AFTER THE DUST HAS SETTLED: A LARGE DAM PROJECT AND ITS IMPACT ON FISH AND FISHERIES IN THE LESOTHO HIGHLANDS

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JAMES ROSS MCCAFFERTY

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For Ash

ABSTRACT

Large dams play an important role in addressing energy and water needs, supporting food production, and stimulating economic growth. However, they may also have profoundly negative social and environmental impacts. Large dams significantly transform riverscapes and inherently impact fish populations which directly contribute to the United Nations Sustainable Development Goals (SDGs). With dam building projected to accelerate in developing regions, there is a need to better understand their ecological and social implications for both fisheries development and biodiversity conservation.

This thesis investigated these dynamics through a case study of the Lesotho Highlands Water Project (LHWP), a major inter-basin transfer scheme in Lesotho, southern Africa. Using a mixed-methods approach that integrated natural and social science perspectives, the research explored how the LHWP shaped both fisheries development and aquatic biodiversity outcomes in the Lesotho Highlands by examining (1) The emergence and evolution of fishing practices at Katse Dam, a traditionally non-fishing area; (2) The socio-economic implications of foreign fishing tourism development in dam-affected areas; (3) The impacts of inter-basin water transfer schemes on the endangered and endemic Maloti minnow *Pseudobarbus quathlambae* and community support for their conservation; and (4) The opportunities for fisheries development in Mohale Dam, an invaded aquatic ecosystem.

Results revealed complex and often unexpected outcomes. A significant fishery developed organically at Katse Dam despite no historical fishing traditions, challenging assumptions about cultural barriers while demonstrating that unmanaged development creates substantial risks including conflicts with authorities. Foreign fishing tourism at Katse Dam generated economic benefits but revealed inherent inequalities where location-based advantages favoured some communities over others, which was complicated by historical grievances from dam-induced displacement. The endangered Maloti minnow experienced a significant reduction in its extent of occurrence, primarily due to habitat loss and predation by invasive species facilitated by inter-basin water transfer tunnel. However, dam-affected communities showed unexpected support for conservation despite worsened living conditions, challenging assumptions about development versus environmental priorities. The study of the invaded Mohale Dam showed that fisheries development was constrained by social dynamics, and how timing of resource exposure and historical grievances significantly influence adaptation trajectories.

This thesis demonstrates that the relationship between large dams, fish populations, and fisheries development demands a holistic, context-sensitive approach to assessment and management. The findings advance our understanding of community adaptive capacity in response to large dam development and emphasise the need to: (1) establish governance frameworks before dam construction to prevent unmanaged development; (2) integrate social dimensions into fisheries development and biodiversity planning; (3) recognise that communities can be conservation allies when properly engaged; (4) address historical grievances that undermine trust in development initiatives; and (5) develop adaptive management systems that respond to both ecological and social changes.

These insights offer valuable guidance for policymakers and stakeholders involved in large dam projects globally, particularly in developing regions where balancing development needs with environmental and social concerns remains a challenge. Successful outcomes will require moving beyond traditional impact assessments to understand how communities adapt to and derive value from new aquatic resources, while ensuring equitable access and sustainable management for future generations.

PREAMBLE

This thesis consists of a general introduction, a detailed description of the study area, four research chapters, and a general discussion chapter. The research chapters were written as stand-alone scientific publications and, as such, there may be some overlap in content. Efforts were made to reduce repetition wherever possible. A single reference list is presented at the end of the thesis, and a single ethics approvals summary is provided below.

APPROVALS

All interactions with human participants were approved by Rhodes University Human Research Ethics Committee (NHREC Registration number: RC-241114-045).

The research uses experimental gillnetting and electrofishing data belonging to the Lesotho Highlands Development Authority (LHDA), and collected by the student with and while in the employ of the LHDA. Approval for the use of these data was obtained from the Chief Executive of the LHDA. All LHDA research was pre-authorised and conducted according to:

- LHWP Treaty (1986)
- LHDA Order (1986, amended 2000)
- National Strategy on Lesotho's Biological Diversity (2000)
- Environment Act 2008 (Act 10)
- LHDA Environment Policy (2020)
- UN Convention on Biological Diversity

The Rhodes University Animal Research Ethics Committee (RUAREC) granted approval to use these data, with the RUAREC Chair and Executive Committee members determining no full ethical review was required (RUAREC – CW02/2024).

All research activities involving the capture and handling of fish adhered to internationally recognised ethical standards and the Rhodes University Policy on Animal Ethics. At all times, efforts were made to minimise stress and ensure the welfare of captured fish. Electrofishing and gillnetting were conducted in accordance with best practices to reduce physiological stress and injury, following the principles of Reduction and Refinement as outlined in SANS 10386:2019 (South African National Standard: The Care and Use of Experimental Animals). Fish handling procedures, including capture, holding, and release, were designed to minimise air exposure, avoid unnecessary physical harm, and ensure a rapid return to the water where appropriate. Methods followed ethical guidelines such as those from the South African MRC

Guidelines on Ethics for Medical Research: Use of Animals in Research and Training (Book 3, 2004) and international standards for humane fish capture and sampling in ecological research.

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To the wonderful *mme* Palesa Monongoaha, *mme* Nthabiseng Morokole, *mme* Mamello Mapheelle and *mme* Refiloe Ntsohi of the Lesotho Highlands Development Authority (LHDA) - our times spent in the Highlands looking for *thoboshana*, measuring SMYs, eating *likahare*, and falling off horses are some of the most cherished of my life. *Mme* Palesa, thank you for planting the seed all those years ago to embark on this journey and for facilitating the entire research process in Lesotho. *Mme* Nthabi and *mme* Mamello, I cannot thank you enough for your support in the field and your inputs and expert knowledge on the fish and fisheries of the Highlands. I would also like to extend my thanks to *ntate* Tente Tente of the LHDA who approved the research and the use of secondary data. To all of the wonderful *bontate and bomme* in the Highlands who told us their stories and provided horses, donkeys, food, ale, and a roof over our heads while sampling in the most remote areas of the country…*ke a leboha haholo*.

To Rachel Wright - this has been a long, long road and you helped me with many aspects of this thesis. It is a true joy to work with and learn from you and I look forward to helping you one day on your own PhD journey. Fred Formanek, your support and backing for all these years eventually got me here. To my other friends and colleagues, Ben Pellegrini, Tammy Bean-Klette, Nyiko Mabasa, Rikalize Vosloo, Gill van Niekerk, Cara Joubert, and Nicolas Watson, thank you for your inputs and assistance along the way which are much appreciated.

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I would like to thank my parents for supporting my fish and fisheries passions from a young age and for their continued encouragement and well-wishes throughout my PhD. Thank you, Mom and Dad. To my in-laws Christine and Alan, thank you too for all your support and encouragement towards becoming a “Rhodes Doctor”!

Lastly, but most importantly, to my wife Ash. None of this would have been possible without you. Your support never wavered, despite the sacrifices it meant for us and our family over a period of over four years. Thank you for your constant encouragement, belief in me, and for always backing my ambitions. I love you so very much.

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ACRONYMS AND ABBREVIATIONS

AfDB	African Development Bank
AIC	Akaike information criterion
AW	African Waters (tour agency)
BMU	Biodiversity management unit
CI	Confidence interval
CPUE	Catch per unit effort
EC	Electrical conductivity
EIB	European Investment Bank
EOO	Extent of occurrence
ESIA	Environmental and social impact assessment
ESS	Effective sample size
ESU	Evolutionary significant unit
FAO	Food and Agriculture Organization
FFT	Foreign fishing tourism
FGD	Focus group discussion
FI	Fork length
FPIC	Free, prior and informed consent
FSL	Full supply level
GAM	Generalised additive modelling
GAMs	Generalised additive models
GDP	Gross domestic product
IBWT	Inter-basin water transfer
ICM	Integrated catchment management
IFR	Instream flow requirements
IRI	Index of relative importance

IUCN	International Union for Conservation of Nature
KII	Key informant interview
LEC	Lesotho Electricity Company
LFP	Lesotho Fisheries Project
LHDA	Lesotho Highlands Development Authority
LHWC	Lesotho Highlands Water Commission
LHWP	Lesotho Highlands Water Project
LIDC	Low income developing country
masl	Metres above sea level
MCC	Makhangoa Community Camp
MCMC	Markov Chain Monte-Carlo
MCS	Monitoring, control and surveillance
MW	Megawatts
NDB	New Development Bank
NGO	Non-governmental organisation
NRF	National Research Foundation
PCA	Proactive conservation area
RCA	Reactive conservation area
REML	Restricted maximum likelihood
RUAREC	Rhodes University Animal Research Ethics Committee
S-C	Sub-catchment
SAIAB	South African Institute of Aquatic Biodiversity
SDG	(United Nations) Sustainable Development Goal
SELECT	Share Each Length-Classes Catch Total
SF	Selection factor
TCTA	Trans-Caledon Tunnel Authority

UN	United Nations
VCA4D	Value Chain Analysis for Development

GLOSSARY

Morena	Chief (plural *Marena*)
Mofumahali	Chief or Wife of Chief (plural *Mafumahali*)
thoboshana	Maloti minnow *Pseudobarbus quathlambae*
skelm	Orange River mudfish *Labeo capensis*
lithabeng	the highlands
mabalane	the lowlands
mme	mother
ntate	father
holimo	up (the highlands)
tlase	down (the lowlands)

CHAPTER 1 – GENERAL INTRODUCTION

1.1. Background

Few engineering feats are as emblematic of humankind's ability to manipulate and regulate the natural environment as large dams (Kaika 2006; Nüsser and Baghel 2017; Kornfeld 2020). Perhaps fewer still have sparked as much controversy (McCully 2001; Moore et al. 2010; Scudder 2012; Boelens et al. 2019). Since the mid-1950s, these massive infrastructure projects have become increasingly ubiquitous, transforming the watercourses of more than half of the world's major river systems (Nilsson et al. 2005) to meet the growing need for fresh water, food, and energy (Chen et al. 2016). Today, there are more than 58 000 large dams worldwide (defined as dams over 15 m high or with a capacity of at least 3 000 000 m^3) (Commission on Dams 2001) that support approximately 12–16% of global food production; contribute to 17% of the global electricity supply (Mulligan et al. 2020); and provide other important societal services, including drinking water, flood control, navigation, and recreation (Tortajada 2015) (Figure 1.1). In their shadow lies a history of human displacement (Dharmadhikary 2001), landlessness (Cernea 1997), lost livelihoods (Richter et al. 2010), social disarticulation (Scudder 2012), conflict (Del Ben et al. 2018), corruption (Dogmus and Nielsen 2020), degraded ecosystems (Nilsson and Berggren 2000), species extinctions (He et al. 2019), and considerable public outcry (Leslie 2005). Despite the debate surrounding their development (Schulz and Adams 2019), it is likely that the number of large dams will continue to increase in the coming decades, along with a rapidly growing global population (Shi et al. 2019) and an increasing demand for water, food, and clean energy (Mulligan et al. 2020). The continued growth in dam construction, particularly in developing countries, underscores the need to apply and expand our knowledge of their ecological and social impacts to contemporary contexts, where gaps in knowledge remain.

The aim of this introductory chapter is to provide fundamental context to the changes brought about by damming rivers, with a particular focus on fish populations and fisheries. It presents an overview of this body of work and its contribution towards understanding the biological, ecological, and social impacts of large dams on fish and fisheries. This chapter sets the stage for the subsequent in-depth examination of the Lesotho Highlands Water Project (LHWP) and provides context for the thesis to follow.

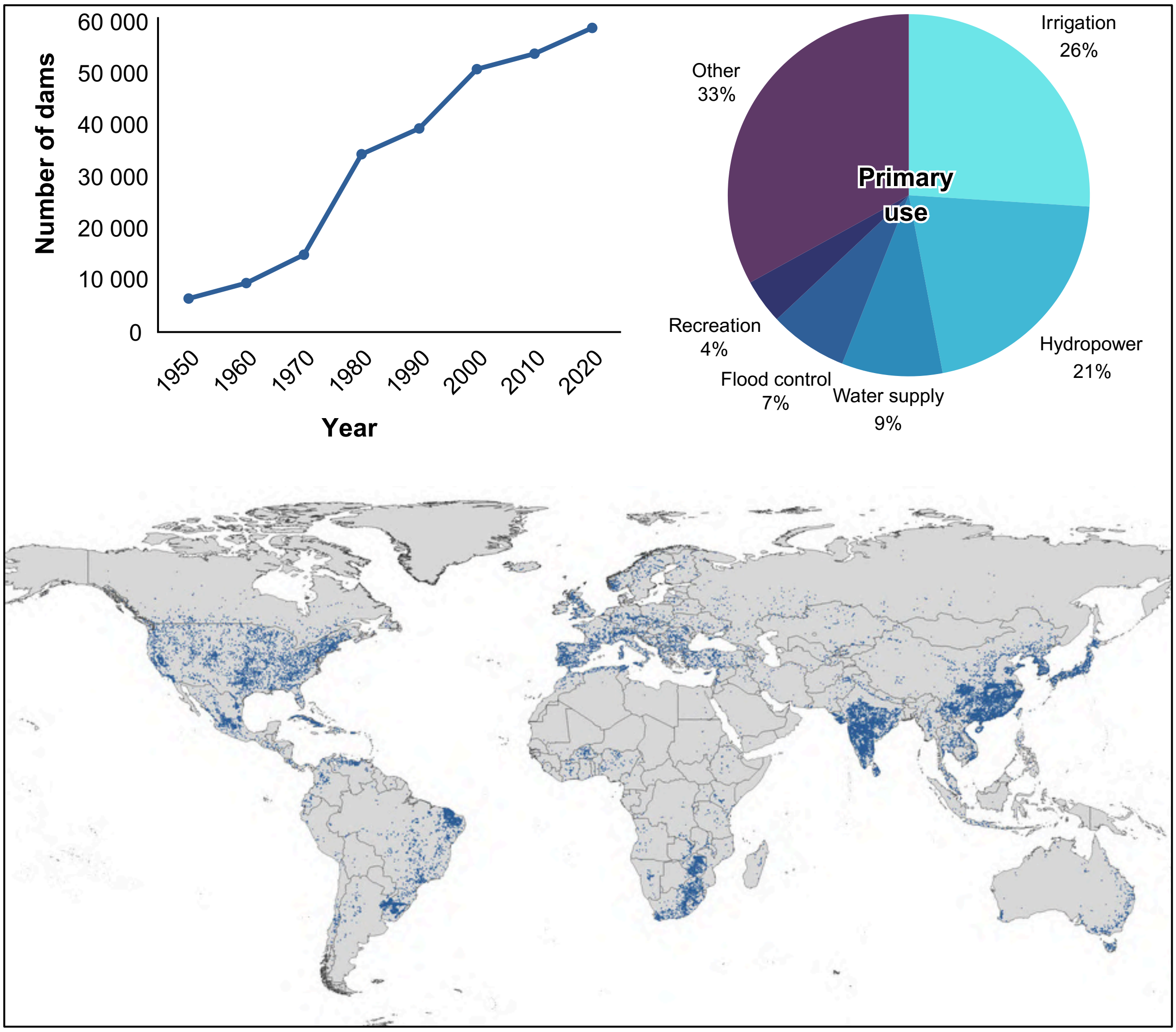

Figure 1.1: Number of large dams globally, 1950–2020 (top left); primary uses of large dams globally (top right); location of world's large dams (bottom) (Source: Mulligan et al. 2020).

1.2. Large dams, fish, and fisheries

Large dams significantly transform riverscapes (McCartney and Sally 2007). They fragment habitats, create new artificial lentic environments upstream, and modify upstream and downstream flow patterns, sediment transport regimes, water temperature, and water quality (Poff et al. 1997). Dams can also connect isolated riverine ecosystems via inter-basin water transfer (IBWT) schemes (Turgeon et al. 2019). These alterations inherently impact fish populations (Keppeler et al. 2022), which may have significant ecological and social implications given their contribution to ecosystem functioning (Holmlund and Hammer 1999), biodiversity (Dudgeon et al. 2006), food security and livelihoods (Funge-Smith and Bennett 2019), and overall human well-being (Lynch et al. 2016).

Freshwater fish are among the most biodiverse taxa on Earth, comprising almost 18 000 species (Van der Sleen and Albert 2022) and representing a quarter of global vertebrates (Su et al. 2021). They occupy almost all aquatic habitats and play an important role in nutrient cycling, energy transfer, maintaining ecosystem function, and as indicators of ecosystem health (Holmlund and Hammer 1999; Lynch et al. 2016).

Beyond their ecological significance, freshwater fish contribute significantly to global food and nutrition security (Youn et al. 2014) by providing an important source of protein, omega-3 fatty acids, vitamins, and minerals, particularly in developing countries (O'Meara et al. 2021). Global inland capture fisheries production was 11.3 million tonnes in 2022 (FAO 2024). While recent data are scarce, it has been estimated that 90% of inland fisheries production is used for human consumption (Welcomme et al. 2010). Inland fisheries also generate employment and support the livelihoods of millions of people worldwide, particularly in developing countries (Lynch et al. 2016). In 2014, approximately 17–21 million people were directly employed in inland fisheries, of whom 50% were women, while another 36 million were employed in post-harvest activities linked to these fisheries (FAO 2014; Lynch et al. 2016; McCartney et al. 2018). Inland fisheries can often serve as safety nets, offering alternative income and food when other sources fail (Virdin et al. 2023).

In addition to capture fisheries, freshwater fish also provide important recreational services (Lynch et al. 2016; Embke et al. 2022). Global participation in inland recreational fishing was recently estimated at approximately 280–290 million people (Lynch et al. 2024), with direct and indirect values estimated at over USD 44 billion and USD 100 billion per year, respectively (Funge-Smith 2018). Moreover, recent research has highlighted how inland recreational fisheries constitute an important source of food, with a total consumptive value estimated at almost USD 10 billion (Lynch et al. 2024).

Healthy inland fish and fisheries are now considered integral" to achieving several of the United Nations Sustainable Development Goals (SDGs) (UN 2015), particularly No Poverty (SDG 1), Zero Hunger (SDG 2), Clean Water and Sanitation (SDG 6), Responsible Consumption and Production (SDG 12), and Life on Land (SDG 15) (Lynch et al. 2020). With large dams back on the development agenda, furthering our understanding of their impacts on people, fish and fisheries is important for developing effective management and conservation strategies.

1.2.1 Some common mechanisms of ecosystem change caused by large dams and their impacts on fish populations

Dams influence fish in various ways across space and time (Keppeler et al. 2022). The key drivers include habitat fragmentation and connection of isolated basins, transformation of lotic habitats to lentic habitats (i.e., creation of reservoirs), and upstream and downstream modifications to water flow, water quality, temperature, and sediment transport (Turgeon et al. 2019; Chen et al. 2023). Depending on the specific environment, these drivers may act synergistically (Chen et al. 2023), benefitting some species while detrimentally affecting others (Turgeon et al. 2019; Fernandez et al. 2024) (Figure 1.2).

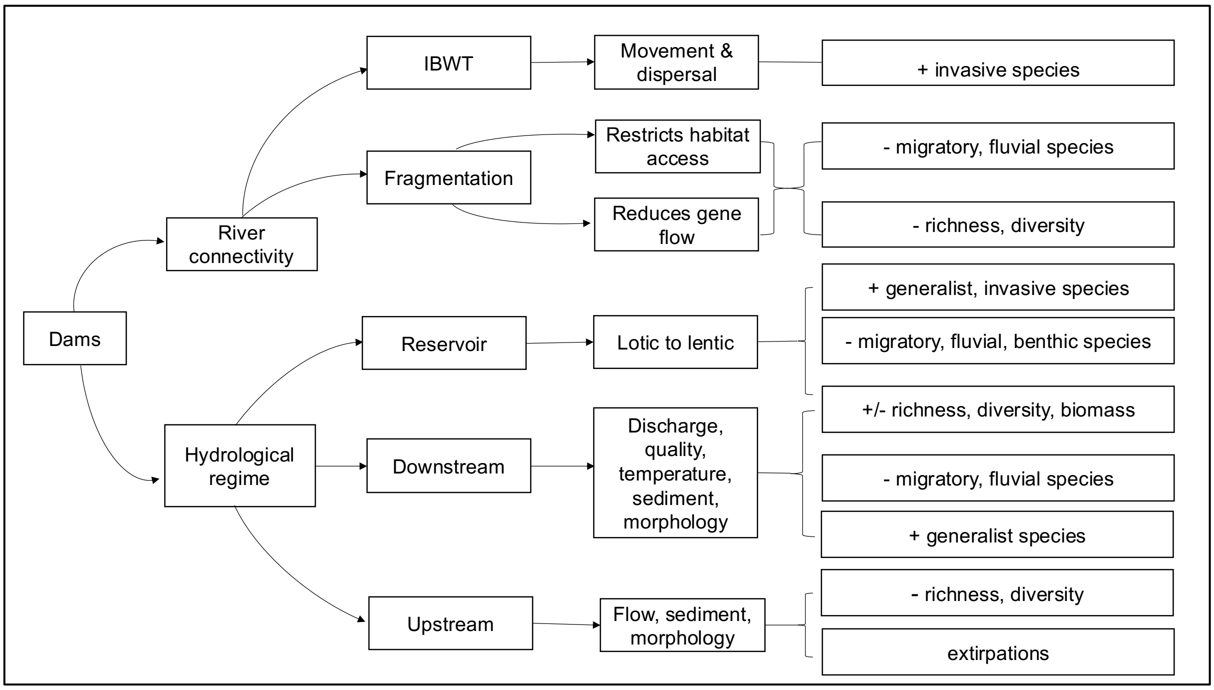

Figure 1.2: Examples of common post-impoundment mechanisms of change, and species- and community-level responses in fish.

Habitat fragmentation restricts movement and dispersal, affecting the ability of fish to access habitats (Chen et al. 2023) and restricting gene flow (Machado et al. 2022). Habitat fragmentation is particularly detrimental to species whose life cycles are dependent on specific spawning, nursery, and/or feeding grounds (Liermann et al. 2012; O'Mara et al. 2021; Chen et al. 2023). Population declines in migratory and rheophilic species caused by dam-induced habitat fragmentation have been observed globally (Yi et al. 2010; Ferguson et al. 2011; Agostinho et al. 2016; Pelicice et al. 2017; Brinker et al. 2018; Capra et al. 2018; Arantes et al. 2019; He et al. 2019, 2021; Van Puijenbroek et al. 2019; Zambaldi and Pompeu 2020; Duponchelle et al. 2021; Šmejkal et al. 2023; Sun et al. 2023; Huang and Li 2024). At the community level, declines in species richness (Cumming 2004; Morita et al. 2009; Nislow et al. 2011; Cheng et al. 2016; Sor et al. 2023), diversity (Baldan et al. 2023; Díaz et al. 2023; Sor et al. 2023), functional diversity (Zhang et al. 2020), and genetic diversity (Dehais et al. 2010; Pavlova et al. 2017; Ferreira et al. 2022) have also been attributed to dam-induced habitat fragmentation.

Dams can also connect geographically distinct rivers through IBWTs (Turgeon et al. 2019), allowing for the movement of fish between previously isolated catchments where they may become invasive (Gallardo and Aldridge 2018; Schmidt et al. 2020; Waine et al. 2024). Globally, cases of fish invasion have been reported across IBWT schemes in Australia (Waters et al. 2002), Brazil (Bellafronte et al. 2010; Silveira et al. 2017), China (Qin et al. 2019; Zhan et al. 2015), South Africa (Kadye and Booth 2013), Lesotho (Shelton et al. 2017), and the United States (Howard and Booth 2016; Swift et al. 2015). Invasive species may predate on and compete with native species, promote genetic introgression, introduce pathogens and parasites, and modify food webs and foraging behaviour (Cucherousset and Olden 2011). These impacts can affect ecosystem functioning (Weber and Brown 2009) and lead to biodiversity loss (Mollot et al. 2017).

The transformation of lotic habitats to lentic habitats caused by dams essentially creates an entirely new lacustrine ecosystem (reservoir) typically characterised by fluctuating water levels, thermal stratification, seasonal turnovers, trapped sediments, low dissolved oxygen levels or anoxic conditions in the hypolimnion, and increased susceptibility to eutrophication (Schmutz and Moog 2018). These conditions typically favour the establishment of eurytopic or generalist fishes with greater plasticity, while adversely affecting fluvial specialists whose life-history strategies are adapted and strongly linked to lotic conditions (Liermann et al. 2012; Agostinho et al. 2016; Turgeon et al. 2019; Arantes et al. 2019; Schmutz and Moog 2018), as well as benthic species owing to oxygen depletion (Arantes et al. 2019). Subsequent homogenisation (Gido et al. 2010; Clavero and Hermoso 2011; Petesse and Petrere 2012; Vitule et al. 2012; Havel et al. 2015) and declines in species richness and diversity are common (Sá-Oliveira et al. 2015; Loures and Pompeu 2019). However, in some cases, no change or increase in richness or diversity has been observed (Irz et al. 2006; Restrepo Santamaria et al. 2022; Fernandez et al. 2024). Reservoirs frequently provide conditions that facilitate the establishment of non-native species, particularly in tropical and temperate regions where increases have been widely reported (Turgeon et al. 2019). However, such colonisation occurs only where propagules are available through deliberate introductions, unintentional releases, or new hydrological connections (Johnson et al. 2008; Restrepo Santamaria et al. 2022).

Downstream of the dam, changes in the frequency, timing, duration, and magnitude of water discharge, as well as reduced sediment transport, may also affect migratory and rheophilic fishes, particularly those that rely on flood pulses for spawning and recruitment (Arantes et al. 2019). General declines in riverine fish abundance and diversity in North America, Europe, and Oceania have been directly linked to both elevated and decreased flow (Poff et al. 2010), although a recent global synthesis found no consistent patterns in the relationship between water flow and biomass (Harper et al. 2022). Other studies have highlighted declining diversity and homogenisation downstream of dams (Ngor et al. 2018). Changes in water temperature may also negatively affect species with narrow thermal tolerance limits (Chen et al. 2023). Upstream of the reservoir, hydrological alterations and habitat loss may lead to shifts in community structure (Guenther et al. 2006; Franssen and Tobler 2013), declines in richness and diversity (Sá-Oliveira et al. 2015), and extirpations (Winston et al. 1991).

In addition to the impacts of individual dams, it is important to recognise that multiple dams within a river system can have cumulative and often synergistic effects on fish populations and ecosystems (Dean et al. 2023). These cumulative impacts can amplify habitat fragmentation, alter flow regimes more severely, and create a series of barriers that may be insurmountable for migratory species (Grill et al. 2019). The combined effect of multiple dams can lead to more pronounced changes in community structure, greater reductions in biodiversity, and potentially more severe disruptions to ecosystem functions than a single dam alone (Winemiller et al. 2016). The ecological outcomes of damming also vary with the dam type and operation (Petts 1984). Impounding dams, which create large reservoirs, differ from run-of-river systems that pass most flow downstream with limited storage. Operational regimes, such as seasonal releases or hydropeaking for hydropower, together with reservoir morphology and catchment position, further influence flow patterns, sediment transport, and biological responses (Petts 1984; Jackson and Marmulla 2001; Chen et al. 2023).

A meta-analysis conducted by Turgeon et al (2019) of the impacts of large dams on fish communities demonstrated that these vary considerably at different latitudes. In tropical regions, dams typically cause declines in species richness and diversity, favouring non-native species and disrupting flood pulses, which are important for migratory and rheophilic fishes. In temperate regions, biodiversity declines are less marked, with communities typically shifting towards non-native species, particularly piscivores. In contrast to tropical and temperate regions, the impact of dams on fish in boreal regions is minimal, which has been attributed to the typically lower species richness in these water bodies and the resilience of cold-adapted species. Across biomes, the greatest impact of dams on fish assemblages is an increase in the mean trophic level and proportion of generalist species (Turgeon et al. 2019). However, at the species level and based on life-history traits, another recent meta-analysis demonstrated that there was no universal response to damming (Fernandez et al. 2024).

The varied impacts outlined above highlight that although extensively studied, the divergent effects of dams on fish make it challenging to draw general conclusions. As noted by Fernandez et al. (2024), there is a clear need for further Figure 1.2case-by-case" studies to better understand the impacts of dams on freshwater fish biodiversity. Given the varying responses of freshwater fishes to damming, it is logical to extend this case-by-case approach to inland fisheries.

1.2.2. Dams and inland fisheries

The adverse impacts of large dams on inland fisheries have historically been overlooked by planners and decision-makers (Doria et al. 2018). In addition, the opportunity to create, develop, and/or manage fisheries, if considered, has been viewed as "an optional extra" rather than something to be prioritised (Lowe-McConnell 1973; McCartney et al. 2018). In many instances, dams have been shown to negatively affect fisheries (Richter et al. 2010), and therefore the food security (Golden et al. 2019), income (Smederevac-Lalić et al. 2012), and livelihoods (Amabel and Parlee 2020) of fishing communities. In other cases, dams have created conditions allowing for the establishment of productive fisheries that may constitute a critical source of food, livelihoods and recreation (Jackson and Marmulla 2001; Tsoumani et al. 2015; Gratz 2017; Huntington et al. 2017; Oladimeji et al. 2020; Melstrom et al. 2022; Nduwayesu et al. 2023). Ultimately, dams present both constraints and opportunities for fisheries, which are linked to several social and ecological factors as well as the spatial and temporal scales of interest (Jackson and Marmulla 2001; McCartney et al. 2018).

Broadly, at the watershed scale and where there are already well-established, socio-economically valuable, and culturally important capture fisheries, the net benefit of large dams is usually negative from a fisheries perspective (Jackson and Marmulla 2001; Kolding and van Zwieten 2006; McCartney et al. 2018). This is particularly the case when fishery yields are linked to natural flow patterns, flood pulses, sediment transport regimes, and/or the abundance of migratory and/or rheophilic species (Bernacsek 1984; McCartney et al. 2018; Arantes et al.

2022). Post-impoundment declines in catch, catch rates, income, livelihoods, and other socio-economic impacts, such as induced migration, have been recorded in Africa, Asia, Europe, and South America (Figure 1.3), although dams have also been linked to declining catches in several other important riverine fisheries (Ainsworth et al. 2021). Although some species may adapt well to the new lacustrine environment (Ellender et al. 2016), they may be culturally inappropriate, less palatable and desirable for consumers, undermining food security and food sovereignty (Lukhele and Msagati 2024), and of lower economic value (Lima et al. 2020), therefore negatively affecting income and livelihoods of fishing communities (Jackson and Marmulla 2001; Hoeinghaus et al. 2009; Agostinho et al. 2016). In some instances, declines in fish supply have significantly increased fish prices with adverse effects on local communities (Lima et al. 2020). Local communities that are intricately connected to riverine fisheries through cultural and spiritual ties may also suffer significant psychosocial trauma (Jackson and Marmulla 2001), and struggle to adapt to fishing in the new environment (Santos et al. 2018). The negative impacts of dams on riverine recreational fisheries are less well-documented, although there is evidence of declining fisheries for salmonids in North America and Europe (Morey et al. 1993).

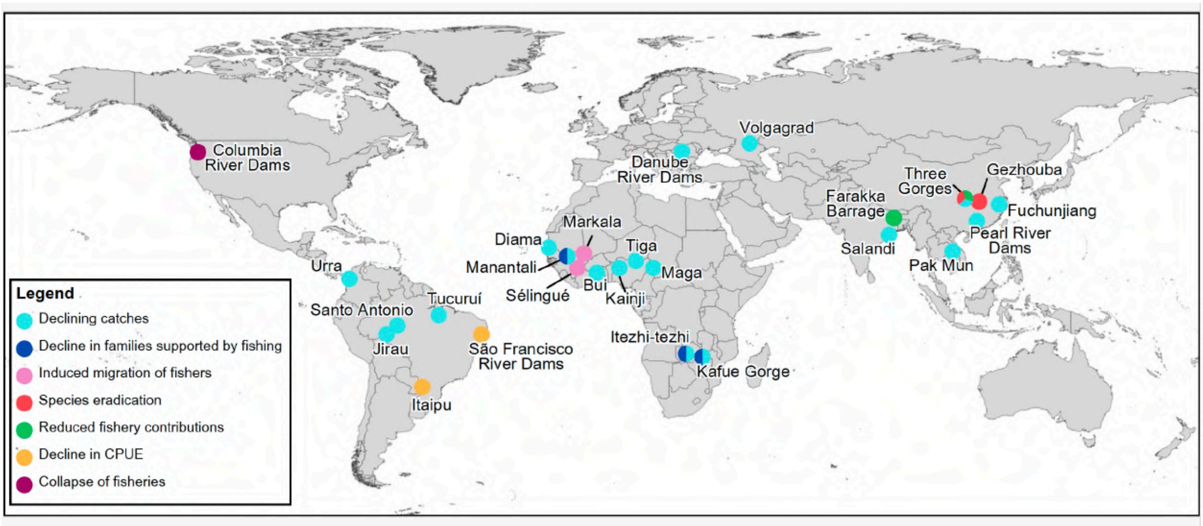

Figure 1.3: Examples of the negative impacts of large dams on inland fisheries. Source: Tiga (Thomas et al. 1994); Kafue Gorge and Itezhi-tezhi (Acreman 2000); Maga (IUCN 2001); Markala and Sélingué (Laë 1992); Kainji (Jackson and Marmulla 2001); Manantali and Dia (Falaye et al. 2015); Bui (Asiedu et al. 2018); Three Gorges (Xie et al. 2007); Gezhouba Dam (Cheng et al. 2015); Farakka Barrage (DoF 2004); Pearl River (multiple) ((Liao et al. 1989); Fuchunjiang (Chen et al. 1990); Salandi (Larinier and Marmulla 2003); Pak Mun (Amornsakchai et al. 2000); Volgograd (Khodorevskaya et al. 1997; Górski et al. 2012); Danube River (multiple) (Tockner et al. 1999); Tucuruí Dam (Odinetz-Collart 1993; Fearnside 2001); São Francisco (Funge-Smith 2018); Itaipu (Barletta et al. 2015); Santo Antonio and Jirau (Santos et al. 2018); Urra (Correa 1999); Columbia River (multiple) (Lumley et al. 2016).

Although dams can have negative impacts on fisheries, they may also provide opportunities to establish new fisheries, which may have an overall net positive impact on fisheries production, particularly where existing riverine fisheries are less established and/or provide little socio-economic benefit (Jackson and Marmulla 2001). Although rarely a primary consideration during the planning phase of dams (McCartney et al. 2018), if fisheries can be established and sustainably managed, they may enhance food security, diversify income sources, and stimulate economic development (Kolding and van Zwieten 2012). This could be an appealing prospect for decision-makers looking at ways to mitigate the negative social and economic impacts of large dams (Jackson and Marmulla 2001).

Since the 1950s, fisheries in dams (also called reservoir fisheries) have become increasingly important contributors to global inland capture fisheries production (Fernando and Holcik 1991; Moreau and DeSilva 1991; Welcomme 2001). It is difficult to quantify their contribution given that they are highly dispersed and often inadequately monitored (van Zwieten and Kolding 2011). While empirical models suggest that reservoirs are typically more productive than lakes and rivers, with theoretical global harvests of up to 2.5 million tonnes per year (Lymer et al. 2016) (, outcomes vary considerably between systems, and it is difficult to generalise about reservoir productivity (Lorenzen et al. 2016). Nevertheless, recent research by Parisek et al. (2024) indicated that the total standing stock in USA reservoirs alone was approximately 3.4 million tonnes. This significant biomass highlights the potential of reservoir fisheries to significantly contribute to global food security and economic development.

Table 1.1), outcomes vary considerably between systems, and it is difficult to generalise about reservoir productivity (Lorenzen et al. 2016). Nevertheless, recent research by Parisek et al. (2024) indicated that the total standing stock in USA reservoirs alone was approximately 3.4 million tonnes. This significant biomass highlights the potential of reservoir fisheries to significantly contribute to global food security and economic development.

Table 1.1: Mean inland capture fisheries yields (kg/ha/yr) by continent and water bodies (adapted from Lymer et al. 2016).

	Continent					
	North America	**South America**	**Europe**	**Africa**	**Asia**	**Oceania**
Lakes	2.8	54.9	13.0	73.0	156.1	50.1
Reservoirs	37.0	112.5	41.3	81.0	57.6	83.7
Rivers	12.4	12.4	39.3	30.7	48.9	30.7
Floodplains	13.3	182.1	13.3	50.4	166.6	132.9

Wetlands	6.0	59.8	6.0	3.1

In Africa, approximately 10% of total inland fisheries production comes from reservoir fisheries (De Feu 2003). Major reservoirs, such as Lake Volta, Lake Kariba, and Lake Cahora Bassa, account for approximately 90% of national inland fish production in Ghana, Zimbabwe, and Mozambique, respectively (Funge-Smith 2018; FAO 2024). In certain Asian countries, reservoirs contribute up to 75% of total inland fisheries production (De Feu 2003; Funge-Smith 2018).

The contribution of fisheries development in large dams to food and nutrition security and livelihoods is noteworthy in many instances. For example, Lake Volta in Ghana sustains the livelihoods of approximately 300 000 fisherfolk, including fishers and fish traders, who rely on the lake as their primary source of income and food security (van Zwieten et al. 2011). Similarly, Lake Kariba in Zimbabwe and Zambia has greatly increased fish production, providing an important source of protein and employment for local communities, particularly through the introduction of kapenta (*Limnothrissa miodon*) from Lake Tanganyika between 1967 and 1969 (Bell-Cross and Bell-Cross 1971; Magqina et al. 2020). The Cahora Bassa reservoir in Mozambique produces approximately 26 000 tonnes of fish annually, including about 10 000 tonnes of kapenta, supporting thousands of local fishers and significantly contributing to the local and national economy (van Zwieten et al. 2011). In Egypt and Sudan, Lake Nasser, formed by the Aswan High Dam, has estimated fish yields of 36–39 kg/ha per year, supporting substantial fisheries that provide food security and livelihoods for local communities (van Zwieten et al. 2011). Kainji Lake in Nigeria produces an annual catch of approximately 28 850 tonnes and plays an important role in providing food security and employment to surrounding communities (De Feu 2003). Furthermore, Sri Lanka's inland reservoirs produce the highest inland capture fishery production relative to renewable surface water resources in the South Asian subregion, enhancing local food security and providing substantial livelihoods to the communities involved (Funge-Smith 2018).

Reservoirs also offer significant opportunities for recreational fisheries within the reservoir as well as upstream and downstream of the impounded river. Studies in North America, South America, Australia, Europe, and Africa have shown that recreational fisheries in reservoirs are important contributors to local economies and employment (Chen et al. 2003; Driscoll and Myers 2014; Baigún et al. 2006; Rolfe and Prayaga 2007; Britz et al. 2015; Hupfeld et al. 2018). For instance, the trophy largemouth bass (*Micropterus salmoides*) fishery at Lake Fork, Texas, resulted in USD 27.5 million in spending in 1995, creating USD 18.6 million in total economic impact and supporting 367 jobs (Chen et al. 2003). Similarly, bass (*Micropterus* spp.) angling at the Sam Rayburn Reservoir, Texas, had an economic value of USD 46.7 million and supported local businesses (Driscoll and Myers 2014). The economic benefits of recreational fisheries extend beyond direct fishing-related expenditures to include indirect effects on local businesses such as hotels, restaurants, and equipment suppliers (Cooke and Murchie 2015).

In sum, the development of reservoir fisheries is influenced by multiple factors. While biophysical conditions, such as reservoir morphometry, climate, and available habitat, create the fundamental basis for fish production, the success of these fisheries is equally linked to several social, economic, and governance dimensions (Cowx and Gerdeaux 2002; Arlinghaus et al. 2016a; McCartney et al. 2018).

1.2.3. Mitigation and Management Approaches

Large dams have distinct characteristics that uniquely influence aquatic ecosystems and broader social and ecological environments (Bernacsek 2001). Effectively managing the impacts of large dams on biodiversity and fisheries is a complex undertaking that requires careful consideration (Jackson and Marmulla 2001). Past management interventions have typically focussed on mitigating the effects on both downstream and upstream environments as well as on the newly formed reservoir itself (Bernacsek 2001; Hortle and So Nam 2017; McCartney et al. 2018).

Managing the downstream impacts of large dams has commonly involved the use of fish passage structures, such as fish ladders or fish ways, to facilitate fish migration and maintain connectivity between upstream and downstream habitats (Silva et al. 2018; Foldvik et al. 2022), and environmental flow releases to mimic natural flow patterns (Richter et al. 2010; Arthington et al. 2018; McCartney 2018). In certain instances, fish ladders have successfully facilitated the migration of fishes, particularly salmonids (Noonan et al. 2012; Keefer et al. 2021; Foldvik et al. 2022). However, in other cases, fish passage structures have been less effective. For example, fish passages in the Mekong River basin have been unable to cater to the great diversity of species, their morphology, and their migratory patterns (Ziv et al. 2012). The success of environmental flow management depends on accurately assessing the water requirements of different fish species and ensuring sufficient water release, which can be challenging, particularly in highly diverse systems (Arthington et al. 2018). However, environmental flow releases have been successful in promoting fish movement, reproduction, and the overall health of fish communities in several river basins e.g., Murray-Darling (Carpenter-Bundhoo et al. 2022).

Management approaches for upstream catchments have focussed on preserving river connectivity and safeguarding existing fish habitats, particularly spawning grounds, in inflowing tributaries (Bernacsek 2001; McCartney et al. 2018). A notable example is the Ubolratana Reservoir and Sirinthon Reservoirs in Thailand; the establishment of protected areas in the affluent rivers of the Ubolratana Reservoir led to a significant increase in fish production, while in the nearby Sirinthon Reservoir the lack of protected areas led to a severe decline in catches (Bernacsek 2001). Effectively managing the upstream watershed also plays a role in mitigating sediment and pollutant inputs as well as preventing excessive nutrient loads, all of which contribute to the degradation of fish habitats, contamination of aquatic systems, and eutrophication (McCartney et al. 2018).

Historically, the management of reservoir fisheries was similar to that applied to lakes and rivers, namely, a top-down approach where decisions were centralised in the hands of authorities (De Feu 2004; Kolding and van Zwieten 2006). Over time, this approach has largely shifted towards co-management, where local fishers and stakeholders are encouraged to actively participate in the identification of management goals, the development of management plans, and the implementation of conservation and sustainable use strategies (Allison and Badjeck 2004). Fisheries regulations in reservoirs commonly include input (e.g. gear, closed seasons, closed areas) and output (e.g. size and bag limits) controls (Kolding and van Zwieten 2006; McCartney et al. 2018). However, the efficacy of these measures, particularly in developing countries, is commonly constrained by a lack of resources for monitoring, control and surveillance (MCS) (FAO 2022). Beyond regulatory controls, a wide range of mitigation and enhancement measures have been applied to support fisheries production. Physical interventions commonly include nutrient enrichment to increase carrying capacity (Welcomme and Bartley 1998) and habitat modifications such as brush parks and vegetation structures that provide spawning and nursery areas (Welcomme 2002). Hydrological management that maintains flood-pulse dynamics in littoral zones is also practiced (Welcomme and Halls 2001), and the timing of reservoir releases to mimic natural flood regimes that sustain spawning habitats (Jul-Larsen et al. 2003). Other measures include species introduction, such as that of *Limnothrissa miodon* in African reservoirs which support productive pelagic fisheries (Marshall 1995), stock enhancement through the regular release of hatchery seed, widely practiced in China, India, Cuba, Mexico, and the former USSR (Welcomme and Bartley 1998), the development of culture-based fisheries (De Silva 2001), and cage aquaculture (Halwart et al. 2007). The efficacy of any of these mitigation and management approaches, however, ultimately depends not only on ecological conditions but on the broader sociocultural, economic, and political context (Jackson and Marmulla 2001).

1.2.4. Towards holistic approaches in assessing and managing the impacts of large dam projects on fish and fisheries

It is increasingly recognised that ensuring the sustainability of fish, fisheries, and inland waters requires holistic, transdisciplinary research and management approaches (Beard et al. 2011; Downing et al. 2014; Cooke et al. 2016; Heck et al. 2016; Nguyen et al. 2017; Arlinghaus et al. 2017; 2019; Song et al. 2018; Cooke et al. 2021). Historically, research on inland fisheries was (and still is) conducted within a "fisheries-science silo", focussing primarily on biological and population dynamics aspects (Aas and Ditton 1998; Arlinghaus et al. 2017). While this approach may be valuable for establishing exploitation guidelines, for example, it fails to capture the complex relationships between fish, people, and the broader aquatic environment (Beard et al. 2011; Heck et al. 2016; Arlinghaus et al. 2019) which ultimately determine how resources are utilised, and the efficacy of management measures (Welcomme et al. 2010; Nguyen et al. 2017; Cowx and Ohguto-Ohwayo 2019; Cooke et al. 2021).

Similarly, aquatic biodiversity conservation action planning has not adequately considered the link between ecological imperatives and social realities (Ban et al. 2013; Bennett 2016; Ochien et al. 2020). While ecological studies play an important role in, for example, determining the status of and threats to biodiversity, the attitudes and perspectives of people towards biodiversity often underpin the practicality and sustainability of conservation measures (Ban et al. 2013).

In recent decades, various frameworks, approaches, and analytical concepts have been developed to integrate social and ecological dimensions in natural resource management. Ostrom's social-ecological systems (SES) framework provides a systematic approach for analysing complex interactions between resource systems, governance structures, and user groups (Ostrom 2009). The FAO Ecosystem Approach to Fisheries (EAF) emphasises the importance of considering human well-being alongside ecological objectives (FAO 2003). Complementary approaches and concepts include resilience-based management (Folke et al. 2005), coupled human-natural systems analysis (Liu et al. 2007), and integrated ecosystem-based management (Long et al. 2015). While these differ somewhat in their specific focus and application, they share a common principle: understanding and managing natural resources requires explicit consideration of the characteristics of, and linkages between, social and ecological dimensions.

The documented impacts of large dams on fish populations and fisheries demonstrate considerable variation across different contexts, making it challenging to draw universal conclusions or predict outcomes. Although the biophysical mechanisms driving these changes are increasingly well-understood, the influence of large dams on fisheries and aquatic biodiversity depends on complex interactions between ecological and human systems, which may be difficult to anticipate. However, a common characteristic of many large dam projects is their profound social impact, including increased unemployment; food and nutrition insecurity; lost livelihoods; cultural disruption; and severe psychosocial trauma (Scudder 2012). These changes shape how communities adapt to new environmental conditions (Castro-Diaz et al. 2023), their patterns of resource use (McDonald-Wilmsen and Webber 2010), and their willingness to engage in resource management (Agrawal and Redford 2009). Therefore, it follows that the impacts of large dams on fish and fisheries are intrinsically linked to broader social disruption and reconfiguration processes that characterise these projects. As such, attempting to understand how dams affect fish and fisheries must consider both ecological changes and the social transformations that influence how resources are perceived, utilised, and managed.

1.3. Thesis rationale

The ubiquity of dams around the world has led to a new state of affairs; practically all of the world's major river systems have been dammed, and these artificial ecosystems have become a defining feature of our landscapes (Parisek et al. 2024). The increasing number of dams worldwide, combined with their mixed effects on aquatic ecosystems and fisheries, emphasise the need for further case-by-case studies. The need for research is particularly pronounced in developing countries where the number of large dams is expected to increase significantly in the coming decades (Zarfl et al. 2015; Moran et al. 2018), data are often limited or absent, and there is a dual challenge of pursuing economic development while safeguarding native biodiversity (Siciliano et al. 2018). Case studies of specific dam projects in developing countries can provide insights into the complex interactions between dams, people, fish, and fisheries. These studies can serve as models for understanding dam-fishery interactions and inform best practices for balancing conservation with sustainable development.

The LHWP (described in Chapter 2) provides an opportunity to examine these issues in a developing country context. As a multiphase large-scale dam project in a region with high poverty rates and endemic aquatic biodiversity, the LHWP embodies many challenges and potential benefits associated with dam construction and management. However, despite its significant social and environmental impacts, its impacts on fish and fisheries in the Lesotho Highlands have never been comprehensively assessed. This represents a knowledge gap and an opportunity for research that could contribute to improving our understanding of the impacts of large dams on fish and fisheries and the development of key principles for improved assessment and management both in Lesotho and globally.

This thesis aims to provide a holistic understanding of the impact of the LHWP on fish populations and fisheries in the Lesotho Highlands by investigating ecological changes and the unique social context in which they have occurred. Using a tailored, transdisciplinary approach adapted from social-ecological systems (SES) principles and combining natural and social science methods, this thesis examines how these changes have collectively shaped both aquatic biodiversity and fisheries development outcomes. Here, transdisciplinary refers to the integration of knowledge and methods across ecological, social, and governance domains, incorporating perspectives from relevant stakeholder groups including local communities, governance actors, and academics. This approach makes it possible to examine how biophysical changes associated with large dams intersect with social disruption and adaptation processes, providing a holistic understanding of the outcomes for both biodiversity and fisheries. The research sought not only to generate scientifically robust findings but also to ensure that the knowledge produced was contextually relevant and applicable to policy and management. In doing so, it aims to generate insights that can inform decision-making around fisheries development, management, and aquatic biodiversity conservation in future large dam projects globally.

The thesis begins with a general introduction (this chapter), followed by Chapter 2, which introduces the LHWP and situates it within the ecological, social, and governance context of the Highlands. The subsequent chapters address the following specific objectives, each of which examines a different dimension of how large dams have shaped fish populations, fisheries, and conservation in the Lesotho Highlands:

1. To examine the emergence, development, and status of fisheries in Katse Dam following large dam construction and to assess the social, ecological, and economic drivers that shaped community adaptation in a traditionally non-fishing area (Chapter 3).
2. To evaluate the potential and challenges of foreign fishing tourism (FFT) as a development pathway in dam-affected areas, with attention to social, economic, and management implications (Chapter 4).
3. To assess the impacts of large dams and inter-basin water transfers on the conservation of the endemic Maloti minnow *Pseudobarbus quathlambae*, and to examine how community perspectives influence support for biodiversity protection in dam-affected areas (Chapter 5).
4. To examine invasive fish colonisation in LHWP reservoirs and evaluate the opportunities and risks it presents for small-scale fisheries development, with attention to the social, economic, and governance factors shaping fisheries outcomes in dam-affected communities (Chapter 6).

Chapter 7 draws together the ecological and social findings of the thesis, situating them within wider debates on large dams, fisheries, and conservation, and outlines the recommendations and global implications.

CHAPTER 2 – OVERVIEW OF THE LESOTHO HIGHLANDS WATER PROJECT

2.1. The Kingdom of Lesotho

The Kingdom of Lesotho is a small (30 350 km^2), high-altitude (> 1 400 m) country surrounded by the Republic of South Africa (Rosenberg and Weisfelder 2013). The country is divided into 10 districts and four geographic zones: the Lowlands (1 400 – 1 800 m), Foothills (1 800 – 2 000 m), Highlands (2 000 – 3 400 m), and Senqu River Valley (1 400 – 1 800 m) (Nhemachena et al. 2017) (Figure 2.1). However, many nationals (Basotho) refer only to the Highlands, known in the vernacular as *lithabeng* ("in the mountains") or *holimo* ("up"), and the Lowlands, known as *mabalane* ("lowlands") or *tlase* ("down") (*mme* Palesa Monongoaha, Head of Environment, Lesotho Highlands Development Authority, pers. comm. July 2024) (Figure 2.2). The major urban centres, including Maseru (the capital), are in the Lowlands.

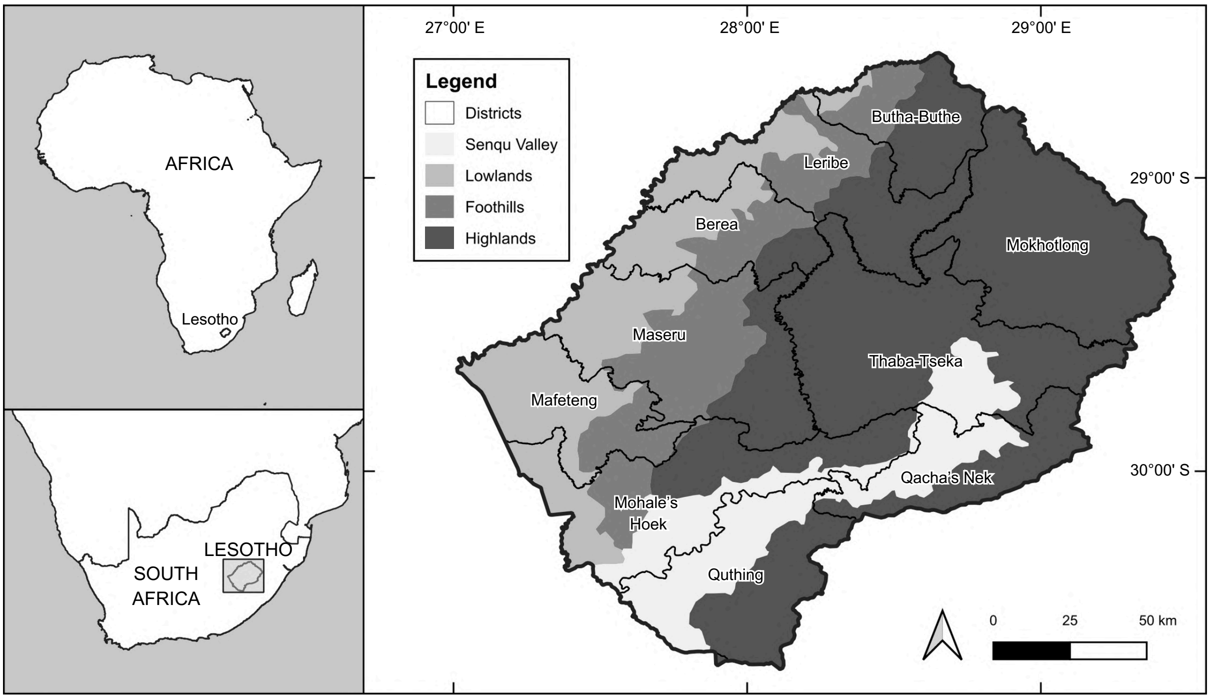

Figure 2.1: Map of Lesotho showing its ten districts and four geographic zones.

Lesotho has a population of approximately 2.3 million people (UNFPA 2024). The majority (74%) of the population resides in rural areas in the Highlands (FAO 2020). Lesotho's economy is based largely on manufacturing, mining, agriculture, and services, and is strongly tied to neighbouring South Africa, which is its most important trade partner and source of employment (Tromp 2006; OEC 2024). Lesotho is classified as a lower-middle income country, although poverty rates are still high, particularly in rural areas where most of the population resides

(World Bank 2024). Nearly half of the population (49.7%) lives below the poverty line, and the unemployment rate is estimated to be 25.3% (World Bank 2024).

Figure 2.2: Lesotho can be broadly split into the Lowlands or *mabalane* (in the foreground) and the Highlands or *lithabeng* (in the background).

2.2. The Lesotho Highlands

The Lesotho Highlands (17 906 km^2) are a rugged and rural area encompassing approximately 60% of Lesotho (Figure 2.3). The Highlands form part of the Maloti-Drakensberg Mountains, a globally recognised biodiversity hotspot with unique alpine and sub-alpine habitats, and several endemic plant and animal species (Kingdom of Lesotho 2019). The topography of the area is characterised by rocky slopes, high peaks, and valleys up to 500 m deep (LHDA 1997). The geology consists of horizontally layered basalt that forms part of the Lesotho formation, itself part of the Stormberg group (Moleko et al. 2011). The vegetation consists primarily of montane grasslands, alpine meadows, and shrublands (Turpie et al. 2014a, 2014b). Suitable arable land is limited (Nhemachena et al. 2017). Natural water resources are abundant, and include numerous high-order clear streams and meandering lower-order rivers (LHDA 1997; Braun and McLees 2012) which primarily form part of the greater Senqu (Orange) River catchment (Figure 2.4). The fish fauna in the Highlands is depauperate and limited to seven native species and three non-native species. Native species include the Maloti minnow

Pseudobarbus quathlambae, smallmouth yellowfish *Labeobarbus aeneus*, largemouth yellowfish *L. kimberleyensis*, Orange River mudfish *Labeo capensis*, rock catfish *Austroglanis sclateri*, sharptooth catfish *Clarias gariepinus*, and moggel *L. umbratus*. The latter two species are largely restricted to lower parts of river catchment areas close to the lowlands. Non-native species include rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* which were introduced into various rivers between the 1930s and the 1960s for sportfishing purposes (Shortt-Smith 1963; Jubb 1972).

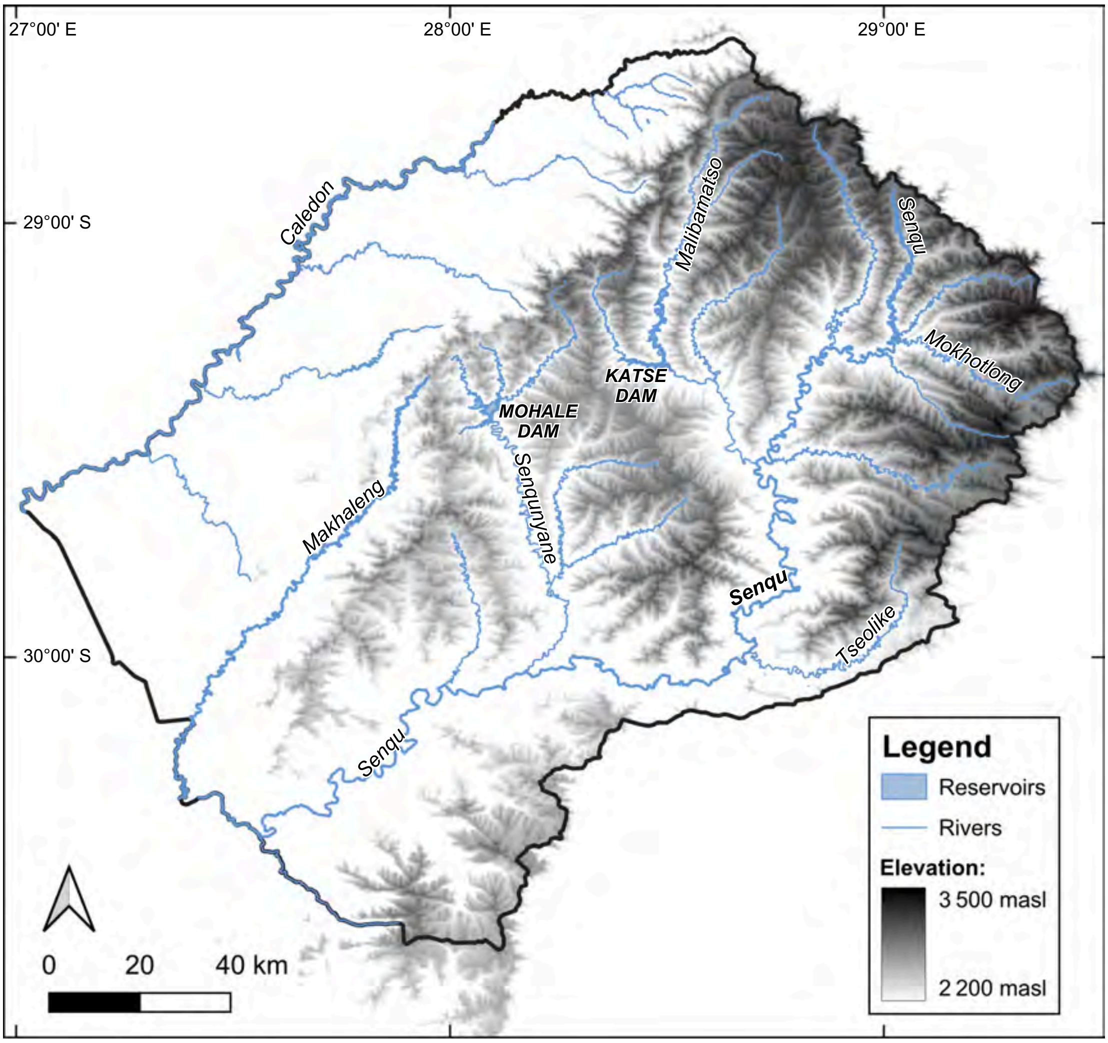

Figure 2.3: Elevation map of the Lesotho Highlands water resources and districts.

The climate is characterised by a cool-temperate summer rainfall season from October to March, and a cold, dry season in the winter months from April to September (Moeletsi 2004). Mean annual temperatures range from below 4°C to 19°C, while mean annual rainfall is approximately 850 mm, 80% of which falls during the summer months (Sene et al. 1998). Snowfall is common, particularly in June and July (Moeletsi 2004; Grab and Nash 2009). The climate is projected to become hotter and drier by the middle of the 21st century, with an increased frequency and magnitude of extreme weather events, most notably droughts and floods (Lewis and Oosthuizen 2014).

Figure 2.4: The biophysical environment in the Lesotho Highlands is characterised by rocky slopes, grasslands, peaks, valleys, and numerous rivers and streams.

There is very little recent information on the demography of the Highlands; the last census was conducted in 2016 (Ministry of Development Planning, Bureau of Statistics 2018). Broadly, the Highlands are characterised by a young population, with the majority (approximately 39%) of persons under the age of 15, and a sex ratio of around 100 females for every 86 males (ERM 2018). The skewed age and gender structure is indicative of the migration of 15–59-year-old males outside the study area to seek employment opportunities. Female-headed households are often more vulnerable to food insecurity and poverty due to gender norms surrounding access to employment and the burden of balancing childcare with work (Letsie and Grab 2015) (Figure 2.5).

Figure 2.5: Households in the Highlands are often female-headed due to the migration of males to seek employment in urban areas in Lesotho and South Africa.

Livelihoods in the Highlands are primarily based on crop and livestock farming (Liphoto 2020) (Figure 2.6). Major crops include maize, wheat, sorghum, beans, potatoes, cabbages that are grown for subsistence purposes, and cannabis, which is grown for commercial and, to a lesser extent, recreational purposes. Important livestock species include sheep and goats for commercial wool and mohair production; multi-purpose cattle that are kept for beef and dairy products, ploughing and as a source of transactional wealth; and horses and donkeys that are used for transport (Liphoto 2020).

Crop yields are typically low (< 1 ton/ha). The available arable land often has thin, poorly anchored, and low fertility soils, and farmers still rely largely on traditional, rainfed, low technology farming methods (Nhemachena et al. 2017). Poor yields are compounded by environmental stressors such as drought, floods, and land degradation (Bosch et al. 2021).

Other traditional livelihood strategies include beer brewing and harvesting and selling medicinal plants and thatching grass (Liphoto 2020).

Figure 2.6: Livelihoods in the Lesotho Highlands are primarily based on crop farming and livestock farming.

Income-earning opportunities in the Highlands are scarce. The main sources, in addition to wool and mohair production, include cash compensation for the development of the Lesotho Highlands Water Project (LHWP) (see Section 2.3); small business ventures e.g., trading, transport, employment e.g., at small, informal retailers and diamond mines; and mining remittances from South Africa (Liphoto 2020). In 2015, male and female unemployment rates were approximately 55–57% and 30–35%, respectively (ERM 2018). Thus, many households face challenges in meeting their basic needs (Mwangi 2007). Most houses have no access to electricity, running water, plumbing, or roads, and are constructed using soils, rocks, and grasses (Figure 2.7). Household energy demands are largely met by harvesting woody shrubs and cow dung for burning (ERM 2018).

Health facilities are few and far between with many residents walking long distances to access medical care. Many of these facilities lack personnel, medical equipment and supplies. Educational facilities are similarly dispersed and difficult to access for some communities, particularly during the rainy season when flooding occurs. There is also a shortage of qualified teachers (ERM 2018). In 2015, approximately 50% of people had a basic education, and 25% had a formal education (Liphoto 2020). Enrolment and completion rates at the secondary education level are generally low; while data specific to the Highlands are lacking, a recent study highlighted that only one in five boys and one in four girls completed secondary schooling in rural areas in Lesotho (Thulare et al. 2023). As such, people lack skills for formal employment (ERM 2018).

Figure 2.7: Examples of typical dwellings in the Lesotho Highlands.

Unemployment and low agricultural productivity in the Highlands (and other rural regions in Lesotho) have historically compelled many people, particularly men, to seek work in urban areas and neighbouring South Africa (Maloka 1995). However, the number of migrant workers has declined significantly over the years, from approximately 127 000 in 1990 to just over 43 000 in 2010, with the contraction of the South African gold mining industry (Mensah and Naidoo 2011).

In summary, communities in the Lesotho Highlands are vulnerable due to the challenging physical environment, demographic structure, limited economic opportunities, and inadequate infrastructure (Letsie and Grab 2015). At the same time, the high altitude and climatic conditions have played a significant role in shaping the livelihoods and culture of its inhabitants, the Basotho, a "fiercely independent" and "proud" people who have adapted to the hostile, physical environment (LHDA 1997) (Figure 2.8). It is within this complex social-ecological context that the LHWP was constructed.

Figure 2.8: The rugged terrain and harsh climatic conditions in the Lesotho Highlands have shaped the culture and traditions of its inhabitants, the Basotho.

2.3. The Lesotho Highlands Water Project

2.3.1. Overview

The LHWP is a large multi-purpose dam project and one of Africa's largest IBWT schemes (Hitchcock 2015) (Figure 2.9). The project supplies water to South Africa's Gauteng Province and generates electricity and export revenue for Lesotho (Matlosa 1998; Hitchcock 2015).

The LHWP was conceived in the 1950s when rapid urbanisation, industrialisation, and population growth in the then Transvaal (now Gauteng) in South Africa led to a significant increase in water demand, which could not be met by domestic supply (Ninham Shand 1956). After years of negotiations, and following a series of feasibility studies, the Governments of Lesotho and South Africa signed a treaty in 1986 to establish, operate, and maintain the project (Government of Lesotho and Government of South Africa 1986).

The LHWP is designed as a multiphase scheme. Phase IA, developed from 1991–1998, involved the construction of the 185 m high Katse Dam (36 km^2) on the Malibamatso River; 82 km of water transfer tunnels; the Muela Tailpond Dam on the Liqoe River; and the 72-megawatt Muela Hydropower Station (LHDA 2023). Phase IB (1998–2004) involved the construction of the 145 m high Mohale Dam (22 km^2) on the Senqunyane River; a 32 km water transfer tunnel to Katse Dam; the Matsoku Weir and a 5 km tunnel linking it to Katse Dam (LHDA 2023) (Figure 2.10) (Table 2.1).

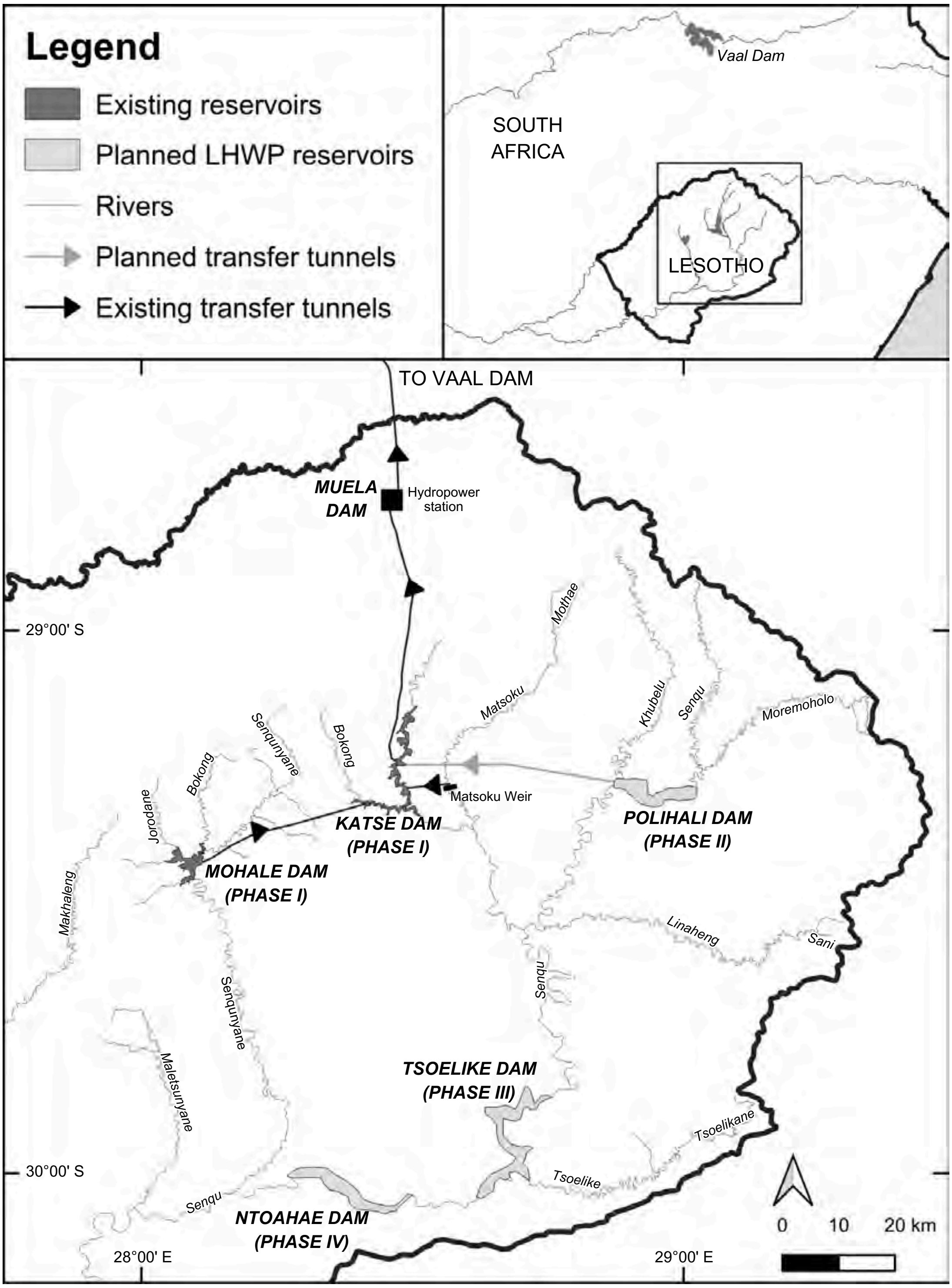

Figure 2.9: The Lesotho Highlands Water Project comprises four phases: Phase I includes three reservoirs, Katse Dam, Muela Dam, Mohale Dam, the 72 MW Muela Hydropower Station, the Matsoku Weir, and 140 km of water transfer tunnels. Phase II is currently under cons

Figure 2.10: Phase I of the Lesotho Highlands Water Project includes the Katse Dam (top left) (Source: Stuart Slabbert); the Mohale Dam (top right) (Source: LHDA); the Muela Tailpond Dam (middle left) (Source: LHDA); the Matsoku Weir (middle right) (Source: LHDA); and 140 km of tunnels (bottom left and bottom right) (Source: Beniamino Pellegrini) that deliver water from the Lesotho Highlands to South Africa.

The total cost of Phase I was approximately USD 3 billion (Haas et al. 2010). Financing for the project came from both international sources, including export credit agencies, the World Bank, the EU Commission, and the European Investment Bank (EIB), and South African sources through export credits and capital markets in the form of "Water Bonds" (Head 2006).

Phase II is currently under construction and includes the Polihali Dam on the Senqu and Khubelu Rivers; a 38 km long water transfer tunnel to the Katse Dam; and the 80 MW Oxbow Hydropower Station (LHDA 2024). The budget for Phase II has been estimated at USD 2.3 billion with financing provided by the African Development Bank (AfDB), the New Development Bank (NDB), other multilateral development banks, and commercial and institutional investors (AfDB 2021). Phases III and IV will see the construction of the Tsoelike Dam and Ntoahae Dam respectively (LHDA 2003). Once completed, the project will comprise five dams and 200 km of IBWT tunnels (Mwangi 2007), with a total water transfer capacity of 2–2.2 billion m^3 per annum (Boers 1987).

Table 2.1: Phases, status, and associated major infrastructure/components of the Lesotho Highlands Water Project.

Phase	**Status**	**Infrastructure/Component**
Phase IA	Completed	Katse Dam (185 m high; 36 km^2)
		Katse–Muela Transfer Tunnel (45 km)
		Muela Hydropower Station (72 MW)
		Muela Tailpond Dam
		Delivery Tunnel South & North (37 km)
		Ash River Outfall
Phase IB	Completed	Mohale Dam (145 m high; 22 km^2)
		Mohale–Katse Transfer Tunnel (32 km)
		Matsoku Weir
		Matsoku–Katse Transfer Tunnel (5 km)
Phase II	Under construction	Polihali Dam (164 m high; 51 km^2)
		Polihali–Katse Transfer Tunnel (38 km)
		Oxbow Hydropower Scheme (80 MW)
Phase III	Future implementation	Tsoelike Dam
Phase IV	Future implementation	Ntoahae Dam

2.3.2. Operations

Phase IA became operational in January 1998 with the first successful water transfer to South Africa (LHDA 1998). Power generation commenced in January 1999 (LHDA 1999). The completion of Phase IB in 2004 provided additional capacity. The fundamental functions and operations of Phase I are shown in Figure 2.7. Water is transferred from the Katse reservoir through a 45 km transfer tunnel to the Muela Hydropower Station. At Muela, the water generates electricity before it enters the Muela Tailpond Dam. From there, it flows through a 15 km tunnel to the Lesotho-South Africa border and then via a 22 km tunnel to the Ash River Outfall near Clarens in South Africa. At the outfall, the water is discharged into the Ash River, where it flows into the Liebensbergsvlei River, and finally into the Wilge River before reaching the Vaal Dam, a journey of 200 km (Hitchcock 2015) (Figure 2.11).

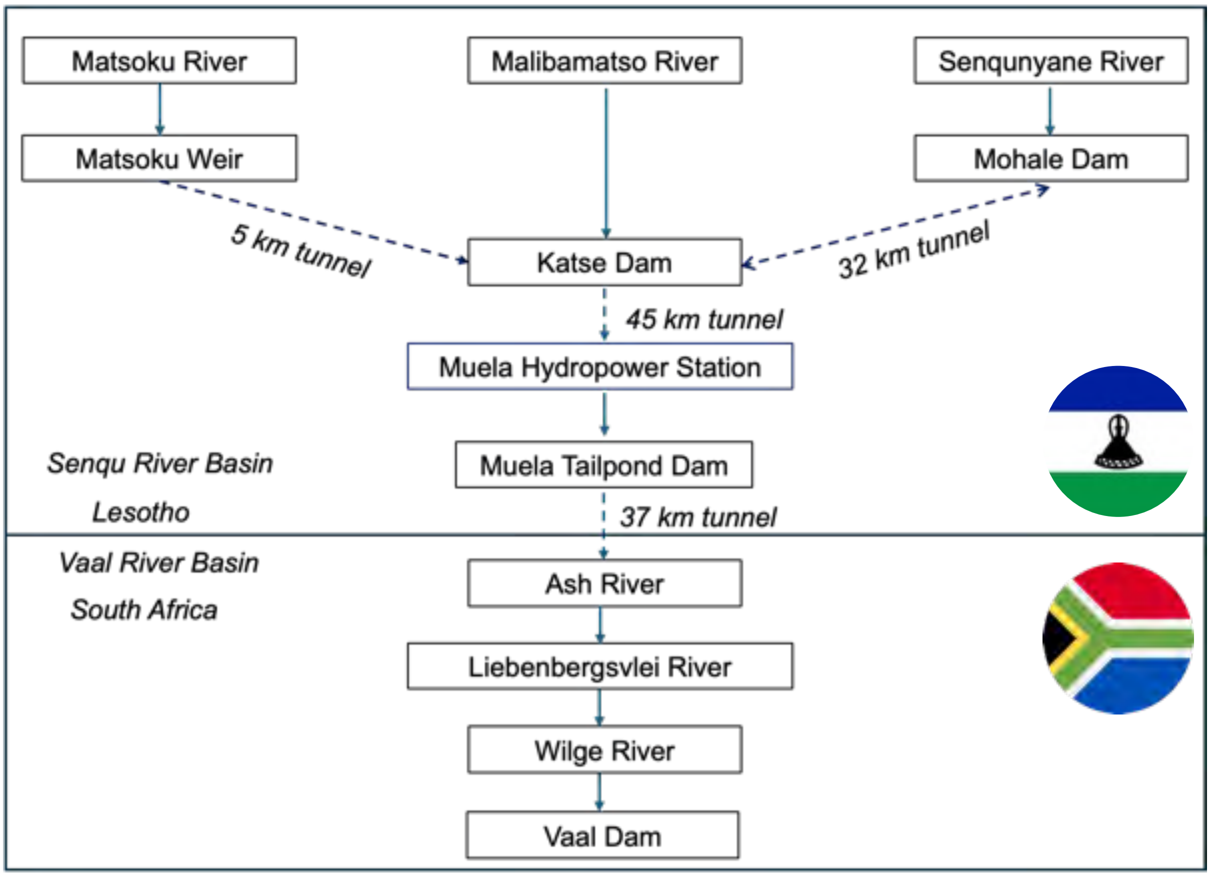

Figure 2.11: Conceptual overview of the key components and water transfer process of Phase I of the LHWP. Dashed lines indicate tunnels; solid lines represent flow of water in natural watercourses.

From 2000 to 2023, 17 billion m^3 of water was transferred to Gauteng, while total electricity generation over the same period was approximately 10 940 gigawatt hours. On average, the project transfers in the region of 750 million m^3/annum to South Africa (equivalent to c. 300 000 Olympic-sized swimming pools) and generates 475 gigawatt hours of electricity per year (LHDA, unpublished data, 2024), sufficient to cover roughly half of Lesotho's domestic demand (Figure 2.12).

2.3.3. Governance

Three primary institutions are involved in governing the project: the Lesotho Highlands Water Commission (LHWC), the Lesotho Highlands Development Authority (LHDA), and the Trans-Caledon Tunnel Authority (TCTA) (Figure 2.13) (LHDA 2023). The LHWC is a bi-national body with representatives from Lesotho and South Africa. It has overall responsibility for the project, sets strategic and policy directions, monitors the activities of both the LHDA and TCTA, and advises both the Lesotho and South African governments on all LHWP-related matters (LHDA 2023).

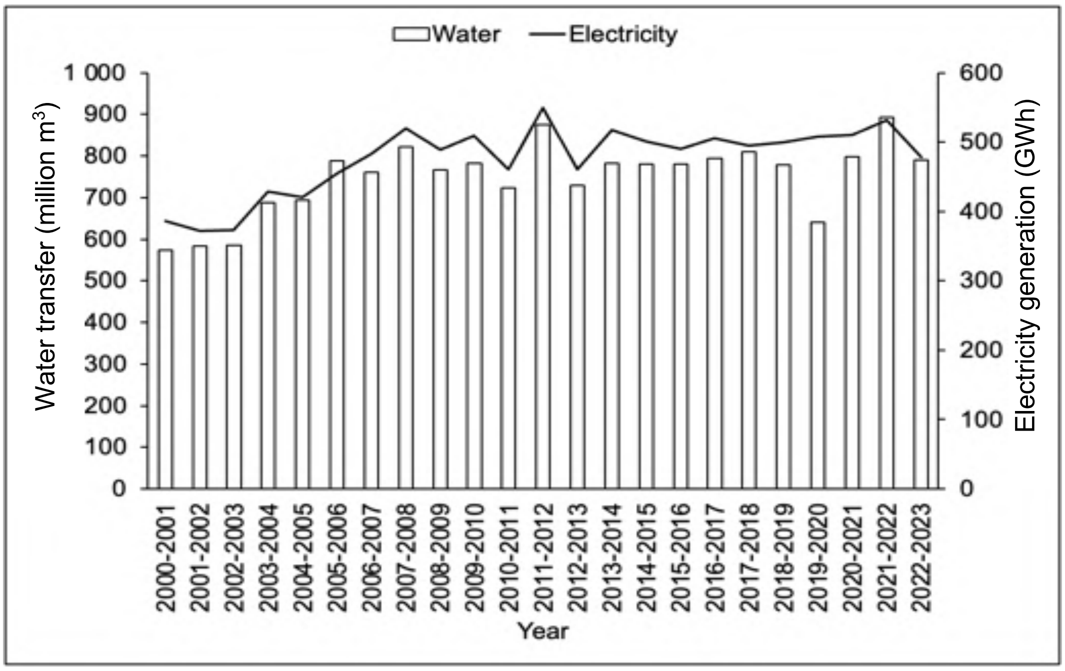

Figure 2.12: Water transfers (million m3) and electricity generation (GWh) from Phase I, 2000/1–2022/23.

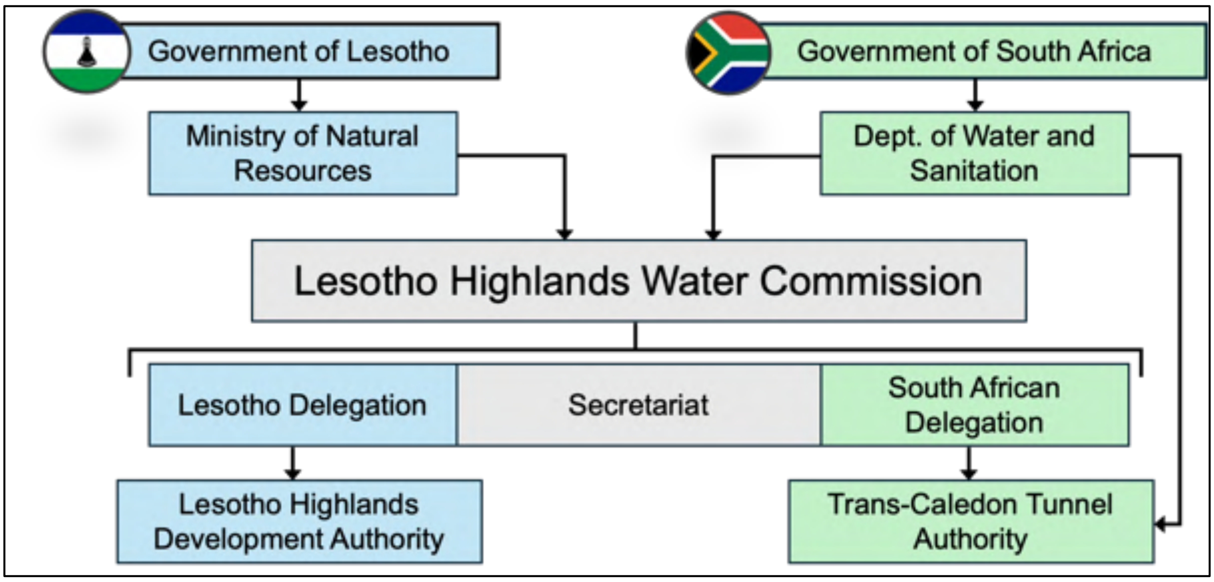

Figure 2.13: Governance framework of the Lesotho Highlands Water Project.

The LHDA reports to the LHWC and is responsible for the implementation, operation, and maintenance of the project in Lesotho. This includes aspects related to relocation, resettlement, compensation, community development, livelihood restoration, environmental monitoring and management. The LHDA collaborates with various central government ministries in sectors such as agriculture, energy, and mining (LHDA 2023).

The TCTA is responsible for implementing, operating, and maintaining project components within South Africa. The TCTA also manages funding and debt payments, including raising finance (TCTA 2023).

The cost allocation for infrastructure and other project components is clearly defined in the LHWP Treaty (Government of Lesotho and Government of South Africa 1986). South Africa, through the TCTA, is responsible for financing all aspects related to water delivery. This includes the cost of constructing and maintaining dams, tunnels, and other water transfer infrastructure in both Lesotho and South Africa. The TCTA covers these costs by raising loans from financial markets, which are guaranteed by the South African government. These loans are serviced through water sales (TCTA 2023). Lesotho is solely responsible for funding the hydroelectric power generation components of the project. Similarly to the TCTA, the LHDA is responsible for raising finance, typically from development banks and other financiers, for these components (LHDA 2023). These loans are serviced through water and electricity sales. Other components of the project, including compensation, social development and environmental management programmes, are funded by the LHDA through a combination of monies received from royalties and/or international donor organisations (LHDA 2023).

South Africa pays for its water by collecting tariffs from water users which are then disbursed by the Department of Water and Sanitation to the TCTA. The TCTA pays royalties for the water to the Government of Lesotho. The royalties include both a fixed component paid over 50 years and a variable component based on the quantum of water delivered. Monies are also allocated to LHDA for operational, maintenance, and construction costs, and to debtors (TCTA 2023). The LHDA sells power to both the Lesotho Electricity Company (LEC) in Lesotho and the Electricity Supply Commission (ESKOM) in South Africa (LHDA 2024).

2.3.4. Impacts

Since it became operational, the LHWP has made a significant contribution to Lesotho's economy. From 2000/2001 to 2022/2023, Phase I of the LHWP generated revenues from water and electricity sales of approximately USD 1.3 billion. Over the same period, annual revenues from water sales increased by approximately 14% from USD 18.4 million to USD 77.0 million. The contribution of Phase I revenues to gross domestic product (GDP) and total government revenues largely fluctuated from 3–5% and 5–7%, respectively (Figure 2.14). In 2022/2023, the LHWP's contribution to GDP (3.4%) was more than half of that of the agriculture sector (6.2%) and a third of that of the diamond mining sector (approximately 10%). In the same period, water was the fourth most exported commodity (9.5%), after textiles (44%) and diamonds (19%) (BOS 2023).

The project has also enhanced Lesotho's energy security and self-sufficiency. While revenues from electricity have largely stayed consistent since the project became operational, the Muela hydropower station generates around 72 megawatts (MW) of power, approximately half of national demand (145 MW), reducing the country's expenditure on electricity imports from South Africa and Mozambique (LHDA 2022).

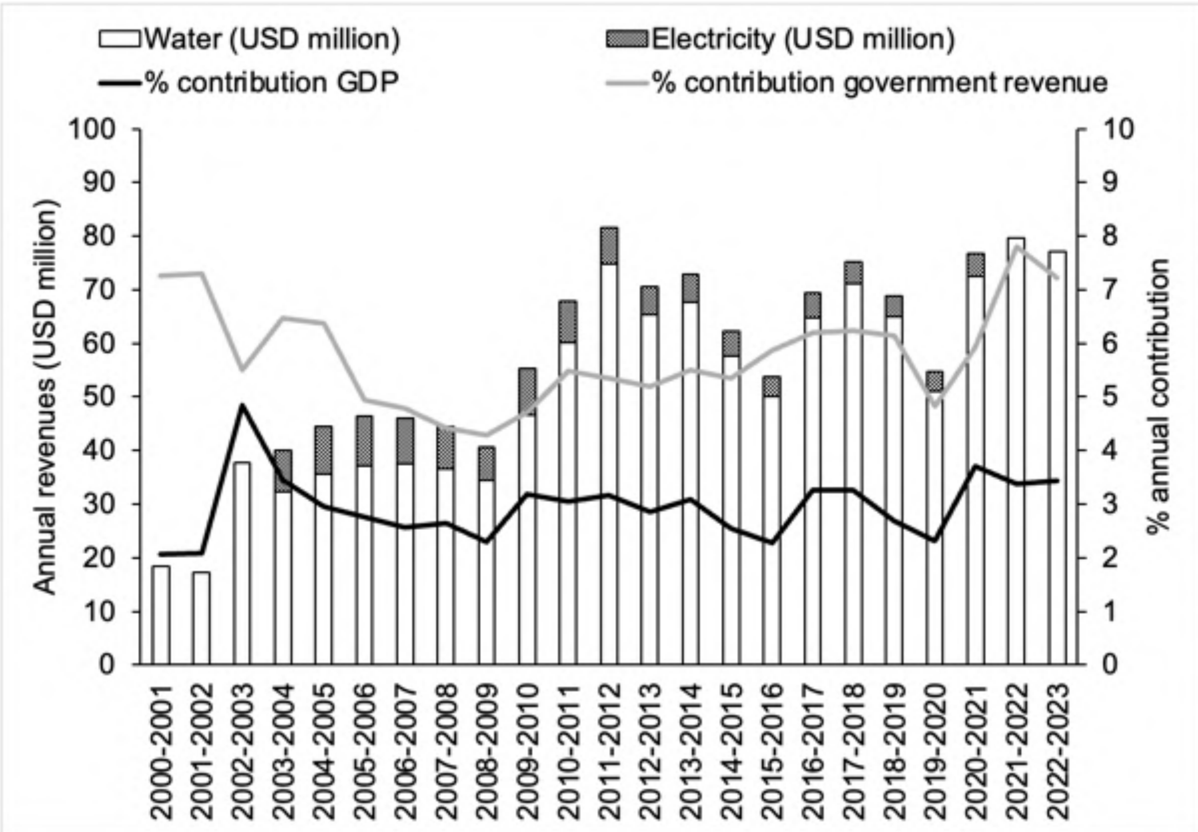

Figure 2.14: Annual revenues derived from water and electricity sales from Phase I of the LHWP and their contribution to GDP and government revenue, 2000/2001–2022/2023 (no data were available on electricity sales for 2021/2022 and 2022/2023).

An estimated 37 400 jobs were created during the construction of Phase I (Mofokeng 2013). In addition, the construction of over 700 km of new roads, the rehabilitation of over 1 100 km of existing roads, the installation of more than 300 km of power lines, and a series of electrification projects improved access to basic services for some rural communities, and stimulated trade, local economic development, and livelihood diversification (Manwa 2012). Commercial buildings, houses, clinics, and schools constructed specifically for the project were also handed over to the local communities at the end of the Phase I construction period (LHDA 2022).

Nevertheless, while the economic benefits of the project to date have been significant, as with other large dam projects there is some debate over the extent to which the LHWP has improved the livelihoods of communities in the project area (Hoover 2001; Keketso 2003; Turton et al. 2003; Matete 2006; Ramaili 2006; Mwangi 2007; Letsebe 2012; Mofokeng 2013; Makoro 2014; Manwa 2014; Hitchcock 2015; Liphoto 2020).

As per the LHWP Treaty, the LHDA is obligated to compensate all communities affected by the project works to ensure that affected people maintained a standard of living "not inferior to that obtaining at the time of first disturbance" (Government of Lesotho and Government of South Africa 1986). However, the development of Phase I of the LHWP, and associated compensation measures, were largely imposed on local communities; the project proponents did not obtain "Free, Prior and Informed Consent" (FPIC) and, as such, the local communities had little to no say on whether the project should go forward and how they should be compensated (Hitchcock 2015). Community members were often unable to grasp the enormity of the project and the impact it would have on their lives (*ntate* Moea, Morena of Ha Kekane, Katse Dam, pers. comm. June 2024). Moreover, initial consultations were sometimes led by the military government of Lesotho at the time creating an environment which prevented people from questioning or speaking freely about their concerns (*ntate* Moea, Morena of Ha Kekane, Katse Dam, pers. comm. June 2024).

Phase I directly displaced approximately 400 households and caused the loss of agricultural land, other natural resources (e.g., medicinal plants, wild vegetables), traditional and cultural assets, and religious and burial sites (Hitchcock 2015). The resettlement process was challenging for many families. Some households were moved from their ancestral lands in the highlands to urban areas in the lowlands, where they struggled to adapt to a new way of life and faced difficulties maintaining their traditional livelihoods (Liphoto 2020). Others were relocated to other villages in the Highlands close to their original lands but still suffered from a deep sense of loss and difficulties integrating into the new community (*mme* Nthabiseng Morokole, Head of Fisheries and Aquaculture, LHDA, pers. comm. 2024). Displacement also led to health and other psychosocial impacts; HIV/AIDS transmission rates skyrocketed, families were separated, social relations were strained, and belief systems were devalued, leading to a heightened sense of insecurity and vulnerability, as well as social conflict and resentment towards authorities (Mwangi 2007).

The compensation approach taken by the LHDA has involved resettlement, cash payments, land-for-land swaps, the distribution of grain, the construction of housing, schools, bridges, and clinics, electrification and sanitation projects, and community development programmes in enterprise development, agriculture, tourism, and fisheries (Hitchcock 2015; LHDA 2023). Historically, governance and management challenges undermined the efficacy of certain compensation measures in addressing the needs of affected communities. The resettlement processes were often mishandled due to their complexity, with accusations of unfair distribution of land and resources among affected households. Power dynamics and the lack of transparency in these processes further complicated the situation, leaving many resettled families feeling disenfranchised (Moleko et al. 2011; Lehema 2020). Mismanagement of funds and instances of corruption eroded trust between project authorities and local communities (Devitt and Hitchcock 2010; Moleko et al. 2011). Despite the establishment of community liaison committees, meaningful participation from those most affected by the project was often lacking. This exclusion led to the implementation of solutions that did not fully address the needs and concerns of affected populations (Hoover 2001; Moleko et al. 2011). For example, the cash compensation provided often fell short of addressing issues including the loss of social cohesion and cultural heritage (Scudder 2012). The LHDA has made concerted efforts to address these and other issues, with many lessons learned over the last 35 years (*mme* Nthabiseng Morokole, Head of Fisheries and Aquaculture, LHDA, pers. comm. June 2024). Nevertheless, there is still a degree of resentment and ill-feeling among some project-affected communities towards the authorities and other implementing partners, and many are of the opinion that the quality of their lives is now worse (*ntate* Moea, Morena of Ha Kekane, Katse Dam, pers. comm. June 2024).

The environmental impacts of Phase I were also significant (Mwangi 2007; Hitchcock 2015). The construction of Katse and Mohale significantly altered the hydrological landscape of the Highlands. Inundation of the catchment areas not only led to significant habitat loss, but also intensified livestock grazing and agriculture in the smaller areas of arable land that remained for the affected communities (Hoover 2001). The most recent comprehensive ecological studies of these catchments showed that the project had “seriously impaired” the health of wetlands, “largely impaired” land cover and vegetation, and “moderately impaired” river health and the health of avifauna and mammalian fauna (Turpie et al. 2014a, 2014b). Downstream of the dams, the project has led to increased sedimentation, habitat degradation, and habitat fragmentation (Schrijvershof 2015). The IBWT tunnels have also facilitated the invasion of

Mohale Dam by non-native fishes which has led to population declines of the endemic *P. quathlambae* (Shelton et al. 2017; see Chapter 5).

The LHDA has implemented a range of environmental programmes and mitigation efforts to address the environmental impacts of the project. These include, amongst others, the establishment of a dedicated Biodiversity Management Unit (BMU), an Integrated Catchment Management (ICM) programme, wetland rehabilitation efforts, the translocation of wildlife, water quality and instream flow requirements (IFR), monitoring, solid waste management programmes, and environmental awareness initiatives. These environmental programmes have demonstrated success, although issues remain in terms of funding as well as knowledge gaps, especially surrounding the impact of the project on the endangered *P. quathlambae* and the sustainability of fishing activities in the project area (*mme* Palesa Monongoaha, Head of Environment, LHDA, pers. comm. 2021).

2.4. Summary

The Lesotho Highlands Water Project (LHWP) mirrors the impacts and complexities associated with many large dam projects worldwide. As demonstrated in this chapter, while the LHWP has brought economic benefits and infrastructure improvements to Lesotho, it has also created issues in a socially vulnerable and ecologically sensitive region (Figure 2.15).

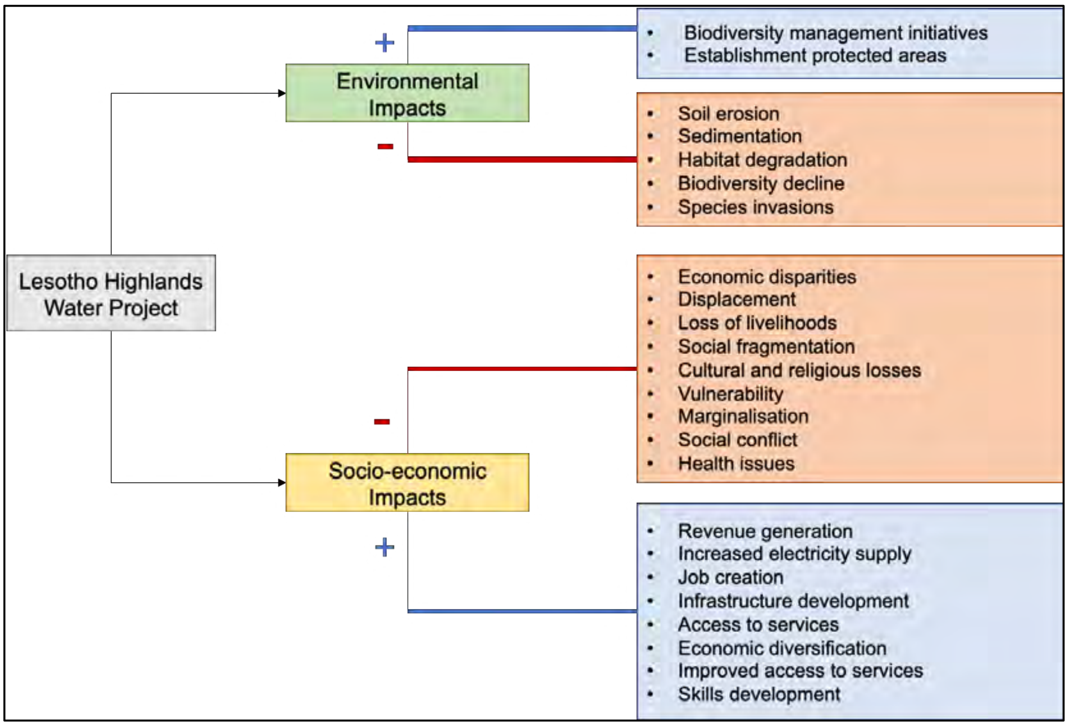

Figure 2.15: Environmental and social impacts of the Lesotho Highlands Water Project; "+" denotes positive impact, "-" denotes negative impact.

The creation of major reservoirs like Katse and Mohale, and a large inter-basin water transfer system, has significantly altered the environmental and socio-economic dynamics of the project area and the Lesotho Highlands as a whole. However, in contrast to other large dam projects (see Chapter 1), how these changes have shaped the fish and fisheries landscape is largely undocumented. Since the completion and filling of the Katse Dam, only two post-impoundment studies have been conducted on its fish populations, both more than twenty years ago (Tweddle and Davies 1997; Nthimo 2000). Even less is known about the fisheries of Mohale Dam. The only quantitative assessment of the fish populations was conducted in 2011 (Hecht and McCafferty 2011). While slightly more research on *P. quathlambae* has been conducted (see Rall and Sephaka 2008; Shelton et al. 2017), the last study was over a decade ago and focussed only on the impacts of the Mohale Dam and not the broader project area.

The LHDA remains committed to "improving the standard of living of communities affected by the LHWP" and ensuring the "sustainable management of [the] biophysical environment within the LHWP area" (LHDA 2020). This includes strategies focussed on sustainable development and management of fisheries as a means of promoting alternative livelihoods and food security and ensuring the conservation of aquatic biodiversity (*mme* Palesa Monongoaha, Head of Environment, LHDA, pers. comm. 2020). However, there is a lack of necessary information to achieve these goals. As the project continues to develop, there is a need for a more holistic assessment of its impacts on fish and fisheries, both to inform management practices and to guide future phases of the project. This will be explored in the chapters that follow.

CHAPTER 3 – BREAKING TRADITION: THE DEVELOPMENT OF AN INLAND CAPTURE FISHERY IN A LARGE ALPINE DAM IN LESOTHO, SOUTHERN AFRICA

3.1. Introduction

Large dams play an important role in addressing energy and water needs, supporting food production, and stimulating economic growth (Shi et al. 2019). However, they may also have profoundly negative social and environmental impacts (Schulz and Adams 2019). It is conservatively estimated that at least 80 million people have been directly and involuntarily displaced by large dams in the last century, with millions more indirectly displaced by losing access to resources and assets that supported their livelihoods (Cernea 1997; Commission on Dams 2001; Scudder 2012). Displacement caused by large dams has led to unemployment, food and nutrition insecurity, lost livelihoods, social and cultural disruption, and psychosocial trauma (Richter et al. 2010). These impacts were described as "unacceptable" by the Commission on Dams (2001) at the turn of the century. Despite these concerns, large dams remain firmly on the social and economic growth agenda, particularly in the developing world where there are untapped water resources and considerable political appetite for mega-infrastructure development (Shumilova et al. 2018; Shi et al. 2019). As such, furthering our understanding of how communities adapt to their new environments following large dam construction may contribute towards identifying strategies that can mitigate their negative social and economic impacts (Randell 2022).

Adaptation strategies following dam-induced displacement are diverse and context-specific (Scudder 2012), and often linked to several interacting socio-economic (e.g., income, education, health); cultural (e.g., traditional livelihoods and food systems, spiritual beliefs, heritage); environmental (e.g., biophysical changes, and changes in access to and availability of natural resources); and governance factors (e.g., compensation policies, transparency, consultation) (Cernea 1997).

Some communities impacted by large dam projects successfully adapted their livelihoods to the new "landscape". In Vietnam, households displaced by the Son La Dam adopted new agricultural practices and aquaculture, promoted by government and non-governmental organisations (NGOs), which helped improve their livelihoods (Nguyen et al. 2017). Similarly, communities displaced by the Manwan Dam in China adapted to tea and rubber farming livelihoods (Tilt 2015). In Brazil, some communities displaced by the Tucuruí Dam found new employment opportunities in urban areas, supported by government-led vocational training programmes (Fearnside 1999).

However, many other displaced communities struggle to adapt to their new environments, particularly where alternative livelihood opportunities do not align with their traditional practices and knowledge. For instance, rural communities displaced by the Three Gorges Dam in China faced significant challenges in adopting urban livelihoods due to a lack of relevant skills (Wilmsen 2011), while traditional farming communities displaced by the Nam Theun 2 Dam in Laos struggled to convert to new agricultural techniques (Lawrence 2009). Broadly, although a few studies have reported instances of improved livelihoods for displaced people (Agnes et al. 2009; Galipeau et al. 2013), most of the research indicates the opposite (Kura et al. 2017).

In the context of large dam development and inland capture fisheries (the extraction of living aquatic organisms from natural or man-made inland waters excluding aquaculture (Funge-Smith 2018)), much of the research has focussed on understanding the negative impacts of these projects on ecosystems supporting major inland fisheries, and in areas where fishing is a traditional livelihood and an intrinsic part of the social and cultural fabric of communities. These negative impacts are well documented (see Chapter 1). In comparison, there is a notable gap in the literature of how fishing might emerge as a new livelihood option for dam-affected communities where it was never an important activity or tradition. Increasing our understanding of these cases could provide further insights into the adaptive capacities of dam-affected people, and potentially reveal opportunities for livelihood diversification that can inform displacement mitigation strategies in future.

In many parts of Africa, particularly in sub-tropical and tropical latitudes with abundant and productive water resources, inland fishing is a centuries-old livelihood (Bruton 2016) (Figure 3.1). Here, fishing not only constitutes an important source of food and nutrition, income, and employment (FAO 2014; Lynch et al. 2016) but also holds significant socio-cultural value, often shaping local traditions, diets, and identities (Bulengela 2024). The Kingdom of Lesotho, however, is somewhat anomalous in the context of African inland fisheries. A semi-arid, high-altitude country, Lesotho lacks large, productive, natural water resources, which in other parts of the continent support important inland fisheries. The indigenous people of Lesotho, the Basotho, are traditionally pastoralists whose identities, culture and livelihoods are founded on livestock and crop farming, and for whom fishing has never been a traditional or important activity (Turner 1978; Bain 1990; Skelton 1996). These factors, coupled with the real or perceived cultural resistance among Basotho to consuming fish as opposed to other sources of protein (such as chicken), meant that inland capture fisheries in Lesotho were never developed or promoted to any significant extent (Sen 1989). Rather, the trajectory of inland fisheries development was influenced primarily by colonial-era introductions in the early 20th century of non-native fishes such as trout for recreational angling (Shortt-Smith 1963).

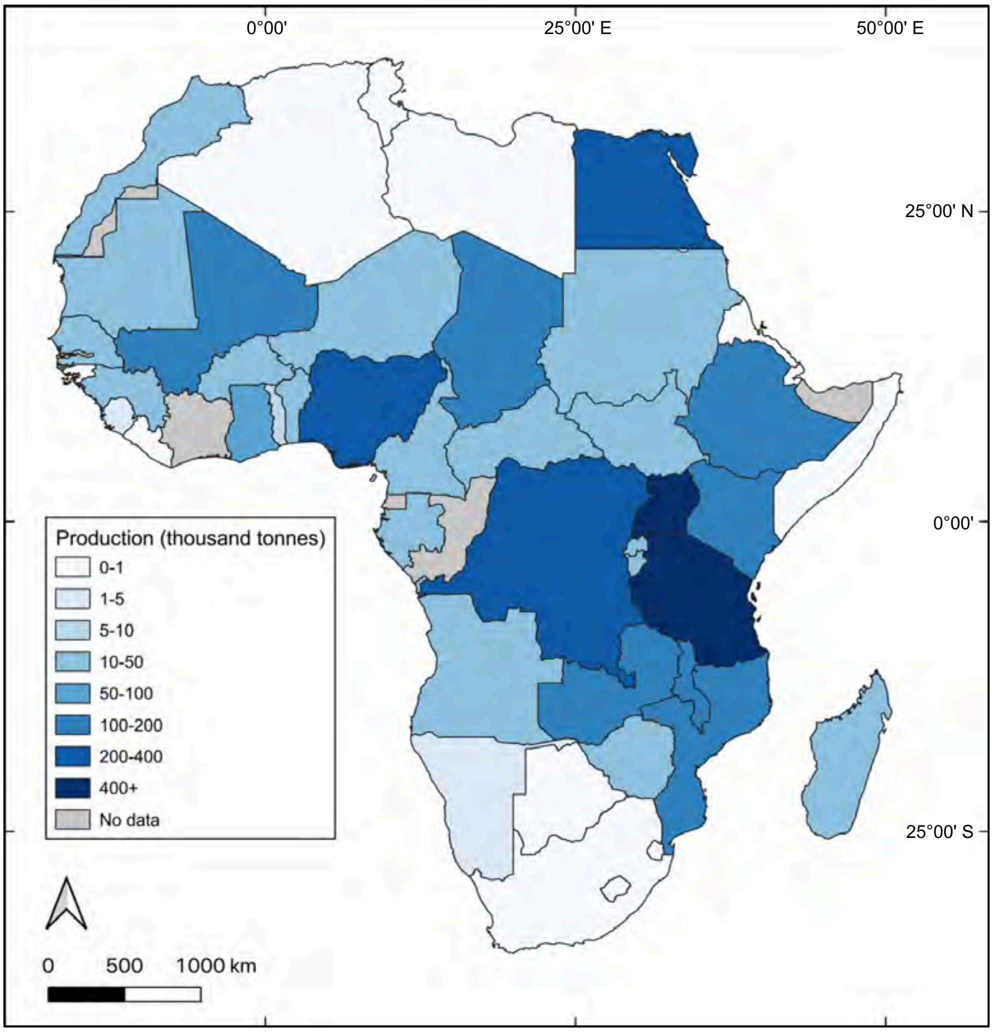

Figure 3.1: Inland fisheries production (tonnes) in Africa, 2022; major producer countries are located largely at tropical and sub-tropical latitudes with abundant water resources (Source: FAO FishStatJ 2024; figure adapted from Funge-Smith 2018).

The construction of the Katse and Mohale dams comprising Phase I of the Lesotho Highlands Water Project (LHWP) (see Chapter 2) in the 1990s and early 2000s significantly altered the hydrological landscape of the Lesotho Highlands, creating entirely new aquatic environments in a region traditionally characterised by small, seasonal, mountain streams. Katse Dam, completed in 1997, is the largest dam in Lesotho and the highest and deepest dam in Africa (Doyle et al. 2001; Hitchcock 2015).

In the 1980s, prior to the development of the LHWP, it was recognised that the project would negatively impact the livelihoods of some local communities, and that there was a need to identify potential alternative livelihood or income-generating opportunities once the dams had been constructed. The pre-impoundment LHWP Phase I feasibility study, conducted from 1983–1986, identified capture fisheries development in the dams as one such opportunity worth pursuing (Lahmeyer Macdonald Consortium and Olivier Shand Consortium 1986; Van Robbroeck 1986). Subsequently, the opportunity was formally recognised in the LHWP treaty signed by the Governments of South Africa and Lesotho in 1986, which states that both parties can undertake "ancillary developments" including the development of fisheries (Government of the Kingdom of Lesotho and Government of the Republic of South Africa 1986).

However, expectations that Katse Dam could support capture fisheries of any significance were tempered after a series of pre-impoundment studies were conducted in the late 1980s and 1990s (Bain 1990; Eccles 1990; Skelton 1996). Based on the climate and topography of the area, and the anticipated depth, low conductivity, and low water temperatures of the dam, maximum fish yields were predicted to be "low" at around 14–28 tonnes per year (Eccles 1990). In addition, the limited diversity of the fish fauna (namely three species, the native smallmouth yellowfish *Labeobarbus aeneus* and Orange River mudfish *Labeo capensis*, and non-native *Oncorhynchus mykiss*); the lack of a tradition of fishing and fish handling among local communities; and the "very minor" contribution of fish to local diets, were considered major barriers to the establishment of any notable capture fisheries (Bain 1990; Eccles 1990; Skelton 1996). Indeed, Bain (1990) concluded that any move to even initiate subsistence fishing and the consumption of fish by local communities would require concerted training and community sensitisation, a view supported by Skelton (1996) given that there was "absolutely no tradition of fishing in the area".

Katse Dam was completed in 1996 and filled with water in 1997 (LHDA 1998). Tweddle and Davies (1997) and Nthimo (2000) conducted the only post-impoundment studies of the fish populations of the dam. Tweddle and Davies (1997) concluded that *L. aeneus* could support a "subsistence gillnet fishery" although potential harvest volumes were not stated. Nthimo (2000) suggested establishing a 25 tonnes per year gillnet fishery for *L. aeneus* and *L. capensis*, a production volume largely aligned with previous empirical estimates of productivity (Eccles 1990). Nthimo (2000) also provided the first evidence that hook-and-line fishing had started on the dam following the "large" influx of people from South Africa and other parts of Lesotho who were employed by, or sought employment with, the dam construction companies. It was also noted that some residents had also begun fishing at this time (Nthimo 2000).

In 1999, the *Lesotho Highlands Water Project (Reservoirs) Fishing Regulations, 1999* (the Regulations) (Kingdom of Lesotho 1999) were formulated by the Lesotho Highlands Development Authority (LHDA) (the authority charged with fisheries management and monitoring in the LHWP area). The Regulations permit hook-and-line fishing, with a total bag limit of four fish per day and a minimum size limit of 250 mm. Seasonal closures apply in inflowing rivers and designated upstream areas from May to August each year. Fishing permits are compulsory, and permit holders must present permits, catches, and tackle for inspection when requested by LHDA staff. The regulations only provide for hook-and-line fishing; the existing gillnet fishery therefore operates illegally. The decision-making process that led to the provisions in the Regulations is unclear.

The findings of Nthimo (2000) later informed the development and implementation in 2002 of the Lesotho Fisheries Project (LFP) in the LHWP reservoirs. During the LFP, fishing groups were established, provided with fishing gear, and trained in making and using gillnets with a view to revising and formalising gillnet fishing. Ultimately, however, no formalised fishery was established. This was linked to administrative issues and budgetary constraints (*mme* Palesa Monongoaha, Head of Environment, LHDA, pers. comm. 2019). The Regulations were never revised, meaning that despite the training provided during the LFP, gillnet fishing remained illegal.

No further efforts were made to develop fisheries, and no further studies were conducted. Over the last decade, however, a rapidly-growing hook-and-line fishery and an illegal, small-scale commercial gillnet fishery have emerged. Anecdotal reports suggest that fish is increasingly becoming an important income and protein source for local communities, and that a value-chain has developed which supplies local, national, and South African markets. These developments would appear to challenge previous assumptions that no fisheries of any significance would develop in the area given the perceived cultural barriers to fishing and fish consumption among local communities and the Basotho people at large, as well as the limited productivity and ichthyofauna of Katse Dam. They also raise questions as to how communities respond to social and ecological change caused by large dams, and how they may adapt to the challenges and opportunities they provide.

Using the case study of the Katse Dam fishery, this chapter examines how new livelihood opportunities can emerge following large dam development. By assessing the evolution of fishing practices in a traditionally non-fishing area, and characterising the current scale and structure of the fishery and its value chain, this research aimed to further our understanding of how dam-affected communities reorganise and adapt when confronted with new social and ecological realities.

To address these aims, the chapter considers the following research questions:

1. What were the origins and pathways that shaped the emergence of the Katse Dam fishery?
2. What are the characteristics, levels of participation, and catch of the hook-and-line fishery?
3. What is the extent, composition, and dynamics of the illegal gillnet fishery?
4. How has a local value chain developed around these fisheries, and what are its main features?
5. How do these fisheries and their associated value chain reflect broader processes of community adaptation to the ecological and social changes brought about by dam construction?

Practical recommendations for improving fisheries management and value chain development are outlined, alongside key lessons for broader fisheries development and dam planning globally.

3.2. Materials and methods

3.2.1. Conceptual overview of study approach

The study used a mixed-methods approach grounded in social-ecological systems (SES) principles (Berkes and Folke 1998; Ostrom 2009) focussed on understanding both the ecological and human dimensions of the fishery. (Note: the theoretical orientation and SES framing that guide this approach are outlined in Chapter 1). Mixed-methods approaches that integrate qualitative and quantitative social and ecological data have been shown to provide a fuller understanding of complex inland fisheries (Downing et al. 2014; Lorenzen et al. 2016), including those with illegal fishing activities (Free et al. 2015), and in studies examining livelihood changes following large dam development (Obour et al. 2015; Roquetti et al. 2024). They are also well aligned with emerging approaches to inland fisheries research and management that emphasise the importance of integrating ecological and human dimensions (Beard et al. 2011; Nguyen et al. 2017; Cooke et al. 2021) and using local ecological knowledge (LEK) in data-poor situations (Russell et al. 2012; Nunes et al. 2019; Cooke et al. 2021; Petriki et al. 2024). A conceptual overview of the approach is shown in Figure 3.2.

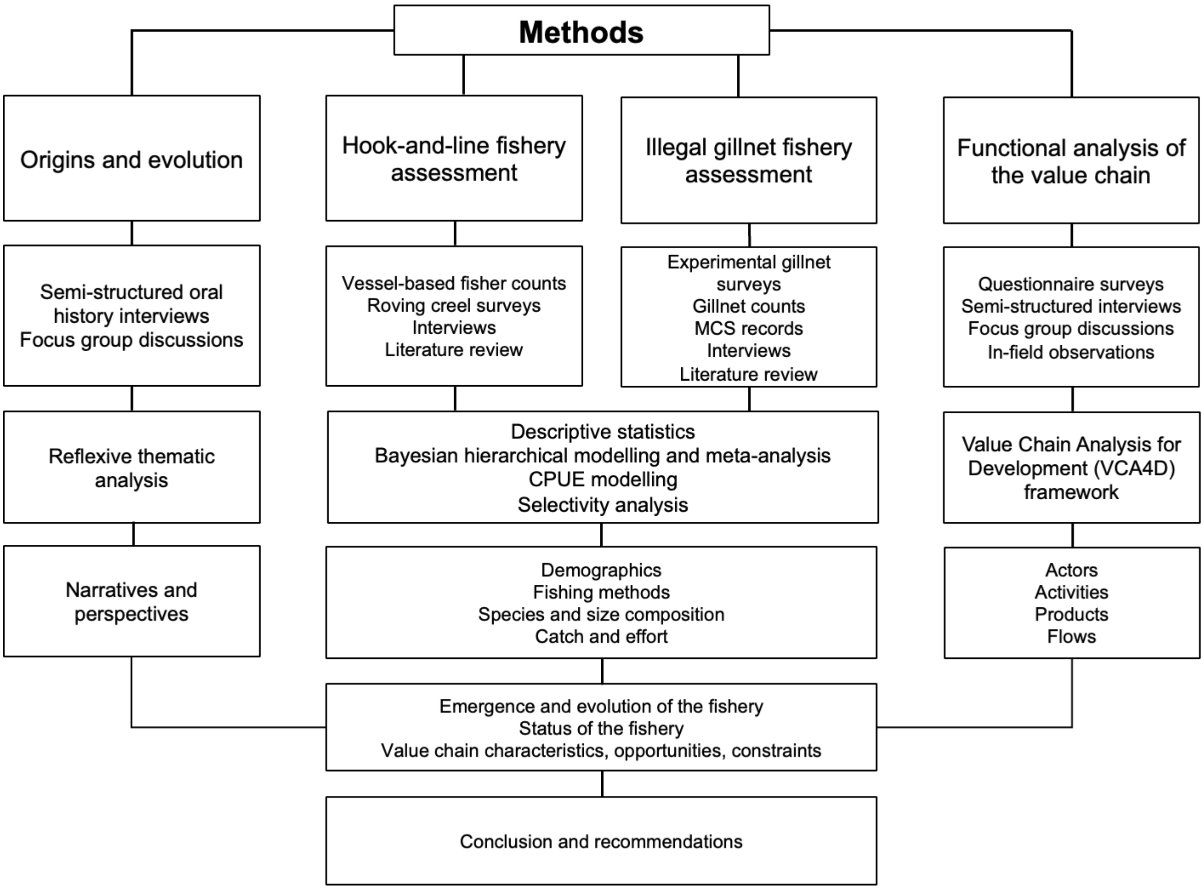

Figure 3.2: Conceptual overview of the mixed-methods approach used in this study.

The specific methods included:

1. Semi-structured oral history interviews, focus group discussions, and reflexive thematic analyses to explore the emergence and evolution of fishing in Katse Dam and its catchment.
2. Fisheries-dependent and -independent surveys, questionnaire surveys, semi-structured interviews, focus group discussions, Bayesian modelling, CPUE standardisation, and selectivity analyses to assess the scale and characteristics of the hook-and-line fishery and the illegal gillnet fishery.

3. A functional analysis of the fisheries value chain based on questionnaires, semi-structured interviews, focus group discussions, and in-field observations using the Value Chain Analysis for Development (VCA4D) framework .

All interactions with human participants were approved by Rhodes University Human Research Ethics Committee (NHREC Registration number: RC-241114-045). Animal ethics approvals were obtained from the Chairperson of the Rhodes University Animal Research Ethics Committee (RUAREC) and the Executive Committee of RUAREC (RUAREC – CW02/2024).

3.2.2. Study site

Katse Dam is a double curvature, 180 m high, concrete arch dam on the Malibamatso River (MacKellar 1994). The Katse Dam catchment can be split into two sub-catchments: (1) the Malibamatso River sub-catchment, and (2) the Bokong River sub-catchment (Figure 3.3).

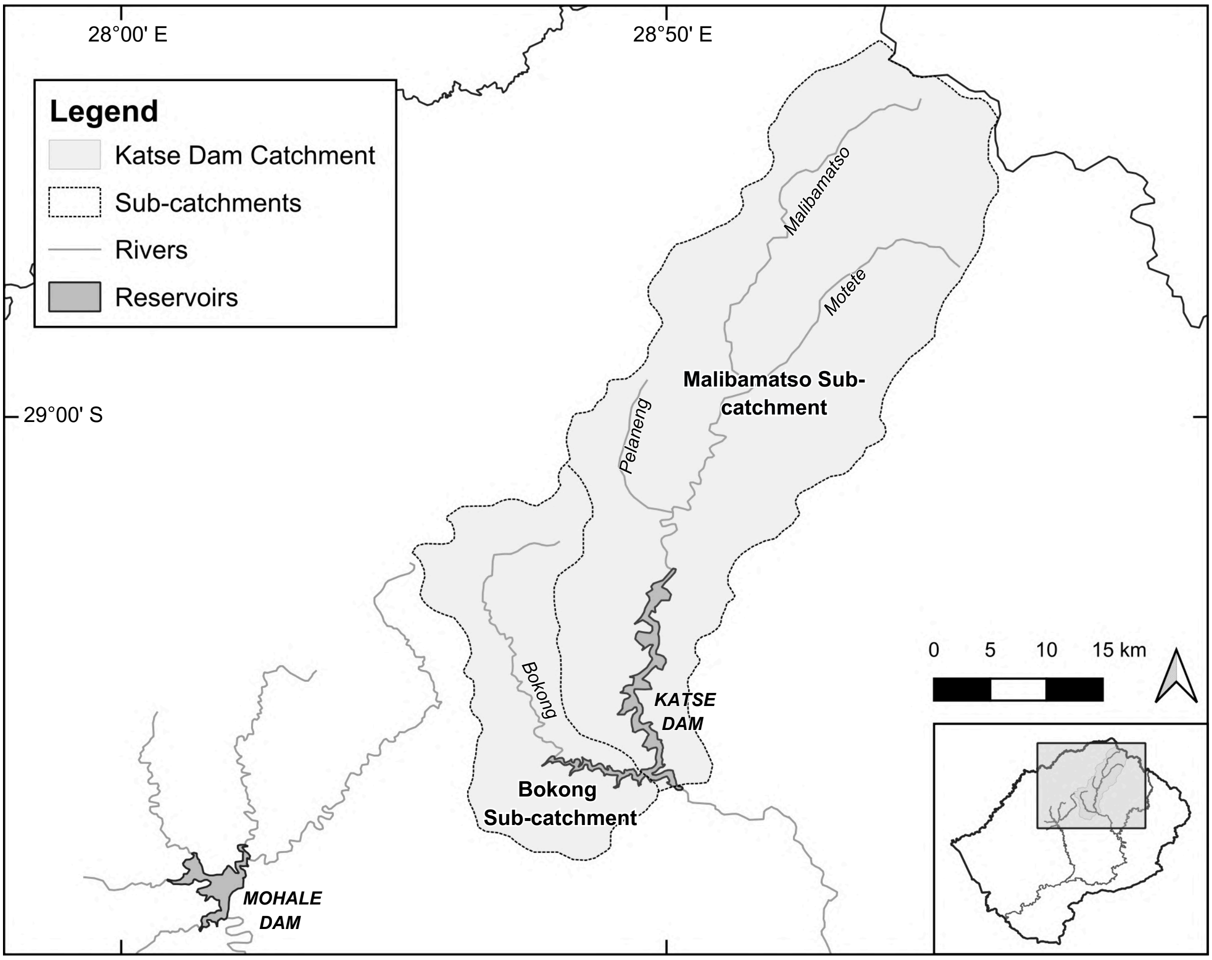

Figure 3.3: Map showing the Katse Dam catchment with its two sub-catchments, the Malibamatso River sub-catchment (S-C) and the Bokong River sub-catchment (S-C).

The Malibamatso River sub-catchment covers an area of approximately 1 460 km^2 and includes the Malibamatso River (108 km long) and its major tributaries, the Motete (39 km long) and Pelaneng (20 km long). The Malibamatso River originates close to the edge of Lesotho's eastern escarpment, flowing in a south, south-westerly direction before entering the Katse Dam near the settlement of Ha Lejone to form the eastern "Malibamatso arm" of Katse Dam. The Bokong River sub-catchment covers an area of approximately 400 km^2 that extends from Katse Dam to the source of the Bokong River in the Bokong Nature Reserve. The Bokong River forms the western "Bokong arm" of the Katse Dam before joining the Malibamatso River close to the Katse Dam wall.

At full supply level (FSL) (2 053 metres above sea level (masl)), Katse Dam has a surface area of 35.8 km^2, and a mean and maximum depth of 51.3 m and 170 m, respectively (Nthimo 2000) (Table 3.1). Katse is a clear (mean secchi depth > 5 m), oligo-mesotrophic impoundment (total phosphorous 0.05 mg/L; chlorophyll-a 2.2 µg/L) (Roos 2000). Both its surface and bottom waters are well-oxygenated; mean annual dissolved oxygen levels at the surface range from 7–9 mg/L whereas bottom waters range from 3–6 mg/L. Average annual surface water temperature is around 16.4°C with a minimum of 4.1°C and 21°C recorded during the winter (June–August) and summer months (November–February), respectively (Hecht 1999). Overturn occurs at the onset of winter (April/May) and complete mixing occurs from June to August. In spring and summer, the water column is stratified with a thermocline at around 10–12 m (Roos 2000). The dam experiences significant fluctuations in water levels; annual average fluctuation in water level is around 33 m and maximum fluctuation is 64 m (Hecht 1999). The lakeshore is characterised by a steep, rocky and/or grassy shoreline and a limited littoral zone (Nthimo 2000) (Figure 3.4).

Situated adjacent or near Katse Dam are 40 villages; the two largest are Katse Village (Khokhoba) and Ha Lejone which support most of the economic activity in the area (*mme* Nthabiseng Morokole, Fisheries and Aquaculture Division, LHDA, pers. comm. July 2024) (Figure 3.5). Traditional livelihoods are like those commonly observed elsewhere in the Highlands (see Chapter 2) and include crop and livestock (sheep, goats, and cattle) farming, the harvest and sale of rosehip and thatching grass, and traditional beer brewing (Skefu 2018). Approximately 40% of households live below the poverty line (Skefu 2018).

Table 3.1: Biophysical characteristics of Katse Dam which forms part of Phase IA of the Lesotho Highlands Water Project. Values presented are means from water quality data covering the period 2002–2024 (Source: LHDA, unpublished data, 2024).

Biophysical parameters	**Katse Dam**
Location	29°20’11” S; 28°30’25” E
Altitude (masl)	2 053
Catchment area (km^2)	1 886
Surface area at FSL* (km^2)	36
Storage volume (million m^3)	1 950
Mean depth (m)	51.3
Maximum depth (m)	170
Mean temperature (°C)	16.22
Mean dissolved oxygen (DO) (mg/L)	7.90
Mean pH	8.37
Mean conductivity (mS/m)	7.56
Mean Secchi depth (m)	4.68
Mean total dissolved solids (TDS) (mg/L)	57.96
Mean chlorophyll-a (µg/L)	5.05
Mean total phosphorous (mg/L)	0.15

Figure 3.4: Katse Dam is situated on the Malibamatso River and forms part of Phase IA of the Lesotho Highlands Water Project; the dam is characterised by steep rocky and grassy shorelines with a limited littoral zone.

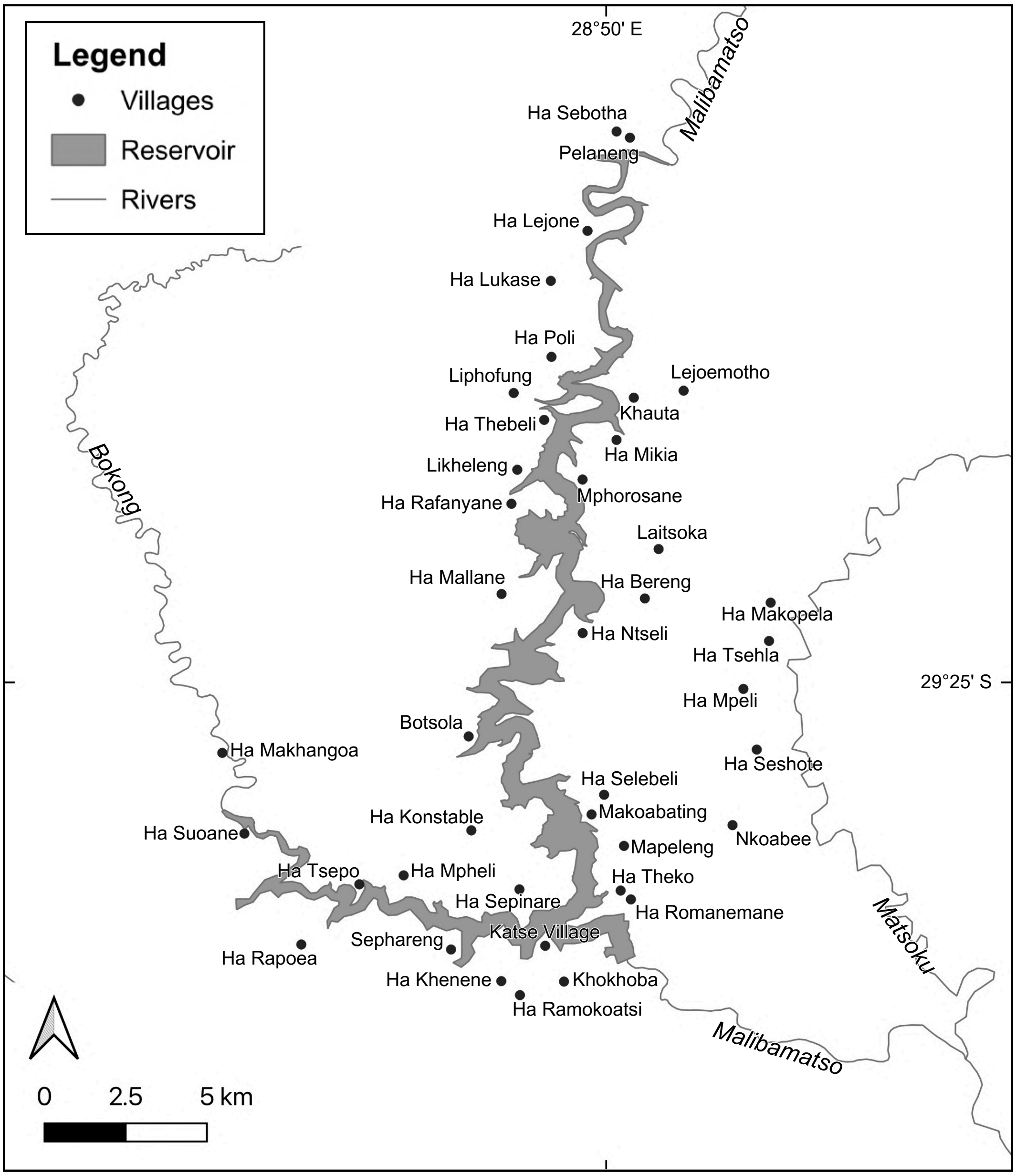

Figure 3.5: Map showing the locations of major villages in the vicinity of Katse Dam.

3.2.3. Investigating the emergence and evolution of the fishery

Oral histories

Semi-structured oral history interviews and focus group discussions (FGDs) were used to obtain personal narratives and community perspectives on the emergence and evolution of fishing in the Katse Dam area. Oral histories have been recognised for their utility to capture historical changes in catch and effort; species abundance and distribution; fishing methods and technologies; and market dynamics, particularly in data-poor situations (Daw et al. 2011; Shackeroff et al. 2011; Colburn and Clay 2012; Tesfamichael et al. 2014; Calhoun et al. 2016; Thurstan et al. 2016; Olson and da Silva 2019; Wilson et al. 2025). They have also been used to assess the impact of large dams on community livelihoods and resource use (Isaacman 2001; Richter et al. 2010; Isaacman and Isaacman 2013; Hoominfar and Radel 2020; Owuor et al. 2023).

Oral histories were captured through semi-structured interviews conducted in February/March and July/August/September of 2024. Participants were selected using a purposive snowball method (Bernard 2017; Mazur and Johnson 2020; Hoschke et al. 2024). Selection criteria focussed on community members that had lived in the study area before, during, and after the construction of Katse Dam. A total of 16 semi-structured interviews were conducted in communities located on both the Bokong (n = 5) and Malibamatso (n = 11) arms of the dam. The participants included fishing (n = 6) and non-fishing (n = 3) community members, *Marena* (male chiefs) (n = 3), *Mafumahali* (female chiefs or male chiefs' wives) (n = 1), and community councillors (n = 3). Efforts were made where possible to include both male and female participants. During the oral history interviews, participants were encouraged to recount their experiences and perspectives on fishing in the area, focusing on the periods before, during, and after the construction of Katse Dam, as well as livelihood impacts and community adaptation strategies. Open-ended questions guided the discussions (Appendix A1) allowing participants to direct the conversation towards topics they deemed most significant, while also ensuring that key themes were addressed (Leavy 2011). While the oral history interviews provided important insights, the small sample size means they should be considered illustrative rather than representative of all fishing villages.

It should be noted that the extent to which semi-structured interviews could be conducted was limited to some extent by customary leadership norms and protocols in the study area, which were always respected. In some instances, the *Morena* and/or *Mofumahali* requested that engagements be held with numerous members of the community (up to 40 people) simultaneously, rather than with individual community members. In these instances, focus group discussions (FGDs) were held to gather historical perspectives at a broader community level. A total of eight FGDs were conducted in communities located on both the Bokong (n = 3) and Malibamatso (n = 5) arms of the dam. The communities were selected on the basis that they served as central meeting points for surrounding smaller villages. This ensured that there was representation from a wider catchment area. The number of participants in the FGDs ranged from eight to 40. The FGDs followed a semi-structured format guided by a topic guide (Appendix A1) that included open-ended questions to encourage participants to discuss key themes such as historical fishing practices, community adaptations, market and trade development, and the socio-economic impacts of the dam. This approach allowed participants to explore topics that were most relevant to them while providing a platform for group interaction to reveal shared understandings, collective concerns, and community-level insights (Kitzinger 1994).

Participants were generally reluctant for audio recordings to be made. As such, the interviews and FGDs were conducted with the lead researcher directing questions in English, which were translated into Sesotho by a Mosotho research assistant. Responses were translated back into English in real time and transcribed by the lead researcher, who also asked clarifying questions where needed. After each session, the transcripts were reviewed together with the assistant to ensure accuracy before analysis.

Data analysis

Interview and FGD transcripts were analysed using Braun and Clarke's (2019) reflexive thematic analysis (RTA) approach. The analysis was recursive rather than linear, moving back and forth as interpretations developed and themes were refined. This involved repeated returns to the data and ongoing refinement of interpretations, moving between individual accounts, emerging patterns, and the entire dataset. Coding and theme development were managed manually in Microsoft Excel. Themes were organised chronologically to construct a timeline of key events, developments and changes in fishing practices (Miles 2018). Thematic saturation was not assessed as this concept aligns with codebook or coding reliability approaches rather than RTA, where meaning is generated through interpretation rather than "discovered" in the data (Braun and Clarke 2019; Byrne 2022). Although RTA cannot demonstrate systematic coverage of the data, the approach provided sufficient depth on how participants interpreted changes in fishing practices through their experiences of environmental and social transitions.

3.2.4. Assessing the hook-and-line fishery

The characteristics of the hook-and-line fishery were assessed using a range of quantitative and qualitative, primary and secondary data collected between 2018 and 2024 (Table 3.2). Primary data on fishing effort, catch, catch composition, and fisher demographics were obtained through vessel-based fisher counts, roving creel surveys, and fisher interviews. Secondary data on seasonal trends in effort were obtained from interviews with government fisheries officers stationed at the dam, while biological information on length-at-maturity was collected from the literature (Nthimo 2000).

Table 3.2: Sources of data used in the hook-and-line fishery assessment.

Survey method	**Data collected**
Vessel-based fisher counts and interviews (February/March 2024; July/August 2024)	Effort (number and location of fishers)
Roving creel surveys and interviews (January–March, July–September 2018–2020; 2022–2024)	Demographics; fishing methods; effort; catch rates; species composition; length frequencies
Interviews with government fisheries officers (2018-2024)	Supplementary information on catch and effort
Literature reviews	Length-at-50% maturity estimates

Effort

Effort in the hook-and-line fishery was assessed using vessel-based fisher counts, creel surveys and Bayesian modelling techniques adapted from Tucker et al (2024). The method allows for the integration of different sources of effort data (e.g., instantaneous count data and fisher interview data on trip duration) which are analysed using Bayesian models that can account for the uncertainty associated with data-poor fisheries (Lorenzen et al. 2016; Rufener et al. 2017; Doll and Jacquemin 2018). Given financial and logistical constraints, and its data-poor status, this method was deemed appropriate for providing a first estimate of effort in the Katse Dam fishery. Nevertheless, it is recognised that repeated surveys over long time periods would provide a more robust estimate.

Vessel-based fisher counts were conducted due to the topography and steep shoreline of the dam which limited the ability to count or intercept fishers on foot. A total of 12 fisher counts were conducted, six in February 2024 and six in August 2024. Fishers observed on the shoreline were counted from a motorised vessel making a single pass around the entire shoreline of the dam from a set starting point to a set end point. To minimise spatial bias, the pass order was randomised across survey days (Pollock et al. 1994). During each pass, three crew members counted the fishers independently to reduce the potential for observer bias (Mahtani et al. 2018). If the count was consistent across all crew members, the count was accepted. If not, the fishers were counted again until consensus was reached between all three crew members. The time at which the vessel passed each fisher was also recorded.

To complement the count data, information on fishing trip duration and fishing frequency was obtained by interviewing a subset of fishers encountered on the shoreline during the vessel-based fisher counts. To minimise selection bias (Heckman 2010), efforts were made to ensure that the subset was representative of the broader fisher population by systematically varying the intervals at which fishers were approached along the survey route, independent of their activity or location. The fishers were interviewed to obtain information on (1) the time they had started fishing that day; (2) the time they expected to end fishing that day; (3) the number of days and approximate hours that they had fished in the preceding seven days; and (4) the approximate number of days per week that they fished in summer and winter (Appendix A2). Summer and winter were defined as the periods of October–March and April–September, respectively, based on engagements with hook-and-line fishers and confirmed by government officials. As such, the information collected during the surveys in February and August was assumed to be representative of the summer and winter seasons, respectively, although the limitations of this assumption are acknowledged. In particular, the estimates are based on two seasonal snapshots and therefore do not account for transitional turnover events, interannual variability, or the influence of reservoir drawdown on fish productivity (Petts 1984).

The number of hand lines used by the fishers was also counted for CPUE standardisation purposes.

The count and interview data were modelled using a Bayesian hierarchical model applied using the *R* software package Stan (Stan Development Team 2020). Key equations are provided below. Explanations of the model selections, distributions, priors, fitting, checks, and additional technical information are provided in Appendix A2.

The observed number of fishers y_{ij} was assumed to follow a Poisson distribution:

$$y_{ij}^{\text{fishers}} \sim \text{Poisson}\left(E_{ij}^{\text{fishers}}\right) \tag{3.1}$$

where y_{ij}^{fishers} and E_{ij}^{fishers} represent the observed and expected number of fishers on any given day i in season j, respectively.

Mean daily fishing effort E_{ij}^{fishers} was then modelled as the expected number of fishers present on any given day i in season j, such that:

$$E_{ij}^{\text{fishers}} = \mu_{ij}^{\text{fishers}} \cdot p_{ij}^{\text{survey}} \tag{3.2}$$

where $\mu_{ij}^{\text{fishers}}$ represents the mean number of fishers on any given day i in season j, and p_{ij}^{survey} is the probability of encountering them during the survey on day i.

The estimated mean daily fishing effort $\mu_{ij}^{\text{fishers}}$ was calculated as:

$$\mu_{ij}^{\text{fishers}} = \mu_{j}^{\text{fishers}} + \sigma_{\text{daily}}^{\text{fishers}} \cdot \varepsilon_i, \quad \varepsilon_i \sim N(0,1) \tag{3.3}$$

where μ_j^{fishers} is the overall mean daily number of fishers for season j , $\sigma_{\text{daily}}^{\text{fishers}}$ is the standard deviation of daily variation in fisher numbers, and $\varepsilon_i \sim N(0,1)$ is a standard normal random variable representing day-to-day variation. Seasonal differences in fishing effort were assessed using the posterior distributions of fishing effort for summer (μ_{summer}) and winter (μ_{winter}) by calculating the sum of the probabilities that the summer mean exceeds the winter mean vice versa.

Mean daily fishing duration *d* for fisher *i* in season j (d_{ij}^{duration}) was calculated as:

$$d_{ij}^{\text{duration}} = t_i^{\text{spent}} + t_{0i}^{\text{remaining}} \tag{3.4}$$

where t_i^{spent} is the time the fisher had already spent fishing at the time of the survey on day *i* and $t_{0i}^{\text{remaining}}$ is the additional time the fisher expected to continue fishing on day *i*.

Mean seasonal fishing duration (d_j) was calculated as the average of individual durations for each season j ($j \in \{\text{summer}, \text{winter}\}$). Seasonal differences were assessed by comparing the posterior distributions of mean seasonal fishing duration in summer (d_{summer}) and winter (d_{winter}).

The probability of encountering anglers *p* on any given day *i* during a survey event (p_i^{survey})was calculated based on the reported fishing times and survey duration as:

$$p_i^{\text{survey}} = \frac{t_{0i}^{\text{remaining}}}{t_i^{\text{spent}} + t_{0i}^{\text{remaining}} \cdot S_i^{\text{survey}}} \tag{3.5}$$

where t_i^{spent} is the time the fisher had already spent fishing at the time of the survey on day *i*, $t_{0i}^{\text{remaining}}$ is the additional time the fisher expected to continue fishing on day *i*, and S_i^{survey} is the duration of the survey (in hours) on day *i*.

An estimate of the total number of participants in the hook-and-line fishery was then derived by combining the mean daily summer participation estimates with the probability that a fisher goes fishing on any given day in summer. Since all fishers who fished in winter also fished in summer, and no fishers exclusively fished during winter (see Section 3.3.2), the total number of fishers was based on the summer estimate.

The probability of a fisher going fishing on any given day (p_i^{fishing}) was modelled using a Beta distribution:

$$p_i^{\text{fishing}} \sim \text{Beta}(\alpha, \beta) \tag{3.6}$$

with the expected probability equal to the reported fishing frequency:

$$\mathrm{E}\left[p_i^{\text{fishing}}\right] = \frac{d_i^{\text{days}}}{D^{\text{week}}} = \frac{\alpha}{\alpha + \beta} \tag{3.7}$$

where d_i^{days} is the number of days per week that fisher i reported fishing, D^{week} is the total number of days in a week (set to seven as fishers reported that their fishing frequency was independent of weekdays or weekends), and parameters α and β estimated from the interview data to match the reported weekly fishing frequencies.

The total number of fishers $N_{\text{total}}^{\text{fishers}}$ was then estimated as:

$$N_{\text{total}}^{\text{fishers}} = \mu_{\text{summer}}^{\text{fishers}} \cdot E\left[p_i^{\text{fishing}}\right] \tag{3.8}$$

where $\mu_{\text{summer}}^{\text{fishers}}$ is the mean number of daily summer fishers and $E\left[p_i^{\text{fishing}}\right]$ is the overall daily fishing probability from the Bayesian model. Credible intervals for N_{total} were calculated from its posterior distribution using MCMC sampling (Gelman et al. 2013).

Catch

Catch data were obtained from randomly stratified, roving creel surveys conducted in summer (February/March) and winter (July/August) of 2018–2020 and 2022–2024. The roving creel survey approach was adapted from that used by Ellender et al (2010) in a similar study on a large dam in South Africa. Each survey comprised a four-day sampling event. Sampling was conducted in two areas of the dam divided into strata: the Bokong River arm (four strata) and the Malibamatso River arm (six strata). The vessel moved at a constant speed through each stratum in a random direction, intercepting all fishers observed on the shoreline. Fish caught by each fisher were counted, measured for fork length (FL) (mm), and weighed (kg). In cases where fish had already been gutted, these were measured and the weight subsequently approximated using a length-weight relationship for that species derived by Nthimo (2000). Seasonal differences in species composition were analysed using χ^2 tests of independence (McHugh 2013). Length frequencies of sampled fish were compared to length-at-50% maturity estimates obtained from Nthimo (2000) to understand the extent to which the fishery harvested immature and mature individuals (Ellender et al. 2010).

Catch per unit effort (CPUE) was estimated numerically (number of fish) ($\mathrm{CPUE}_n^{\text{fishers}}$) and by weight (kilograms of fish) ($\mathrm{CPUE}_w^{\text{fishers}}$). This was for two reasons: (1) the hook-and-line fishery and its value chain operate based on numbers of fish rather than weight (see Section 3.3.4) while (2) CPUE by weight estimates allowed for comparisons with fisheries productivity estimates from previous studies (Nthimo 2000).

Catch per unit effort ($\mathrm{CPUE}_{\mathrm{x}}^{\mathrm{fishers}}$) was standardised (Maunder and Punt 2004) by numbers (*n*) and weight (w) to account for differences in fishing duration and the number of lines used by fishers such that:

$$\mathrm{CPUE}_{\mathrm{x}}^{\mathrm{fishers}} = \frac{C_x}{l \cdot h}\ , x \in \{n, w\} \tag{3.10}$$

where $x \ \in \{n, w\}$, C_x is the catch in numbers or weight, l is the average number of lines used per fisher, and h is the average number of hours fished per day, calculated separately for summer and winter.

The CPUE data were right-skewed and contained a large proportion of zero-catch observations. As such, a delta-lognormal model was applied, as it effectively handles zero-inflated data by separating the probability of catching a fish from the catch quantity, providing more accurate CPUE estimates and realistic confidence intervals (Lo et al. 1992; Ellender et al. 2010).

The non-zero CPUE data were log-transformed and then scaled based on the probability of a non-zero catch P_i^{catch} such that:

$$\mathrm{CPUE}_{\mathrm{x,i}}^{\mathrm{fishers}} = p_i^{\mathrm{catch}} \cdot \exp\left(\log \mathrm{CPUE}_{\mathrm{pos,i}} + \frac{\sigma^2}{2}\right), x \in \{n, w\} \tag{3.11}$$

where $x \ \in \{n, w\}$, $\mathrm{CPUE}_{\mathrm{x,i}}^{\mathrm{fishers}}$ are the estimated CPUEs for observation *I* (by numbers or weight), p_i^{catch} is the probability of capturing a fish during observation *i*, $\log \mathrm{CPUE}_{\mathrm{pos},i}$ is the log-transformed CPUE for non-zero catches, and σ^2 is the variance of the log-transformed non-zero values (Ellender et al. 2010).

Non-parametric bootstrap resampling (Efron and Tibshirani 1986) was performed 1 000 times on the estimates of p_i^{catch} and $\log \mathrm{CPUE}_{\mathrm{pos},i}$ to calculate CPUE estimates and confidence intervals (Appendix A2). The mean CPUE estimates ($\overline{\mathrm{CPUE}}_{x,j}^{\mathrm{fishers}}$) were pooled by season and statistical differences were assessed using a non-parametric Kruskal Wallis test (Kruskal and Wallis 1952).

Estimates of CPUE, fishing effort and fishing days were then used to derive an initial estimate of total catch by numbers ($C_{j,n}^{\mathrm{fishers}}$) and weight ($C_{j,w}^{\mathrm{fishers}}$) in summer and winter, such that:

$$C_{j,x}^{\mathrm{fishers}} = \overline{\mathrm{CPUE}}_{x,j}^{\mathrm{fishers}} \cdot D_j^{\mathrm{fishing}} \cdot \mu_j^{\mathrm{fishers}}, \quad x \in \{n, w\} \tag{3.12}$$

where $\overline{\text{CPUE}}_{x,j}^{\text{fishers}}$, $x \in \{n, w\}$ represents the mean CPUE by numbers and weight for season j, D_j^{fishing} is the number of fishing days in season j, and μ_j^{fishers} is the mean daily number of fishers in season j.

The number of fishing days D_j^{fishing} was estimated based on the total number of days available for fishing in season j and the overall probability that a fisher fished on any given day in that season ($E\left[p_i^{\text{fishing}}\right]$) (as derived in Equation 3.7). Specifically, D_j^{fishing} was calculated as:

$$D_j^{\text{fishing}} = p_{f,j} \cdot d_j \tag{3.13}$$

where d_j is the total number of days in that season. For summer, d_j corresponded to the number of days from October to March (182 days), while for winter, it corresponded to the number of days from April to September (181 days).

To account for uncertainty in the total catch estimates, a Monte Carlo simulation (Caddy and Mahon 1995) was conducted drawing 1 000 samples from the posterior distribution of $E\left[p_i^{\text{fishing}}\right]$ and the bootstrapped distributions of $\overline{\text{CPUE}}_{x,j}^{\text{fishers}}$, $x \in \{n, w\}$. These samples were then used to recalculate $C_{j,x}^{\text{fishers}}$ ($x \in \{n, w\}$) for each draw, constructing confidence intervals from the 2.5$^{\text{th}}$ and 97.5$^{\text{th}}$ percentiles of the simulated values Appendix A2.

Seasonal differences were assessed by comparing the posterior distributions of catch estimates for summer ($C_{\text{summer}}^{\text{fishers}}$) and winter ($C_{\text{winter}}^{\text{fishers}}$).

Demographics

A semi-structured questionnaire was used during the vessel-based fisher counts and roving creel surveys to obtain socio-economic information including gender, age, household size, employment status, and the primary source of income of hook-and-line fishers (Appendix A2). Additional data used to inform the value chain analysis (see Section 3.2.6) were also collected (Appendix A2). Descriptive statistics were used to summarise the demographic profile of the respondents, and χ^2 tests of independence were conducted to examine associations between categorical variables.

3.2.5. Assessing the illegal gillnet fishery

Multiple sources of qualitative and quantitative data and a Bayesian framework were used to assess the illegal gillnet fishery, drawing on methods used to assess illegal fishing activities outlined in Free et al (2015) and Donlan et al (2020). Data sources used are shown in Table

3.3. Primary data on gillnetting effort (including the number, type, dimensions and mesh sizes of gillnets) were obtained through in-field gillnet counts, interviews with self-confessed illegal gillnet fishers, and experimental gillnet surveys. Secondary data on catch and effort were obtained from government fisheries officers stationed at the dam while information on gillnet efficiency and target species biology was obtained from the scientific literature.

Table 3.3: Sources of data used in the illegal gillnet fishery assessment.

Survey method	**Data collected**
LHDA Monitoring, Control and Surveillance (MCS) records (quarterly; 2017–2022)	Effort (number and location of gillnets)
In-field gillnet counts (February/March and July/August 2024)	Effort (number, location, length, height, material, mesh sizes of gillnets)
Interviews with illegal gillnet fishers (February/March and July/August 2024)	Effort (soak times, seasonal effort; mesh sizes of gillnets); demographics; fishing methods
Experimental gillnet sampling (January/February and July/August 2018–2020; 2022–2024)	Catch per unit effort, selectivity
Interviews with government fisheries officers (2018–2024)	Supplementary information on catch and effort
Scientific literature; unpublished data (1965–2022)	Information on gillnet efficiency
Biological data (Nthimo 2000)	Length-at-50% maturity estimates

Effort

The number of gillnets in use was estimated using historical data on the number of gillnets confiscated during monitoring, control and surveillance (MCS) patrols undertaken by government authorities four times a year from 2017 to 2022, and in-field gillnet counts undertaken over two weeks during February and August of 2024. During the in-field gillnet counts, the material (monofilament or multifilament), length, mesh sizes (mm), and locations (GPS coordinates) of the gillnets were also recorded.

Gillnet soak times (hours), daily, monthly and seasonal effort (fishing events per week, month and season), and additional information on gillnet mesh sizes was obtained during in-depth, semi-structured interviews with 12 self-confessed illegal gillnet fishers (

Appendix A3). The fishers agreed to participate on condition of anonymity and were open to providing information with a view that this could contribute towards the revision of regulations and legal recognition of their fishing activities. However, information on the number of gillnets per fisher was generally difficult to obtain, and only four participants provided this information. These data were used to estimate of the total number of gillnet fishers; however, it is recognised that there is considerable uncertainty in this estimate.

To estimate the total number of gillnets used in the fishery, while accounting for the inherent uncertainty in assessing illegal fishing activities (Free et al. 2015), a Bayesian hierarchical model was applied using the *R* software package Stan (Stan Development Team 2020). The model included a detection probability parameter to account for the likelihood that some gillnets were not observed during the survey due to their being set outside survey times or in areas that could not be covered by the vessel during that survey. Key equations are provided below; detailed explanations of model selections, distributions, priors, fitting, checks, and additional technical information are provided in

Appendix A3.

The observed number of gillnets was modelled as:

$$g_i^{\text{gillnets}} \sim \text{Negative Binomial}\left(\lambda_i^{\text{gillnets}} \cdot p_{\text{detect}}, \phi\right) \tag{3.14}$$

where g_i^{gillnets} represents the observed number of gillnets from source i (which includes MCS patrols and in-field gillnet counts), $\lambda_i^{\text{gillnets}}$ is the expected number of gillnets observed from that source, p_{detect} is the detection probability, and ϕ is the dispersion parameter accounting for overdispersion.

The posterior distribution for the total number of gillnets, $N_{gillnets}$, was obtained by modelling the observed counts from both MCS patrols and in-field gillnet counts as arising from a single latent total *N*, adjusted for detection probability:

$$N_{\text{gillnets}} = \frac{\sum_i g_i^{\text{gillnets}}}{p_{\text{detect}}} \tag{3.15}$$

The credible interval for the estimate of $N_{gillnets}$ reflects the range of plausible values based on the variability and uncertainty inherent in the observed data and model parameters.

Monte Carlo simulation was used to quantify the uncertainty in $N_{gillnets}$ and propagate this uncertainty into effort estimates (Crowder et al. 2020) (

Appendix A3). The posterior estimate of the total number of gillnets, $N_{gillnets}$, was multiplied by the estimated average soak time to derive an estimate of daily gillnet effort.

Information obtained from illegal gillnet fishers indicated that some set their nets in the evening and retrieved them in the morning (soak time of approximately 10–12 hours), while others left their nets in the water permanently, removing fish every morning (soak time of approximately 22–24 hours).

Based on this information, the average soak time set_h (hours/set) was calculated as a weighted average such that:

$$\mathrm{set}_{\mathrm{h}}^{\mathrm{gillnets}} = 0.5 \cdot 11 + 0.5 \cdot 23 = 17\,\mathrm{hours} \tag{3.16}$$

Gillnet fishing effort in terms of daily gillnet hours E_{gillnets} was then calculated as:

$$E_{\mathrm{gillnets}} = N_{\mathrm{gillnets}} \cdot \mathrm{set}_{\mathrm{h}}^{\mathrm{gillnets}} \tag{3.17}$$

where N_{gillnets} is the posterior estimate of the total number of gillnets in use, adjusted for detection probability, and $\mathrm{set}_{\mathrm{h}}^{\mathrm{gillnets}}$ is the average soak time (17 hours).

For each Monte Carlo iteration, daily effort in terms of total gillnet hours was estimated as:

$$E_{\mathrm{gillnets},i} = N_{\mathrm{gillnets},i} \cdot \mathrm{set}_{\mathrm{h}}^{\mathrm{gillnets}} \tag{3.18}$$

where $N_{\mathrm{gillnets},i}$ is the i-th sample from the posterior distribution of N_{gillnets}.

In-field observations and information obtained from illegal gillnet fishers showed that the number of gillnets in use did not vary seasonally. As such, gillnet effort was assumed to be constant across seasons. The sensitivity of this assumption was tested through additional simulations (

Appendix A3).

Catch

Gillnet catch data were obtained from experimental gillnet surveys. The experimental gillnet fleet comprised 3 x 100 m long, 2.5 m deep, six-ply, brown, multifilament gillnets comprised of ten 10 m panels of 12 mm, 16 mm, 22 mm, 28 mm, 35 mm, 45 mm, 57 mm, 73 mm, 110 mm and 150 mm manufacturer-quoted stretched mesh. Gillnets were set parallel to the shore in the afternoon (15h00–18h00) and retrieved the following morning (07h00–09h00) as per Nthimo (2000) and other gillnet surveys conducted in southern African impoundments (Weyl 1998; Potts 2003; Weyl et al. 2007; Ellender 2008; Winker 2010; McCafferty 2012; Sara et al. 2017; Swanepoel 2022). Sampling was conducted in different habitat types including river mouths, steep rocky embankments, and shallow bays. Sampling sites are shown in Figure 3.6 and a summary of sampling events is shown in Table 3.4.

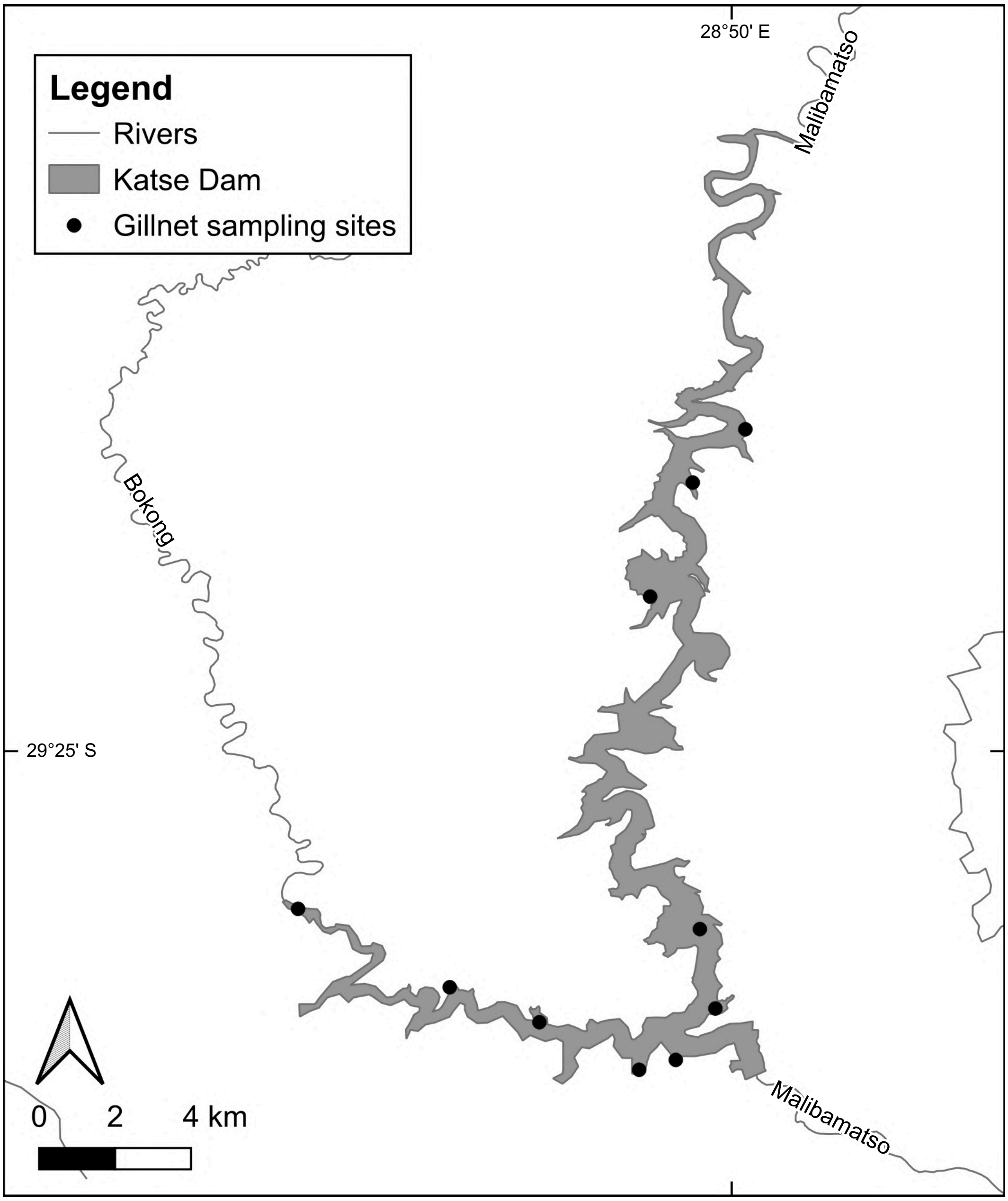

Figure 3.6: Gillnet sampling sites on Katse Dam.

Gillnet catches were identified to species level, enumerated, measured for fork length (FL) to the nearest millimetre, and weighed (g). Water quality parameters (water temperature (°C), dissolved oxygen (mg. L^{-1}), electrical conductivity (EC) (µS.cm^{-1}) and pH were recorded at each site. Water quality data were supplemented with historical data collected by the LHDA from 2010 to 2022.

Seasonal differences in species composition were analysed using χ^2 tests of independence (McHugh 2013). Estimates of CPUE were derived using (1) the experimental multifilament gillnet data; (2) information on the material, mesh sizes, height, and length of the illegal gillnet fleet obtained during in-field gillnet counts and through interviews with illegal gillnet fishers;

and (3) a meta-analysis of the literature on CPUE of multifilament and monofilament gillnets, to account for expected differences in catch rates of the experimental multifilament gillnet fleet and the illegal gillnet fleet (Hovgård and Lassen 2000).

Table 3.4: Experimental gillnet sampling events, Katse Dam.

Year	Month	Net nights
2017	January/February	9
2018	August	9
2019	February	5
	July/August	5
2020	February	9
	July	9
2021	August	6
2022	February/March	9
	July	8
2023	January/February	8
	August	8

Catch per unit effort from the experimental gillnet fleet ($\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}}$) was calculated as:

$$\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} = \frac{C_{m,x}}{T_i \cdot M_i}, \quad x \in \{n, w\} \tag{3.19}$$

where $C_{m,x}$ represents the catch by numbers n or weight w in a 10 m panel of experimental gillnet mesh size m, T_i is the gillnet soak time (in hours), and M_i is the mesh size during sampling event i.

The illegal gillnet fleet differed from the experimental gillnets in their material (which included both multifilament and monofilament nets), mesh sizes, and dimensions (Table 3.5). To account for these differences and derive a more accurate estimate of catch rates from the illegal gillnet fishery using the experimental gillnet data, a combination of methods was used.

To obtain more reliable estimates of CPUE, the data were standardised to account for the high proportion of zero catches in the experimental gillnet CPUE data (Lo et al. 1992; Ellender et al. 2010). A delta-lognormal, generalised additive modelling (GAM) approach was applied where the delta model captured the probability of a non-zero catch, and the lognormal component modelled the magnitude of CPUE for non-zero observations (Wood 2017). This allowed for predictions of CPUE in mesh sizes not present in the experimental gillnet fleet by fitting smooth functions to capture the assumed non-linear relationship between mesh size and CPUE.

Table 3.5: Properties of the experimental gillnet fleet and the illegal gillnet fleet; data on the illegal gillnet fleet was obtained from in-field illegal gillnet counts supported by information obtained from illegal gillnet fishers.

Properties	**Experimental gillnet fleet**	**Illegal gillnet fleet**
Composition	100% multifilament, multi-meshed nets	100% monofilament, mono-meshed nets 100% multifilament, mono-meshed nets
Mesh sizes (mm)	35; 45; 57; 73; 93; 118; 150	40; 50; 60; 80; 90; 100; 110; 125; 135
Height (m)	3	1.8 ± 2.4
Length (m)	70 (seven x 10 m panels)	49 ± 28.7 (single panel)

To model the probability of a non-zero catch ($P\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right)$), a binomial GAM with a logit link function was fitted such that:

$$\mathrm{logit}\left(P\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right)\right) = \beta_0 + s_{\mathrm{Mesh_i}} + \beta_{\mathrm{Year}} \cdot \mathrm{Year} + \beta_{\mathrm{Season}} \cdot \mathrm{Season} + \beta_{\mathrm{Site}} \cdot \mathrm{Site} + \varepsilon_i, \quad x \in \{n, w\} \tag{3.20}$$

where s_{Mesh_i} is a smooth function of mesh size *i* using cubic splines with six knots (i.e., $k = 6$), β_{Year}, β_{Season}, and β_{Site} are the coefficients for the year, season, and site effects, respectively, and ε_i is the random error term.

For non-zero CPUE observations, a Gaussian GAM with an identity link function was applied to the log-transformed CPUE data such that:

$$\log\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} \mid \mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right) = \alpha_0 + s_{\mathrm{Mesh_i}} + \alpha_{\mathrm{Year}} \cdot \mathrm{Year} + \alpha_{\mathrm{Season}} \cdot \mathrm{Season} + \alpha_{\mathrm{Site}} \cdot \mathrm{Site} + \varepsilon_i, \quad x \in \{n, w\} \tag{3.21}$$

where $\log\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} \mid \mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right)$ represents the magnitude of CPUE_e for non-zero catches.

The predicted CPUE ($\widehat{\mathrm{CPUE}}_e$) was calculated by combining the two models such that:

$$\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} = P\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right) \cdot \exp\left(E\left[\log\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} \mid \mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right)\right]\right), \quad x \in \{n, w\} \tag{3.22}$$

where $P\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right)$ is the probability predicted from the delta model, and $E\left[\log\left(\mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} \mid \mathrm{CPUE}_{\mathrm{e,x}}^{\mathrm{gillnets}} > 0\right)\right]$ is the expected log-transformed CPUE for non-zero observations.

Both models were fitted in *R* using the mgcv package (Wood 2017), with restricted maximum likelihood (REML) estimation used as it typically provides more reliable estimates of the smooth terms compared to Maximum Likelihood (Wood 2011). The Akaike Information Criterion (AIC) was used for model selection based on its effectiveness in balancing model fit and complexity (Burnham and Anderson 2002). Several models were compared, with the final model being selected based on the lowest AIC value (

Appendix A3)

The $\widehat{\mathrm{CPUE}}_e$ estimates were adjusted to account for expected differences in the catching efficiency of the experimental multifilament gillnets and the illegal monofilament gillnets (Hovgård and Lassen 2000). For the purposes of this study, differences were assumed to be primarily related to net material effects (θ_1) (monofilament or multifilament) and net height effects (a simple scaling factor). Net length was not explicitly modelled in the calculation as the variation in net length between fleets was assumed to be implicitly captured by standardising CPUE estimates to kg. 10m $mesh^{-1}$. $hour^{-1}$ before scaling. It was recognised that several factors influence the efficiency of gillnets, including twine diameter, colour, and other material properties (Hamley 1975). However, it was assumed that these factors were captured within θ_1 which accounted for the overall influence of gillnet material differences on CPUE.

A literature review on the efficacy of monofilament nets in comparison to multifilament nets was conducted. A Boolean search (Bramer et al. 2018) was conducted across the EBSCOhost database. Search terms combined "gillnet*" OR "gill net*" with ("monofilament" OR "multifilament") AND ("efficiency" OR "catch rate" OR "CPUE"). Additional searches included "cyprinid*" OR "salmonid*" to target the relevant species found in Katse Dam. However, where other studies were deemed relevant, for example, those that looked at other fusiform freshwater species, these were also reviewed. A total of 16 studies met these criteria (

Appendix A3).

A meta-analysis of the studies was conducted to extract quantitative information on differences in CPUE between monofilament and multifilament nets, as well as any associated statistical measures like confidence intervals and *p*-values. A Bayesian random-effects meta-analysis was used (Smith et al. 1995) using the *R* software package bayesmeta (Röver 2020) to account for between-study heterogeneity. For each study i, the effect size e_i was calculated as the natural logarithm of the ratio of CPUE for monofilament nets ($\mathrm{CPUE}_{\mathrm{mono,x}}^{\mathrm{gillnets}}$) and multifilament nets ($\mathrm{CPUE}_{\mathrm{multi,x}}^{\mathrm{gillnets}}$) such that:

$$e_i = \ln\left(\frac{\mathrm{CPUE}_{\mathrm{mono,x}}^{\mathrm{gillnets}}}{\mathrm{CPUE}_{\mathrm{multi,x}}^{\mathrm{gillnets}}}\right), \quad x \in \{n, w\} \tag{3.23}$$

These effect sizes were combined to estimate the overall material effect θ_I. The specifics of the meta-analysis model and prior distributions are detailed in (

Appendix A3).

A simple height scaling factor (H) was calculated as the ratio of net heights between fleets such that:

$$H^{\text{gillnets}} = \frac{H_{\text{illegal}}^{\text{gillnets}}}{H_{\text{experimental}}^{\text{gillnets}}} \tag{3.24}$$

The adjusted $\text{CPUE}_{\text{m,x}}^{\text{gillnets}}$ for each mesh size *m* was then calculated as:

$$\text{CPUE}_{\text{m,x}}^{\text{gillnets}} = \text{CPUE}_{\text{e,x}}^{\text{gillnets}} \cdot H^{\text{gillnets}} \cdot \left(p_{\text{mono}} \cdot e^{\theta_1} + p_{\text{multi}}\right) \tag{3.25}$$

where H^{gillnets} is the height scaling factor, p_{mono} and p_{multi} are the proportion of monofilament and multifilament gillnets observed in the illegal gillnet fleet, and θ_1 is the material effect estimated from the Bayesian meta-analysis.

To estimate overall CPUE per net per set, the $\text{CPUE}_{\text{m}}^{\text{gillnets}}$ estimates were combined with the observed proportions of different mesh sizes in the illegal gillnet fishery:

$$\text{CPUE}_{\text{net,x}}^{\text{gillnets}} = \sum_{m} \text{CPUE}_{\text{m}}^{\text{gillnets}} \cdot p_m, \quad x \in \{n, w\} \tag{3.26}$$

where $\text{CPUE}_{\text{m}}^{\text{gillnets}}$ is the adjusted CPUE for mesh size m, and p_m is the proportion of mesh size m in the illegal gillnet fleet.

Preliminary analyses of the CPUE data showed that they did not meet the criteria for normality and homogeneity of variances required for using parametric tests. As such, yearly and seasonal differences between CPUE were assessed using the non-parametric Kruskal Wallis test (Kruskal and Wallis 1952).

The total seasonal catch of the illegal gillnet fishery was estimated by integrating the results from the Bayesian analysis of gillnet numbers, adjusted CPUE estimates, and information from interviews with illegal gillnet fishers.

Total seasonal catch (C_s^{gillnets}) was calculated as:

$$C_s^{\text{gillnets}} = \text{CPUE}_{\text{net,s}}^{\text{gillnets}} \cdot N^{\text{gillnets}} \cdot D_s^{\text{fishing}} \tag{3.27}$$

where $\text{CPUE}_{\text{net,s}}^{\text{gillnets}}$ is the adjusted catch per unit effort in numbers (*n*/net/set) and weight (kg/net/set) in season *s*, N^{gillnets} is the estimated total number of gillnets in use, and D_s^{fishing} is the number of fishing days in season *s*. N^{gillnets} was derived from the posterior distribution of the Bayesian hierarchical model used to estimate the total number of gillnets (see Effort Estimation section and Appendix A7 for details). D_s was set to 183 days for summer (October to March) and 182 days for winter (April to September), based on information from interviews with illegal gillnet fishers who confirmed that fishing occurred year-round.

To account for uncertainties in all components, a Monte Carlo simulation approach (Caddy and Mahon 1995 was implemented where 1 000 samples were drawn from the bootstrapped distribution of adjusted $\mathrm{CPUE}_{\mathrm{net,s}}^{\mathrm{gillnets}}$ and the posterior distribution of N^{gillnets}. For each iteration, C_s^{gillnets} was recalculated using the fixed values of D_s^{fishing} for each season. Credible intervals (95%) for seasonal catch were constructed using the 2.5$^{\mathrm{th}}$ and 97.5$^{\mathrm{th}}$ percentiles of the simulated C_s^{gillnets} values for each season. Results of the Monte Carlo simulations, including sensitivity analyses on the assumption of constant fishing effort across seasons, are presented in (

Appendix A3).

To assess differences between summer and winter harvests, the distribution of differences between seasonal estimates derived from the Monte Carlo simulations was examined. Credible intervals (e.g., 95%) were used to determine if the differences excluded zero, providing evidence of significant seasonal variation.

Selectivity

Selectivity was assessed for *L. capensis*, *L. aeneus* and *O. mykiss* (those comprising more than 20% of the catch, as per Richardson et al. (2009)). All individuals of these species sampled from the experimental gillnet fleet were grouped into 10 mm size classes (L) for any given mesh size m_i. Selectivity was estimated using the SELECT (Share Each Length-Classes Catch Total) method (Millar and Holst 1997). SELECT is a maximum likelihood method that estimates selectivity parameters from a general log-linear model under the assumption that the data are Poisson-distributed.

The parameters were estimated by fitting the general log-linear model of the form:

$$\log(n_{ij}) = \text{factor}(j) + \beta_1 \cdot f_1(m_i, j) + \beta_2 \cdot f_2(m_i, j) \tag{3.28}$$

where $\log(\hat{n}_{ij})$ is the expected catch of fish in length class j by mesh size i, $f_1(m_i, j)$ and $f_2(m_i, j)$ are the selectivity functions for mesh size m_i and length class j, and $\text{factor}(j)$ denotes that a length class is fitted as a factor in the model.

Four selectivity curve forms (normal fixed spread; normal proportional spread; gamma; lognormal) were fitted to the catch data, assuming equal fishing intensity across mesh sizes. The lognormal model was the best fitting model (

Appendix A3).

The Selection Factor (SF) for the lognormal model was then calculated as:

$$SF = \exp\left(\mu + \frac{\sigma^2}{2}\right) \tag{3.29}$$

where *SF* represents the ratio of the optimal fish length to the mesh size, and μ and σ are the estimated parameters from the lognormal model.

The illegal gillnet fleet comprised approximately 70% monofilament nets and 30% multifilament nets, with mesh sizes ranging from 40 mm to 135 mm. To estimate the selectivity of the illegal fleet, separate selectivity curves were generated for the monofilament and multifilament nets.

For multifilament nets, it was assumed that selectivity characteristics were like those in the experimental gillnet fleet. As such, the *SF* and spread parameter (σ) estimated from the experimental gillnet data was applied.

For monofilament nets, *SF* was derived using unpublished data from a previous study conducted in Mohale Dam (Hecht and McCafferty 2011). Mohale Dam shares several characteristics with Katse Dam (see Chapter 6) including similar depth profiles, water quality conditions, and target species composition (except for *O. mykiss* which does not occur in Mohale Dam). Although limited, this data provided measurements of fish lengths caught in monofilament nets of various mesh sizes, allowing for the calculation of monofilament-specific *SF*. Given the similarities between the study sites, these data were considered a reasonable proxy for monofilament net selectivity in Katse Dam.

The combined selectivity curves for the illegal gillnet fleet were computed as a weighted sum of the individual selectivity curves for monofilament and multifilament nets:

$$S_{\text{illegal}}(L,m) = p_{mono} \cdot S_{\text{mono}}(L,m) + p_{multi} \cdot S_{\text{multi}}(L,m) \tag{3.30}$$

where $S_{\text{illegal}}(L,m)$ is the combined selectivity of the illegal gillnet fleet, p_{mono} and p_{multi} are the proportions of monofilament and multifilament nets in the illegal gillnet fleet, and $S_{\text{mono}}(L,m)$ and $S_{\text{multi}}(L,m)$ are the selectivity curves for the monofilament and multifilament nets.

Demographics

Qualitative demographic information was obtained, where possible, during semi-structured in-person and telephonic (WhatsApp®) interviews with self-confessed illegal gillnet fishers. The interviews focused on gathering information about the age, gender, income, and livelihoods of those involved in the illegal gillnet fishery (

Appendix A3).

3.2.6. Functional analysis of the value chain

To gain additional insights into how communities have adapted to the development of the fishery, the different fisheries-related livelihood activities that have emerged, and to gain a better understanding of the fishery's role in fish supply and income generation, a functional value chain analysis was conducted, adapted from Attaie and Fourcadet (2003) and the Value Chain Analysis for Development (VCA4D) framework (Dabat et al. 2018). The functional analysis in this study focussed on describing and mapping the key components of the value chain, including the products, the actors involved and their functions, the geographical location(s) of activities, and the main flows. Given data collection constraints related to the informal nature of some activities, market flows were mapped qualitatively rather than attempting to quantify precise volumes through each channel.

The analysis relied primarily on data collected through questionnaire surveys with hook-and-line fishers, semi-structured interviews with illegal gillnet fishers, traders, and retailers, community FGDs, and in-field observations (Table 3.6).

Table 3.6: Sources of data used in the fisheries value chain assessment.

Source	Type
Questionnaire surveys with hook-and-line fishers (January–March, July–September 2018–2020; 2022–2024)	Consumption, sales, processing, product forms and prices
Semi-structured interviews with illegal gillnet fishers, traders, retailers (February/March and July/August 2024)	Processing, product forms and prices, distribution, markets
Community focus group discussions (FGDs) (February/March and July/August 2024)	Value chain actors, consumption, processing, product forms and prices, distribution, markets
In-field observations (February/March and July/August 2024)	Product forms and prices, distribution, markets

Questionnaires: hook-and-line fishers

Questionnaires (Appendix A2) were administered to a total of 152 hook-and-line fishers intercepted during the roving creel surveys and fisher counts. The questionnaires were designed to capture quantitative information on fish consumption, processing methods, distribution channels, sales, and prices of different species and size classes.

Semi-structured interviews with illegal gillnet fishers

None of the illegal gillnet fishers agreed to participate in a questionnaire survey. However, some qualitative information was obtained through semi-structured interviews; this included information on gillnet suppliers, the proportion of the catch that was consumed and/or sold, income, product forms and processing, distribution and trade, and market destinations (

Appendix A3). The fishers were identified through a combination of local introductions and snowball sampling techniques (Bernard 2017). Initial contact was facilitated by a village *Marena*, who provided introductions to individuals known to be involved in gillnetting. Subsequent participants were recruited through referrals from these initial contacts. The interviews were conducted both in-person and virtually using WhatsApp (Mwanda 2022) and guided by open-ended questions to allow participants to share their experiences comfortably. Given the sensitivities associated with discussing participation in an illegal fishery, respondents were assured of strict confidentiality and anonymisation, and no identifying information was recorded. To check the validity of responses, narratives were compared across different respondents and cross-checked against direct field observations (e.g., gillnet locations, mesh sizes, fishing practices) and secondary sources such as LHDA patrol reports and previous studies.

Semi-structured interviews with fish traders and retailers

Obtaining information from traders and retailers was challenging. This may have been because participants felt that revealing such information would implicate them in participating in illegal activities associated with the harvesting of fish exceeding bag limit regulations. Nevertheless, some traders (n = 5) and retailers (n = 3) that participated in community FGDs (see below) were willing to divulge information on their activities including their commercial relationships with fishers, the types and quantities of fish purchased, processing, storage, transport, and retail (

Appendix A4). Discussions also explored the factors influencing pricing decisions, variations in demand for different species, sizes, and product forms (e.g., fresh, frozen, dried), as well as barriers to distribution and market access. Engagements were either held in-person or virtually using WhatsApp and social media platforms.

Community focus group discussions

A total of six FGDs were held to gather community perspectives on the fisheries value chain. The FGD participants were convened by the community *Morena* and/or *Mofumahali* and included fishers, traders, retailers, non-fishing community members, and community councillors. The FGDs followed a semi-structured format guided by a topic guide (

Appendix A4) that included open-ended questions to encourage participants to discuss various aspects of the value chain, including the different actors involved, processing and product forms, sales, distribution channels, markets, and trade.

In-field observations

Field observations were conducted to complement the survey and interview data. These observations focused on fish sales on the roadside and in communities surrounding the dam. Species composition, size, product forms, and sales prices were documented.

It was not possible to arrange visits to informal retailers outside of the study area; this was also likely due to the real or perceived illegal nature of the trade and the associated reluctance of these actors to divulge information that could implicate them in illicit activities.

Data analyses

Analysis of the value chain data followed the VCA4D framework (Dabat et al. 2018). The data were consolidated and systematically reviewed to identify core value chain functions, from harvesting through to final sale. Each distinct activity was mapped sequentially, noting where functions were combined or separated between different actors. Actors were categorised based on their fishing methods (hook-and-line versus gillnet), scale of operation, and role in the value chain (fishers, traders, retailers). Linkages between actors were mapped in two dimensions: vertical linkages between actors at different functional stages, and horizontal linkages between actors performing the same function. Market channels were mapped by tracing product flows from point of harvest through various intermediaries to end markets. A geospatial map was also prepared using QGIS software (QGIS Development Team 2024) to indicate distribution channels and the geographic extent of the value chain.

Quantitative data on production (Sections 3.2.4 and 3.2.5), and fish consumption, sales, and price data obtained from the questionnaires, semi-structured interviews, and FGDs, were used to determine the contribution of the hook-and-line and illegal gillnet fisheries to fish consumption in the project area, the contribution of these fisheries to the income of fishers, and the total value of fish at first point of sale. Due to the partially informal (and illegal) nature of the fishery and associated data collection challenges, quantification of fish volumes and values across the value chain was not possible.

The contribution of the hook-and-line fishery (C_{hook}) and the illegal gillnet fishery (C_{gill}) to fish consumption in the Katse Dam area was estimated as

$$C_{hook} = H_{catch} \times p_h \tag{3.31}$$

and

$$C_{gill} = G_{catch} \times p_g \tag{3.32}$$

where H_{catch} is the total hook-and-line catch and p_h is the proportion consumed locally, and G_{catch} is the total gillnet catch and p_g is the proportion of gillnet catch consumed locally.

The contribution of the hook-and-line fishery ($I_{h,\mathrm{total}}$) and illegal gillnet fishery ($I_{g,\mathrm{total}}$) to the income of fishers was estimated as:

$$I_{h,\mathrm{total}} = \sum_{s} \left(T_h \times P_{s,h} \times M_{s,h}\right) \tag{3.33}$$

and

$$I_{g,\mathrm{total}} = \sum_{s} \left(T_g \times P_{s,g} \times M_{s,g}\right) \tag{3.34}$$

where T_h and T_g are the total harvests from each fishery, $P_{s,h}$ and $P_{s,g}$ are the proportions of species *s* in the catch composition of each fishery, and $M_{s,h}$ and $M_{s,g}$ are the mean incomes per fish for species *s* from each fishing method.

The total annual production value of the hook-and-line fishery (V_h)and the illegal gillnet fishery (V_g) was estimated as:

$$V_h = I_{h,\mathrm{total}} \times P_h \tag{3.35}$$

and

$$V_g = I_{g,\mathrm{total}} \times P_g \tag{3.36}$$

where $I_{h,\mathrm{total}}$ and$I_{g,\mathrm{total}}$ are the total incomes and P_h and $P_g$are the mean prices per fish in each fishery.

3.3. Results

3.3.1. Emergence and evolution of the fishery

Three key periods marking the emergence and evolution of fishing in the Katse Dam area were identified: a "Pre-Dam Period" from the 1940s until the mid-1990s, an "Early Post-Dam Period" from 1997 until 2004, and an "Established Post-Dam Period" from 2005 until the present. Each period was characterised by several key subthemes (Figure 3.7) which are presented in more detail below.

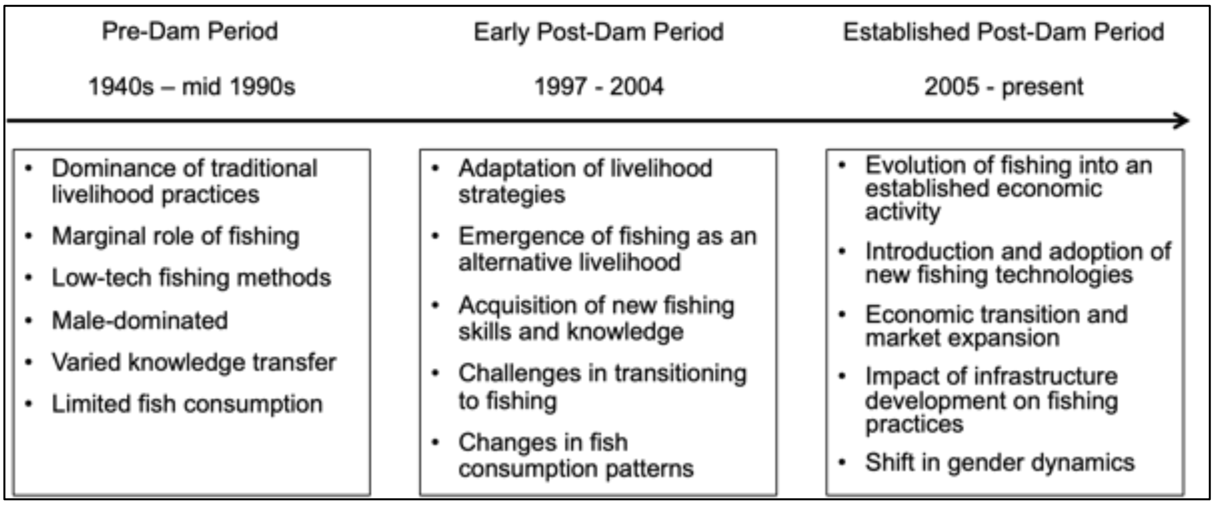

Figure 3.7: Key periods and subthemes emerging from interviews and focus group discussions with community members on the origins and evolution of fishing in Katse Dam.

Pre-Dam Period – 1940s to mid-1990s

Participants in the semi-structured interviews and FGDs reported that traditional livelihood practices dominated the Pre-Dam Period, with fishing playing a marginal role. The primary economic activities centred on agriculture, as evidenced by Participant 2's statement that "*We used to farm the land before the dam, and many still do. That was how we lived. We had our crops, and we had our livestock. Fishing was not something we relied on for food or money*". This was supported by Participant 12, who stated that "*Only three people in our community were fishing before the dam, it was not a common thing*".

Participants described fishing at this time as an activity undertaken using low-tech gears and traditional methods. Gears used included spears, stones, handmade lines fashioned from twine, and hooks crafted from safety pins. For example, Participant 4 described his grandfather's fishing methods where "*In winter, he would catch fish that became trapped in the ice. Then in summer, they would also use stones which they would throw at the fish when they were moving up the river*".

The acquisition and transmission of fishing knowledge varied widely among the survey participants. Some noted that they acquired their skills from their elders while others were self-taught. However, the arrival of foreign contract workers and, to a lesser extent, tourists, played an important role in exposing community members to different fishing techniques and gear types. Participant 1 noted that "*Some tourists came here to do fishing in the river, and we learnt about fishing then. They were using lines and hooks and caught a lot of fish*".

Gender roles in fishing activities were clearly defined, with fishing being a predominantly male endeavour. Participant 12 stated "*There were no ladies fishing at that time*" while Participant 5 (a female) noted that "*We only started fishing later once we saw that it was a good way to make money*".

Fish consumption at this time was limited with Participant 12 noting that: "*People in the community were eating a bit of fish but not very much and we didn't see it very often*".

<u>*Early Post-Dam Period – 1997 to 2004*</u>

Participants reported changes in livelihood strategies during the Early Post-Dam Period. Participant 5 stated "*I started fishing when the dam was built. I started fishing because my fields were flooded*". This sentiment was echoed by Participant 2, who explained that "*After the dam came, I had to try and find a way to make a living. Unemployment was very bad. So, I began fishing*".

Some community members highlighted that the dam presented new and more lucrative economic opportunities. Participant 7 observed "*I started fishing after the dam. I saw that there were opportunities to catch and sell fish because there were more fish once the dam had been built*".

Community members reported acquiring fishing skills through various means, including learning from family members and community elders, peer learning, and outsiders including tourists. Participant 10 noted that "*I met tourists who told me that they wanted to eat fish, so I began fishing as I realised I could maybe make some money off it*".

This period also marked the introduction of gillnets to the fishery. Opinions differed, however, as to when these were first seen. Some participants recalled first seeing them during the LFP in 2002. However, others mentioned seeing and subsequently using gillnets in 1997.

Challenges in adopting fishing as a source of livelihood were also noted. Participant 5 expressed these difficulties stating that "*It was not easy to change from farming to fishing. Then we started using nets in 1997 because we were not catching enough fish. It was not easy because we were afraid of the water and drowning*".

This period also saw changes in fish consumption patterns, with community members noting an increase shortly after the filling of the dam. Participant 5 said that "*We also started eating* *more fish since the dam was built. We heard that it was good for health reasons and my doctor recommended it. Also eating fish helped because there was less food available after the dam*".

Established Post-Dam Period – 2004 to current

Participants reported changes in fishing practices during the Established Post-Dam Period. Several interviewees described a shift from fishing as a supplementary activity to a more full-time, commercially-oriented activity.

The widespread adoption of gillnets was frequently reported during this period. Participant 12 recalled "*We started to see gillnets more; I remember around 2008. We then began gillnet fishing, and it has become a very important thing for us*", while Participant 14 said that "*there was an explosion of gillnets maybe since 2018 or 2019*".

The theme of economic transition was closely linked to changes in fishing techniques from entirely subsistence-based to more commercially oriented, and the expansion of local and regional markets and distribution networks. Participant 6 shared that "*After the dam came, I started fishing more and selling my fish. Fishing became much better after the dam. Now I sell my fish to people around the dam but also in other places in Lesotho. It provides me with a quick source of cash*". Participant 10 described how he established his network in the early 2010s: "*I decided to go and try to sell my fish in other urban centres away from the dam. I sold there on the streets. I managed to make contacts and now have buyers who contact me for fish*".

A commonly cited theme during this period was fishing as a poverty alleviation strategy. Participant 12 said that "*We make money, and I have been able to build a shelter and pay for my children's uniforms and to go to school*". Participant 8 noted the increase in fishing activity due to economic factors: "*Before the dam, very few people were fishing. Now there are lots because they can make money which can help them survive*".

Participants highlighted that infrastructure development had played an important role in supporting more intensive fishing activities, particularly the rural electrification projects supported by the LHDA. Before these projects, participants reported that they were unable to harvest large volumes of fish as they could not store and aggregate them for buyers, and drying was time-consuming and often led to spoilage. With the introduction of electricity in some villages, participants highlighted that they were now capable of freezing fish and storing them for longer periods.

The Established Post-Dam period was also marked by changing gender dynamics in the fishery. Participant 13, a woman who started fishing in 2019, shared: "*I began fishing when I saw that* *it could be a source of income for the family. I learnt from other men in the village and have become a good fisher. I can leave my nets in the water while I look after the household*".

Many participants expressed awareness that their use of gillnets was illegal. Participant 12 voiced this concern: "*Our problem is we know it is illegal, and we are scared of the authorities. But fishing can help us with poverty*". This sentiment was echoed by Participant 13: "*Fishing has improved my life, but I know that it is illegal, and this scares me with the authorities. However, other opportunities to make money are scarce*".

Catalysts and outcomes

The analysis of interviews with community members in the Katse Dam area revealed several key catalysts that drove the evolution of fishing, along with their associated outcomes (Figure 3.8). "Environmental Transformation" was an important catalyst, leading to the creation of a new aquatic ecosystem and the loss of agricultural land. "Displacement and Livelihood Loss" forced some community members to seek alternative income sources, resulting in increased participation in fishing and changing social norms. "Technological Innovation" involved the introduction of new fishing methods, particularly gillnets, leading to the adoption of these new techniques. "Market Development" was characterised by local and regional market expansion, driving the commercialisation of fishing and the expansion of value chains. "Socio-economic Pressures" led to increased participation, including youth involvement and shifts in gender roles within the fishing sector. "Infrastructure Improvements", particularly rural electrification projects, enabled better fish storage and distribution, and supported increased sales. Finally, "External Influences", notably the influence of foreign labourers and tourists, played a role in stimulating technological innovation and contributing to learning and skills development among community members.

Figure 3.8: Catalysts and outcomes in the development of the Katse Dam fishery, based on thematic analysis of interviews with community members.

3.3.2. The hook-and-line fishery

The following section presents the results from the assessment of the Katse Dam hook-and-line fishery.

Demographics

The survey respondents were predominantly male (95.3%). The average age of the respondents was 41.9 ± 13.4 years. Average household size was 4.9 ± 1.9 members. The majority (90.5%) of respondents were unemployed. Fishing was the main source of income for 68.3% of respondents; the remainder (31.7%) reported that non-fishing activities, primarily agriculture or part-time work, was their primary source of income (Table 3.7). There was a significantly positive relationship between being unemployed and having fishing as the main source of income ($p < 0.05$).

Table 3.7: Demographic characteristics of the Katse Dam hook-and-line fishery. "Employment" refers to formal wage-earning jobs. Respondents who reported themselves as unemployed may still derive their main livelihood from fishing (including gillnetting) or farming.

Characteristics		**Respondents**
Gender (%)	Male	95.3%
	Female	4.7%
Age (*n*)		41.9 ± 13.4
Household size (*n*)		4.9 ± 1.9
Employment status	Employed	9.5%
	Unemployed	90.5%
Main source of income	Fishing	68.3%
	Non-fishing	31.7%

Fishing methods

Fishing was conducted entirely with handlines to which a single hook was attached. The mean number of lines per fisher was 2.75 ± 1.52. Hook sizes ranged from 4 (20%) to 6 (75%) and 8 (5%). Bait included maize meal (locally known as *papa*) (53.8%) (Figure 3.9), a mix of maize meal and earthworms (16.3%), earthworms (13.8%), locusts (6.3%), a mix of maize meal and locusts (6.3%), fish intestines (3%), and fish feed (1%).

Figure 3.9: A fisher on the Katse Dam shoreline (left); the most used bait was maize meal (*papa*) which was softened and moulded onto the hook.

Most fishers only fished in summer (66.4%). A smaller proportion fished in both summer and winter (33.6%). No fishers only fished in winter. The major fishing areas, based on the average number of fishers observed during the vessel-based fisher counts, are shown in Figure 3.10.

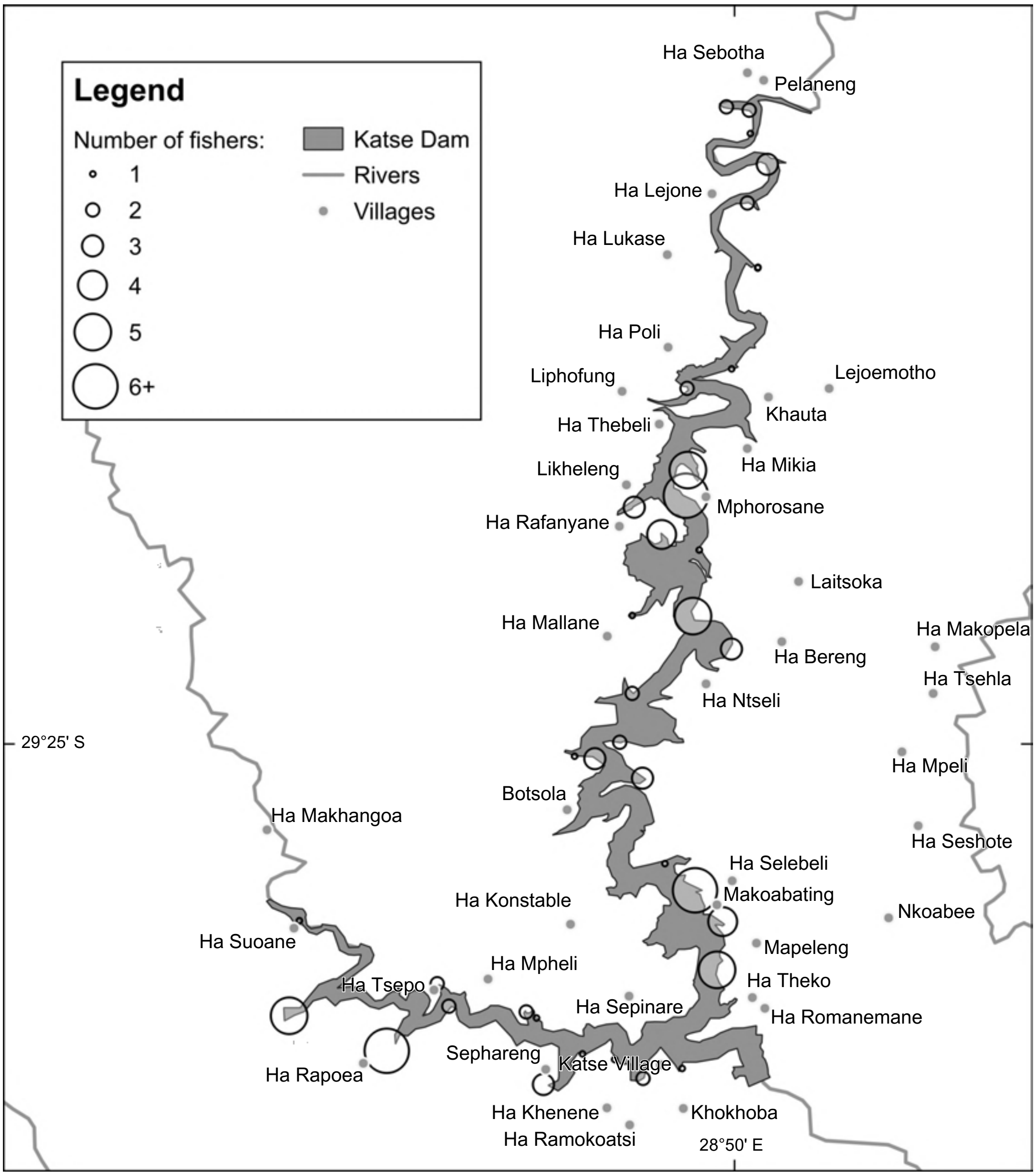

Figure 3.10: Hook-and-line fishing locations on Katse Dam; the counts are averaged from the vessel-based fisher counts conducted in summer and winter of 2024.

Species composition

Four species were recorded in hook-and-line catches during the roving creel surveys: *L. aeneus*, *L. capensis*, *O. mykiss*, and brown trout *S. trutta* (Table 3.8). There was a significant difference ($\chi^2 = 54.17$; $p < 0.05$) in species composition between seasons. In both summer and winter, *L. aeneus* was the most abundant species. However, while *L. aeneus* dominated catches in summer (71.6%), their contribution to winter catches was markedly lower (43.3%). Conversely, the contribution of *O. mykiss* to catches increased from 16.7% in summer to 43% in winter. The contribution of both *L. capensis* and *S. trutta* was relative consistent across seasons, with *S. trutta* comprising a minor component of the catch.

Table 3.8: Seasonal catch composition of the Katse Dam hook-and-line fishery expressed as a percent of total number (*n*).

Species	**Summer (%; *n* = 282)**	**Winter (%; *n* = 298)**
Labeobarbus aeneus	71.6	43.3
Labeo capensis	10.6	12.1
Oncorhynchus mykiss	16.7	43.0
Salmo trutta	1.1	1.7

<u>*Length frequencies*</u>

Length frequency distributions of the three major target species are shown in Figure 3.11. The *L. capensis* ranged from approximately 170 mm to 470 mm FL, with a mean FL of 345 ± 116.9 mm. Most individuals (91.8%) were above length-at-50% (L_{50}) maturity (240 mm FL).

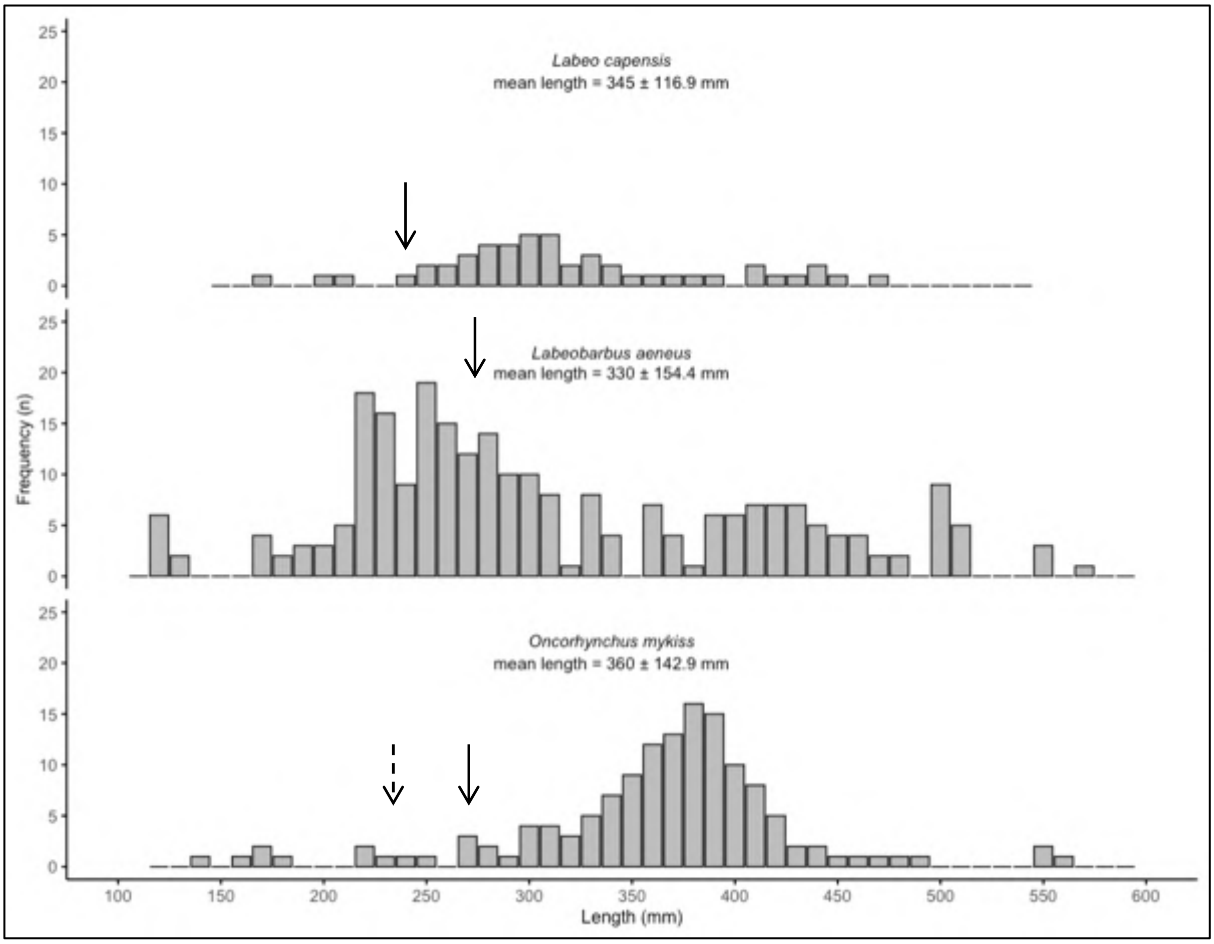

Figure 3.11: Length frequency distributions (FL mm) for the three major target species in the Katse Dam hook-and-line fishery, based on data collected during fisher intercept surveys. The arrows indicate estimates of length-at-50% maturity (FL) obtained from Nthimo (2000). For *Oncorhynchus mykiss*, the dashed arrow indicates length-at-50% maturity for males while the solid arrow indicates length-at-50% maturity for females.

Two dominant cohorts of *L. aeneus* were observed: a cohort around 200–300 mm FL and a cohort around 350–400 mm FL. The mean FL of *L. aeneus* (330 ± 154.4 mm) was above L_{50} (280 mm FL) although almost half (47.1%) of the individuals sampled were below L_{50}.

The length frequency distribution for *O. mykiss* showed a distinct peak at around 380 mm FL; mean FL (360 ± 142.9 mm) was well above L_{50} for both males (240 mm FL) and females (280 mm FL).

<u>*Catch and effort*</u>

Total participation in the fishery was estimated at 319 fishers [95% CI: 215, 434]. Fishing effort was credibly higher in summer (162.8 fishers/day [95% CI: 109.4, 217.4]) than in winter (48.8 fishers/day [95% CI: 32.3, 66.7]) ($P(\mu_{\text{summer}} \neq \mu_{\text{winter}})$). There was no credible difference ($P(d_{\text{summer}} = d_{\text{winter}})$) in mean fishing duration between summer (5.7 hours [95% CI: 5.0, 6.3]) and winter (95% CI: 5.9 hours [4.7, 7.3]) (Figure 3.12).

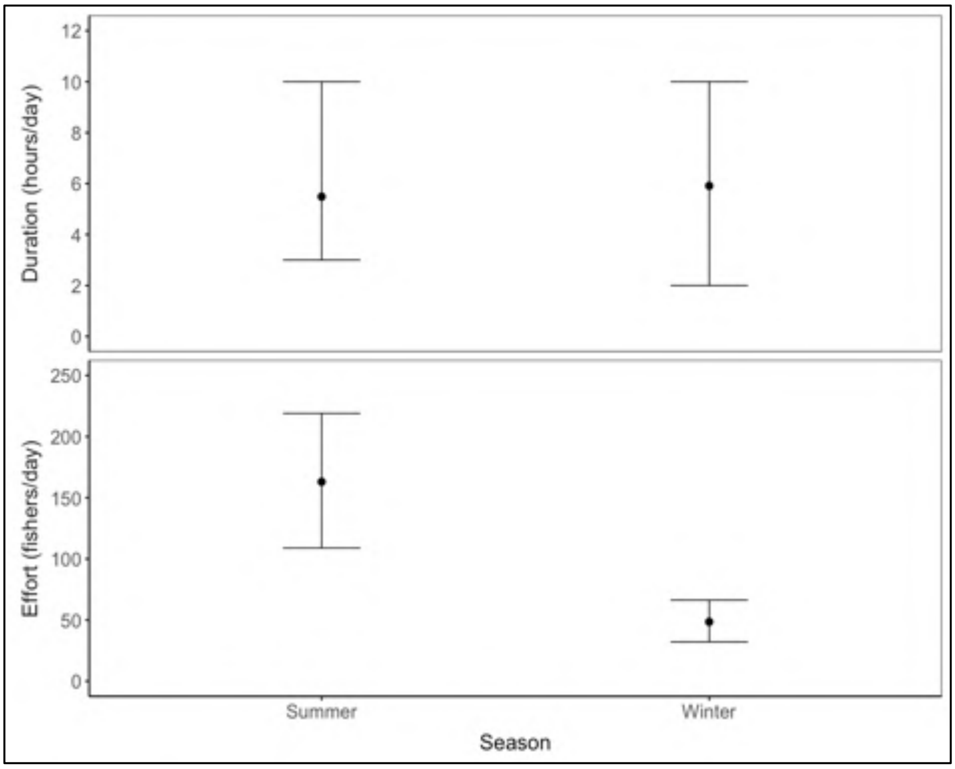

Figure 3.12: Seasonal fishing duration (hours/day) (top) and daily fishing effort fishers/day (bottom) of the Katse Dam hook-and-line fishery. Error bars represent 95% confidence intervals.

Mean CPUE by number and weight differed significantly ($p < 0.05$) between seasons, with a mean CPUE of 5.1 fish/day [95% CI: 4.2, 6.1] and 1.5 kg/day [95% CI: 1.1, 2.0] in summer compared to 2.8 fish/day [95% CI: 1.9, 3.8] and 0.8 kg/day in winter [95% CI: 0.5–1.3] (Figure 3.13).

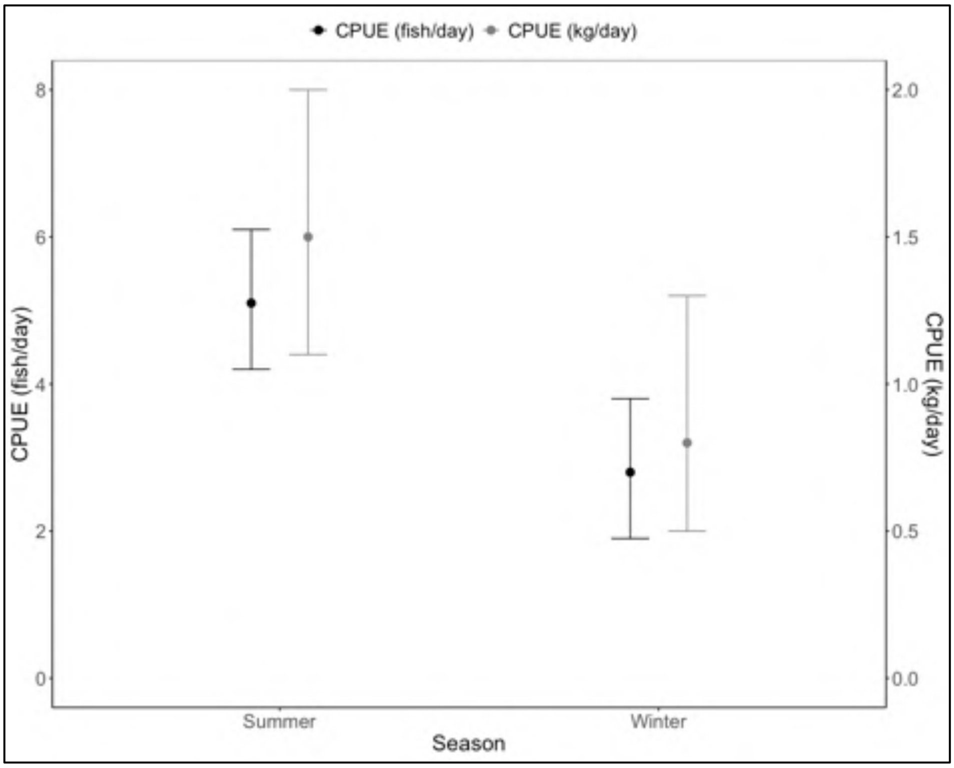

Figure 3.13: Seasonal catch per unit effort (CPUE) in numbers (fish/day) and weight (kg/day) of the Katse Dam hook-and-line fishery. Error bars represent 95% confidence intervals.

Total seasonal catch by number and weight was credibly higher in summer than winter ($C_{\text{summer}} > C_{\text{winter}}$) (Figure 3.14). Total catch in summer was estimated as 94 893.6 fish [95% CI: 76 049.5, 117 769.6] with a combined weight of 28.7 tonnes [95% CI: 21.5, 39.7], compared to 8 322.7 fish [95% CI: 4 534.4, 13 477.3] and 2.4 tonnes [95% CI: 1.3, 4.1] in winter (Figure 3.14). Assuming these periods are representative of an entire calendar year, as stated by local fishers, the total annual harvest from the hook-and-line fishery was estimated at 103 216.3 fish [95% CI: 80 583.9, 131 246.9], equivalent to 31.1 tonnes [95% CI: 22.8, 43.8].

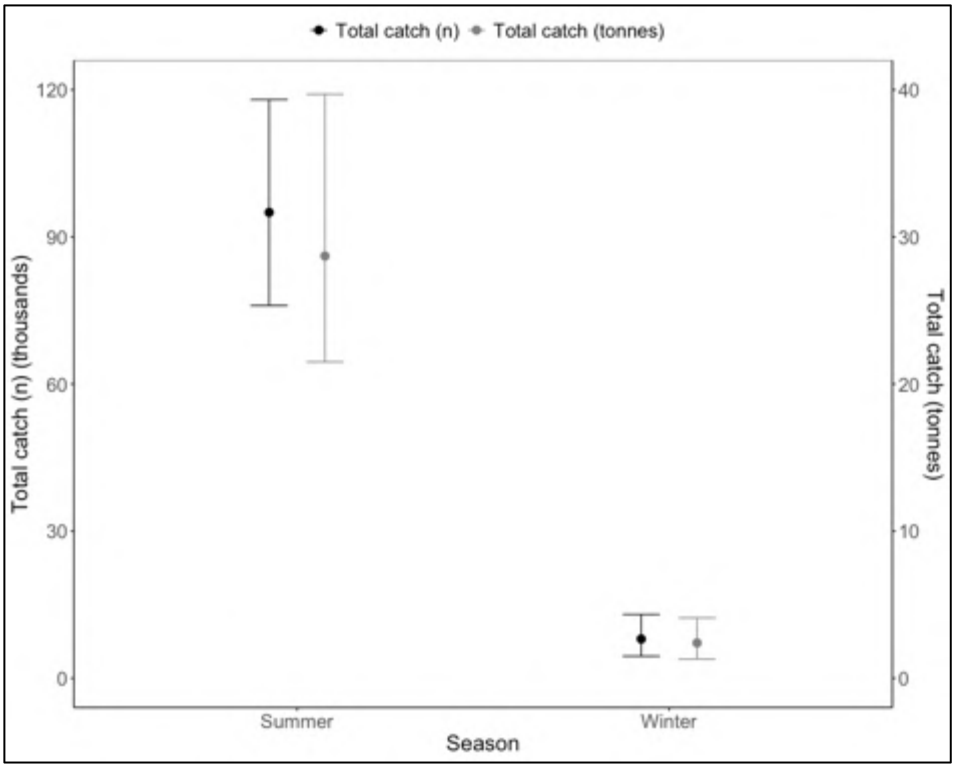

Figure 3.14: Total catch in summer and winter by numbers and tonnes of the Katse Dam hook-and-line fishery. Error bars represent 95% confidence intervals.

3.3.3. The illegal gillnet fishery

Demographics

No quantitative demographic information could be obtained for the illegal gillnet fishery. However, the self-confessed illegal fishers stated in interviews that participants in the illegal gillnet fishery were "mostly younger" than those in the hook-and-line fishery, and commonly between the ages of 20 and 45 years. Participants were "mostly men"; however, respondents reported that more women participated in the gillnet fishery than in the hook-and-line fishery. Fishing was the primary source of income for the self-confessed illegal gillnet fishers that this study engaged with; other livelihood activities included part-time contract work e.g., construction, livestock and crop farming, and harvesting of rosehip.

Fishing activities

The major gillnet fishing areas on Katse Dam are shown in Figure 3.15. Most gillnets were observed in small baylets (53%) adjacent to inflowing streams, or in the Malibamatso River estuary (45%). Gillnets set in small baylets were stretched across the bay and anchored in place on either side by tying the net to rocks (Figure 3.16). Gillnets set in the Malibamatso River were stretched across the entire river and similarly tied to rocks on either side. Fishers indicated that they set the nets from land or used foam mattresses as vessels. No gillnets were observed in open water areas.

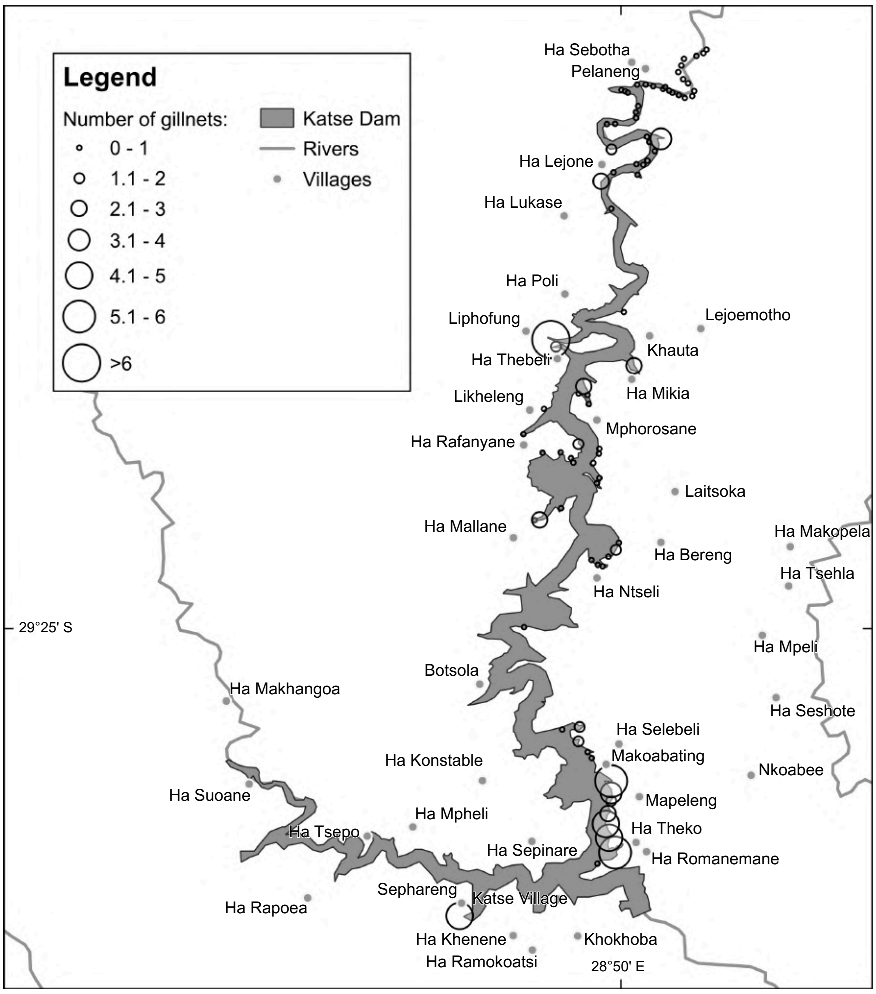

Figure 3.15: Major gillnet fishing locations; the number of gillnets is expressed as an average of the number of gillnets observed during in-field gillnet counts in summer and winter of 2024 and data obtained from MCS patrols conducted from 2018–2022.

Figure 3.16: Gillnets were commonly set in small bays next to small-stream inlets (left); gillnets were attached to rocks and stretched across bays and/or river mouths (right).

The length of the gillnets ranged from 5 m to 120 m, with a mean length of 48.1 ± 27.5 m. The height of the gillnets ranged from 1.1 m to 2.4 m, with a mean height of 1.81 m ± 0.25 m (Figure 3.17). Most gillnets were monofilament nets (69.4%) with a smaller proportion of multifilament nets (30.6%). All gillnets were comprised of a single mesh size. Mesh sizes ranged from 40 mm to 135 mm. The most common mesh size was 90 mm (33%; of which 67% monofilament and 33% multifilament) and 100 mm (19%; of which 71% monofilament and 29% multifilament). The smaller mesh sizes (40, 50, 60, 80 mm) were all monofilament whereas the larger mesh sizes were mostly multifilament (125 mm: 75% multifilament, 25% monofilament; 135 mm: 67% multifilament, 33% monofilament) (Figure 3.17).

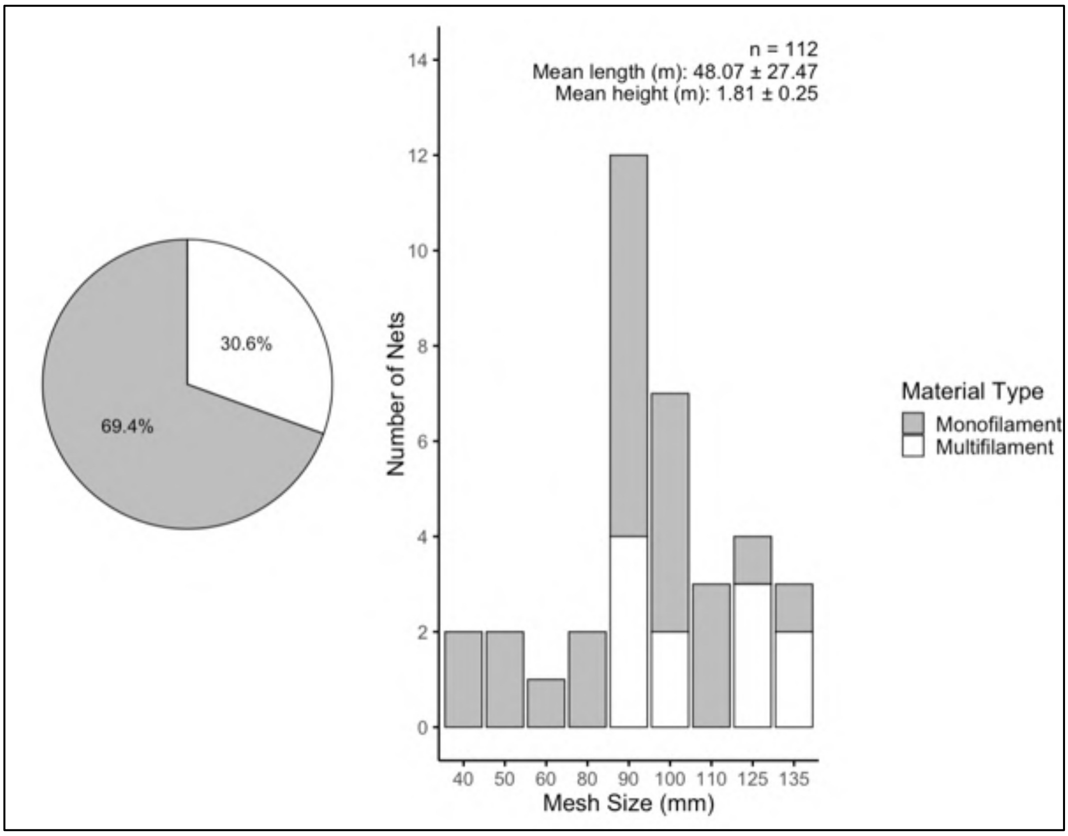

Figure 3.17: Composition, mesh sizes, mean length and mean height of illegal gillnets.

<u>*Species composition*</u>

Five species were recorded during the experimental gillnet surveys: *L. aeneus*, *L. capensis*, *O. mykiss*, rock catfish *Austroglanis sclateri*, and *S. trutta* (Table 3.9). There was a significant difference in species composition between seasons ($\chi^2 = 286.84$, $p < 0.001$). In both summer and winter, *L. aeneus* was the most abundant species. *L. aeneus* dominated catches in summer (76.9%), though its contribution decreased slightly in winter (66.1%). The contribution of *L. capensis* was relatively stable across seasons, accounting for 21.5% of the catch in summer and decreasing to 16.7% in winter. The contribution of *O. mykiss* increased substantially from 1.3% in summer to 16.6% in winter. *A. sclateri* was only recorded in summer, contributing a minor 0.2% to the catch. *S. trutta* remained a minor component of the catch in both seasons, comprising 0.1% in summer and increasing slightly to 0.7% in winter.

Table 3.9: Seasonal catch composition of experimental gillnet catches expressed as a percent of total number (*n*).

Species	**Summer (%; *n* = 2 293)**	**Winter (%; *n* = 737)**
Labeobarbus aeneus	76.9	66.1
Labeo capensis	21.5	16.7
Oncorhynchus mykiss	1.3	16.6
Austroglanis sclateri	0.2	–
Salmo trutta	0.1	0.7

Catch and effort

The total number of gillnets in use was estimated at 155 nets [95% CI: 114, 204]. Based on the limited data on the average number of nets per fisher (1.25), this equated to a total of 123 gillnet fishers.

Seasonal CPUE by mesh size in both numbers (*n*/net/set) and weight (kg/net/set) is shown in Figure 3.18. In summer, the highest CPUE by numbers was observed in the smallest mesh sizes: 40 mm (7.24 fish [95% CI: 5.13, 10.5]), 50 mm (6.64 fish [4.73, 9.65]), and 60 mm (6.10 fish [4.17, 8.68]). These meshes had significantly higher CPUE than larger sizes ($p < 0.05$). By weight, the highest summer CPUE was found in larger mesh sizes: 90 mm (4.14 kg [95% CI: 2.93, 6.36]), 80 mm (3.80 kg [2.69, 5.70]), 100 mm (3.84 kg [2.58, 5.66]), and 110 mm (3.22 kg [1.89, 4.77]). The lowest summer CPUE was recorded for the 135 mm mesh in fish numbers (0.990 fish [0.504, 1.71]) and the 40 mm mesh in weight (0.643 kg [0.452, 0.934]).

In winter, CPUE showed less variation between mesh sizes for both metrics. By number, the 40 mm and 50 mm meshes had the highest CPUE (3.09 fish [95% CI: 2.00, 4.66] and 3.00 fish [1.98, 4.55], respectively), significantly higher than larger meshes (100–135 mm, $p < 0.001$). By weight, the 80 mm and 90 mm mesh sizes had the highest CPUE (1.50 kg [0.984, 2.28] and 1.49 kg [0.957, 2.37], respectively), which was significantly higher than both smaller (40 and 50 mm) and larger (125–135 mm) meshes ($p < 0.001$). The lowest winter CPUE values were observed in the largest mesh sizes for both fish numbers (135 mm: 0.196 fish [0.0685, 0.402]) and weight (135 mm: 0.315 kg [0.106, 0.617]).

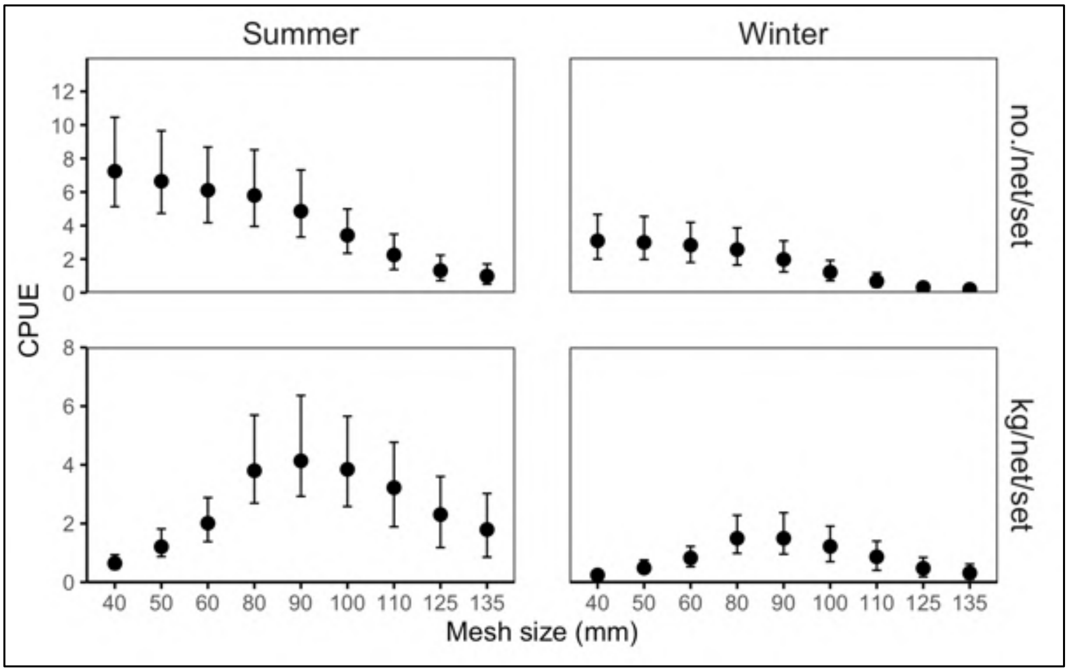

Figure 3.18: Predicted catch per unit effort (CPUE) (*n*/mesh/set) in summer and winter in different mesh sizes used by the illegal gillnet fleet.

Daily CPUE in number and weight are shown in Figure 3.19. Daily CPUE was significantly higher in summer than in winter for both metrics ($p < 0.05$). By number, summer CPUE was 18.9 fish/set [95% CI: 18.2, 19.7] while winter CPUE was 8.02 fish/set [7.57, 8.47]. By weight, summer CPUE was 3.01 kg/set [1.66, 4.34], while winter CPUE was 0.98 kg/set [0.31, 1.64].

Initial estimates of total catch reflected this seasonal pattern (Figure 3.20). Total catch in summer was estimated at 415 331 fish [95% CI: 369 002, 461 660] or 84.41 tonnes [39.30, 129.52], whereas winter harvest was lower at 175 163 fish [154 404, 195 921] or 27.34 tonnes [7.02, 47.69]. Assuming these periods are representative of an entire calendar year, as stated by local fishers, the total annual harvest from the gillnet fishery was estimated at 590 494 fish [523 406, 657 581], equivalent to 111.75 tonnes [46.32, 177.21].

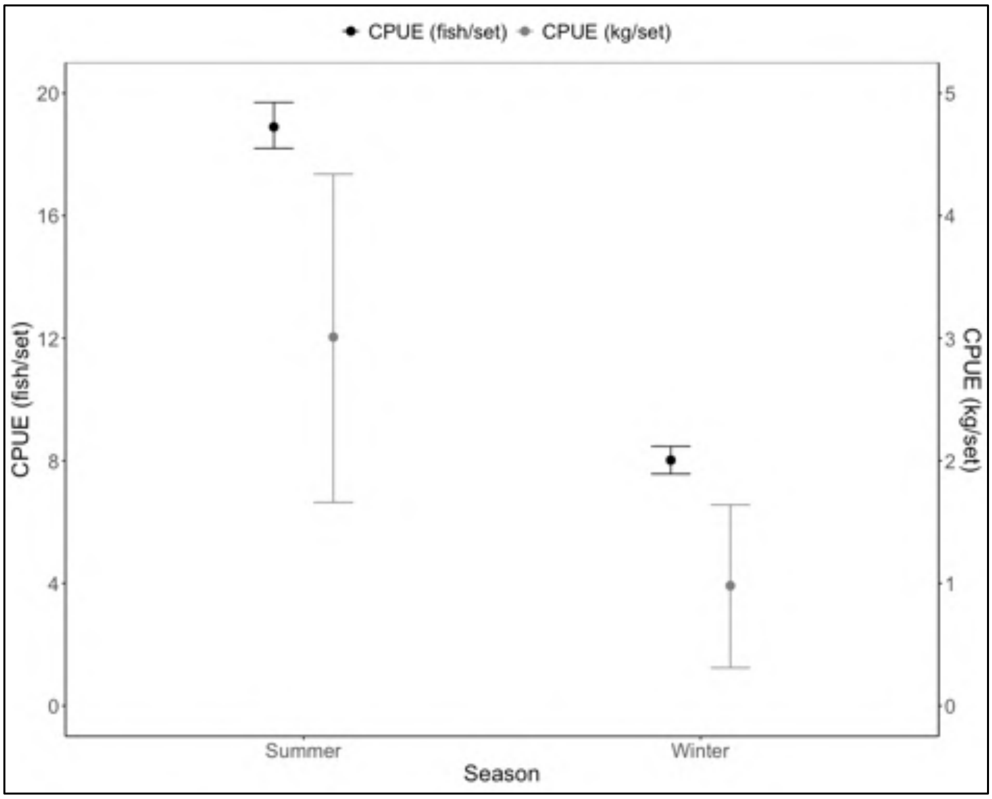

Figure 3.19: Seasonal catch per unit effort (CPUE) in numbers (fish/set) and weight (kg/set) of the Katse Dam illegal gillnet fishery. Error bars represent 95% confidence intervals.

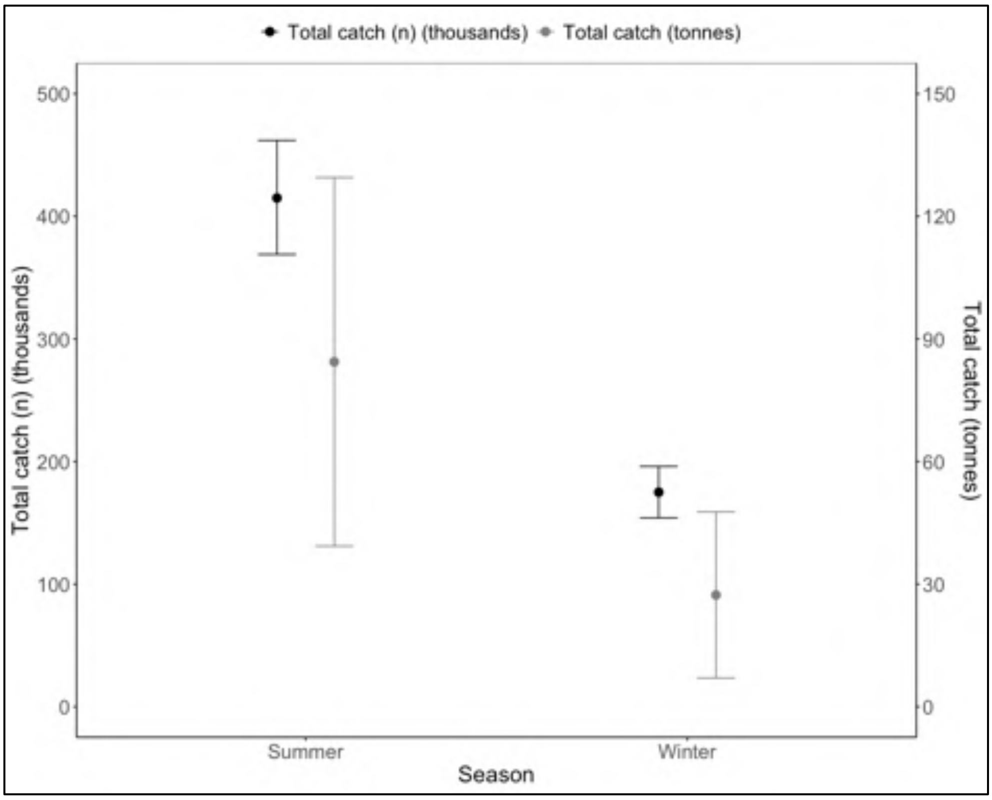

Figure 3.20: Total catch in summer and winter by numbers and tonnes of the Katse Dam illegal gillnet fishery. Error bars represent 95% confidence intervals.

Selectivity

The selectivity curves for *L. capensis* (Figure 3.21) show that mesh sizes of 40 mm and 50 mm capture fish predominantly below L_{50} (244 mm; Nthimo (2000)), while the 60 mm mesh selects fish at sizes close to L_{50}. Smaller proportions of fish below L_{50} are selected by the 80 mm and 90 mm mesh sizes. The most used mesh sizes in the fishery (90 mm and 100 mm) mostly harvest *L. capensis* above L_{50}.

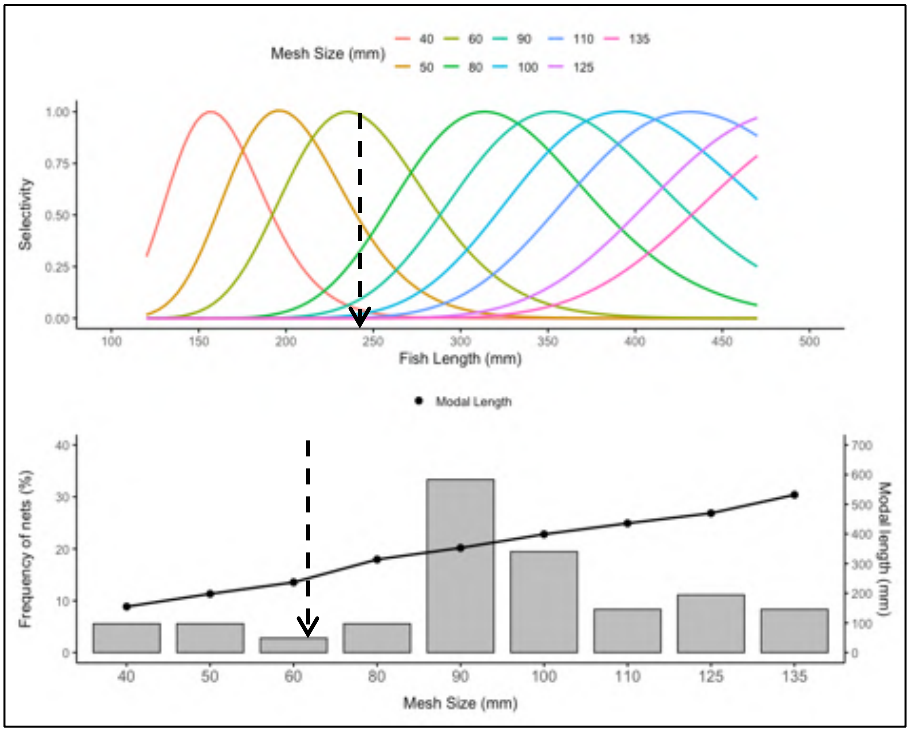

Figure 3.21: Selectivity curves and mesh size frequency for *Labeo capensis* in the Katse Dam illegal gillnet fishery. The top panel shows selectivity curves for different mesh sizes (40–135 mm). The bottom panel displays the frequency of nets used for each mesh size and modal lengths. The vertical dashed lines indicate the estimated length-at-50% maturity (FL) (Nthimo 2000).

For *L. aeneus* (Figure 3.22), mesh sizes of 40 mm and 50 mm capture fish below L_{50} (285 mm; Nthimo (2000)). Most fish selected in the 60 mm mesh size are below L_{50} while a smaller proportion are selected in the 80 mm. Mesh sizes of 90 mm and larger select for fish above L_{50} indicating that the most used mesh sizes in the fishery mostly harvest *L. aeneus* above L_{50}. For *O. mykiss* (Figure 3.23), separate L_{50} values are shown for males and females (235 mm and 275 mm, respectively (Nthimo 2000)). Mesh sizes up to 60 mm select both male and female fish below their respective L_{50} estimates, while larger mesh sizes, particularly those above 90 mm, select for fish above both maturity thresholds. As observed with *L. capensis* and *L. aeneus*, the dominant mesh sizes in the fishery harvest fish above L_{50}.

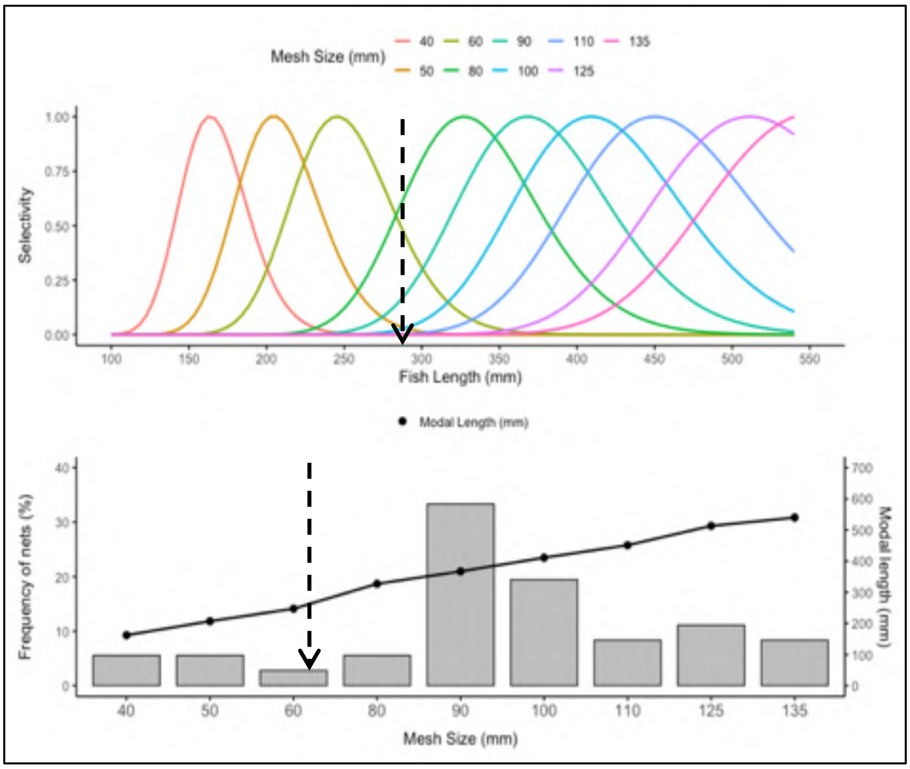

Figure 3.22: Selectivity curves and mesh size frequency for *Labeobarbus aeneus* in the Katse Dam illegal gillnet fishery. The top panel shows selectivity curves for different mesh sizes (40–135 mm). The bottom panel displays the frequency of nets used for each mesh size and modal lengths. The vertical dashed lines indicate the estimated length-at-50% maturity (FL) (Nthimo 2000).

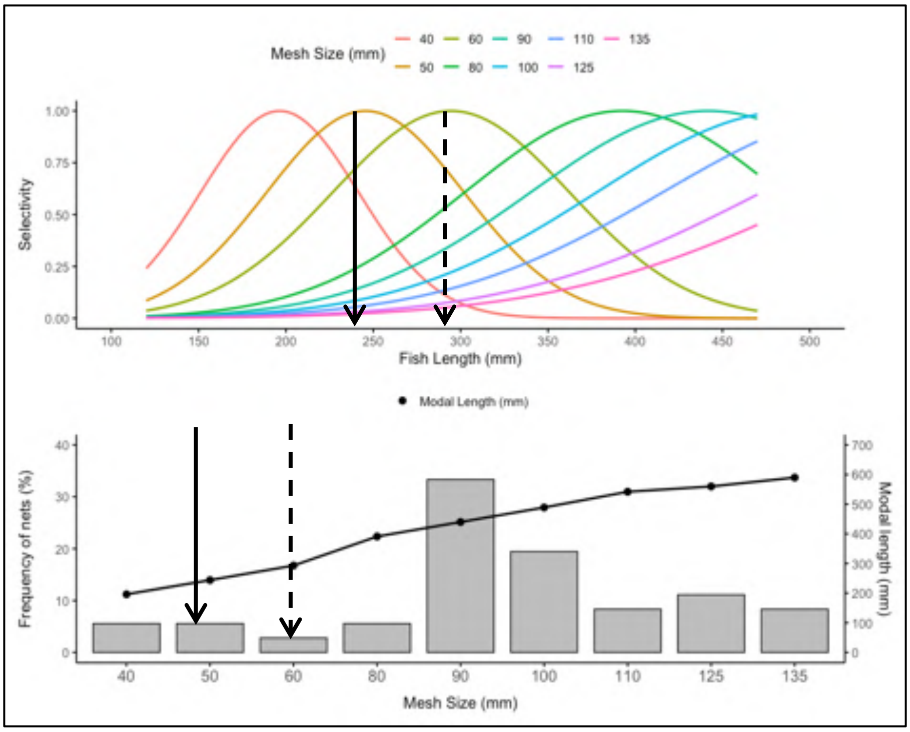

Figure 3.23: Selectivity curves and mesh size frequency for *Oncorhynchus mykiss* in the Katse Dam illegal gillnet fishery. The top panel shows selectivity curves for different mesh sizes (40–135 mm). The bottom panel displays the frequency of nets used for each mesh and modal lengths. The vertical

dashed line indicates the estimated length-at-50% maturity of females and the vertical solid line indicated the estimated length-at-50% maturity for males (Nthimo 2000).

3.3.4. Overview of the Katse Dam fishery value chain

The Katse Dam fisheries value chain comprised multiple actors, including input suppliers, hook-and-line and illegal gillnet fishers, output suppliers, traders, transporters, local, national and South African markets and consumers (Figure 3.24; Figure 3.25).

Inputs

Inputs for the hook-and-line fishery included hooks and nylon fishing line which were sourced from hardware stores in urban (e.g., Maseru, Leribe) and peri-urban centres (e.g., Hlotse), as well as small local general stores. Some community members also sold hooks and line. Gillnet fishing inputs included machine-made monofilament gillnets purchased directly from local or regional hardware stores, hand-sewn monofilament and multifilament gillnets purchased from local netmakers, and thread and fishing line which was used by netmakers and gillnet fishers to manufacture their own multifilament and monofilament gillnets.

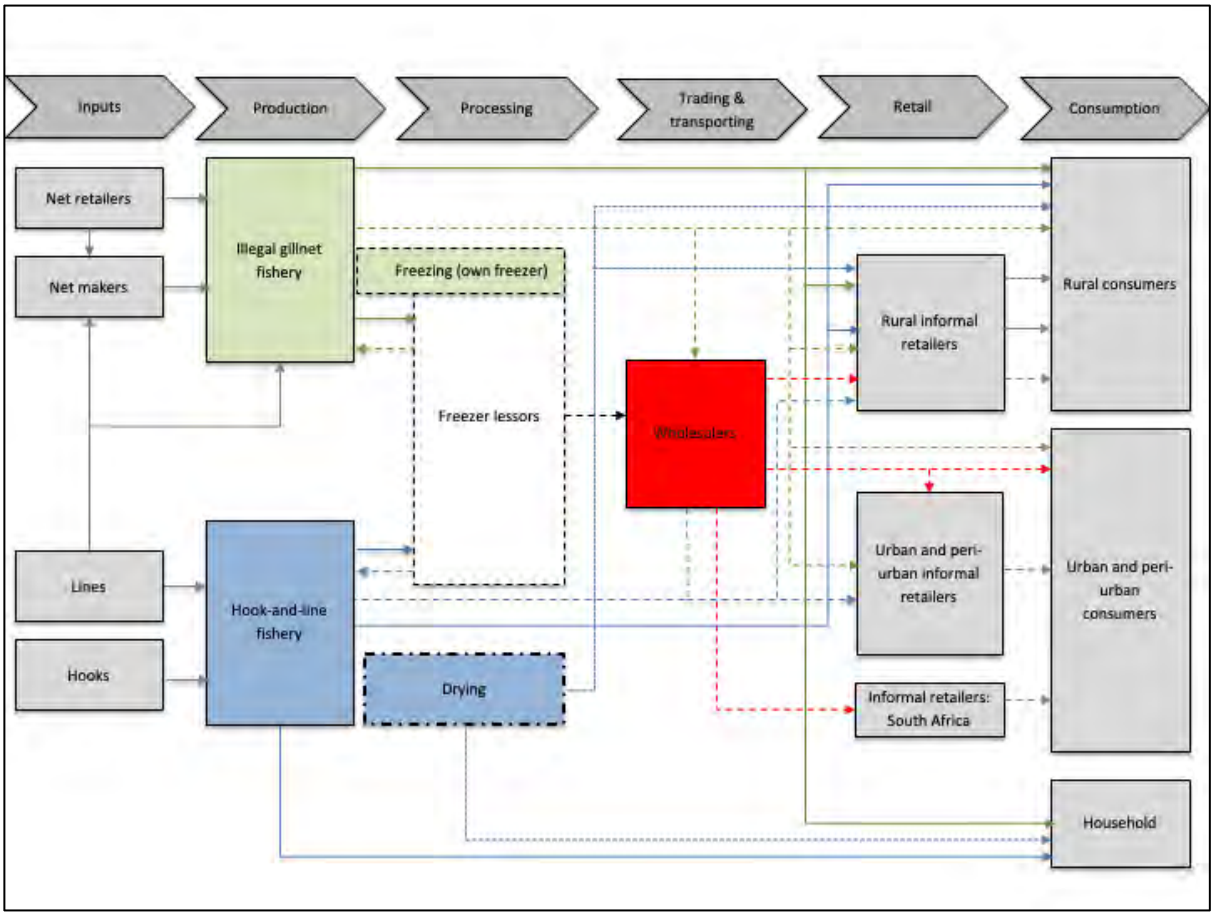

Figure 3.24: The Katse Dam fisheries value chain.

Production

The characteristics of the hook-and-line fishery and illegal gillnet fishery are described in detail in Section 3.3.2 and Section 3.3.3, respectively. Production from the hook-and-line fishery was estimated at approximately 31.1 tonnes [95% CI: 22.8, 43.8] per annum (Section 3.3.2). Of this, an estimated 33%, or 10.26 tonnes [7.52, 14.45] is consumed at the household level, while the remainder, approximately 20.84 tonnes [15.3, 29.4], is sold.

Production from the gillnet fishery was estimated at approximately 111.75 tonnes [95 % CI: 46.32, 177.21] (Section 3.3.3). Quantitative data on the proportion consumed at household level or sold could not be obtained. However, interviews with gillnet fishers, traders, and government fisheries officers suggested that approximately 95%, equivalent to 106.16 tonnes [44.00, 168.35], is sold with a smaller proportion of approximately 5.59 tonnes [2.32, 8.86] retained for household consumption (Figure 3.26).

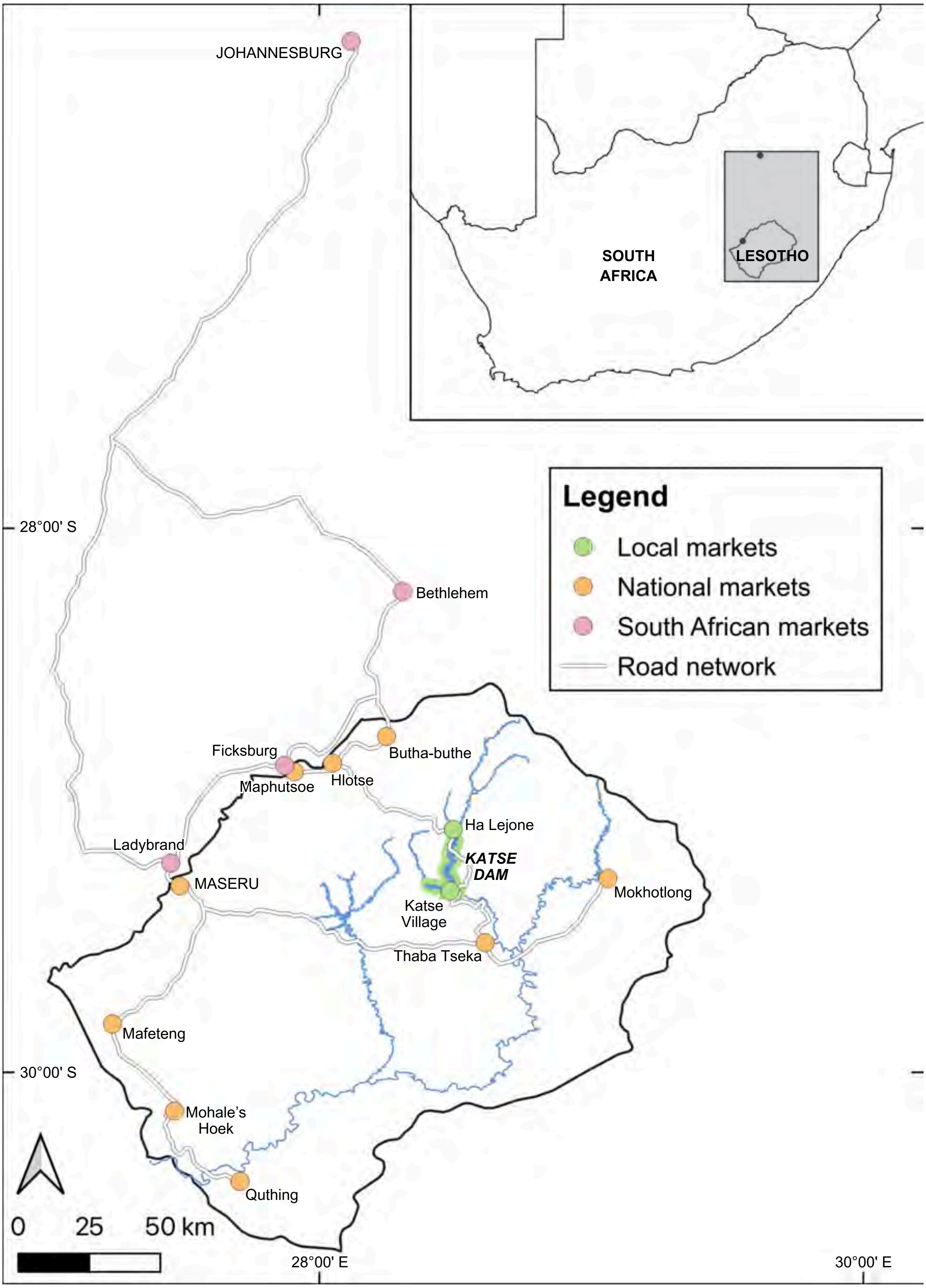

Figure 3.25: Geospatial product flow value chain map indicating the flow of fish from Katse Dam to various local, national, and South African markets.

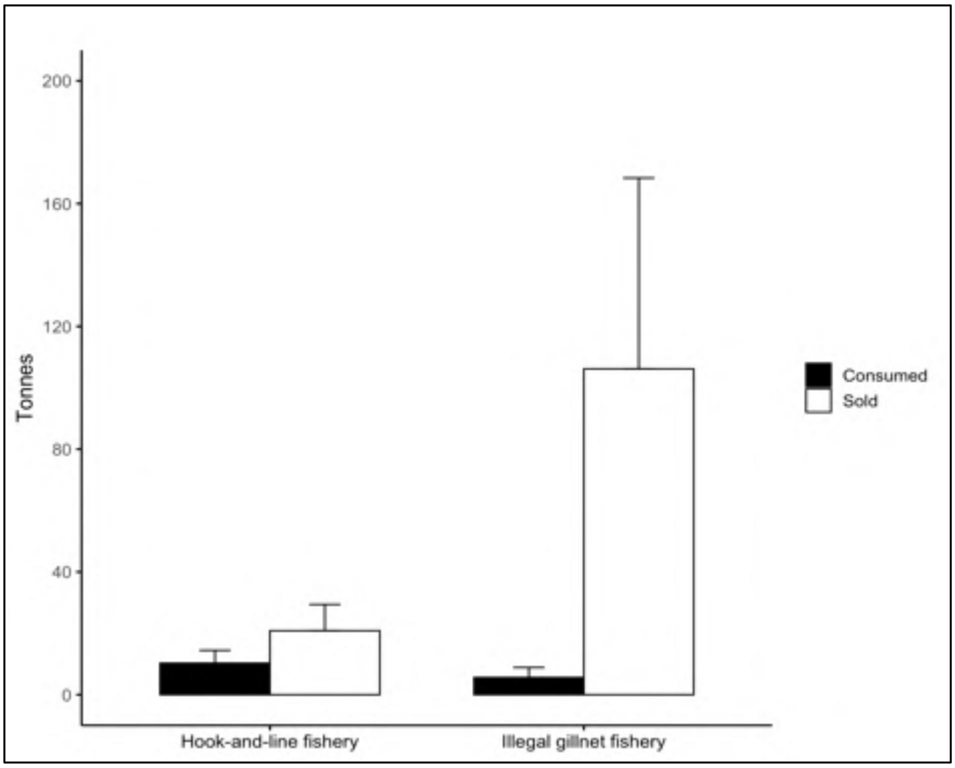

Figure 3.26: Volumes of fish from the hook-and-line fishery and illegal gillnet fishery that are either consumed or sold.

In both the hook-and-line and illegal gillnet fishery, fishers categorised their fish into three broad size classes of fish, irrespective of species. These included a “small” size class, ranging in length from 10–20 cm (approximately 50–200 g), a “medium” size class, ranging in length from 20–40 cm (approximately 200 g – 1 kg), and a “big” size class, with fish above 40 cm (> 1 kg). Fish in the “medium” and “big” size classes were typically sold while smaller fish were retained for household consumption.

In the hook-and-line fishery, the proportion of fish sold versus consumed varied among species (Figure 3.27). *O. mykiss* was mostly sold (78.6%), as was *L. capensis* (62.5%) and *L. aeneus* (58.3%). A positive correlation was observed between the proportion of fish sold and the mean income per fish across the three species. Fishers received an average of USD 1.83 ± 1.29/fish for *O. mykiss* which was significantly ($p < 0.05$) higher than that received for *L. capensis* (USD 1.06 ± 0.39/fish) and *L. aeneus* (USD 0.92 ± 0.42/fish) (Figure 3.27). On average, and irrespective of species, the mean income received per fish was USD 1.27 ± 0.33.

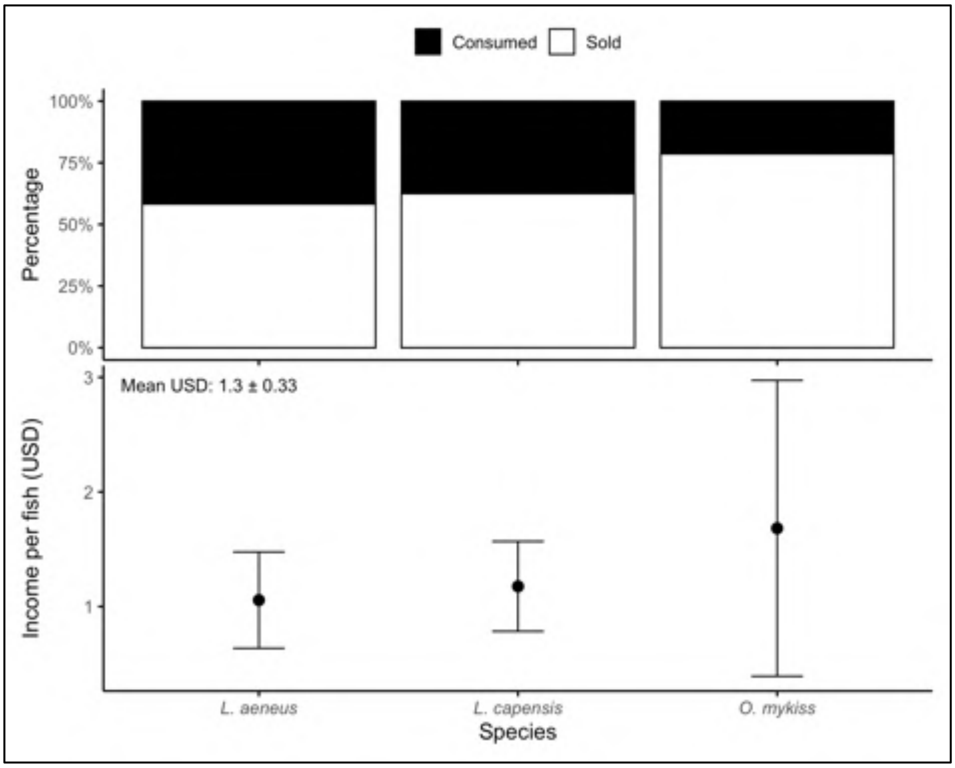

Figure 3.27: Utilisation and income per fish of the major target species in the hook-and-line fishery.

The total annual income derived by hook-and-line fishers was estimated at approximately USD 83 371 [95% CI: 65 090, 106 012]. Species-specific contribution to income was highest for *O. mykiss* (USD 37 776 [29 493, 48 035]), followed by *L. aeneus* (USD 36 432 [28 443, 46 326]) and *L. capensis* (USD 8 320 [6 496, 10 580]) (Figure 3.28).

Estimating the total income from the illegal gillnet fishery was constrained by a lack of quantitative data on species composition and prices. However, assuming that species composition is like that recorded in the experimental gillnet fleet, and that price per species is the same as that in the hook-and-line fishery, the total income was estimated at approximately USD 606 508 [95% CI: 316 795, 1 318 424] (Figure 3.28). Species-specific contribution to this income estimate was highest for *L. aeneus* (USD 387 160 [209 835, 564 486]), followed by *L. capensis* (USD 119 551 [75 340, 163 763]) and *O. mykiss* (USD 96 714 [28 539, 164 890]).

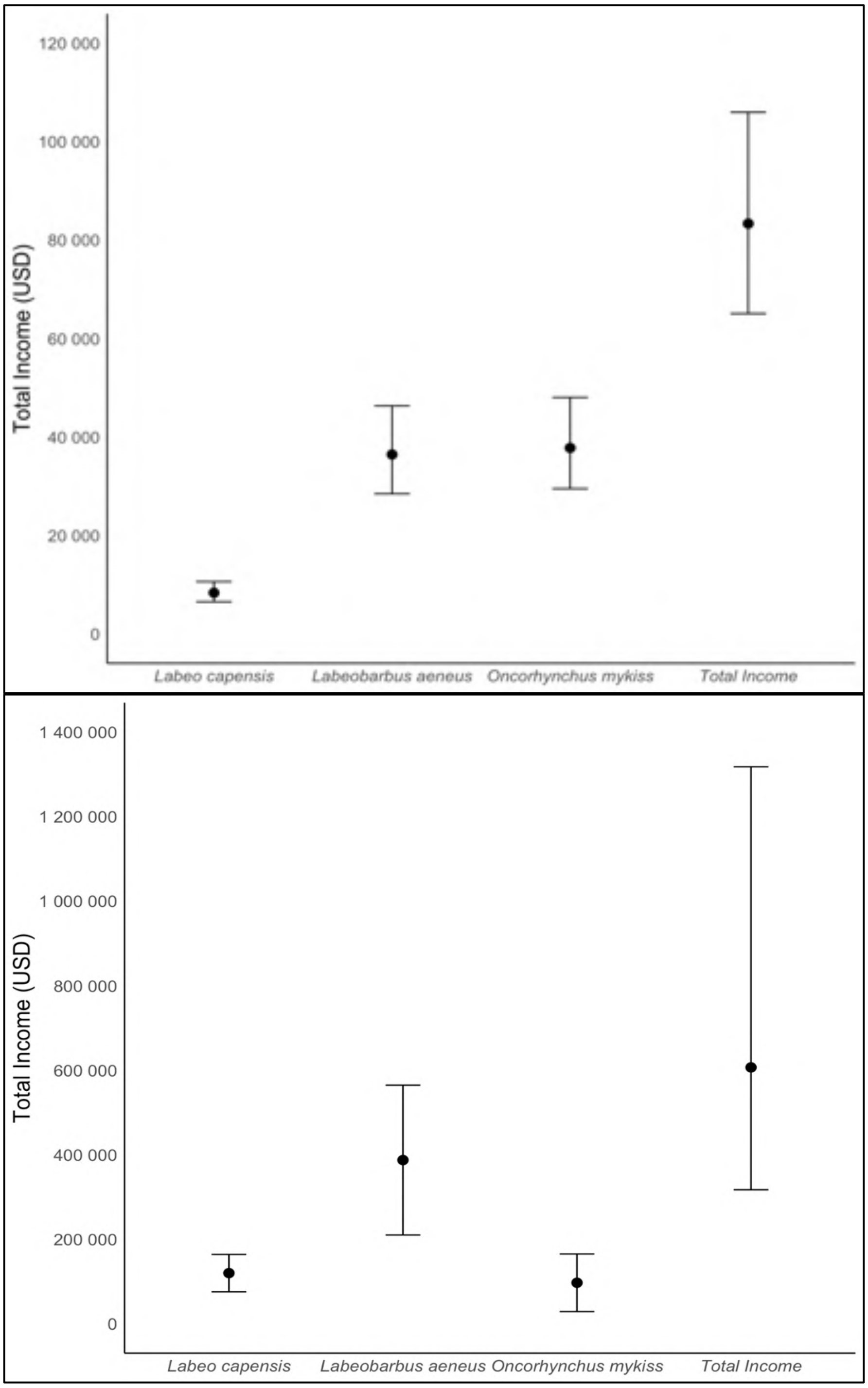

Figure 3.28: Estimated species-specific and total income from the Katse Dam hook-and-line fishery (top), and the illegal gillnet fishery (bottom). Vertical lines indicate 95% confidence intervals.

Primary processing

The types of primary processing activities include scaling, gutting, drying, and freezing. Scaling, gutting and drying takes place on the shoreline and in villages close to the dam and is largely undertaken by the fishers themselves. Freezing takes place in small electric freezers which are typically rented from freezer lessors. The cost of freezing space ranges from

USD 8.5–35 per month depending on the quantity of fish. Some fishers own their own freezers. Fresh and dried fish are typically not packed, whereas frozen fish are placed into 10 L or 20 L containers (buckets) for onward sale. Some fishers may also pack their fish in plastic before transport.

Trading and transporting

Fresh and dried *L. aeneus* and *L. capensis* from the hook-and-line fishery are sold by fishers directly to consumers in local villages, to informal retailers in local rural towns, namely Ha Lejone and Katse/Khokhoba, and to roadside vendors who sell the fish on the road surrounding Katse Dam. Fish are typically traded by number and not by weight. Some fish is also bartered for other goods, such as grain and liquor. Fishers charge from USD 0.30 (small size class) to USD 1.75 (large size class) per fish.

Frozen *L. aeneus*, *L. capensis*, and *O. mykiss* are sold in bulk units of 10 L and 20 L (not kilogrammes). Fish are typically split into two batches: one a mix of *L. aeneus* and *L. capensis* (sometimes only *L. aeneus*), and one comprising only *O. mykiss*. Once a fisher or group of fishers have accumulated sufficient volumes of fish (a minimum of one 10 or 20 L container), they contact wholesalers who collect the fish and transport it in cooler boxes to retailers in rural, urban and peri-urban areas, in Lesotho as well as South Africa. Wholesalers typically collect batches of frozen fish every two to four weeks. Prices paid by wholesalers for *O. mykiss* range from USD 50–60 (10 L) and USD 90–115 (20 L) while the price of *L. aeneus* and *L. capensis* is somewhat lower, ranging from USD 40–50 (10 L) to USD 70–80 (20 L). Wholesalers may also act as retailers, selling directly to individual consumers. Fishers themselves may also act as both wholesalers and retailers, using public transport to access markets in rural, urban, and peri-urban areas.

Retail and consumption

Retail functions along the value chain are largely informal. In the Katse Dam area, fresh, fried and dried fish (predominantly *L. capensis* and *L. aeneus*) from both the hook-and-line fishery and, to a lesser extent, fresh fish from the illegal gillnet fishery, are sold directly to community members in villages and by roadside vendors. A smaller proportion is formally retailed at small takeaway shops in rural towns. Consumers include residents and, on occasion, visitors passing through the area. Prices range from USD 0.60–4 per fish, depending on size.

Smaller volumes of medium and large frozen *L. capensis*, *L. aeneus* and *O. mykiss* are also sold at local spaza shops. Prices may range from USD 2.90–8.75 per fish. However, most frozen fish, in particular *O. mykiss* which fetches the highest price, is set aside for sale in more lucrative urban markets.

In regional peri-urban and urban areas, frozen fish, particularly *O. mykiss* and to a lesser extent *L. aeneus*, are in higher demand. Frozen fish are sold by individuals or, less frequently, dedicated fish shops (which predominantly market farmed *O. mykiss*). Consumers in these regions are typically in the lower-middle and middle-income bracket and prepared to pay a premium for large (> 40 cm) *O. mykiss* and *L. aeneus*. Prices range from USD 4.60–11.50 per fish for *O. mykiss* and USD 2.90–8.75 per fish for *L. aeneus*.

3.4. Discussion

Research has extensively documented the negative impacts of dam projects on established inland fisheries and traditional fishing communities, but there is a notable gap in our understanding of how fishing might emerge as a new livelihood option in areas where it was never previously significant, how such fisheries develop over time, and what the outcomes might be for dam-affected communities. This study aimed to address this knowledge gap by using a mixed-methods approach to assess the emergence, evolution, and current status of fishing on Katse Dam in Lesotho, a traditionally non-fishing region. The findings challenge assumptions about the rigidity of traditional practices and demonstrate that fishing can develop into an important livelihood when dam-affected people are forced to confront new social and ecological realities.

Reflections on the emergence and evolution of the fishery, and implications for future dam development

The use of oral history methodology to explore the emergence and evolution of the Katse Dam fishery provided insights on the multiple interacting social and ecological catalysts that drove systems transformation and adaptive responses following its construction.

In the Pre-Dam Period, fishing played a marginal role in the area, and was limited to subsistence practices using low-tech methods such as spears and hand-crafted lines. Agriculture dominated rural livelihoods, making communities vulnerable to external shocks due to their reliance on a limited number of traditional livelihoods (Holling 1986; Gunderson and Holling 2002; Folke 2006). The influx of migrant workers from South Africa exposed local community members to new and more effective fishing methods and gears such as hooks and lines and, to a lesser extent, gillnets. These cross-scale interactions (Holling 2001) and social learning processes

(Olsson et al. 2004; De Kraker 2017) stimulated the uptake of fishing as supplementary, subsistence-based livelihood. Rather than being a directed intervention, this was a self-organising response to changing social conditions (Folke et al. 2005; Ostrom 2009; De Kraker 2017).

Immigrant fishers have been shown to be vectors for knowledge and technology transfer in small-scale fisheries (Moussa 2011; Sabinot 2021). Here, the incremental accumulation of knowledge and skills transferred by migrant workers likely contributed to building the latent adaptive capacity of local communities (Gunderson and Holling 2002; Davidson-Hunt and Berkes 2003), which would play an important role in the future trajectory of the fisheries. This highlights the need for large dam planning processes to recognise that external factors such as migrant labour may influence future fisheries development and management strategies, a consideration currently lacking in environmental and social impact assessment frameworks (AfDB 2015; World Bank 2016).

The Early Post-Dam Period was characterised by ecological and socio-economic disturbance and early adaptation. Firstly, some community members lost agricultural land and/or access to natural resources which compelled them to seek out alternative or supplementary livelihood opportunities. Secondly, the new large reservoir quite suddenly (as is commonly the case in the early years following impoundment (Baxter 1977) contained a biomass of fish far greater than that found in the catchment rivers prior to the development of the dam. These changes represented a socio-ecological threshold (Walker et al. 2004) which provided a "window of opportunity" for new resource-use activities (Westley et al. 2011). Emerging markets and technology, both drivers of systems change (Ostrom 2009; McGinnis and Ostrom 2014), played a key role in incentivising participation in the fishery.

Tourists stimulated market formation while the introduction of gillnets represented a technological shift. While the adoption of gillnets was slow, as their efficacy in comparison to hook-and-line fishing methods became evident, and market demand continued to grow, more participants were encouraged to enter this fishery even though it was illegal. Similar trends have been observed elsewhere in Africa, sometimes leading to overexploitation (Jul-Larsen et al. 2003; De Graaf et al. 2006; Gebremedhin et al. 2018; Mpomwenda et al. 2022). However, not all community members were equally positioned to benefit, as barriers such as limited gear access, fishing skills, and gender norms restricted participation. Unlike the climate adaptation or post-disaster recovery literature, where unequal adaptation pathways are well documented (Dade et al. 2022; Dev and Manalo 2023), they remain underexplored in large dam studies which tend to focus on formal interventions rather than spontaneous adaptation processes. Future planning for large dams needs to anticipate and monitor how early post-dam dynamics interact to create new fishing opportunities, while developing adaptive fisheries management approaches that can respond to these dynamics and address barriers to equitable participation.

The Established Post-Dam Period marks the transition to a predominantly market-driven and commercial-oriented fishery, which now yields approximately 140 tonnes per annum and generates USD 700 000 at the production stage of the value chain. This far exceeds pre- and post-impoundment expectations.

The dam's morphometry and physicochemical characteristics (low conductivity and temperature), as well as the dominance of rheophilic fish species, were expected to constrain production (Bain 1990; Eccles 1990; Skelton 1996; Nthimo 2000). Eccles (1990) predicted yields in the region of 14–28 tonnes per annum, significantly lower than the current estimate of total annual production (142.9 tonnes [69.1, 221.0]), and the post-impoundment estimate of 65–198 tonnes (Hecht and McCafferty (2011). Yields from high-altitude African lakes and reservoirs are generally poorly documented (Hecht and McCafferty 2011), and the discrepancy may stem from a model that over-accounted for the influence of temperature. Without the model parameters used by Eccles (1990), it is difficult to say. It is possible that conductivity was underestimated as Eccles (1990) assumed that the scale of livestock farming and grazing pressure in the area would remain similar. Grazing pressure and soil erosion has increased since the construction of the dam which has been linked to increased nutrient inputs (Turpie et al. 2014a). However, data collected over the period 1999–2021 show that there has been a striking lack of change in conductivity, total dissolved solids, phosphorous, and chlorophyll-a in the dam (LHDA unpublished data, July 2024). As such, it is most likely that temperature did not influence fish yields as predicted. Empirical yield models may be a useful tool during the planning and/or EIA process for large dam projects (Moreau and De Silva 1991; Jackson and Marmulla 2001). However, their limitations should be recognised. Flexibility should be built into the development planning process and monitoring programmes implemented early to respond to emerging post-impoundment dynamics.

Skelton (1996) and Nthimo (2000) hypothesised that the species composition of the dam would limit productivity. This was on the basis that *L. aeneus*, *L. capensis*, and *O. mykiss* were primarily rheophilic species and it was unlikely that they could fully utilise the primary productivity of the dam. However, both *L. aeneus* and *L. capensis* have been shown to adapt well to lacustrine environments (Eccles 1986; Ellender et al. 2016). *Labeobarbus aeneus* prefer, but are not entirely reliant on, lotic environments for spawning (Ellender et al. 2016), and the author has observed the species spawning on gravel close to the dam wall. An additional factor that was not considered in previous studies is the possibility that the water transparency of the dam may have allowed *L. aeneus* to more effectively utilise zooplankton, as observed in Van Der Kloof Dam in South Africa (Eccles 1986). This highlights the need for multifaceted approaches to predicting species adaptation and productivity during the planning process, incorporating aspects including life history (Fernandez et al. 2024) and functional trait analysis (Arantes et al. 2019), while drawing on evidence from comparable systems.

Another pre-impoundment assumption was that the steep-sided shoreline of the dam would limit the areas which could be fished and therefore limit yields (Bain 1990; Skelton 1996). However, angler counts showed that fishers were widely dispersed and fished along steep and gentle slopes. It is possible that Bain (1990) and Skelton (1996) did not consider the extent to which the Basotho have adapted to the hostile, rugged environment of the Highlands (LHDA 1997).

Early assessments also suggested that the lack of a fishing tradition and low fish consumption in the area would hinder fisheries development, unless addressed through extensive training and community sensitisation efforts. However, the oral histories show that fishing emerged organically as a self-organising response to social and ecological disturbance, rather than a result of structured interventions. Declining agricultural productivity, expanding fisheries production, and beliefs around the nutritional benefits of fish drove consumption. Currently, an estimated 26 tonnes of fish from Katse Dam are consumed by communities in the area, equating to a direct per capita supply of 2.4 kg/annum which surpasses the national average (2.01 kg/annum) (FAO 2024). This suggests that, in contrast to other regions where low freshwater fish consumption rates have constrained inland fisheries development (Andrew et al. 2000; Britz et al. 2015), demand can emerge in non-traditional fishing areas when large dams shift social and economic conditions. This highlights how future fisheries planning for large dams should move beyond deficit-based, blueprint approaches (Ostrom 2009; Young et al. 2018) focussed on a narrow range of preconceived outcomes. Rather, planners will need to recognise that multiple, interacting, social and ecological factors operating across different spatial and temporal scales determine fisheries development outcomes following large dam development.

The status of the fishery and future directions

The mixed-methods approach integrating qualitative and quantitative data sources was useful in capturing important dynamics of the Katse Dam fishery and its value chain, especially given data constraints. While there is still uncertainty around some of the estimates, this assessment provides a foundation for evidence-based management and policy decisions which can be further strengthened with future research.

The Katse Dam fishery supports two distinct sub-sectors: a subsistence/small-scale hook-and-line fishery, which has its origins in the Pre-Dam Period, and a small-scale illegal gillnet fishery, which has grown rapidly since its emergence in the Early Post-Dam Period. The Katse Dam fishery is unique in the context of other large dam fisheries in Africa. As a result of its high-altitude and latitude (Miranda et al. 2020), its fish assemblage is limited (see Chapter 2). Catches are dominated by three species which are exploited using two gear types. This contrasts with the typically more diverse multispecies, multi-gear artisanal fisheries found elsewhere on the continent, such as those in Lake Kariba (Marshall et al. 1982), Lake Volta (De Feu 2003), Lake Itezhi-tezhi (Cowx and Kapasa 1995), and others at lower latitudes (Weyl 1998; Obour et al. 2015). Although unique in Africa, the Katse Dam fishery has come to play a similarly important role in contributing towards local food security and income generation.

The hook-and-line fishery supports over 300 participants, most of whom are unemployed (90.5%), and rely on fishing as their primary source of income (68.3%). As such, the fishery is an important source of livelihoods, generating a total first sale value of USD 83 371 [95% CI: 65 090, 106 012], equivalent to about USD 278 per participant annually, and contributing 10.3 tonnes [7.5, 14.5] to household consumption. This likely constitutes an important and supplementary source of income and protein for local communities where this was previously lacking.

Hook-and-line fishing in Katse Dam is largely seasonal, using low-tech methods and the most readily available and cost-effective bait (typically *papa*). Both fishing effort (fishers/day) and CPUE (kg/day) of the hook-and-line fishery was higher in summer (163 fishers/day; 1.5 kg/day) than in winter (49 fishers/day; 0.8 kg/day). Similar trends have been observed in other hook-and-line fisheries in temperate impoundments in southern Africa (Cochrane 1987; Ellender et al. 2010). Participation is often closely linked to expected catch rates, i.e., fishers are likely to fish more when catch rates are expected to be high, which is typically the case in summer due to warmer water temperatures and increased metabolic rates (Cooke et al. 2003;

Ellender et al. 2010). Fishing effort was also strongly shaped by access and physical constraints. Most activity was concentrated near roads, villages, and accessible shoreline entry points. The rugged terrain of the study area partly explains why effort was concentrated in specific locations but also highlights a broader constraint on production. If the fishery is to expand in future, the use of boats may be necessary. However, this would represent a significant shift in fishing practices with safety and regulatory implications.

The seasonal nature of the fishery means that supply and income for most participants is inconsistent across the year. This was highlighted as a key constraint during the FGDs. This could be mitigated through improvements in cold-chain infrastructure, i.e., freezers, which would allow fishers to aggregate catches in the summer months. However, an intervention such as this will require a precautionary approach. Cold-chain and other market-based interventions may increase participation and increase the risk of overexploitation (Leadbitter et al. 2008; Cramer and Kittinger 2021). The dominant target species in the fishery is *L. aeneus* which, in summer, typically congregates in river mouths, and gravel and rocky areas close to the shoreline, to spawn. As such, it may be vulnerable to increased fishing pressure and overexploitation in these areas (Tweddle and Davies 1997), if fishers are able to aggregate larger volumes of fish during the summer.

While the mainstay of the hook-and-line fishery is *L. aeneus*, which comprised most of the catch in both summer (71.6%) and winter (43.3%), *O. mykiss* was almost as important in the winter months (43%). This pattern is unsurprising given the thermal preferences of these species (Skelton 2024). The comparatively minor contribution of *L. capensis* to the catch is likely a function of the hook sizes used in the fishery and the inferior mouth of this species which limits hook-up rates. This was hinted at during interviews with fishers who colloquially called the species *skelm* (thief) as it would remove their bait without being hooked. This may constitute a missed opportunity given that *L. capensis* attracts higher prices (USD 1.06 ± 0.39/fish) than *L. aeneus* (USD 0.92 ± 0.42/fish). Promoting the use of smaller hooks (#10–#14) may improve hook-up rates (Salomon 1978) and constitute a low-cost technological intervention. Similarly, however, this will require precaution, particularly if effort is concentrated in river mouths where the species congregates in large numbers to spawn (Nthimo 2000).

The mean length (FL) at capture for all species harvested by the hook-and-line fishery was greater than L_{50} which provides some indication that growth overfishing may not be occurring (Froese 2004). Given the greater demand and price for larger fish, it is unlikely at this stage that hook-and-line fishers would move to smaller hook sizes that might select for fish below L_{50}. However, this may change in future if the numbers of larger fish decline, as has been observed in other inland fisheries, e.g., Lake Victoria (Nyamweya et al. 2020), which emphasises the need for ongoing monitoring.

The mean CPUE estimate in summer of approximately 5 fish/day exceeds the bag limit of four fish/day as stipulated in the Regulations. It is quite possible that this estimate is conservative given the potential for social-desirability bias (Bova et al. 2022) towards underreporting catches to avoid sanction. The Regulations are difficult for hook-and-line fishers to comprehend, and there is a sense of injustice, particularly given the higher catches observed in the illegal gillnet fishery (approximately 19 fish/day). This is exacerbated by a history of mistrust towards the LHDA and a perceived lack of consultation (see Chapter 2). There is an urgent need for the LHDA to review these regulations and closely engage with hook-and-line fishers during this process. This will likely help in addressing the existing trust deficit and ultimately contribute towards a sustainable fishery. This should be conducted on the back of a comprehensive fisheries management plan which is currently severely lacking. More detailed quantitative studies on consumption, employment, income and value are required to showcase the importance of this fishery to decision-makers. This could "elevate the profile" of the fishery (Taylor et al. 2016) and potentially enhance resource allocation towards its future development and management.

In contrast to the hook-and-line fishery, the illegal fishery operates year-round, is almost entirely market-driven and likely constitutes the primary source of income for its participants. The illegal gillnet fishery has a first sale value of approximately USD 606 508 [316 795, 1 318 424]) which is considerably higher than in the hook-and-line fishery (USD 83 371 [95% CI: 65 090, 106 012). While the income accruing to each fisher could not be ascertained, the profitability of the fishery is clearly the primary incentive for participating in illegal fishing activities. This is commonly the case with illegal, unreported and unregulated (IUU) fishing (Sumaila et al. 2006) and has been documented in other African inland fisheries (Kariuki 2012).

Similarly to the hook-and-line fishery, gillnet CPUE was predicted to be significantly higher in summer (3.01 kg/set) than in winter (0.98 kg/set). The higher predicted catches in summer may be linked to the areas in which the gillnets are commonly set, which includes the main branch of the Malibamatso River and embayments with inflowing ephemeral streams. In summer, *L. aeneus* move into these areas to spawn (Nthimo 2000) and are more susceptible to being captured in gillnets during this period. Given this concentration of fishing effort in spawning areas, the potential for spatial management approaches used in other African inland fisheries, such as seasonal spawning area closures (Jamu et al. 2023), should be investigated for future management purposes.

In contrast to the hook-and-line fishery, discussions with gillnet fishers suggest that the issue of lower catch rates in winter and consequently lower supply was less of a constraint. The comparatively higher economic returns from gillnetting had allowed them (either singly or collectively) to invest in freezers or rent freezer space, and they were therefore capable of aggregating their catches during the summer months to supply the market during winter. This was inadvertently facilitated by rural electrification projects and has helped address seasonal market supply issues. There may be potential to improve winter catches by adapting existing fishing tactics. While not documented in reservoirs, *L. aeneus* in riverine environments typically move to deeper water during winter (Jacobs 2013). If the fishery is formalised, research on alternative gillnetting methods including bottom-set gillnets (Tweddle and Davies 1997) and strategic selection of fishing areas could help increase winter catch rates.

The experimental gillnet data, and discussions with illegal gillnet fishers, suggest that *L. aeneus* is the most important species in the illegal gillnet fishery, dominating catches in summer (76.9%) and winter (66.1%). Higher proportions of *L. capensis* were recorded in the gillnet catches compared to the hook-and-line fishery, highlighting their greater susceptibility to gillnets as opposed to hook-and-line. While the seasonal differences in catches of *O. mykiss* were expected, their lower contribution in winter (16.6%) compared to the hook-and-line fishery (43%) was surprising given that they also undertake spawning migrations in the winter months and would be particularly susceptible to gillnets during this period (Tweddle and Davies 1997. The reason for the difference is unclear at this stage but may be related to area-specific effects not captured in the gillnet CPUE model.

The selectivity predictions showed that the most used mesh sizes (90 mm and 100 mm) predominantly captured fish of all target species above L_{50}. This would suggest that the fishery is primarily harvesting mature individuals and growth overfishing is not occurring (Froese 2005). Similar to the hook-and-line fishery, greater market demand and prices for larger fish encourage the use of larger mesh sizes, a trend which was confirmed during interviews with illegal gillnet fishers. Several illegal gillnet fishers reported that they tried to release the "small fish" (approximately 10–20 cm) that they caught as they could not be sold and were of greater value if allowed to grow to market size rather than consumed. Community members also recognised the risks of removing large numbers of juvenile fish. This knowledge should be used as a platform for developing regulations and a management plan in close consultation with local communities (Cooke et al. 2021; Hamelin et al. 2024). The illegal gillnet fishery in Katse Dam has continued to expand and now generates substantial economic value (USD 606 508). Enforcement activities undertaken by the Lesotho Defence Force (LDF), which have allegedly resulted in severe reprisals for illegal gillnet fishers, including assault and intimidation, have failed to curtail illegal fishing activities. All of the factors outlined here suggest that formalisation rather than criminalisation is the most pragmatic path forward. As a start, a regulated gillnet fishery with a minimum mesh size of 90 mm could be proposed which aligns with current fishing practices and would largely harvest mature fish. Establishing this fishery will require legal recognition of gillnet fishers' rights, the development of appropriate and adaptable input and output controls in close consultation with communities, as well as allocating sufficient resources to ongoing monitoring and management. In this scenario, it is unlikely that the LHDA will be able to enforce management measures on their own, therefore a co-management approach is advisable to allow ownership and agency to local communities to protect their resources. Participatory governance structures could be promoted by supporting the establishment of fisher associations and co-management committees at community level. These bodies could be mandated to regulate access, allocate permits, and oversee compliance through locally appropriate spatial controls and monitoring (Kaluma and Omar 2021). The involvement of traditional authorities would be central to the legitimacy of such arrangements. Evidence from Malawi demonstrates that chiefs play critical roles in decentralised fisheries governance: co-management institutions imposed without their involvement often fail due to weak legitimacy and elite capture, whereas those that align with traditional authority can sustain more resilient outcomes (Russell and Dobson 2011). For Katse Dam, aligning new regulatory provisions with local leadership structures would help build legitimacy, reduce conflict, and incentivise community participation in fisheries management. It would also contribute towards relationship-building between the LHDA and fishers, which is important given the legacy of community mistrust since the inception of the LHWP.

In conclusion, the total first sales value from the hook-and-line and gillnet fishery of USD 689 879 [381 885, 1 424 436] represents a substantial injection of "new" cash into a rural area with high levels of unemployment. This number also does not capture the value generated by other activities further down the value chain. An estimated 26.4 tonnes [17.6, 38.3] produced by the fishery is consumed by communities in the Katse Dam area. Census data were unavailable but, based on a high-level estimate of the number of households (approximately

2 500) and the average household size (approximately five) in the area, this equates to a direct per capita supply of 2.4 kg/annum from the fishery, higher than the national average (2.0 kg/annum) (FAO 2024). This would suggest that the lack of a fish-eating culture was not a constraint to the development of the fishery as has been observed in parts of South Africa for example (Andrew et al. 2000; Britz et al. 2015). Rather, resource-poor communities have responded to the social upheaval and hardships caused by the dam by capitalising on the economic opportunities and food security benefits it provides.

Value chain characteristics, constraints, opportunities

A multi-faceted fisheries value chain has emerged organically since the construction of Katse Dam, further highlighting the capacity of dam-affected communities to adapt, self-organise and harness alternative livelihood opportunities in response to social and environmental change. In the space of 25 years, different value chain actors have not only adopted new skills but adapted them to meet different consumer demands. Although a detailed qualitative and quantitative study of the value chain was not conducted in this study, the results still provide insights on its characteristics, constraints and opportunities.

The value chain comprises several actors and activities, from input suppliers to local, regional, and South African consumers. Relationships and transactions are fluid, with some actors playing multiple roles, and trading at various points along the value chain depending on supply, product forms, and price dynamics, as well as household needs.

A price differentiation system has developed that reflects both market demand and product characteristics – for instance, *O. mykiss* consistently commands premium prices in urban markets while *L. aeneus* and *L. capensis* are marketed more flexibly across different market segments. In addition, size and product forms (fresh, frozen, dried) also have market niches and price points across local to urban markets. Actors have developed the capacity to direct different products (species, sizes, forms) to specific markets to maximise returns while working within infrastructure constraints. In the absence of formal cold storage infrastructure, an informal freezer rental system has emerged where community members lease freezer space to fishers at rates scaled to volume. While some fishers have invested in their own freezers, others rely on this peer-to-peer rental system which helps overcome cold chain barriers while creating additional income opportunities within the community. However, participation in higher-value market segments is limited to those with sufficient capital who can overcome these infrastructure barriers, potentially reinforcing existing socio-economic inequalities among value chain participants while pushing those without access to cold storage towards lower-value local markets.

These infrastructure constraints particularly affect hook-and-line fishers, who must often resort to drying fish when unable to sell fresh, receiving much lower prices. Access to cold storage infrastructure would enable broader participation in lucrative peri-urban, urban and regional markets throughout the year. Future research priorities should include quantification of economic losses from inadequate cold chain infrastructure, assessment of infrastructure needs, and cost-benefit analysis of different storage and transport options. Importantly, the development of cold chain infrastructure needs to be carefully planned to ensure benefits do not accrue mainly to already-advantaged actors such as gillnet fishers who have existing market connections and capital.

The value chain further demonstrates adaptability through flexible trading arrangements. While cash transactions dominate urban trade, local exchanges often incorporate barter arrangements where fish are traded for goods like grain and liquor. This flexibility in transaction types helps the value chain serve different market segments while accommodating local economic conditions and liquidity constraints. Such informal institutions demonstrate how communities can develop sophisticated trading systems that work within local constraints while still linking to formal markets.

This adaptability extends to how individuals participate in the value chain, with many actors shifting roles in response to opportunities and constraints. Role shifting along the value chain is likely a response to limitations in formal market infrastructure and may serve to mitigate risk through diversification. However, some of these actors reported that this can result in missed opportunities if the decision is made to participate in one activity (e.g., transporting fish) when, at that point in time, economic gains may be higher in another (e.g., productive fishing events). Similar trade-offs have been documented in the Barotse floodplain fishery, where fishers must "gamble" between immediate fresh fish sales versus processing, or between fishing versus trading activities, with each choice carrying different risks and potential rewards (Kaminski et al. 2020). Further research is required here to understand the economic trade-offs of role-shifting versus specialisation, including quantification of opportunity costs when value chain actors divide their time between different activities. This would help inform interventions to formalise the value chain which might increase its efficiency.

Gender characteristics of the value chain were not investigated in any detail in this study. In many other African inland fisheries, there is demand for diverse products including dried, salted, and smoked fish, and women play a key role in processing and other post-harvest activities (De Graaf and Garibaldi 2014). However, in this case, strong consumer demand for fresh and/or frozen fish, particularly in higher-value urban markets, appears to shape value chain participation patterns differently. The dominance of fresh/frozen products over processed fish products likely constrains opportunities for women's participation in processing activities that are common in other African fisheries. There may be opportunities to increase the participation of women, particularly in storage, distribution and trade. However, further research is needed to understand how gender roles, power dynamics and social relationships influence participation in different value chain activities (Cole et al. 2014; Rajaratnam et al. 2016; Kaminski et al. 2020).

In sum, the characteristics of the Katse Dam fisheries value chain demonstrate both the innovative capacity of dam-affected communities and the challenges they face in fully harnessing livelihood opportunities. While informal institutions and flexible arrangements have enabled market participation despite infrastructure constraints, these same constraints likely reinforce existing inequalities and limit value chain efficiency. In future, early consideration of post-harvest infrastructure, market linkages, and equitable access to opportunities aligned with holistic assessments of fisheries potential could accelerate the development of sustainable fisheries-based livelihoods for dam-affected communities. Any infrastructure and market development interventions should aim to enhance, rather than replace, activities along the value chain.

Limitations

This study was subject to several limitations. Oral histories and focus group discussions were influenced by leadership protocols that sometimes restricted opportunities for individual interviews, while reluctance to allow audio recording meant that data relied on real-time transcription and translation. The seasonal scope of surveys was limited, with effort and catch data collected during representative summer and winter periods only, and small sample sizes, particularly among illegal gillnet fishers, introduced further uncertainty. Analytical assumptions, including the use of proxy data for gillnet selectivity and the simplification of gear efficiency differences, add to these constraints. Reluctance among traders and retailers to provide information also prevented a full quantification of value chain flows. Nevertheless, the triangulation of multiple data sources and methods provides confidence that the findings capture the main dynamics of fishery emergence, adaptation, and value chain development.

3.5. Conclusion and recommendations

This study aimed to examine the emergence, development, and status of fisheries in Katse Dam, Lesotho, following the construction of a large dam in a traditionally non-fishing area. The findings show that a significant fishery has developed in Katse Dam over the past two decades. This has happened organically, in the absence of concerted interventions, and was driven primarily by a combination of interacting social, ecological, and economic drivers which shaped the adaptation response of local communities.

While fishing as an adaptation strategy following large dam construction is not new, most documented cases come from regions with established fishing cultures and fish-eating traditions and/or from settings where fisheries were deliberately promoted through development efforts (Petr 1978; Petr and Kapetsky 1983; van der Knaap 1994; Cowx and Kapasa 1995; De Silva 2002; Kolding and van Zwieten 2006, 2012). In South Africa, inland capture fisheries remain poorly developed. The absence of a fishing tradition and cultural resistance to freshwater fish consumption meant that efforts to promote inland fisheries have yet to translate into sustained outcomes, and most dams today support recreational angling rather than capture fisheries (Andrew et al. 2001; Weyl et al. 2007; McCafferty et al. 2012; Britz et al. 2015; Weyl et al. 2021). The emergence of the Katse Dam fishery in a similar cultural setting to that in South Africa is therefore somewhat unique, and carries implications for how fisheries development and management are approached in large dam projects globally. Historically, the opportunity to create and manage reservoir fisheries has often been viewed as "an optional extra" rather than a planning priority (Lowe-McConnell 1973; McCartney et al. 2018), especially in regions without strong fishing traditions where their potential has been overlooked (Britz et al. 2015; Weyl et al. 2021). Emphasis on cultural barriers, rather than adaptive potential, has likely contributed to missed opportunities for dam-affected communities in such contexts to develop alternative livelihoods that could mitigate the negative social impacts of large dams. This chapter shows that productive fisheries and value chains may emerge even in areas without prior fishing and fish eating traditions. Decision-makers should therefore avoid limiting development interventions based on preconceived notions of cultural norms.

Nevertheless, the process was not rapid, nor did it come without risk. Communities had to struggle through years of trial and error, barriers to participation, and social conflict while exposing themselves to the dangers of drowning and reprisals from authorities based on outdated legislation. Without knowledge on their sustainability or potentially negative impacts, the uncontrolled adoption of gillnets by local communities both created and continues to pose risks of overexploitation. This unmanaged development also exacerbated existing mistrust between communities and the LHDA that have complicated efforts to establish effective fisheries management systems. Many of these issues continue to persist.

While the emergence of the fishery has created new livelihood opportunities, it should also be understood as part of a broader set of trade-offs associated with dam construction. Communities experienced the loss of agricultural land, grazing resources, and other aspects of their traditional livelihood base, and fishing did not immediately compensate for these losses. Rather, it developed gradually as an adaptive response to hardship. The case of Katse Dam therefore illustrates how new opportunities can arise alongside livelihood disruption, but also highlights the need for future dam planning to anticipate and support such transitions rather than leaving them to unfold organically.

The findings from this chapter provide insights that can guide fisheries governance in large dam projects, particularly in regions without a fishing tradition. The following recommendations outline key principles for decision-makers to ensure sustainable and equitable fisheries development. These include:

1. Decision-makers should assess and recognise the potential for fisheries to emerge in dam-affected areas, even where fishing has not historically been practiced or where there is a lack of fish eating culture. The assumption that a lack of fishing tradition will prevent fisheries development may be misplaced, as ecological conditions, livelihood disruptions, and market demand can drive the adoption of fishing. While ESIAs for large dam projects often mention fisheries development and management in broad terms, they seldom assess in detail the adaptability of local species, the availability of resources, or the socio-economic drivers that determine whether new fisheries can realistically be established. Environmental and social impact assessments (ESIAs) should move towards assessments grounded in SES principles, recognising that fisheries development is shaped by complex interactions between ecological change, market dynamics, infrastructure development, and social adaptation.

2. Fisheries governance should be incorporated into dam planning from the outset rather than being treated as an afterthought. The absence of clear policy frameworks at the time of impoundment often results in unmanaged or illegal fisheries emerging to fill the regulatory vacuum. Developing a policy framework ahead of dam construction ensures that rights of access, regulatory structures, and institutional responsibilities are clearly defined. This should include clear distinctions between subsistence, small-scale commercial, and recreational fisheries, as well as explicit rules on gear types, access rights, and spatial or seasonal restrictions where necessary.
3. Co-management arrangements should be established early to facilitate inclusive and participatory governance. Effective governance of emerging fisheries requires mechanisms that allow dam-affected communities to be involved in decision-making, rule-setting, and monitoring. Imposing rigid, top-down regulations without engagement is likely to undermine compliance, particularly where enforcement capacity is weak. Co-management structures should be built into governance frameworks, giving fishers an active role in shaping policies that reflect local realities and priorities. A key component of this approach is the recognition of traditional ecological knowledge (TEK) and LEK which provide valuable insights into fish behaviour, habitat use, and ecological changes that may not be captured by scientific assessments alone. Incorporating TEK and LEK into decision-making processes strengthens legitimacy, enhances ecological understanding, and improves compliance with management measures.
4. Barriers to fisheries participation should be identified and addressed to prevent inequitable access to resources. While fisheries may emerge organically, participation is often constrained by factors such as access to gear, knowledge, and capital. Early-stage interventions, if applied during the initial post-dam years, could help reduce livelihood hardship by enabling quicker uptake of fishing opportunities. At the same time, such interventions should be carefully designed to complement rather than override community-led adaptation pathways. dynamics in particular should be considered, as market structures and value chain participation may be shaped by social norms that limit women's engagement. Addressing these issues from the outset can help ensure that the benefits of fisheries development are more equitably distributed.
5. Monitoring systems should be developed to track both ecological and socio-economic impacts, ensuring that fisheries management remains responsive to change. The absence of structured monitoring is a common shortfall in new fisheries that emerge in

dam-affected areas, resulting in poor data availability for decision-making. Data collection should be embedded within governance structures from the outset, with clear responsibilities for tracking fish stocks, effort levels, and value chain outcomes. Monitoring should also capture socio-economic trends, including employment, food security contributions, and market access, to ensure that fisheries development aligns with broader community needs.

6. Governance frameworks should be adaptive, recognising that fisheries in new reservoirs evolve over time and must remain flexible in response to ecological and social change. Environmental factors such as water temperature shifts, productivity changes, and species composition dynamics will shape long-term fisheries potential, requiring regulatory systems that can adjust as conditions change. Similarly, as local fishers gain experience and markets expand, fisheries may transition from subsistence-based activities to more commercialised operations. Governance systems should allow for these transitions while ensuring sustainability, preventing resource depletion, and maintaining equitable access to benefits. Adaptive management frameworks should also account for the coexistence of fisheries with other resource uses, such as tourism, ensuring that multiple livelihood strategies can be supported within dam-affected communities.
7. Planning should also recognise the deep mistrust dam-affected communities often harbour towards authorities. Early engagement with communities, transparent dialogue about fisheries opportunities, and ensuring meaningful involvement in decision-making must be prioritised early. This will go a long way towards establishing legitimate cooperative governance structures and co-management frameworks that are equitable and sustainable.

CHAPTER 4 – ANGLING TOURISM AND DAM-AFFECTED RURAL COMMUNITIES: A CASE STUDY FROM THE LESOTHO HIGHLANDS WATER PROJECT AREA, SOUTHERN AFRICA

4.1. Introduction

It is estimated that 220–700 million people worldwide participate in recreational fishing (broadly defined as fishing for leisure rather than profit, subsistence, or scientific research purposes) (Arlinghaus et al. 2015), spending approximately USD 190 billion per year, and contributing around USD 70 billion per year to global gross domestic product (GDP) (Cooke and Cowx 2004; Funge-Smith 2018). Recreational fishers now outnumber commercial capture fishers five to one, and catch approximately 47 billion fish per year, as much as 12% of the global finfish catch (Cooke and Cowx 2004; Arlinghaus et al. 2019; Potts et al. 2020; Bower et al. 2020). In many developed countries, recreational fisheries have become the dominant use of fish resources (Cowx et al. 2010; Arlinghaus et al. 2016b) generating economic benefits that are frequently greater than those from commercial fisheries (Southwick et al. 2018). Moreover, recreational fisheries are growing rapidly in developing countries, where they may provide a source of employment and livelihoods for poorer rural communities (Ditton et al. 2002; Potts et al. 2009; Cowx et al. 2010; Potts et al. 2020; Bower et al. 2020; Butler et al. 2020; FAO 2020).

Over recent decades, there has been significant growth in foreign fishing tourism (FFT) in the developing world (Barnett et al. 2016; Sheaves et al. 2016; Bower et al. 2020; Butler et al. 2020). Foreign fishing tourism (FFT) destinations are typically located in remote and rural areas (e.g., Mongolia, Gabon, Kenya), where highly prized species are targeted by foreign, affluent anglers (Potts et al. 2009; Barnett et al. 2016; Belhabib et al. 2016; Butler 2020; Kadagi et al. 2020). The allure of FFT destinations lies in their blend of adventure and exclusivity, which draws a clientele willing to pay a premium for a particular angling experience (Barnett et al. 2016; Butler et al. 2020).

The growth of FFT in the developing world has generated interest in its potential to contribute to socio-economic development in rural areas while promoting ecologically sustainable fishing practices (Potts et al. 2009; Barnett et al. 2016; Belhabib et al. 2016; Butler et al. 2020; Uddin et al. 2021). Most FFT operations have a “conservation focus”, with an increasingly strong emphasis placed on catch-and-release angling practices (Barnett et al. 2016). However, studies have also highlighted the risks of FFT, notably economic leakages (generally defined as the proportion of tourist expenditure that does not reach or remain in the destination economy (Garrigós-Simón et al. 2015)) and inequitable distribution of rents (Potts et al. 2009; Butler 2020). Some FFT operations may target vulnerable or threatened species (Shiffman et al. 2014; Cooke et al. 2016; Sheaves et al. 2016); negatively impact fish populations through post-release mortality (Moxham et al. 2019; Tracey et al. 2023); and/or operate in sensitive habitats such as spawning grounds (Ostrega et al. 2023). In addition, conflict may also arise between local fishing communities, tourism operators and participants, and authorities, as well as among communities themselves particularly where some benefit more than others or are less negatively impacted (Bower et al. 2014; Llompart et al. 2017; Kadagi et al. 2020).

Despite increasing research interest in recent years, FFT is poorly understood and receives little scientific attention in comparison to recreational fisheries in developed countries (Butler et al. 2020). Quantitative information on the social and economic value of FFT is generally scarce, and there is a lack of awareness at multiple levels, from institutional to community-level stakeholders, of their benefits and impacts and how best to develop and manage them (Cisneros-Montemayor and Sumaila 2010; Belhabib et al. 2016). This knowledge gap is particularly evident in the context of large dam projects.

The proliferation of large dams since the mid-20th century has inadvertently created several popular FFT destinations in the developing world. Notable examples include the Nile perch (*Lates niloticus*) fishery on Lake Nasser in Egypt (Weyl and Cowley 2015); the tigerfish (*Hydrocynus vittatus*) fishery on Lake Kariba in Zimbabwe/Zambia (Magadza 2006); peacock bass (*Cichla* spp.) and golden dorado (*Salminus brasiliensis*) fisheries in numerous reservoirs in South America (Ribeiro et al. 1995; Freire et al. 2016); and trophy carp (*Cyprinid* spp.) and catfish (*Pangasiidae* spp.) fisheries in south east Asia (Funge-Smith 2018). However, there is a dearth of information on their social and economic value. While studies on reservoirs in North America, South America, Australia, Europe, and South Africa have highlighted the social and economic importance of recreational fisheries on large dams generally (Chen et al. 2003; Driscoll and Myers 2014; Baigún et al. 2006; Rolfe and Prayaga 2007; Ellender et al. 2009, 2010), there is a lack of research specific to FFT that has developed following the establishment of large dams.

Large dam projects significantly disrupt livelihoods and have been associated with increased levels of unemployment (Richter et al. 2010). At the same time, they may also create new opportunities, for instance through irrigated agriculture, urbanisation, and tourism development (Scudder 2012; Moran et al. 2018). Within this broader landscape, the development of recreational fisheries and foreign fishing tourism (FFT) has been cited as one potential offset mechanism which can contribute towards local economic development in dam-affected areas (Sivongxay et al. 2017; Yankson et al. 2017; Schulz and Skinner 2022; Owusu et al. 2024). Therefore, FFT may complement other emerging livelihood pathways by creating additional sources of employment and income for dam-affected communities. However, studies have also shown that tourism development that follows large dam development may create conflict, particularly when scarce livelihood options are threatened, and benefits from natural resources are inequitably distributed (Mhlanga 2009). The broader context of displacement, upheaval, and socio-economic hardship in dam-affected communities, and how these factors influence FFT development and management, remains poorly understood. Communities that have experienced livelihood disruptions, resettlement challenges, and deteriorating trust in authorities may have complex and varied responses to FFT initiatives. The lack of information on the potential benefits and/or risks of FFT development in the context of large dam projects could lead to missed opportunities for social development and/or negative consequences for local communities and ecosystems. In developing countries, where many large dam projects are currently being planned or implemented, there is clearly a need to better understand the opportunities that FFT provides, and how best to develop and manage these fisheries.

In the Kingdom of Lesotho (hereafter Lesotho), a low-income developing country (LIDC) located in southern Africa, there is increasing interest on the part of decision-makers in the potential for FFT development (*mme* Palesa Monongoaha, Head of Environment, LHDA, pers. comm. 2021), particularly given the opportunities provided by the reservoirs and rivers that form the Lesotho Highlands Water Project (LHWP) (see Chapter 2). The LHWP is a large dam project situated in the Lesotho Highlands, a montane and rural area with water resources that include reservoirs and streams with popular angling species such as rainbow trout *Oncorhynchus mykiss*, brown trout *Salmo trutta*, and smallmouth yellowfish *Labeobarbus aeneus* (Skelton 1996).

The LHWP has had mixed impacts on the livelihoods of local communities in the project area (Keketso 2003). While the project has provided some economic opportunities, and improved access to bulk services, it has also disrupted livelihoods through resettlement and reduced access to land and resources (see Chapter 2). The Lesotho Highlands Development Authority (LHDA), the principal institution charged with the implementation and management of the

LHWP, remains committed to "improving the standard of living of communities affected by the LHWP" and ensuring the "sustainable management of [the] biophysical environment within the LHWP area" (LHDA 2020). One strategy in this regard includes sustainably developing and managing capture and recreational fisheries as a means of promoting alternative livelihoods and food security (*mme* Monongoaha, Head of Environment, LHDA, pers. comm., 2020).

The history of FFT in the Malibamatso River catchment (now part of the Katse Dam catchment) can be traced back to the 1960s when South African tourists engaged in recreational angling for *O. mykiss*, which were introduced in 1957 into the Malibamatso River and its tributaries, the Motete and Pelaneng Rivers (Shortt-Smith 1963, 1964) (Figure 4.1). Shortt-Smith (1963) also mentioned angling for *L. aeneus* in the Malibamatso River, although they were considered an inferior angling target to *O. mykiss*. There is no information on the scale of fishing activities then, although it was probably small given the logistical challenges associated with accessing the area at that time. However, it is worth noting that the fishing experience was rated highly, primarily because of the large average size of the *O. mykiss* in these rivers compared to those in South African rivers (Bradlow 1966).

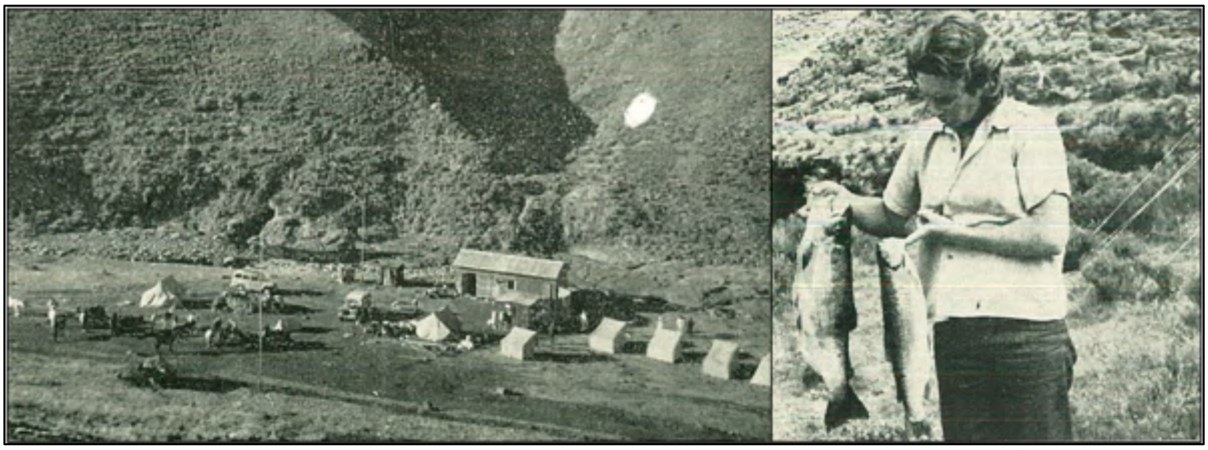

Figure 4.1: A recreational fishing camp on the Malibamatso River, Lesotho, in the 1960s (Source: Shortt-Smith 1964). This area is located upstream of Katse Dam which forms part of the LHWP (see Chapter 3).

Pre- and post-impoundment studies of the Katse Dam catchment area in the late 1980s and 1990s highlighted the potential to develop a formalised recreational fishery for trophy *O. mykiss* (Eccles 1990; Skelton 1996; Tweddle and Davies 1997; Nthimo 2000). In 1999, the *Lesotho Highlands Water Project (Reservoirs) Fishing Regulations, 1999* (the Regulations) were gazetted which made provision for "Angling" using artificial flies.

While recreational angling in the Lesotho highlands pre-dates the LHWP, the landscape changed significantly with the creation of Katse Dam and the establishment of bulk services infrastructure which allowed easier access to and increased tourism in the area (Thetsane 2019). In 2012, the first (and only) dedicated FFT operation, the Makhangoa Community Camp (MCC), was established in the LHWP area by a South African-based tour agency Tourette Fishing (now African Waters (AW)). The MCC is jointly managed by AW and the Makhangoa Tourism Council, under the auspices of the LHDA. The management model is based on "community beneficiation" where, in return for access rights, AW pay a community levy, offer employment, and support social and economic development programmes for local community members (Clover 2015).

Since its establishment, the MCC has gained popularity and is being considered as a potential model for replication in other areas of the LHWP (*mme* Palesa Monongoaha, Head of Environment, LHDA, pers. comm. June 2020). However, as with numerous FFT operations in the developing world, there are significant knowledge gaps on its benefits and risks. This chapter aims to examine the role of recreational angling tourism associated with the LHWP in shaping social and economic outcomes for dam-affected communities. Specifically, it seeks to:

1. Characterise participation levels, catch composition, and motivations of FFT anglers in the Lesotho Highlands.
2. Assess the economic contributions and leakages associated with FFT operations in the region.
3. Explore local community perspectives on FFT activities, including opportunities, challenges, and perceptions of benefits.
4. Evaluate the extent to which FFT can contribute to livelihood diversification and fisheries management in a dam-affected context.

4.2. Materials and methods

4.2.1. Study site

The MCC is situated on the Bokong River, upstream of its confluence with the Katse Dam, approximately 1.7 km downstream of the village of Ha Makhangoa and approximately 2.4 km upstream of the northernmost part of Ha Souane (Figure 4.2; Figure 4.3). Ha Makhangoa has a population of around 330 people (*Morena* Mokhula, Chief, Ha Makhangoa, pers. comm. August 2024) while Ha Souane has a population of around 365 people (*Morena* Sekeleme, Area Chief, Ha Souane, September 2024).

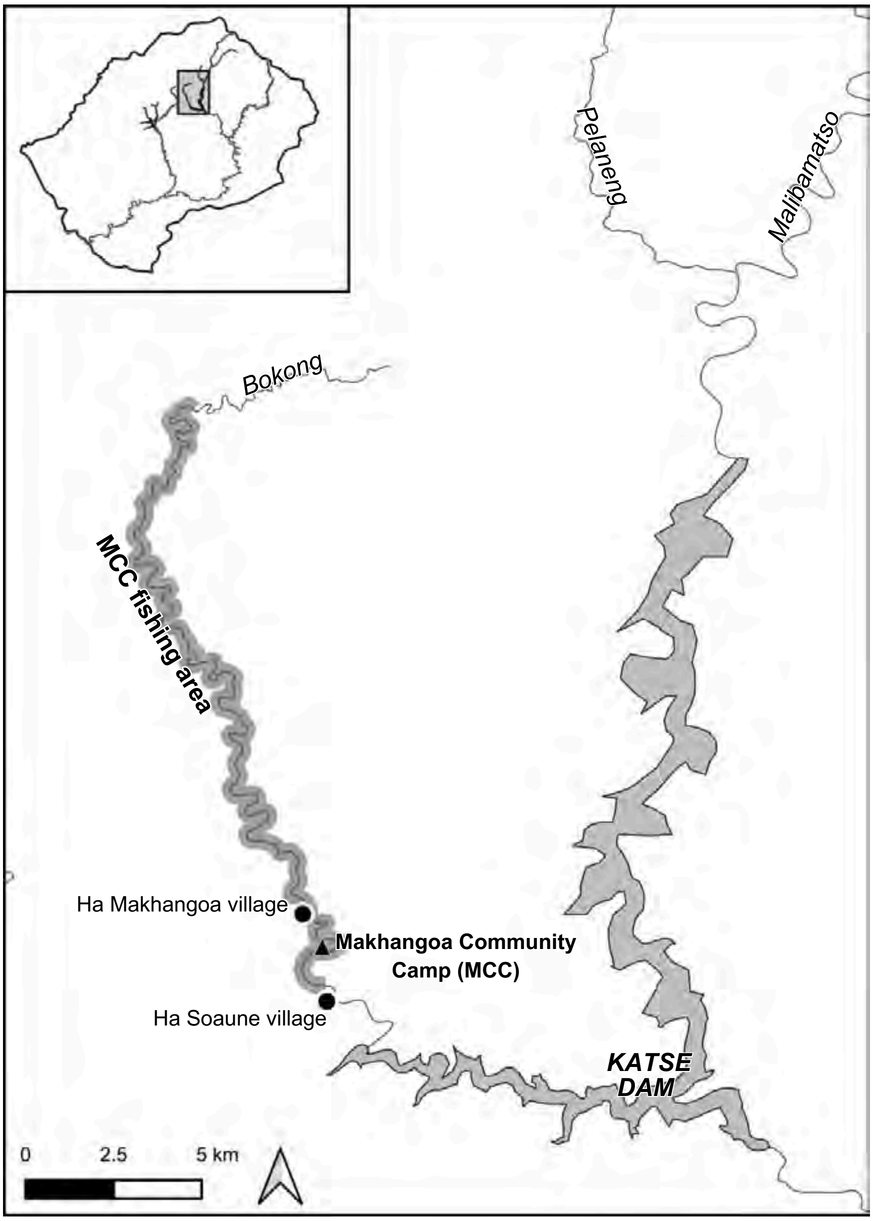

Figure 4.2: The Makhangoa Community Camp is situated on the Bokong River in the Katse Dam catchment, between the villages of Ha Makhangoa and Ha Souane. The fishing area extends over 35 km.

Figure 4.3: The Makhangoa Community Camp is situated on the Bokong River in the Katse Dam catchment close to where the river meets the dam (Photo: Chris Matthews) (top). The bottom panel shows a stretch of the fishing area upstream of the MCC (Photo: African Waters).

The Bokong River is a 52 km long, oligotrophic to oligo-mesotrophic, cool (15.92 ± 5.77 °C), well-oxygenated (8.62 ±1.25 mg/L), alkaline (pH 8.29 ± 0.77), low-medium order stream. Dominant riverine habitats include slow, shallow flats (40%); slow, deep pools (40%); and fast, shallow riffles (20%). Substrates are primarily comprised of cobbles and boulders (50%) and bedrock (40%), with some areas of sand and gravel (10%).

The MCC lodge accommodates a maximum of 12 people and offers three- to 14-night packaged trips that include accommodation, meals, and guided angling on ± 35 km stretch of the Bokong River. Fishing on this stretch of the Bokong River is managed in accordance with the *Lesotho Highlands Water Project (Reservoirs) Fishing Regulations, 1999* (the Regulations) and the "Fishery Management Plan for the MCC and Bokong River" (FMP) developed by African Waters. The tourist angling season extends from November to March. Tourist angling is restricted to catch-and-release fly fishing with a maximum of eight anglers permitted per day, while subsistence fishing is limited to hook-and-line methods with a four-fish daily bag limit as per the Regulations. Subsistence fishers may not fish in spawning areas or in areas where tourists are actively angling on a given day, but when no tourists are present, these areas remain open to subsistence fishing. Compliance is overseen through the FMP which provides for arrangements where community-based River Rangers employed by the MCC monitor activities and report violations to the LHDA or the Lesotho Mounted Police Service. Traditional authorities also play a role in ensuring local adherence to these rules.

4.2.2. Catch composition

To document the species targeted in the FFT operation at MCC, catch data were collected during the November 2022 to March 2023 angling season. During each fishing session, MCC guides recorded the number of fish landed by species. Animal ethics approvals were obtained from the Chairperson of the Rhodes University Animal Research Ethics Committee (RUAREC) and the Executive Committee of RUAREC (RUAREC – CW02/2024).

4.2.3. Angler questionnaire

An online survey form (questionnaire) was developed using Kobo Toolbox (see Appendix B1 for the questionnaire). The online survey method was chosen given its suitability for specialised small-scale recreational fisheries where there is a well-defined sampling frame e.g., a list of anglers (Ashford et al. 2009; Ryan et al. 2024). The MCC maintains a database of all visiting anglers, which provided a suitable sampling frame. The questionnaire requested information on demographics, fishing-specific motivations, non-fishing specific motivations for visiting both the MCC and Lesotho, favoured target species, trip satisfaction, attitudes towards capture fishing activities, and their perspectives on the efficacy of the current fisheries management arrangement. The motivation categories were developed by conducting key informant interviews (KIIs) (Pollock et al. 1994) with international recreational fisheries scientists, experienced anglers, previous MCC visitors, AW management, and LHDA personnel, and by drawing on the scientific literature (Fedler and Ditton 1994). The questionnaire was pre-tested with the key informants and refined based on their feedback (Jeanson et al. 2021). Several iterations were produced and re-tested to address ambiguities and improve clarity prior to launching the survey form.

The target population for the questionnaire survey was any angler that had stayed and fished at the MCC during the 2022–2023 fishing season. Survey participants were recruited using two methods: (1) AW management contacted anglers via email during the week following their trip and provided the link to the questionnaire, and (2) a poster advertising the survey were displayed at the MCC lodge with a QR code. To incentivise participation, respondents were entered into a lucky draw competition to win a prize (fly fishing reel). The prize was determined in consultation with AW management.

The questionnaire began with an information page outlining the study aims, objectives, and importance, and a consent question. Only after consenting could participants proceed to the questionnaire. Questions were either multiple choice, ranked, or Likert-type questions (Likert 1932). The questionnaire was kept as short as possible to reduce survey response fatigue and non-response bias (Steeh 1981; De Heer 1999; Porter et al. 2004). Fifty-five anglers completed the survey, representing a response rate of 23.5% which is comparable with response rates to online surveys recorded in other recreational angling surveys (Barrett et al. 2017; Bachiller et al. 2022; Ryan et al. 2024). All interactions with human participants were approved by Rhodes University Human Research Ethics Committee (NHREC Registration number: RC-241114-045).

For multiple choice questions, frequencies and percentages were calculated for each option. For ranked questions, the frequency of each option being ranked in each position was calculated to determine overall preference patterns. Likert-type questions used a five-point scale (1 = strongly disagree to 5 = strongly agree) to measure angler attitudes and preferences, as used similar studies examining angler motivations and satisfaction (TenHarmsel et al. 2019; Gundelund et al. 2022; Bower et al. 2024; Ryan et al. 2024).

For each Likert-type question, a mean response level was calculated to indicate the average answer of respondents (L), using the following formula:

$$L = \sum R / n \tag{4.1}$$

where R is the sum of all response values for a given question and n is the total number of respondents who answered that question.

4.2.4. Economic contribution and leakages

An economic contribution analysis was conducted to assess how the MCC contributes to the local economy through direct expenditure and to identify economic leakages to national and international economies. This approach is commonly used to assess the economic impact of recreational fisheries (Lovell et al. 2016; McLeod and Lindner 2018; Southwick et al. 2018; Butler et al. 2020) and nature-based tourism in rural areas (Sandbrook 2010a, 2010b).

Economic contribution and leakage were determined based on angler expenditures and the annual operational costs of the MCC (as per Butler et al. 2020). Angler expenditure data were obtained using the online questionnaire (**Error! Reference source not found.**1), and included the trip package, airfares, car hire, car fuel, fishing equipment, fishing clothing, food and beverages (excluding that provided by the MCC), souvenirs, staff gratuities and other. Annual operational costs of the MCC (MCC costs) were provided by AW management, and included fuel, food and beverages, community levies and fishing licences, staff wages, donations, communication costs, administrative expenses, and any other operational expenditures.

Angler expenditures and MCC costs were all standardised into United States Dollars (USD) and categorised into:

1. International: expenditures/costs outside of Lesotho.
2. National: expenditures/costs in Lesotho but outside of the local area.
3. Local: expenditures/costs in the local area including the towns of Katse and Ha Lejone adjacent to Katse Dam (Figure 4.4).

The local economic contribution (LEC) of the MCC was calculated as:

$$LEC = E_{al} + C_{ml} \tag{4.2}$$

where E_{al} is the angler expenditures made in the local area and C_{ml} is the MCC operational costs in the local area.

Local economic leakage (LEL) was calculated as:

$$LEL = (E_{ai} + E_{an} + C_{mi} + C_{mn}) - LEC \tag{4.3}$$

where E_{ai} and E_{an} are angler international and national expenditures, respectively, C_{mi} and C_{mn} are MCC international and national operational costs, respectively, and LEC is the local economic contribution as calculated in Equation 4.2.

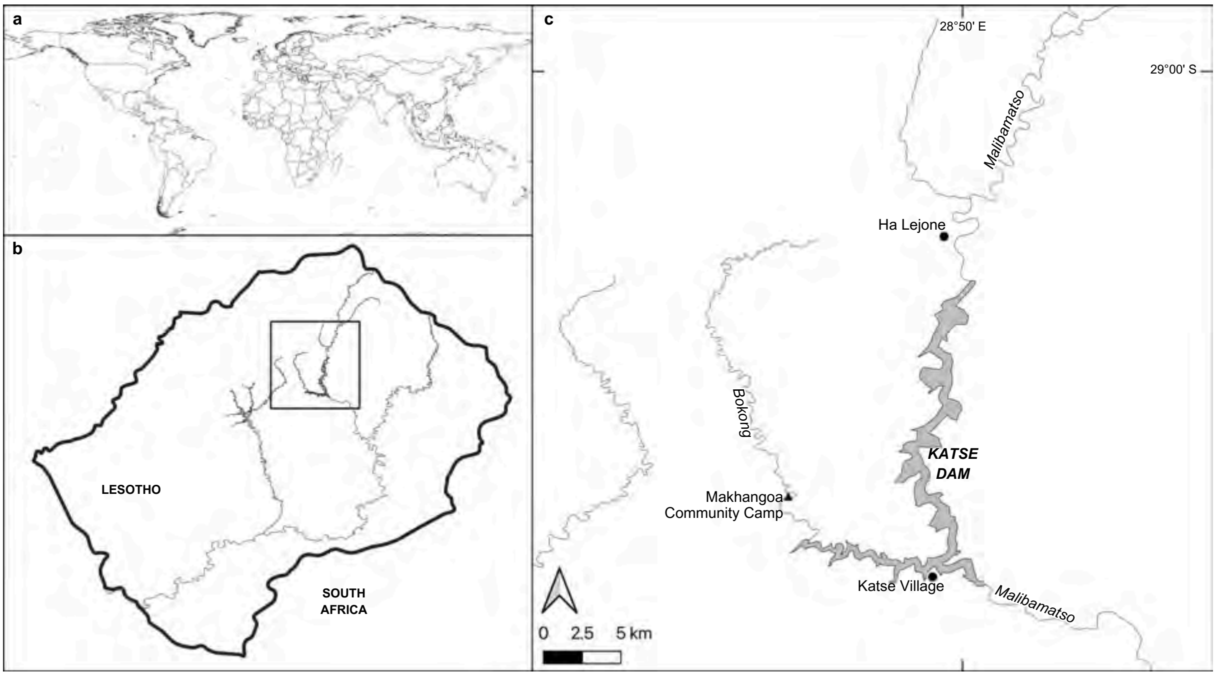

Figure 4.4: International (a), national (b), and local (c) geographic scales used to categorise angler- and MCC expenditures.

4.2.5. Community engagements

Focus group discussions (FGD) were conducted in Ha Makhangoa and Ha Souane in August 2024 to explore community experiences and perceptions of the MCC, with a focus on how benefits, challenges, and opportunities were distributed within and between the two communities. The FGDs took place outside of the fishing season (November – March) due to fieldwork scheduling and community access constraints. While recall bias is recognised as a potential limitation, the FGDs were designed to capture broader livelihood experiences and perceptions rather than quantitative data, and were therefore considered less sensitive to seasonal timing. The FGD in Ha Makhangoa included a total of 45 fishing and non-fishing community members. The participants included both men (n = 28) and women (n = 17) between the ages of 18 and 70. Due to logistical constraints, only seven people from Ha Souane were able to attend the FGD. The participants were all male and comprised both fishers and non-fishers. To supplement these discussions and address potential gaps due to the lower attendance in the Ha Souane FGD, seven KIIs were conducted with fishers from Ha Souane encountered during roving creel surveys of the hook-and-line fishery (see Chapter 3), and with the Area *Morena* of Ha Souane.

The FGDs followed a semi-structured format, guided by open-ended questions that encouraged participants to discuss their experiences with the MCC and their perceptions of its benefits and/or its drawbacks. This approach allowed participants to explore topics that were most relevant to them while providing a platform for group interaction to reveal shared understandings, collective concerns, and community-level insights (Kitzinger 1994). The FGDs were conducted with the author directing questions in English, which were translated into Sesotho by a Mosotho research assistant. Responses were translated back into English in real time and transcribed by the lead researcher, who also asked clarifying questions where needed. After each session, the transcripts were reviewed together with the assistant to ensure accuracy before analysis.

All interactions with human participants were approved by Rhodes University Human Research Ethics Committee (NHREC Registration number: RC-241114-045).

Transcripts were analysed using reflexive thematic analysis (RTA) following the same approach detailed in Chapter 3 (see Section 3.2.3) to identify any divergent or convergent perceptions of the MCC's impact, with particular attention to differences in experiences regarding community roles, access to MCC benefits, and perceived equity in resource distribution. Although RTA cannot demonstrate systematic coverage of the data, the approach provided sufficient depth on how participants interpreted their experiences with the MCC through their varied roles and perspectives within the communities.

4.3. Results

4.3.1. Participation and catch composition

A total of 234 anglers visited the MCC during the 2022–2023 season. Of the 55 questionnaire respondents, most were South African (80.9%), with smaller proportions from neighbouring African countries (Botswana, Zambia) and overseas (Ireland, United Kingdom, United Arab Emirates, and Canada). Respondents were predominantly male (84.4%) with a mean age of 45 ± 10.2 years and an average of 25 ± 16.8 years of angling experience. Most classified themselves as "competent" (53.7%) or "proficient" (33.3%) anglers, while only 1.9% identified as novices (Figure 4.5).

A total of 3 037 fish were caught and released over the course of the 2022–2023 season. Catches were primarily comprised of *L. aeneus* (*n* = 2 486; 81.9%) and *O. mykiss* (*n* = 542 17.8%). Very few *S. trutta* (*n* = 4; 0.1%) and *L. capensis* (*n* = 5; 0.2%) were caught.

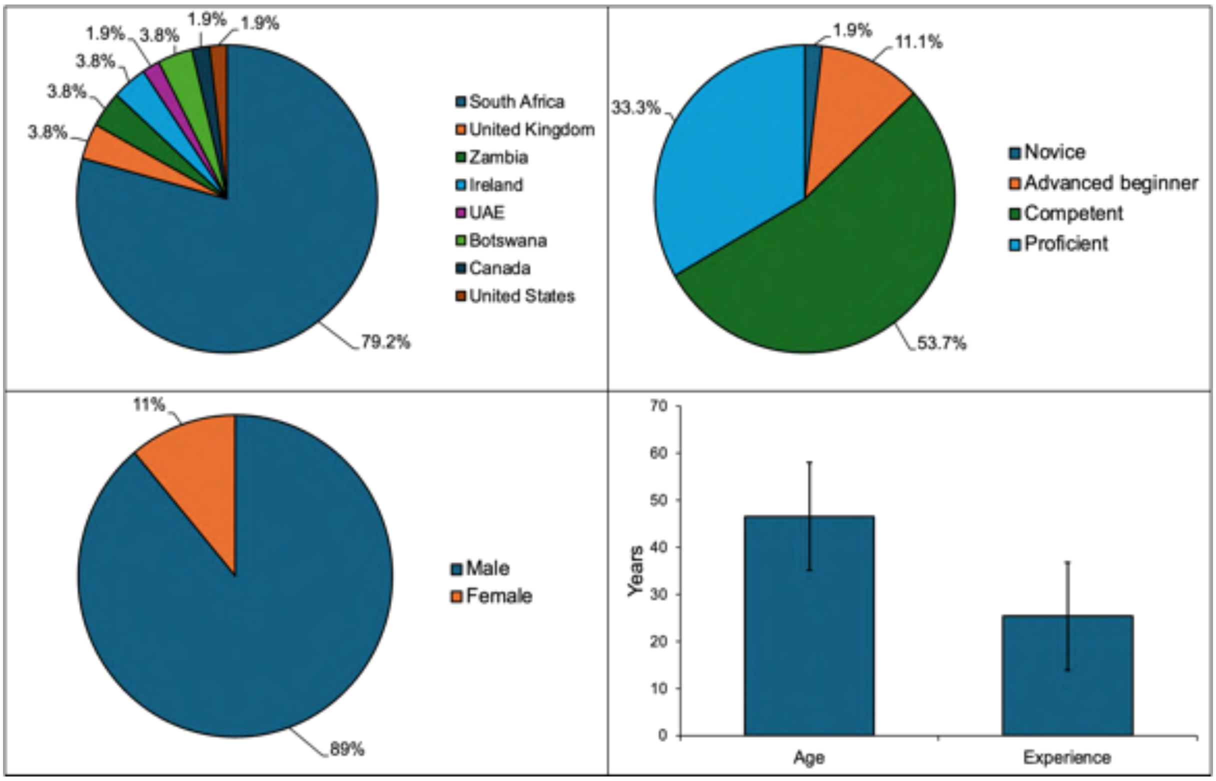

Figure 4.5: Origins (top left), gender (bottom left), experience level (top right), and age and years of experience (bottom right) of questionnaire respondents.

4.3.2. Angler motivations

The primary fishing-specific motivations for visiting the MCC were sight fishing and dry fly fishing, both highlighted by over 80% of respondents (Figure 4.6; Figure 4.7).

Figure 4.6: *Labeobarbus aeneus* can often be spotted, stalked, and sight fished in the Bokong River; this was the primary motivation for anglers to visit the Makhangoa Community Camp (Source: African Waters).

Other fishing-specific motivations included guided experiences and the number of fish caught, while fish size ranked lowest. Other motivations centred on scenery, relaxation, and social aspects, while affordability and novelty were the most cited reasons for visiting Lesotho (Figure 4.8). Angler species preferences were strongly skewed towards *L. aeneus* (Figure 4.9).

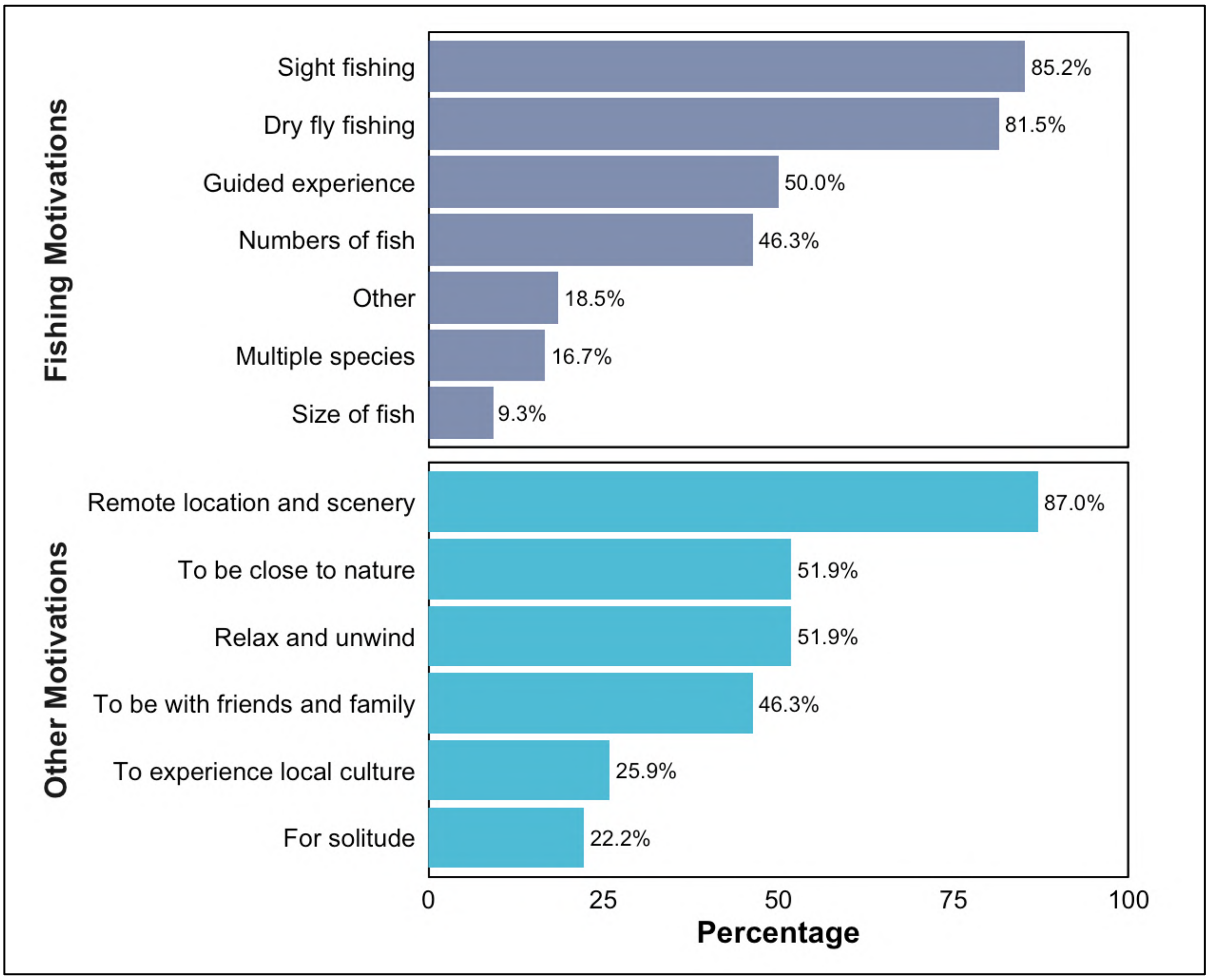

Figure 4.7: Fishing- and other motivations expressed by questionnaire respondents for visiting the Makhangoa Community Camp (closed-ended questions).

Most anglers were positive about their trip to the MCC (88.9%) with 72.2% of respondents being either "Very satisfied" and 16.7% being "Somewhat satisfied". Dissatisfaction was relatively low (11.1%), with 9.3% reporting being "Very dissatisfied" and only 1.9% "Somewhat dissatisfied".

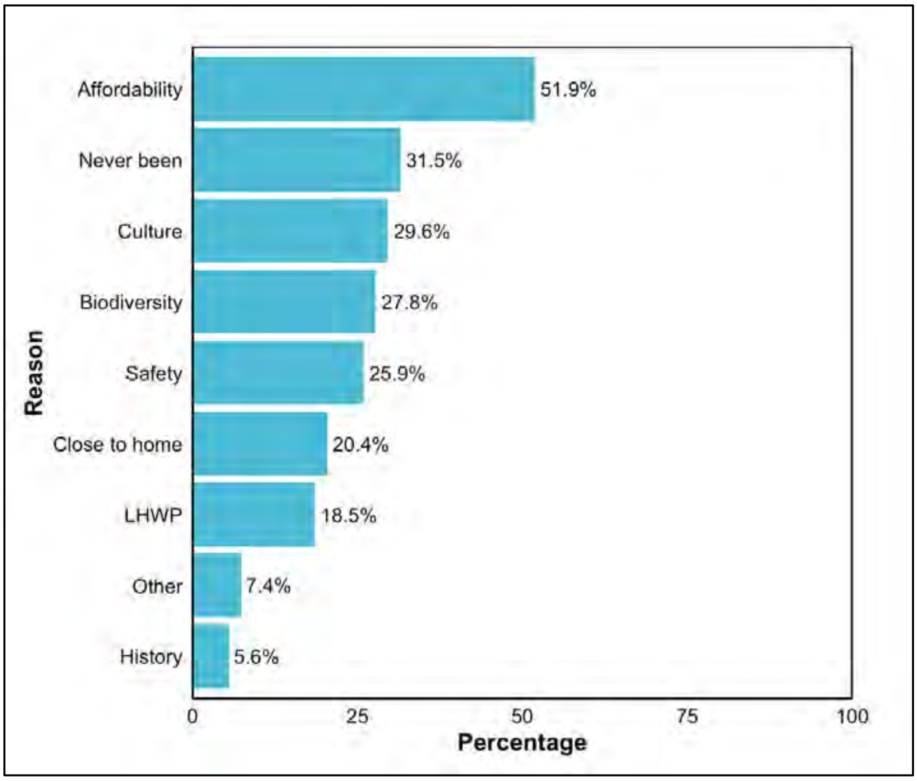

Figure 4.8: Reasons expressed by questionnaire respondents for visiting Lesotho (close-ended question).

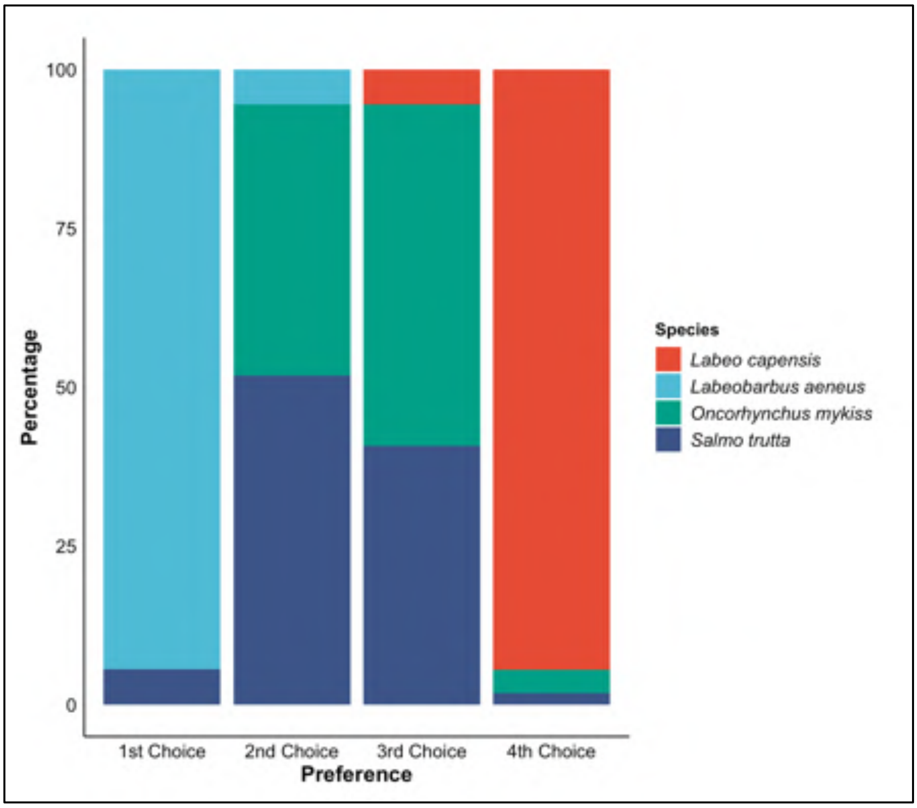

Figure 4.9: Angler species preferences ranked by percentage of anglers selecting each fish species as their 1st, 2nd, 3rd, and 4th choice of target species.

4.3.3. Perspectives on activities of local fishers and management

Most anglers (76%) encountered local hook-and-line fishers during their visit to the MCC. Perspectives on the sustainability of the capture fishery were mixed; most anglers (44.4%) were either of the view that it was "Sustainable" or were "Unsure" (31.2%). Smaller proportions of respondents believed it was "Unsustainable" (18.5%). Despite these mixed views, most anglers (81%) believed capture fishing activities should be allowed in the MCC fishing area. A small proportion were of the view that fishing activities should not be allowed (13.2%) or should be banned completely (1.9%).

More broadly, most anglers were of the view that AW was managing the fishery "effectively" (94.5%). A small proportion of anglers believed that management was "ineffective" (1.9%) or were "unsure" (3.7%).

4.3.4. Economic contribution

Angler expenditures

The average international, national, and local expenditures of anglers who visited the MCC from 2022–2023 are presented in Table 4.1. Total expenditures were estimated at USD 517 670 of which international expenditures accounted for 77.4% (USD 400 821) followed by local- (USD 59 095; 11.4%) and regional expenditures (USD 57 753; 11.2%). International expenditures were primarily on package trips (USD 831/angler; 49.3%) and airfares (USD 349/angler; 20.7%) while national- and local expenditures were primarily on food (USD 69.84/angler; 28.8%) and fuel (USD 67.02/angler; 27.6%), and gratuities (USD 248.30/angler; 100%), respectively.

MCC operational expenses

The international, national, local, and total operational expenses of the MCC over the financial year (FY) 2022–2023 are presented in Table 4.2. Total operational costs were USD 93 285. Local costs accounted for 50.8 % (USD 47 425) followed by international costs (USD 34 671; 37.2 %) and national costs (USD 11 189; 12 %). Local costs were primarily comprised of staff wages and gratuities (USD 14 045; 29.6%), community donations (USD 13 133; 27.7%), and a community levy (USD 9 305; 19.6%). Major national- and international costs included food and beverages (USD 6 360; 56.8 %) and other operational expenses (OPEX) (USD 13 005; 37.51%), respectively.

Table 4.1: Average international, national, local, and total expenditures (USD) of anglers who visited the MCC, November 2022 to March 2023.

Expenditures	**USD (average/angler)**
International	
Package trips	831
Airfare	349
Car hire	87
Fuel	126
Fishing equipment	214
Other	76
Average	*1 684*
Total	*400 821*
National	
Food	70
Beverages	47
Souvenirs	39
Fuel	67
Other	20
Average	*244*
Total	*57 753*
Local	
Staff gratuities	248
Total	*59 095*
Total	***517 669***

Local economic contribution and leakage

The total economic contribution of the MCC was estimated at USD 93 285, of which USD 47 425 (50.8%) was retained in the local economy. The major sources of leakage were food and beverages sourced regionally or from South Africa, wages paid to South African staff, and operational/overhead costs associated with running the business from an office in South Africa.

Table 4.2: African Waters' international, national, local, and total operational costs of running the Makhangoa Community Camp, Financial Year 2022–2023.

Costs	**International (USD)**	**National (USD)**	**Local (USD)**	**Total (USD)**
Petrol/diesel	1 781	1 068	795	3 644
Vehicle maintenance	2 078		530	2 608
Food and beverages	4 240	6 360	1 908	12 508
Fishing licences			1 010	1 010
Communication			212	212
Hardware and building materials	3 180	2 615	2 918	8 713
Local staff wages and gratuities			14 045	14 045
Guide wages	9 010			9 010
Community levy			9 305	9 305
Community donations			13 133	13 133
Client transfers	1 378			1 378
Import duties		1 145		1 145
OPEX	13 005			13 005
International	34 671	11 189	47 425	93 285

4.3.5. Community perspectives

Six key themes emerged from the FGDs and RTA on community perceptions of the MCC and its impacts: (1) "Employment and Livelihoods"; (2) "Equity and Benefit Sharing"; (3) "Conflicts and Resource Access"; (4) "Psychosocial Impacts"; (5) "Trust, Consultation and Transparency"; and (6) "Ecological Concerns". Around each of these themes, community members from Ha Makhangoa and Ha Souane had differing perspectives on the impact of the MCC (Figure 4.10).

Employment and livelihoods

Ha Makhangoa residents reported positive employment and livelihood impacts arising from the MCC, including direct employment in the form of operational management and guiding roles, domestic work, repairs and maintenance, and part-time construction jobs. Community development projects, including school repairs and infrastructure e.g., footbridges, solar panels, were well received as was the community levy paid by the MCC. In contrast, Ha Souane respondents felt excluded from employment and livelihood benefits. It was reported that only one community member was directly employed by the MCC. Engagements with the Ha Souane Area *Morena* confirmed that this was a widely held view in the Ha Souane community.

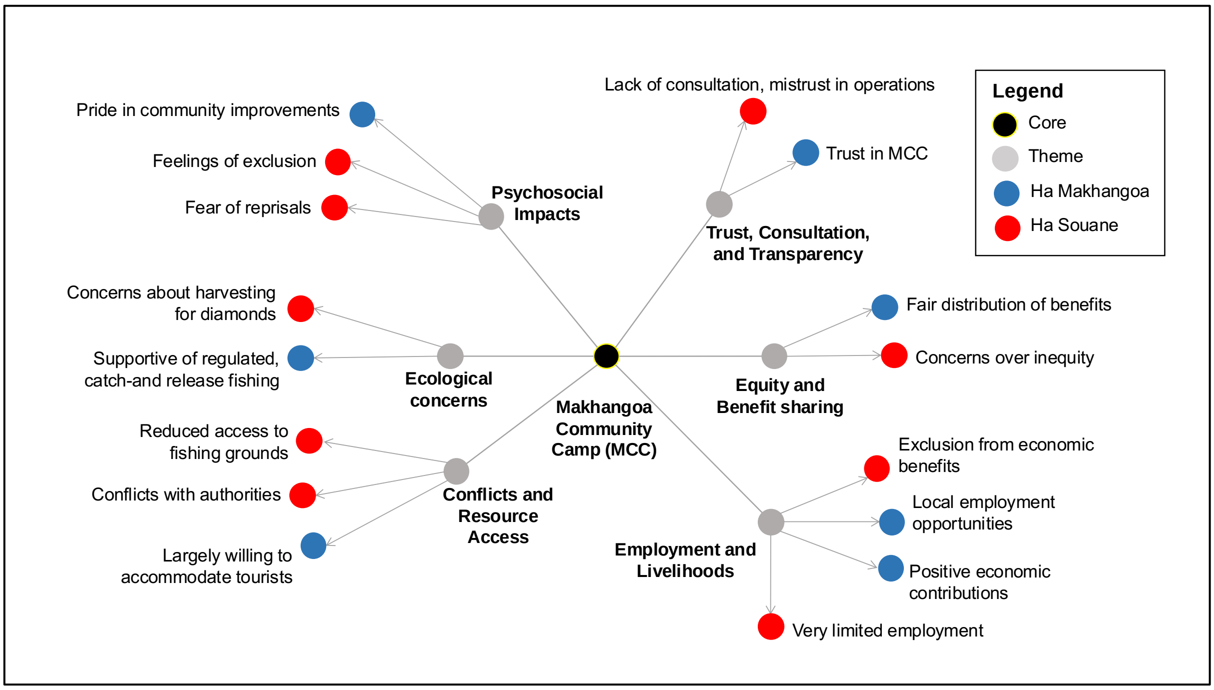

Figure 4.10: Key themes and perspectives of Ha Makhangoa and Ha Souane community members on the Makhangoa Community Camp that emerged from focus group discussions. Themes reflect interpretive patterns identified through reflexive thematic analysis; frequency counts

Equity and benefit sharing

Ha Makhangoa participants generally viewed the distribution of MCC-related socio-economic benefits as fair. A rotational employment scheme had been established by the community to ensure that opportunities for employment were equitably distributed among residents. Two residents reported that they would welcome opportunities to become fishing guides and that this had largely been supported by MCC but not yet implemented. On the other hand, Ha Souane residents expressed some concerns over inequity and a lack of benefit sharing and were of the view that Ha Makhangoa had been prioritised by the MCC for job allocation and community development projects. While Ha Souane respondents perceived inequity in benefit sharing, this concern was directed primarily toward the MCC rather than toward neighbouring communities, and no other explanatory factors were identified in the data.

Conflicts and resource access

Ha Makhangoa residents expressed some frustration about being instructed by MCC guides to vacate fishing areas to allow tourist anglers to fish. However, they were generally willing to accommodate tourists given the community-wide benefits that had resulted from the MCC.

One resident stated that "*When the tourists come, we should give way to allow them access*". Despite a desire to engage in more intensive fishing in the area, most respondents agreed that this should not interfere with tourism, with one respondent stating that "*We don't want to jeopardise tourism by fishing in some areas*".

The primary conflict reported by fishers from Ha Souane was with the Lesotho Defence Force (LDF). It was reported that fishing taking place in the MCC area would sometimes result in forceable removal by LDF military personnel. Engagements with MCC management confirmed that they did not condone this behaviour. Nevertheless, Ha Souane fishers felt that the MCC had restricted their access to fish resources, both for subsistence and income. This frustration was heightened by the lack of alternative income opportunities. One respondent mentioned that they had "*already been negatively impacted by this dam*. [The] *fishing at least is better now. But now we can't use the fish*". All the fishers interviewed did not have and could not afford fishing licences.

Psychosocial impacts

Ha Makhangoa reported generally positive psychosocial impacts since the establishment of the MCC, including pride in community improvements. One resident stated they were "*Very happy with the camp and what it has done for our community*". Other participants mentioned the MCC's contributions to health and emergency services which had lessened stress and improved well-being. Community members from Ha Souane reported primarily negative impacts, notably feelings of exclusion, marginalisation, and resentment towards the LDF.

Trust, consultation and transparency

Ha Makhangoa residents generally trusted the MCC, highlighting that they were consulted frequently on developments at the camp and contributed to decision-making. On the other hand, Ha Souane respondents felt they were not consulted on issues related to MCC operations and that they felt left out of decision-making processes. The community also felt that their fishing practices had been disrupted by tourism and that no clear explanation had been provided as to why access to certain areas was now restricted.

Ecological concerns

Ha Souane residents expressed concerns that tourist anglers were harvesting large numbers of yellowfish, putting them in cooler boxes carried by the angling guides, and subsequently opening them up to look for diamonds in the gut cavity. The concept that anglers would pay to catch and release fish was considered implausible. In contrast, Ha Makhangoa residents were in support of catch-and-release fly fishing practices, with no participants expressing concerns about fish harvesting or diamond extraction.

4.4. Discussion

Large dam projects in the developing world support well-established recreational fisheries that attract tourists from around the world (Weyl and Cowley 2015; Funge-Smith 2018). Given the often-reported negative impacts of large dams on local livelihoods (Scudder 2012), foreign fishing tourism (FFT) has been identified as a potential mechanism which could provide socio-economic benefits for dam-affected communities (Jackson and Marmulla 2001). However, there is a lack of information on the socio-economic benefits and risks of FFT in these settings which constrain decision-making. Understanding operational models which have achieved positive outcomes is important for guiding future FFT development in similar contexts. This case study of the MCC aimed to provide insight into the opportunities for, and challenges faced in, developing FFT after the development of a large dam project in the Lesotho Highlands. The results showed that FFT can contribute towards local economic development and livelihood diversification of dam-affected communities with structured approaches to community engagement and local employment playing an important role in achieving these outcomes. However, it also highlights difficulties in benefit sharing and conflicts over resource access which may present challenges for future development.

Historically, fly fishing in Lesotho was associated largely with non-native *O. mykiss*. Both pre- (Bain 1990; Eccles 1990; Skelton 1996) and post-impoundment studies (Tweddle and Davies 1997; Nthimo 2000) only discussed the potential to develop a recreational fishery for this species. However, FFT activities at the MCC operation are almost entirely based on the native *L. aeneus* which is the preferred target species for most visitors.

Fly fishing for native yellowfishes *Labeobarbus* spp., particularly *L. aeneus*, in South Africa has increased in popularity since the late 1990s (Wolhuter and Impson 2007; Brigg and Herbst 2017). Historically considered a “bait-fishing quarry”, it is now regarded as a flagship angling species and targeted in many areas of the Orange-Vaal River catchment, particularly in the Vaal River close to Gauteng province (FOSAF 2024). Higher nutrient levels in this part of the catchment, particularly in the Vaal River (Mararakanye et al. 2022), generally dictate the use of blind fishing techniques (i.e., casting without seeing the fish) with nymphs (weighted, sunken, small flies imitating aquatic insects). In contrast, the Bokong River at the MCC is mostly oligotrophic to oligo-mesotrophic, with greater water transparency, allowing anglers to target *L. aeneus* using sight fishing techniques and dry flies. Sight fishing has become an increasingly popular form of fly fishing globally (Mayer 2009; Karas 2016) with studies showing that anglers are prepared to pay a premium for this experience (Hoogendoorn 2017; Scheld et al. 2020). Moreover, a number of destinations offering sight fishing experiences e.g., tropical flats fishing in the Caribbean and Seychelles, trout fishing in New Zealand are regarded as "bucket-list" FFT destinations (Santella 2011). Similarly, dry fly fishing is highly sought after particularly among more experienced fly anglers (Weamer 2021). Suitable conditions for this specific type of fishing are scarcely available in South Africa, and essentially limited to a single large dam, Sterkfontein Dam, in the Free State Province (Hoogendoorn 2017). In essence, it is this "scarcity" which underpins the popularity of the MCC.

While the results from the questionnaire survey revealed that Katse Dam itself (and the LHWP in general) was not an important drawcard for anglers, it is unlikely that this fishery would have developed in the absence of the dam. No pre-impoundment data on fish abundance in the Bokong River were available; however, community members around Katse Dam were all of the opinion that the numbers of *L. aeneus* had increased in the catchment after the construction of the dam (see Chapter 3). Katse Dam is more productive than the rivers in its catchment (Turpie et al. 2014a). In addition, rivers in the Lesotho Highlands, including the Bokong, are subject to significant flow and temperature fluctuations (Sene et al. 1998), both of which have been shown to influence the movement of *L. aeneus* (O'Brien et al. 2013). During winter, *L. aeneus* possibly move great distances downstream from headwater habitats (see Chapter 5), with their return to these areas in summer ultimately dependent on sufficient river flows. The barrier formed by Katse Dam essentially "trapped" *L. aeneus* in the upper part of Malibamatso River catchment, subsequently creating a large pool of biomass. This has likely increased both the numbers of, and the consistency with which, fish enter the Bokong River to spawn, providing anglers with more sight fishing opportunities which in turn has provided the platform for the successful establishment of the MCC.

The establishment of the MCC highlights how dam-induced changes in fish biomass and emerging market demands created the opportunity for successful native species-based FFT development. However, this opportunity could have been identified and developed earlier through better planning. Pre- and post-impoundment fisheries assessments focused solely on non-native trout and lacked consultation with anglers and industry representatives who could have provided insight on emerging markets and opportunities. Instead, it was AW that identified the yellowfish sight fishing potential and developed the fishery. This highlights how dam planners can promote FFT development by proactively identifying and leveraging unique environmental conditions and native species rather than defaulting to costly and ecologically-risky introductions, or development and management measures for non-native species. Future assessments of recreational fishery development opportunities must therefore include broader consultation with anglers and industry to ensure such opportunities are identified and promoted from the outset.

The economic assessment of the MCC operation provides important insights into the potential for FFT to contribute to local economies in dam-affected areas. The total economic contribution of the MCC was estimated at USD 93 285 per year, of which USD 47 425 (50.8%) was retained in the local economy and USD 45 960 (49.2%). This represents a substantial injection of cash into what is otherwise a relatively isolated rural economy where alternative livelihood opportunities are generally limited – revenue which would likely not have been generated in the absence of Katse Dam. Although modest in absolute terms, this contribution is notable when compared to other established FFT destinations. For example, South Africa's Sterkfontein Dam, widely regarded as one of the country's premier flyfishing destinations, generated an estimated USD 67 300 annually (2023 terms) from angler expenditure (Hoogendoorn 2017). Sterkfontein benefits from proximity to urban centres, multiple accommodation providers, and established tourism infrastructure, yet the scale of contribution is of a similar order to that of the MCC. This comparison demonstrates that even small, community-based operations in remote, dam-affected areas can produce economic contributions comparable to larger and more accessible fisheries. Of particular significance is the local economic retention rate of 50.8% (USD 47 425), which is notably higher than rates reported for other FFT operations in developing countries. For example, Butler et al. (2020) found that only 13.9% of the economic value generated by a FFT operation in Angola was retained in the local economy. Studies of other ecotourism operations in Africa have also documented much lower retention rates of 10–27% (Mazibuko 2007; Rid et al. 2014).

The relatively high local economic retention rate can be attributed largely to direct employment of community members from Ha Makhangoa as well as community levies and donations. Nevertheless, economic leakage remains a challenge and stems primarily from the external sourcing of goods and services, particularly food and beverages from South Africa, and the reliance on non-local staff for skilled positions such as fishing guides. These findings mirror trends observed in other regions, where weak local supply chains and a lack of trained personnel have contributed to economic leakages from tourism operations (Ankomah 1991, Meyer 2007; Butler et al. 2020; FAO 2023).

Discussions with MCC management revealed that while increasing local procurement was a priority, they were unable to locally source most of the goods that were required by their international clientele (Keith Clover, Director, African Waters, pers. comm., September 2024). This is a common challenge in rural tourism economies, where inadequate infrastructure and low production capacity constrain supply chains and prevent local businesses from fully benefiting from high-value tourism operations (Sandbrook 2010a; FAO 2023). Establishing stronger linkages between FFT operations and local producers could enable greater procurement of goods and services from local communities (Meyer 2007). Capacity-building initiatives aimed at improving local supply chains, such as training farmers to meet tourism industry standards and enhancing the consistency and quality of locally produced goods, could help reduce dependence on external suppliers and increase local economic retention while creating employment. In addition, formalising supplier relationships could reduce supply volatility and strengthen economic linkages with the community (Meyer 2007; FAO 2023).

A second major source of leakage was the reliance on non-local staff for high-paying positions, particularly fishing guides. At MCC, South African guides occupy these roles, while local employment is largely limited to lower-paying support positions. Currently, local community members lack experience, technical skills, and most significantly, are unable to speak English (Keith Clover, Director, African Waters, pers. comm., September 2024). One potential solution is the implementation of language courses coupled with structured training programmes to equip local community members with the necessary skills to transition into guiding positions. Evidence from Karang Talun Mangrove Forest, Indonesia, demonstrated that targeted language training significantly improved local participation in ecotourism (Widianingsih et al. 2021), while fishing guide training programmes for local communities have been successfully implemented in other regions e.g., the mahseer (*Barbus tor*) fishery in Bhutan (Nature Conservation Division 2022).

While leakage is a concern, caution should be applied in considering the implementation of any policies or regulations to address it. Strict and onerous mandates around local sourcing and employment are unrealistic under current circumstances and will likely discourage private sector investment and inhibit growth (Meyer 2007; Sandbrook 2010a; Rios-Morales et al. 2011). In this case, a more balanced approach focused on providing incentives rather than strict mandates would help maximise economic benefits while maintaining operational viability.

Results from the community engagements highlight some of the complexities and challenges associated with developing FFT operations in dam-affected areas, notably the issues of natural strategic advantage, benefit sharing, resource access, conflict, communication, and education and awareness. While the MCC's community-beneficiation model has succeeded in generating substantial local economic benefits, the proximate community of Ha Makhangoa received greater benefits than the peripheral community of Ha Souane. Discussions with MCC management revealed that efforts to distribute benefits and integrate community members from Ha Souane into their operations where possible were ongoing (Keith Clover, Director, African Waters, pers. comm., September 2024), and this was confirmed by the Area *Morena* of Ha Souane (*ntate* Sekeleme, Area *Morena*, Ha Soauane, pers. comm. September 2024). However, the exclusivity of the operation (maximum of 12 guests per week) and its niche sight fishing and dry fly fishing sales proposition, limited the number of suitable areas where it could have been established. In this case, the village of Ha Makhangoa held greater natural strategic advantage in terms of its location and environment than Ha Souane and, consequently, the greatest benefits have accrued to the community of Ha Makhangoa. The spatial distribution of tourism benefits, including its unevenness, has been documented in other studies on rural and remote tourism development (e.g., Zhang et al. 2020). Although the MCC differs from traditional tourism enclaves in its attempts at community integration and higher local economic retention (50.8%), it still exhibits some characteristics of enclave tourism development, particularly in its spatial concentration of benefits and creation of socio-economic disparities between adjacent communities (Mbaiwa 2005; Monterrubio et al. 2018). This disparity manifested across multiple dimensions: direct employment opportunities, with Ha Makhangoa benefiting from operational management, labour positions and domestic work; community development projects including school repairs and infrastructure improvements; and involvement in decision-making processes. Future development of similar operations should explore innovative approaches to distribute benefits beyond immediately proximate areas, while maintaining the exclusive nature of the experience that underpins their economic viability.

While this study was able to demonstrate differences in benefits and opportunities between the two participating communities, it did not examine how these gains were distributed within each community. Evidence from other contexts shows that tourism does not benefit all households equally, and that social hierarchies strongly shape access to opportunities. For instance, community-based tourism in India has been shown to reproduce existing inequalities of gender, class, and caste, with some groups excluded from benefits or disproportionately bearing costs (Nimble 2023). These equity dimensions were not directly assessed here, but remain critical for understanding who wins and who loses from dam-induced tourism, and should be a focus of future research.

Although the MCC has made commendable efforts to integrate communities into their operations, resource access and conflict issues emerged that mirror trends seen in other FFT development contexts (Moksness et al. 2011; Bower et al. 2014; Voyer et al. 2017; Mosepele et al. 2022). These issues were exacerbated by the broader historical context of dam development in the area, where communities had already experienced resource access modifications and disenfranchisement. This "legacy" issue highlights the additional complexities in developing FFT in large dam projects and further emphasises the need to consider benefit sharing mechanisms for those experiencing access restrictions. The involvement of the LDF in aggressively enforcing restrictions, unsanctioned by the MCC, also points to significant communication gaps. While the MCC developed a management plan in consultation with communities and authorities, the emergence of these issues suggests the need for more comprehensive communication and consultation strategies. In addition, a minority of visiting anglers expressed the view that subsistence fishing should not be allowed or should be banned entirely. Although not representative, such perspectives likely reflect concerns that consumptive fishing could undermine the sustainability of the fishery, underscoring the need to recognise and manage divergent stakeholder values.

The need for improved communication is further highlighted by the misconception held by the Ha Souane respondents that the MCC is a mining operation which is unsustainably harvesting fish to extract diamonds. The idea that tourists would pay significant sums to catch and release fish was inconceivable. Similar disconnects between the values ascribed to fish by subsistence/artisanal fishers (i.e., fish for food) and recreational fishers (i.e., fish for leisure) have been documented elsewhere e.g., Alaska (Lyman 2002), and was highlighted by AW management as a common occurrence in establishing their other FFT operations in Africa (Keith Clover, Director, African Waters, pers. comm., September 2024). These misconceptions have given rise to concerns regarding unsustainable fish harvesting and have likely fuelled further mistrust and tensions. These misconceptions clearly need to be addressed through targeted education and awareness initiatives which will also contribute towards improving relations between communities and the MCC.

Although this study did not assess the socio-cultural influence of foreign visitation, evidence from other African contexts shows that tourism can reshape community values, traditions, and social structures, often with both positive and negative effects (Mbaiwa 2005; Chilembwe 2014). Similar dynamics have been observed globally, where increased exposure to foreign tourists may lead to cultural exchange but also to commodification and the erosion of authenticity (Smith 1992; Jamal and Getz 1995). In the context of recreational fisheries tourism, recent international studies suggest that visiting anglers may facilitate cultural exchange and mutual learning when interactions are managed with respect and sensitivity (Yfantidou et al. 2024). These potential impacts were outside the scope of this research but represent an important area for future work in dam-affected communities where fishing tourism is being promoted.

Limitations

This study was subject to several limitations. The angler questionnaire achieved a modest response rate and covered only one fishing season, limiting representativeness and introducing the risk of recall bias. Catch data relied on MCC guides for recording, while community perspectives were influenced by uneven participation between villages and real-time transcription that may have introduced errors. The economic contribution analysis was confined to direct expenditures and operational costs, and results reflect only a single year of operation. Despite these limitations, the triangulation of angler, economic, and community data provides confidence that the findings capture the main dynamics of FFT development in the Lesotho Highlands.

4.5 Conclusions and recommendations

This chapter demonstrates both the potential and challenges of developing FFT tourism operations in dam-affected areas in developing countries. While large dams often negatively impact local communities, this study shows how they can create new opportunities for tourism-based economic development. The success of the MCC operation, driven by sought-after sight fishing and dry fly fishing opportunities, has resulted in substantial local economic benefits with a notably high local retention rate of 50.8% which exceeds rates typically observed in similar operations across Africa.

In establishing and managing the MCC, AW has got several things right. Their structured approach to community engagement, including the establishment of a rotational employment scheme, community levies, and involvement in operational decision-making, has helped achieve substantial local economic benefits. The co-development of management plans with community leadership, while not perfect, provides a foundation for sustainable resource management.

However, the study also reveals constraints and complexities in developing FFT in dam-affected areas, and rural areas in the developing world more broadly. The natural strategic advantage held by certain locations creates inherent inequalities in benefit distribution, as demonstrated by the disparate experiences of Ha Makhangoa and Ha Souane communities. While the former has benefited from employment opportunities, community development projects, and levy payments, the latter has experienced feelings of exclusion and conflict over resource access. This highlights how the social outcomes of FFT may be context-dependent, and what works for one community may not necessarily translate to others.

While the emergence of capture fisheries on Katse Dam represents one pathway for utilising new aquatic resources, the development of recreational foreign fishing tourism (FFT) offers another avenue for dam-affected communities to derive socio-economic benefits. The case study of a foreign fishing tourism (FFT) operation at Katse Dam demonstrates how such operations can create meaningful economic opportunities in dam-affected areas, while highlighting implementation challenges. The MCC demonstrates how these ventures can succeed through structured community engagement approaches, including employment schemes, revenue sharing, and involvement in operational decisions. However, the case study also exposes inherent complexities in FFT development, particularly how location-based advantages can create uneven benefit distribution between communities as evidenced by the contrasting experiences of Ha Makhangoa and Ha Souane. These findings suggest that successful FFT development in dam-affected areas requires careful attention to several factors: pre-development market assessment; early stakeholder consultation to address historical grievances; balanced local participation policies that don't deter investment; structured capacity building to overcome skills deficits; and innovative benefit-sharing mechanisms that can extend opportunities beyond immediately proximate areas while maintaining the exclusive nature that underpins economic viability.

These findings have important implications for the development of foreign fishing tourism in other parts of the Lesotho Highlands Water Project and similar contexts globally. First, pre-development assessments need to extend beyond ecological considerations to include consultation with anglers and industry representatives regarding market opportunities and operational requirements. Second, historical context and legacy issues around displacement and disenfranchisement in dam-affected areas are likely to complicate FFT development, highlighting the importance of early and comprehensive stakeholder consultation to identify potential conflicts, develop appropriate management plans, and ensure equitable opportunities for affected communities. In addition, the interaction between recreational and subsistence fisheries will need to be carefully managed. Mechanisms such as spatial or temporal zoning, or resource partitioning between angling and subsistence users, may help reduce conflict. Third, while policies promoting local sourcing and employment are important, these need to be balanced to avoid deterring private sector investment and development. A gradual, incentive-based approach to increasing local participation may be more effective than strict mandates. Options such as cooperative benefit-sharing arrangements or community-managed funds may be more appropriate than individualised mechanisms. Fourth, language barriers, cultural differences and skills deficits are likely to constrain local participation in FFT operations across the developing world – these challenges need to be addressed through structured capacity building programmes including language training, hospitality skills development, and guide training initiatives that can help local community members transition from support roles to higher-paying positions. Fifth, comprehensive education and awareness programmes are needed to build understanding of recreational fishing practices, address misconceptions, and establish trust. Finally, innovative approaches to benefit-sharing should be explored to help distribute economic opportunities beyond immediately proximate areas while maintaining the exclusive nature of operations that underpin their economic viability.

CHAPTER 5 – MINNOWS AND MEGAPROJECTS: INTEGRATING ECOLOGICAL AND HUMAN DIMENSIONS INTO CONSERVATION STRATEGIES FOR AN ICONIC ENDANGERED FISH SPECIES

5.1. Introduction

In recent decades, rapid population growth, urbanisation, and industrial development have led to unprecedented demands for fresh water (Evaristo et al. 2023). Water scarcity affects around four billion people globally, with demand expected to increase by 20–30% by 2050 (UN 2023). Addressing this issue is a key objective of governments and development agencies worldwide, and largely involves implementing measures to reduce water demand or increase water supply (Katz 2016). One common approach is developing large dams and inter-basin water transfer schemes (IBWTs), which move water from surplus to deficit catchments (Gupta and van der Zaag 2008; Rollason et al. 2022).

An unintended consequence of inter-basin water transfers (IBWTs) is that they can facilitate the movement of aquatic organisms between previously isolated catchments, where they may become invasive (Gallardo and Aldridge 2018). Invasive fishes disrupt native ecosystems by altering behaviour, modifying prey morphology and food webs, and introducing pathogens (Cucherousset and Olden 2011), often leading to displacement of native species (Kadye and Booth 2013), shifts in community composition (Zhan et al. 2015), biotic and genetic homogenisation (Bellafronte et al. 2010; Schmidt et al. 2020), trophic cascades (Howard and Booth 2016), and reduced ecosystem resilience (Schmidt et al. 2020). The construction of large dams transforms rivers into reservoirs, creating novel lacustrine habitats with fluctuating water levels, stratification and overturns, sediment retention, hypolimnetic anoxia, and higher susceptibility to eutrophication and invasion (Schmutz and Moog 2018; Turgeon et al. 2019). Such environments typically favour generalist species while disadvantaging fluvial and benthic specialists (Liermann et al. 2012; Agostinho et al. 2016; Arantes et al. 2019). Documented impacts on fish biodiversity include biotic homogenisation, changes in species richness and diversity, and even extirpation (Gido et al. 2010; Clavero and Hermoso 2011; Petesse and Petrere 2012; Vitule et al. 2012; Havel et al. 2015; Lima et al. 2015; Sá-Oliveira et al. 2015; Loures and Pompeu 2019; Turgeon et al. 2019).

While the negative ecological impacts of large dams and IBWTs on freshwater biodiversity are relatively well-documented (see Chapter 1; Gallardo and Aldridge 2018), and there is increasing awareness of the need for urgent and drastic conservation action (Deinet et al. 2024), the social context in which these occur, and how this influences the practicality of conservation measures, is less well-studied. Large dams are estimated to have directly displaced at least 80 million people globally, while millions more have been indirectly displaced by losing access to the resources and assets that supported their livelihoods (Commission on Dams 2001). Displacement has, in many instances, led to increased unemployment, food and nutrition insecurity, lost livelihoods, social and cultural disruption, and severe psychosocial trauma (Scudder 2012). Given these hardships, displaced communities may have very different perspectives to decision-makers on the need for biodiversity conservation (Agrawal and Redford 2009), particularly those species from which they do not derive any direct benefit. A further consideration is the mistrust that displaced communities may feel towards authorities, which is likely to influence the degree to which they are willing to believe in and accept conservation proposals (Saif et al. 2022). This disconnect between ecological imperatives and social realities can lead to conservation strategies that are unfeasible, impractical or unsustainable in the long-term (Bennett 2016; Ochieng et al. 2021). Too often, conservation action planning has inadequately considered the human dimensions that ultimately underpin success or failure (Ban et al. 2013).

Globally, but particularly in the developing world, the number of large dams and IBWTs is expected to increase potentially ninefold over the next thirty years in response to ever-growing demands for water, power, and food (Shumilova et al. 2018). Given their social and ecological impacts, there is a pressing need to both (1) further our understanding of their effects on freshwater biodiversity; and (2) identify realistic and practical conservation strategies and management approaches aligned with the socio-economic realities of dam-affected people.

The Republic of South Africa (hereafter South Africa) is a water-scarce country (Du Plessis 2023). Rapid population growth and urbanisation in the 20th century, particularly in the country's economic heartland of Gauteng, led to a significant increase in the demand for fresh water and the realisation that water would have to be imported from outlying areas (Dippenaar 2015). In the 1950s, South Africa's then Natural Resources Development Council identified the opportunity to import water from the water-rich, montane Highlands of the neighbouring Kingdom of Lesotho (hereafter Lesotho) (Meissner 2015). After years of negotiations, a treaty was signed between the Governments of South Africa and Lesotho in 1986 to develop the

Lesotho Highlands Water Project (LHWP) (Government of the Kingdom of Lesotho and Government of the Republic of South Africa 1986). The principal aim of the LHWP was to transfer water from the Senqu River catchment in the Lesotho Highlands to the Vaal River catchment, the primary source of water for Johannesburg, while simultaneously generating electricity for Lesotho (Hitchcock 2015).

Phase IA, developed from 1991 to 1998, involved the construction of the 185 m high Katse Dam (36 km²) on the Malibamatso River, 82 km of water transfer tunnels, the Muela Tailpond Dam on the Liqoe River, and the 72-megawatt Muela Hydropower Station (LHDA 2023). Phase IB (1998–2004) involved the construction of the 145 m high Mohale Dam (22 km²) on the Senqunyane River, a 32 km water transfer tunnel to Katse Dam, the Matsoku Weir and a 5 km tunnel linking it to Katse Dam (LHDA 2023) (see Chapter 2). Phase I directly displaced approximately 400 households and caused the loss of agricultural land, natural resources, and cultural sites (Hitchcock 2015). The resettlement process was challenging for many families and had wide-ranging social and health impacts, leaving some communities vulnerable and insecure (Mwangi 2007). Although the LHDA has made efforts to address these challenges, ill-feeling towards authorities and implementing partners remains in some areas (Liphoto 2020; Lehema and Thebe 2024).

The LHWP is situated in the Maloti-Drakensberg, a transboundary mountain range characterised by diverse alpine and sub-alpine habitats supporting several unique flora and fauna (Everson and Morris 2006) including Lesotho's only endemic vertebrate, the Maloti minnow *Pseudobarbus quathlambae* or *thoboshana* in the vernacular (Figure 5.1). This small (< 130 mm total length), endangered (IUCN B2ab) redfin minnow species inhabits clear, low-order mountain streams, and is considerably different in its morphology and behaviour to other redfin minnows (*Pseudobarbus* spp.) found in South Africa's Cape Fold Ecoregion (Swartz 2005). As such, it is regarded as an important component of the biological heritage of Lesotho (Skelton 2000).

Like other redfin minnows, *P. quathlambae* is highly susceptible to predation and habitat degradation (Pike and Tedder 1973; Rondorf 1975, 1976; Gephard 1978; Cambray and Meyer 1988; Skelton 2000; Skelton et al. 2001; Swartz 2005). In 1987, the discovery of *P. quathlambae* in the Senqunyane River, later impounded by Mohale Dam, raised concerns that the project would flood critical habitat, degrade riverine environments during construction, and risk further impacts from possible trout stocking (Cambray and Meyer 1987; Skelton 1988).

Figure 5.1: The Maloti minnow *Pseudobarbus quathlambae* (Photo: Author).

In the 1990s, the Lesotho Highlands Development Authority (LHDA) commissioned studies on *P. quathlambae* in the proposed Mohale Dam catchment (Rall 1993, 1999; Steyn et al. 1996). These revealed that it was the only species present upstream of the 20 m Semonkoaneng Falls, which blocked *Labeobarbus aeneus* and *O. mykiss* from moving upstream, effectively creating a natural refuge. However, the placement of Mohale Dam above the falls and the planned Mohale–Katse inter-basin water transfer tunnel raised the risk of non-native fishes colonising this previously isolated catchment (Steyn et al. 1996; Rall 1999) (Figure 5.2).

The LHDA responded by initiating the "Maloti Minnow Conservation Project" in 2000 (Skelton et al. 2001). This multi-disciplinary study gathered baseline data on the distribution and abundance of *P. quathlambae*, surveyed other rivers for undiscovered populations, conducted genetic analyses, and identified potential conservation options. The project confirmed two genetically distinct lineages or evolutionarily significant units (ESUs): an "eastern ESU" in the Matsoku, Moremoholo, Sani, Mangaung, Senqu and Tsoelikane catchments, and a "Mohale ESU" in the Mohale Dam catchment (Swartz 2005). The species' total extent of occurrence (EOO) was 4.57 km², of which 77% was in the Mohale ESU and

20% in the Matsoku population. Phase IB of the LHWP was predicted to impact 97% of this range and reduce the EOO by 80% within a decade, primarily due to IBWT tunnels enabling the spread of non-native fishes from Katse Dam into previously isolated catchments. Given its abundance, distribution, unique genetics, and vulnerability, the Mohale ESU was prioritised for immediate conservation action (Skelton et al. 2001).

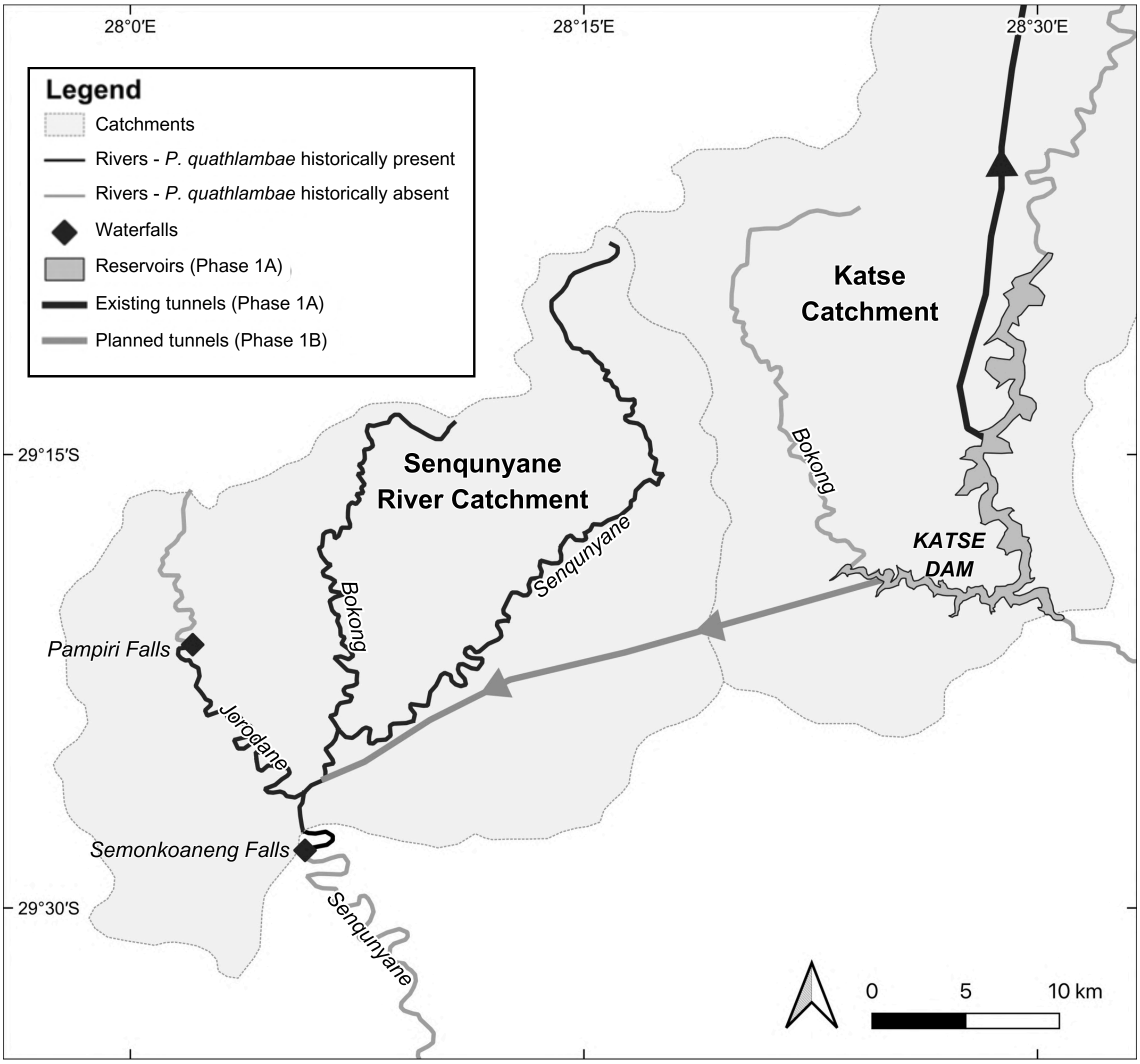

Figure 5.2: Map showing pre-Phase IB distribution of Pseudobarbus quathlambae above the Semonkoaneng Falls and the placement of the tunnel connecting Katse Dam to Mohale Dam above the falls.

Several conservation measures were proposed, including constructing artificial barriers to block *O. mykiss* from entering the Mohale catchment, translocating Mohale ESU individuals to rivers outside their native range, establishing a breeding facility, developing a monitoring network, proclaiming reserves, and strengthening regulations, awareness, and training initiatives (Skelton et al. 2001). In 2002, 1 700 Mohale ESU individuals from the Senqunyane, Bokong, and lower Jorodane Rivers were translocated to the upper Jorodane, Makhaleng, Maletsunyane, and Quthing Rivers (Rall et al. 2002). A barrier was never constructed.

A 2004 survey, two years after the Mohale–Katse IBWT tunnel opened, confirmed that *L. aeneus* and Orange River mudfish *Labeo capensis* had spread from Katse into Mohale Dam (Rall and Sephaka 2008). By 2006, *L. aeneus* had become well established in the dam, though not yet in its catchment rivers, where Mohale ESU populations of *P. quathlambae* persisted. Rall and Sephaka (op. cit.) warned, however, that river invasion was "imminent" and again recommended a barrier on the Senqunyane.

By 2013, electrofishing surveys of the Jorodane, Bokong, and Senqunyane Rivers recorded L. aeneus throughout, but only five *P. quathlambae*—three in the Bokong, two in the lower Jorodane, and none in the Senqunyane (Shelton et al. 2017). These results indicated that the Mohale ESU was on the verge of extinction in its natural range following invasion via the IBWT tunnel.

With the reported collapse of the *P. quathlambae* Mohale ESU populations, and uncertainty regarding the status of the translocated Mohale ESU and eastern ESU populations, it was important that new information be obtained on the status of the species to inform a revised conservation strategy. However, it was also recognised that such a conservation strategy would need to carefully consider the social and economic realities of people in the LHWP area. The awareness, perceptions, and attitudes of local Basotho people on the species and its conservation needs have never been documented, and there is no evidence that the species ever held historical or cultural significance to communities. Previous conservation recommendations have largely ignored these aspects.

This chapter aims to address these needs by exploring the following research questions:

1. What is the status and distribution of *P. quathlambae* populations in the Lesotho Highlands, and how has this been affected by the LHWP?
2. What is the level of awareness, knowledge, and perceived importance of *P. quathlambae* among dam-affected communities?
3. What are the attitudes of project-affected people towards different conservation measures?
4. What are the conservation implications for *P. quathlambae*?

To this end, this chapter provides updated information on the status of *P. quathlambae* in the Lesotho Highlands and, using a case study of communities in the LHWP, explores the human dimensions of its conservation. As the number of large dam projects in the developing world is expected to increase, the findings from this study may inform future strategies that aim to find a balance between biodiversity and socio-economic needs.

5.2. Methods

A combination of ecological and social methods was used to assess the status of *P. quathlambae* and community perspectives on its conservation. Historical records and electrofishing surveys provided data on distribution, abundance, and extent of occurrence, while a case study in the Mohale Dam catchment was designed to capture community knowledge, values, and support for different conservation scenarios. Together, these methods allowed for an integrated assessment linking ecological status with social dimensions of conservation planning.

5.2.1. Literature search

A literature search (Snyder 2019) of the Web of Science database was conducted to collate all available historical data on the distribution and abundance of P. *quathlambae* in Lesotho prior to the completion of Phase I of the LHWP in 2003 (hereafter termed pre-Phase I data), providing a baseline for comparison with post-Phase I surveys. Search terms included the previous and existing scientific names ("*Pseudobarbus quathlambae*", "*Oreodaimon quathlambae*"), and common names of the species ("Maloti minnow", "Maluti minnow", "thoboshana"), and related terms ("Lesotho", "Highlands", "Lesotho Highlands Water Project", "LHWP"). Additional project-specific documentation was obtained directly from the Lesotho Highlands Development Authority (LHDA), including environmental impact assessments (EIAs), risk assessments, pre-impoundment biodiversity assessments, and conservation plans. The coordinates of sampling sites from previous surveys, and information on any other fish species recorded during these surveys, were also collected. The pre-Phase I data were then sorted by population into four groups: (1) the native Mohale ESU populations ("*P. quathlambae* (Mohale native)"); (2) the translocated Mohale ESU populations ("*P. quathlambae* (Mohale translocated)"); (3) the eastern ESU populations ("*P. quathlambae* (Eastern native)"); and (4) the translocated eastern ESU population ("*P. quathlambae* (Eastern translocated)"). The types of data collected, and their sources, are shown in Table 5.1.

Table 5.1: Types and sources of data used to assess the distribution and abundance of *P. quathlambae* populations before the completion of Phase I of the Lesotho Highlands Water Project.

Population/s	Data	Year	Source
P. quathlambae (Mohale native)	Sampling site coordinates	1995; 1999	Steyn et al. (1996); Rall (1999)
	Presence/absence, density, population size, extent of occurrence	1995; 1999	Rall (1999); Skelton et al. (2001)
P. quathlambae (Mohale translocated)	Translocation site coordinates	2002	Rall (2002)
P. quathlambae (Eastern native) and *P. quathlambae* (Eastern translocated)	Sampling site coordinates, presence/absence, density, population size, extent of occurrence	2000	Skelton et al. (2001)

5.2.2. Electrofishing survey

Post-Phase I data on the distribution, abundance, and extent of occurrence of *P. quathlambae* were collected from 2017 to 2022 during electrofishing surveys at 88 sites in 14 rivers (Figure 5.3; Appendix C1). Approval for the use of these data was provided by the RUAREC Chair and Executive Committee members (RUAREC – CW02/2024). The sampling sites corresponded with those from previous surveys (Table 5.1). Sampling sites for *P. quathlambae* (Mohale translocated) populations were the same locations where fish were translocated in 2002 (Rall et al. 2002) (Table 5.1). Additional sites were also sampled on the upper Jorodane, Makhaleng, Maletsunyane, Quthing for *P. quathlambae* (Mohale translocated) populations, and Senqu, Matsoku, and Moremoholo Rivers for *P. quathlambae* (Eastern native) populations as previous surveys of these rivers had only sampled one or two sites. The additional sampling sites were selected randomly from the lower known distribution limit to as far upstream as possible, where the gradient approached or exceeded 1:40 (regarded as the gradient limit for *P. quathlambae* (Skelton et al. 2001)), and on the basis that they were representative of at least two of the dominant biotopes observed in each river.

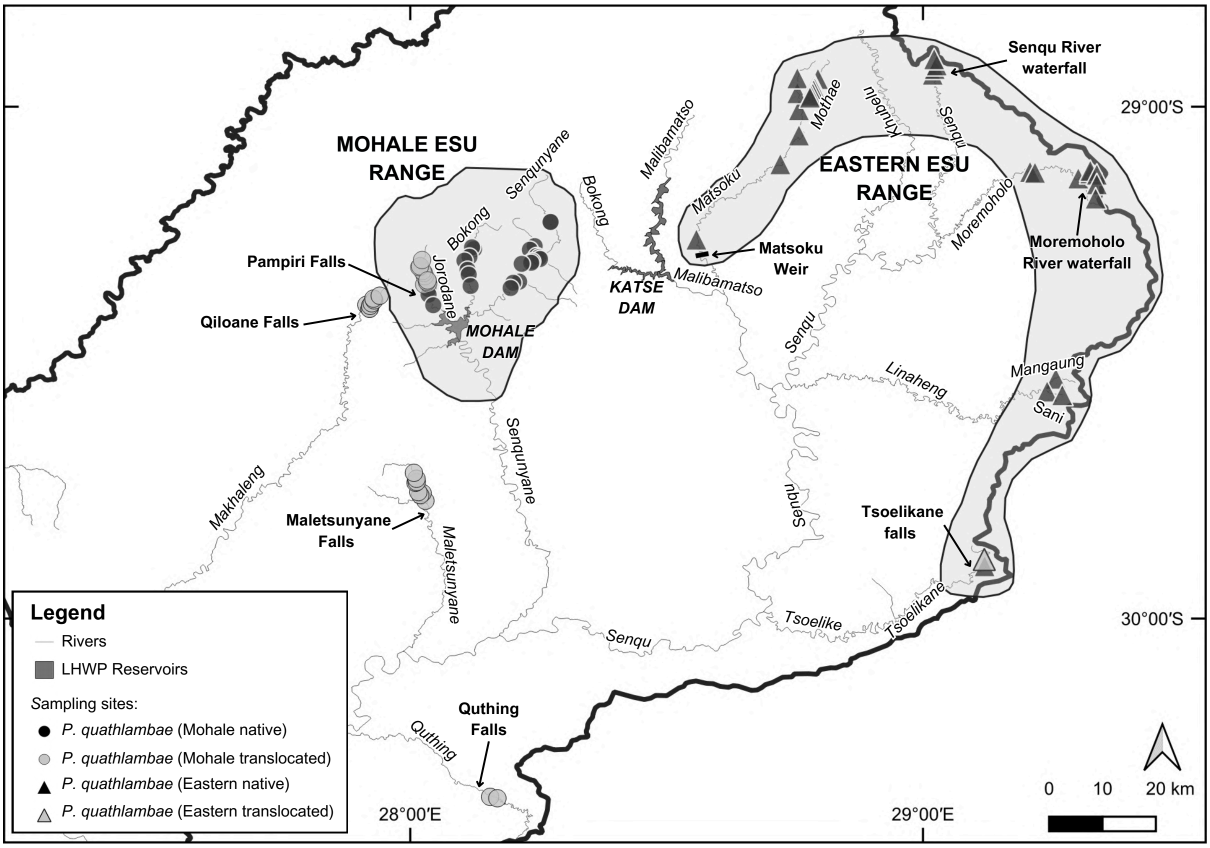

Figure 5.3: Sampling sites surveyed from 2017 to 2022.

Sampling methods were the same as those used in the pre-LHWP Phase I surveys undertaken by Rall (1999) and Skelton et al. (2001). All rivers were sampled with a SAMUS SE 1000 backpack electrofisher, a 12V battery, trailing cathode and an anode attached to a hand-held net. Electrofishing was conducted using the zigzag, single-pass method (Bateman et al. 2005). Although three-pass depletion electrofishing is widely recommended to derive site-specific capture efficiencies (Rosenberger and Dunham 2005), it was not employed here. The priority was to align with the methods of Rall (1999) and Skelton et al. (2001) to enable valid temporal comparisons, while also accommodating the logistical constraints of 88 remote sites and minimising repeated exposure of this endangered species to electrical current. Captured fish were kept alive in a bucket filled with river water, identified to species level, counted, measured for fork length (FL) (mm), and then released. At each sampling site, three random channel width measurements and total channel length were recorded. The location and elevation (m) at each sampling site were recorded using a hand-held GPS. Animal ethics approvals were obtained from the Chairperson of the Rhodes University Animal Research Ethics Committee (RUAREC) and the Executive Committee of RUAREC (RUAREC – CW02/2024).

Estimates of density, population size and extent of occurrence (post-Phase I estimates) were derived such that they were directly comparable with pre-Phase I estimates from 1996–2000. Following Skelton et al. (2001) and Rall (1999), a capture efficiency of 60% was assumed for single-pass electrofishing, rather than empirically calibrated in this study. This ensured methodological consistency with earlier surveys but introduces uncertainty, meaning that the density and population size values were indicative estimates rather than precise absolute abundances.

Density of *P. quathlambae* (fish/100 m^2) was calculated as per Skelton et al. (2001), where the probability of capture (PC) is assumed to be 60% (based on the average conductivity of rivers in the Lesotho Highlands) such that:

$$\text{Density} = \left(\frac{\frac{\sum C}{PC}}{A} \right) \cdot 100 \tag{5.1}$$

where C is the total number of *P. quathlambae* sampled, PC is the probability of capture (60%), and A is the area sampled which is the product of mean channel width (m) and total channel length (m).

Population size of *P. quathlambae* was estimated as:

$$\text{Population size} = \left(\frac{\frac{\sum C}{PC}}{A} \right) \cdot (R \cdot W) \tag{5.2}$$

where R is the distance (km) from the lower to the upper distribution limit, as described in the literature or inferred from the point where fish density was greatly reduced, and W is the mean width of the river over its length (km).

Extent of occurrence (EOO) (km^2) of *P. quathlambae* was then calculated as per Skelton et al. (2001) where:

$$\text{EOO} = R \cdot W \tag{5.3}$$

5.2.3. Case study: Community knowledge and perspectives on the conservation of *P. quathlambae* in the Mohale Dam catchment

To understand how community perspectives might influence the feasibility and design of conservation strategies for *P. quathlambae*, a case study was conducted in the Mohale Dam catchment. This area was selected because it encompasses both areas where the species has been extirpated (requiring reactive conservation measures) and areas where translocated populations remain viable (requiring proactive conservation measures). The case study aimed to assess local knowledge of the species, determine community values and attitudes towards its conservation, and evaluate support for different conservation approaches that might have social or economic implications for local residents.

<u>*Study area*</u>

Study areas were identified in consultation with the LHDA and selected based on the current status of *P. quathlambae* populations as determined by the electrofishing survey results, with the aim of comparing community perspectives in areas requiring different conservation approaches. Two distinct areas were designated within the Mohale Dam catchment: (1) a proactive conservation area (PCA) where *P. quathlambae* had been deliberately introduced and populations were viable, creating opportunities to implement measures to conserve these populations before threats materialised, and (2) a reactive conservation area (RCA) where *P. quathlambae* had historically occurred but was now extirpated or severely depleted, requiring management to focus on mitigating existing threats and responding to population declines (Figure 5.4).

Proactive Conservation Area (PCA): This area was defined as the upper Jorodane River catchment above the Pampiri Falls, where translocated *P. quathlambae* populations established in 2002 were found to be healthy during the electrofishing survey. The Pampiri Falls constitute a natural barrier that has prevented invasion by *L. aeneus* from downstream areas. Three villages were included in this area: Leropong, Ha Lira, and Ha Setene. These villages were selected because: (i) they are the only permanent settlements within the catchment area above the falls, (ii) residents engage in activities (livestock grazing, water collection) that bring them into contact with riverine environments where *P. quathlambae* occurs, and (iii) their proximity to the river means that future conservation measures in this catchment would likely affect their access to natural resources.

Reactive Conservation Area (RCA): This area encompassed the original native range of the Mohale ESU *P. quathlambae* in the Senqunyane, Bokong, and lower Jorodane Rivers, where populations had collapsed following invasion by *L. aeneus* through the Mohale-Katse IBWT tunnel. Six villages were included: Ha Nyakane (Jorodane River), Ha Korporale (Senqunyane River), Ha Mantsi (Bokong River), Ha Sankong (Bokong River), Ha Mohale (Likalaneng and Senqunyane Rivers), and Ha Rakopoloane (Jorodane River). Village selection was based on:

(i) proximity to rivers where *P. quathlambae* historically occurred, (ii) likelihood that residents would have knowledge of the species from the pre-LHWP period, and (iii) potential impacts from future conservation interventions such as fish eradication programmes or habitat restoration activities.

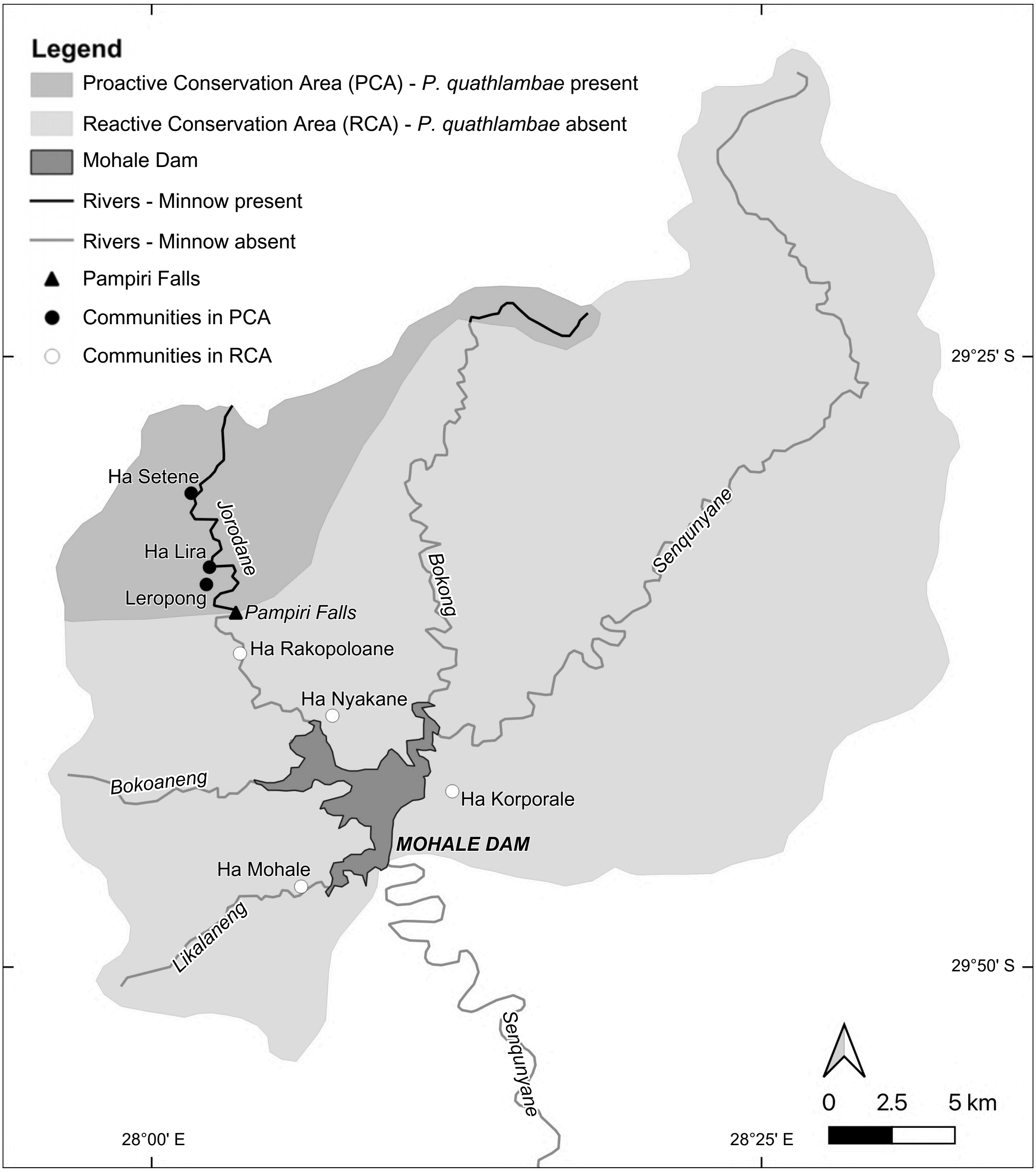

Figure 5.4: The case study was conducted in communities located in proactive conservation areas, where P. quathlambae still occurred, and reactive conservation areas, where P. quathlambae was threatened, in the Mohale Dam catchment area.

Identification of conservation measures and scenarios for community consultation

A conservation planning workshop was conducted to systematically identify potential conservation actions for *P. quathlambae* populations and assess their likely social implications for local communities. The workshop followed a structured two-day format based on the International Union for Conservation of Nature (IUCN) Strategic Planning for Species Conservation (2008) framework (IUCN/SSC 2008).

The workshop included one local and four international scientists with expertise in *P. quathlambae* research and conservation (including ichthyologists, conservation biologists, and aquatic ecologists), two LHDA personnel involved in environmental management and biodiversity conservation, two LHDA socio-economic specialists responsible for community development and compensation programmes in the LHWP area, and one LHDA community liaison officer familiar with the study villages.

The workshop was held in Maseru, Lesotho, from 25-26 November 2019. Participants first reviewed the electrofishing survey results and systematically identified threats to each population group (Mohale native, Mohale translocated, Eastern native, Eastern translocated). Threats were ranked using impact severity (High/Medium/Low) and likelihood of occurrence (High/Medium/Low), with composite threat rankings combining both criteria (see Appendix C2). Subsequently, participants brainstormed potential conservation interventions for each ranked threat and evaluated their feasibility considering technical capability, resource requirements, and stakeholder support.

Conservation actions identified during the workshop were then evaluated for potential social implications through a screening process facilitated by the LHDA socio-economic specialists. Actions were categorized as having potential negative community impacts if they met one or more of the following criteria: (1) could restrict community access to natural resources currently used for livelihoods (grazing areas, water sources, medicinal plants), (2) would require construction activities or physical interventions in areas where communities live or work, (3) would involve chemicals or other materials that could affect human health or livestock, or (4) would require government funding allocation that might otherwise support community development projects.

Following the screening process, two conservation actions with significant potential social implications were selected for presentation to communities: (1) “Eradication, barrier, restocking” - a reactive approach involving piscicide use to eliminate invasive fish, construction of barriers, and restocking with *P. quathlambae*, and (2) "Protected areas with compensation" - designation of formal protected areas with restrictions on resource use, coupled with compensation mechanisms. These actions were selected because they addressed the highest-priority threats identified in the workshop while representing different conservation approaches (reactive vs. proactive) and different types of potential community impacts (direct intervention vs. resource restrictions).

Semi-structured interviews and focus group discussions

Semi-structured interviews (Appendix C3) with residents of the villages within the case study area were conducted in August 2024. The semi-structured interviews were used to elicit individual perspectives on the species, its importance, and potential conservation actions. A total of 71 semi-structured interviews were conducted; 21 with residents of villages in the PCA and 50 with residents of villages in the RCA. The disparity in sample size between the PCA and RCA was a result of the limited geographic extent of and small number of communities in the PCA. Participants were recruited with the assistance of local chiefs, with the aim of covering as many villages as possible to capture broad perspectives. The respondents provided with an overview of the aims and objectives of the study, and asked for their informed consent to participate. Interviews proceeded once informed consent had been received. All interviews were conducted in Sesotho and performed by two researchers.

Demographic (e.g., age, gender, household size) and socio-economic information (e.g., livelihood, employment status) was obtained at the beginning of each interview. The respondent was then shown photographs of *P. quathlambae* and asked a series of questions to ascertain:

- whether they knew the fish;
- what they called the fish;
- whether they had observed the fish and, if so, whether numbers had increased, declined, or remained the same;
- whether they thought the fish was important or had value and, if so, why they thought this; and
- whether they thought that the fish should be protected or "looked after" and, if so, why they thought this.

The interviewer then presented the two conservation scenarios identified through the workshop process: "Eradication, barrier, restocking" (presented only to RCA respondents where *P.*

quathlambae had been extirpated) and “Protected areas with compensation” (presented to both PCA and RCA respondents) (Table 5.4). The “eradication, barrier, restocking” measures were grouped as a single scenario because, in practice, these interventions would need to be implemented together to be effective, rather than as standalone options. The PCA respondents were presented with only one scenario (“protected areas with compensation”) because eradication and restocking were not relevant in areas where viable populations were still present and protected by natural barriers.

For each conservation action, the potential implications identified during the workshop screening process were explained to participants in Sesotho using locally relevant examples. For instance, “protected areas” were described in terms of specific restrictions on grazing livestock or collecting medicinal plants, while “eradication programs” were explained as involving chemicals that could temporarily affect water and fish in local rivers. Respondents were given several response options: they could select one of the presented conservation actions, indicate they did not support any conservation action, state they were unsure about conservation measures, or suggest alternative conservation approaches not covered by the presented options. For each response, participants were asked to provide reasoning for their choices.

In addition to the semi-structured interviews, three focus group discussions (FGDs) (Appendix C4) were conducted in the PCA and seven in the RCA. The FGDs were conducted to capture collective community perspectives, highlight shared concerns, and generate dialogue around conservation scenarios. The number of participants in the FGDs ranged from seven to 50.

The FGDs focused on:

- Perspectives on the impact of the LHWP on the community;
- Awareness of the existence of *P. quathlambae*; and
- General attitudes towards the conservation of the species and potential conservation measures.

Responses from the FGDs were transcribed verbatim *in situ* in Sesotho by a Mosotho researcher and translated into English for further analyses. All interactions with human participants were approved by Rhodes University Human Research Ethics Committee (NHREC Registration number: RC-241114-045).

The use of either semi-structured interviews or FGDs was partly dictated by circumstances encountered in the field, where group meetings were sometimes more practical or the only option available. It is acknowledged that not all participants contributed equally in the larger FGDs, but themes were generated through collective discussion and further substantiated with smaller FGDs and semi-structured interviews.

Data analyses

Descriptive statistics (Holcomb 2016) were used to summarise the responses to the structured questions posed during the semi-structured interviews. Responses on the importance and value of P. quathlambae (from both interviews and FGDs) were coded inductively (Miles et al. 2018; Young et al. 2018), to systematically identify and categorise all stated reasons for valuing the species (e.g., responses about “our special fish” and “part of my life” were grouped under “natural heritage”). The frequency of each value category was then calculated as a percentage of total responses for both PCA and RCA communities separately. The order in which categories are presented is descriptive only and does not indicate priority or weighting.

Chi-square tests of independence were conducted to examine associations between categorical variables when sample sizes were sufficiently large (expected cell frequencies ≥ 5 for a minimum of 80% of cells). Where sample sizes were small, Fisher’s Exact Tests were employed.

5.3. Results

5.3.1. Presence/absence of *P. quathlambae*

The presence/absence of *P. quathlambae* and non-native species prior to and post the completion of LHWP Phase IB is shown in Table 5.2. Site-specific presence/absence of Mohale *P. quathlambae* populations (native and translocated), and eastern *P. quathlambae* populations (native and translocated), are shown in Figure 5.5 and Figure 5.6, respectively.

In 1999–2000, *P. quathlambae* (Mohale native) was recorded at multiple sites in the Bokong, Jorodane, and Senqunyane Rivers, and no other species were observed (Figure 5.5a). During this survey, no *P. quathlambae* (Mohale native) were recorded in the Senqunyane River, while only one individual was recorded in each of the Bokong and Jorodane Rivers, both in the uppermost reaches of their known distribution. In addition, *L. aeneus* was widespread throughout the Senqunyane, Bokong, and Jorodane Rivers (Figure 5.5b).

Translocated Mohale *P. quathlambae* were recorded in the upper Jorodane River, Maletsunyane River, Makhaleng Rivers, and Quthing River (Figure 5.5b). No other fishes were recorded in these localities.

P. quathlambae (Eastern native) was recorded in the Matsoku, Moremoholo, Sani, Senqu, and Tsoelikane Rivers as it was in 1999–2000 (Figure 5.6). Translocated eastern *P. quathlambae* were also recorded above the Tsoelikane Falls in the Tsoelikane River. In contrast to the 1999–2000 survey, *P. quathlambae* (Eastern native) was not recorded in the Mangaung River or the lower reaches of the Matsoku River. While non-native *O. mykiss* was previously recorded in the Sani River (Figure 5.6), none were recorded during this survey. Both *O. mykiss* (n = 1) and *L. aeneus* (n = 1) were recorded for the first time in the lower reaches of the Matsoku River during this survey (Figure 5b).

Table 5.2: Presence/absence of *Pseudobarbus quathlambae*, and non-native *Labeobarbus aeneus* and *Oncorhynchus mykiss*, in rivers throughout its known distribution from surveys conducted in 1999–2000 (prior to the completion of Mohale Dam) (Rall 1999; Skelton et al. 2001) and during this study (following the completion of Mohale Dam under LHWP Phase IB). "*" indicates translocated individuals; "+" = present; "-" = absent; "^" represents reaches of rivers above waterfall barriers; the number (n) of fish sampled is shown in brackets where n < 5.

River	**Species (Populations)**	**1999/2000 (pre-LHWP Phase IB)**	**This study (post-LHWP Phase IB)**
Bokong	*P. quathlambae* (Mohale native)	+	+(1)
	L. aeneus	-	+
Jorodane	*P. quathlambae* (Mohale native)	+	+(1)
	L. aeneus	-	+
Senqunyane	*P. quathlambae* (Mohale native)	+	-
	L. aeneus	-	+
Jorodane^	*P. quathlambae* (Mohale translocated)		+
Makhaleng^	*P. quathlambae* (Mohale translocated)		+
Maletsunyane^	*P. quathlambae* (Mohale translocated)		+
Quthing^	*P. quathlambae* (Mohale translocated)		+
Mangaung	*P. quathlambae* (Eastern native)	+	-
	O. mykiss	+	-
Matsoku	*P. quathlambae* (Eastern native)	+	+
	O. mykiss	-	+(1)
	L. aeneus	-	+(1)
Moremoholo^	*P. quathlambae* (Eastern native)	+	+
Mothae	*P. quathlambae* (Eastern native)		+
Sani	*P. quathlambae* (Eastern native)	+	+
	O. mykiss	+	-
Senqu^	*P. quathlambae* (Eastern native)	+	+
Tsoelikane	*P. quathlambae* (Eastern native)	+(1)	+
	O. mykiss	+	+
Tsoelikane^	*P. quathlambae* (Eastern translocated)	+	+

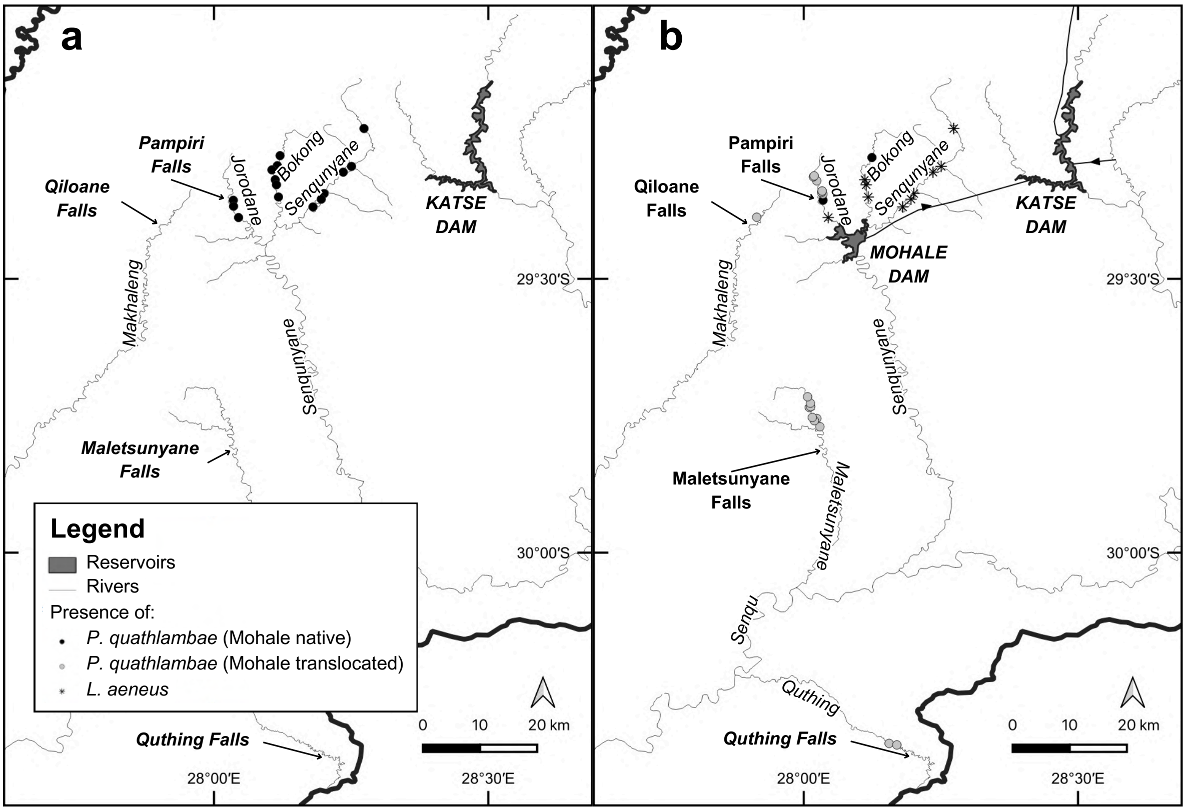

Figure 5.5: Presence/absence of Mohale populations of *Pseudobarbus quathlambae* (native and translocated), and non-native *Labeobarbus aeneus* in 1999/2000 (prior to the construction of Mohale Dam) (a) and during this study (b).

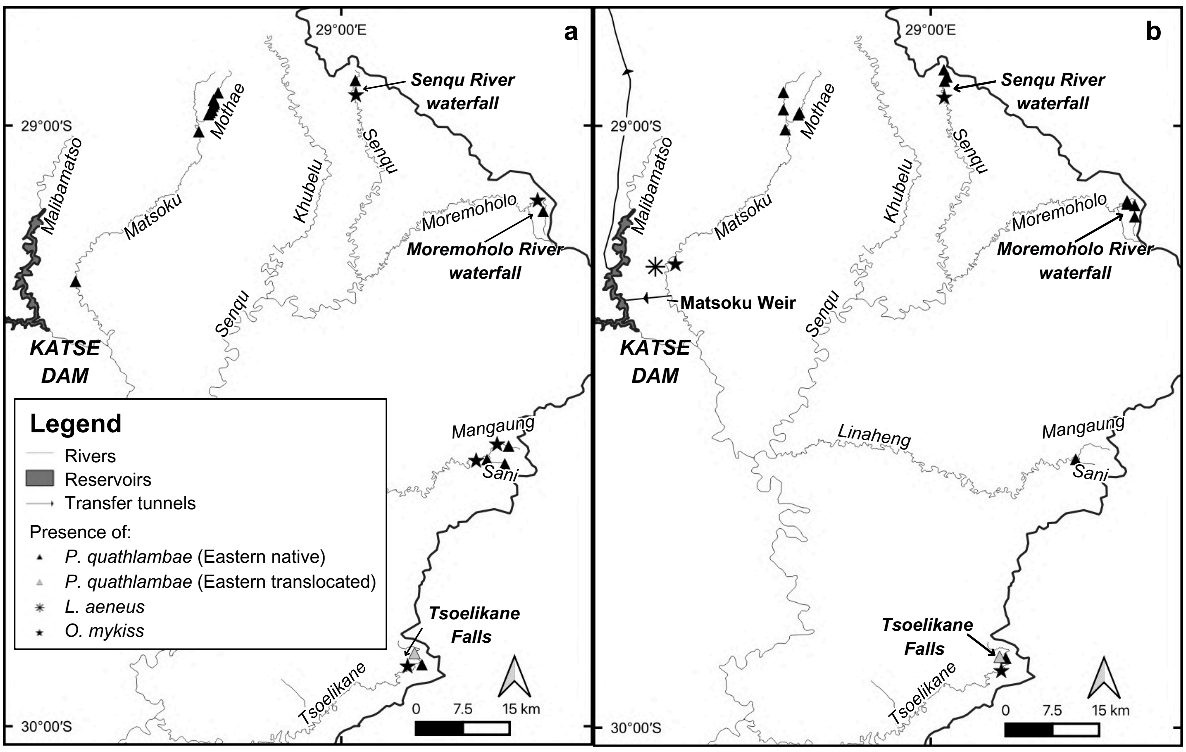

Figure 5.6: Presence/absence of eastern *Pseudobarbus quathlambae* populations (native and translocated), and non-native *Labeobarbus aeneus* and *Oncorhynchus mykiss*, in 1999/2000 (a) and during this study (b).

5.3.2. Estimated population size and extent of occurrence

Population size and EOO estimates of *P. quathlambae* in 1999/2000 and during this study are shown in Table 5.3. Since 1999/2000, the estimated EOO of *P. quathlambae* (Mohale native) has declined from 0.80 km^2 to 0.06 km^2 in the Bokong River; from 0.52 km^2 to 0.05 km^2 in the Jorodane River; and from 2.19 km^2 to 0 km^2 in the Senqunyane River. Similarly, estimated population size declined from 3 500 to 50 in the Bokong River, from 4 800 to 40 in the Jorodane River, and from n = 9 400 to n = 0 in the Senqunyane River (Table 5.3). Collectively, the estimated total population size of *P. quathlambae* (Mohale native) has declined 99.5% from approximately 17 700 to 90 individuals, while the total EOO has shrunk by 97% from 3.51 km^2 to 0.11 km^2.

The translocation of Mohale *P. quathlambae* populations took place in 2002. No historical data were available to compare temporal trends in density, abundance, and EOO of *P. quathlambae* (Mohale translocated). Current estimated population sizes of *P. quathlambae* (Mohale translocated) ranged from 640 individuals in the Quthing River to 25 100 individuals in the Maletsunyane River. The population in the Maletsunyane River was estimated to be the largest in Lesotho. Collectively, the *P. quathlambae* (Mohale translocated) populations comprised 63% (0.69 km^2) of the total EOO of the species with an estimated total population size of 29 440 individuals.

Since 1999/2000, estimated population sizes of *P. quathlambae* (Eastern native) increased in the Matsoku (156%), Moremoholo (116%), and Senqu (150%) Rivers and decreased (−83%) in the Sani River. Estimated population size was highest in the Moremoholo River (n = 5 400) and lowest in the Mothae River (n = 50). The estimated size of the translocated *P. quathlambae* (Eastern translocated) in the Tsoelikane River has also increased (71%) from 2 100 to 3 600 individuals. While estimated population size increased in the Matsoku River, the EOO of this population contracted 91% from 0.90 km^2 to 0.08 km^2. A small population of *P. quathlambae* (Eastern native) (estimated at 100 individuals) was also recorded in the lower Tsoekilane River below the Tsoelikane Falls. Collectively, the estimated total population size of *P. quathlambae* (Eastern native) increased from 5 550 to 11 750 individuals, while total EOO decreased from 1 km^2 to 0.25 km^2.Considering all populations, the total EOO of *P. quathlambae* has declined by 76% from 4.56 km^2 to 1.1 km^2, while estimated total population size has increased by 95% from approximately 23 250 to 44 880 individuals.

Table 5.3: Estimated population size (n) and extent of occurrence (EOO) of *Pseudobarbus quathlambae* in rivers throughout its known range from surveys conducted in 2000 (Rall 1999; Skelton et al. 2001) and during this study. Estimates are presented as point values consistent with historical surveys to enable temporal comparison "-" indicates where no estimate was provided.

		Estimated population size (*n*)			Extent of occurrence (km^2)		
Population/s	**River**	**1999/2000**	**This study**	**(Δ %)**	**1999/2000**	**This study**	**(Δ %)**
P. quathlambae (Mohale native)	Bokong	3 500	50	−99	0.80	0.06	−92.5
	Jorodane	4 800	40	−99	0.52	0.05	−90.4
	Senqunyane	9 400	0	−100	2.19	0	−100
	All	17 700	90	-99.5	3.51	0.11	−97
P. quathlambae (Mohale translocated)	Upper Jorodane		2 100			0.10	
	Makhaleng		1 600			0.04	
	Maletsunyane		25 100			0.40	
	Quthing		640			0.15	
	All		29 440			0.69	
P. quathlambae (Eastern native)	Mangaung	-	0		-	0	-
	Matsoku	1 800	4 600	+156	0.90	0.08	−91.11
	Moremoholo	2 500	5 400	+116	0.06	0.06	0
	Mothae*	-	100		-	0.02	-
	Sani	600	100	−83	0.02	0.04	+100
	Senqu	600	1 500	+150	0.02	0.04	+100
	Tsoelikane	50	100	+100	-	0.01	-
	All	5 550	11 750	+112	1	0.25	−75
P. quathlambae (Eastern translocated)	Tsoelikane^	2 100	3 600	+71	0.05	0.05	0
All	**All**	**~23 250**	**44 880**	**95**	**4.56**	**1.10**	**−76**

5.3.3. Community perspectives on the conservation of *P. quathlambae* in the Mohale Dam catchment

A total of 71 semi-structured interviews were conducted (21 in the PCA, 50 in the RCA) along with 10 focus group discussions (3 in the PCA, 7 in the RCA).

Community demographic profile

The survey respondents were predominantly male in both areas, with a higher proportion of males in the PCA (75.0%) compared to the RCA (67.3%). The average age of respondents in the PCA was 49.4 ± 11.2 years, while in the RCA it was slightly lower at 43.4 ± 12.8 years. Average household size was similar in both the PCA (4.9 ± 1.7 members) and RCA (4.9 ± 1.8 members).

Farming was the primary occupation for 65% of respondents in the PCA, followed by fishing (15%), artisanal work (10%), and wild plant harvesting (10%). In the RCA, farming remained the dominant occupation (36.4%), followed by wild plant harvesting (25.5%), fishing (16.4%), and a mix of other activities including construction, part-time work, and trading.

Impact of LHWP on community livelihoods

Most respondents in both the PCA (92%) and RCA (89%) stated that their lives had worsened since the development of the LHWP. A smaller proportion indicated that their lives had improved (PCA = 4%; RCA = 5%) or they were unsure of the impacts (PCA = 4%; RCA = 5%). The key socio-economic challenges identified by respondents were similar for both groups and included unemployment (PCA = 44.1%; RCA = 56.1%), lack of skills (PCA = 14.96%; RCA = 9.79%), and lack of access to electricity (PCA = 14.63%; RCA = 10.3%). Other notable challenges included the combined lack of transport and inaccessibility to road networks (PCA = 9.99%; RCA = 10.17%), limited access to cold storage (PCA = 5.8%; RCA = 4.84%), limited access to health facilities (PCA = 7.47%; RCA = 5.33%), and inadequate sanitation infrastructure (PCA = 3.05%; RCA = 3.48%) (Figure 5.7).

Knowledge of P. quathlambae

Approximately 57% of all respondents interviewed knew of *P. quathlambae*. Knowledge varied significantly by gender ($\chi^2 = 10.087$, df = 1, $p < 0.05$) and by age group ($\chi^2 = 15.907$, df = 4, $p < 0.05$). The majority (66.1%) of males, particularly those in the older age groups (51–60 years) (84.2%), knew of the species, compared to only 9.1% of females. Most younger individuals (18–30 years) (84.6%) were unaware of the species' existence.

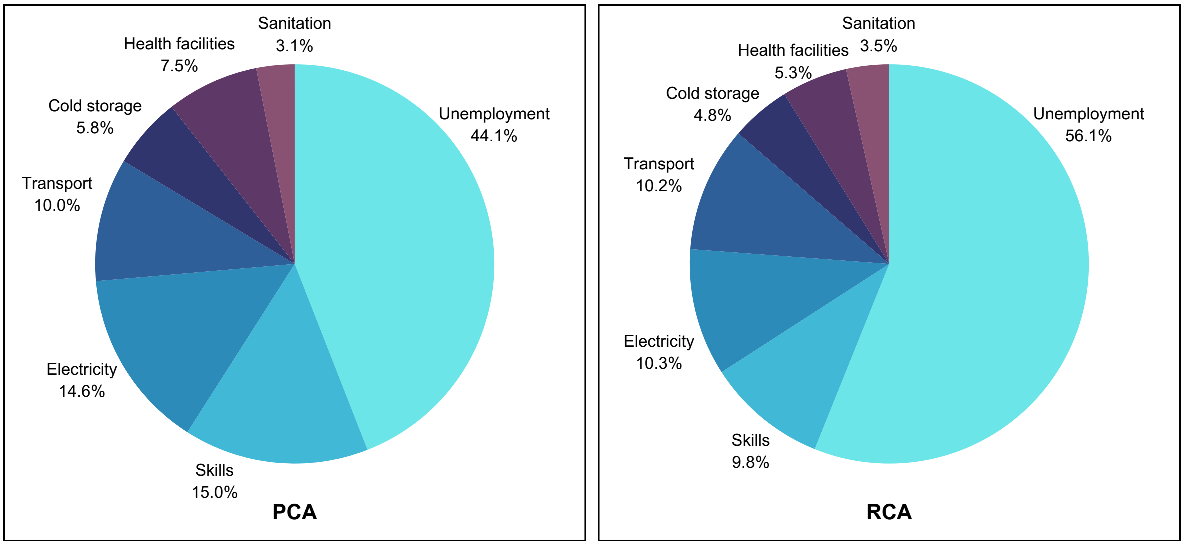

Figure 5.7: Socio-economic challenges faced by communities in both proactive and reactive areas of the Mohale Dam catchment.

Knowledge of *P. quathlambae* was slightly higher in the PCA (66.7%) than in the RCA (54.5%). In the RCA, there was a significant increase in knowledge with age ($p < 0.001$), ranging from 8.3% in the 18–30 age group to 94.3% in the 61+ age group. Knowledge in the PCA showed the opposite trend with 90% of participants in the 18–30 and 31–40 age groups aware of the species declining to 33.3% in the 61–70 age group (Figure 5.8). In both the PCA and RCA, knowledge of *P. quathlambae* was significantly higher among males than females ($p < 0.05$).

Among all the respondents who knew of *P. quathlambae*, approximately 62.5% used the name "*thoboshana*" while 37.5% had no name for the species. More respondents used the name *thoboshana* in the RCA (75%) compared to the PCA (37.5%). In the RCA, reference to *thoboshana* mostly increased with age, from 20% in the 31–40 age group to 75%, 86% and 83% in the 41–50, 51–60, and 61+ age groups, respectively. Conversely, in the PCA, except for the 18–30 age group, the use of the name *thoboshana* decreased with age from 100% of respondents in the 31–40 age group to 0% of respondents in the 61+ age group (Figure 5.9).

In the PCA, 54.5% of respondents were "Unsure" of the status of *P. quathlambae* while 45.5% said it was "Healthy". In contrast, 93.6% of respondents in the RCA stated that the species had "Disappeared", with 3.2% being "Unsure" of the status of species and 3.2% responding that it was "Healthy".

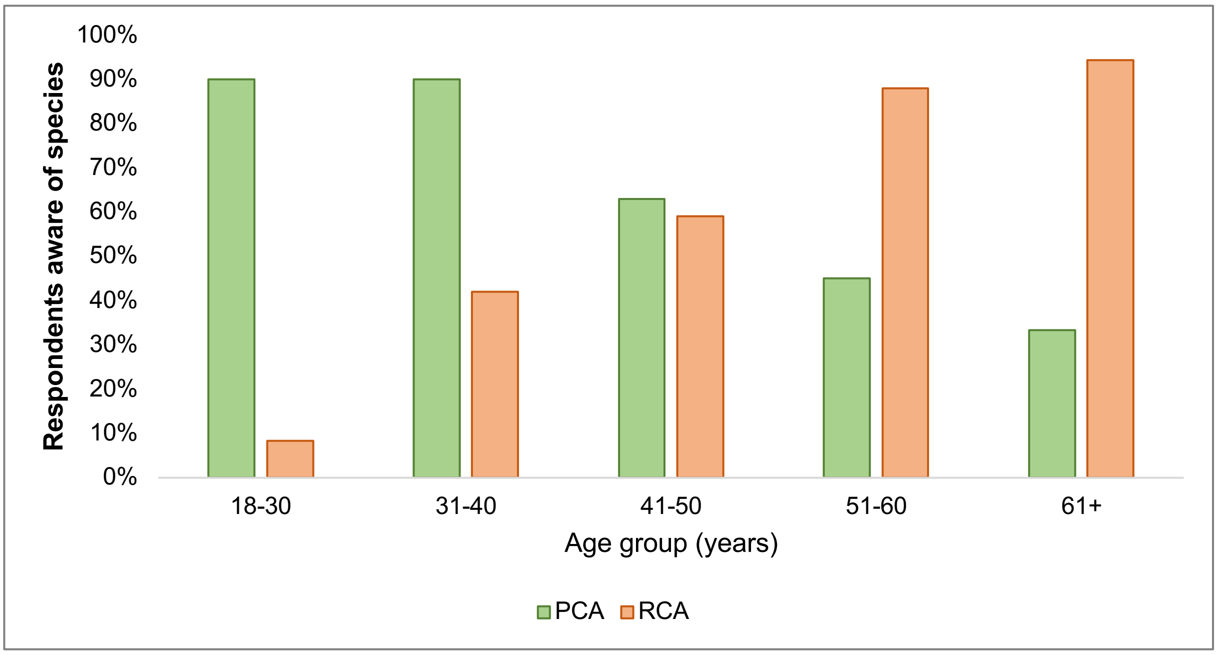

Figure 5.8: Respondents' awareness of *Pseudobarbus quathlambae* across age groups in proactive and reactive conservation areas.

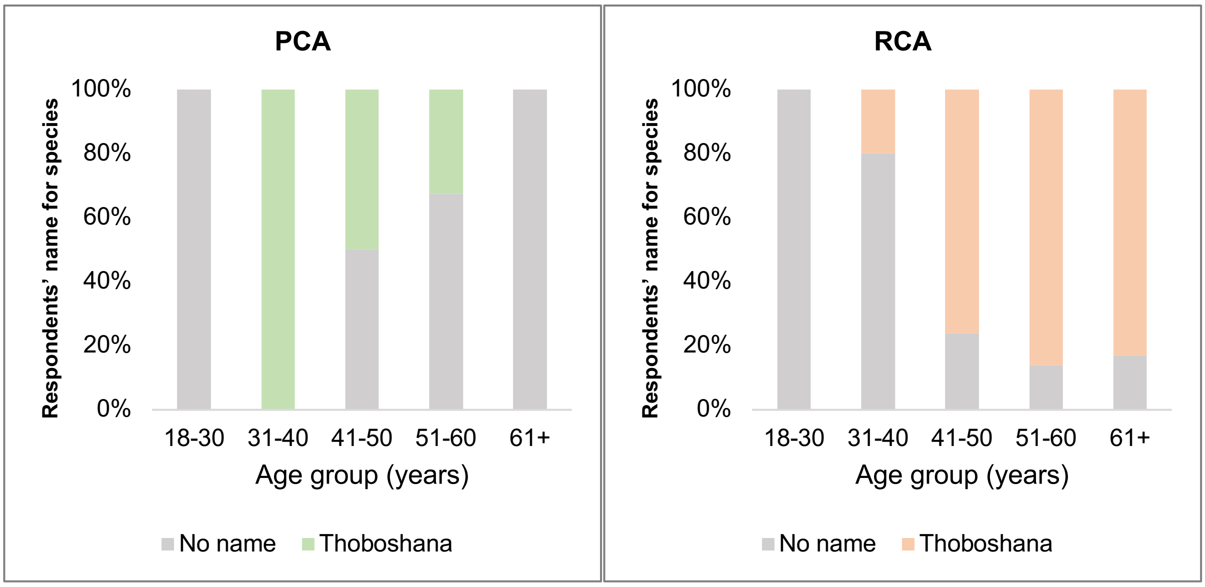

Figure 5.9: The proportion (%) of respondents in proactive (left) and reactive (right) conservation areas that had no name or used the name thoboshana for *Pseudobarbus quathlambae*.

Importance of P. quathlambae

The thematic analysis of the responses to the open-ended questions in the semi-structured interviews and the FGDs revealed eight distinct "value" categories: (1) natural heritage, (2) cultural identity, (3) mineral value (specifically that they believed the fish contained diamonds), (4) tourism value, (5) endemic species, (6) water quality indicator, (7) prey item, and (8) consumption value.

In the PCA, participants believed the species was important because "it contains diamonds" (50%), because of its tourism value (33.7%), or because of its natural heritage value (16.3%) (Figure 5.10). In the RCA, most respondents (50.1%) felt the species was important for its natural heritage value, followed by its cultural identity value (13.7%), and its endemicity or "uniqueness" value (9.7%). Smaller proportions of respondents also cited its tourism (7.1%) and "diamond" value (7.1%), its value as a prey item for *L. aeneus* (5.7%), and its value as an indicator of water health (5.1%). A small proportion of respondents (1.5%) also cited its importance as a food item for human consumption (Figure 5.10).

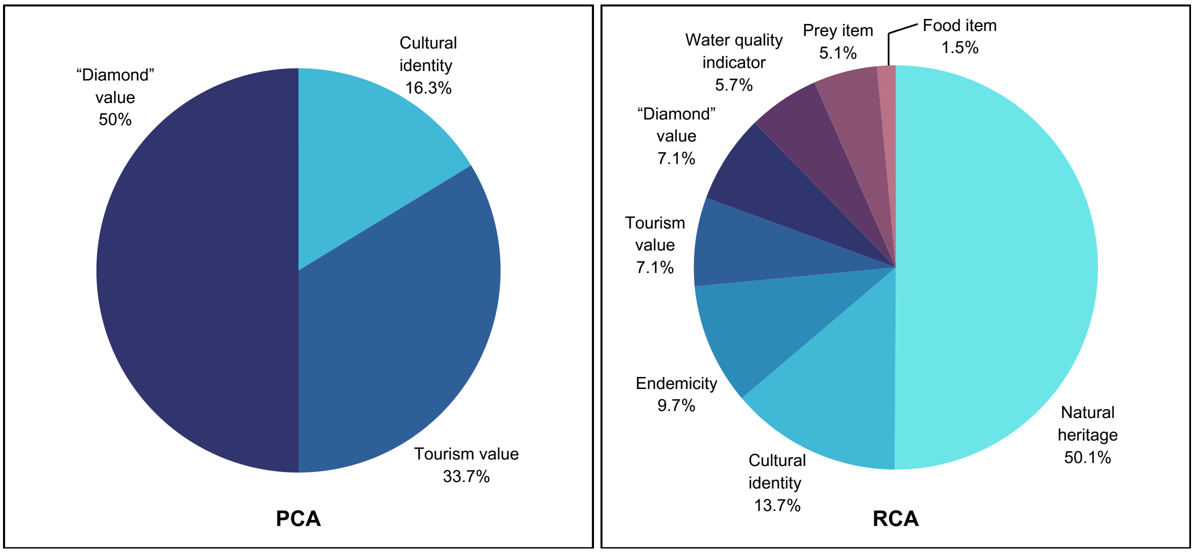

Figure 5.10: Perspectives of community members in proactive (left) and reactive (right) areas on the importance of *Pseudobarbus quathlambae*.

<u>Attitudes towards conservation measures</u>

Two conservation actions were identified based on the conservation workshop and screening process. These actions and their implications are shown in Table 5.4. In the PCA and RCA, 75% and 83.6% of respondents expressed support for some form of conservation, respectively (Figure 5.11). In the PCA, 55% of respondents in support of conservation actions favoured the "Protected areas with compensation" option, whereas 45%, while supporting conservation action, were unsure about what form this action should take (Figure 5.11). The most frequently supported conservation action in the RCA was "Eradication, barrier, restocking" (56%). This was followed by "Other" conservation measures suggested by the respondents (20%) which included "Stocking above existing barriers" and "Stocking as fodder fish" for yellowfish. Approximately 7% of respondents supported "Protected areas with compensation" while 16% were "Unsure" (Figure 5.11).

Table 5.4: Conservation actions presented to communities in the reactive conservation area (RCA) and proactive conservation area (PCA) of the Mohale Dam catchment. “Eradication, barrier, restocking” was only presented to communities in the RCA due to the absence of *Pseudobarbus quathlambae* in that area. Participants could select from these actions, indicate no support for conservation, express uncertainty, or suggest alternative approaches.

Area	Action	Action type	Description	Implications
RCA	Eradication, barrier, restocking	Reactive	Non-native fish eradication programme using piscicide, construction of barrier to prevent re-invasion by non-native fish species, and restocking of *P. quathlambae*	Poison in water; yellowfish in river killed; construction activities in catchment; allocation of government funds to conservation
RCA, PCA	Protected areas with compensation	Proactive	Demarcate and enforce protected areas in the catchment with compensation provided to offset resource loss	Restricted access to grazing and crop planting areas; in-kind or monetary compensation; allocation of government funds to conservation

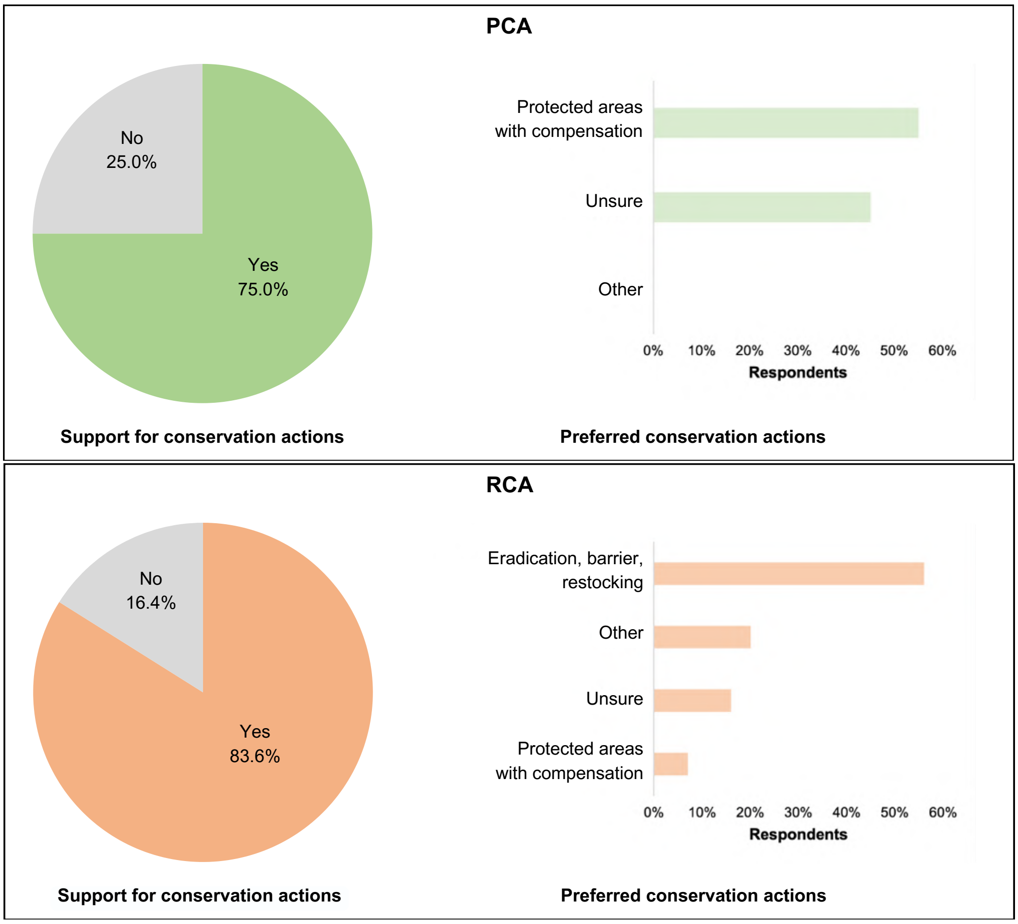

Figure 5.11: Support for conservation actions for *Pseudobarbus quathlambae*, and preferred conservation actions, amongst community members in proactive (top) and reactive (bottom) areas.

5.4. Discussion

Numerous studies have documented the negative impacts of large dam projects and IBWT tunnels on freshwater fish biodiversity (Gallardo and Aldridge 2018; Schmidt et al. 2020; Waine et al. 2024) but comparatively few have assessed, in combination, how the needs and perspectives of project-affected communities might influence the practicality of conservation strategies. This study investigated changes in the status and distribution of the endangered *P. quathlambae* following the development of the Lesotho Highlands Water Project (LHWP) and gauged the attitudes of dam-affected communities towards its conservation. The findings highlight how the project, and a combination of conservation inaction and proaction, has rapidly reshaped the distribution and abundance of the species. The study also reveals that communities in the Mohale Dam catchment area expressed supportive attitudes toward *P. quathlambae* conservation despite the socio-economic challenges they face.

The impact of the LHWP on P. quathlambae

The comparison of pre- and post-LHWP Phase IB electrofishing data showed that the EOO of *P. quathlambae* has shrunk by 76%. The biggest contractions have occurred in the rivers forming part of Phase IB providing clear evidence of the rapid and severe impacts of the project on an endemic fish species. The primary drivers of population decline were habitat inundation by dam construction and subsequent invasion by *L. aeneus* through inter-basin transfer tunnels, leading to predation on naive *P. quathlambae* populations.

The native Mohale *P. quathlambae* populations in the Mohale Dam catchment, once regarded as the "stronghold" of the species (Skelton et al. 2001), have collapsed. At least 30–50% of suitable *P. quathlambae* habitat was lost to inundation following the completion and filling of the dam in 2004 and as predicted, the IBWT tunnel connecting Katse to Mohale Dam allowed *L. aeneus* and *L. capensis* (but not *O. mykiss*) to invade the catchment. The newly lentic and productive habitat likely facilitated the colonisation and subsequent population explosion of *L. aeneus* in Mohale Dam (Hecht and McCafferty 2011). The *P. quathlambae* (Mohale native) populations, having evolved in the absence of predators, and now confined to smaller areas of the catchment, were highly vulnerable to predation by *L. aeneus* and have since largely disappeared (Shelton et al. 2017; this study). The decline of the *P. quathlambae* (Mohale native) populations means that loss of genetic diversity is highly likely. As population sizes dwindle, the risk of inbreeding depression increases, and populations may be unable to maintain their ability to adapt to stochastic environmental events (Swartz et al. 2023). The well-established and abundant population of *L. aeneus* in Mohale Dam (see Chapter 6) will continue to exert predation pressure on the remaining populations. In sum, in the absence of drastic conservation action, the *P. quathlambae* (Mohale native) populations appear to be facing effective extinction.

The distribution range of the *P. quathlambae* (Eastern native) population in the Matsoku River was previously the greatest of all populations in Lesotho, extending over 87 km (Skelton et al. 2001). Less than twenty years after the completion of Phase IB, this population has disappeared from the lower and middle reaches of the Matsoku River and is now confined to an 11 km stretch of river in the upper area of the catchment. Skelton et al. (2001) noted that the Matsoku River population co-occurred with and was threatened by *O. mykiss* which were introduced in the early 1980s (although no *O. mykiss* were recorded during their survey). It was hypothesised that the Katse–Matsoku Tunnel would allow "increased numbers…[of] aliens" from Katse Dam to invade the Matsoku River, further increasing pressure on this *P. quathlambae* (Eastern native) population. During this survey *L. aeneus* was officially recorded for the first time in the Matsoku River, confirming that the species has invaded through the Katse–Matsoku Tunnel. The disappearance of *P. quathlambae* in the lower and middle reaches was likely hastened by this invasion, as predicted by Skelton et al. (2001), and linked to habitat degradation in the lower reaches of the catchment caused by poor agricultural practices (McCafferty et al. 2019). While the results from the electrofishing survey conducted during this study showed that the *P. quathlambae* population in the upper Matsoku River is healthy, the magnitude of decline in its EOO (91%) is cause for concern as genetic diversity is likely to have declined significantly (Ernst Swartz, NRF-South African Institute of Aquatic Biodiversity (NRF-SAIAB), pers. comm. July 2022). The population currently occurs above a waterfall although it is unclear whether this constitutes a large enough barrier to prevent invasion under all flow scenarios. Given that the Matsoku River population represents around 21% of the total genetic diversity of the Eastern ESU (Swartz 2005), its extinction would constitute a major threat to the survival of *P. quathlambae*.

Phase IB has also indirectly influenced the distribution and abundance of *P. quathlambae* by spurring the conservation action that led to the translocations undertaken in 2002. All four translocation sites show evidence of population establishment and persistence over 20 years, providing a potential lifeline for the Mohale ESU that would otherwise be facing effective extinction. The translocated populations of the *P. quathlambae* Mohale ESU now comprise 63% (0.69 km^2) of the total EOO and around 65% of the estimated total population size of *P.*

quathlambae. The greatest threats to the *P. quathlambae* (Mohale translocated) populations are the possible introductions of non-native fishes, specifically *O. mykiss* and brown trout *S. trutta*, for sportfishing purposes, as well as habitat degradation from poor agricultural practices in the catchments. The Maletsunyane River, which now supports the largest population of *P. quathlambae* in Lesotho, is especially susceptible to non-native fish introductions given that there is an established population of *S. trutta* directly below a barrier which already supports foreign fishing tourism (FFT) activities (see Chapter 4). In addition, it is possible but unknown whether the founder effect and potential loss of genetic diversity have occurred in these translocated populations, which could impact their long-term viability and adaptive potential (Ernst Swartz, NRF-SAIAB, pers. comm. June 2022).

The establishment and persistence of *P. quathlambae* populations in all four rivers into which it was translocated within the Mohale Dam catchment may highlight the potential efficacy of translocation as a future conservation tool, but significant caution is warranted. Comprehensive pre-translocation surveys in 2001 covering the entirety of the Lesotho Highlands identified only two other potentially suitable rivers, the Ketane River and the Bokoaneng River (in the Mohale Dam catchment). While the status of these rivers is unknown, they were not selected for translocation at the time based on their comparatively poor habitat quality (Rall et al. 2002). This suggests that translocation may not be the straightforward "fallback" conservation solution it might appear to be (Berger-Tal et al. 2019). Furthermore, long-term population viability, genetic diversity maintenance, and ecological impacts on recipient river ecosystems remain unassessed, limiting conclusions about translocation success.

The results from the survey of the other Eastern ESU *P. quathlambae* populations showed that the native populations in the Senqu and Moremoholo Rivers, and the translocated population in the upper Tsoelikane River, have increased since 2000 (Skelton et al. 2001). The upper catchments of the Senqu and Moremoholo Rivers are extremely remote and uninhabited, while the upper Tsoelikane River is in the Sehlabathebe National Park. These rivers can be considered sanctuary streams for *P. quathlambae*, free from significant land-use impacts and protected by waterfall barriers that are impassable to non-native *O. mykiss* and *L. aeneus* (McCafferty et al. 2019). As such, there is no risk of upstream invasion from the planned Polihali Dam and Tsoelike Dam developments under Phases II and III of the LHWP.

The “small” native Eastern ESU population in the Sani River persists and contrary to the findings of Skelton et al. (2001) and Swartz et al. (2023), the native eastern population below the Tsoelikane Falls is not extinct. The persistence, relative stability, and even growth of the native Eastern ESU *P. quathlambae* populations provide a stark contrast to the declines observed in areas directly affected by Phase IB.

Perspectives of LHWP-affected communities on conservation of P. quathlambae

The community case study showed that awareness and knowledge of *P. quathlambae* was evident among 57% of respondents, and that these were influenced by societal and gender norms and the historical ecological context of the area. The higher awareness of the species among males compared to females across the case study area can likely be attributed to livelihood activities and gender norms. Males are more involved in livestock farming, which involves moving cattle or sheep, often over large distances, to different areas in the catchment to graze and drink. Females, on the other hand, are primarily engaged in horticultural and other activities near the household. Since males typically spend greater periods outdoors managing their livestock, it follows that they are more exposed to different terrestrial and aquatic environments than females and are more likely to regularly encounter different flora and fauna. This would naturally lead to greater levels of awareness of local species among males. Similar examples of this gendered relationship between biodiversity and awareness have been documented in other parts of Africa (Browne-Nuñez 2010; Sundström et al. 2020; Ochieng et al. 2021).

The age-related variations in awareness of the species and the use of the local name *thoboshana* between the two areas reflect temporal patterns in the presence of *P. quathlambae* linked to the impact of the LHWP. In the area defined here as the reactive conservation area (RCA), awareness of the species and the use of its local name were highest among older males, which is likely due to their familiarity and cultural association with the species before the construction of Mohale Dam, when it was still abundant. The lower levels of awareness and the more limited use of the local name for the species among younger males (who are still responsible for managing livestock) correspond with the disappearance of *P. quathlambae* post-LHWP Phase IB. This points towards a gradual erosion of both traditional ecological knowledge (TEK) and linguistic diversity associated with biodiversity loss, consistent with findings from similar studies (Gorenflo et al. 2012; Kai et al. 2014; Aswani et al. 2018; Agnihotri et al. 2021). While the correlation between species knowledge and population trends might suggest that fishing plays a greater role in local social systems than initially apparent, the results of this study indicate otherwise. Despite open-ended questioning about the fish's importance, only 1.5% of respondents cited consumption as a value, with the remaining responses focusing on cultural, environmental, and symbolic significance rather than economic or subsistence use

Conversely, in the area defined here as the proactive conservation area (PCA), younger males (18–40 years) were more likely to know of *P. quathlambae* than older males (40+ years). This can likely be attributed to the comparatively recent introduction of *P. quathlambae* into this area in 2002, coupled with the previously mentioned societal roles and responsibilities of younger males. Unsurprisingly, given the species' historical absence from the area, fewer respondents in the PCA used the name *thoboshana* than in the RCA, and most had no name for the species. This also suggests that education and awareness efforts before, during, and after the translocation exercise were limited, perhaps driven by the ecological urgency of the situation. Indeed, little mention of community engagement is made in the translocation plan (Rall 2005) although it is likely that there were concerns about making this information public.

There were also notable differences in the values ascribed to *P. quathlambae* by communities in the PCA and RCA. Only three different value categories were recorded in the PCA, and the two most important were utilitarian in nature, namely their "diamond value" and "tourism value". The "diamond value" attributed to *P. quathlambae* by communities in the PCA reflects a local belief that the fish contains diamonds in its gut cavity. This belief likely emerged due to the broader cultural and economic context of Lesotho, where formal and informal diamond mining is practised, and probably misconceptions on why the fish had received research attention in the past. While there was no evidence of targeted harvesting of *P. quathlambae* for this perceived diamond value, such beliefs could potentially pose a threat to the species. While this belief has no scientific basis, it represents an important example of how local cultural contexts can shape community perceptions and valuations of biodiversity. Future conservation planning must include education and awareness programmes that address this misconception while respecting local cultural perspectives. The "tourism value" mentioned reflects a perception of the species' potential to attract tourists rather than current tourism activity. There is currently no organised tourism centred around the species. However, community members viewed the fish's uniqueness and endemic status as a potential tourism draw, suggesting local recognition of the scientific and conservation importance of the species.

In contrast, communities in the RCA cited eight different value categories, of which the most important were intrinsic values, notably "natural heritage" as well as "cultural identity". The natural heritage value stemmed from community pride in having a unique endemic species in their area. The cultural identity value was particularly evident among male community members who, as discussed earlier, spent considerable time growing up around rivers during livestock management activities and expressed personal connections through statements like "*it was part of my life and my environment*".

The greater diversity of values ascribed to *P. quathlambae* in the RCA, where the species was historically abundant, as well as the dominance of intrinsic value categories, highlights how community perceptions on the biodiversity value are shaped by "collective meaning-making". This process occurs as historical narratives on the function and importance of a species are formed and transmitted from generation to generation (Roszczynska-Kurasinska et al. 2021). In the RCA, these long-term interactions and evolving historical narratives have likely contributed to the idea that *P. quathlambae* has intrinsic value (Louder and Wyborn 2020). The predominance of utilitarian values in the PCA suggests that communities in this area, who had no historical association with the species, could only speculate that its introduction was to generate tangible, economic benefits. The latter further highlights that education and awareness efforts on the ecological importance and biodiversity value of the species were, and remain, inadequate.

Attitudes towards conservation actions in the PCA and RCA were closely linked to knowledge, awareness, and the perceived value of *P. quathlambae*. The most supported conservation action in the PCA (where the species does not hold traditional significance) was "Protected areas with compensation" (55%) which corresponds with the largely utilitarian values that communities in the PCA ascribed to the species and highlights their concerns about the economic impact that conservation could have on their livelihoods. These economic concerns were also reflected in the proportion of respondents who did not support any conservation action (20%). In the RCA, most of the respondents opted for "Eradication, barrier, restocking" as the most suitable conservation action (67%) while few (11%) suggested that they should be compensated for conservation actions. This would appear to reflect the largely non-utilitarian, intrinsic values ascribed by communities in the RCA to *P. quathlambae* and their awareness and concerns about the status of the species, which was widely reported to have disappeared (93.6%).

Conservation implications for P. quathlambae

The EOO of *P. quathlambae* in Lesotho has shrunk from 4.56 km^2 to 1.1 km^2 in the space of 20 years. The decline in distribution can largely be attributed to the invasion of rivers by non-native fishes through the IBWT tunnels of the LHWP and subsequent predation. Targeted conservation actions are required but these will differ across areas based on both the status and threats faced by the population, the need for reactive or proactive conservation measures, and the perspectives of communities revealed during this study.

In the absence of resolute conservation efforts, the native Mohale ESU *P. quathlambae* populations are at serious risk of extinction. The well-established population of *L. aeneus* in Mohale Dam effectively limits rehabilitation options for *P. quathlambae* to a comprehensive fish eradication programme by constructing barriers and using rotenone in the catchment rivers, and the reintroduction of *P. quathlambae* using individuals from the translocated Mohale ESU populations. Similarly, the lack of a natural barrier in the Matsoku River means that the only conservation option for this population is to construct an artificial barrier above the Katse–Matsoku tunnel and conduct a comprehensive *L. aeneus* and *O. mykiss* eradication programme above the barrier.

The results of the case study suggest that there may be support for these reactive conservation measures given the existing knowledge base and cultural significance of the species. The intrinsic values of the species held by community members may present an opportunity to frame conservation action as a means of preserving community customs and traditions even when immediate economic benefits are not apparent. However, knowledge and awareness of *P. quathlambae* was not uniform across generations and genders. Implementing these measures will therefore be contingent on concerted education and awareness efforts targeted at women and youth (Vencatesan 2008). Maintaining conservation momentum will also require actively involving younger generations to ensure that TEK is not eroded over time. Nevertheless, before any action is taken, additional consultation with local communities and other interested and affected parties will be required.

The greatest threats to the translocated Mohale ESU *P. quathlambae* populations are the introduction of non-native fishes and habitat degradation from poor agricultural practices in the catchments. As such, proactive conservation measures are required to ensure that these populations, and activities in the catchment areas, are routinely monitored and managed to prevent the introduction of non-native fishes and to contain poor land-use.

The case study results suggest potential support for the proactive conservation measures. Where *P. quathlambae* was recently introduced, awareness and cultural connections are less established, and community perceptions tend to focus more on utilitarian values. This suggests that conservation efforts in these areas may need to emphasise potential economic or practical benefits to gain community support coupled with education and awareness-building efforts.

The need for catchment management to control agricultural practices suggests that such measures may face resistance unless coupled with economic incentives or compensation. While there may be less inherent cultural value attached to the species, there is potential to build new narratives around its conservation, possibly linking it to community development and sustainable resource management.

Limitations

The use of single-pass electrofishing with an assumed capture efficiency of 60% introduces uncertainty into the abundance and EOO estimates presented here. Capture probability is known to vary with habitat, operator experience, and fish behaviour (Rosenberger and Dunham 2005), and depletion sampling would have provided more robust calibration for this study. However, the priority was to maintain consistency with earlier surveys to enable temporal comparisons, while minimising handling stress for this endangered species. As such, the estimates are best interpreted as relative indices of population size and distribution.

It is acknowledged that the case study was geographically limited to the Mohale Dam catchment, which may not fully represent the perspectives of communities in other areas where *P. quathlambae* occurs. The smaller geographic scope of and disparity in sample sizes between the PCA (n = 21) and RCA (n = 50) may also affect the comparability of results. Reported support for protected areas must be interpreted with caution, as it may reflect positive views of the compensation package rather than agreement with conservation restrictions themselves. More broadly, findings may be affected by biases linked to small sample sizes, participant selection, and the hypothetical framing of conservation scenarios. Despite these limitations, the study provides useful insights into the impacts of large dam projects on endemic fish species and the role of community perspectives in conservation planning.

5.5. Conclusion

This study on the impacts of the Lesotho Highlands Water Project (LHWP) on *P. quathlambae* populations and associated community perspectives provides insights into the interplay between large-scale infrastructure development, biodiversity conservation, and social dynamics. The dramatic reduction in the EOO of *P. quathlambae* following the LHWP's implementation emphasises the rapid impacts that large dam projects and IBWT schemes can have on endemic species. Simultaneously, the establishment of translocated populations demonstrates that proactive conservation measures can mitigate some of these impacts.

The social dimensions of this case study reveal that community support for conservation efforts is likely to be influenced by cultural connections, TEK, and perceived economic implications. In areas where *P. quathlambae* has historical presence, conservation efforts can leverage cultural ties and intrinsic values associated with the species. Conversely, in areas where the species was recently introduced, conservation strategies may need to emphasise potential economic or utilitarian benefits to garner support.

The results provide the basis for the development of a revised conservation action plan which should consider a range of reactive and proactive measures including:

1. assessing the feasibility of constructing barriers, implementing eradication programmes for non-native fishes in the Mohale Dam catchment rivers and Matsoku River, and reintroducing *P. quathlambae* into the Mohale Dam catchment rivers from rivers supporting translocated populations;
2. assessing the feasibility of establishing areas of protected areas or areas of aquatic biodiversity significance and compensating communities for associated resource loss; and
3. monitoring and managing threats (non-native species, habitat degradation) to the translocated Mohale and eastern populations.

The effectiveness of these interventions will be dependent on creating and sustaining public and political awareness of the importance of *P. quathlambae* as part of Lesotho's national heritage. This, in turn, will provide the impetus for ongoing monitoring of *P. quathlambae* populations and the catchments in which they occur; the development of legislation and regulations that afford *P. quathlambae* and its catchment areas adequate protection; and financial support for the conservation of this iconic fish.

In conclusion, dam-affected communities often face significant disruptions to their traditional ways of life, including displacement, alterations to local ecosystems, and changes in economic structures. The common expectation is that these communities would prioritise socio-economic development or mitigation efforts over long-term environmental conservation. Of notable interest was the general support for conservation of *P. quathlambae* in both areas despite most respondents indicating that their lives had worsened since the development of the LHWP. The willingness of the communities to accept that implementing conservation actions would require some degree of government investment, which hypothetically would not be allocated to socio-economic development programmes, for example, highlights the value that these communities place in their natural environment. Given that successful conservation initiatives usually depend on local community support and engagement, this provides a foundation for future conservation efforts in the LHWP area. However, to fully understand the extent of this trade-off acceptance, more detailed studies are needed. Future research should present communities with quantified socio-economic trade-offs associated with specific conservation actions. Such studies would provide deeper insights into the threshold at which economic costs might outweigh perceived environmental benefits. In addition, the effective long-term conservation of *P. quathlambae* will depend on consistent investment and accountability from the Lesotho Highlands Development Authority (LHDA), supported by national government and partners. Dedicated funding streams linked to LHWP revenues are required to ensure continuity of recovery actions, including research, monitoring, habitat management, and awareness programmes. This responsibility is consistent with the CBD's provisions on resource mobilisation (Article 20), which call for sustained financing of biodiversity conservation. More broadly, the protection of *P. quathlambae* must be aligned with international conservation frameworks and institutional commitments. As Lesotho's only endemic vertebrate, the species warrants priority under the Convention on Biological Diversity (Articles 6 and 8) and recognition under the IUCN Red List process. Linking community-based measures with these frameworks provides a formal basis for sustaining conservation beyond project cycles and embeds local initiatives within global standards of biodiversity protection. These findings provide insights into the conservation challenges posed by large dams and inter-IBWT schemes, particularly their rapid and often irreversible impacts on endemic freshwater species. The following recommendations outline key principles for decision-makers involved in biodiversity conservation in dam-affected areas, particularly where endemic species are at risk. These are that decision-makers should:

1. Integrate conservation planning into dam feasibility studies and environmental and social impact assessments (ESIAs) from the outset. Conservation of endemic species should not be treated as an afterthought once dams and IBWT schemes are operational. Pre-development assessments should identify potential ecological impacts, assess the feasibility of mitigation measures, and explicitly consider conservation strategies such as fish barriers, protected areas, or translocations, before impoundment occurs. This requires moving beyond traditional biodiversity impact assessments to include long-term monitoring frameworks that track both species responses and ecological changes over time.

2. Recognise the role of inter-basin water transfers in facilitating species invasions and incorporate preventative measures. The invasion of *L. aeneus* into Mohale Dam catchment through IBWT tunnels illustrates how such infrastructure accelerates biodiversity loss. Engineering designs for future IBWT schemes should incorporate species-specific barriers to prevent invasive fish movement, and where existing tunnels already facilitate invasions, targeted eradication programmes may be considered to protect endemic populations.
3. Balance reactive and proactive conservation measures based on the ecological and social context. In areas where endemic species have suffered major declines, reactive conservation approaches, such as fish eradication and reintroductions, may be necessary. However, in areas where species remain stable, proactive conservation – such as establishing legally protected aquatic reserves, monitoring non-native species, and controlling habitat degradation – should take precedence. Decision-making should be informed by both ecological assessments and community values, ensuring that conservation interventions align with local perceptions of biodiversity importance.
4. Embed traditional ecological knowledge (TEK) and local ecological knowledge (LEK) in conservation strategies. The loss of *P. quathlambae* from parts of the LHWP area has contributed to the erosion of LEK, highlighting the link between biodiversity decline and cultural memory loss. Conservation planning should actively incorporate TEK and LEK, recognising how local communities understand species distributions, behaviours, and ecological changes. This can enhance monitoring efforts, improve engagement with affected communities, and support conservation narratives that resonate with cultural identities and historical relationships with biodiversity.
5. Ensure community engagement and transparent decision-making to build support for conservation initiatives. The case study findings demonstrate that local communities can be supportive of conservation efforts even when facing socio-economic challenges. However, support is contingent on early and sustained engagement, where communities are not only consulted but involved in shaping conservation strategies. Engagement efforts should address knowledge gaps, provide clear justifications for conservation actions, and establish mechanisms for communities to benefit from conservation initiatives, such as ecotourism or research collaborations.
6. Develop conservation strategies that account for economic and social trade-offs. While intrinsic and cultural values were important drivers of support for *P. quathlambae* conservation in some communities, other areas emphasised potential economic

benefits. Conservation planning should be flexible, incorporating both intrinsic and utilitarian value perspectives, and where necessary, exploring economic incentives for conservation participation.

7. Strengthen legal protections and enforcement mechanisms for endemic fish conservation. The rapid decline of *P. quathlambae* in the Mohale and Matsoku rivers highlights the need for stronger legal frameworks to prevent further biodiversity loss. National fisheries and conservation legislation should formally recognise the status of endemic species, integrate specific provisions for habitat protection, and establish enforceable regulations against non-native species introductions. However, enforcement should prioritise community-based monitoring approaches over punitive models to ensure long-term compliance and local stewardship.
8. Commit to sustained monitoring and adaptive management in order to respond to emerging threats. The impact of large dams on endemic fish species extends beyond initial impoundment, requiring long-term monitoring of ecological and social indicators. Conservation frameworks should incorporate adaptive management principles, allowing for periodic re-evaluation of conservation actions based on new data. Monitoring programmes should track species populations, habitat conditions, invasive species expansion, and community perceptions over time, ensuring that conservation interventions remain relevant and effective.

It is acknowledged that some of the recommendations outlined here are idealised and would require careful piloting, adaptation, and sustained support to be effective in practice. The participatory scenario approach applied in this study provides decision-makers with useful insights into community perspectives, but its results should be viewed as indicative rather than prescriptive, given the hypothetical framing of scenarios. When applied alongside ecological assessments and feasibility studies, such perspectives can nonetheless guide the design of conservation strategies that are both socially acceptable and ecologically sound.

CHAPTER 6 – THE INVASIVE FISH OF MOHALE DAM AND ALTERNATIVE LIVELIHOOD OPPORTUNITIES FOR DAM-AFFECTED COMMUNITIES IN THE LESOTHO HIGHLANDS

6.1. Introduction

Large dams have become ubiquitous worldwide, transforming more than half of the world's major river systems (Nilsson et al. 2005). While essential for water supply, energy, food production, and flood control, large dams may come with significant social and ecological costs, including displacement, lost livelihoods, ecosystem degradation, and species extinctions (Cernea 1997; Nilsson and Berggren 2000; Richter et al. 2010; Scudder 2012; see Chapter 1). In developing countries, particularly in Africa, Asia, and South America, where dam construction continues to increase (Shumilova et al. 2018), there is growing recognition of the need to ensure that dam planning adequately considers environmental sustainability and the needs of dam-affected communities (Burke et al. 2023). This includes identifying and promoting alternative livelihood opportunities which may contribute towards offsetting the negative socio-economic impacts of these projects.

Large dam projects can potentially offer opportunities for fisheries development that may enhance food security, diversify income sources, and stimulate economic development (Kolding and van Zwieten 2012). Since the 1950s, fisheries in dams (also called reservoir fisheries) have become increasingly important contributors to global inland capture fisheries production (Fernando and Holcik 1991; Moreau and DeSilva 1991; Welcomme 2001).

Developing reservoir fisheries may be an appealing prospect for decision-makers looking at ways to mitigate the negative social and economic impacts of large dams. However, as Jackson and Marmulla (2001) noted, "...the presence of fish in a reservoir does not automatically constitute a fishery." For a reservoir fishery to exist and persist, people must exploit the fish resources and do so in a sustainable manner, and this is closely tied to several interacting social and ecological factors (McCartney et al. 2018). From an ecological perspective, reservoir productivity, and the presence and abundance of candidate fisheries species, are important considerations. However, even if these conditions are met, the success of reservoir fisheries development also depends on human-related factors. These include fishing practices and skills, attitudes towards fish consumption and fishing as a livelihood, market opportunities (Jackson and Marmulla 2001; McCartney et al. 2018), and, importantly, the adaptive capacity of dam-affected communities (see Chapter 3). Moreover, the governance environment, which encompasses fisheries development and management strategies, policies and regulations, and the management of relationships between authorities and different stakeholders, may also influence the success or failure of a reservoir fishery.

The Lesotho Highlands Water Project (LHWP) is a large dam project and inter-basin water transfer (IBWT) scheme located in the Kingdom of Lesotho, a southern African country (see Chapter 2 for a detailed overview of the project). Phase I of the project, undertaken from 1991–2004, included the construction of two dams, Katse Dam and Mohale Dam, and a 32 km IBWT tunnel connecting the two.

The potential to develop reservoir fisheries in the dams was first formally recognised in the LHWP Treaty of 1986 (Government of Lesotho and Government of South Africa 1986). Subsequently, pre-impoundment (Bain 1990; Eccles 1990; Skelton 1996) and early post-impoundment studies (Tweddle and Davies 1997; Nthimo 2000) of the fisheries potential of Katse Dam were conducted (information on the status of the capture fishery and a foreign fishing tourism (FFT) operation is presented in Chapter 3 and Chapter 4, respectively). In contrast, no pre-impoundment studies of fisheries development opportunities in Mohale Dam were undertaken because the catchment area contained only the endemic Maloti minnow *Pseudobarbus quathlambae* (Rall 1993), a small cyprinid with biodiversity value but no fisheries potential. This changed in the mid-late 2000s following the invasion of smallmouth yellowfish *Labeobarbus aeneus* and Orange River mudfish *Labeo capensis* from Katse Dam via the IBWT tunnel, and the subsequent collapse of the *P. quathlambae* populations in the Mohale Dam catchment due to predation by *L. aeneus* (see Chapter 5).

While the negative impacts of invasive *L. aeneus* on *P. quathlambae* in the Mohale dam catchment are now well documented, only one quantitative fisheries survey of the fish populations in the dam has been undertaken since the invasion (Hecht and McCafferty 2011). The survey revealed that the population of *L. aeneus* had exploded, with total catch rates higher than those in Katse Dam and several other dams in South Africa (Hecht and McCafferty 2011; McCafferty 2012). It was concluded that there was potential for the development of a reservoir fishery, although it was recommended that follow-up surveys be undertaken over a longer period to determine sustainable harvest limits. However, no further surveys were conducted.

The LHDA has recently expressed interest in promoting the sustainable utilisation of fish resources in both Mohale Dam and Katse Dam. However, the fisheries in the two dams are at different stages of development. A sizeable hook-and-line and illegal gillnet fishery emerged organically at Katse Dam (Chapter 3), which requires reactive management interventions to ensure sustainability. In contrast, fishing in Mohale Dam is still developing. This set of circumstances provides a unique opportunity to assess the attitudes of dam-affected communities towards the proactive development and management of fisheries, following the invasion of potential candidate species into a catchment where none existed before.

To this end, this chapter aims to provide an assessment of the fisheries potential of Mohale Dam by examining both the status of fish populations and community attitudes towards fisheries development. To achieve this, the research addressed the following key questions:

1. What is the species composition, size structure, and relative abundance of fish populations in Mohale Dam; what are the patterns in catch rates; and what is the potential yield?
2. What knowledge have communities acquired about these fish populations, and how is the resource utilised?
3. What are the attitudes of communities towards fishing as a livelihood activity, and how have socio-cultural beliefs, historical experiences, and community-specific challenges shaped these attitudes?
4. What is the outlook for fisheries development and management in Mohale Dam?
5. What implications do the findings have for developing and managing new reservoir fisheries in other large dam projects?

6.2. Materials and methods

6.2.1. Study site

The Mohale Dam catchment covers an area of 938 km^2 and comprises the Senqunyane, Bokong, Jorodane, Likalaneng, and Bokoaneng River sub-catchments (Figure 6.1). The Senqunyane River originates near the village of Ha Ramabele and flows in a south-westerly direction for approximately 68 km before entering the Mohale Dam. The Bokong and Jorodane Rivers originate to the north of Mohale Dam at the mountains of Litsebe and Ha Mamalapi, respectively, flowing south for approximately 30 kms before entering the dam. The Bokoaneng and Likalaneng Rivers are short rivers (12 km and 14 km, respectively) that flow in an easterly direction and form the western and southwestern arms of the dam.

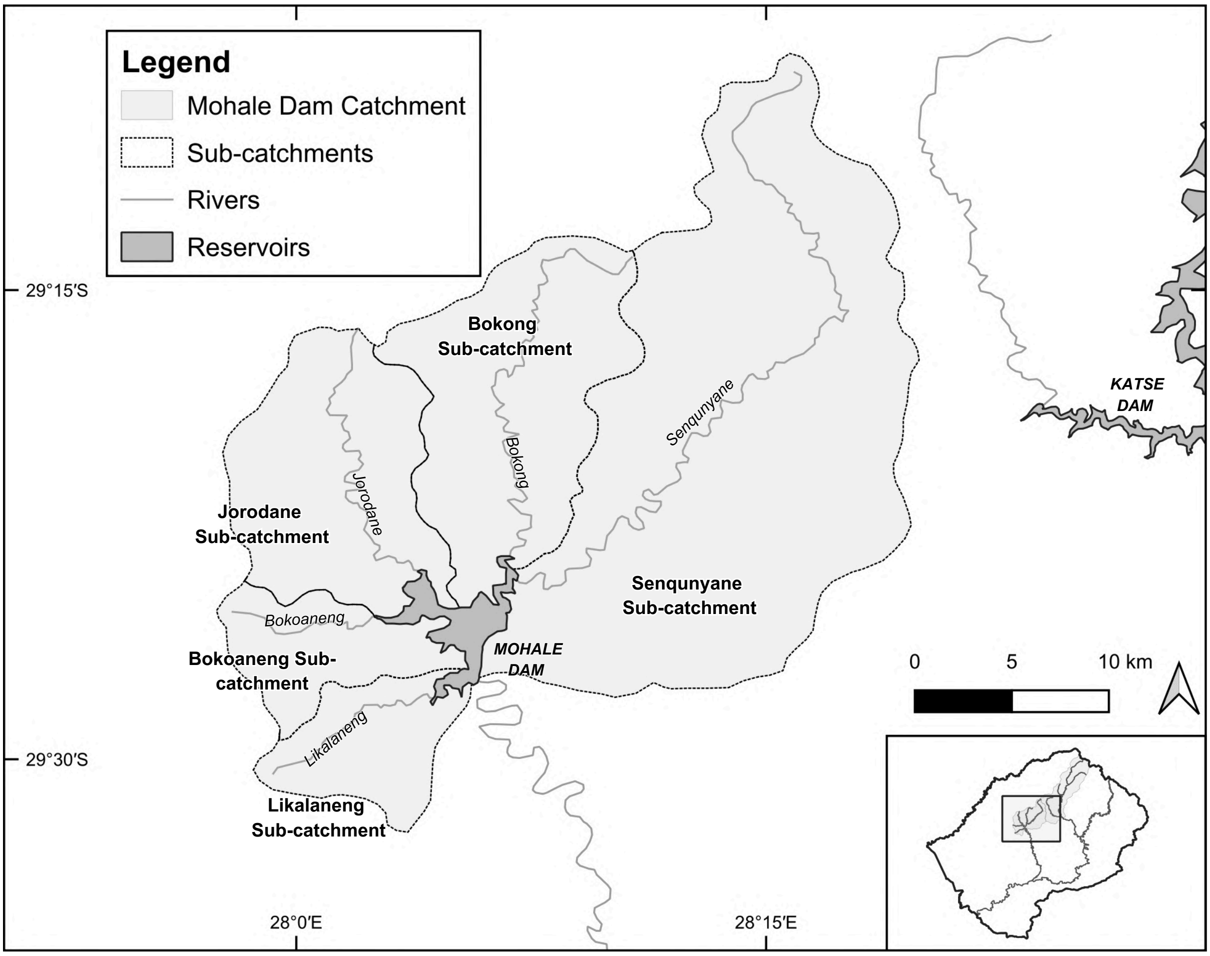

Figure 6.1: Map showing the Mohale Dam catchment with its five sub-catchments.

There are 33 villages in the Mohale Dam catchment area. The largest is Ha Mohale which is located close to the housing infrastructure developed for labourers and other personnel during dam construction. Traditional livelihoods in the area include crop and livestock farming (sheep, goats, and cattle); harvesting and selling rosehip and thatching grass; and traditional beer brewing (Skefu 2018).

Mohale Dam (2 075 masl) is an oligo-mesotrophic to mesotrophic, monomictic, concrete-faced, rockfill impoundment situated on the Senqunyane River in the Lesotho Highlands (Figure 6.2). At full capacity, it has a surface area of 22.1 km^2, water storage capacity of 938 million m^3, and mean and maximum depths of 42.6 m and 130 m, respectively (Hecht 1999) (Table 6.1). The major habitat types include steep rocky and grassy shorelines, limited rocky littoral zones, and some shallower inlet areas. The average annual surface water temperature is around 16.3°C. Water temperatures show clear seasonal patterns: summer (December–February) temperatures average 21°C (20–22°C; autumn (March–May) temperatures average 15°C, fluctuating from 11–18°C; winter (June–August) temperatures average 10°C, falling between 9–11°C; and spring (September–November) temperatures average 18°C, varying from 13–21°C.

Figure 6.2: Mohale Dam is situated on the upper Senqunyane River catchment and forms part of Phase IB of the Lesotho Highlands Water Project (Source: Stuart Slabbert 2012).

Table 6.1: Biophysical characteristics of Mohale Dam, part of Phase IB of the Lesotho Highlands Water Project (Source: LHDA Environment Division 2023).

Characteristic	**Mohale Dam**
Location	29°27'28" S; 28°05'47" E
Altitude (masl)	2075
Catchment area (km^2)	938
Surface area at FSL* (km^2)	22.1
Storage volume (million m^3)	938
Mean depth (m)	42.6
Maximum depth (m)	130
Mean temperature (°C)	16.3
Mean dissolved oxygen (DO) (mg/L)	7.61
pH	8.08
Conductivity (mS/m)	7.29
TDS	64.89
Mean Secchi depth (m)	4.77
Total dissolved solids (mg/L)	64.89
Chlorophyll-a (µg/L)	3.46
Total phosphorous (mg/L)	0.13

6.2.2. Fisheries assessment

The fisheries assessment approach was adapted from methods used in other southern African data-poor fisheries (e.g., Weyl 1998; Potts 2003; Weyl et al. 2007; Ellender 2008; Richardson et al. 2009; McCafferty 2012; Sara et al. 2017). This included fisheries-independent gillnet surveys to assess catch composition, size structure, relative abundance (CPUE), gillnet selectivity, and the application of empirical yield models with a view towards understanding the potential for the establishment of a gillnet fishery.

Experimental gillnet surveys

Experimental gillnet surveys were conducted in February and August from 2020–2023 (Table 6.2). The experimental gillnet fleet comprised 3 x 70 m long, 2.5 m deep, six-ply, brown, multifilament, surface set gillnets comprised of seven 10 m panels of 35 mm, 45 mm, 57 mm, 73 mm, 93 mm, 118 mm, and 150 mm manufacturer-quoted stretched mesh. Gillnets were set in the afternoon (15h00–18h00) parallel to the shore at depths ranging from 3 – 12 m (~ 4.8 m)and retrieved the following morning (07h00–09h00). Sampling was conducted across a range of habitat types including river mouths, steep rocky embankments, and shallow bays. Sampling sites are shown in Figure 6.3.

Gillnet catches were identified to species level, counted, measured for fork length (FL) to the nearest mm, and weighed (g). Water quality parameters (water temperature (°C), dissolved oxygen (mg. L^{-1}), electrical conductivity (EC) (µS.cm^{-1}) and pH were recorded at each site.

Table 6.2: Experimental gillnet sampling events, Mohale Dam, 2020–2023.

Year	Month	Net nights
2020	February	5
	August	3
2021	February	5
	August	5
2022	February	5
	August	5
2023	February	5
	August	5

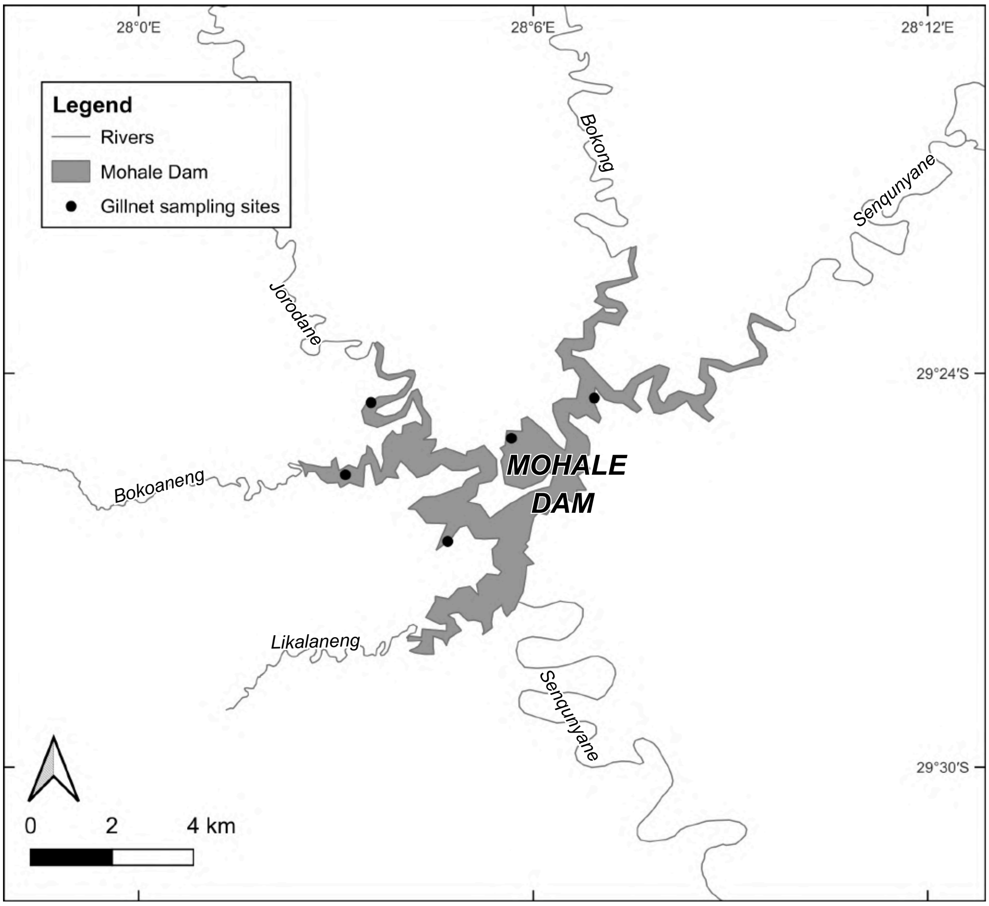

Figure 6.3: Gillnet sampling sites on Mohale Dam; gillnetting was conducted bi-annually from 2020–2023.

Catch composition

The Index of Relative Importance (IRI) (Pinkas et al. 1971) was used to reflect the most important species in gillnet catches by number, weight, and frequency of occurrence. IRI was calculated as:

$$IRI = (\%N + \%W) \cdot (\%FO) \tag{6.1}$$

where $\%N$ and $\%W$ represent the the percentage contribution of each species by number and weight to the total catch, respectively, and $\%FO$ is the percentage frequency of occurrence of each species in the gillnet samples.

Catch per unit effort

The gillnet data were aggregated over the 2017–2023 sampling period and pooled by season where August and February data were categorised as winter and summer periods, respectively. Mean catch per unit effort (CPUE) was calculated as:

$$CPUE = C_i/E_i \tag{6.2}$$

where C_i represents the catch (either by weight or number of fish) for fishing gear type i and E_i is the effort expended for that gear type (Pollock et al. 1994). CPUE was standardised as kg/net.night^{-1} and fish/net.night^{-1}.

To obtain more reliable estimates of CPUE, the data were standardised to account for the high proportion of zero observations in the experimental gillnet CPUE data (Lo et al. 1992; Ellender et al. 2010). A delta-lognormal model was used where the delta model captures the probability of a non-zero catch, and the lognormal component models the magnitude of CPUE for non-zero observations, such that:

$$CPUE_i = P_i \cdot \exp\left(\log\left(CPUE_{pos,i}\right) + \frac{\sigma^2}{2}\right) \tag{6.3}$$

where $CPUE_i$ is the estimated CPUE for observation i, P_i is the probability of capturing a fish during observation i, $\log\left(CPUE_{pos,i}\right)$ is the log-transformed CPUE for non-zero catches, and σ^2 is the variance of the log-transformed non-zero values.

Preliminary analyses of the CPUE data showed that they did not meet the criteria for normality and homogeneity of variances required for using parametric tests. As such, seasonal and mesh-specific differences in CPUE were assessed using the non-parametric Kruskal Wallis test (Kruskal and Wallis 1952).

Selectivity

Selectivity was assessed for major target species. The major target species were identified as those comprising more than 20% of the catch (Richardson et al. 2009; Sara et al. 2017). All individuals of the target species were grouped into 10 mm F_L sizes classes (L) for any given mesh size m_i. Selectivity was estimated using the SELECT (Share Each Length-Classes Catch Total) method (Millar and Holst 1997). SELECT is a maximum likelihood method that estimates selectivity parameters from a general log-linear model under the assumption that the data are Poisson distributed (Millar and Holst 1997; Millar and Fryer 1999).

Four selectivity curve forms were fitted to the catch data under the assumption of equal fishing intensity: normal fixed spread, normal proportional spread, gamma, and lognormal curve. Parameters for the curves were estimated by fitting the general log-linear model of the form:

$$\log\left(\hat{n}_{ij}\right) = \text{factor}(j) + \beta_1 \text{ x } f_1(m_i, j) + \beta_2 . f_2(m_i, j)$$

where $\hat{n}_{ij}$ is the expected catch of fish by length class j by mesh size i, and $f_1(m_i, j)$ and $f_2(m_i, j)$ are the selectivity functions of m_i and j. Factor (j) indicates that the length class is fitted as a factor in the model. The normal, gamma, and lognormal models observe geometric symmetry whereas the normal (fixed) model has a fixed spread and is therefore not geometrically symmetric. Model performance was assessed using the Akaike Information Criterion (AIC) (Akaike 1973) to compare different candidate models for fitting gillnet selectivity. The model with the lowest AIC value was selected.

Potential yield

For African reservoir fisheries, where prior biological and fisheries data are typically absent, management has largely relied on rapid assessment of potential yield using empirical approaches (Weyl 1998). One of the most widely applied methods is the morphoedaphic index (MEI), which incorporates both lake fertility and morphometry to predict potential fish yields (Ryder et al. 1974). There are a myriad of empirical yield models; in this case, first estimates of total potential fish yield were obtained using two MEI models that have been previously applied in temperate southern African reservoirs (Ellender 2008; Richardson et al. 2009). These included the Schlesinger and Regier (1982) global, temperature-adapted morphoedaphic index (MEI) model:

$$\mathrm{Yield}(\mathrm{kg}\cdot\mathrm{ha}^{-1}\cdot\mathrm{yr}^{-1}) = 10^{\left(0.044T+0.482\log_{10}\left(\frac{\mathrm{TDS}}{\mathrm{MD}}\right)+0.021\right)} \tag{6.4}$$

and the Marshall and Maes (1994) model:

$$\mathrm{Yield}(\mathrm{kg}\cdot\mathrm{ha}^{-1}\cdot\mathrm{yr}^{-1}) = 23.281\times\left(\frac{\mathrm{EC}}{\mathrm{MD}}\right)^{0.447} \tag{6.5}$$

where T is the mean annual water temperature in °C, *TDS* is the total dissolved solids (mg. L^{-1}), *EC* is electrical conductivity (µS.cm^{-1}) and *MD* is the mean depth (m) of the impoundment. Biophysical data for the model parameters were obtained from the LHDA.

6.2.3. Human dimensions

The extent to which human dimensions data could be collected was influenced to some extent by customary leadership norms and protocols in the study area, which were always respected. In some instances, *Marena* (male chiefs) and/or *Mafumahali* (female chiefs or male chiefs' wives) requested that engagements be held with numerous members of the community (up to 70 people) simultaneously, with the respective *Morena* or *Mofumahali* managing introductions and formalities. In other instances, the *Morena* or *Mofumahali* arranged for consultations with smaller groups of up to 10 people; in some instances these groups were dominated by fishers. Given these circumstances, a flexible mixed-methods approach was used which included a structured questionnaire administered to individual respondents (where possible) and focus group discussions (FGDs). Although such non-probabilistic sampling has inherent limitations regarding population-level inference and representativeness (Schreuder et al. 2001), this approach was deemed appropriate given the cultural context, the hard-to-reach nature of the study population, and the study's focus on understanding complex socio-cultural perspectives rather than generating population-level statistics (Howarth et al. 2024). All interactions with human participants were approved by Rhodes University Human Research Ethics Committee (NHREC Registration number: RC-241114-045).

Questionnaire survey

The questionnaire survey was conducted in August 2024. The questionnaire was developed using key informant interviews with LHDA officials who worked with the communities in the area. The questionnaire was pre-tested with the key informants and refined based on their feedback. Several iterations were produced and re-tested to address ambiguities and improve clarity prior to conducting the survey. The questionnaire was kept as short as possible to reduce survey response fatigue and non-response bias (Steeh 1981; De Heer 1999; Porter et al. 2004).

For participant selection, the respective *Morena* and/or *Mofumahali* identified both non-fishers (n = 47) and fishers (n = 25) from their communities. While this approach may not have captured all informal fishing activities, it was necessary to respect cultural norms and gain community access. At the beginning of each engagement, the respondent was provided with an overview of the aims and objectives of the study and asked for informed consent to participate. The questionnaire was administered only once informed consent had been obtained. The questionnaire was administered face-to-face by two Mosotho research assistants in Sesotho.

The questionnaire had two sections (Appendix D1). The first section was administered to all respondents (n = 72), and structured to obtain information on demographics, livelihood activities, changes in livelihood activities since the construction of the dam, knowledge of fish resources, fish consumption and preferences, interest in fishing, and support for fisheries development and management. The second section was administered to fishers (n = 25) and structured to obtain information on fishing methods, catch, motivations, fishing-specific needs and constraints, and perspectives on fisheries development and management.

Focus group discussions

Six focus group discussions (FGDs) were conducted in August 2024 in villages located on the Likalaneng, Jorodane, Senqunyane, and Bokong arms of the dam. The number of participants in the FGDs ranged from 20 to 70. At the beginning of each FGD, after formal introductions by the *Morena* or *Mofumahali*, the participants were provided with an overview of the research aims and objectives and were asked for their informed consent to participate in the study. Once informed consent had been received, open-ended discussion points were raised structured around the impact of the dam on livelihoods, current socio-economic challenges, knowledge of fish and fishing, fish consumption behaviours and preferences, and attitudes towards fisheries development and management. The discussions were transcribed *in situ* in Sesotho for subsequent analyses.

Data analyses

The questionnaire data were analysed using descriptive statistics (Holcomb 2016) to generate means with standard deviations for demographic variables like age and household size, along with percentage distributions for categorical variables such as livelihood activities, fish consumption patterns, and management preferences across different groups (fishers, non-fisher males, and non-fisher females).

The FGD transcripts were analysed using reflexive thematic analysis (Braun and Clarke 2019). The analysis involved iterative coding and theme development, moving between individual accounts and the broader dataset as interpretations were refined. Thematic saturation was not assessed as this aligns with codebook rather than reflexive approaches (Braun and Clarke 2019). While this approach cannot demonstrate systematic code coverage, it enabled deep interpretation of how participants made sense of dam impacts and fishing opportunities through their lived experiences (Byrne 2022), which was particularly valuable given the varied group dynamics across the FGDs.

6.3. Results

6.3.1. Fisheries assessment

Catch and size composition

A total of 4 629 fish with a combined weight of 672.8 kg were sampled over 38 net nights. Catches by number, weight, and index of relative importance (% IRI) were dominated by *Labeobarbus aeneus* with a small component of *Labeo capensis* (Table 6.3).

Table 6.3: Gillnet catch composition in Mohale Dam expressed as a percent of total number (No.), total weight (Weight), and index of relative importance (IRI).

Species	**%N (*n* = 4 629)**	**%W (672.8 kg)**	**%IRI**
Labeobarbus aeneus	96.0	83.9	90.0
Labeo capensis	4.0	16.1	10.0

L. aeneus dominated gillnet catches in both summer and winter in all years (Figure 6.4). No significant difference ($p > 0.05$) in IRI by species was observed in different years. At a seasonal level, *L. capensis* was significantly more important ($p < 0.05$) in gillnet catches in summer (IRI: 13.4–19.9%) than in winter (IRI: 0–2.8%).

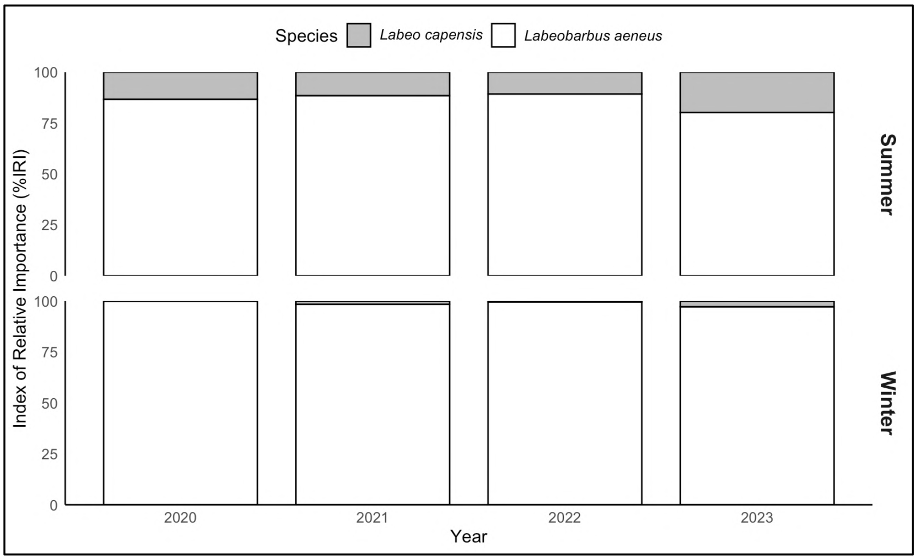

Figure 6.4: Seasonal index of relative importance (% IRI) of species sampled during experimental gillnet surveys of Mohale Dam conducted from 2020–2023.

The importance of different species in different gillnet mesh sizes is shown in Figure 6.5. In winter, *L. aeneus* was dominant across all mesh sizes (IRI: 98.8–100%) The pattern was different in summer, with *L. capensis* becoming increasingly important in larger mesh sizes, particularly in the 73 mm mesh (IRI: 28.6%), 93 mm mesh (IRI: 46%), and the 118 mm mesh (IRI: 86%) where it was more important than *L. aeneus.*

The size of *L. aeneus* ranged from 100 mm to 540 mm (mean = 205 ± 58 mm), with prominent cohorts at around 140–170 mm and 200–220 mm (Figure 6.6). The *L. capensis* ranged from 100 mm to 480 mm (mean = 317 ± 90 mm) with fewer distinct cohorts. The length frequency distribution for *L. aeneus* showed a higher proportion of smaller individuals (100–250 mm), whereas a greater proportion of the *L. capensis* sampled comprised individuals in the 290–390 mm range.

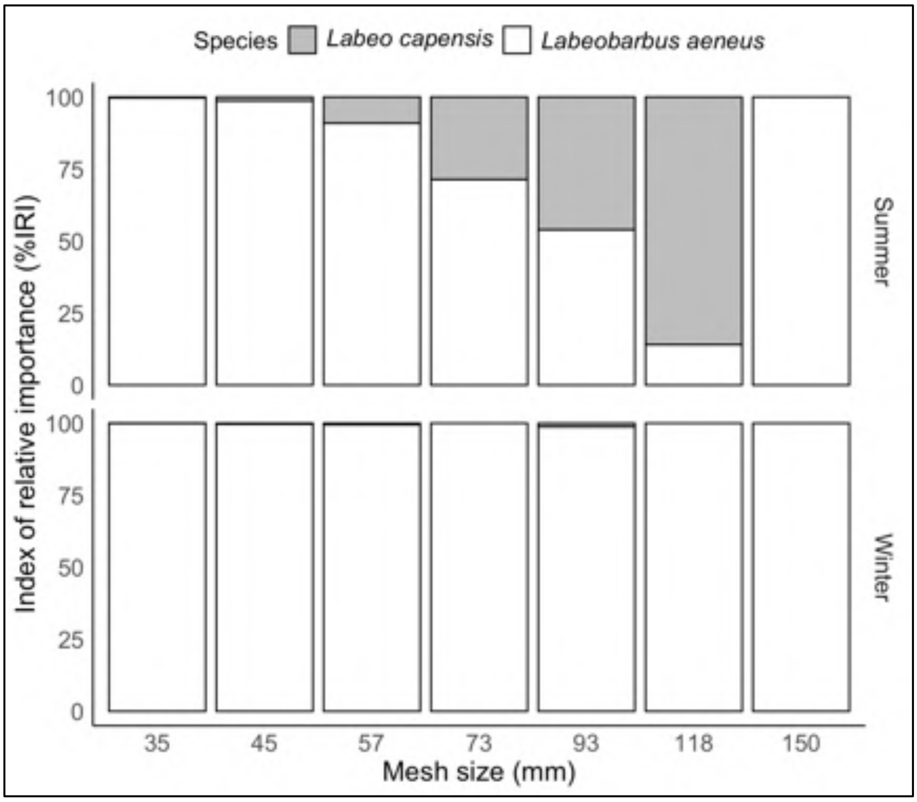

Figure 6.5: Seasonal index of relative importance (% IRI) of species sampled in different mesh sizes during experimental gillnet surveys of Mohale Dam conducted from 2020–2023.

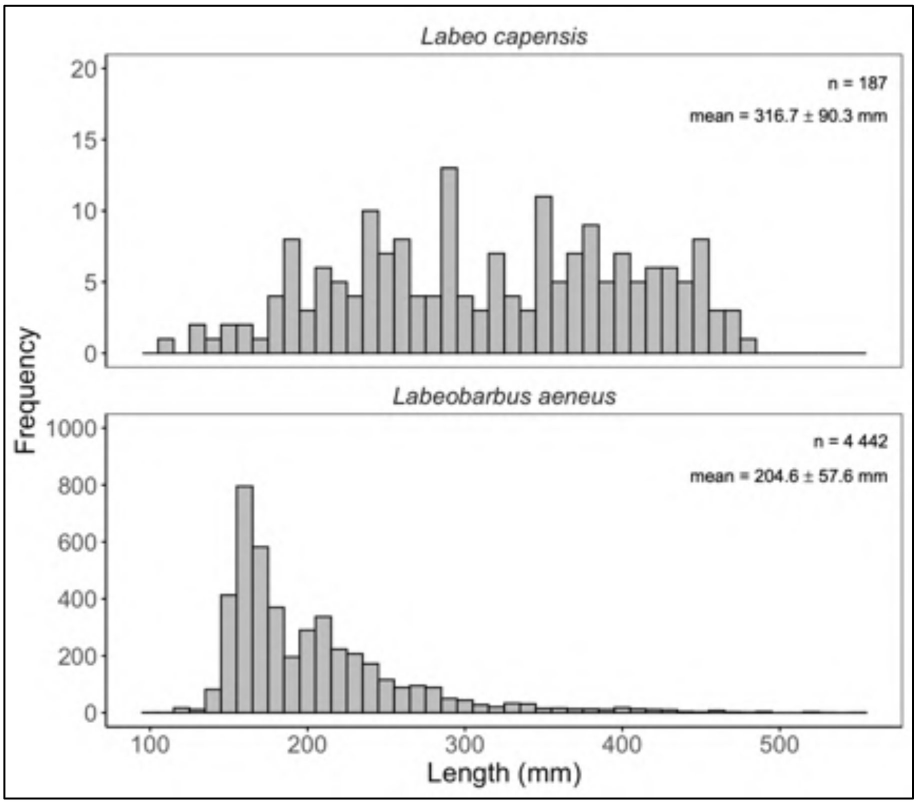

Figure 6.6: Length frequency distributions of *Labeo capensis* and *Labeobarbus aeneu*s sampled in experimental gillnets, Mohale Dam, 2020–2023.

Selectivity

Based on the catch composition, the target species for a gillnet fishery for Mohale Dam was *L. aeneus*. The relative selectivity curves for this species are shown in Figure 6.7. Mesh sizes up to 57 mm harvested *L. aeneus* below their length-at-50% maturity L_{50} (285 mm) (in Katse Dam). Around 20% of the *L. aeneus* in the 73 mm mesh were also below L_{50} although peak selectivity (327 mm) was well above this threshold.

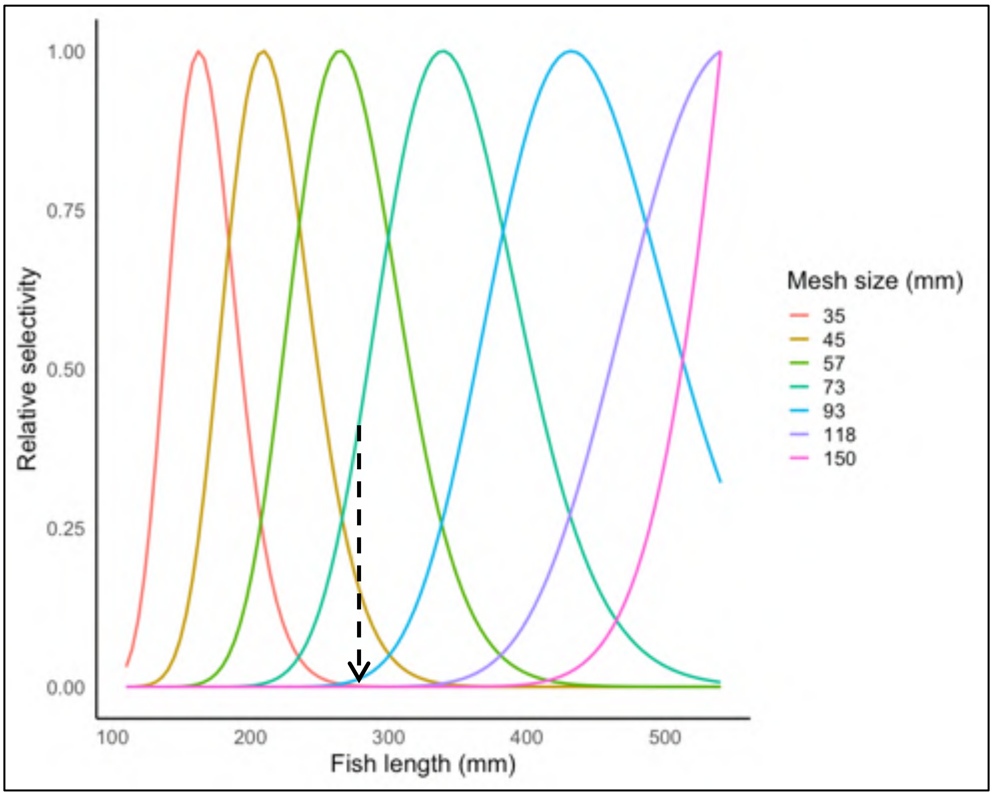

Figure 6.7: Relative selectivity curves for *Labeobarbus aeneus* estimated using the SELECT model. The dashed line indicates estimated length-at-50% maturity in Katse Dam as per Nthimo (2000).

The predicted lengths (mm) at maximum selectivity for *L. aeneus* ranged from 171.2 mm for a 35 mm mesh to 733.5 mm for a 150 mm mesh. Intermediate predicted lengths were 220.5 mm (45 mm mesh), 278.7 mm (57 mm mesh), 356.9 mm (73 mm mesh), 454.8 mm (93 mm mesh), and 577.9 mm (118 mm mesh).

Catch per unit effort

Mean *CPUEn* and *CPUEw* aggregated across years and seasons was 119 fish/net/night [95% CI: 93, 144] and 19.7 kg/net/night [16.2, 23.2], respectively. There was no significant difference ($p > 0.05$) in mean total *CPUEn* and *CPUEw* in different years (Figure 6.8). When disaggregated by season, mean *CPUEn* was and *CPUEw* was significantly higher ($p < 0.05$) in summer (90.4 ± 15.8 fish/net/night; 15.9 ± 3.45 kg/net.night^{-1}) than in winter (45.4 ± 11.5 fish/net/night; 8.1 ± 2.4 kg/net/night) (Figure 6.9).

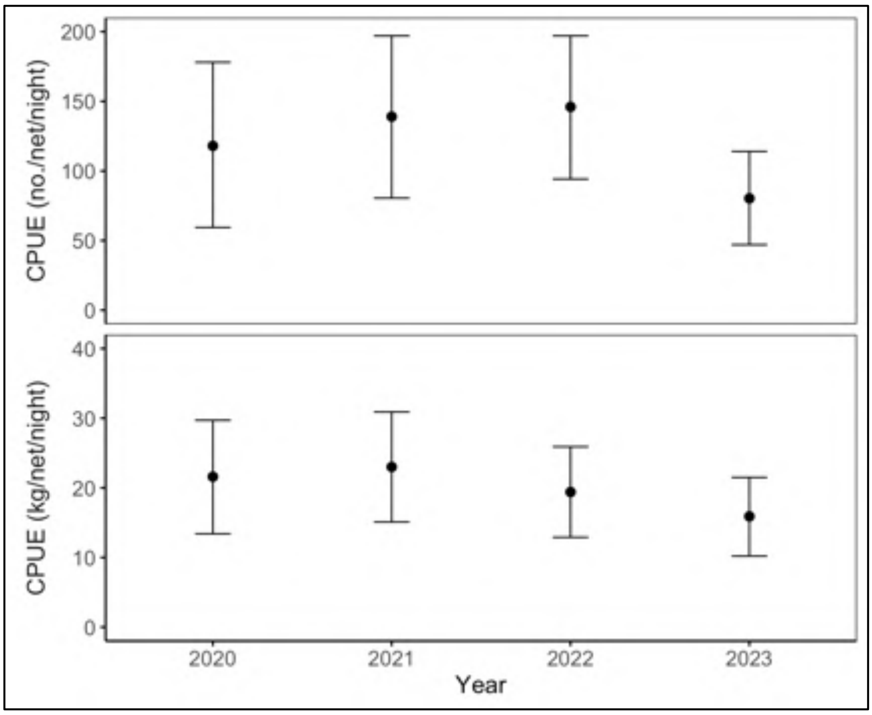

Figure 6.8: Experimental gillnet CPUE by number (top) and weight (bottom) in Mohale Dam, 2020–2023.

Seasonal *CPUEn* and *CPUEw* in different mesh sizes is shown in Figure 6.10. In summer, the highest *CPUEn* was observed in the smallest mesh sizes: 45 mm (44.4 ± 8.8 fish), 35 mm (41.3 ± 6.3 fish), and 57 mm (16.4 ± 2.1 fish). These meshes had significantly higher *CPUEn* than other mesh sizes ($p < 0.05$). The pattern was similar in winter, with the highest *CPUEn* recorded in the 35 mm (14.9 ± 3.1 fish) and 45 mm meshes (12.8 ± 2.3 fish), significantly higher than the larger meshes (73–150 mm, $p < 0.05$). In summer, *CPUEw* was highest in the 45 mm (4.92 ± 0.49 kg), 57 mm (3.59 ± 0.46 kg), and 93 mm (3.12 ± 0.58 kg) mesh sizes. In winter, the 93 mm and 57 mm mesh sizes had the highest *CPUEw* (2.00 ± 0.63 kg and 2.03 ± 0.43 kg, respectively), significantly higher than both smaller (35 mm) and larger (118–150 mm) meshes ($p < 0.05$).

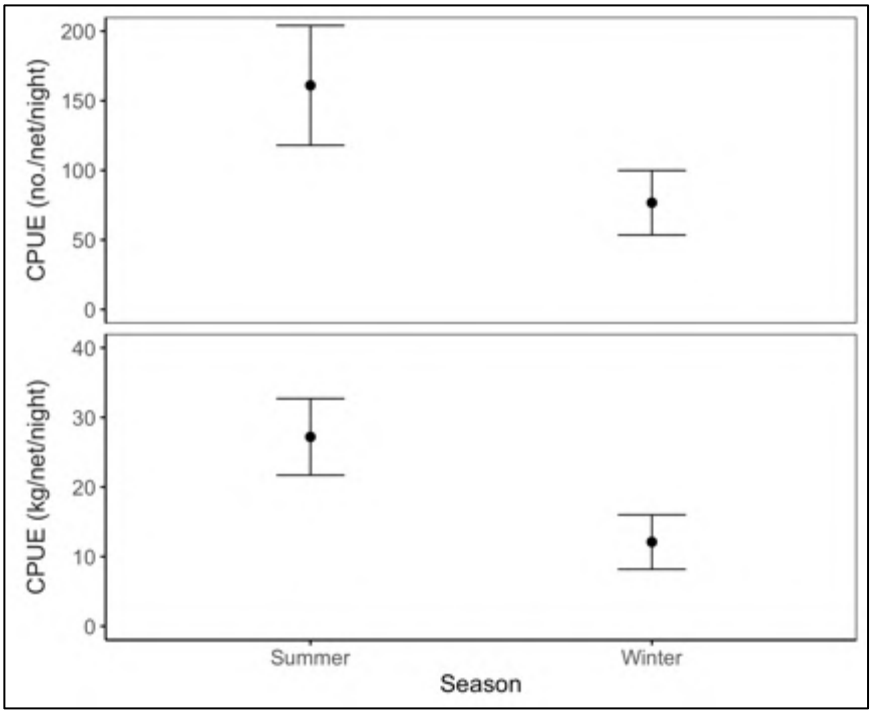

Figure 6.9: Experimental gillnet CPUE by number (top) and weight (bottom) in summer and winter seasons, Mohale Dam, 2020–2023.

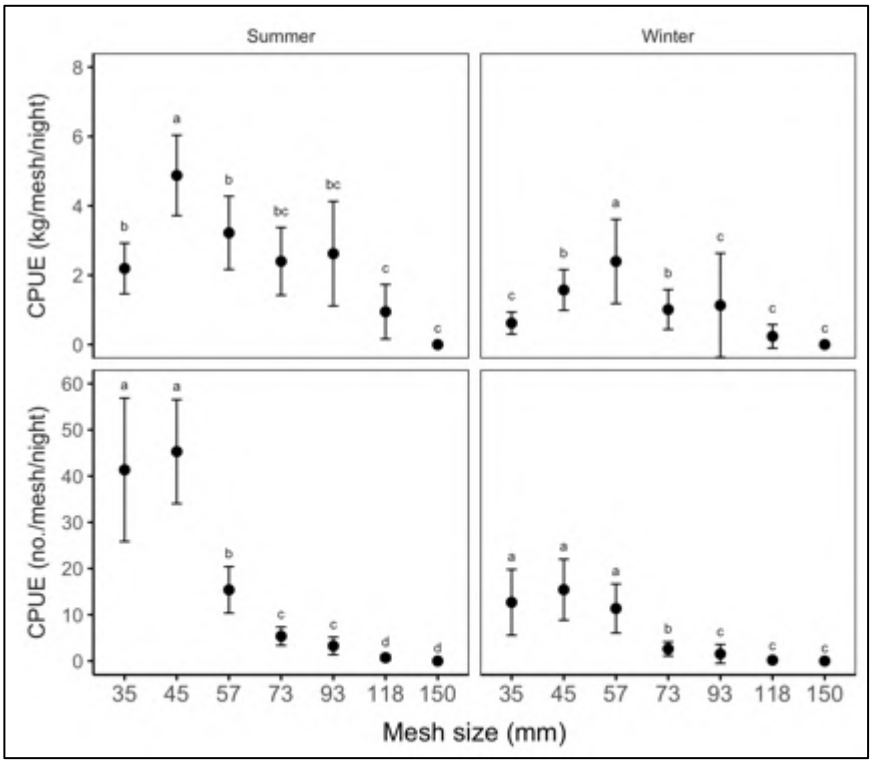

Figure 6.10: Experimental gillnet CPUE by number (top) and weight (bottom) in different mesh sizes in summer and winter, Mohale Dam, 2020–2023.

Potential yield

Yield estimates ranged from 14.8 to 65.4 tonnes/year (Table 6.4). The yield estimate obtained from the Schlesinger and Regier (1982) model was more conservative than that obtained from the Marshall and Maes model.

Table 6.4: Estimates of potential yield from Mohale Dam based on empirical models.

Model	**Yield (kg/ha/yr)**	**Yield (tonnes/y)**
Schlesinger and Regier (t/yr)	6.7	14.8
Marshall and Maes (t/yr)	29.6	65.4

6.3.2. Questionnaire surveys

Non-fishers

A summary of the results from the structured questionnaire administered to non-fishers is shown in Table 6.5. The non-fisher questionnaire respondents included both males (53.3%) and females (46.7%) with an average age of 44 ± 12.1 years and 42.2 ± 12.5 years, respectively. The average household size was 5.3 ± 1.5 people.

Wild plant harvesting (71.4%) was the dominant livelihood activity for females followed by agriculture (9.5%), crafts e.g., broom-making (9.5%), and temporary or seasonal jobs (4.8%). The most common livelihood for males was agriculture (58.3%), followed by temporary or seasonal jobs (20.8%), and trading (8.3%). A small proportion of males (12.5%) and females (4.8%) engaged in multiple livelihood activities. Females combined agriculture with crafts while males combined agriculture with temporary or seasonal jobs, or trading. Most respondents (91.1%) reported that they had not changed their livelihood activities since the construction of Mohale Dam. Approximately 6.7% had stopped farming entirely because of the construction of the dam, while 2.2% had gained formal employment.

All non-fishers were aware of the presence of fish in Mohale Dam. Knowledge of fish species varied between genders. The majority (76.2%) of females did not know what the fish in Mohale Dam were called, while 14.3% were aware of both *L. aeneus* ("yellowfish") and *L. capensis* ("mudfish"), and 9.5% believed that "trout" (rainbow trout *Oncorhynchus mykiss*) occurred in the dam. In contrast, 63.2% of males were aware of the presence of both *L. aeneus* and *L. capensis* in the dam, 20.8% believed that only trout occurred in the dam, and 16.0% were unable to name the fish species.

Table 6.5: Results from the questionnaire survey administered to non-fishers in communities around Mohale Dam.

Category	Characteristics	Females (*n* = 21)	Males (*n* = 24)
Demographics	Age	44.1 ± 12.1	42.2 ± 12.5
	Household size	5.4 ± 1.2	5.2 ± 1.7
Livelihoods (%)	Wild plant harvesting (%)	71.4	-
	Agriculture (%)	9.5	58.3
	Crafts (%)	9.5	-
	Trading (%)	-	8.3
	Temporary jobs (%)	4.8	20.8
	Multiple	4.8	12.5
Awareness and knowledge of species (%)	*L. aeneus* and *L capensis*	14.3	63.2
	O. mykiss	9.5	20.8
	Don't know	76.2	16.0
Fish consumption (%)	Only canned	23.8	8.3
	Only dam-caught	9.5	4.2
	Canned + dam-caught	66.7	87.5
Fish preference (%)	Canned	21.4	20.8
	Dam-caught	78.6	79.2
Interest in fishing (%)	Yes	71.4	75
	For income	53.3	50.0
	For income + subsistence	26.7	38.9
	For subsistence	23.0	11.1
	No	29.6	25
	Fear of drowning	66.7	
	Fear of water snakes	33.3	
	Too busy	-	100
Support for fisheries management (%)	Yes	66.7	75
	No	-	4.2
	Unsure	33.3	20.8

All respondents consumed dam-caught fish from Mohale Dam and/or canned fish. Consumption patterns differed between genders. Among female respondents, 66.7% consumed both dam-caught and canned fish, 23.8% consumed only canned fish, and 9.5% consumed only dam-caught fish. Male respondents were more likely to consume both dam-caught and canned fish (87.5%). Approximately 8.3% consumed only canned fish, and 4.2% consumed only dam-caught fish. Among respondents who consumed both types of fish, preferences were similar between genders: 78.6% of females and 79.2% of males preferred dam-caught fish, while 21.4% of females and 20.8% of males preferred canned fish.

Most non-fishers showed interest in starting fishing, with 71.4% of females and 75% of males expressing interest. Among interested female respondents, 53.3% were motivated by potential income, 26.7% by both income and subsistence opportunities, and 23% by subsistence alone. Similarly, among interested male respondents, 50% were motivated by income, 38.9% by both income and subsistence, and 11.1% by subsistence alone. Of the respondents not interested in fishing (29.6% of females and 25% of males), reasons differed by gender. Female respondents cited fear of drowning (66.7%) and fear of water snakes (*linoha ea metsi*) (33.3%) as deterrents, while male respondents exclusively cited being too busy with other livelihood activities.

Most non-fishers had no knowledge of fisheries regulations. Support for developing and managing fisheries varied by gender: 66.7% of females were supportive and 33.3% were unsure, while 75% of males were supportive, 20.8% were unsure, and 4.2% were opposed.

Fishers

All fishers interviewed were male with an average age of 47.9 ± 13.8 years. The average household size was 4.4 ± 2.3 people (Table 6.6). Most fishers engaged in multiple livelihoods, with only 11.5% relying solely on fishing.

Among those with multiple livelihoods, farming was the primary source for 46.2% of fishers, followed by fishing (15.4%), temporary jobs (15.4%), hunting (7.7%), and trading (3.8%). In terms of livelihood changes after the construction of Mohale Dam, 30.8% of respondents indicated that they had stopped farming while all respondents had begun fishing. Fishing was learnt primarily through interactions with tourists and expatriates from Maseru.

All fishers were aware of and could identify *L. aeneus* and *L. capensis* in Mohale Dam; none erroneously referred to *O. mykiss*.

All fishers consumed fish, with 61.5% consuming both dam-caught and canned fish, and 38.5% consuming only dam-caught fish. Among all fishers, there was a strong preference for dam-caught fish (88.5%) over canned fish (11.5%).

Most fishers (54%) were motivated by both income and subsistence needs, while 29% fished primarily for income and 5% for subsistence alone. All fishers reported using hook-and-line gear which was sourced from Maseru. Fishers used a variety of baits including *papa* (a stiff maize meal porridge), locusts, worms, crabs, and frogs. On average, fishers spent 3.3 (± 2.0) days per week fishing during summer and 0.6 (± 1.9) days per week during winter. Most of the fishers sold their fish in the immediate vicinity of the dam; some reported occasionally transporting their fish to areas in the lowlands, including Nazareth and Maseru.

Table 6.6: Results from the questionnaire survey administered to fishers in communities around Mohale Dam.

Category	**Characteristics**	**Fishers (*n* = 26)**
Demographics	Age	47.9 ± 13.8
	Household size	4.4 ± 2.3
Livelihoods (%)	Fishing only	11.5
	Primary – fishing	15.4
	Primary – hunting	7.7
	Primary – agriculture	46.2
	Primary – temporary jobs	15.4
	Primary – trading	3.8
Awareness and knowledge of species (%)	*L. aeneus* and *L capensis*	100
	O. mykiss	-
	Don't know	-
Fish consumption (%)	Only canned	-
	Only dam-caught	38.5
	Canned + dam-caught	61.5
Fish preference (%)	Canned	11.5
	Dam-caught	88.5
Motivation to fish (%)	Subsistence	5
	Income	29
	Income + subsistence	54
Fishing frequency (days/week) (*n*)	Summer	3.3 ± 2
	Winter	0.6 ± 1.9
Support for fisheries management (%)	Yes	74.7
	No	15.3
	Unsure	-

Most fishers (74.7%) supported fisheries management and development, while 15.3% were opposed. Responses to the open-ended questions on development and management showed that the primary motivation for supporting management was protecting future income, with some participants citing food security and sustainability for future generations. Most participants favoured a co-management approach combined with specific regulatory measures such as seasonal restrictions, size limits, and designated fishing areas. Those opposed to management primarily expressed concerns about specific regulatory measures, such as size limits and seasonal restrictions, although they were in the minority.

6.3.3. Community perspectives

Three key themes emerged from the FGDs on community attitudes towards fishing as a livelihood activity and the factors shaping these attitudes: (1) “Livelihood Disruption” (2) “Enthusiasm and Concerns”, and (3) “Community Agency”.

Livelihood disruption

Community members highlighted several negative socio-economic impacts following the construction of Mohale Dam. One resident explained, “*The dam has not made me stop farming altogether, but now the land that I have is no longer as productive*”. Another noted that, “*I stopped farming after the dam; we receive compensation, but I think life was better before*”. The participants also highlighted that the dam had created additional challenges, such as transport difficulties, issues of accessibility to previously connected areas, and livestock losses. Another commonly cited issue was that the dam had made it colder in the catchment area.

Communities also faced broader socio-economic challenges. Unemployment emerged as a common issue compounded by lack of skills and limited alternative livelihood options. Basic services challenges included sanitation and access to healthcare facilities. Inaccessibility was commonly cited by respondents, specifically the inundation of previous transport networks by the dam which had cut people off from previously easily accessible areas. However, some participants noted that since the development of Mohale Dam, they had been provided with electricity.

It is important to note that these livelihood changes were not always framed as disruption. For some participants, the continuation of farming and herding alongside new activities such as fishing was described as adaptation to altered conditions rather than displacement.

Enthusiasm and concerns

There was general agreement among all communities about the potential value of fisheries development, although notably few were currently engaged in fishing activities. Community members expressed a keen interest in fisheries as a potential livelihood opportunity. As one participant noted, "*We are beginning to see that this is a way that we can make money*", while another stated, "*We like to eat the fish from this dam and think that there is opportunity to grow it* (the fishery)".

However, these positive attitudes were tempered by previous experiences with development initiatives. As one participant noted, "*The LHDA has come many times to speak to us but we don't see the delivery*". This history of unfulfilled promises led to scepticism about whether proposed fisheries development would translate into real benefits. In addition, others expressed concerns regarding safety. A widely held belief in the presence of *linoha ea metsi* (water snakes) emerged as a cultural barrier to participating in fishing. Many participants noted their inability to swim, and fears of drowning were heightened by previous drowning incidents in the community.

Equipment and training emerged as primary needs, with participants consistently highlighting them as prerequisites for effective participation. Infrastructure requirements, particularly cold storage facilities, were frequently cited as a prerequisite for fisheries development, along with skills development in areas such as fish handling and marketing.

Community agency

Community members expressed a strong desire for meaningful participation in fisheries management decisions driven by previous experiences of exclusion from development projects. As one participant noted, "*We want our own area for fishing. This will allow us to manage activities sustainably and get the most benefit from fishing*". Specific concerns were raised about consistency in fishing regulations, with one participant questioning why they were "*banned from fishing because of drownings but other communities still fish – why is there no clarity and consistency?*". Key governance requirements that emerged from the FGDs centred on the need for co-management arrangements that would give communities genuine ownership and decision-making power over fisheries resources, supported by clear regulations and regular communication between authorities and communities.

6.4. Discussion

Large dam projects, primarily designed for purposes such as hydropower and irrigation, can create opportunities for reservoir fisheries to contribute to food security, diversify livelihoods, and drive economic growth. This study investigated the potential for fisheries development at Mohale Dam as an alternative livelihood for communities impacted by the Lesotho Highlands

Water Project (LHWP). The findings show that while ecological conditions are favourable for fisheries development, social challenges and the efficacy of the development and management of the process are likely to determine the feasibility and success of the establishment of a small-scale fishery. These opportunities must also be viewed in the context of biodiversity costs. As shown in Chapter 5, the potential for fisheries at Mohale has coincided with the establishment of invasive species and the decline of *P. quathlambae*, highlighting the need to balance livelihood benefits with conservation trade-offs in future planning. These insights emphasise how the success of reservoir fisheries depends on addressing both ecological and social dimensions in dam-affected communities, with implications for fisheries planning in future large dam developments worldwide.

Status of fish populations

The gillnet surveys undertaken from 2020–2023 show that *L. aeneus* is the dominant component of the dam's fish fauna (IRI: 90%), with a smaller component of *L. capensis* (IRI: 10%). This finding is consistent with the results of the previous survey by Hecht and McCafferty (2011). The minor importance of *L. capensis* may be related to its inconsistent recruitment and/or slower growth, as evidenced by its broad and variable size structure, with few distinct cohorts and a larger mean length (316.7 ± 90.3 mm), suggesting a population dominated by older individuals. In comparison, the size structure of *L. aeneus* indicates consistent recruitment success and more predictable growth rates, demonstrated by a higher proportion of younger fish and a smaller mean length (204.6 ± 57.6 mm). The broader size distribution and larger mean length of *L. capensis* may suggest that it takes longer to reach maturity than *L. aeneus* in Mohale Dam, which may lead to lower population turnover rates and consequently reduced abundance and productivity in the system. These recruitment and growth differences may reflect the higher ecological plasticity of *L. aeneus* in impoundments, particularly its ability to successfully spawn and adapt its feeding strategies in lacustrine environments (Ellender et al. 2016), compared with *L. capensis* which, as a periodic strategist, has a narrower range of environmental requirements for successful feeding and reproduction (Winker et al. 2012). Periodic strategists are considered to be the least adapted to habitats that have become temporally stable and that are subject to low resource availability due to decreased inundation of floodplains from damming (Olden et al. 2006).

While the argument could be made that the gillnets used in this study were "top-set", which may have ineffectively sampled the substratum where *L. capensis* feed and thus underrepresented the importance of this species, Hecht and McCafferty (2011) used both top-set and bottom-set gillnets and *L. aeneus* was dominant in both gears. This suggests that the abundance of these species is likely related to their differential success in lacustrine environments, rather than sampling bias. This is consistent with other studies showing that ecological generalists often demonstrate greater recruitment success in modified systems than more rheophilic species (Schmutz and Moog 2018; Arantes et al. 2019; Turgeon et al. 2019).

Pre-impoundment studies of the Mohale Dam catchment area emphasised the risk of an invasion of *O. mykiss* from Katse Dam (Rall 1999; Skelton 2001). The extent to which *L. aeneus* invaded and colonised the dam, subsequently eradicating *P. quathlambae* throughout much of its native range in the catchment rivers, was not anticipated (Chapter 5). This demonstrates the challenges of predicting invasion outcomes in novel ecosystems (Milardi et al. 2022).

The reason why *O. mykiss* does not appear to have invaded Mohale Dam, as predicted, is unclear. However, Mohale Dam provides suitable habitat for this species and there is a well-established source population in Katse Dam (Chapter 3). Its inability to invade Mohale Dam, as opposed to *L. aeneus* and *L. capensis*, may well be linked to flow releases and associated hydraulic dynamics in the IBWT tunnel, as well as differing life-history strategies and swimming behaviours. Flow releases from Mohale Dam to Katse Dam are typically in the summer months, during which time it is likely that *L. aeneus* and *L. capensis* individuals in Katse Dam would aggregate at the tunnel inflow area given seasonal spawning cues. This localised increase in propagule pressure could increase the chance of active dispersal of these species through the tunnel, as opposed to *O. mykiss* which moves into the inflowing rivers of Katse Dam in the winter months when flow releases from Mohale Dam are infrequent. Behavioural differences in swimming strategies may also influence the ability of fish to navigate tunnels successfully (Schmidt et al. 2020). In the Mohale–Katse tunnel, water flow conditions are turbulent, and there is a complete absence of refugia or resting areas. Cyprinids like *L. aeneus* and *L. capensis* have a “bottom-oriented”, epibenthic swimming strategy which may allow them to better exploit lower turbulence areas near the tunnel floor (Silva et al. 2012). In contrast, *O. mykiss* tends to swim higher in the water column and is, therefore, more exposed to greater turbulence. Moreover, smooth tunnel walls provide no structure to create predictable vortex patterns that *O. mykiss* typically exploits through Kármán gaiting for energy-efficient swimming (Wilkes et al. 2013). As such, it is possible that *L. aeneus* and *L. capensis* possess a higher tolerance than *O. mykiss* for prolonged exposure to flow conditions within the tunnel which has allowed them to successfully invade Mohale Dam. In addition to propagule pressure and dispersal constraints, the absence of *O. mykiss* in Mohale may also reflect limitations to successful establishment. Trout require suitable running water habitats with appropriate spawning substrates, and the Mohale Dam catchment rivers may not provide the conditions necessary for recruitment. This highlights the importance of considering both dispersal pathways and establishment conditions when assessing invasion risk (Schmidt et al. 2020). Further research in this regard could improve invasion risk assessments for water transfer schemes.

The average catch rate in Mohale Dam recorded during this study (19.7 kg/net/night) is higher than that of Katse Dam (13.2 kg/net/night) (McCafferty and Hecht, in prep.) and 81% of dams in South Africa, for which comparable data are available (McCafferty 2012). Catch rates were largely consistent across the study period with no significant difference between the sample years, possibly indicating that the populations of *L. aeneus* and *L. capensis* in Mohale Dam have likely reached a state of equilibrium. The high catch rates in Mohale Dam are at odds with empirically established relationships linking higher productivity to lower elevation, and shallower, warmer dams (Ryder 1965), highlighting how standard empirical models previously used for temperate impoundments (Ellender 2008; Richardson et al. 2009) may not capture the dynamics driving the productivity of high-altitude impoundments. However, yield models based on morphoedaphic principles should also be treated with caution in this context. Such models are known to perform inconsistently (Pitcher 2015), and the divergence in estimates from the two models applied here reflects this uncertainty. While useful as broad indicators, they cannot on their own provide a reliable basis for management and need to be interpreted alongside empirical catch data and selectivity analyses. It is also possible that the high catch rates observed in Mohale Dam are a product of the dominance of *L. aeneus* in the system and the susceptibility of this species to gillnets. In other more species-diverse systems, certain fishes may be less vulnerable to gillnets and catch rates may not provide an accurate reflection of productivity (McCafferty 2012). It should also be noted that the relative productivity of different habitats (e.g., inlets, shallow margins, and drawdown zones) was not quantified in this study, and future work should evaluate how such spatial variation influences catchability and access. This is particularly important given the dynamic nature of reservoir ecosystems, where conditions evolve well beyond the initial trophic surge period.

Knowledge and awareness of fisheries resources

The questionnaire surveys revealed that, while all non-fishers were aware of the presence of fish in Mohale Dam, knowledge of specific species varied markedly by gender. Most females

(76.2%) had no name for the fish species present in the dam, and 9.5% incorrectly believed that *O. mykiss* was present. In contrast, most males (63.2%) identified both *L. aeneus* and *L. capensis*, although a notable proportion (20.8%) incorrectly believed that only *O. mykiss* was present. This gender disparity in knowledge likely reflects traditional livelihood roles in highland communities, where male involvement in livestock farming provides greater opportunities for observation and interaction with aquatic and terrestrial resources. Similar gendered patterns in the knowledge and awareness of *P. quathlambae* were observed in the study area (see Chapter 5). This may also be indicative of the developing state of the fishery, given the role of women in the Katse Dam fishery (Chapter 3) and in established fisheries elsewhere in Africa (Du Preez 2018).

The *O. mykiss* misconception, despite its absence from the system, appeared to be related to awareness of the presence of this species in Katse Dam and the post-harvest colouration of *L. capensis* which may display red and pink hues like *O. mykiss*. During the study, the author was sent photographs from one survey participant of an *L. capensis* individual which was believed to be *O. mykiss* based on the post-harvest colouration of the species (Figure 6.11). This suggests that communities are actively trying to make sense of new resources by drawing on both regional knowledge (the Katse Dam fishery) and direct observations, even if the conclusions drawn are incorrect.

Figure 6.11: A proportion of the survey respondents were of the view that *Oncorhynchus mykiss* occurred in Mohale Dam based on the post-harvest colouration of *Labeo capensis*, notably the red and pink hues (Source: *ntate* Sechaba).

The belief in water snakes (*linoha ea metsi*) highlights how folklore and myth may influence fisheries development on Mohale Dam and indeed elsewhere in remote, poorly educated regions. Human-water interactions among certain societies are strongly shaped by beliefs in supernatural beings (Da Silva et al. 2019). Such beliefs may influence access to and use of aquatic resources (Alonso et al. 2016), as observed in the Parnaíba River in Brazil, where water spirits influenced seasonal and spatial fishing behaviours of local communities (Da Silva et al. 2019). In Basotho culture, *linoha ea metsi* serve as both manifestations of danger and spiritual emissaries (Rakotsoane 2008; Skinner 2022). In Katse Dam, discussions with fishers revealed that they avoided steep-sided areas of the dam with ephemeral streams and tree stands, areas where *linoha ea metsi* were believed to inhabit. This further emphasises the need to consider socio-cultural factors in fisheries development and management planning.

Fishing practices and fish consumption

The livelihood activities of the community members around Mohale Dam provide insight into the integration of fishing as a new activity. Many community members maintained their pre-dam livelihood activities. Fishing has emerged as one of the few new livelihood opportunities since dam construction. However, rather than constituting an entirely new sole source of livelihood, fishing has been integrated into existing activities; 88.5% of the interviewed fishers continued to pursue other livelihood strategies.

Fishing in Mohale Dam is highly seasonal, essentially ceasing in winter, and undertaken using only hook-and-line gear. This contrasts with Katse Dam, where hook-and-line and illegal gillnet fishing methods are used, and fishing is undertaken year-round, often on a full-time, basis (Chapter 3). This highlights the supplementary role of fishing in the local livelihoods of Mohale Dam communities and the developing state of the Mohale Dam fishery in comparison to the Katse Dam fishery.

The results of this study show that there is broad acceptance and preference for dam-caught fish as a food source. This challenges historical assumptions about the cultural aversion of Basotho to fish consumption highlighted in previous studies (Eccles 1990; Skelton 1996). Rather than an inherent resistance, the historical lack of fish consumption in these areas appears to be more related to limited access to and availability of fish than cultural preferences. The marketing of fish was primarily local, with most fishers selling their catch in the immediate vicinity of the dam, although some reported occasionally transporting their fish to lowland areas, including Nazareth and Maseru. This contrasts with the more complex Katse Dam fisheries value chain that has emerged over the past 25 years (Chapter 3). This contrast also highlights that the limited and largely localised nature of fish marketing at Mohale remains a constraint. Without wider market access and supporting value chains, the economic potential of the fishery may remain limited even if ecological conditions are favourable.

The slower uptake and more limited exploitation of fish resources at Mohale Dam than at Katse Dam appears to be related to the timing of resource availability and knowledge exposure. At Katse Dam, pre-existing fish populations in the catchment, some fishing experience (albeit limited), and knowledge transfer from external actors provided early opportunities for communities to experiment with and adopt new and more effective fishing methods (Chapter 3). When post-impoundment conditions (1997) increased fish abundance, communities were positioned to rapidly expand their exploitation of resources, developing sophisticated value chains and market networks. In contrast, Mohale Dam communities only encountered fish resources between 2006 and 2010 after the invasion and have had limited exposure to different fishing practices. This suggests that while communities at Mohale Dam have adapted their livelihoods to some extent to take advantage of the fisheries resources of the dam, the timing and sequence of exposure to fish resources and knowledge have significantly influenced the extent to which fishing and fisheries value chains have developed. This aligns with broader theories of path dependency (Mahoney 2000), in which early conditions and sequences of events can create self-reinforcing development trajectories, and with innovation diffusion theory (Rogers 2003) which emphasises the importance of early knowledge transfer networks in shaping adoption patterns.

Community attitudes towards fisheries development and management

Interest in fishing as a livelihood activity was high among non-fishers (71.4% females, 75% males), with most motivated by the opportunity to generate a source of income. However, previous experiences with socio-economic development initiatives negatively influenced community attitudes towards fishery development and management to some extent. Focus group discussions revealed broad dissatisfaction with post-dam livelihood changes and scepticism about the development and management of fisheries given previous socio-economic project pledges made by authorities which did not materialise. This issue is not new: there is a long history of ongoing community protests made by communities against the LHDA due to "broken promises" dating back to the completion of Phase IA (Meissner 2015), and trust issues remain (Lehema and Thebe 2024).

Several studies have highlighted the importance of trust and linking social capital (relationships that connect individuals or communities with external institutions, authorities, or people in positions of power (Woolcock 1998)) in determining the success of rural development projects (Tillberg Mattsson and Stenbacka 2004; Taruvinga et al. 2017; Sabet and Khaksar 2024). Moreover, there is increasing recognition that trust between fishers and managers is essential for effective fisheries management (De Vos and van Tatenhove 2011; Gutiérrez et al. 2011; Kapembwa et al. 2021; Dixon et al. 2024). In this case, the lack of trust and linking social capital may limit community buy-in and cooperation, and therefore, the feasibility of fisheries development and management.

The high level of community support for formal management, despite historical scepticism of development initiatives, suggests recognition of the need for sustainable resource governance. However, the success of any management framework will likely depend on its ability to address both the technical aspects of fisheries management and the social dynamics of trust-building and community empowerment.

Outlook for fisheries development and management in Mohale Dam

From an ecological perspective, the higher catch rates (19.7 kg/net/night) in comparison with Katse Dam and other South African impoundments suggest that there is potential for the development of a small-scale fishery. Based on the conservative yield estimate of 14.6 tonnes (rounded to 15 tonnes), and using the average *CPUEw* for the 93 mm mesh size (2.56 ± 0.43 kg/10m net/night) which does not select for approximately 80% of immature *L. aeneus*, this initial harvest level could be achieved using 8 × 100 m gillnets operated for around 73 nights, or 6 × 100 m gillnets for around 98 nights. However, CPUE may decline with increased fishing pressure, which emphasises the need for ongoing monitoring to track trends in catch rates and adjust effort as needed.

Social conditions also appear favourable in several respects. There is broad community interest in fishing as a livelihood activity among both men and women, challenging historical assumptions about cultural aversion to fishing in the Lesotho Highlands (Eccles 1990; Skelton 1996). The high level of support for formal management (66.7–75% across groups) highlights recognition of the need to regulate fishing. Moreover, the acceptance of fish consumption and existing local market connections provide a foundation that could support further fishery development. A well-managed fishery on Mohale Dam has the potential to contribute to local food security and diversify household diets (Youn et al. 2014), while also providing both direct employment in fishing and indirect opportunities in processing and trade (Allison and Ellis 2001). Nevertheless, several challenges must be addressed. Market access remains limited, with most sales confined to the immediate area. Infrastructure constraints such as shortages of gear and cold storage restrict opportunities for scaling up fishing activity, while limited knowledge of fishing practices and lack of swimming or water safety skills also constrain participation. Cultural beliefs, including those linked to *linoha ea metsi*, also influence behaviour and restrict fishing in certain areas. The LHWP's legacy of unfulfilled commitments has left many dam-affected communities sceptical of new livelihood interventions. In some cases, socio-economic development interventions have failed to deliver sustainable economic alternatives, reinforcing distrust in development authorities (Chapter 2).

Fisheries development at Mohale Dam must acknowledge this legacy and avoid repeating past mistakes. Success requires careful consideration of what form the fishery should take to maximise benefits while remaining sustainable. Communities (in consultation with authorities) should ultimately decide on the desired form and development pathway for the fishery. This will require further studies on the social and economic benefits, opportunities, risks, and trade-offs between different fisheries development and management options e.g., a gillnet-only fishery and/or a recreational fishery. Implementation should follow co-management arrangements that give communities genuine ownership and decision-making power. This should be complemented with capacity building in fishing techniques, including training to help existing hook-and-line fishers adopt gillnet fishing methods, post-harvest processing, entrepreneurship, and resource monitoring. Given the historical trust issues, transparent communication throughout the entire process should be paramount.

Limitations

This study was subject to several limitations. Fisheries surveys were conducted only twice annually, providing insight into summer and winter dynamics but missing finer seasonal variability. Gillnet sampling may also have underrepresented some benthic species such as *Labeo capensis*. On the social side, data collection was shaped by customary leadership protocols that sometimes required large collective meetings rather than individual interviews, and participant selection by chiefs introduced potential bias. Questionnaire and focus group data relied on real-time transcription and translation, which may have introduced interpretation errors, and the reflexive thematic analysis applied cannot claim systematic coverage. Despite these limitations, the findings still offer a reliable basis for understanding the opportunities and challenges of fisheries development at Mohale Dam.

6.5. Conclusion and recommendations

Large dam projects continue to increase globally despite their negative social impacts, and there is a pressing need to understand alternative opportunities like reservoir fisheries that can contribute to food security, diversify livelihoods, and drive economic growth. The findings from this chapter highlight how future planning must be guided by assessments that go beyond ecological evaluations to incorporate social and economic dimensions. Existing livelihood strategies, power dynamics, and historical grievances must be assessed to understand how new fisheries initiatives might be received and adapted by different community groups. Different fisheries development and management pathways underpinned by realistic estimates of social and economic benefits and risks should be developed. Finally, ecological monitoring should focus not just on stock status but on understanding how communities interpret and interact with new aquatic resources. This integrated approach can better inform the development of appropriate fisheries development and management approaches for large dams where communities must adapt to new livelihoods, navigate resource conflicts, and operate within governance structures often shaped by mistrust and unfulfilled promises.

CHAPTER 7 – GENERAL DISCUSSION

7.1. Introduction

The promise of large dams lies in their potential to address our energy and water needs, support food production, and stimulate economic growth. However, they have also displaced millions of people, disrupted livelihoods, and significantly altered aquatic ecosystems, often leading to biodiversity loss and species extinctions (Chapter 1). While the negative impacts of large dams on communities and ecosystems are well-documented, there remains limited understanding of how remote communities successfully adapt to dam-induced changes and develop new livelihood opportunities. This knowledge gap is particularly significant given continued dam construction in developing countries, where understanding pathways to community benefit is essential for improving development outcomes.

The Lesotho Highlands Water Project (LHWP) exemplifies many of the challenges and potential benefits associated with dam construction and management in the developing world (Chapter 2). However, despite its significant social and environmental impacts, its impact on fish and fisheries had never been comprehensively assessed. This represented a knowledge gap and an opportunity for research that could contribute towards improving our understanding of the impacts of large dams on fish and fisheries, and the development of principles for improved assessment and management in Lesotho and globally.

This thesis aimed to provide a holistic understanding of the impact of the LHWP on fish populations and fisheries in the Lesotho Highlands by investigating ecological changes and the unique social context in which they have occurred. To achieve this, a transdisciplinary, mixed methods approach, grounded in social-ecological systems (SES) principles was used to examine:

1. The emergence, development, and status of fisheries in Katse Dam following large dam construction and to assess the social, ecological, and economic drivers that shaped community adaptation in a traditionally non-fishing area (Chapter 3).
2. The potential and challenges of foreign fishing tourism (FFT) as a development pathway in dam-affected areas, with attention to social, economic, and management implications (Chapter 4).
3. The impacts of large dams and inter-basin water transfers on the conservation of the endemic Maloti minnow *Pseudobarbus quathlambae*, and to examine how community

perspectives influence support for biodiversity protection in dam-affected areas (Chapter 5).

4. Invasive fish in LHWP reservoirs and the opportunities for small-scale fisheries development, with attention to the social, economic, and governance factors shaping fisheries outcomes in dam-affected communities (Chapter 6).

The thesis demonstrates how ecological, social, cultural, and economic dimensions shape fisheries (Chapters 3, 4 and 6) and conservation outcomes (Chapters 5 and 6) in dam-affected regions. Each chapter provides useful context on the opportunities and challenges associated with developing and managing the impacts of large dam projects on fish and fisheries. The aim of this general discussion chapter is to synthesise these findings and provide practical recommendations towards holistically assessing and managing fish and fisheries in the LHWP and large dam projects globally.

7.2. Fish: Winners, losers, lessons learnt, and conservation priorities

Consistent with other studies on large dam projects (Turgeon et al. 2019), the findings of this thesis show that the LHWP has had divergent impacts on fish populations, benefitting some species ("winners") while negatively impacting others ("losers"), with some unexpected outcomes (Fernandez et al. 2024). This aligns with broader patterns observed in impounded river systems, where shifts from lotic to lentic conditions, habitat fragmentation, and invasive species introductions may restructure fish assemblages in unpredictable ways (Turgeon et al. 2019).

In the case of the LHWP, the clear winner has been smallmouth yellowfish *Labeobarbus aeneus*, which has established large populations in Katse Dam (Chapter 3), and in Mohale Dam following its successful invasion through the IBWT tunnel (Chapter 5, 6). The success of *L. aeneus* in these dams can likely be attributed to its ecological plasticity, notably its ability to successfully spawn and adapt its feeding strategies to lacustrine conditions (Eccles 1986; Ellender et al. 2016) which was not adequately considered in previous studies (Skelton 1996; Nthimo 2000). This aligns with previous studies documenting how the shift from lotic to lentic conditions following impoundment typically favours the establishment of eurytopic or generalist fishes (Liermann et al. 2012; Agostinho et al. 2016; Turgeon et al. 2019; Arantes et al. 2019; Schmutz and Moog 2018). The native population of *L. aeneus* in Katse Dam now supports a substantial hook-and-line and illegal gillnet fishery (Chapter 3) and an economically valuable FFT operation (Chapter 4). While the invasive population in Mohale Dam does not yet support fisheries at this scale, the situation is slowly changing (Chapter 6).

The successful invasion of Mohale Dam by *L. aeneus* and Orange River mudfish *Labeo capensis* through the IBWT tunnel is not without precedent; the species invaded several rivers in the Eastern Cape, South Africa from the Orange River system after the development of the Orange-Fish River IBWT in South Africa (Cambray and Jubb 1977; Laurenson et al. 1989). However, pre-impoundment studies largely overlooked this risk, focusing instead on the potential invasion of rainbow trout *Oncorhynchus mykiss* (Rall 1993, 1999; Skelton 1996; Steyn et al. 1996), which ultimately did not occur (Chapter 6). At this stage, the reason why is unclear but may be linked to its mid-water swimming behaviour which exposes it to greater turbulence in the IBWT tunnel, combined with a winter spawning strategy that coincides with reduced flow releases through the tunnel, and therefore reduced abundance near the tunnel inflow. It may also be that riverine habitats in the Mohale catchment do not provide the necessary conditions for *O. mykiss* to spawn, although this seems unlikely given the successful establishment of the species in Katse and other rivers throughout the county. In contrast, both *L. aeneus* and *L. capensis* are epibenthic swimmers, that can exploit lower turbulence areas near the tunnel floor, with spawning seasons that overlap with flow releases from the tunnel which would increase propagule pressure (Turgeon et al. 2019.

Labeo capensis has also established populations in both Katse and Mohale Dam but with less success than *L. aeneus*. The invasive population in Mohale Dam comprised only 4% of gillnet catches, with a population structure indicative of inconsistent recruitment and slow growth (Chapter 6). Similar trends were observed in Katse Dam, where its contribution to illegal gillnet catches was relatively modest (~10–20%) (Chapter 3). Its comparatively limited success is likely related to its periodic life-history strategy which is less adapted to temporally stable environments such as dams (Olden et al. 2006; Winker et al. 2012). Nevertheless, *L. capensis* still forms an important part of the basket of species produced by the hook-and-line and illegal gillnet fishery at Katse Dam that moves through local, regional, and South African market channels (Chapter 3).

The most significant loser has been the Maloti minnow *Pseudobarbus quathlambae*, a small (< 130 mm), endangered, redfin minnow endemic to Lesotho, and highly susceptible to predation and habitat degradation (Pike and Tedder 1973; Rondorf 1975, 1976; Gephard 1978; Cambray and Meyer 1988; Skelton 2000; Skelton et al. 2001; Swartz 2005). Comparisons of pre- and post-LHWP electrofishing data show that the extent of occurrence (EOO) of *P. quathlambae* has shrunk by 76% with the biggest contractions occurring in the Mohale Dam catchment and the Matsoku River catchment forming part of Phase IB of the LHWP (Chapter 5). The Mohale Dam populations (*P. quathlambae* M), once regarded as the stronghold of the species, have collapsed while the distribution range of the Matsoku River population (*P. quathlambae* E) has shrunk from 87 km to 11 km. In the case of the populations in the Mohale Dam catchment, the decline can be attributed to habitat loss and predation by invasive *L. aeneus*. The disappearance of the Matsoku River population from the lower and middle reaches of this river can also be linked to the invasion of *L. aeneus* through the Katse–Matsoku IBWT tunnel.

The decline of *P. quathlambae* mirrors trends seen in other large dam and IBWT projects, where habitat loss and invasive species have led to extirpation and/or extinction of fluvial specialists (Schmidt et al. 2020). It is important to note, however, that the LHWP also indirectly shaped the distribution of *P. quathlambae* by spurring the translocations of the species undertaken in 2002. The translocated populations of the *P. quathlambae* Mohale Evolutionary Significant Unit (ESU) now comprise 63% (0.69 km^2) of the total EOO and around 65% of the estimated total population size of *P. quathlambae* (Chapter 5).

The dramatic reduction in the EOO of *P. quathlambae* following the LHWP's implementation emphasises the rapid impacts that large dam projects and IBWT schemes can have on endemic species. Simultaneously, the successful establishment of translocated populations demonstrates that proactive conservation measures can mitigate some of these impacts. There is general support for conservation of *P. quathlambae* among dam-affected communities and this provides a foundation for future conservation efforts in the LHWP area (Chapter 5).

The impacts of the LHWP on fish populations largely align with those of other large dam projects elsewhere (Keppeler et al. 2022; Turgeon et al. 2019; Chen et al. 2023; Fernandez et al. 2024), although some unexpected outcomes highlight both the importance of and the difficulty in predicting species-specific responses to large dam projects as well as the need to integrate social dimensions into mitigation measures.

Conservative predictions about the adaptation potential of *L. aeneus* likely delayed proactive fisheries development in Katse Dam, where it is native and now supports valuable fisheries (Chapter 3). In other instances, this may have constituted a missed opportunity entirely for fisheries development. Conversely, the failure to consider its invasive potential and the subsequent collapse of *P. quathlambae* populations demonstrate the danger of underestimating the biodiversity risks posed by different species in dam-altered environments (Chapter 5).

While perfect prediction of species-specific responses to damming will remain elusive, continued efforts to improve our understanding can help bridge the gap between forecasts and outcomes and promote proactive and adaptive management of large dam impacts on fish (Fernandez et al. 2024). This requires multifaceted approaches that integrate functional trait analysis (Arantes et al. 2019), life history characteristics (Fernandez et al. 2024) and infrastructure-species interactions (Waine et al. 2024). Drawing evidence from comparable systems could provide valuable insights, though each system's unique characteristics must be considered. Invasion risk assessments should consider both traditional non-native invaders and range-expanding native species particularly given that translocated native species can exert equal or greater impacts on native fish assemblages than exotic species, (Maceda-Veiga et al. 2022).

For effective biodiversity conservation in dam-affected areas, decision-makers should integrate conservation planning into initial feasibility studies and environmental and social impact assessments (ESIAs), recognise the role of IBWTs in facilitating species invasions, embed TEK and LEK in strategies, ensure transparent community engagement, develop strategies accounting for economic trade-offs, strengthen legal protections, and commit to sustained monitoring with adaptive management.

7.3. Fisheries in the LHWP: Outcomes, challenges, and key policy considerations for sustainable development and management

A central contribution of this thesis is its analysis of how fishing emerged as a viable livelihood in Katse Dam's catchment area, despite a lack of historical fishing culture or knowledge (Chapter 3). Expectations that Katse Dam could support capture fisheries of any significance were very low based on its predicted productivity, the lack of a fishing tradition in the area, and limited fish consumption in the Lesotho Highlands (Bain 1990; Eccles 1990; Skelton 1996). However, the increased abundance of fish in the catchment, coupled with a series of social (e.g., displacement and livelihood loss, knowledge transfer, innovation) and economic catalysts (e.g., increasing demand, market development), led to the emergence of a substantial hook-and-line and illegal gillnet fishery far exceeding pre-impoundment expectations. A multi-faceted fisheries value chain has emerged which comprises several actors and activities, from input suppliers to local, regional, and South African consumers. This happened organically, in a traditionally non-fishing area, in the absence of concerted interventions.

While fishing as an adaptation strategy following large dam construction is not novel globally, this has mostly been documented in regions with existing fishing cultures and fish-eating traditions and/or following concerted fisheries development efforts. While historically viewed as "an optional extra" (Lowe-McConnell 1973; McCartney et al. 2018), particularly in regions without fishing traditions (Britz et al. 2015; Weyl et al. 2021), the Katse Dam case demonstrates that productive fisheries and value chains can emerge organically in non-fishing areas when communities have access to new aquatic resources. Nevertheless, this unmanaged development came with significant challenges including physical safety risks and conflicts with authorities. While the fishery has become an important income source, and current exploitation trends appear sustainable, gillnetting activities are illegal. This not only highlights regulatory gaps but also emphasises the economic pressures driving communities to continue fishing despite the risks of reprisals. The lack of alternative livelihood opportunities further compounds these challenges.

Recreational fisheries development outcomes also diverged from expectations. Pre- and post-impoundment studies highlighted the potential for trophy *O. mykiss* angling in Katse Dam (Eccles 1990; Skelton 1996; Tweddle and Davies 1997; Nthimo 2000). However, the first (and only) dedicated FFT operation in the catchment area offers specialised, high-quality angling experiences for *L. aeneus* (Chapter 4). The construction of Katse Dam and the subsequent establishment of a large *L. aeneus* population has provided the platform for the successful establishment of the FFT operation, and resulted in substantial local economic benefits. This has been achieved through structured community engagement approaches, including employment schemes, revenue sharing, and involvement in operational decisions. However, the case study highlighted some inherent inequalities in benefit distribution, with communities closer to prime fishing locations enjoying economic and employment benefits, while more distant communities feel excluded and face conflicts over resource access. Additional challenges include historical grievances from displacement and disenfranchisement, cultural barriers, skills deficits, and a lack of knowledge and awareness on recreational fishing.

In contrast to Katse Dam, fishing in Mohale Dam is still in the early stages of development. While communities have begun integrating fishing into their livelihood strategies, the fishery remains predominantly seasonal, subsistence, and hook-and-line based, contrasting with Katse's year-round fishing activities and established value chains. At Katse, pre-existing fish populations, limited fishing experience, and knowledge transfer from external actors allowed early adoption of effective fishing methods. Post-impoundment, increased fish abundance enabled rapid expansion, with communities developing value chains and market networks. Mohale Dam communities encountered fish only after the invasion, with limited exposure to diverse fishing practices. This highlights how the timing and sequence of exposure to fish resources and knowledge have influenced the extent to which fishing and fisheries value chains have developed. Despite this delayed development, there is ecological potential and substantial community interest in fishing and broad support for formal management, though this is tempered by deep-seated mistrust stemming from unfulfilled LHWP commitments. These findings, when viewed alongside experiences from both Katse's capture fishery and FFT development, emphasise how the success of reservoir fisheries depends not just on ecological potential, but on context-specific social dynamics.

The development of fisheries in the LHWP has followed an unplanned trajectory, shaped by ecological changes, socio-economic pressures, and historical governance failures. While the emergence of fishing has created new livelihood opportunities, it has also introduced a set of complex challenges that have yet to be addressed.

The primary management challenge in the LHWP fisheries is the absence of a fit-for-purpose governance framework, leaving both capture fisheries and FFT in a regulatory void. Gillnet fishing remains illegal under the current regulations which have not been updated to account for the current scale of the fishery and its economic importance, creating ongoing conflicts between communities and enforcement authorities. Current enforcement approaches rely on punitive measures that do little to address the underlying drivers of illegal fishing.

The lack of participatory governance structures further undermines management effectiveness. Unlike well-regulated fisheries where local communities have a role in decision-making through co-management arrangements, LHWP fisheries remain subject to top-down decisions with minimal consultation. This has led to regulatory frameworks that do not reflect local realities, reducing compliance and increasing tensions between fishers and authorities.

Conflicts over resource access and benefit-sharing highlight further management weaknesses. While FFT operations have successfully generated economic benefits, these have not been equitably distributed, with communities closer to prime fishing areas reaping most of the rewards. This has led to disputes between different community groups and created resentment over exclusive access arrangements.

A fundamental gap remains in the form of outdated regulations and the absence of formal management plans. Regulations governing fisheries in the LHWP were developed prior to the emergence of significant fishing activities and have not been updated to reflect current realities. Without clear, context-specific management plans, fisheries operate in a regulatory vacuum where biological sustainability, economic development, and equitable resource access remain unaddressed.

Drawing on the research findings, the following recommendations outline key elements needed to create an effective governance framework for LHWP fisheries:

1. Dam developers should be legally required through concession agreements to provide defined, measurable investments in fisheries development including, for example, dedicated funding for fisheries management and monitoring costs, investments in essential infrastructure, provision of fishing equipment, training programs, and capacity building initiatives. These commitments must be specified as binding legal obligations with clear performance indicators, timelines, and penalty mechanisms for non-compliance, rather than voluntary corporate social responsibility initiatives.
2. Legislate all fisheries sectors in the LHWP. This should include formal recognition of both capture fisheries and FFT operations, define clear access rights and permitting systems, and move gillnet fishing from illegal to regulated status through appropriate legislation.
3. Develop and implement co-management structures at each dam. Co-management arrangements should recognise the existing authority of *Marena* and *Mafumahali* in regulating community activities and incorporate their role in fisheries access control, gear restrictions, and dispute resolution. The specific operational mechanisms - including decision-making procedures, conflict resolution protocols, and enforcement authority boundaries - should be developed through pilot arrangements that test different approaches and allow stakeholders to refine roles and responsibilities based on practical experience. This pilot approach would enable communities, traditional leaders, and regulatory authorities to negotiate appropriate governance structures rather than imposing predetermined frameworks, with successful elements from pilot programs subsequently scaled up and institutionalised.
4. Develop fisheries management plans based on scientific evidence and local knowledge. This should include defining sustainable harvest limits, establishing appropriate gear

restrictions and seasonal closures, implementing catch monitoring systems, and setting clear guidelines for FFT operations.

5. Institute fair and transparent benefit sharing mechanisms. These should establish revenue sharing arrangements, create structured employment schemes, set local content requirements for FFT operations, and develop appropriate compensation systems for affected communities.
6. Support economic development through structured interventions. This should include improving market access for local fishers, enabling formation of fisher cooperatives, providing training and capacity building programmes, and facilitating access to equipment and infrastructure.
7. Facilitate structured knowledge exchange between Katse and Mohale communities. This should focus on practical aspects such as fishing techniques, post-harvest handling, and market development, drawing on the longer history of fisheries activity at Katse to support capacity building at Mohale.
8. Establish comprehensive monitoring and enforcement systems. These should specify clear enforcement protocols, implement monitoring of both ecological and social indicators, create standardised reporting mechanisms, and define appropriate penalties for non-compliance.
9. Develop specific management plans for each dam that translate policy into locally appropriate actions. These should recognise different development stages at each dam, account for local socio-economic contexts, and include regular review and updating mechanisms to ensure continued effectiveness.
10. Create adaptive management frameworks that can respond to changing conditions. These should include procedures for regular policy review, mechanisms for incorporating new information, and processes for adjusting management approaches based on monitoring outcomes.

7.4. Towards a set of key principles for assessing and managing fish and fisheries in large dam projects

Each new dam presents a unique set of characteristics, with diverse ecological, social, and economic impacts that can be positive, negative, or both. No universal framework can be applied to assess and manage all of these impacts perfectly. However, the findings of this thesis provided the platform upon to identify a set of key principles for decision-makers in assessing and managing large dam projects in future. These include:

1. Governments planning large dam projects should explicitly recognise and assess the potential for fisheries to develop, even in areas without historical fishing traditions. Environmental and social impact assessments (ESIAs) and other pre-feasibility studies should comprehensively evaluate fisheries potential, and not only consider yields but also the economic, nutritional, cultural, and livelihood benefits for dam-affected communities that may arise from fisheries development. These assessments should be based on a social-ecological systems approach, integrate both traditional ecological knowledge and empirical scientific data, employ appropriate statistical methods for handling uncertainty, and utilise comparative analyses from similar dam projects to improve predictive capacity. Climate variability and hydrological changes should also be incorporated into pre-feasibility studies to evaluate their impacts on fisheries productivity. Moreover, pre-feasibility studies should identify the potentially competing interests of other sectors, such as agriculture and hydropower, anticipate potential conflicts through scenario-based assessments, and engage with decision-makers early to ensure that fisheries interests are recognised in broader development and management strategies.
2. Fisheries development and management strategies should be incorporated into broader dam planning and governance frameworks. To prevent siloed management approaches that often lead to the marginalisation of fisheries concerns, cross-sectoral coordination and collaboration mechanisms should be established that bring together stakeholders including those from fisheries, water management, energy, agriculture, conservation, and community development. Communication strategies should be developed to ensure that fisheries priorities are clearly articulated to decision-makers across sectors.
3. Many dam-affected communities harbour deep mistrust toward authorities due to past experiences with displacement and unfulfilled commitments. Governments must acknowledge this legacy and prioritise transparent, long-term engagement to rebuild trust. Fisheries development efforts should be accompanied by clear communication to dam-affected communities about rights, roles and responsibilities, and expected benefits, avoiding unrealistic promises that cannot be delivered. Governance structures must be adaptive and participatory rather than top-down, and allow dam-affected communities to play an active role in fisheries decision-making. Capacity-building

should be a priority to ensure that both fishers and authorities have the skills and resources needed to sustainably manage fisheries. Engaging local fishers in the design of management plans and incorporating their TEK/LEK will improve both legitimacy and effectiveness.

4. Monitoring systems should be implemented from the outset to track both ecological and socio-economic aspects of fisheries development. Data collection should be embedded within governance frameworks, with roles and responsibilities clearly defined. Monitoring frameworks should be designed to inform adaptive management, ensuring that regulations and governance structures can respond to environmental variability, shifting fishery dynamics, and socio-economic changes.
5. Biodiversity conservation planning must be integrated into the governance of dam-affected fisheries. Where endemic species are at risk, conservation planning should include both proactive and reactive strategies, such as the establishment of protected areas, invasive species control, and, where necessary, translocation initiatives. Ensuring biodiversity protection requires cross-sectoral coordination between fisheries, water management, and conservation authorities to align conservation objectives with broader reservoir management strategies. Communication mechanisms should be established to ensure that biodiversity concerns are integrated into dam operations and decision-making processes. This should be accompanied by the development of legal protections and enforcement mechanisms.

7.5. Global relevance, theoretical contributions, and future research directions

While this thesis focused on the LHWP, its findings and methodological approach offer broader contributions to our understanding of large dam impacts and management globally. The study advances both theoretical frameworks and practical approaches for assessing and managing dam impacts in developing countries, particularly in data-poor contexts where traditional assessment methods may be inadequate.

This thesis applied SES principles as a heuristic lens rather than as a prescriptive framework. While SES has been interpreted differently across fields (e.g., Ostrom's diagnostic framework, resilience theory, coupled human–natural systems), here the emphasis was on its value for structuring holistic, transdisciplinary analyses of dam impacts on fish and fisheries. The focus was therefore on principles, such as cross-scale linkages, feedbacks between ecological and social systems, and the integration of diverse knowledge systems, rather than on strict application of any one framework. The mixed methods approach employed throughout this thesis, grounded in these principles, provides a robust framework for understanding dam impacts in developing countries where baseline data is often limited (Chapters 3–6). By integrating ecological sampling, socio-economic surveys, and local ecological knowledge, the study demonstrates how multiple data sources can be triangulated to build comprehensive understanding even in data-constrained environments (Chapters 3, 5). This approach proved particularly valuable in documenting both expected and unexpected outcomes, such as the emergence of fishing cultures in non-fishing areas (Chapter 3) and unanticipated invasion pathways (Chapter 5, 6), which might have been missed using conventional single-discipline approaches. The methodology thus offers a template for future research in similar contexts, particularly in developing countries where data limitations often hamper impact assessment and adaptive management (Beard et al. 2011; Lorenzen et al. 2016; Fitzgerald 2018). Extending this approach to other dam systems would allow comparative analysis across ecological and social contexts, including how species invasions, recruitment dynamics, and productivity changes interact with livelihood adaptation pathways such as subsistence fishing and tourism. There is also scope to refine mixed-method designs that combine ecological monitoring, socio-economic surveys, and local knowledge to improve predictive capacity and guide adaptive management in data-poor regions.

The emergence of fishing at Katse Dam (Chapter 3) provides empirical evidence of how communities can develop new livelihood strategies and cultural practices in response to altered ecosystems, challenging traditional assumptions about the rigidity of resource-use patterns (Kura et al. 2017). This contributes to broader theoretical debates about the adaptive capacity of dam-affected communities and the conditions under which communities successfully navigate infrastructure-induced changes (Huang et al. 2018; Kirchherr et al. 2019). Further comparative research across different cultural and ecological contexts would help identify the institutional, economic, and social factors that enable or constrain such adaptive processes.

The findings make significant contributions to ongoing debates about dam development in the developing world. The divergent outcomes for fish species (Chapter 5) and fisheries development (Chapters 3, 4) demonstrate both the opportunities and risks associated with large dam projects, providing empirical evidence that can inform more nuanced policy discussions. This is particularly relevant given the current surge in dam construction in developing countries (Zarfl et al. 2015; Moran et al. 2018) and growing recognition of the need to balance development objectives with biodiversity conservation and local livelihoods (Siciliano et al. 2018). Comparative evaluations across multiple dam projects could clarify how governance arrangements and institutional mechanisms influence the balance between these competing objectives.

The research also advances our understanding of how recreational fisheries can contribute to rural development in dam-affected areas. The analysis of FFT (Chapter 4) provides insights into both the potential and limitations of high-end tourism as a development strategy, contributing to broader debates about pro-poor tourism and benefit-sharing (Harrison 2008; Tolkach et al. 2012; Luo and Bao 2019). These findings have particular relevance for other developing countries seeking to promote recreational fisheries for rural communities (Bower et al. 2020). Long-term assessments are needed to evaluate whether FFT in dam-affected areas can generate broad-based benefits, avoid inequities in access and distribution, and integrate with other local livelihood strategies, and help clarify the conditions under which FFT can contribute meaningfully to pro-poor rural development.

The thesis makes a methodological contribution through its approach to incorporating traditional ecological knowledge (TEK) and local ecological knowledge (LEK) into conservation planning (Chapter 5). The successful integration of community knowledge and scientific data in assessing *P. quathlambae* population changes demonstrates how mixed-knowledge approaches may strengthen conservation efforts in data-poor environments. This approach has broader applicability for conservation planning in developing countries where formal monitoring data are limited (De Ornellas et al. 2011). Future research could explore systematic approaches for integrating TEK and LEK into formal monitoring and conservation planning frameworks, particularly in ways that ensure credibility for decision-makers while retaining community ownership. Comparative studies across regions could also clarify how knowledge systems interact with governance structures in shaping conservation outcomes.

Finally, the principles developed for assessing and managing fish and fisheries in large dam projects (Section 7.4) provide a framework that can be adapted to diverse contexts globally. While specific applications will vary, these principles address universal challenges in dam development, including prediction uncertainty, governance gaps, and the need for adaptive management. This framework contributes to the growing body of knowledge on how to better assess and manage the impacts of large infrastructure projects on fish and fisheries in the developing world.

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APPENDICES

Appendix A1

<u>Oral Histories</u>

<u>Semi-structured interviews and focus group discussion guide templates</u>

Prior to each interview or group discussion:

- Participant(s) provided with study information
- Written/verbal consent obtained following local protocols
- Permission sought to audio record
- Participants reminded they could decline to answer any questions or end participation at any time
- Interviews/discussions conducted in Sesotho with translation where necessary
- Duration approximately 25–30 minutes for interviews, 60–90 minutes for group discussions

Semi-structured interviews were conversational, allowing participants to share their experiences while respecting traditional protocols. Questions were not asked in a fixed order, with discussions following participants' narratives.

Primary questions:

1. What has changed in your community since the dam?
2. How did you become involved with fishing?
3. How has the role of fishing in your household changed over time?

Follow-up areas were explored based on participants' responses regarding:

- Historical fishing practices
- Community adaptations
- Learning and knowledge transfer
- Fish consumption and trade
- Market development

Focus group discussions were arranged through traditional leadership structures and adapted according to community preferences. Group size varied from 8–40 participants.

Discussion areas:

- Community changes since dam construction
- Evolution of fishing practices
- Current fishing activities
- Marketing and trade
- Challenges and opportunities

Appendix A2

Katse Hook-and-Line Fishery Assessment

Questionnaire Survey Template

Date:_____________ Time: _____________ Location: _____________

Interviewer: _____________

A. Fishing Activity

1. Start time today: _________________

2. Expected end time today: ________________

3. Number of hand lines in use: ______________

4. In the last 7 days:

   - Number of days fished: _______________

   - Average hours per day: _______________

5. Summer (Oct-Mar): Average days fished per week: _______________

6. Winter (Apr-Sep): Average days fished per week: ________________

B. Demographics

7. Gender: Male / Female / Other / Prefer not to say

8. Age: ______________

9. Household size: __________

10. Employment status:

    a. Employed full-time
    b. Employed part-time
    c. Self-employed
    d. Unemployed
    e. Other (specify): __________

11. Primary source of income:

    a. Fishing
    b. Agriculture
    c. Formal employment
    d. Other (specify): __________

C. Catch and Utilisation

12. What proportion of your catch is used for:

    a. Household consumption: _______%

b. Sale: _______%

13. Do you categorise your fish by size? Yes / No

    If yes, what are the categories?

    a. Small (<20 cm)
    b. Medium (20–40 cm)
    c. Large (>40 cm)

14. Where do you sell your fish? (tick all that apply)
    - o Local villages
    - o Roadside vendors
    - o Wholesalers
    - o Other: __________

15. How much do you sell fish for on average (per size class)?
    a. Small: ______ USD
    b. Medium: ______ USD
    c. Large: ______ USD

16. What challenges do you face in selling fish?
    - o Low prices
    - o Lack of buyers
    - o Transport issues
    - o Spoilage during transport
    - o Other: __________

17. Do you process your fish before selling or consuming? Yes / No

18. If yes, what types of processing do you do? (tick all that apply)
    - o Scaling
    - o Gutting
    - o Drying
    - o Freezing
    - o Other: __________

19. Do you use your own equipment or rent from someone else?
    - o Own equipment
    - o Rent equipment

20. What challenges do you face in processing fish?
    - o Lack of equipment
    - o High costs
    - o Spoilage
    - o Other: __________

D. Distribution and Markets

21. How do you transport your fish to buyers?
    - On foot
    - Public transport
    - Personal vehicle
    - Other: __________
22. What is your most common market for fish?
    - Local village
    - Nearby towns
    - Urban centres
    - Cross-border (South Africa)
23. Do market demands differ by fish type, size, or form? Yes / No

    If yes, please explain: __________

E. Recommendations

24. What could improve your fishing activities or income?
    - Better equipment
    - Improved access to markets
    - Support for processing (e.g., storage facilities)
    - Other: __________
25. What opportunities do you see for improving fishing and trade in the Katse Dam area?

Notes: ____

Bayesian model of hook-and-line fishing effort

Model Selection

To account for potential overdispersion in the observed fisher counts, a negative binomial model was compared to the Poisson model. The negative binomial model was defined as:

$$y_{ij} \sim \text{Negative Binomial}(E_{ij}, \theta)$$

where y_{ij} represents the observed number of fishers on any given day i in season j, E_{ij} represents the expected number of fishers on any given day i in season j, and θ is the dispersion parameter to account for overdispersion.

LOO was used to evaluate model fit and account for the complexity of the model in selecting the final distribution. A higher expected log predictive density (ELPD) indicates better model performance. The results of the LOO comparison were as follows:

Poisson model: Expected Log Predictive Density ($ELPD_{LOO}$) -48.5 (SE: 2.3); LOO Information Criterion (LOOIC) 97.1 (SE: 4.5)

Negative Binomial model: ($ELPD_{LOO}$) -53.6 (SE: 3.3); LOOIC 107.1 (SE: 6.7)

The LOO comparison ($ELPD_{diff}$ = 5.0, SE = 1.1) indicated that the Poisson model provided a better fit to the data and was thus selected for further analysis.

Model Priors

Weakly informative priors were used to structure the model; the priors were guided by observed seasonal patterns while allowing flexibility for the data to drive the results. For the mean daily fisher numbers μ_j, log-normal priors were chosen based on preliminary observations from the survey and corroborating information from local authorities and fishers.

$$\log(\mu_{summer}) \sim \text{Normal}(\log(100), 0.3) \quad (3.5)$$

$$\log(\mu_{\text{winter}}) \sim \text{Normal}(\log(30), 0.3) \quad (3.6)$$

The choice of log-normal distributions ensures positive fish counts and allows for right-skewed distributions often observed in ecological data. The standard deviation of 0.3 provides a relatively wide range of plausible values, reflecting uncertainty while still offering some structure to the model.

For the daily variation in angler numbers (σ_{daily}), a $Half - Cauchy(0,1)$ $p$rior was selected:

$$\sigma_{\text{daily}} \sim \text{Half} - \text{Cauchy}(0,1) \quad (3.7)$$

This is a standard choice for scale parameters in hierarchical models, as recommended by Gelman (2006). The Half-Cauchy distribution allows for a broad range of daily fluctuations without being overly restrictive, and its heavy tail accommodates potentially large daily variations that might occur due to unforeseen circumstances (e.g., weather events).

For the Beta distribution parameters modelling daily fishing probability, weakly informative priors were selected:

$$\alpha \sim \text{Gamma}\ (1, 0.1) \quad (3.7)$$

$$\beta \sim \text{Gamma}\ (1, 0.1) \quad (3.7)$$

These priors allow for a flexible shape of the Beta distribution while ensuring the parameters remain positive. The Gamma priors with shape parameter 1 and rate 0.1 provide extensive uncertainty appropriate for a data-poor fishery context, while maintaining model stability and avoiding unrealistic fishing probabilities.

Model Fitting

The model was fitted using Markov Chain Monte Carlo (MCMC) sampling with four chains, each run with 2 000 warm up samples followed by 2 000 additional iterations for a total of 4 000 iterations per chain. Four chains are typically recommended as this provides adequate replication for convergence diagnostics while accounting for time and computational power constraints (Margossian and Gelman 2024). Convergence was assessed using the Gelman and Rubin (1992) scale and effective sample size (ESS). Convergence was considered satisfactory when the scale reduction factor was below 1.1 and the ESS was above 1 000 for all parameters.

Model Robustness Checks

To evaluate the sensitivity of the model to prior assumptions, a robustness check was performed by running the model with more diffuse priors. The alternative priors were:

$$\log(\mu_{summer}) \sim \text{Normal}(\log(100)\,, 0.6)$$
$$\log(\mu_{winter}) \sim \text{Normal}(\log(30)\,, 0.6)$$
$$\sigma_{\text{daily}} \sim \text{Half-Cauchy}(0{,}5)$$
$$\alpha \sim \text{Gamma } 0.5, 0.05)$$
$$\beta \sim \text{Gamma } (0.5, 0.05)$$

LOO comparison indicated minimal difference in predictive performance (elpd_diff = -0.6, SE = 0.8). Both models showed excellent convergence (all R-hat < 1.001, minimum n_eff > 3900). Given the minimal performance difference, the more conservative estimates of the original model, and the value of incorporating prior knowledge, the original model was selected for final analysis.

Calculating credible intervals for N_{total}

Credible intervals were derived directly from the posterior distribution generated through Markov Chain Monte Carlo (MCMC) sampling. The process involved generating posterior samples for μ_{summer} and p_f through the Bayesian hierarchical model, calculating N_{total} for each set of posterior samples using:

$$N_{\text{total}} = \frac{\mu_{\text{summer}}}{p_f}$$

and extracting the 95% credible interval from the resulting posterior distribution of N_{total}. Specifically, the 95% credible interval was determined by identifying the 2.5th and 97.5th percentiles of the posterior distribution of N_{total}.

Modelling hook-and-line fishery catch

Monte Carlo simulation process for total catch

To account for uncertainty in the total catch estimates, a Monte Carlo simulation was conducted by drawing 1 000 samples from the posterior distribution of $p_{f,j}$ (the probability that a fisher fishes on a given day), and from the bootstrapped distributions of $\text{CPUE}_{\text{j,n}}$ (non-zero CPUE in summer), $\text{CPUE}_{\text{j,w}}$ (non-zero CPUE in winter), and μ_j (the overall mean catch per unit effort for fisher j). For each sampling iteration $k = 1, 2, \ldots, 1\,000$, the total catch $C_j^{(k)}$ was recalculated as:

$$C_j^{(k)} = p_{f,j}^{(k)} \times \left(\text{CPUE}_{j,n}^{(k)} + \text{CPUE}_{j,w}^{(k)}\right) \times \mu_j^{(k)}$$

where $C_j^{(k)}$ represents the total catch for fisher *j* in the *k*-th draw. After completing the 1 000 iterations, the 2.5th and 97.5th percentiles of the simulated C_j values were used to construct the 95% confidence intervals for the total catch estimates. This process was repeated for each fisher, and the aggregated catch totals were used for the final analysis.

Bootstrapping Procedure for $log\left(CPUE_{pos,i}\right)$

The $\log\left(CPUE_{pos,i}\right)$ (log-transformed non-zero CPUE) values were bootstrapped 1 000 times using the boot package in R. For each bootstrap iteration *b*, $CPUE_i^{(b)}$ was recalculated as follows:

$$\widehat{CPUE}_\iota^{(b)} = \widehat{P}_\iota^{(b)} \cdot \exp\left(\log\left(\widehat{CPUE}_{\mathrm{pos},\iota}^{(b)}\right) + \frac{\widehat{\sigma^2}^{(b)}}{2} \right)$$

The final bootstrap estimates were calculated as:

$$\widehat{CPUE}_\iota^{\mathrm{boot}} = \frac{1}{B}\sum_{b=1}^{B} \widehat{CPUE}_\iota^{(b)}$$

where $B = 1\,000$. The 2.5% and 97.5% percentiles were used to estimate the 95% confidence intervals for the bootstrapped estimates.

Appendix A3

Illegal gillnet fishery assessment

Interviews with illegal gillnet fishers

The topics and prompts explored during open-ended, conversational interviews with illegal gillnet fishers are shown below. The focus was on fishing practices, catch utilisation, income, product forms, processing, distribution, trade, and challenges. The content and flow of each interview was guided by the participant's responses and comfort level, particularly given the mistrust of authorities.

1. Can you describe your typical fishing activities, including how often and for how long you fish?
2. What gear do you use, and where do you get it?
3. How does the season affect your fishing activities and the fish you catch?
4. How much fish do you typically catch in a day or week?
5. What do you usually do with your catch, and what proportion is sold versus consumed at home?
6. Is fishing your primary source of income, and how much do you typically earn from it?
7. Do you process your fish before selling or consuming, and what challenges do you face in processing?
8. Where and to whom do you usually sell your fish?
9. How do you transport your fish to buyers, and what challenges do you face in selling or distributing fish?
10. What are the biggest challenges you face as a gillnet fisher?
11. How has fishing affected your household and community, both positively and negatively?
12. Is there anything else you'd like to share about your fishing practices, income, or challenges?

Illegal gillnet fishery modelling

Model Selection

To account for potential overdispersion in the observed gillnet counts, a Negative Binomial model was compared to the Poisson model. The Negative Binomial model was defined as:

$$y_{ij} \sim \text{Negative Binomial} E_{ij}, \theta$$

where y_{ij} represents the observed number of gillnets on any given day i in season j, E_{ij} represents the expected number of gillnets on any given day i in season j, and θ is the dispersion parameter to account for overdispersion.

LOO (Leave-One-Out cross-validation) was used to evaluate model fit and account for model complexity. A higher expected log predictive density (ELPD) indicates better model performance. The results of the LOO comparison were as follows:

Negative Binomial model: elpd_loo: 0.0 (SE: 0.0)

Poisson model: elpd_loo: -83.5 (SE: 34.9)

The LOO comparison ($\Delta\text{elpd} = 83.5, \text{SE} = 34.9$) showed that the Negative Binomial model provided a better fit to the data and was therefore selected for further analysis.

Model Priors

The selection of weakly informative priors for this model balanced the incorporation of relevant knowledge with allowing the data to primarily drive the results. For the expected number of gillnets from MCS patrols and in-field counts, normal priors were chosen based on historical data and observations from the fishery. These priors centered the estimates around plausible values while still allowing for flexibility and uncertainty, specifically:

$$\lambda_{\mathrm{MCS}} \sim \mathrm{Normal}(100{,}50)$$

This prior reflected an expected average of 100 gillnets per year based on historical data from MCS patrols, with a standard deviation of 50 to account for variation in the observed counts.

Similarly, a prior was assigned for the in-field gillnet counts, reflecting prior expectations about the number of gillnets encountered in the field:

$$\lambda_{\mathrm{field}} \sim \mathrm{Normal}(100{,}50)$$

The detection probability, p_{detect}, was assigned a Beta prior, reflecting uncertainty about the proportion of gillnets that were likely detected during the survey period. The Beta distribution is flexible enough to capture this uncertainty while still allowing the data to adjust the probability estimate:

$$p_{\mathrm{detect}} \sim \mathrm{Beta}(2{,}2)$$

Lastly, the dispersion parameter ϕ which accounts for overdispersion in the data, was assigned a weakly informative prior:

$$\phi \sim \mathrm{Normal}(0{,}10)$$

This choice of priors provided sufficient structure to the model, reflecting prior knowledge while maintaining the flexibility to allow the data to inform the posterior distributions. The priors ensured that estimates for the number of gillnets remained positive and accounted for the variability commonly observed in illegal fishing operations.

Model Fitting

The model was fitted using MCMC (Markov Chain Monte-Carlo) sampling with four independent chains. Four chains are typically recommended as this provides adequate replication for convergence diagnostics while accounting for time and computational power constraints (Margossian and Gelman 2024). Each chain was run with 2 000 warm-up samples followed by 2 000 additional iterations for a total of 4 000 iterations per chain. Convergence was assessed using the Gelman-Rubin scale reduction factor, trace plots, and ESS for all parameters. Convergence was considered satisfactory when the scale reduction factor was below 1.1 and the ESS was above 1 000 for all parameters.

Model Robustness

To evaluate the sensitivity of the gillnet effort model to prior assumptions, robustness checks were conducted by running the model with more diffuse priors. The alternative priors were as follows:

$$\lambda_{\mathrm{MCS}} \sim \mathrm{Normal}(100{,}100)$$

$$\lambda_{\mathrm{field}} \sim \mathrm{Normal}(100{,}100)$$

$$p_{\mathrm{detect}} \sim \mathrm{Beta}(1{,}1)$$

$$\phi \sim \mathrm{Normal}(0{,}20)$$

Comparison of posterior distributions showed changes of -5.92%, 17.40%, -5.82%, -3.68%, and 1.89% for *N*, p_{detect}, λ_{MCS}, λ_{field} and ϕ respectively. LOO comparison indicated minimal difference in predictive performance (elpd_diff = -0.1, SE = 0.2). Both models showed good convergence (all R-hat < 1.1, minimum n_eff > 1000). Given the minimal performance difference, the more conservative estimates of the original model, and the value of incorporating prior knowledge, the original model was retained for final analysis.

Monte Carlo Simulation

To account for uncertainty in the total gillnet effort estimates, a Monte Carlo simulation was conducted by drawing 1 000 samples from the posterior distribution of N and from the bootstrapped distributions of T_{soak}. For each sampling iteration $k = 1, 2, \dots, 1\ 000$, the daily gillnet effort $E_j^{(k)}$ was recalculated as:

$$E_j^{(k)} = N_j^{(k)} \times T_{\text{soak}}^{(k)}$$

where $E_j^{(k)}$ represents the total daily gillnet effort for site j in the *k*-th draw, $N_j^{(k)}$ is the total number of gillnets in the *k*-th iteration, and $T_{\text{soak}}^{(k)}$ is the soak time in the *k*-th iteration.

After completing the 1 000 iterations, the 2.5th and 97.5th percentiles of the simulated E_j values were used to construct the 95% confidence intervals for the gillnet effort estimates. This process was repeated for each site, and the aggregated gillnet effort totals were used for the final analysis.

Diagnostics of the generalized additive model (GAM) used to standardise experimental gillnet data

To select the best-fitting model for standardising experimental gillnet data, several models were tested with different combinations of variables. The Akaike Information Criterion (AIC) was used for model selection. The AIC values for all the models considered were as follows:

- Model 1 (Mesh size only): AIC = 751.9808
- Model 2 (Mesh size and Year): AIC = 723.287
- Model 3 (Mesh size, Year, and Season): AIC = 668.0007
- Model 4 (Mesh size, Year, Season, and Site): AIC = 657.7933

The model with the lowest AIC was Model 4, which included mesh size, year, season, and site as predictors, with an AIC value of 657.7933. This model was selected as the final model for further analysis.

Residuals were checked for patterns that would indicate violations of model assumptions, such as heteroscedasticity or non-normality. Smoothness of the fitted terms was assessed by examining the effective degrees of freedom for each smooth term to prevent overfitting.

Model performance was assessed using Mean Squared Error (MSE = 0.0928) and Mean Absolute Error (MAE = 0.2022), computed via 5-fold cross-validation. The adjusted R-squared for the lognormal model was 0.467, indicating a moderate fit. Cross-validation confirmed the model's generalisability.

Gillnet meta-analysis

Studies used in the meta-analysis

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Meta-Analysis Methodology

A random-effects model was employed to pool effect sizes across studies and account for between-study heterogeneity in the meta-analysis of gillnet efficiency. The model was defined as:

$$y_i = \mu + \mu_i + \epsilon_i$$

where y_i is the observed effect in study i, μ is the overall mean effect size (the pooled effect), μ_i is the study-specific effect, and ϵ_i is the within-study sampling error.

The between study variation (τ^2) was calculated as:

$$\tau^2 = \frac{\sum_{i=1}^{k} w_i (y_i - \bar{y})^2}{(k-1) \cdot \frac{1}{\sum_{i=1}^{k} w_i}}$$

where y_i is the observed effect size for study i, $\bar{y}$ is the overall weighted mean effect size across all studies, k is the total number of studies, and w_i is the weight assigned to study i. Weights were calculated as:

$$v_i = \frac{1}{n_{1i}} + \frac{1}{n_{2i}}$$

where n_{1i} and n_{2i} represent the sample sizes for monofilament and multifilament nets in study i, or:

$$v_i = \sigma_i^2 + \tau^2$$

where σ_i^2 is the stated within-study variance for study i.

The overall effect size $\hat{\mu}$ was then modelled as a normal distribution such that:

$$\hat{\mu} \sim N(\mu, \tau^2)$$

where τ^2 is the estimator of the between-study variance.

Bayesian Meta Analysis

A Bayesian approach was used to implement the random-effects meta-analysis model. The likelihood function was based on the observed effect sizes y_i, assuming a normal distribution. Normal priors were assumed for the overall effect:

$$\theta_1 \sim N(0, \tau^2)$$

where θ_1 is the estimated overall effect size from the meta-analysis and τ^2 is the between-study variance from the meta-analysis.

The likelihood function for the model was based on the observed CPUE ratios from the meta-analysis studies, assuming a log-normal distribution. The posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, specifically the No-U-Turn Sampler (NUTS) algorithm, with four chains of 2 000 iterations each, including 1 000 warm-up iterations.

Selectivity

Four selectivity curve forms were fitted to the catch data under the assumption of equal fishing intensity: the normal fixed spread, the normal proportional spread, the gamma, and the log-normal curve (Table A.3.1).

Table A1. Selectivity curve forms fitted to the catch data under the assumption of equal fishing intensity.

Model	**Parameters**	**Selection Curve**	**$\beta_1.f_1(m_i, lj)+\beta_1.f_1(m_i, l_j)$**
Normal fixed spread	k; σ	$\exp -\left[\frac{(l_j - km_i)}{2\sigma^2}\right]$	$\frac{k}{\sigma^2} + (l_j m_i) + \left(-\frac{k}{2\sigma^2}\right) m_i^2$
Normal spread	k_1, k_2	$\exp -\left[\frac{(l_j - k_1 m_1)^2}{2k_2^2 m_i^l}\right]$	$\frac{k_1}{k_2^2} + \left(\frac{l_j}{m_i}\right) + \left(-\frac{1}{2k_2^2}\right)\left(-\frac{l_j}{m_i}\right)^2$
Gamma: proportional spread	α, k	$\left[\frac{l_j}{(\alpha - 1).k.m_i}\right]^{\alpha-1} \exp\left(\alpha - 1 - \frac{l_j}{k.m_i}\right)$	$(\alpha - 1)\left[\log\left(\frac{l_j}{m_i}\right)\right] + \left(-\frac{1}{k}\right)\frac{l_j}{m_i}$
Lognormal: proportional spread	μ; σ	$\frac{m_i}{l_j m_1} \exp\left\{\mu - \frac{\sigma^2}{2} - \frac{\left[\log(l_j) - \mu - \log\left(\frac{m_i}{m_1}\right)^2\right]}{2\sigma^2}\right\}$	$\frac{1}{\sigma^2}\left[\log(l_j)\log\left(\frac{m_i}{m_1}\right) - \frac{1}{2}\log^2\left(\frac{m_i}{m_1}\right)\right] + \left(1 - \frac{\mu}{\sigma^2}\right)\left[\log\left(\frac{m_i}{m_1}\right)\right]$

Model performance was assessed using the Akaike Information Criterion (AIC) to compare different candidate models for fitting gillnet selectivity. The model with the lowest AIC value was selected.

Appendix A4

Functional Value Chain Analysis

Semi-structured interviews with fish traders and retailers

The topics and prompts explored during open-ended, conversational focus group discussions with traders and retailers are shown below. The focus was on commercial relationships with fishers, fish products purchased, pricing, storage, transport, retail practices, and challenges. The content and flow of each discussion were guided by the participants' responses and comfort level, particularly given the sensitivity around regulations and mistrust of authorities.

1. What types of fish do you typically purchase, and in what quantities?
2. Do you focus on specific sizes or species of fish when buying?
3. How much do you usually pay fishers for the fish you buy?
4. How do you decide the price you pay to fishers?
5. How do you store the fish after purchasing?
6. How do you transport the fish from the fishers to your location?
7. What difficulties, if any, do you face during transportation?
8. Where and how do you sell the fish you purchase?
9. What prices do you charge when selling the fish?
10. Do prices vary by species, size, or product form (e.g., fresh, frozen, dried)?
11. What factors influence the prices you set for the fish you sell?
12. What are the biggest challenges you face in your trading or retail activities?

Focus group discussions

Focus group discussions were arranged through traditional leadership structures and adapted according to community preferences. Group size varied from 8-40 participants.

Discussion Areas:

1. Value Chain Evolution & Changes
2. Key actors and their roles
3. Processing and storage methods
4. Marketing & Trade Networks
5. Challenges & Opportunities

Appendix B1

<u>Recreational angler questionnaire</u>

The purpose of this questionnaire is to assist researchers from the SAFER lab (www.safisheriesecologyresearchlab.com) at the Department of Ichthyology and Fisheries Science, Rhodes University, in understanding the social and economic contributions of the recreational fishery in the Katse Dam catchment area. The research will ultimately guide the Government of Lesotho in formulating a management framework for the sustainable management and conservation of its fisheries resources. This research has been approved by the Rhodes University Human Ethics Committee, Approval Number: 2021-4854-6048

Any questions/concerns about the research and/or the questionnaire may be addressed to Mr Jim McCafferty at Rhodes University:

jimm@advanceafrica.co.za

+27 71 290 5084

Participation in the survey is completely voluntary and you may refuse to answer any questions that you are uncomfortable with.

1. Do you agree to participate in the survey and are you 18 years or older?
2. Age
3. Gender
    a. Male
    b. Female
    c. Other
    d. Prefer not to say
4. Nationality (country of current residency)
5. Are you a return visitor to Makhangoa Community Camp (MCC)?
6. In comparison to the average fly angler, how would you rate your angling skill on a scale of 1 to 5? (1- Novice 5 – Expert)
7. How many years have you been fly-fishing?
8. In addition to fishing, what else motivated you to visit MCC?
9. What is the main reason you wanted to fish in Lesotho?
10. How many days did you spend in Lesotho on your most recent trip?
11. How many days did you <u>spend fishing</u> in Lesotho on your most recent trip?
12. Apart from the Bokong River and Katse Dam at MCC, did you fish anywhere else during your trip to Lesotho? If yes, please state where and for how long.
13. How much money (ZAR) did you spend on your trip **<u>prior to arriving</u> in Lesotho**? Please provide estimates for the following expenses:
    a. Package trips or tours (Note: we will obtain further details from African Waters on how this money is used to benefit local communities in Lesotho).
    b. Airfares
    c. Car hire
    d. Fuel
    e. Fishing equipment
    f. Fishing clothing
    g. Other (please specify)
14. How much money (ZAR/Maloti) did you spend on your trip **<u>while in Lesotho</u>?** Please provide estimates for the following expenses:
    a. Food

   b. Liquor
   c. Souvenirs
   d. Petrol
   e. Staff Gratuities
   f. Other (please specify)
15. Please rank the following species in order of their importance to you as a target species at MCC. (1 = most important; 4 = least important; species can be scored the same where relevant)
    a. Smallmouth yellowfish
    b. Rainbow trout
    c. Brown trout
    d. Orange River mudfish
16. Which of the following species did you catch?
    a. Smallmouth yellowfish
    b. Rainbow trout
    c. Brown trout
    d. Orange River mudfish
17. How satisfied were you with your recent fishing experience at MCC?
    a. Very dissatisfied
    b. Somewhat dissatisfied
    c. Neither dissatisfied or satisfied
    d. Somewhat satisfied
    e. Very satisfied
18. In your opinion, how effective is the current management of the MCC fishery?
    a. Very effective
    b. Effective
    c. Neither effective nor ineffective
    d. Ineffective
    e. Very ineffective
    f. Not sure
19. Are you aware of the regulations for recreational fishing in Lesotho?
20. Do you think there is a need to implement additional regulations for the fishery? If yes, please specify
21. Management of Lesotho's fisheries has become increasingly challenging and the pressure on fisheries resources has increased over the years. Under the hypothetical scenario that Lesotho was to close its recreational fisheries, how much would you be willing to pay to maintain access to the fishery?
22. Did you encounter fishers from local communities during your trip? If yes, please indicate what fishing activities you observed
    a. Handline
    b. Rod and reel
    c. Gillnet
23. Which of the following best describes how you feel about the fishing activities of local fishers?
    a. Should not be allowed
    b. Allowed but outside of MCC fishing area
    c. Local fishers should be allowed to utilise the MCC area under the current management arrangement with African Waters.
    d. It's their resource and they can do what they want.
    e. Unsure

24. How sustainable do you believe the fishing activities of local anglers are?
    a. Very sustainable
    b. Sustainable
    c. Not sure
    d. Unsustainable
    e. Very unsustainable
25. How much impact do you think your fishing activities have on the health of the ecosystems?
    a. Extremely high impact
    b. High impact
    c. Medium impact
    d. Low impact
    e. No impact
26. Have you noticed anything in Lesotho that concerns you with regards to the state of the environment

Appendix B2

<u>Focus Group Discussion Guide</u>

Opening

- Welcome and introductions by Morena/Mofumahali
- Explanation of research aims
- Obtain informed consent

Discussion Prompts

1. Can you share your thoughts on how the MCC has affected your community?
2. What changes have you noticed in your daily life or livelihood since the MCC was established?
3. Are there any opportunities or benefits from the MCC that your community has received?
4. Do you feel that these opportunities or benefits are shared fairly among all community members?
5. What challenges, if any, has your community experienced as a result of the MCC?
6. Have there been any conflicts over resources like fishing areas, and how have they been resolved?
7. What has been your experience with accessing fish resources or fishing areas near the MCC?
8. What role does fishing play in your household or community, and has this changed due to the MCC?
9. How do you feel about the MCC's involvement in tourism and its impact on your ability to use resources like fish?
10. How would you describe the MCC's communication or engagement with your community?
11. Do you feel involved in decisions made by the MCC that affect your community?
12. How has the MCC influenced your sense of pride or wellbeing in the community?
13. Do you have any concerns about the long-term impact of the MCC on your environment or livelihoods?
14. What suggestions would you make for improving the relationship between the MCC and your community?

Appendix C1

<u>Electrofishing sampling site coordinates</u>

River	Site	Coordinates
Senqunyane	S34	-29.22528; 28.27378
Senqunyane	S29	-29.29451; 28.25093
Senqunyane	S28	-29.30505; 28.23596
Senqunyane	S25	-29.34406; 28.20098
Senqunyane	S24	-29.35438; 28.19587
Senqunyane	S22	-29.36854; 28.18075
Bokong	B9	-29.2783; 28.12456
Bokong	B5	-29.31878; 28.11187
Bokong	B4	-29.32806; 28.11413
Bokong	B3	-29.3504; 28.11782
Jorodane	J6	-29.38793; 28.04498
Jorodane	J8	-29.35635; 28.03543
Tsoelikane	JR18	-29.89750; 29.12050
Mangaung	JR14	-29.53110; 29.25940
Sani	JR14B	-29.55620; 29.24250
Sani	DT11	-29.56320; 29.27210
Mothae	MOT1A	-28.94530; 28.79540
Mothae	MOT2A	-28.95700; 28.78790
Mothae	MOT2B	-28.95800; 28.78790
Mothae	MOT2C	-28.96090; 28.78940
Mothae	MOT2D	-28.96410; 28.78890
Mothae	MOT3A	-28.96770; 28.78680
Mothae	MOT3B	-28.97450; 28.78530
Mothae	MOT3C	-28.97800; 28.78190
Mothae	MOT3D	-28.98160; 28.77980
Matsoku	DT4	-29.01002; 28.76331
Matsoku	JR22	-29.25930; 28.55830
Senqu	JR10	-28.92556; 29.02312
Moremoholo	JR11	-29.12486; 29.32668
Senqu	SEN1	-28.936914; 29.019293
Senqu	SEN2	-28.925627; 29.023162
Senqu	SEN3	-28.918674; 29.027133
Senqu	SEN4	-28.906766; 29.022046
Moremoholo	MOR4	-29.129691; 29.326495
Moremoholo	MOR5	-29.124807; 29.326666
Moremoholo	MOR6	-29.132342; 29.339415
Moremoholo	MOR7	-29.151055; 29.33937

Matsoku	MAT	-29.230883; 28.559588
Matsoku	MAT3	-29.00627; 28.7583
Matsoku	MAT4	-28.97309; 28.75522
Matsoku	MAT5	-28.94403; 28.75522
Tsoelikane	TSO1	-29.884882; 29.120042
Jorodane	JOR2	-29.345097; 28.035108
Jorodane	JOR3	-29.342174; 28.032757
Jorodane	JOR7	-29.320884; 28.023954
Jorodane	JOR9	-29.311796; 28.019204
Makhaleng	MAK1	-29.38734; 27.91447
Makhaleng	MAK2	-29.394776; 27.920822
Maletsunyane	MAL3	-29.7551; 28.0241
Maletsunyane	MAL4	-29.75908; 28.01959
Maletsunyane	MAL5	-29.75315; 28.01583
Maletsunyane	MAL6	-29.73488; 28.01039
Maletsunyane	MAL7	-29.73342; 28.01278
Quthing	Q1	-30.349004; 28.157513
Quthing	Q2	-30.375944; 28.2253333
Quthing	Q3	-30.37325; 28.2155833
Quthing	Q4	-30.374361; 28.2093333

Appendix C2

Conservation planning workshop and IUCN framework

The conservation planning workshop was held in Maseru, Lesotho, from 25-26 November 2019. The workshop followed the IUCN/SSF Strategic Planning for Species Conservation (2008) framework. The workshop was attended by five scientists with expertise in *Pseudobarbus quathlambae* research and conservation, and LHDA personnel.

Based on the electrofishing survey results, participants applied the IUCN methodology through three key steps:

1. Threat Identification and Assessment

Participants systematically identified threats to each minnow population group

- Threats were evaluated using two criteria:
- Impact: Severity of effect on population viability (High/Medium/Low)

Likelihood: Probability of occurrence (High/Medium/Low)

A composite threat ranking was calculated combining impact and likelihood scores

2. Conservation Action Planning

For each ranked threat, participants:

- Identified specific conservation actions
- Evaluated feasibility considering:
- Technical capability
- Resource requirements
- Stakeholder support
- Prioritised actions based on:
- Urgency of threat
- Cost-benefit analysis
- Implementation capacity

The workshop outputs informed the population-specific conservation strategies detailed in the main text.

Appendix C3

<u>Community survey</u>

Date: ________________________________ Village: _____________________________

Area (PCA/RCA): ______________

Interviewer: ___________________________ Respondent ID: ______________________

A. Demographics

1. Gender: Male / Female / Other
2. Age: _______
3. Household size: _______
4. Primary occupation:
    a. Farming
    b. Fishing
    c. Wild plant harvesting
    d. Artisanal work
    e. Other (specify): _______

B. LHWP Impact Assessment

5. How has your life changed since the development of LHWP?
    a. Improved
    b. Worsened
    c. Unsure
6. What are the main challenges you face? (Check all that apply)
    a. Unemployment
    b. Lack of skills
    c. No electricity access
    d. Transport/road access
    e. Limited cold storage
    f. Limited health facilities
    g. Inadequate sanitation
    h. Other (specify): _______

C. *P. quathlambae* Knowledge Assessment

[Show photograph of *P. quathlambae*]

8. Do you know this fish? Yes / No
9. If yes:

a. What do you call it? ________________________

b. When did you last see it? ____________________

c. Current status: Healthy / Disappeared / Unsure

D. Species Value & Conservation

9. Is this fish important? Yes / No
10. If yes, why? (Open-ended)

____

11. Should this fish be protected? Yes / No

    If yes, why? ________________________

E. Conservation Actions

13. Which conservation measure do you support?
    a. None
    b. Protected areas with compensation
    c. Eradication, barrier, restocking (RCA only)
    d. Other (specify): _______
14. Additional comments/suggestions:

Appendix C4

<u>Focus Group Discussion Guide</u>

Date: ____________ Village: _____________ Area (PCA/RCA): ______________

Facilitator: _________________ Number of Participants: _________________

Discussion Topics

1. LHWP Impact
   - How has LHWP affected your community?
   - What are the main challenges faced since LHWP implementation?
   - What improvements or deteriorations have you noticed?

2. *P. quathlambae* Awareness

[Show photograph of *P. quathlambae*]
   - Do you recognise this fish?
   - What names do you use for it?
   - When was it last seen in your area?
   - What changes have you noticed in its population?

3. Conservation Attitudes
   - Should this fish be protected? Why/why not?
   - What conservation measures would you support?
   - What local solutions could work?
   - What concerns do you have about conservation measures?

Notes: Record key quotes verbatim in Sesotho

Number of Males: ___________ Number of Females: ___________

Duration: Start time: _________ End time: ____________

Appendix D1

Questionnaire Survey Template

Date: _______________ **Time:** _______________ **Location:** _______________
Interviewer: _______________

A. Demographics

1. Gender: ☐ Male / ☐ Female / ☐ Other / ☐ Prefer not to say
2. Age: _______________
3. Household size: _______________

B. Livelihoods

4. How do you support your livelihood? *(Tick all that apply)*
   ☐ Wild plant harvesting
   ☐ Agriculture
   ☐ Crafts
   ☐ Trading
   ☐ Temporary job
   ☐ Fishing
   ☐ Hunting
   ☐ Other (specify): _______________
5. If you engage in multiple livelihood activities, which is your primary source of income?
   a. Fishing
   b. Hunting
   c. Agriculture
   d. Temporary job
   e. Trading
   f. Other (specify): _______________

C. Awareness and Knowledge of Fish Species

6. Do you know any of the following fish species? *(Circle the appropriate answer)*
   L. aeneus: Yes / No
   L. capensis: Yes / No
   O. mykiss Yes / No

D. Fish Consumption and Preferences

7. When you eat fish: *(Tick all that apply)*
   ☐ I only eat canned fish
   ☐ I only eat dam-caught fish
   ☐ I eat both canned and dam-caught fish

8. What is your preference? *(Circle the appropriate answer)*
   Canned fish / Dam-caught fish

E. Fisheries Development and Management

9. Do you have knowledge of fisheries regulations? ☐ Yes / ☐ No

10. Would you support the development of fisheries regulations? ☐ Yes / ☐ No

11. If *No* or *Unsure*, why?
    ☐ I do not think regulations are needed
    ☐ I do not understand what the regulations would involve
    ☐ Other (specify): _______________

12. What changes would improve fishing in your area? *(Open-ended)*

13. Do you think the government or local authorities should support fishers? If so, how?
    ☐ Yes / ☐ No
    If *Yes,* please explain:

F. Fishing Activity *(Only for fishers)*

14. Are you interested in fishing? ☐ Yes / ☐ No

15. If *No*, why not? *(Tick all that apply)*
    ☐ Fear of drowning
    ☐ Fear of water snakes
    ☐ Too busy with other activities
    ☐ Other (specify): _______________

16. If *Yes*, why do you fish? *(Tick all that apply)*
    ☐ For income
    ☐ For subsistence (food for household)
    ☐ For both income and subsistence

17. How often do you fish? *(Indicate number of days per week)*

- *Summer (Oct–Mar):* ______ days/week
- *Winter (Apr–Sep):* ______ days/week

18. What type of fishing gear do you use? *(Tick all that apply)*
    ☐ Handline
    ☐ Rod and reel
    ☐ Gillnet
    ☐ Other (specify): ______________

19. What species do you usually catch? *(List the names if known)*

20. What do you do with the fish you catch? *(Tick all that apply)*
    ☐ Consume at home
    ☐ Sell at the market
    ☐ Give to family/friends
    ☐ Other (specify): ______________

21. What challenges do you face when fishing? *(Tick all that apply)*
    ☐ Lack of fishing gear
    ☐ Low fish availability
    ☐ Restrictions on fishing areas
    ☐ Competition with other fishers
    ☐ Environmental changes (e.g., water quality, climate)
    ☐ Other (specify): ______________

G. Recommendations

22. What could improve your fishing activities or income? *(Tick all that apply)*
    ☐ Better equipment
    ☐ Improved access to markets
    ☐ Support for processing (e.g., storage facilities)
    ☐ Other (specify): ______________

23. What opportunities do you see for improving fishing and trade in your area? *(Open-ended)*

Notes: ____