebrekiros, 2016; Piczak et al., 2023).

In recent years, a variety of methods have been employed to assess fish communities, including investigating the correlation between land use and watershed characteristics with fish community structures and evaluating the impact of human activities such as hydroelectric development (Fausch et al., 1990; Borgwardt et al., 2019; Hamidifar et al., 2022). These approaches contribute to a better understanding of fish populations' overall health and dynamics within freshwater ecosystems (Fausch et al., 1990; Harris, 1995; Li et al., 2024).

Fish communities are seen as a reliable representation of the natural environment and are used to measure the anthropogenic stressors in freshwater ecosystems (Fausch et al., 1990; Wolter et al., 2000; Meador and Goldstein, 2003; Maloney et al., 2022). Consequently, there is a need for better management of freshwater fisheries to ensure the long-term health of these ecosystems and the species that depend on them (Allan et al., 2005; Cooke et al., 2016). Therefore, evaluations of fish communities aid in managing freshwater fisheries (Allan et al., 2005).

Fishers' catch data are important because of their inherent scientific value and usefulness and are essential for fisheries research and management (Bradley et al., 2019). Fish capture measurements, such as species composition, abundance, size class, and body mass, shed light on the state, dynamics, and sustainability of fish populations (Jacquet et al., 2010; Robin et al., 2010; Bona et al., 2016; Gebremedhin et al., 2021).

It is essential to analyse the impact of fishing activities, assess the health of fish stocks, and provide information for evidence-based decision-making to ensure the long-term survival of fisheries resources (Robin et al., 2010; Jacquet et al., 2010; Allan et al., 2005; Cooke et al.,

2016). It was estimated that all large South African impoundments have a production potential of ~15,000 tons of fish per year (Britz et al., 2015); however, this is significantly lower than the annual yield of ~600,000 tons from marine fisheries (Pauly and Zeller, 2016). This indicates that developing large-scale or commercial fisheries in the inland waters of South Africa would not be productive or economically viable compared with marine fisheries (Harrison, 2002; Bene and Heck, 2005; Weyl et al., 2010). In the case of Pongolapoort Dam, an assessment of fish catch was conducted in 1989, and instead of assessing individual fish species, all species were combined to estimate a yield of 7.5 t yr⁻¹ (Britz et al., 2015). In the North West Province, it was found that the potential annual yield in tons for ten dams supported up to 484 full-time subsistence fishers where the average fish price of R6/kg and the minimum rural wage of R10,440 p.a. were a benchmark for determining the total value of the fish and potential employment opportunities (Weyl et al., 2007).

Although recreational fisheries are well established in KwaZulu-Natal, there is little evaluation of how impoundments support these fisheries (Potts et al., 2022). Seasonality also plays a role in the use of fisheries in the region, as many indigenous fish show seasonal movements and activity patterns (Burnett et al., 2021; Evans et al., 2022). Our study aimed to evaluate the present and potential fisheries associated with two impoundments of varying sizes near peri-urban settlements in KwaZulu-Natal. We predicted that the native *L. natalensis* would be an important component in these inland fisheries because of their relatively high abundance across KwaZulu-Natal (Evans et al., 2022). We also predicted a high percentage of non-native species based on the present recreational fisheries directed at common carp *Cyprinus carpio* and largemouth bass *Micropterus salmoides*. We hoped these findings would underscore the critical importance of sustainable management practices in ensuring the long-term economic viability of fisheries in the region.

4.3 Methods

4.3.1 Questionnaires

We first obtained ethical clearance from the University of KwaZulu-Natal Humanities Ethics Committee (HSSREC/00003175/2021) to collect data using a questionnaire (Supplementary information Table S3.1, Chapter 3). We used the questionnaire to interview fishers from March 2021 until October 2023 in the uMngeni catchments in KwaZulu-Natal, South Africa. The sites for conducting questionnaires included communities near and around selected dams, Midmar Dam and Henley Dam (Fig. 4.1). Some of the questions were used in a corollary study examining the importance of the river for cultural and domestic reasons, and the importance of eels (Nkomo, 2023).

Following guidelines from the ethical clearance, we only interviewed fishers above the age of 18. Each fisher first had to confirm if they would be interviewed since it was voluntary, and they were informed they could withdraw at any stage. We clarified to the participants what we were recording in the data sheets (time, date, location, and other questions, including their reasons for fishing) (Supplementary information Table S3.1, Chapter 3). If an individual did not want to participate, they were exempted. Each interview was ~15 min. We approached people who were fishing or had a fishing rod with them along the dams. Ezemvelo KwaZulu-Natal Wildlife, based at Midmar Dam, near the town of Howick, kindly assisted with contacts of local fishers to interview them around Midmar Dam, including the Mpophomeni local township.

4.3.2 Study sites for ecological surveys

We selected two impoundments similar in proximity to urban communities, Midmar Dam (29.5131° S, 30.1819° E), near Howick, and Henley Dam (29.629452° S, 30.24432° E), near Pietermaritzburg, KwaZulu-Natal, South Africa (Fig. 4.1). Midmar Dam (~1788 ha surface

area) was selected because it is a large impoundment in the Ezemvelo KZN Wildlife protected area with popular recreational fisheries. It was built in Howick to supply water to Pietermaritzburg and, during drought years, has reduced water levels (Zondi, 2015). Midmar Dam has fishing regulations that fishers need to follow through an entry permit system. It does not encourage or discourage invasive species harvesting but protects native *L. natalensis*. While Henley Dam (~32.21 ha surface area) has little to no inland fisheries data, it lacks fishing regulations and lies in a peri-urban community easily accessible to subsistence fishers. The type of fisheries here is limited to rod and reel gear since the present inland water policies regard gillnets as an illegal fishing method (Britz et al., 2015; Tapela et al., 2015; Hara, 2022). Henley Dam was built in Henley Edendale but became too small to supply Pietermaritzburg with its water needs.

We conducted seasonal ecological surveys in the two impoundments. For Midmar Dam, surveys took place from the 25th to the 29th of August 2022 and the 26th of February to the 2nd of March 2023 for the low- and high-flow seasons, respectively. For Henley Dam, two seasonal surveys were conducted in June 2022 and February 2023, including low- and high-flow seasons, respectively, with each survey being a single overnight effort because of its small size.

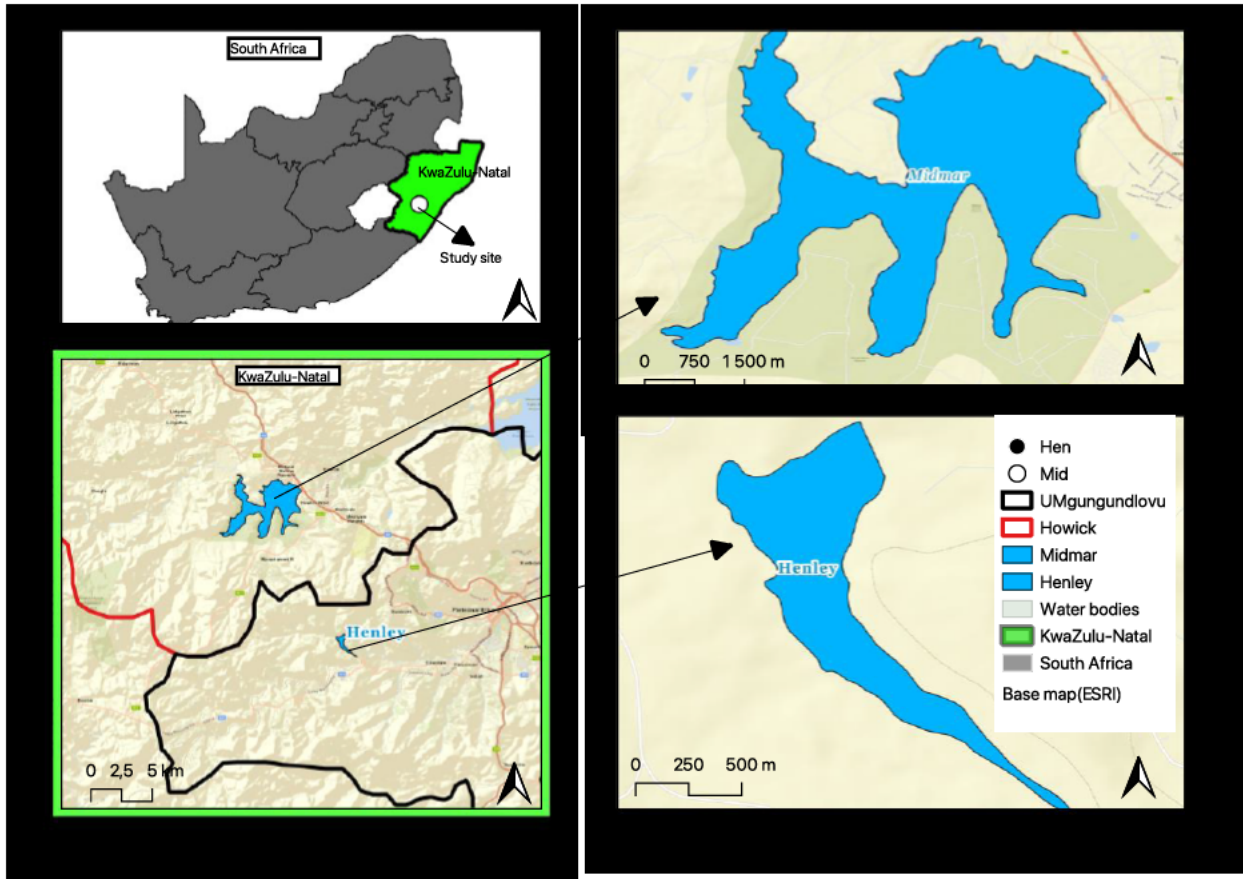


Figure 4.1: Study sites in the uMngeni River catchment in KwaZulu-Natal Province, South Africa, used in the present study.

4.3.2 Water and fish sampling

We used a water quality meter calibrated XS Instruments PC 5 Tester multiparameter tool (XS Instruments, Italy) to measure water quality parameters of the surface of the dams, such as temperature, turbidity, conductivity, and pH. We used a measuring tape with a weight in the end (2 kg) to accurately determine water depth during the surveys in Midmar Dam and Henley Dam. Water depth measurements were recorded at each deployment point for every net.

To assess the fish communities of both dams, our sampling methodology was informed by existing literature on inland fisheries research and recommendations for effective sampling techniques. To assess the fish communities of both dams, we used 32 m long gill

nets (Eigevis group of companies, Cape Town, South Africa) with various mesh sizes ranging from 60 to 150 mm when stretched. We combined two gill nets varying in mesh size (<45 mm), with a small mesh attached to a large mesh (>52 mm) to form a single 64 m long gill net for deployment. We used nine (32 m long joined in pairs) 64 m long gillnets and 11 fyke nets (including one large fyke net for Midmar Dam only) for both Midmar Dam and Henley Dam.

We conducted the fish surveys using two boats: a 40 hp engine-driven boat on Midmar Dam and a sneaker motor-driven inflatable boat on Henley Dam. These boats facilitated the deployment of all nets at different sites in the respective dams. We randomly divided Midmar Dam into eight survey sites to ensure comprehensive coverage of the entire reservoir. For each survey site, we deployed gill nets and fyke nets in the afternoon and retrieved them in the morning to assess the captured fish. Similar fishing methods and equipment were used during surveys to gather data on fish populations in Henley Dam. We processed and released captured fish where we caught them. We measured their body mass using a scale with a small bucket net that was tared before weighing each fish. All fish caught were identified to species level using Skelton (2001, 2016). We measured each fish's total and standard lengths using a custom-made half-cylinder tube measure before releasing it.

4.3.4 Data analyses

We calculated the mean water depth of Midmar Dam and Henley Dam, respectively, by dividing the lake volume by the surface area of the dam. We used the Morpho-Edaphic Index (MEI) (Ryder, 1965; Ryder et al., 1974) to calculate the potential fish yield for each dam, inputting the calculated mean depth and relevant water quality parameters. Following the study done by Weyl et al. (2007), we calculated the potential fish yield estimations using the Schlesinger and Regier (1982) model and the Marshall and Maes (1994) model for each dam.

The Schlesinger and Regier (1982) model considers temperature and total dissolved solids (TDS) as additional predictors of fish yield. It is a global, temperature-adapted model and may provide a broader perspective on the potential fish yield in dams (Ryder, 1965; Ryder et al., 1974) and acknowledges the influence of these factors (temperature and TDS) on fish productivity. For the present study, we used the Schlesinger and Regier (1982) global, temperature-adapted MEI model as follows:

$$\text{Log Yield (kg / ha} \cdot \text{yr)} = 0.044T + 0.482 \text{ Log MD} + 0.021$$

(Note: T is the temperature in degrees Celsius, TDS is the total dissolved solids in mg/L, MD is the mean depth of the reservoir in meters).

We also used the Marshall and Maes (1994) model, which focuses on the mean depth of the reservoir and mean conductivity as predictors of fish yield. The inclusion of conductivity recognises its potential impact on fish populations in African contexts (Ryder, 1965). The Marshall and Maes (1994) model was developed for African reservoirs according to the formula: $\text{Yield (kg/ha} \cdot \text{yr)} = 23.281 * \frac{\text{MD}^{0.447}}{\text{CON}}$

(Note: CON is the mean conductivity measured in $\mu\text{S}\cdot\text{m}^{-2}$, MD is the mean depth of the reservoir in meters).

Due to its consistent presence in our catch records during the low-flow seasons, particularly in deeper pools or dams during winter, we selected *Labeobarbus natalensis* as our focal species for further analysis. While other species may have healthy populations accessible year-round, our interest in managing *L. natalensis* stemmed from its ecological relevance in our dataset and its consistent occurrence during specific seasons. Unlike some other species, which may not be as prevalent during winter months, *L. natalensis* exhibited consistency in its presence across both Midmar Dam and Henley Dam. To compare the populations of *L. natalensis* between the two dams, we utilised a Kruskal-Wallis test.

We used descriptive statistics to summarise the trends. For comprehensive data analyses, we employed a blend of techniques, including R Studio, Excel©, and QGIS (<https://qgis.org/es/site/about/index.html>). Initially, R Studio served as the primary platform for data pre-processing, encompassing data importing and cleaning using various packages like tidyverse and ggplot2 (R Core Team, 2016; Wickham et al., 2022, 2023). This allowed for efficient data manipulation, visualisation, and statistical computations (e.g., frequency analysis), generating graphical representations such as bar plots and geographic maps. We used Excel for a variety of tasks, including data cleaning, descriptive analyses, and additional visualization using charting tools. Primarily, Excel was utilised to organise and arrange our data. It facilitated basic data checks and summary statistics that were complementary to those obtained using R Studio. We used QGIS, a geographic information system software, to conduct geospatial analyses. We integrated geographical location data with the fish species data, creating spatial visualisations to facilitate an understanding of fish species distribution across KwaZulu-Natal and aid in interpreting the regional dominance of native versus invasive species.

4.4 Results

4.4.1 Questionnaire fish data

For the questionnaire responses from fishers, our attention in this chapter was directed towards the feedback received concerning Midmar Dam and Henley Dam (Fig. 4.2). The responses revealed that *Cyprinus carpio* primarily dominated Midmar Dam, succeeded by *Micropterus* spp, *Clarius gariepinus*, cichlids, *L. natalensis*, and *Lepomis macrochirus*. On the other hand, respondents who fished around Henley Dam reported that they predominantly caught *Anguilliformes*, closely followed by cichlids (Fig. 4.2). The results further indicated

that in areas where the native *L. natalensis* is targeted, there was also a notable presence of invasive species such as *C. carpio*, *Micropterus* spp., and cichlids which were also targeted.

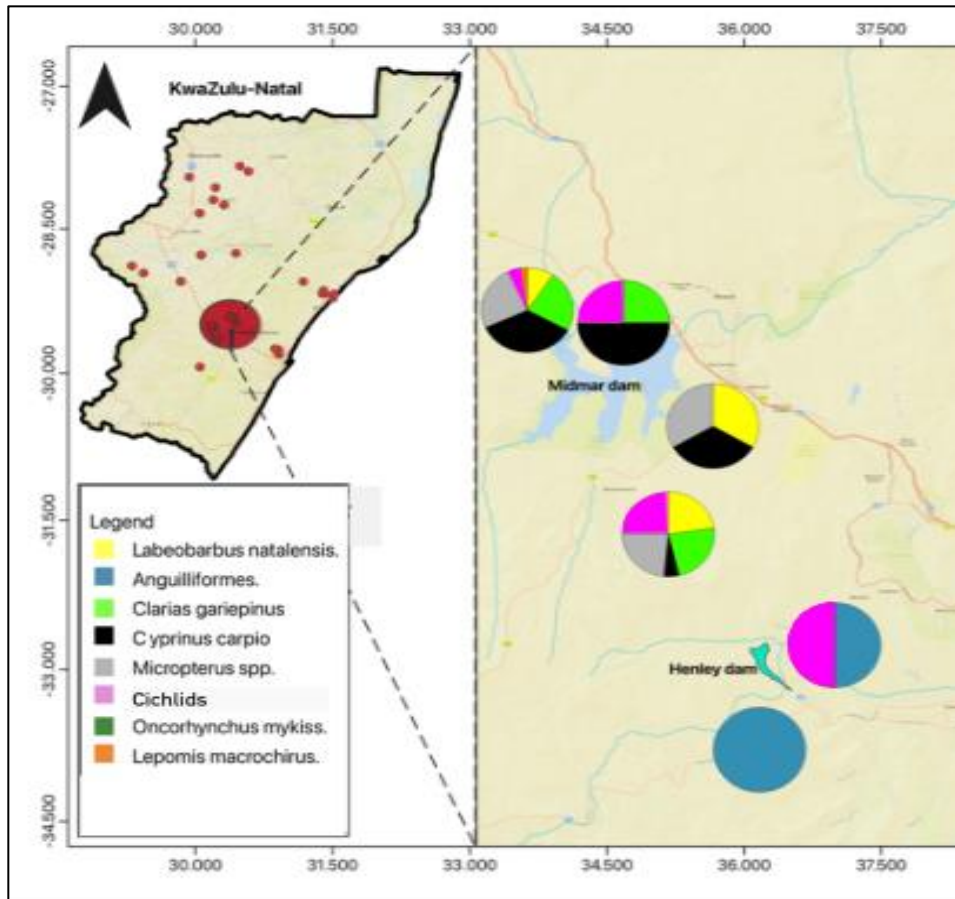


Figure 4.2: Fish species targeted by fishers around Midmar, Henley Dam and Albert Falls Dam in the present study.

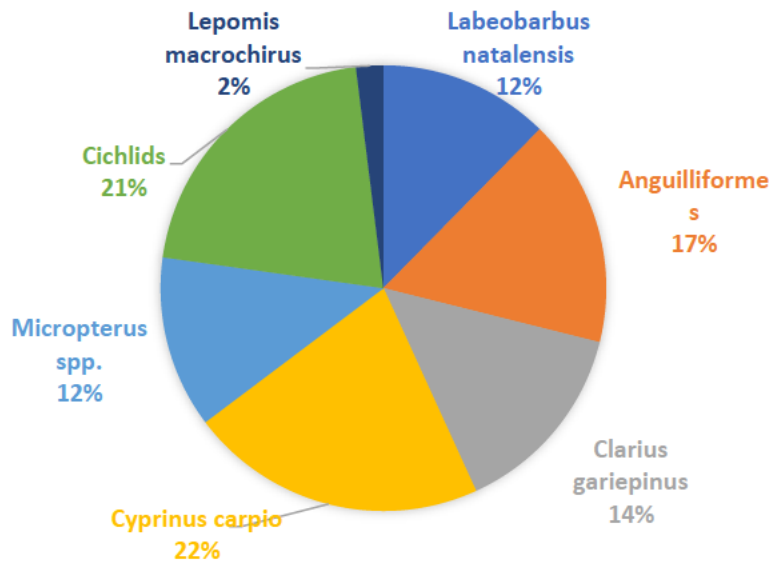


Figure 4.3: Fish species targeted in percentages across Midmar Dam, Albert Falls Dam and Henley Dam according to fishers' responses.

From the questionnaire responses (Fig. 4.2 and Fig. 4.3) from fishers, our attention in this chapter was directed towards the feedback received concerning Midmar Dam and Henley Dam. The fish species targeted showed a pattern indicating that invasive species generally outnumbered other fish species. Common carp *Cyprinus carpio* primarily dominated Midmar Dam, succeeded by black bass *Micropterus spp.*, sharptooth catfish *Clarius gariepinus*, cichlids, *L. natalensis*, and bluegill *Lepomis macrochirus*. From the questionnaire responses (Fig. 4.2 and Fig. 4.3), the fish species targeted by fishers indicated a preference for invasive species generally outnumbering targeted native species (i.e., *C. carpio*, was the highest, 22%). Species of fish preferred by fisher respondents were detected in our ecological survey; however, not in the same relative abundances, i.e., *C. carpio* was the most abundant targeted fish from fisher respondents, and *L. natalensis* was the most abundant caught species in the ecological assessment.

Table 4.1: Fish caught in Midmar Dam and Henley Dam in the present study in 2022 and 2023.

Latin names	Common names	Abbreviation	Native / invasive	Midmar Dam	Henley Dam
<i>Labeobarbus natalensis</i>	KwaZulu-Natal yellow fish	Lnat	Native	160	15
<i>Micropterus salmoides</i>	Largemouth bass	Msal	Invasive	71	0
<i>Clarias gariepinus</i>	African sharptooth catfish	Cgar	Native	44	0
<i>Oreochromis mossambicus</i>	Mozambique tilapia	Omos	Native	25	3
<i>Cyprinus carpio</i>	Common carp	Ccar	Invasive	12	0
<i>Lepomis macrochirus</i>	Bluegill	Lmac	Invasive	8	1
			Total	320	19

4.4.2 Ecological assessment

During the ecological surveys of Midmar Dam and Henley Dam, a cumulative number of 339 fish were caught across the study. However, only six species were caught (three native and three invasive species, Table 4.1). Out of the 51 freshwater fish species expected in KwaZulu-Natal (Supplementary information Table S4.1), our data only revealed six fish species (17.8%) (ecological survey and the questionnaires surveys) were present (Table 4.1 and Fig. 4.1).

In terms of body mass, *L. natalensis* had a higher cumulative body mass of 139890 g (mean 865.62 g, range 30 g and 270 g, Table 4.2) compared with the other fish species caught at Midmar Dam. *Clarias gariepinus* had the second-highest cumulative body mass of 5500 g (1587.39 g, range 11 g to 2600 g, Table 4.2). *Micropterus salmoides* was the third highest with a cumulative body mass of 4140 g (mean 348.3 g, range 10 g to 2759 g). Of all the fish caught, the mean (\pm SD) body mass of fish caught at Midmar Dam was 917.3 ± 895.54 g

(high flow season) and 289.4 ± 116.66 g (low flow season) ($n = 151$). The cumulative body mass of all fish caught at Midmar Dam amounted to 155116 g, higher than Henley Dam's 8200 g (Table 4.3). At Henley Dam, fish were only caught during the low flow season; *L. natalensis* had a cumulative body mass of 4250 g (mean 283.3 g, range 35 g to 880 g). *Oreochromis mossambicus* had a cumulative body mass of 3830 g (mean 1276.6 g, range 230 g to 2100 g, Table 4.3). The mean (\pm SD) body mass of fish caught at Henley Dam was 431.6 ± 548.46 g ($n = 19$). The body mass of *L. natalensis* was significantly higher at Midmar Dam than at Henley Dam (Kruskal-Wallis chi-squared = 5.9005, $df = 1$, $p = 0.01514$).

Table 4.2: Summary of the morphometrics of fish species caught in Midmar Dam for potential yield estimation in the present study. (Note BM = body mass, SL = standard length).

Species	Midmar Dam																
	High flow								Low flow						Total		
	No.	Body mass (g) (mean \pm SD)	BM min	BM max	SL (mm) (Mean \pm SD)	SL min	SL max	No.	Body mass (g) (mean \pm SD)	BM min	BM max	SL (mm) (Mean \pm SD)	SL min	SL max	No.	Body mass (g)	
<i>L. natalensis</i>	-	-	-	-	-	-	-	160	865.6 \pm 769.05	30	2070	291.8 \pm 112.38	95	485	160	139890	
<i>C. gariepinus</i>	43	1587.4 \pm 815.39	11	2600	423.4 \pm 143.42	75	620	1	-	290	0	2900	-	570	570	44	5500
<i>O. mossambicus</i>	22	1174.5 \pm 467.97	100	1675	271.4 \pm 59.12	135	340	-	-	139	-	-	-	-	-	22	1675
<i>M. salmoides</i>	67	348.26 \pm 585.60	10	2750	162.7 \pm 84.74	70	400	1	-	0	1390	-	390	390	68	4140	
<i>C. carpio</i>	17	1237.5 \pm 1099.30	11	3800	276.4 \pm 111.51	75	490	-	-	-	-	-	0	0	17	3800	
<i>L. macrochirus</i>	2	21 \pm 0	21	21	125 \pm 0	125	125	4	46.3 \pm 30.92	20	90	98.75 \pm 27.80	70	125	6	111	
Total	151	917.3 \pm 895.54	10	3800	265.1 \pm 151.26	70	620	166	861.3 \pm 782.91	20	2900	289.4 \pm 116.66	70	570	317	155116	

Table 4.3: Summary of the morphometrics of fish species caught in Henley Dam for potential yield estimation in the present study. (Note BM = body mass, SL = standard length).

Species	Henley Dam															
	High flow							Low flow							Total	
	Number	Body Mass (g) (mean + SD)	BM min	BM max	SL (mm) (Mean + SD)	SL min	SL max	Number	Body mass (g) (mean + SD)	BM min	BM max	SL (mm) (Mean + SD)	SL min	SL max	Number	Body mass (g)
<i>L. natalensis</i>	-	-	-	-	-	-	15	283.3 ± 270.20	35	880	165.1 ± 70.16	71	300	15	4250	
<i>C.s gariepinus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	
<i>O. mossambicus</i>	-	-	-	-	-	-	3	1276.7 ± 954.79	230	2100	243.3 ± 50.33	190	290	3	3830	
<i>M. salmoides</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>C. carpio</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>L. macrochirus</i>	-	-	-	-	-	-	1	-	120	120	-	71	71	1	120	
Total	-	-	-	-	-	-	19	431.6 ± 548.46	35	2100	172.5 ± 74.59	71	300	19	8200	

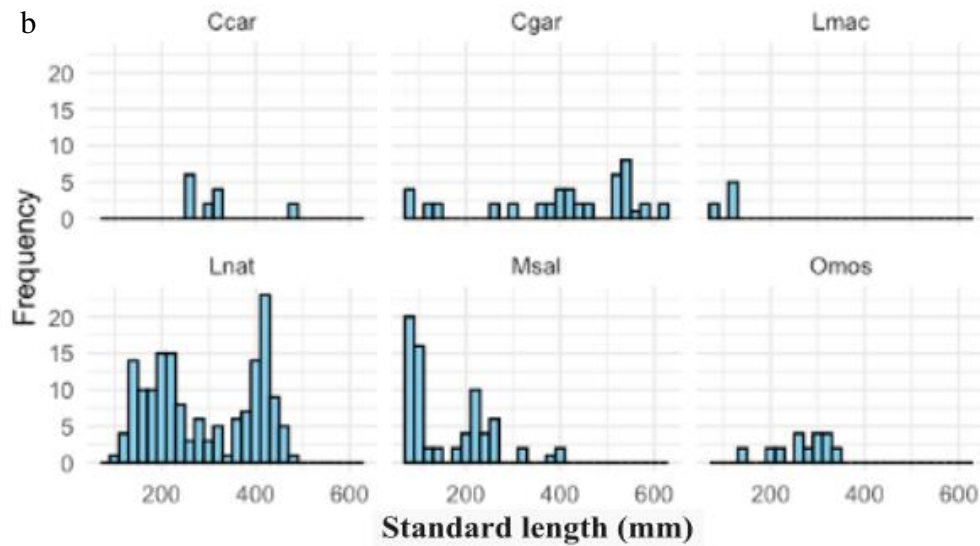
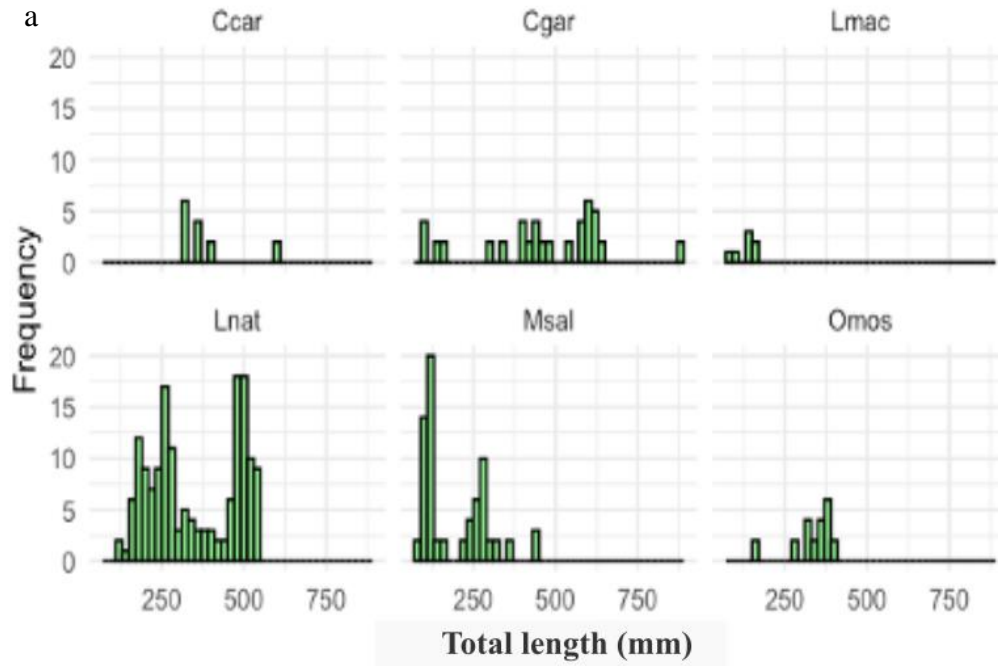


Figure 4.4: Frequency of size classes of the respective fish species according to standard length (a) and total length (b) caught at Midmar Dam in the present study. (Note: See Table 4.1 for species abbreviations).

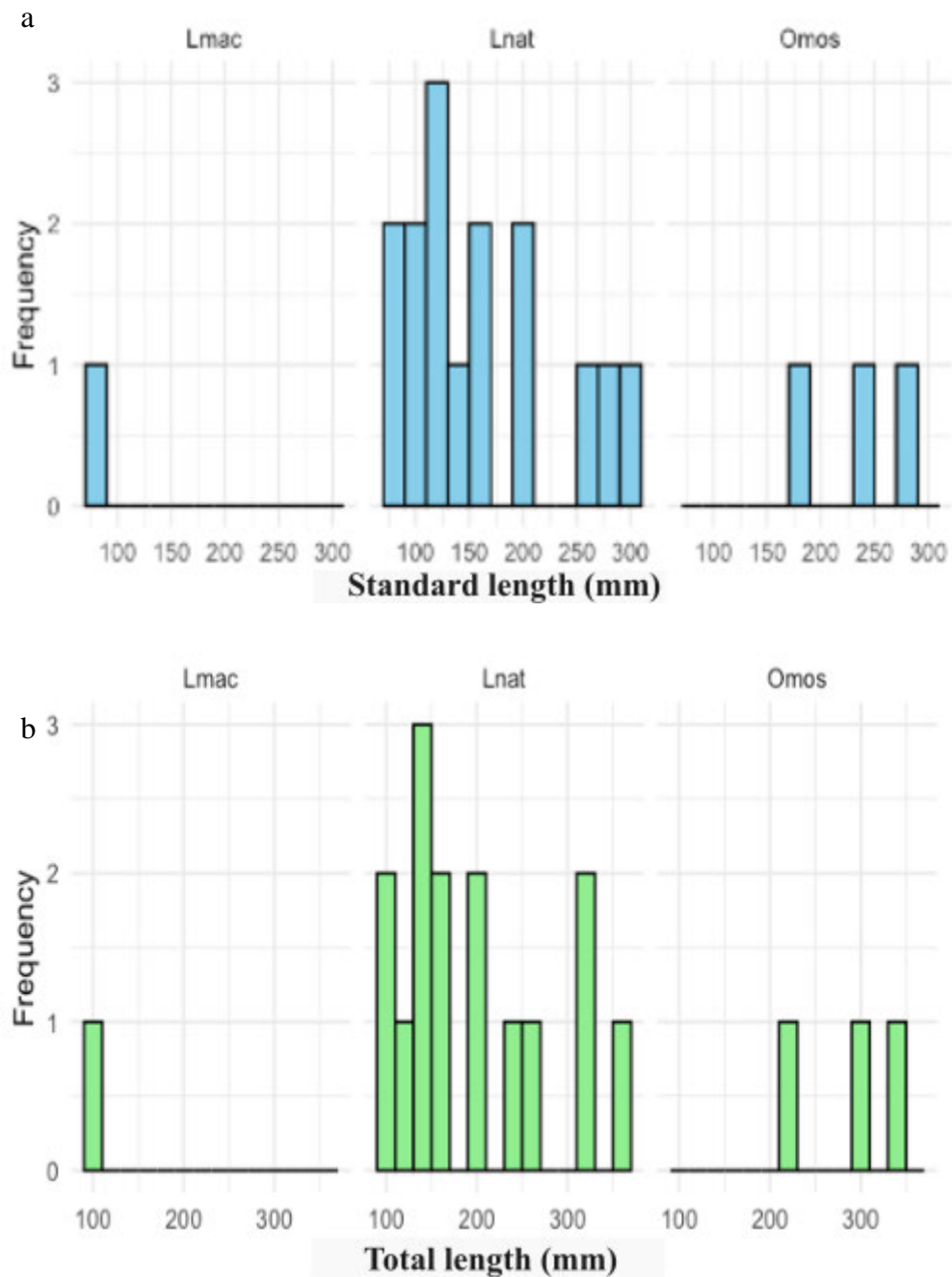


Figure 4.5: Frequency of size classes of the respective fish species according to standard length (a) and total length (b) caught at Henley Dam in the present study. (See Table 4.1 for species abbreviations).

The total length size classes of *L. natalensis* in Midmar Dam dominated the 250-500 mm size classes, followed by *C. gariepinus* (Fig. 4.4). *Clarias gariepinus* was the only fish

species caught that was over 750 mm in length in Midmar Dam. Most other fish species (*L. macrochirus*, *M. salmoides*, and *O. mossambicus*) were only found in the size classes below 500 mm (Fig. 4.4). Similarly, at Henley Dam, *L. natalensis* was dominant in most size classes (Fig. 4.5). The *O. mossambicus* were dominant in a few size classes ranging from 190-230 mm, 250-310 mm, and 290-350 mm. Lastly, *L. macrochirus* dominated the size range of 71-90 mm (Fig. 4.5).

4.4.3 Water quality parameters

For Midmar Dam, which covers an area of 1788 ha, the mean (\pm SD) water depth (MD) was measured at 15.1 ± 5.94 m (Table 4.4). The total dissolved solids (TDS) in the water was 61.21 mg/L in high flow and 52.70 mg/l in low flow, and the mean (\pm SD) water temperature was 13.5 ± 1.13 °C in low flow and 24.7 ± 1.9 °C in high flow (Table 4.4). The mean (\pm SD) electrical conductivity was 72.1 ± 13.23 $\mu\text{S}\cdot\text{m}^{-2}$ in low flow and 83.2 ± 2.41 $\mu\text{S}\cdot\text{m}^{-2}$ in high flow. In contrast, Henley Dam, covering an area of 0.0219 ha, had a shallower mean water depth (MD) of 10.4 ± 2.87 m (Table 4.4). The TDS in Henley Dam was measured at 59.33 mg/l, and the mean water temperature was higher at 23.8 ± 0.28 °C in low flow compared with Midmar Dam (Table 4.4). The electrical conductivity in high flow at Henley Dam was 82.75 $\mu\text{S}\cdot\text{m}^{-2}$ (Table 4.4).

Table 4.4: Midmar Dam and Henley Dam water quality data obtained in the present study.

Dam	Flow	Mean water			
		temperature (surface) (°C)	Mean TDS (mg/l)	Mean depth (m)	Mean conductivity (µS·m-2)
Henley	Low flow	23.8	59.32	10.37	82.75
Henley	High flow	25.3	60.12	10.37	84.56
Midmar	High flow	24.7	61.21	15.53	83.17
Midmar	Low flow	13.5	52.70	15.53	72.07

4.4.4 Catch per unit effort (CPUE)

The mean catch per unit effort for gill nets and fyke nets for both Midmar Dam and Henley Dam are shown in Table 4.5. There was no significant difference between the CPUE means for both dams (Kruskal-Wallis chi-squared = 1, df = 1, p-value = 0.3173).

Table 4.5: Comparative analysis of catch per unit effort (CPUE) between fishing methods at Henley Dam and Midmar Dam in the present study for all captured fish species.

Dam	Method	Mean CPUE (kg/net/time) HF	SD CPUE (kg/net/time) HF	Mean CPUE (kg/net/time) LF	SD CPUE (kg/net/time) LF
Henley Dam					
	Fyke	-	-	0	0
	Gill	-	-	0.2	0.3
Midmar Dam					
	Fyke	0	0.1	0	0
	Gill	0.2	0.6	0.1	0.3

4.4.5 Morpho-Edaphic Index (MEI)

The potential fish yield estimations based on the Schlesinger and Regier (1982) model and the Marshall and Maes (1994) model gave insights into the productivity of Midmar Dam and Henley Dam. According to the Schlesinger and Regier Model, the potential yield for Midmar Dam was calculated to be 0.926 g/net/night. In contrast, Henley Dam had a higher potential yield of 2.971 g/net/night (Table 4.6). According to Marshall and Maes (1994) model, Midmar Dam had a potential yield of 3.806 g/net/night, and Henley Dam was lower by 2.965 g/net/night.

Table 4.6: Potential yield estimate for Henley Dam and Midmar Dam in the present study for all captured fish species.

Parameter	Midmar Dam	Henley Dam
Surface (ha)	1788	0.0219
Mean depth (m)	15.0	10.4
Volume (m ³)	268 563 200	2 281
Mean water temperature (°C)	13.5	23.8
Mean TDS (mg/l)	52.7	59.32
Mean conductivity (µS·m ⁻²)	72.07	82.75
Schlesinger and Regier Model (g/net/night)	3.806	2.965
Marshall and Maes Model (g/net/night)	0.926	2.971

4.5 Discussion

Fishers' responses to our questionnaire showed that invasive fish species were found and targeted throughout KwaZulu-Natal in the various impoundments and associated rivers (Chapter 3, present study). *Cyprinus carpio* were found in the northern, central, and southern parts of the province. Other invasive fish species, *Micropterus* spp. were mostly in all the regions of central and southern KwaZulu-Natal. These species were introduced into South

African inland water for recreational fishing (Kimberg et al., 2014; Hargrove et al., 2015, 2017). They appear to outnumber native species, according to the fishers. The prevalence of invasive species highlights their potential threats to local ecosystems, such as competition with native species, change of habitat architecture, and disruption of ecological balances, as found in other studies (Kimberg et al., 2014; Hargrove et al., 2015).

Fishers reported that for Midmar Dam and Henley Dam, a mix of native and invasive fish species were targeted, e.g., *C. carpio* and *L. natalensis*. *Labeobarbus natalensis*, native to the KwaZulu-Natal region, was targeted primarily at Midmar Dam along with *C. carpio* and *Micropterus* spp. This was surprising as only anguillid species and cichlids were targeted at Henley Dam despite the presence of *L. natalensis*. This is surprising as *C. carpio* is a commonly targeted species across the uMngeni and uThukela catchments (Chapter 3).

Similarly, our ecological fish surveys focussing on Midmar Dam and Henley Dam showed a mix of native and invasive fish species, with six total fish species present. The native *L. natalensis* was the dominant fish species in these two impoundments, followed by an invasive species, *M. salmoides*. In KwaZulu-Natal, *M. salmoides* is present in these impoundments with *L. natalensis*, but unlike *L. natalensis*, it was present in all seasons and relatively easier to catch with a rod and line (Hargrove et al., 2015, 2017; Evans et al., 2022).. The equal representation of native and invasive species, with three of each, underscores potential competition and ecological challenges in Midmar Dam and Henley Dam.

KwaZulu-Natal Province has a significant absence of available data on fish-catch assessments. Despite having 19 government-recognised dams (Table 4.7), comprehensive information is lacking. The intricate and pivotal interplay between small dams and their associated riverine ecosystems plays a critical role in the sustenance of local communities and is of particular concern (Mantel et al., 2017).

Table 4.7: A summary list of the 19 KwaZulu-Natal Provincial dams and associated rivers in 2023. (Source: www.dws.gov.za)

Dam	River
Albert Falls Dam	Mgeni River
Bivane Dam	Bivane River
Craigie Burn Dam	Mnyamvubu River
Driel Barrage Dam	Tugela River
Goedertrouw Dam	Mhlatuze River
Hazelmere Dam	Mdloti River
Hluhluwe Dam	Hluhluwe River
Inanda Dam	Mgeni River
Klipfontein Dam	Wit Mfolozi River
Mearns Dam	Mooi River
Midmar Dam	Mgeni River
Nagle Dam	Mgeni River
Ntshingwayo Dam	Ngagane River
Pongolapoort Dam	Phongolo River
Spioenkop Dam	Tugela River
Spring Grove Dam	Mooi River
Wagendrift Dam	Boesmans River
Woodstock Dam	Tugela River
Zaaihoek Dam	Slang River

As a result, this study emphasises the critical need for expanded research efforts and thorough inland fishery assessments for smaller impoundments like Henley Dam and the role they have in subsistence fisheries. Such studies are critical in understanding the nuanced contribution of inland fisheries to the livelihoods of KwaZulu-Natal's people, especially rural communities around small impoundments and rivers. Furthermore, advocacy for conservation strategies for protected species and now threatened fishes is becoming increasingly important,

particularly considering the multifaceted effects of small dams and invasive species on freshwater ecosystems.

In terms of fish species for potential yield estimation in Midmar Dam and Henley Dam, the native *L. natalensis* had the greatest cumulative body mass, suggesting that it may play a significant role in the ecosystem by contributing biomass. We suspect that *C. carpio* was under-sampled based on fishing technique; this is similar for the other species, i.e. *Micropterus* spp. and *C. gariepinus* (Allan et al., 2005). In Henley Dam, *L. natalensis* dominated all the fish size classes, indicating a healthier, smaller population than at Midmar Dam, according to their body mass to standard length ratio. Similarly, the fish size classes at Midmar Dam showed the most common species in the 250–500 mm size classes was *L. natalensis*, indicating its presence in various size classes. The second most common species at Midmar Dam in these size classes was the invasive *C. carpio*. This was the only species longer than 750 mm, indicating its uniqueness in longer length size class categories, suggesting that this species occupies a unique ecological niche within the dam, potentially indicating its role as a top predator or a species with specific habitat requirements. Other species, *L. macrochirus*, *M. salmoides*, and *O. mossambicus* were only in the smaller size classes below 500 mm in length, showing that they are more common in smaller size ranges in Midmar Dam. This was expected for *L. macrochirus* as this is not a large growing species (<10 cm). While *O. mossambicus* typically falls within smaller size classes below 500 mm in length, it's important to note that they may not commonly reach lengths above this threshold in Midmar Dam. Because *O. mossambicus* is known to grow larger in warmer regions, the specific conditions of Midmar Dam, including its milder water temperatures, may limit the growth potential of this species (Brits et al., 2015). Therefore, it's possible that *O. mossambicus* in Midmar Dam primarily have smaller size ranges, as observed in this study. Further research may be needed to confirm the upper obtainable size limits of *O. mossambicus*

and growth rates for Midmar Dam (Brits et al., 2015). *Micropterus salmoides* dominating in the smaller size class could be an indication of angling pressure. Harvesting larger individuals can result in a greater number of smaller individuals (Schramm et al., 2012).

Fish species caught in each dam provided additional insights into their contributions to the overall potential yield. In Midmar Dam, six fish species (three native and three invasive) caught gave a cumulative fish body mass of 155.116 kg, with *L. natalensis* exhibiting the highest individual contribution. In contrast, in the relatively small Henley Dam, three fish species (two native and one invasive) caught gave a cumulative fish body mass of 8.2 kg, with *L. natalensis* again contributing significantly. These results indicate the importance of native fish species like *L. natalensis* in each dam and their potential impact on local fisheries, as found in other studies (Lynch et al., 2016; Burnett et al., 2021, 2023).

The higher CPUE for gill nets in both Midmar Dam and Henley Dam than fyke nets suggests that gill nets are more effective in capturing fish. The CPUE at Midmar Dam suggests that fishing efforts were more productive during the low flow season, possibly because of several factors, including increased fish concentrations in certain areas of the dam. These conditions may have facilitated the effectiveness of the fishing gear used, leading to a higher capture rate. The decline in CPUE during the low flow season at Midmar Dam could be attributed to changes in fish behaviour and distribution in response to the decrease in water temperature (Wright and Coke, 1975a; b). The movement of fish during high flow conditions might make them less susceptible to capture by the fishing gear used, resulting in a lower CPUE as in other studies (Wright and Coke, 1975a; 1975b; Karssing, 2007).

Considering the potential yield estimation models, Henley Dam appears to have a higher productivity potential than Midmar Dam, according to the Schlesinger and Regier (1982) model, despite its smaller size. This result may be attributed to the location of Henley Dam within a rural/township community, potentially benefiting from less intensive

management practices compared with the reserve-like conditions of Midmar Dam. Henley Dam, being smaller, is more susceptible to water pollution events and changes in water quality, particularly TDS, which is used in the Schlesinger and Regier (1982) model. Midmar TDS value was low compared with Henley Dam during both seasons, while EC readings were relatively similar and explained similar results for the Marshall and Maes (1994) model. These models are guidelines and should be considered alongside other factors, for example, fish species and fishing gears (Weyl et al., 2007).

The higher total dissolved solids (TDS) levels observed in Henley Dam compared with Midmar Dam may be attributed to the geographical placement of Henley Dam within a community that extensively utilises the water upstream. Variations in water quality in each dam during the low flow season could influence fish movement and feeding patterns (Bash et al., 2001; Portz et al., 2006; Olson and Hawkins, 2017; Mohseni-Bandpei et al., 2018). For instance, differences in electrical conductivity and total dissolved solids may affect fish osmoregulation and influence their habitat preferences (Bash et al., 2001; Portz et al., 2006; Olson and Hawkins, 2017). Similarly, variations in water temperature can influence fish metabolic rates, impacting their energy expenditure and feeding activity (Bash et al., 2001; Portz et al., 2006; Olson and Hawkins, 2017). Notably, no fish were captured during the high-flow summer season in Henley Dam. This absence may suggest a fish behaviour or distribution shift in response to changing environmental conditions during this period. Factors contributing to the absence of fish could include alterations in water velocity resulting from changes to their habitat because of anthropogenic or natural processes (Scanes, 2018). The significant differences in water quality parameters between Midmar Dam and Henley Dam show substantial implications for the composition and productivity of fish species in each ecosystem, as seen with the MEI indices. Feng et al. (2023) showed how elevated temperatures, which accelerate fish metabolic rates, might enhance growth but also lead to

smaller-sized fish. Conversely, lower temperatures may impose limitations on food intake, potentially resulting in unfavourable growth patterns (Feng et al., 2023). The larger size, deeper water, and lower temperature of Midmar Dam likely created a more favourable environment for certain fish species, leading to a higher potential yield than the smaller and warmer Henley Dam. The potential yield estimations also further support this observation, indicating that Midmar Dam can potentially support a higher fish yield per ha than Henley Dam when considering Marshall and Mae's (1994) model.

4.5.1 Conclusions

Our study underscored the significance of indigenous fish species, notably the KwaZulu-Natal yellowfish *L. natalensis*, in impoundments and their associated rivers across KwaZulu-Natal, but especially in the two impoundments we focused our ecological study. The dominance of specific size classes in each dam and season provides valuable insights into fish populations' age structures and responses to changing environmental conditions. However, invasive species, like largemouth bass *M. salmoides*, in dams pose potential challenges to the freshwater ecosystem's balance and the sustainability of local fisheries. This likelihood of competition raises the possibility of a conflict between local native fish species and invading fish species over resources or habitat (Kimberg et al., 2014; Hargrove et al., 2015; Evans et al., 2022). There is a necessity for all-encompassing approaches to control and lessen the effects of invasive species on native biodiversity in KwaZulu-Natal's aquatic habitats.

Our findings also underscored the need for tailored fisheries management strategies that consider the unique environmental characteristics of each dam, the age structures of fish populations, and associated fisher groups. Understanding the complexities of fish productivity and species composition is essential for developing sustainable management practices that preserve aquatic resources, support local livelihoods, and protect vulnerable communities that

rely on subsistence fishing. By incorporating water quality data, CPUE results, and responses from fishers' in fisheries management, decision-makers can make science-based and effective choices to ensure the long-term viability of fish populations in dams and promote the overall health of these freshwater ecosystems across KwaZulu-Natal. The successful conservation and sustainable management of fish populations in these dams rely on carefully considering water quality parameters and their influence on fish productivity and overall ecosystem health.

4.6 Acknowledgements

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4.8 Supplementary information

Supplementary information Table S4.1. The expected freshwater fish species in KwaZulu-

Natal (Source: <https://freshwaterbiodiversity.org>)

Species	Common Name	Native or Exotic
<i>Ambassis natalensis</i>	Glass perch	Native
<i>Amphilius natalensis</i>	Natal mountain catfish	Native
<i>Amphilius uranoscopus</i>	Variable mountain catfish	Native
<i>Anguilla marmorata</i>	Giant mottled eel	Native
<i>Anguilla mossambica</i>	African longfin eel	Native
<i>Brycinus lateralis</i>	African tigerfish	Native
<i>Carassius auratus</i>	Goldfish	Exotic
<i>Chiloglanis anoterus</i>	Hillstream dwarf sucker	Native
<i>Chiloglanis swierstrai</i>	Mountain catfish	Native
<i>Clarias gariepinus</i>	African sharptooth catfish	Native
<i>Clarias theodora</i>	Malagarasi catfish	Native
<i>Coptodon rendalli</i>	Banded tilapia	Native
<i>Ctenopoma multispil</i>	Ornate ctenopoma	Native
<i>Cyprinus carpio</i>	Common carp	Exotic
<i>Engraulicypris brevianalis</i>	Shortfin minnow	Native
<i>Enteromius annectens</i>	Zambian barb	Native
<i>Enteromius anoplus</i>	Highland barb	Native
<i>Enteromius argenteus</i>	Silver barb	Native
<i>Enteromius eutaenia</i>	Congo barb	Native
<i>Enteromius gurneyi</i>	Straightfin barb	Native
<i>Enteromius lineomaculatus</i>	Lined barb	Native
<i>Enteromius neefi</i>	Neef's barb	Native
<i>Enteromius paludinosus</i>	Swamp barb	Native
<i>Enteromius toppini</i>	Toppi's barb	Native
<i>Enteromius trimaculatus</i>	Threespot barb	Native
<i>Enteromius unitaeniatus</i>	One-stripe barb	Native
<i>Enteromius viviparus</i>	Gambia barb	Native
<i>Gambusia affinis</i>	Western mosquitofish	Exotic
<i>Glossogobius callidus</i>	Marbled sleeper goby	Native
<i>Labeo cylindricus</i>	Nembwe	Native
<i>Labeo molybdinus</i>	Nkhotakota labeo	Native
<i>Labeo rosae</i>	Rose labeo	Native
<i>Labeo rubromaculatus</i>	Redspot labeo	Native
<i>Labeobarbus marequensis</i>	Orange River labeo	Native
<i>Labeobarbus natalensis</i>	Natal yellowfish	Native

<i>Labeobarbus polylepis</i>	Natal yellowfish	Native
<i>Lacustricola katangae</i>	Katanga lampeye	Native
<i>Lacustricola myaposae</i>	Myapo lampeye	Native
<i>Lepomis macrochirus</i>	Bluegill sunfish	Native
<i>Marcusenius caudisquamatus</i>	Saddled elephantfish	Native
<i>Megalops cyprinoides</i>	Indo-Pacific tarpon	Native
<i>Oreochromis aureus</i>	Blue tilapia	Exotic
<i>Oreochromis mossambicus</i>	Mozambique tilapia	Native
<i>Oreochromis niloticus</i>	Nile tilapia	Native
<i>Poecilia reticulata</i>	Guppy	Exotic
<i>Pseudobarbus afer</i>	Clanwilliam yellowfish	Native
<i>Pseudobarbus trevelyani</i>	Trevelyan's yellowfish	Native
<i>Pseudocrenilabrus philander</i>	Northern mouthbrooder	Native
<i>Pterygoplichthys disjunctivus</i>	Vermiculated sailfin catfish	Exotic
<i>Tilapia sparrmanii</i>	Banded tilapia	Native
<i>Xiphophorus helleri</i>	Swordtail	Exotic

Chapter 5

General discussion and conclusions

5.1 Background

Freshwater fisheries in South Africa are largely overlooked and understudied despite their economic importance to fishers, especially subsistence fishers (McCafferty et al. 2012; Chapter 1). In addition, fisheries are essential to vulnerable communities as a source of protein or income. Little is known about the potential for rivers and impoundments to support subsistent fisheries and the resilience of indigenous species impacted by invasive alien species. Native yellowfish *Labeobarbus natalensis*, catfish *Clarias gariepinus* and tilapia Cichlidae are socio-economically important fish species harvested by subsistence fishers and targeted by recreational anglers (Welcomme et al. 2010; Funge-Smith and Bennett 2019; Potts et al. 2022). Research on subsistence fisheries in South Africa has primarily focused on coastal and marine environments, leaving a significant gap in understanding inland fisheries, especially in terms of fishery output and participation (Kalina et al., 2019; Weyl et al., 2021; Nyboer et al., 2022).

The main aim of this study was to address the paucity of knowledge about economically and biologically important indigenous fish species that support inland fisheries in KwaZulu-Natal. The composition and contribution of native and invasive fish species and their offtake by fishers were assessed. Fishers across the uThukela and uMngeni catchments were interviewed using in-person questionnaires. In addition, assessment of fish communities and population structures in Midmar Dam and Henley Dam, two selected dams on the uMngeni River, coupled with questionnaire data, were used to determine the offtake trends by fishers (subsistence and recreational). These will contribute to a potential subsistence

fisheries management plan for these dams based on the findings to guide the development of the provincial and national inland fisheries plan.

5.2 Summary of findings

The systematic review (Chapter 2) indicates a clear disparity in publications on subsistence inland fisheries, emphasising the need for further research to inform comprehensive policies and practices that benefit both the environment and local communities engaged in this often-overlooked aspect (McCafferty et al., 2012). KwaZulu-Natal, the second most populous province in South Africa, faces ecological challenges such as habitat loss and freshwater stressors due to anthropogenic activities (Jewitt et al., 2015; Evans et al., 2022).

The construction of dams has disrupted local ecosystems, leading to the collapse of fisheries and food security issues (Mngomezulu, 2017; Brown et al., 2018). Droughts and poor management exacerbate the situation, threatening downstream fisheries (Napier et al., 2005; Mann et al., 2021; Weyl et al., 2007). Despite attempts by conservation organisations to co-manage fisheries and include subsistence fishers, some communities resist these efforts, highlighting the importance of striking a balance between conservation and the socio-economic needs of local communities in managing inland fisheries (Sayer et al., 2018; Mann et al., 2021).

5.2.1 State of Inland fisheries in Africa and how they are categorised

Inland fisheries are crucial for livelihoods in Africa, playing a vital role in food security and economic development (Chapter 2). However, they confront formidable challenges, including climate change, overfishing, illegal practices, and weak governance (Weyl et al., 2011; Abate et al., 2015; Weyl and Ellender, 2016; Weyl and Nagelkerke, 2016; Weyl and Tweddle, 2016).

West Africa's inland fisheries, while essential for millions, grapple with issues like overfishing and habitat destruction (Kashindye et al., 2020; Berté et al., 2015; Ogutu-Ohwayo et al., 2017). Successful co-management initiatives have demonstrated the potential to enhance fish stocks and improve livelihoods (Cochrane et al., 2016; Dube et al., 2016; Ogutu-Ohwayo et al., 2018). In East Africa, fisheries are pivotal for food security, yet challenges persist, including climate change and governance inadequacies. Meanwhile, southern Africa relies significantly on small-scale and commercial fisheries for sustenance and income, particularly in South Africa and Zimbabwe. Unfortunately, unsustainable practices and poor management have led to declining fish stocks, necessitating initiatives such as mesh size regulations (Weyl et al. 2011; Abate et al. 2015).

The significance of rivers, dams, and lakes for inland fisheries varies across regions (Chapter 2). Some prioritise rivers, while others rely on dams or lakes. Large dams impact river fisheries, but reservoirs can offer valuable fish habitat (Choudhury and Mearns, 2011; Funge-Smith and Bennett, 2019). According to available literature, inland fisheries are categorised into subsistence, recreational, small-scale, and commercial types (Chapter 2). Each faces distinct challenges, such as overfishing, pollution, and climate change (Weyl et al., 2011; Funge-Smith and Bennett, 2019).

The interconnection of subsistence, small-scale, and recreational fisheries underscores their reliance on inland fish resources (Welcomme and Cowx, 2006; Lorenzen et al., 2012). Sustainable management practices are deemed crucial for their viability, with potential synergies between different types of fisheries. Identified threats to African inland fisheries include overfishing, pollution, climate change, and habitat destruction (Kolding et al., 2018). Conservation efforts, however, encounter obstacles like inadequate funding, population growth, and urbanisation (Ficke et al., 2007; Jentoft et al., 2009; Marshal, 2015; Bhilave, 2018).

When examining KwaZulu-Natal in South Africa, literature shows that inland fisheries are grappling with sustainability challenges (Chapter 2, Næsje et al., 2009; James et al., 2012; Begg et al., 2013; Hecht and Kaiser, 2014; Moloi, 2012; Smith, 2020). Issues include limited knowledge of fish species, inadequate monitoring hindering effective management, impoundments, invasive species, overfishing, and the impact of climate change on fish populations (James et al. 2005; Evans et al. 2022). Consequently, comprehensive management strategies are required. The overarching call to action emphasises the need for further research, effective governance, and conservation measures to foster the continued development of fisheries and support livelihoods (Chapter 2).

5.2.2 Fishers responses

Inland fishing in South Africa presents a complex scenario, marked by challenges in categorising fishers and a limited distinction between recreational and subsistence fishers (Chapter 3; Weyl et al., 2015). The prevailing knowledge gap in self-identification excludes small-scale and commercial fishers, with only recreational and subsistence categories acknowledged by fishers (Chapter 3; Britz et al., 2015; Bhilave, 2018). This confusion stems from the post-Apartheid emergence of small-scale fishing, characterized by diverse ancillary activities and provincial-level access permissions for commercial fisheries (Britz et al., 2015). The impact of these policies is particularly significant for subsistence fishers, who primarily engage in inland fisheries to provide food for local communities yet may not qualify as 'small-scale fishers' under current regulations, affecting low-income recreational fishers reliant on fishing for nutrition (Hara et al., 2021; Nyboer et al., 2022).

The study also brought attention to the reluctance of 6.1% of fishers to disclose their motivations, reflecting distrust and potential bias that may contribute to mislabelling fishers in the recreational category (Chapter 3; Hara et al., 2021; Nyboer et al., 2022). This hesitation

hinders honest reporting and underscores the need for clear policies to facilitate rural fishers' understanding of inland fishing regulations, promoting transparency and equitable categorization (Hara et al., 2021; Nyboer et al., 2022).

Furthermore, the economic significance of various fish species, exemplified by pricing variations in the market, revealed *Cyprinus carpio* as the species commanding the highest value, 300ZAR (175 ZAR, average price) sold per individual, which was more valuable than the native *Labeobarbus natalensis*, which had a max selling price of 240 ZAR (150 ZAR, average price) per individual (Chapter 3). Interestingly, recreational fishers (mostly bass fishers) preferred fishing in dams, while subsistence fishers exhibited a pronounced inclination towards river fishing (Chapter 3). This observed difference in fishing environments highlighted the prevalence of fishing restrictions in most dams, typically located within reserves. The valuation of these invasive species creates a two-way scenario. For instance, in the case of *C. carpio*, fishers sell it at a higher price, indicating elevated market demand. Therefore, despite its invasive nature, fishers actively work to maintain its populations in balance due to their vested interest. On the flip side, the invasive *Micropterus* spp. find value among recreational fishers who prioritise species protection. This is because it contributes to bass tournaments organised by recreational fishers, fostering a belief in the conservation of this particular species (Chapter 3). A similar example is the construction of the Inchbrakie Weir in the Mooi River to protect *Salmo trutta* (an invasive species) from invasive species like *Micropterus* spp. (Burnett et al., 2023), showing how valuable these invasive fish species are to recreational fishers.

Navigating the complexities of managing inland water bodies involves multiple government departments, including the Department of Environmental Affairs, Department of Agriculture, Forestry, and Fisheries, and the Department of Sport and Recreation South Africa (Van Zyl, 2010; Department of Forestry, 2021). Recognising the challenges faced by

subsistence fishers, the study advocates for policy modifications to accommodate their unique needs, address potential misclassifications, and enhance fishers' comprehension of regulations (Chapter 3). A comprehensive approach that considers ecological, economic, and social aspects is crucial for sustainable inland fisheries management, ensuring the well-being of rural communities dependent on these resources (Chapter 3).

5.2.3 Fish assessment

Fishers responses to the questionnaire survey and the ecological survey revealed the pervasive presence of invasive fish species, particularly *C. carpio* and *Micropterus* spp., throughout the region of KwaZulu-Natal (Chapter 4). The fishers responses indicated that they predominantly catch invasive species (Chapter 3; Chapter 4). This observation was further corroborated by the findings of our ecological survey, wherein invasive species like *Micropterus salmoides*, which is part of the *Micropterus* spp. grouping, were observed as second to the most caught species (n = 71) to the native *L. natalensis* (n = 160) in both survey sites (Chapter 4). This showed that since the introduction of these invasive species in the early 1900s, they have successfully spread in all the surveyed catchments in KwaZulu-Natal (Chapter 3; Chapter 4; Kimberg et al., 2014; Hargrove et al., 2015, 2017). Despite the prevalence of invasive species, native fish species like the *L. natalensis* still persist in the KwaZulu-Natal. However, their dominance is challenged by invasive species, indicating potential competition for resources or habitat (Evans et al., 2022). Furthermore, the scarcity of available data on fish-catch assessments in KwaZulu-Natal's dams and rivers highlights a critical gap in knowledge. The lack of comprehensive information impedes effective fisheries management and conservation efforts, especially considering the crucial role of small dams in sustaining local communities.

The results of this study contribute to several of the 17 Sustainable Development Goals (SDG), set out by the United Nations (United Nations, 2015) and the African Union's Agenda 2063 (AU2063). The results contribute to SDG 14 (life below the surface) through the ecological components of the project on fish (SDG 14). Improving ecological knowledge of fish can guide the conservation of associated species. The increased threat to freshwater ecosystems globally and regionally (Tickner et al. 2020) requires a better understanding of fish biology and ecology, especially in Africa, where fish biology and ecology are lacking. The results also contribute to SDG 12 (responsible consumption and production) to guide decisions about the responsible harvest of fish. The results of the present study contribute to the AU2063 goal 5 (modern agriculture for increased productivity and production) to facilitate policy and technological advancements in the use of integrated models and decision tools that optimise the use of natural ecosystems in producing food to achieve sustainability. The fish consumption needs of the local communities are linked to AU2063 goal 3 (healthy and well-nourished citizens) and 7 (environmentally sustainable and climate resilient economies and communities). Understanding the production of harvestable fish and the ecological and social demand can guide practices that meet sustainability and align with the response of fish production in the face of climate change (SDG3 and AU2063 7). The results of the present study indirectly contribute to SDG 1 (no poverty) and 2 (zero hunger). Here, inland fisheries contribute to SDG 1, particularly because subsistence fishing is practised by the poorest of the poor and contributes significantly to reducing poverty by providing a basic income or food source (SDG 2). Fisheries provide food from the natural ecosystem for communities with access to this, and if practised sustainably, this can continue to be a resource for future generations. The findings from the study hope to demonstrate that cultural and recreational fishing practices, with some advancements, can be sustainable and that harmful fishing practices that are not culturally driven can be mitigated, which feeds into AU2063 11

(democratic values, practices, universal principles of human rights, justice and the rule of law entrenched) and 16 (African cultural renaissance is pre-eminent). There is a need to develop decision tools to facilitate a social compact within the community, to guide existing community regulatory structures, and to enforce sustainable practices, thus contributing to AU2063 11.

5.3 Recommendations and conclusions

To address these challenges, this study advocates for expanded research efforts and thorough inland fishery assessments, aligning with and complementing recent work by the late Professor Olaf Lawrence Fredrick Weyl (Chapter 3; Chapter 4; Weyl and Tweddle, 2016; Weyl et al., 2021). Such initiatives are vital for understanding the nuanced contributions of inland fisheries to local livelihoods and for advocating conservation strategies to mitigate the adverse effects of invasive species and ensure the sustainability of freshwater ecosystems (Chapter 4).

In conclusion, the findings underscore the necessity for tailored fisheries management strategies that consider the unique environmental characteristics of each dam and the structures of fish populations. By integrating water quality data, catch-per-unit-effort (CPUE) results, and insights from fishers, decision-makers can formulate science-based approaches to preserve fish populations, support local livelihoods, and safeguard vulnerable communities dependent on subsistence fishing (Marshall and Maes, 1994; Bash et al., 2001; Portz et al., 2006; Olson and Hawkins, 2017; Chapter 3; Chapter 4). Ultimately, successful conservation and sustainable management of fish populations hinge on informed decision-making prioritising ecosystem health and resilience across KwaZulu-Natal's freshwater habitats.

5.4 References

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